EUROPEAN SPACE AGENCY

INDUSTRIAL POLICY COMMITTEE

Science Programme Technology Development Plan: Programme of Work for 2023, 2024 and 2025, and Related Procurement Plan

SUMMARY

This document presents the activities in the Science Core Technology Programme (CTP) and in the Technology Development Element (TDE, replacing the TRP) of the Discovery, Preparation & Technology Development Basic Activities supporting the implementation of ESA's Science Programme. Activities funded through the Industrial Policy Task Forces (IPTFs) and of relevance to the Science Programme are also provided for information.

June 2023

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1 Background and Scope

This document provides an update to the Science Programme Technology Development Plan (TDP). The plan contains the description of the technology development activities (TDAs) required for the technological preparation of all mission candidates in the Agency's Science Programme. Critical mission-enabling developments that are generically applicable to several possible future space science missions are also addressed. This plan was first issued in 2008 as ESA/IPC(2008)33,add.1, and the last significant update was presented in ESA/IPC(2022)81 rev 2, approved by the IPC in December 2022.

As regularly done for past versions of the plan, activities to be initiated by ESA in the year following the work plan approval are presented for a decision, while activities identified for potential implementation at a later stage are presented for information. When identified, national activities in support of payload developments are recommended for implementation under national funding.

2 Science Programme Missions

The European Space Science Programme addresses a number of high-level science questions, originally described in the document "Cosmic Vision Space Science for Europe 2015-2025". New missions are proposed by the science community and follow a thorough competitive process before being proposed for selection to the Science Programme Committee (SPC). This bottom-up selection process aims at scientific and technical excellence by identifying the best mission to implement at a given time and for specified budget and schedule boundaries. The current implementation status of the Science Programme is briefly recalled below.

The first Call for Missions in the context of the Cosmic Vision plan was issued in March 2007 targeting one M-Class and one L-Class mission. This Call has ultimately led to the implementation of the M1, M2 and L1 missions: Solar Orbiter was selected as M1 and was launched in February 2020; Euclid was selected as M2 and is planned for launch in July 2023; JUICE was selected as L1 and is planned for launch in April 2023. The second Call for Missions in the same framework was issued in July 2010 for the third M-Class mission (M3), and led to the implementation of PLATO, which is planned for launch in 2027. The Call for the fourth M mission (M4) has led to the adoption of the ARIEL mission in November 2020 with a launch targeted in 2029. The Call for the fifth M-mission (M5) was issued in April 2016 and resulted in the selection of EnVision in June 2021. The mission is devoted to investigate the surface and subsurface of Venus, in collaboration with NASA. The Phase B1 is running, with adoption expected in 2024 and launch in early 2030s.

The two remaining Large Missions of the Cosmic Vision plan that are being prepared are LISA and Athena. LISA is a mission consisting of a constellation of three spacecraft for measuring gravitational waves using laser interferometry, building on the successful demonstration achieved in orbit by LISA Pathfinder. LISA is currently in the Phase B1 aiming at adoption in late 2023 and phase B2/C/D kick-off end 2024. Athena is an X-ray telescope with two focal plane instruments, a Wide Field Imager (WFI) and a Cryogenic X-ray Spectrometer (XIFU). The Athena study phase A/B1 led to a feasible concept but with increased ESA responsibilities for the payload and a cost to ESA significantly exceeding the foreseen envelope.In 2022, in consultation with the ESA Science Advisory Structure and the Science Policy Committee (SPC) it was decided to initiate a reformulation phase of the mission by following a strict design-to-cost approach (NewAthena).

In parallel to the M and L mission developments, the SPC issued a Call for a small mission in 2012, aiming at a fast implementation schedule, typically 4 to 5 years from mission adoption to launch. This call resulted in the CHEOPS mission, launched in 2019 and currently in operation in orbit. In 2015, a second call was jointly issued with the Chinese Academy of Sciences (CAS), and resulted in the adoption of the SMILE CAS-ESA mission, planned for launch in 2025. Comet-Interceptor was selected following the Call for “Fast” F-mission issued in July 2018 for a modest-sized mission to be launched as a passenger to ARIEL in 2029. The mission adoption occured mid-2022.

The Voyage 2050 programme is the successor to the Cosmic Vision plan and will define science missions for the timeframe of 2035-2050, following Athena. Shortly after the appointment of the Senior Committee, the Executive organised an open consultation of the scientific community on Voyage 2050 themes. Following this consultation process, the Senior Committee provided its recommendations for Voyage 2050 themes, which were unanimously approved by the SPC in June 2021 (SPC(2021)20). The recommendations included in particular the scientific themes to be addressed by the next three Large missions: moons of the giant Solar System planets; temperate exoplanets or the galactic ecosystem with astrometry; and new physical probes of the early Universe. This work plan initiates some early technology developments in relation with Voyage 2050, in addition to the mission-enabling activities for the current candidate missions of the Cosmic Vision plan. The first Voyage 2050 Call was issued late 2021, soliciting mission proposals for both an F and M mission. In November 2022, the Science Programme Committee (SPC) has selected ARRAKIHS as the mission candidate for the F2 mission opportunity, and has been informed that the following missions have been selected for further study for the M7 missionopportunity: CALICO, HAYDN, M-MATISSE, Plasma Observatory, and THESEUS.

Figure 1 summarises the Science Programme plan as of March 2023.

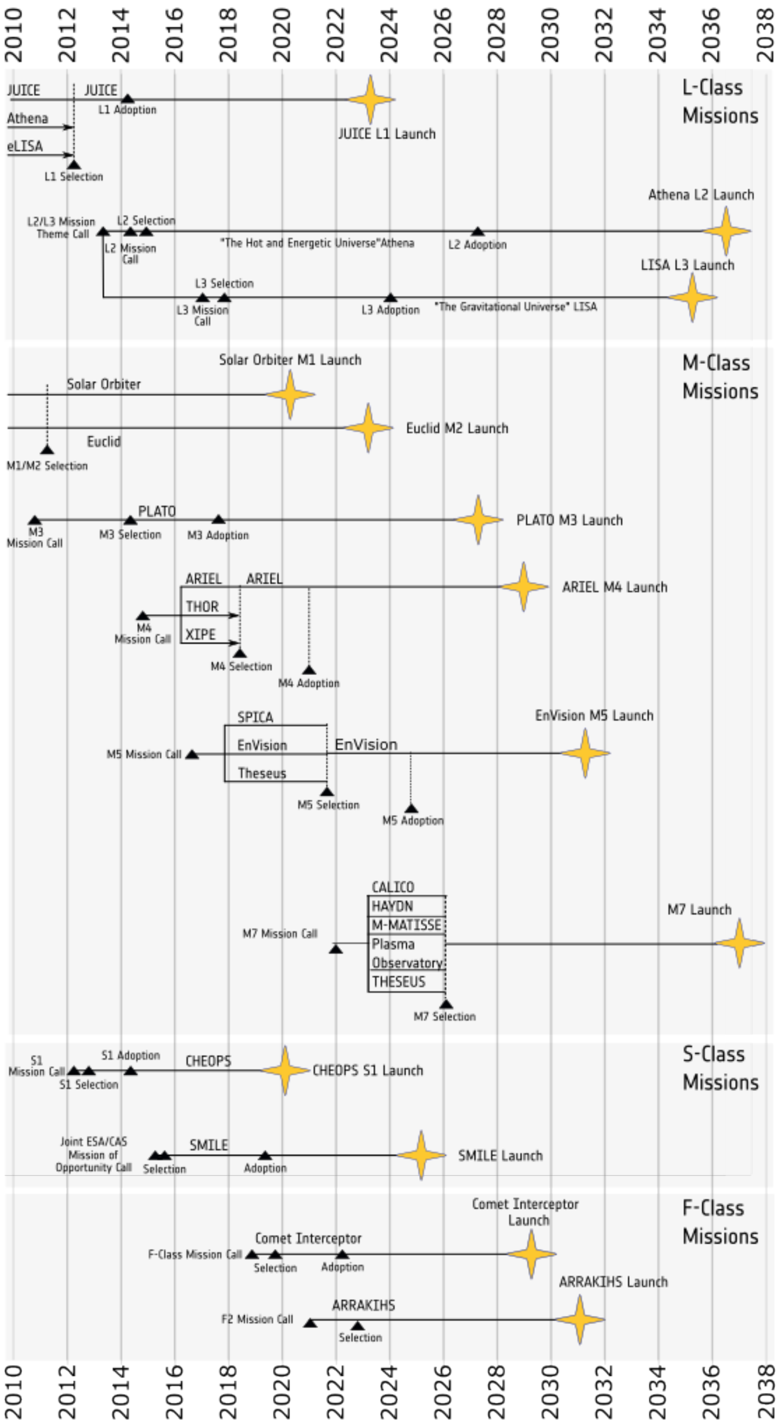

Figure 1: ESA Science Programme Mission Plan Timeline Summary

3 Science Programme Technology Development Plan

Present Technology Development Plan Update

This technology plan was defined, as for previous versions, using the ESA End-to-End technology management process as described in ESA/IPC(2005)39, involving a Technology Network (TECNET) of technical and mission experts from ESA. The proposed technological activities are based on:

- Critical technologies that were identified based on internal ESA studies.
- Technology development activities identified by industry in the course of the mission candidates assessment studies.
- Technology development activities identified by the science community, through studies done by institutes or consortia in parallel to the industrial studies.
- An assessment of the technological needs and maturity with respect to on-going running activities, urgency and funding availability.
- Relevance to the themes raised for the Voyage 2050 programme.

The new activities are addressing the L missions Athena (L2) and LISA (L3), EnVision, Voyage 2050 and technologies applicable to several missions.

Implementation Principles and Payload-Related Activities

A guiding principle of the Science Programme is that critical basic technology developments of the spacecraft and science instruments must be completed before entering the Definition Phase. As a general rule, Technology Readiness Level 5-6 (in ISO scale) is expected for both the space segment and the payload at the start of the Implementation Phase. A summary of the current assumptions on the payload procurement scheme is provided in Table 1 for the M and L missions. Category A = ESA-provided payload; Category B = payload provided by Member States; Category C = payload shared between ESA and Member States.

Mission	Payload Category	Member State Provision	ESA Payload Provision
Athena (L2 mission)	C	Focal plane instrumentation: Wide Field Imager X-ray Spectrometer (with NASA contributions)	X-ray telescope (Silicon Pore Optics)
LISA (L3 Mission)	C	Optical bench, Gravitational Reference Sensor, Phasemeter	Telescope, Laser system (NASA)

Mission	Payload Category	Member State Provision	ESA Payload Provision
EnVision (M5)	B	Complete Payload (except NASA provided SAR)	SRS-dipole antenna Venpsec-H Integrated Cooler detector Assembly VenSpec-U detector Master Reference Oscilator (NASA is foreseen to provide the SAR)
Comet Interceptor (F mission)	B	Complete payload	

Table 1: Assumptions for the payload provision of the selected missions in the preparation phase. Category A = ESA-provided payload; Category B = payload provided by the Member States; Category C = payload shared between ESA and Member States

It is assumed that the Member States will be in charge of the technology developments of the instruments they plan to provide, while ESA will implement the technology developments related to the rest of the spacecraft and payload elements remaining under ESA responsibility. A good coordination between the technology developments under Member States and ESA responsibility is imperative, thereby avoiding duplication of effort, enabling identification of missing activities and providing ESA with visibility of the payload development.

Budgets and Implementation Aspects

The ESA technology development activities in the Science Programme mainly rely on the CTP and TDE technology budgets and are submitted to the Industrial Policy Committee (IPC) for approval and implementation. GSTP is marginally used, and recommendations are provided by the TECNET-SCI as appropriate. Some technology system studies on future mission themes may be funded by the GSP for supporting the technology development definition when necessary.

The Technology Development Element of ESA's Discovery, Preparation and Technology Development Basic Activities is generally devoted to initial technology developments leading to an experimental feasibility verification of critical functions or to a validation at breadboard level in a laboratory environment (TRL 3/4). In the case of components this might be extended, e.g. for radiation hardening, since otherwise a proof of feasibility is not possible.

The CTP budget generally focuses on reaching a higher level of technology maturity by demonstrating the element performance in the mission relevant environment, before the start of the implementation phase (TRL 5-6).

In many cases, developments are started under the TDE budget in early phases and pursued under the CTP budget for reaching TRL 5-6. Therefore, the overall technology maturation process requires a close technical coordination of the activities, which is the rationale for providing a joint CTP/TDE technology work plan.

The Executive will implement the plan according to the Agency's procurement rules, and unless duly justified, activities will be awarded through unrestricted open competition aiming at technical excellence and cost efficiency. The new activities submitted for decision are to be initiated within the year following the approval by the IPC.

In general, phased contracts are considered wherever required and possible in order to accommodate any upcoming selections or other programmatic decisions and to minimise spending for non-selected missions.

The baseline approach is to have a single contract for each activity, unless otherwise stated in the work plan. In case of specific interest for the Programme e.g. risk reduction, investigation of different technical solutions, or for enabling competition on critical hardware in the future phases, the Executive may envisage placing parallel contracts following competitive tenders, provided that good quality offers are received, and subject to budget compatibility. In such a case, the parallel contracts will be reflected in the regular update of the work plan, which occurs as a minimum on a yearly basis, keeping the IPC and SPC fully informed of the work plan implementation.

Furthermore, in application of Article VII and Annex V (Article V) of ESA Convention and of the Council decisions contained in ESA/C(2020)138, the Executive undertakes measures to identify technological activities capable to support the integration of New Member States and of under-returned countries, in view of a structural effect. Procurement Preferential Clauses will be included in Invitation to Tenders as relevant. Some changes in procurement policy are also possible in the frame of the measures necessary to avoid geo-return deficits in the Science Programme by using available tools in the Agency (e.g. open competition with minimum geo-return requirement to some countries, competition limited to specific countries). In this context, structuring measure activities can baseline a procurement scheme with a competition limited to a specific country. In case this procedure fails in producing acceptable offers, and subject to the programme schedule needs, the Executive may re-issue the Invitation to Tenders by fully opening the competition (still possibly with specific geo-return requirements or Preferential Clauses).

Information relevant to the procurement policy and budgets is generally provided under the remarks column of the Summary Table.

Work Plan Content and Updates

The ESA technology development activities required for the L-Class, M-Class, and F-Class missions (selected and candidate missions) are presented in Summary Tables and a brief description of each activity can be found in the work plan Annexes. Additionally, activities applicable to several missions are listed.

The first Summary Table provides the list of new (or modified) activities planned to be initiated within the year following the work plan approval by the IPC. Activities that are planned to be initiated beyond the one-year horizon following the work plan approval (or beyond the next update of the work plan) can be listed but are provided for information only.

Following the Summary Table for the new activities seeking IPC approval, some additional tables are provided for information, such as:

- Activities under implementation for which urgent additional activities were placed resulting in an increased approved amount herby submitted to IPC for Ratification.

- Activities recommended for implementation under the Member States responsibility. These activities are generally presented in the work plan update that is following their identification and are not recalled in the following updates;

- Activities that have been approved in previous versions of the work plan and are cancelled for a given reason and removed from the work plan.

- Industrial Policy Task Force Activities of relevance to the Science Programme.

The last set of Summary Tables provides a comprehensive overview of the activities seeking approval and those that have been approved from previous work plans and are being implemented. The activities are grouped per mission and some useful status information can be found in the remarks column.

The work plan is a living document with, for each update, new activities being added (submitted for approval) and other activities being removed, since their implementation is completed or because of cancellation.

4 Candidate Missions in the Preparation Phase

Overview of Candidate Missions

This section provides an overview of L-Class, M-Class and F-Class mission candidates that are currently in the preparation phase and requiring technology development activities. More details can be found at: http://sci.esa.int/science-e/www/area/index.cfm?fareaid=100.

4.1.1 L2 Mission: NewAthena

The Athena mission has been selected as L2 addressing the theme "The hot and energetic Universe". Athena is a next-generation X-ray space observatory designed to study the hot, million-degree Universe (e.g. supermassive black holes, evolution of galaxies and large-scale structures and matter under extreme conditions). The observatory concept is based on novel telescope optics with the focal plane instrumentation consisting of a Wide Field Imager (WFI) and Cryogenic X-ray Spectrometer – the X-ray Integral Field Unit (X-IFU). The envisaged launch date is the late 2030s.

NewAthena reformulation is converging on the most promising solution, based on a passive cooling stage (down to 50 K, using V-grooves) to simplify X-IFU instrument, leading to a less expensive mission and instrument cost. The minimum mission scenario features a large X-ray mirror (collecting aperture larger than 1 m2 at 1 keV), a high-performance cryogenic calorimeter for spectral measurements and a wide field imager. Mission adoption could take place in early 2027, provided the mission baseline scenario is confirmed.

4.1.2 L3 Mission: LISA

The LISA mission has been selected for the L3 theme "The gravitational Universe". It consists of a gravitational wave observatory based on laser interferometry to observe gravity waves emitted by compact cosmic sources, and builds on the successful in-orbit demonstration of LISA Pathfinder. The mission concept consists of three identical spacecraft in a quasi-equilateral triangular constellation and located on an Earth trailing orbit. Each spacecraft carries two reference test masses in free fall, and laser interferometry is used for measuring the distance variations between test masses on separate spacecraft. The mission launch is foreseen in the mid 2030s.

4.1.3 M5 Mission: EnVision

Carrying 3 cutting-edge instruments: an S-band Synthetic Aperture Radar (VenSAR), a Subsurface Radar Sounder (SRS) and spectrometer suite covering uv-vis-ir (VenSPEC EM), EnVision will observe the subsurface and surface of Venus and probe its atmosphere at an unprecedented resolution, investigating signs of active geology and looking for evidence of the past existence of oceans. The mission will provide a range of global maps, images, topographic and subsurface data at a resolution rivalling that available for Earth and Mars. EnVision will help in understanding why the most Earth-like planet in the solar system has turned out so differently, opening a new era in the exploration of our closest neighbour. EnVision is proposed as a mission in cooperation with NASA.

4.1.4 M7 Mission Candidates

CALICO (Ceres Autonomous Lander Into Crater Occator) proposes to perform in-situ investigations of the organic and ammoniated materials and salt deposits on the dwarf planet Ceres, potentially offering insights into whether Ceres provides or provided the conditions to support life.

HAYDN (High-precision AsteroseismologY of DeNse stellar fields) is an asteroseismological mission focused on homogenous, controlled large samples of stars in order to provide calibrators for several aspects of fundamental astrophysics, fostering the understanding of stellar physics and the internal structure of stars, inaccessible with other techniques.

M-MATISSE (Mars Magnetosphere Atmosphere Ionosphere and Surface Science) aims to study Mars as a global dynamic system using a 2-spacecraft configuration, targeting atmosphere-ionosphere-magnetosphere-solar wind interactions, and aiming to disentangle spatial and temporal effects on various processes driving the Martian system.

Plasma Observatory is a multi-spacecraft mission to study the coupling of fluid and ion scales within astrophysical plasmas in near-Earth space, advancing the knowledge of particle energisation and energy transfer.

THESEUS (Transient High Energy Sky and Early Universe Surveyor) is a multi-instrument mission for transient astronomy, with focus on Gamma Ray Bursts, aiming at the exploration of the high-redshift Universe through studies of the explosions of the first massive stars and the identification of GW counterparts.

4.1.5 F1 Mission: Comet Interceptor

‘Comet Interceptor’ has been selected as a Fast Mission. Comprising the main spacecraft carrying two small probes, it will be the first to visit a truly pristine comet or other interstellar object that is only just starting its journey into the inner Solar System. The spacecraft will be in waiting mode around SEL2 Lagrange point for a typical duration not exceeding two years, and will travel from there to an as-yet undiscovered comet, making a flyby of the chosen target when it is on the approach to Earth’s orbit. The two small probes will be released close by the comet, performing simultaneous observations from multiple points around the comet, creating a 3D profile of a ‘dynamically new’ object that contains unprocessed material surviving from the dawn of the Solar System. Comet Interceptor is planned in collaboration with JAXA, who intends to provide one of the small probes.

4.1.6 F2 Mission: ARRAKIHS

ARRAKIHS (Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys) will image about one hundred nearby galaxies and their surroundings, using innovative twin binocular assemblies of small telescopes, to characterize the number and nature of low-mass dwarf galaxies and stellar streams in their vicinity. This survey, in visible and infrared wavelengths, will far exceed what is currently possible from ground-based telescopes and will provide the possibility to make tests of the so-called ΛCDM cosmology as well as producing a dataset of significant legacy value.

Technology Themes for Future Missions

A limited fraction of the technology activities are addressing multipurpose generic areas that are applicable to several science missions. They are included in the Technologies Applicable to Several Science Missions section of this plan. The budget used is generally from the TDE, with a small relative contribution of CTP (typically below 20% of CTP budget). Generic activities can also be proposed targeting at structuring geo-return impact in the science programme, in particular for under-returned countries and in New Member States.

5 Critical Technologies

Tables 2, 3 and 4 present the lists of critical technologies that have been identified for selected missions and candidate missions within the Science Programme. This listing includes both ESA and national TDAs.

L2 and L3 Missions		
Mission	Technology Area	Technology Development Activities
Athena	X-ray Optics	Mirror Module ruggedizing and environmental testing
		X-ray optics mass production processes
		Mirror module performance including at inner and outer radii
		Mirror coatings and coating facilities
		Mirror structure
		AIT of mirror modules into structure
		Straylight baffling
		X-ray test facilities upgrading
	Payload	Instrument Selection Mechanism
		Instrument read out electronics (cryogenic)
		Entrance windows and filters

		Detector developments – Wide Field Imager and X-ray Integral Field Unit (X-IFU)
		Performance studies, anti-coincidence methods, radiation and environmental modelling
	Cryogenics	Coolers, superconducting cryogenic harness
		End-to-end cooling chain for transition edge sensor based cryogenic x-ray spectrometer including cryostat

Table 2 L2 Mission Critical Technologies.

Mission	Technology Area	Technology Development Activities
LISA	Payload	Laser system Telescope/Optical Bench Metrology System including backlink and phasemeter Gravitational Reference Sensor and Electronics
	Spacecraft	Micropropulsion

Table 3 L3 Mission Critical Technologies.

M5 Mission		
Mission	Technology area	Technology Development Activities
EnVision	Payload	IDCA detector for Venspec-H
	Spacecraft	Flaps for Aerobraking High temperature MLI Leros-4 High Thrust Apogee Engine, 150W TWTA Ka-Band (32 GHz)

Table 4 M5 Mission: Critical Technologies.

6 Key to Table and Activity Template Fields

The following Table provides a summary of the information contained in the Summary Tables and activity templates.

Field	Description
Programme:	Programme budget foreseen for the activity
IPC Approval:	Indicates approval status of activity. “IPC” means approval of that activity is requested in the current document. “N/A” means e.g. TDA value is below 500kEuro and has had approval if applicable. A year entry e.g. “Y2008” indicates prior IPC/ approval of an activity.
IPC Ratification:	Indicates ratification by the IPC of the total increased Contract amount including CCNs needed to be urgently placed.
Reference:	Unique ESA generated reference for TDA
Activity Title:	Title of the proposed TDA
Budget:	The total budget values are given in kEuro, at current economic conditions. The year for which the budget is intended is specified.
Procurement Policy (PP):	Procurement Types: C = Open Competitive Tender; (Ref. ESA Procurement Regulations) C(1)* = Activity restricted to non-prime contractors (incl. SMEs). C(2)* = A relevant participation (in terms of quality and quantity) of non-primes (incl. SMEs) is required. C(3)* = Activity restricted to SMEs & R&D Entities C(4)* = Activity subject to SME subcontracting clause DN/C = Direct Negotiation/Continuation; the contract will be awarded in continuation to an existing contract; (Ref. ESA Procurement Regulations). DN/S = Direct Negotiation/Specialisation; the contract will be awarded by direct negotiation in implementation of a defined

	industrial policy or resulting from a sole supplier situation; (Ref. ESA Procurement Regulations). DN = Direct Negotiation; the contract will be awarded by direct negotiation in implementation of a defined procurement scheme, such as a structuring measure aiming at geo-return balance. * See ESA/IPC(2009)91,rev.1 Industry has been informed, through the EMITS "News", of the content of that document.
Country:	Indicates the country in the case of a special initiative or direct negotiation.
ITT:	The quarter when the ITT is intended to be issued.
SW Clause Applicability:	Special approval is required for activities labelled: either *"Operational Software"* or *"Open Source Code"*, for which the Clauses/sub-clauses 42.8 and 42.9 ("Operational Software") and 42.10 and 42.11 ("Open Source Code") of the General Clauses and Conditions for ESA Contracts (ESA/REG/002), respectively, are applicable.
Remarks:	Additional information of relevance to the procurement e.g. DN with a specific contractor.
Objectives:	The aims of the proposed TDA.
Description:	Overview of the work to be performed.
Deliverables:	Provides a short description of the tangible outcome e.g. breadboard, demonstrator, S/W, test data. A final report is standard for every activity.
Current TRL:	Describes the current Technology Readiness Level of the product that is going to be developed in this activity.
Target TRL:	The TRL expected for the product at the end of the activity. For equipment TDE usually concludes with TRL 3, CTP at TRL 5/6. However in the case of components target TRL in TDE could be higher. It is also understood that TRLs do not apply to S/W and tools. For these cases description of

	SW quality, i.e.: architecture, beta version, prototype, or full operational, achieved at the end of the activity.
Application Need/Date:	Describes the required TRL and date for the technology development of which the respective activity is part of on the base of the maturity required by the application. The general rule is that a requirement specifies the need date for a product. For equipment/payloads this is in general TRL 5/6, - the level generally required for Phase B of a project. The exceptions are components, where TRL 8 (flight readiness) should be achieved. For S/W and tools separate readiness levels are defined below
Technology Readiness Level Definition used in this Technology Development Plan:	TRL 1 - Basic principles observed and reported TRL 2 - Technology concept and/or application formulated TRL 3 - Analytical and experimental critical function and/or characteristic proof-of-concept TRL 4 - Component and/or breadboard functional verification in laboratory environment TRL 5 - Component and/or breadboard critical function verification in relevant environment TRL 6 – Model demonstrating the critical functions of the element in a relevant environment TRL 7 – Model demonstrating the element performance for the operational environment TRL 8 - Actual system completed and accepted for flight ("flight qualified") TRL 9 - Actual system "flight proven" through successful mission operations
Technology Readiness Levels for S/W and Tools	Algorithm: Single algorithms are implemented and tested to allow their characterisation and feasibility demonstration.

	Prototype: A subset of the overall functionality is implemented to allow e.g. the demonstration of performance. Beta Version: Implementation of all the software (software tool) functionality is complete. Verification & Validation process is partially completed (or completed for only a subset of the functionality). S/W Release: Verification and Validation process is complete for the intended scope. The software (software tool) can be used in an operational context.
Application Mission:	Possible mission application/follow-on.
Contract Duration:	Duration of the activity in months.
Consistency with Harmonisation Roadmap and Conclusion:	Identifies the related Harmonisation Roadmap Requirement

Table 5 Technology Development Plan Field Description.

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Annex 0

7 New Activities Budget Summary Table

	Programme	2023	2024	2025
L2-Mission: New Athena	CTP	8000	0	0
	TDE	0	0	0
	TOTAL	**8000**	**0**	**0**
L3-Mission: LISA	CTP	2200	0	0
	TDE	0	500	0
	TOTAL	**2200**	**500**	**0**
L4-Mission: Moons of the Giant Planets	CTP	0	0	0
	TDE	700	0	0
	TOTAL	**700**	**0**	**0**
M5-Mission: EnVision	CTP	600	0	0
	TDE	0	0	0
	TOTAL	**600**	**0**	**0**
M7-Mission candidates	CTP	2000	0	0
	TDE	0	0	0
	TOTAL	**2000**	**0**	**0**
Several missions	CTP	950	0	0
	TDE	0	5500	0
	TOTAL	**950**	**5500**	**0**
IPTF Structuring Activities	CTP	150	0	0
	TOTAL	**150**	**0**	**0**
Total CTP (including IPTF)		**13900**	**0**	**0**
Total TDE		**700**	**6000**	**0**
Total ESA		**14600**	**6000**	**0**

This table provides a summary of the budgets for new activities in 2023, 2024 and 2025 for missions in preparation.

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Annex I

8 List of ESA Science Programme Technology Development Activities

This annex contains per mission a complete listing of the technology development activities that are both running and planned.

Also included for information is a listing of activities funded through the Industrial Policy Task Forces that are of relevance to the Science Programme.

Annex II contains detailed activity descriptions.

Summary of all new esa activities including those seeking approval for implementation

8.1.1 L2-Mission: NewAthena

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2023	Budget 2024	Budget 2025	PP	Country	SW Clause	Remarks
CTP	IPC	C216-181FT	Silicon Pore Optics process consolidation for reformulated Athena	8000	0	0	DN/C	NL	N/A	CCN 13 to cosine SPO Contract 4000107655. Bringing the approved amount to 51778 kEuro.
CTP	N/A	C204-134FT	Adaptation of the charged particle diverter system to the new configuration of Athena	150	0	0	DN/C	CZ	N/A	Frentech. Structuring activity for Czech Republic. Will be included in the next CZ-IPTF. Continuation of C204-119FM and C204-128FI. Bringing the approved amount for contract 4000123540 to 850 kEuro.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
Total – L2-Mission: NewAthena				**CTP:8000 TDE:0 IPTF:150**	**0**	**0**	**8500 Total = 8000 CTP + 0 TDE + 500 IPTF**			

8.1.2 L3-Mission: LISA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	IPC	T217-076MM	In-situ detection and alert system for micron-sized particle contamination on laser optical surfaces during AIT	0	500	0	C		N/A	
CTP	IPC	C219-014FT	Novel Manufacturing Technologies for Low-Noise Pressure Regulators	1000	0	0	DN/S	AT	N/A	RHP Technology. Structuring measure to Austria.
CTP	IPC	C219-015MP	Delta-developments of heritage Cold Gas Micro-thruster for LISA – CCN	1200	0	0	DN/C	IT	N/A	Leonardo. Possibly to be implemented as CCN to current contract 4000125100 bringing the approved amount

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
										to a total of 2700kEUR
Total – L3-Mission: LISA				**CTP:2200 TDE:0**	**CTP:0 TDE:500**	**0**	**2700 Total = 2200 CTP + 500 TDE**			

8.1.3 M5-Mission: EnVision

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	IPC	C203-117EP	Solar Cells for EnVision – Life test extension	600	0	0	DN/C	DE	N/A	ADS. Follow up as CCN to activity C203-115EP. Bringing the approved amount for contract 4000141226 to a total of 1400 kEuro
Total – M5-Mission: EnVision				**CTP:600 TDE:0**	**0**	**0**	**600 Total = 600 CTP + 0 TDE**			

8.1.4 L4-Mission: Moons of the Giant Planets

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	Y2021	T203-122FM	Spin in of Terrestrial Solid Oxide Fuel Cell (SOFC) Technology for Outer Planet Exploration Power Generation	700	0	0	C	DE	N/A	Fraunhofer-Gesellschaft This is a parallel contract of an activity already approved in 2021 (T203-120NA).
Total – L4-Mission: Moons of the Giant Planets				**CTP:0 TDE:700**	**CTP: 0 TDE:0**	**0**	**700 Total = 0 CTP + 700 TDE**			

8.1.5 M7-Mission Candidates: CALICO, HAYDN, M-MATISSE, Plasma Observatory, and THESEUS

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	IPC	C217-102FI	CIS300 Detector Radiation and Performance Testing	1000	0	0	DN/S	UK	N/A	Teledyne e2v Structuring activity to UK. Activity needed for HAYDN but also other missions.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	IPC	C217-101FI	CMOS Image Sensor for X-ray Applications – CCN	1000	0	0	DN/C	UK	N/A	Open University Structuring activity to UK. To be implemented as follow up to 4000133151 if THESEUS is selected as M7 candidate.
Total – M7-Mission Candidates				**CTP:2000 TDE:0**	**CTP: 0 TDE: 0**	**0**	**2000 Total = 2000 CTP + 0 TDE**			

8.1.6 Technologies Applicable to Several Science Programme Missions

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	N/A	T205-130SA	Augmented inertial navigation solutions for medium-accuracy landing	0	350	0	C		N/A	
TDE	IPC	T220-057MS	Consolidation of CFRP Anisogrid Tubes and Booms for Science Missions	0	600	0	DN/S	DK	N/A	Space Composite Structure Structuring activity for Denmark

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	N/A	T207-069EP	Electrically Conducting Thermal Insulators	0	250	0	C		N/A	
TDE	IPC	T207-070EP	Modelling and Prediction of Magnetic Field Perturbations by Thermo-Electric Effects	0	350	0	DN/S	RO	Open source code	Cluj-Napoca Structuring activity for Romania.
TDE	N/A	T223-104ED	Reliability of electronic assemblies in cryogenic environment	0	400	0	C		N/A	
CTP	AC	C205-129SA	Enhancements of Radiation Hard Gyroscope for Science Missions	400	0	0	DN/C	IE	N/A	INNALABS. Structuring activity for Ireland. To be procured as CCN to C205-114SA bringing the approved amount for contract 4000123078 to 4MEuro
TDE	N/A	T214-003FI	Lab-on-a-Chip Instrument for Future Planetary Missions	0	200	0	C		N/A	
TDE	N/A	T205-129SA	Ultra-High performance gyroscope for future X-ray Interferometer missions	0	300	0	C(2)		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	AC	T215-020EP	Magnetically clean rotary actuator for optical bench application	0	400	0	DN/S	DK	N/A	PCBMotor Structuring activity for Denmark.
TDE	N/A	T224-012QE	Development of an in orbit cleaning tool for optical instruments	0	350	0	C		N/A	
TDE	N/A	T204-140EP	Advanced demagnetisation methods	0	250	0	C(2)		N/A	
TDE	AC	T216-175FT	Optical element to focus soft gamma rays	0	300	0	DN/S	NL	N/A	Cosine
TDE	IPC	T217-077MM	Germanium on Silicon CCD structure development	0	500	0	DN/C	UK	N/A	Teledyne e2v
CTP	IPC	C217-103FT	Evaluation of infrared linear mode avalanche photodiode arrays for time delay integration type operation	550	0	0	DN/S	UK	N/A	Cambridge University Structuring activity for UK.
TDE	N/A	T206-025ES	In-flight adaptive pre-distortion techniques for TT&C subsystems with high-order modulations	0	400	0	C		N/A	
TDE	IPC	T206-026EF	Improved TT&C Sub-System Architecture	0	650	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	N/A	T204-141EP	Saturn Moons Environment Models and their effects on spacecraft	0	200	0	C		N/A	
Total – Technologies Applicable to Several Science Programme Missions				**CTP: 950 TDE:0**	**CTP:0 TDE: 5500**	**0**	**9100 Total = 950 CTP + 5500 TDE + 2650 IPTF**			

8.1.7 Modified or Cancelled Activities

Prog.	IPC App.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	IPC	C226-001FM	Adaptation of small satellite technologies for deep space applications	0	0	0	DN	DK	N/A	Initially approved in 2018. The initial budget of 3.9 MEuro has been reduced by ~1.9 MEuro due to the cancelation of Phase 3.
CTP	IPC	C206-026NA	150 W 32 GHz TWT EM for Payload Data Transmitter	0	0	0	C		N/A	Activity already approved at the IPC in November 2021. The title has been changed due to a

Prog.	IPC App.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
										typo from “120 W 32 GHz TWT EM for Payload Data Transmitter” to “150 W 32 GHz TWT EM for Payload Data Transmitter”

8.1.8 Existing Activities with enhancements placed raising the approved Contract amount for IPC ratification

This new table is added to this document in order to enhance visibility of the implementation progress and the resulting total contract amount for approved activities hereby submitted to IPC for Ratification. This is applied to urgent activities implemented recently.

Prog.	IPC App.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
TDE	N/A	C216-177FT	Silicon Pore Optics consolidation during the transition period towards the implementation phase	1000	0	0	DN/C	NL/UK	N/A	CCN to C216-177FT with Cosine(NL) for Teledyne E2V (UK). Structuring measure to the UK aiming at Teledyne E2V contribution to the

Prog.	IPC App.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
										NewAthena optics bringing the approved contract number 4000107655 amount to 43,779 kEuro
CTP	N/A	C221-017FT	Graphene based thermal straps	98	0	0	DN/C	FI	N/A	CCN to C221-017FT has been placed. The running activity with the contract number 4000127886/19/NL/HB has now a total contract value of 598 kEur. Structuring measure to Finland.

8.1.9 Industrial Policy Task Force Activities of relevance to the Science Programme

This table includes IPTF activities that are of relevance to the Science Programme. The first activity C220-054FT has been approved by IPC [ESA/IPC(2023)33], the activities C217-100FT and C206-027FM have been approved by IPC (ESA/IPC(2023)85), while the last activity (C204-134FT) is planned to be submitted to the next IPTF. The justifications for DN, if applicable, are provided at the end of the document.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	Y2023	C220-054FT	Delta qualification of CFRP and Aluminium skin panels	800	0	0	DN	PL		Structuring measure to Poland. DN/S with the company SCNTPL
CTP	Y2023	C217-100FT	High performance x-ray source for compact x-ray facility	350	0	0	DN/S	PL	N/A	Auxilia. Structuring activity for Poland. Approved by PL-IPTF
CTP	Y2023	C206-027FM	X-band transponder qualification finalisation	2650	0	0	DN/C	NO	N/A	Kongsberg. Structuring activity for Norway. Approved by NO-IPTF. Bringing the approved amount of contract 4000128298 to 11.86MEuro.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2023	2024	2025				
CTP	N/A	C204-134FT	Adaptation of the charged particle diverter system to the new configuration of Athena	150	0	0	DN/C	CZ	N/A	Frentech. Structuring activity for Czech Republic. Will be included in the next CZ-IPTF. Continuation of C204-119FM and C204-128FI. Bringing the approved amount for contract 4000123540 to 850 kEuro.
Total – IPTF funded activities of relevance to the Science Programme				**IPTF: 3950**	**0**	**0**	**3950 Total**			

Complete list of running and planned activities

The following tables are a complete list of those activities which are:

- Running since 2019 i.e. activities for which contracts have been signed.
- In preparation for implementation.
- Foreseen to be implemented up to and including 2024.

The tables are grouped by:

- Activities for candidate missions in the science programme that are under preparation.
- Activities applicable for several science programme missions.
- Activities for missions in the science programme that are in implementation.

8.1.10 Candidate Missions in Preparation

8.1.10.1 L2-Mission: NewAthena

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	IPC	C216-181FT	Silicon Pore Optics process consolidation for reformulated Athena	0	0	8000	0	0	DN/C	NL	N/A	CCN 13 to cosine SPO Contract 4000107655. Bringing the approved amount to 51778 kEuro.
CTP	N/A	C204-134FT	Adaptation of the charged particle diverter system to the new configuration of Athena	0	0	150	0	0	DN/C	CZ	N/A	Frentech. Structuring activity for Czech Republic. Will be included in the next CZ-IPTF.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
												Continuation of C204-119FM and C204-128FI. Bringing the approved amount for contract 4000123540 to 850 kEuro.
CTP	Y2023	C217-100FT	High performance x-ray source for compact x-ray facility	0	0	350	0	0	DN/S	PL	N/A	Auxilia Structuring activity for Poland. Approved by PL-IPTF.
CTP	Y2022	C216-180FT	Panter beam time provision - continuation	0	1000	0	0	0	DN/C	DE	N/A	Implemented as a CCN to C216-142MM (4200023066) with MPE (DE). Bringing the approved amount to 3150 kEuro.
CTP	Y2022	C216-001MS	ATHENA FMS demonstration	0	1700	0	0	0	C	AT	N/A	Structuring measure to AT. 1000 kEuro approved as procurement proposal for C216-001MS ESA/IPC(2021)81, rev.1. Additional 700 kEuro required

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												bringing the total contract value to 1700 kEuro.
CTP	Y2021	C216-009MM	SPO AIT facility implementation - CCN	0	355	0	0	0	DN/C			Implemented as a CCN to C216-163FT. Bringing the total approved value of contract number 4000114931 to 5892 kEuro. DN with Media Lario (IT)
CTP	Y2021	C216-002MS	Implementation of the MAM MGSE for x-ray testing at XRCF - CCN	0	600	0	0	0	DN/C	DE	N/A	To be implemented as a CCN to C216-142MM (4000128450)
CTP	Y2021	C200-004MS	Characterisation of thermal and mechanical performance of SIM cryostat straps	300	0	0	0	0	OC	CZ	N/A	Open competition restricted to CZ
CTP	Y2020	C204-133EP	Athena High-Energy Particle Monitor	400	0	0	0	0	C			TDA is running. CAU (DE)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
			(AHEPaM) Interface Definition									
CTP	Y2014	C204-110EE	Athena Radiation Environment Models and X-ray Background Effects Simulators	0	0	0	0	0	C(3)	IT	Open Source Code	TDA is running. INAF (IT) + subs. 600 kEuro in 2016.
TDE	Y2015	T204-120EE	Focussing of Micrometeoroids in X-ray optics	0	0	0	0	0	C(3)	DE	N/A	TDA is running Uni. Stuttgart (DE) + subs 600 kEuro in 2016.
CTP	Y2017	C204-119FM	Athena - Magnetic Diverter	0	0	0	0	0	C	CZ	N/A	TDA is running. Frentech Aerospace S.R.O. (CZ)
CTP	Y2021	C204-129MS	ATHENA SIM structural large metallic parts	380	0	0	0	0	DN/S	CZ	N/A	DN with Frentech
CTP	Y2019	C204-128FI	Maturation of the ATHENA Charged Particle Diverter System	0	0	0	0	0	DN/C	CZ	N/A	To be possibly implemented as a CCN to C204-119FM (previous total contract number 4000123540 price 500 k). DN with Frentech Aerospace S.R.O. (CZ).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2018	C204-123FT	Characterisation of micro-meteoroid induced dark current increase in silicon detectors	0	0	0	0	0	C		N/A	
TDE	Y2016	T209-001EC	Autonomous Targets of Opportunity for astronomy missions	0	0	0	0	0	C	ES	N/A	TDA is running. GMV (ES) + subs
CTP	Y2016	C215-128FM	Athena Hold Down Release Mechanism	0	0	0	0	0	C	PL	N/A	TDA is running, contract placed for 800k in 2019 to Sener (PL). Competition limited to Poland Structuring activity for PL
CTP	Y2022	C215-037MS	ATHENA ISM hexapod based on linear actuators	0	800	0	0	0	DN/C	PL	N/A	Previously approved in 2021. Procurement policy changed. Implemented as a CCN to 4000137851 with Astronika. Bringing the approved amount to 1040 kEuro.
CTP	Y2019	C215-138MS	Athena ISM launch vibration damper	0	0	0	0	0	DN/C	PL	N/A	TDA is running CCN to C220-038FM and

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												follow-up. DN with Sener (PL) (previous total contract price 1200 k).
CTP	Y2022	C215-141MT	15 K Pulse Tube Cryocooler Unit Engineering Model developments phase 1	0	0	0	0	0	DN/C	FR	N/A	Already approved. DN/C with ALAT. Budget reduced to 1500 kEuro for reduced scope.
CTP	Y2015	C216-136MM	Silicon Pore Optics Ruggedisation and Testing - Phase 3	0	0	0	0	0	DN/C	NL	N/A	TDA is running. DN with cosine (NL). 3000 kEuro in 2016. This activity is implemented as a CCN to C216-006MM, price 1000 kEuro. Phased activity with Phase 1 1200 kEuro and Phase II 1800 kEuro (total current contract price 4200 k).
CTP	Y2018	C216-160FT	Silicon Pore Optics modelling and simulations for telescope	0	0	0	0	0	DN/C	IT	Open Source	TDA is running. CCN to C216-132FT, (total current contract price 800 kEuro).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												DN with INAF/OAB (IT)
CTP	Y2022	C216-177FT	Silicon Pore Optics consolidation during the transition period towards the implementation phase	0	8000	0	0	0	DN/C	NL	N/A	CCN to C216-177FT with Cosine(NL) for Teledyne E2V (UK). Structuring measure to the UK aiming at Teledyne E2V contribution to the NewAthena optics bringing the approved contract number 4000107655 amount to 43,779 kEuro
CTP	Y2020	C216-164FT	Silicon Pore Optics Consolidation for the ATHENA Mission Adoption	8500	0	0	0	0	DN/C	NL	N/A	Continuation of C216-117MM and follow on to C216-125M, C216-140MM, C216-128MM, C216-148MM, and C216-149MM. Cosine SPO placed as CCN to 4000107655
CTP	Y2019	C216-149MM	Silicon Pore Optics Engineering Qualification Model	0	0	0	0	0	DN/C	NL	N/A	TDA is running. DN with Cosine (NL) led consortium

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2019	C216-163FT	Implementation of the long lead items for the Ultraviolet Vertical Integration Facility for the integration of the Athena Mirror Assembly	0	0	0	0	0	DN/C	IT	N/A	TDA is running. Implemented as a CCN to C216-127MM and C216-141MM (total 2730 kEuro). DN with Media Lario (IT). Contract placed for 1850 kEuro.
CTP	Y2018	C216-162FT	Figuring of Large Precision UV Optics	0	0	0	0	0	DN	FI	N/A	TDA is running. Structuring activity for Finland. DN with Opteon Oy (FI)
CTP	Y2019	C216-007MM	Telescope mirror structure and optics integration demonstrator	0	0	0	0	0	C		N/A	TDA is running with ADS, total contracted amount 2800 kEuro
CTP	Y2019	C216-007MM-B	Telescope mirror structure and optics integration demonstrator	0	0	0	0	0	C		N/A	TDA is running with TAS, total contracted amount 2800 kEuro
CTP	Y2020	C216-174FT	Diamond like coating device	450	0	0	0	0	DN/S	RO	N/A	TDA is running. Structuring Activity for Romania. Unique capability confirmed with sample tests. DN

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												with The Plasma Coatings Research Group of the National Institute for Laser, Plasma & Radiation Physics (INFLPR) in Romania.
CTP	Y2022	C216-178FT	Synchrotron beam time and monochromator beamline maintenance - continuation	0	400	0	0	0	DN/C	DE	N/A	To be implemented as a CCN to 4200019338
CTP	Y2018	C216-161FT	Synchrotron beam time and monochromator beamline maintenance continuation	0	0	0	0	0	DN/C	DE	N/A	TDA is running. CCN to C216-129FT. Continuation to cover additional 4 years. DN with PTB (DE) (total current contract price 2440 k).
CTP	Y2016	C216-142MM	X-ray facility design and verification for the Athena flight mirror performance testing and calibration	0	0	0	0	0	DN/C	DE	N/A	TDA is running. DN with MPE (DE) CCN to C216-131FT (total current contract price 2150 kEuro).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2017	C216-153MM	Advanced and Compact X-ray Test Facility for the Athena SPO module	0	0	0	0	0	DN/C	IT	N/A	TDA is running. DN with INAF/OAB (IT)
CTP	Y2016	C216-150FT	Panter beam time provision	0	0	0	0	0	DN/C	DE	N/A	TDA is running. DN with MPE (DE) CCN to C216-131FT (total current contract number 4200023066 price 3150 k Euro).
CTP	Y2019	C216-168FT	ALBA fixed energy beamline	0	0	0	0	0	DN/S	ES	N/A	TDA is running with ALBA Synchrotron (ES)
CTP	Y2019	C216-170FI	Low-Energy X-ray Coating Development and plate production improvements for the ATHENA SPO plates	0	0	0	0	0	DN/C	NL,DK, UK	N/A	Implemented as a CCN to C216-135MM and C216-166FT (previous total contract price 3600 kEuro), bringing the total to 4800 kEuro
TDE	Y2019	T216-171FT	Carbon nanotube-based filters for x-ray applications	0	0	0	0	0	DN/C	FI	N/A	To be possibly implemented as a CCN to T217-061MM (previous total contract number 4000120250

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												price 1500 kEuro), bringing the total value to 2000 kEuro.
CTP	Y2019	C216-173FT	Figuring of Large Precision UV optics - CCN	0	0	0	0	0	DN/C	FI	N/A	CCN to C216-162FT. Funded through the Work Plan of the Industrial Policy Task Force with Finland. Bringing the total approved value to 2975 kEur (see ESA-IPC(2021)81rev1).
CTP	Y2022	C216-176FT	Implementation of the critical items to increase the robustness and extend the use of the BEATRIX facility to lower x-ray energies	0	250	0	0	0	DN/C	IT	N/A	Implemented as a CCN to 4000123152, bringing the total amount to 850 kEuro.
TDE/CTP	Y2019	C216-172FT	Demonstration of critical items for x-ray scanning facility	0	0	0	0	0	DN/C	IT	N/A	Implemented as a CCN to T216-110FT (300 k). TDE (500 k) contribution to CTP (2000 k). Bringing the total approved value to

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
												2950 kEur (see ESA-IPC(2021)81rev1).
CTP	Y2019	C217-067FM	Athena On Board Metrology	0	0	0	0	0	C	PT	N/A	TDA is running. Contract with FCUL Structuring activity for Portugal. Competition limited to Portugal.
CTP	Y2015	C217-043FM	Optimization of a European Transition Edge Sensor Array - Large Array Production and Testing	0	0	0	0	0	DN/C	NL	N/A	TDA is running. SRON (NL) 1000 kEuro in 2016.
CTP	Y2018	C217-044FM	Large Area European Transition Edge Sensor Array for X-Ray missions	0	0	0	0	0	DN/S	NL	N/A	Implemented as a CCN to C217-043FM, C217-031FI, (total contract price 1672 kEuro). DN with SRON (NL).
CTP	Y2016	C217-065FM	Athena Superconducting Quantum Interference Device Readout Development	0	0	0	0	0	DN/S	FI	N/A	TDA is running. DN with University of Helsinki (FI)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2019	C217-097FM	Athena SQUID Amplifier Qualification	0	0	0	0	0	DN/C	FI	N/A	To be possibly implemented as a CCN to C217-065FM (total previous 4000123669 contract price 1190k). Funded through the Work Plan of the Industrial Policy Task Force with Finland. In ESA/IPC(2019)74.rev. 1] approved in two slices - slice 1: 1760 kEuro, slice 2: 240 kEuro, Ref code updated. DN with University of Helsinki Finland.
CTP	Y2016	C220-041FM	Athena Focal Plane Module Development Model	0	0	0	0	0	C	PL	N/A	TDA is running. TAS (PL) Structuring activity for PL
CTP	Y2014	C220-038FM	Athena Instrument Selection Mechanism	0	0	0	0	0	C	PL	N/A	TDA is running. SENER (PL) + sub. 1200 kEuro in 2016.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2014	C221-005FI	Cryogenic vibration isolators and thermal disconnects	0	0	0	0	0	C(1)	ES	N/A	TDA is running. MAG SOAR (ES) + subs. 1000 kEuro in 2014.
TDE/ CTP	Y2020	T215-017MS	High performance microvibration isolation system (continuation)	500	300	0	0	0	DN/ C	UK	N/A	Implemented as CCN to T215-011MS. Total contract amount 1206 kEuro.
CTP	Y2014	C221-006FI	Superconducting multilayer flex harness	0	0	0	0	0	C(3)	FR	N/A	TDA is running. CEA (FR) + sub. 300 kEuro in 2016.
CTP	Y2014	C221-007FM	Low vibration 15K Pulse Tube engineering model cooler including cooler drive electronics	0	0	0	0	0	C	FR	N/A	TDA is running. ALAT (FR) + subs 2000 kEuro in 2016.
CTP	Y2021	C221-019MT	Industrialization of the Joule Thomson cooler mechanical assembly	4500	0	0	0	0	DN/ S	UK	N/A	To be possibly implemented as a CCN to C221-008FM, C221-009FM (previous total contract number price 2395 kEuro) through several CCNs to Contract 4000121153 depending on the

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												evolution of NewAthena. DN with RAL (UK) and sub : Honeywell Hymatic (UK). Phased Contract anticipated.
CTP	Y2016	C221-010MT	Athena Wide Field Imager Loop Heat Pipe Engineering Model Development	0	0	0	0	0	C	FR	N/A	TDA is running. Airbus D&S (FR)
CTP	Y2017	C221-012FT	Low temperature radiator panel with embedded heat pipes	0	0	0	0	0	DN	LU	N/A	Direct negotiation with Eurocomposites (LU) Structuring activity for Luxembourg.
CTP	Y2019	C221-020MT	Low temperature radiator panel with embedded heat pipes - CCN	0	0	0	0	0	DN	LU	N/A	Structuring activity for Luxembourg
TDE	Y2019	T221-113FT	Feedthroughs with low thermal parasitic loads for cryogenic applications	0	0	0	0	0	C		N/A	Targeting Athena, but relevant for other cryogenic missions.
TDE	Y2019	T221-114FT	High Temperature Superconductor Harness	0	0	0	0	0	C		N/A	Targeting Athena, but also relevant for SPICA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
			for use in cryogenic applications									
TDE	2019	T221-020MT	Characterisation of Helium Joule-Thomson Vapour Cooling with Return Line	0	0	0	0	0	C		N/A	Targeting Athena, but relevant for other cryogenic missions.
CTP	Y2018	C223-057FI	Customisation of the qualification of components for science missions	0	0	0	0	0	DN	FI	N/A	TDA is running. Structuring activity for Finland. DN with RUAG (FI)
Total – L2-Mission: NewAthena				**CTP: 14080 TDE: 500**	**CTP: 13105 CTP/TDE: 300**	**CTP: 8150 TDE: 0**	**0**	**0**	**36135 Total = 35335 CTP + 800 TDE**			

8.1.10.2 L3-Mission: LISA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
TDE	IPC	T217-076MM	In-situ detection and alert system for micron-sized particle contamination on laser optical surfaces during AIT	0	0	0	500	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	IPC	C219-014FT	Novel Manufacturing Technologies for Low-Noise Pressure Regulators	0	0	1000	0	0	DN/S	AT	N/A	RHP Technology Structuring measure to Austria.
CTP	IPC	C219-015MP	Delta-developments of heritage Cold Gas Micro-thruster for LISA - CCN	0	0	1200	0	0	DN/C	IT	N/A	Leonardo. Possibly to be implemented as CCN to current contract 4000125100 bringing the approved amount to a total of 2700kEUR
TDE	Y2021	T201-052ED	High-Speed High Resolution Quad-ADC for Science Instruments	0	200	0	0	0	C	IE/PT	N/A	Activity approved IPC 2020. Not successful under DN (S3/Adesto IE/PT), TDA updated to C with budget increase from 500 kEuro to 700 kEuro
CTP	Y2018	C201-037FT	LISA Phasemeter Unit Development	0	0	0	0	0	DN	DK	N/A	TDA is running. Structuring activity for Denmark. DN with DTU Space (DK)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2019	T204-125EP	Test mass charging toolkit and LPF lessons learned	0	0	0	0	0	C		Open Source	TDA is running with Univ. Trento (IT)
CTP	Y2017	C204-120EP	Development and validation of a contamination package in SPIS for Liquid based Electrical Propulsion systems for LISA	0	0	0	0	0	C	FR	Open Source	TDA is running. ONERA (FR) + subs 200 kEuro in 2018
TDE	Y2021	T205-126NA	Response Time Improvement of Micro-Propulsion Thrusters for Precise Science Missions	0	400	0	0	0	DN/S	IT	N/A	TDA to be implemented with Leonardo
TDE	Y2022	T205-127SA	Optimal actuation algorithm for test mass suspension control in drag-free missions	0	250	0	0	0	C		N/A	
TDE	Y2016	T205-033EC	Assessment and Preliminary Prototyping of a Drag Free Control System for the L3 Gravity Wave Observatory	0	0	0	0	0	C(1)	IT	N/A	300 kEuro in 2016. TDA is running. Politecnico di Torino (IT) & subs.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2019	T208-022MM	Straylight LIDAR OGSE verification tool, hardware pre-development	0	0	0	0	0	C		N/A	
TDE	Y2019	T215-016FT	Development of prototype Active Aperture Mechanism for LISA	0	0	0	0	0	C		N/A	TDA is running with OHB (DE)
CTP	Y2019	C215-137FT	LISA Optical Assembly Tracking Mechanism Development	0	0	0	0	0	C		N/A	1500 kEuro in 2019. TDA is running. Parallel contracts placed with Sener (PL) 4000138648 and OHB (DE) 4000138660.
CTP	Y2019	C215-136FT	Antenna Pointing Mechanism for the LISA High-Gain Antenna - Concept and Verification	0	0	0	0	0	C		N/A	TDA is running. Parallel contracts placed with ADS (UK) 4000138714 and SENER (PL) 4000138642.
CTP	Y2018	C216-164MM	Molecular contamination de-risking activities for LISA	0	0	0	0	0	C(3)		N/A	TDA is running with DLR (DE)
TDE	Y2021	T217-074NA	High-power fibre-coupled optical switch for space applications	0	500	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Coun try	SW Cla use	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2012	C217-030MM	High-power laser system for eLISA	0	0	0	0	0	DN/S	PT	N/A	TDA is running. DN with LUSOSPACE (PT) + subs. Special Measure for PT. 3000 kEuro in 2014
CTP	Y2018	C217-084FT	Photonic components analysis in support of the LISA laser system development	0	0	0	0	0	DN/S	IE	N/A	TDA is running. Structuring activity for Ireland. DN with Tyndall (IE)
CTP	Y2019	C217-092FI	Photonic Components analysis in support of the LISA laser system development	0	0	0	0	0	DN/S	IE	N/A	(CCN to C217-084FT) total budget (400k + 200k CCN), funded through the Work Plan of the Industrial Policy Task Force with Ireland. TDA is running.
CTP	Y2019	C217-088FI	Gravitational Wave Observatory Metrology Laser - CCN	0	0	0	0	0	DN/C	DE	N/A	Continuation of C217-046FM
CTP	Y2019	C217-095FI	LISA Laser System Performance Metrology	0	0	0	0	0	DN/S	CH	N/A	TDA is running with CSEM (CH)
CTP	Y2015	C217-045FM	Phase Reference Distribution for Laser Interferometry	0	0	0	0	0	C(2)	DE	N/A	TDA is running. Max Planck Institute for Gravitational Physics

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												(DE) 1200 kEuro in 2016.
TDE	Y2017	T217-066MM	Hollow core fibre gas cell for laser frequency stabilisation (I2 and C2HD)	0	0	0	0	0	C	DK	N/A	TDA is running. Structuring activity for Denmark. Direct negotiation with DMU (DK). 100 kEuro in 2019
CTP	Y2019	C217-089FI	Laser Pre-stabilisation System for the LISA Mission	0	0	0	0	0	DN/S	UK	N/A	DN with NPL (UK)
TDE	Y2021	T219-004NA	Assessment and Breadboarding of Pressure Regulator Alternatives for Micropropulsion Systems	0	400	0	0	0	C		N/A	
CTP	Y2020	C219-012MP	Delta-developments of heritage Cold Gas Micro-thruster for LISA	1500	0	0	0	0	DN/C	IT	N/A	Implemented as CCN to running activity with Leonardo (C219-011MP and C219-009MP). Total new budget 2000 kEuro (250k+250k+1500k). Activity intended to

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												preserve and enhance cold gas micropropulsion for LISA needs
TDE	N/A	T217-072MT	Optical fiber micro-Kelvin temperature sensor network for sensitive optical payloads	400	0	0	0	0	C			
CTP	Y2017	C221-016MT	Enhanced temperature measurement for LISA	0	0	0	0	0	C	ES	N/A	TDA is running, IIEEC (ES) with parallel contracts
CTP	Y2017	C221-016MT-B	Enhanced temperature measurement for LISA (B)	0	0	0	0	0	C	DK	N/A	TDA is running, TERMA (DK) parallel contracts
TDE	Y2022	T221-017MT	High Performance Time-Domain based Temperature Diagnostics for Science Missions	0	500	0	0	0	DN/S	DK	N/A	Continuation of activity C221-016MT-B
TDE	N/A	T207-064EP	Advanced DC and AC Magnetic Verification	400	0	0	0	0	C		N/A	
CTP	Y2021	C217-076MM	Delta Development Assessment of the LISA GRS GPR mechanism	450	0	0	0	0	DN/S	IT	N/A	DN with OHB Italy with RUAG (CH) as potential subcontractor

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2022	C215-143FT	Delta Development Assessment of the LISA GRS GPR mechanism - CCN	0	490	0	0	0	DN/C	IT	N/A	
Total – L3-Mission: LISA				**CTP: 1950 TDE: 800**	**CTP: 490 TDE: 2250**	**CTP: 2200 TDE: 0**	**CTP:0 TDE:500**	**0**	**6990 Total = 3440 CTP + 3550 TDE**			

8.1.10.3 L4-Mission: Moons of the Giant Planets

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2021	T203-122FM	Spin in of Terrestrial Solid Oxide Fuel Cell (SOFC) Technology for Outer Planet Exploration Power Generation	0	0	700	0	0	C	DE	N/A	Fraunhofer-Gesellschaft. This is a parallel contract of an activity already approved in 2021 (T203-120NA).
TDE	Y2022	T215-019MP	Lightweight Thrust Mechanism for Large Engines Configurations (LiTMEC)	0	0	600	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2022	T221-115MT	Heat Recovery and Thermal Management Sub-System for Deep Space Missions	0	0	500	0	0	C		N/A	
TDE	Y2022	T203-121EP	Adaptation of Existing Solar Arrays for Missions to Saturn	0	300	0	0	0	C		N/A	
TDE	Y2022	T205-128SA	De-risking active damping of large flexible appendages in the AOCS loop for planetary missions	0	0	300	0	0	C		N/A	
TDE	Y2022	T204-138EP	Particle radiation modelling for interplanetary missions extending to low energies	0	0	300	0	0	C		NA	
TDE	Y2022	T204-139EP	Dust Model for the Saturnian System	0	0	300	0	0	C		NA	
Total – L4-Mission: Icy moons of Giant Planets, Voyage 2050				**0**	**CTP:0 TDE: 300**	**CTP:0 TDE: 2700**	**CTP:0 TDE: 0**	**0**	**3000 Total = 0 CTP + 3000 TDE**			

8.1.10.4 M5-Mission: EnVision

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	IPC	C203-117EP	Solar Cells for EnVision - Life test extension	0	0	600	0	0	DN/C	DE	N/A	ADS. Follow up as CCN to activity C203-115EP. Bringing the approved amount for contract 4000141226 to a total of 1400 kEuro
CTP	Y2022	C217-099FM	MRO EM test campaign and critical process / parts qualification	0	0	1000	0	0	DN/S	HU	N/A	DN with BHE (HU). Structuring measure to Hungary.To be possibly placed as CCN to 4000140456, bringing the total amount to 1200 kEuro
CTP	Y2022	C203-115EP	Solar Cells for EnVision - de-risking activity under representative environment, at coupon level	0	800	0	0	0	C		N/A	
CTP	Y2021	C203-114NA	Solar Cells for EnVision - de-risking activity under representative environment	0	200	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2021	2022	2023	2024	2025	PP	Country	SW Clause	Remarks
TDE	Y2021	T204-135NA	Update of the Venus Climate Database for Improved Atmospheric Predictability	0	130	0	0	0	DN/C	FR	Open Source	Follow up to T204-129EP (150 kEuro) Neutral atmosphere models for future missions
TDE	Y2019	T204-129EP	Neutral atmosphere model for future science missions	0	0	0	0	0	C		Open Source	
TDE	Y2019	T205-121SA	Control/structure co-design for planetary spacecraft with large flexible appendages	0	0	0	0	0	C		N/A	
TDE	Y2021	T206-022NA	Dipole Antenna for EnVison	0	150	0	0	0	DN/C		N/A	Running contract with STI
CTP	Y2021	C206-023NA	Relevant environmental testing for Envision Dipole	0	150	0	0	0	DN/C		N/A	Running contract with Sener
TDE	Y2018	T206-011EF	External calibration method for the VenSAR instrument	0	0	0	0	0	C		N/A	
TDE	Y2018	T206-018FI	Analysis and bradboarding of sub-surface radar boom for	0	0	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
			EnVision M5 candidate mission									
CTP	Y2021	C206-024NA	Very high rate TM downlink GMSK Transmitter with pseudo noise ranging upgrade to EM IDST	0	190	0	0	0	DN/C	IT	N/A	iDST EM platform currently being developed in the frame of the GSTP contract 4000125957/18/NL/FE.
CTP	IPC	C206-026NA	150 W 32 GHz TWT EM for Payload Data Transmitter	0	1500	0	0	0	C		N/A	
TDE	Y2019	T206-021GS	Very high rate TM downlink using GMSK with simultaneous pseudo noise ranging	0	0	0	0	0	C		N/A	
TDE	Y2019	T206-015ES	120 W, 32 GHz TWT for Payload Data Transmitter	0	0	0	0	0	C		N/A	
TDE	Y2018	T207-054EF	Broadband Dipole Antenna for Multi-Mode Sub-Surface Radar	0	0	0	0		C		N/A	
CTP	Y2021	C210-002NA	Leros-4 Qualification Hot Firing for EnVision Mission Needs	2000	0	0	0	0	DN/C	UK	N/A	Follow on to contract 4000103359 with NAMMO Westcott UK

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												- High Thrust Apogee Engine
TDE	Y2021	T212-063NA	Offline antenna arraying for EnVision	0	400	0	0	0	DN/C	IE/IT	Operational SW	Follow up to TRP study T212-052GS (450 kEuro) Prototype of off-line correlator for Arraying of large aperture antennas
TDE	Y2019	T212-005GS	Very High Rate Turbo Decoder with interleaver in the TTCP	0	0	0	0	0	C		N/A	
CTP	Y2021	C216-175NA	EnVision VenSpec-H IDCA	1000	0	0	0	0	DN/S	DE	N/A	
CTP	Y2022	C218-006MP	EnVision Aerobraking Flap Assembly	0	0	600	0	0	DN/C	AT	N/A	Follow-on of activity C218-005NA, to be implemented as CCN to contract 400138544 with Beyond Gravity (AT). Bringing the total contract price to 1000 kEuro.
CTP	Y2021	C218-005NA	Design and Characterisation of	0	400	0	0	0	C		N/A	TDA is running. Contract 4000138544

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2021	2022	2023	2024	2025	PP	Country	SW Clause	Remarks
			Aerobraking Flap Assembly									with Beyond Gravity (AT).
Total – M5-Mission Candidate: EnVision				**CTP: 3000 TDE: 0**	**CTP: 3240 TDE: 400**	**CTP: 2200 TDE: 0**	**0**	**0**	**8840 Total = 8440 CTP + 400TDE**			

8.1.10.5 M7-Mission Candidates: CALICO, HAYDN, M-MATISSE, Plasma Observatory, and THESEUS

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2021	2022	2023	2024	2025	PP	Country	SW Clause	Remarks
CTP	IPC	C217-102FI	CIS300 Detector Radiation and Performance Testing	0	0	1000	0	0	DN/S	UK	N/A	Teledyne e2v Structuring activity to UK. Activity needed for HAYDN but also other missions.
CTP	IPC	C217-101FI	CMOS Image Sensor for X-ray Applications – CCN	0	0	1000	0	0	DN/C	UK	N/A	Open University Structuring activity to UK. To be

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												implemented as follow up to 4000133151 if THESEUS is selected as M7 candidate.
Total – M7-Mission Candidates				**0**	**0**	**CTP:2000 TDE:0**	**CTP: 0 TDE: 0**	**0**	**2000 Total = 2000 CTP + 0 TDE**			

8.1.10.6 Technologies Applicable to Several Science Programme Missions

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	N/A	T205-130SA	Augmented inertial navigation solutions for medium-accuracy landing	0	0	0	350	0	C		N/A	
TDE	IPC	T220-057MS	Consolidation of CFRP Anisogrid Tubes and Booms for Science Missions	0	0	0	600	0	DN/S	DK	N/A	Space Composite Structure Structuring activity for Denmark.
TDE	N/A	T207-069EP	Electrically Conducting Thermal Insulators	0	0	0	250	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	IPC	T207-070EP	Modelling and Prediction of Magnetic Field Perturbations by Thermo-Electric Effects	0	0	0	350	0	DN/S	RO	Open Source	Cluj Napoca Structuring activity for Romania.
TDE	IPC	T223-104ED	Reliability of electronic assemblies in cryogenic environment	0	0	0	400	0	C		N/A	
CTP	AC	C205-129SA	Enhancements of Radiation Hard Gyroscope for Science Missions	0	0	400	0	0	DN/C	IE	N/A	INNALABS. Structuring activity for Ireland. To be procured as CCN to C205-114SA bringing the approved amount for contract 4000123078 to 4MEuro
TDE	N/A	T214-003FI	Lab-on-a-Chip Instrument for Future Planetary Missions	0	0	0	200	0	C		N/A	
TDE	N/A	T205-129SA	Ultra-High performance gyroscope for future X-ray Interferometer missions	0	0	0	300	0	C(2)		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	AC	T215-020EP	Magnetically clean rotary actuator for optical bench application	0	0	0	400	0	DN/S	DK	N/A	PCBMotor Structuring activity for Denmark.
TDE	N/A	T224-012QE	Development of an in orbit cleaning tool for optical instruments	0	0	0	350	0	C		N/A	
TDE	N/A	T204-140EP	Advanced demagnetisation methods	0	0	0	250	0	C(2)		N/A	
TDE	AC	T216-175FT	Optical element to focus soft gamma rays	0	0	0	300	0	DN/S	NL	N/A	Cosine
TDE	IPC	T217-077MM	Germanium on Silicon CCD structure development	0	0	0	500	0	DN/C	UK	N/A	Teledyne e2v
CTP	IPC	C217-103FT	Evaluation of infrared linear mode avalanche photodiode arrays for time delay integration type operation	0	0	550	0	0	DN/S	UK	N/A	Cambridge University Structuring activity for UK.
TDE	N/A	T206-025ES	In-flight adaptive pre-distortion techniques for TT&C subsystems with high-order modulations	0	0	0	400	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	IPC	T206-026EF	Improved TT&C Sub-System Architecture	0	0	0	650	0	C		N/A	
TDE	IPC	T204-141EP	Saturn Moons Environment Models and their effects on spacecraft	0	0	0	200	0	C			
CTP	Y2023	C206-027FM	X-band transponder qualification finalisation	0	0	2650	0	0	DN/C	NO	N/A	Kongsberg Structuring activity for Norway. Approved by NO-IPTF. Bringing the approved amount of contract 4000128298 to 11.86MEuro.
CTP	Y2023	C220-054FT	Delta qualification of CFRP and Aluminium skin panels	0	0	800	0	0	DN	PL		Structuring measure to Poland. DN/S with the company SCNTPL
TDE	Y2021	T201-053NA	Ultra Low Power Consumption Unit and Instrument Interface	0	250	0	0	0	C		N/A	
CTP	Y2022	C220-052FT	Manufacturing and AIT processes for equipped CFRP/Aluminium sandwich panels	0	500	0	0	0	DN/C	GR	N/A	Structuring activity to Greece. To be implemented as a CCN to C220-048PL

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												with INASCO (4000128450). Bringing the approved amount to 820 kEuro.
CTP	Y2022	C224-008FT	Titanium reinforced radiation absorbent metal matrix composite casing produced with additive manufacturing for deep space satellite missions	0	0	500	0	0	C	HU	N/A	Structuring measure to Hungary.
CTP	Y2018	C201-036ED	Contribution to High Density European Rad-Hard SRAM-based FPGA	0	0	0	0	0	DN/C	FR	N/A	For information, activity approved (ESA/IPC(2018)1.add. 11). Science Programme CTP contribution to CCN-02 to T701-301ED.
TDE/ CTP	Y2019	C201-039FT	Low Resource Reconfigurable Mission Controller for Future Science Missions	0	0	0	0	0	DN	FI	N/A	Structuring activity for Finland. DN with RUAG (FI). Co-funded by TDE (500k) and CTP (3000k).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2021	T203-117NA	High efficient, ultra light weight solar cells for deep space missions	0	500	0	0	0	C		N/A	
TDE	Y2021	T203-116NA	Concentrator systems as mission enablers for deep space missions	0	500	0	0	0	C		N/A	
TDE	Y2021	T203-115NA	Power Transfer via Optical Links with reduced Electromagnetic Harness Emissions	0	100	0	0	0	C		N/A	
TDE	Y2021	T203-120NA	Solide Oxide Fuel Cell (SOFC) demonstrator for outer planet exploration power generation	800	0	0	0	0	C		N/A	A substantial participation of a Norwegian entity is required, as structuring measure
CTP	Y2018	C203-112FM	SMILE SXI PSU de-risking activity	0	0	0	0	0	DN	DK	N/A	Structuring activity for Denmark. DN with Terma (DK) Implemented as a CCN to Contract number 4000125755, with a current contract value of 1845 kEuro.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2021	T204-136NA	Comprehensive Environment Model Catalogue for the Moons of Giant Planets	0	300	0	0	0	C		N/A	
TDE	Y2016	T204-124EE	Mini Ion emitter for Spacecraft Potential Mitigation on Science Missions	0	0	0	0	0	C	AT	N/A	TDA is running. FOTEC + subs.
TDE	Y2015	T204-118EE	Modelling of Electrostatic Environment of Ion Emitting Spacecraft	0	0	0	0	0	C(3)	FR	N/A	TDA is running. ONERA (FR) 250 kEuro in 2016
CTP	Y2016	C204-116EE	Geant4-based Particle Simulation Facility for Future Science Mission Support	0	0	0	0	0	DN/S	GR	Open Source	DN with IASA (GR). Approved in ESA/IPC(2016)81 500 kEuro in 2016
CTP	Y2018	C205-118SA	High Accuracy Star Tracker Engineering Model Development	0	0	0	0	0	DN/C	DE	N/A	TDA is running. CCN to C205-106EC, total contract price 575 kEuro. DN with Jena Optronik (DE) CTP contribution to GSTP activity GT17-102SA (1000 kEuro).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2013	C205-002EC	Planetary Altimeter Engineering Model	0	0	0	0	0	DN/C	FI, PT	N/A	TDA is running. DN with HARP (FI) and EFACEC (PT).Special Measure for FI/PT. This activity is implemented as a CCN to T905-003EC, price 1471 kEuro. Approved in ESA/IPC(2013)81. 1500 kEuro in 2015
TDE	Y2019	T205-122SA	Pulsar Navigation for Science Missions	0	0	0	0	0	C		N/A	
CTP	Y2019	C205-127SA	3-axis high accuracy accelerometer unit	0	0	0	0	0	DN			
CTP	Y2021	C206-025NA	X band Transponder Qualification Development	0	4500	0	0	0	DN/C	NO	N/A	Follow up to CTP C206-008FM (8630 kEuro). Total approved amount 13,130 kEuro in 2021.
TDE	Y2021	T206-023NA	Fractionated sub-surface sounder configurations for	0	150	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
			Giant Planets satellites exploration									
CTP	Y2013	C206-006ET	GaN MMIC based solid state amplifier for X band for long range high capacity communication	0	0	0	0	0	C	FR	N/A	TDA is running. TAS (FR) + subs. 900 kEuro in 2015
TDE	Y2016	T206-004ET	Miniaturisation of the Deep Space Transponder	0	0	0	0	0	C	IT	N/A	TDA is running. TAS (IT)
CTP	Y2016	C206-008FM	TT&C Subsystem Capability Development	0	0	0	0	0	DN/S	NO	N/A	TDA is running. DN with Kongsberg Norspace (NO). This activity is contractually phased.
TDE	Y2018	T206-017ES	Breadboard for telemetry ranging (CCSDS 401, 2.4.24)	0	0	0	0	0	C		N/A	
TDE	Y2018	T206-012EF	K/Ka-band antenna technology development for future science missions	0	0	0	0	0	C		N/A	
CTP	Y2018	C206-011FV	Cryogenic Polarisation Modulator for CMB science missions	0	0	0	0	0	DN/S	UK, IT	N/A	Implemented as a CCN to C207-022FI and T207-035EE

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												(Contract number 4000130180), DN with Uni. Cardiff (UK) & Sapienza Uni. Rome (IT).
TDE	Y2018	T206-014EF	Development of Large Anti-Reflection Coated Lenses for Passive (Sub)Millimeter-Wave Science Instruments	0	0	0	0	0	C		N/A	
TDE	Y2021	T207-065NA	Innovative Materials and Designs for Magnetic Shielding	0	300	0	0	0	C		N/A	
TDE	Y2021	T207-066NA	Development of a multi-chroic, dual polarization, wide-band on-chip array for CMB spectroscopy	0	350	0	0	0	C		N/A	
CTP	Y2017	C207-022FI	Large radii Half-Wave Plate (HWP) development - CCN	0	0	0	0	0	DN/C	UK	N/A	TDA is running. Uni. Cardiff (UK), implemented as CCN to T207-035EE (600 kEuro).
CTP	Y2016	C207-021EE	Design and development of an electrically steerable	0	0	0	0	0	DN/S	IE	N/A	DN with Arralis (IE).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
			antenna for science missions									Approved in ESA/IPC(2016)81 (current total Contract price 2000 k).
TDE	Y2018	T207-051EF	Compact HF-VHF tubular deployable antenna	0	0	0	0	0	C	ES	N/A	TDA is running SENER (ES)
TDE	Y2019	T207-058EF	Miniaturised antennas for planetary mission probes	0	0	0	0	0	C		N/A	
CTP	Y2015	C207-020FM	Pre-Verification of THOR Electro Magnetic Cleanliness Approach	0	0	0	0	0	C(2)	GR	N/A	TDA is running EMTECH (GR) + subs 700 kEuro in 2016.
CTP	Y2018	C208-001FI	Assessment of Assembly, Integration and Testing Software Support System for ESA Science Missions	0	0	0	0	0	DN/S	IE	N/A	DN with Skytek Ltd. (IE). This activity will be contractually phased: 250 kEuro phase I, 700 kEuro phase II
TDE	Y2018	T208-003SY	End-to-End Performance Simulator Modelling Tool (E2ES Tool)	0	0	0	0	0	C		N/A	TDA is completed
TDE	Y2021	T209-004NA	Giant planets tour design tools for orbiter/lander applications	0	400	0	0	0	C		Operation	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Count ry	SW Clau se	Remarks
				2021	2022	2023	2024	2025				
											al SW	
CTP	Y2018	C209-002OP	Contribution to Machine Learning Science Operations Virtual Assistants	0	0	0	0	0	C	EE	N/A	For information, Science Programme CTP contribution (100 kEuro) to activity ERM-01 Estonia Incentive Scheme (total price 200 kEuro)
TDE	Y2021	T212-062NA	Optical communications for Voyage 2050 missions	0	300	0	0	0	C		N/A	
TDE	Y2015	T212-054GS	X-Band Feed 80 kW Breadboard for ESA Deep Space Antennas	0	0	0	0	0	C(3)	CH	N/A	TDA is running. MIRAD Microwave AG (CH) 250 kEuro in 2016.
TDE	Y2018	T212-059GS	High power (80 kW) X-band uplink for Deep Space missions – development of critical waveguide components	0	0	0	0	0	C		N/A	
TDE	Y2018	T212-057GS	High rate flexible high-order SCCC communications system for Science X-band	0	0	0	0	0	C	IT	N/A	TDA is running TAS (IT)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2021	T215-018NA	Pre-development of de-spin mechanism of IR astrometry mission	0	500	0	0	0	C		N/A	
CTP	Y2013	C215-121MS	Large stable deployable structures for future science missions	0	0	0	0	0	C	PT, GR	N/A	TDA is running. HPS Lda (PT) + subs. In line with recommendations of ESA/SPC(2011)27. 1250 kEuro in 2014
CTP	Y2013	C215-121MS-B	Large stable deployable structures for future science missions	0	0	0	0	0	C	PT, GR	N/A	TDA is running. Adamant Composites (GR) + subs. In line with recommendations of ESA/SPC(2011)27. 1250 kEuro in 2014
TDE	Y2016	T215-011MS	Development of a high performance microvibration isolation system	0	0	0	0	0	C	UK	N/A	TDA is running. Uni. of Surrey (UK) + subs.
CTP	Y2015	C215-127FT	Development of a Large Angle Flexible Pivot for Science Applications	0	0	0	0	0	C(3)	CH	N/A	Parallel contracts TDA is running CSEM (CH) TDA is running Almatech (CH)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												750 kEuro in 2016.
TDE	Y2018	T215-014MS	Piezoelectric motors tribology for space science application	0	0	0	0	0	C(3)		N/A	
TDE	Y2021	T216-172NA	Nulling interferometry techniques with single telescope	0	250	0	0	0	C		N/A	
TDE	Y2012	T216-048PA	Prototype NIR/SWIR large format array detector development	0	0	0	0	0	C	FR	N/A	TDA is running. Sofradir (FR). In line with recommendations of ESA/SPC(2011)27. 2000 kEuro in 2016.
CTP	Y2014	C216-017PA	Optimised ASIC development for large format NIR/SWIR detector array	0	0	0	0	0	C(1)	BE	N/A	TDA is running. Caeleste (BE). 1000 kEuro in 2016.
TDE	Y2015	T216-103MM	Novel In-Vacuum Alignment and Assembly Technologies for Optical Assemblies	0	0	0	0	0	C(3)	DE	N/A	TDA is running. Fraunhofer IOF (DE) 400 kEuro in 2016.
TDE	Y2018	T216-111MM	Joining process for manufacturing of large	0	0	0	0	0	C		N/A	TDA is running Media Lario (IT)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
			aluminium-based optical mirrors									
TDE	Y2018	T216-112MM	Design and Testing of Far and Medium Ultraviolet Coatings	0	0	0	0	0	C		N/A	
CTP	Y2021	C217-058MM	Miniaturised frequency comb for science mission applications	600	0	0	0	0	DN/S	IE	N/A	DN with Pilot Photonics. Funding previously approved for OEwaves LISA master oscillator development, C217-091FI
TDE	Y2021	T217-073NA	TRL and Performance enhancement of Large-format NIR APD Arrays for Astronomy	0	0	1000	0	0	DN/C	GB	N/A	
CTP	Y2016	C217-064FV	Delta-development of PLATO CCD detector for SMILE Soft X-ray Imager	0	0	0	0	0	DN/S	UK	N/A	TDA is running. Scope and budget revised. DN with e2v (UK). Approved in ESA/IPC(2016)81
CTP	Y2015	C217-063MM	Development and cryogenic testing of MWIR detectors	0	0	0	0	0	C(1)	FR	N/A	TDA is running. CEA Leti (FR). PP changed

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
												from C(3) to C(1) in ESA/IPC(2016)81. 1000 kEuro in 2016.
CTP	Y2019	C217-072MM	European Low-Flux CIS Development and Optimisation - CCN	0	0	0	0	0	DN/C	BE	N/A	Implemented as a CCN to T217-054MM (750 kEuro), which is SD2 contribution to T717-301MM in ESA/IPC(2011)3.add. 2. (note total activity budget 1650 kEuro - see ESA/IPC(2015)3.add. 1. DN with Caeleste (BE) + subs
CTP	Y2018	C217-079MM	Development of a large format science grade p-channel CCD	0	0	0	0	0	DN/S	UK	N/A	DN with Open University (UK) + subs. Implemented as a CCN.
TDE	Y2019	T217-069MM	Large-format NIR Avalanche Photodiode Array for Scientific Imaging	0	0	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2017	C217-076FV	Gamma-ray detector prototype module development	0	0	0	0	0	DN/C	IE	N/A	TDA is running. DN with UCD (IE) This activity is implemented as a CCN to S217-014PA and follow on to C217-032FT and C217-047FT, price 1150 kEuro.
CTP	Y2018	C217-081FI	Performance testing of gamma-ray detector prototype module	0	0	0	0	0	DN/C	IE	N/A	TDA is running. CCN to S217-014PA and follow on to C217-032FT, C217-047FT, C217-076FV (total price 1380 kEuro). DN with UCD (IE).
TDE	Y2008	T217-052MP	Kinetic shock tube for radiation data base for planetary exploration	0	0	0	0	0	C	PT	N/A	TDA is running. IST-IPFN (PT) + subs. 1000 kEuro in 2010.
TDE	Y2021	T218-009NA	Development an Entry and Descent Instrument Sensors Suite for Ice Giant Entries	0	300	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2021	T218-008NA	Development of a state-to-state CFD code for the characterization the aerothermal environment of Ice Giants planets entry capsules	0	300	0	0	0	C		N/A	
CTP	Y2011	C218-001MP	Characterisation of radiation for high speed entry	0	0	0	0	0	DN/C	PT	N/A	TDA is running. IST-IPFN (PT). Special measure for PT 750 kEuro in 2015
CTP	Y2018	C219-010FT	Delta-development of electric micropropulsion subsystem for deep space scientific missions	0	0	0	0	0	DN	AT	N/A	TDA is running. Structuring activity for Austria. DN with FOTEC (AT)
CTP	Y2017	C220-042FM	Consolidation of high performance CFRP struts	0	0	0	0	0	DN	DK	N/A	Structuring activity for Denmark. DN with Space Structures Denmark (DK).
CTP	Y2017	C220-043FM	Advanced optical benches using nano-enabled CFRP	0	0	0	0	0	C	GR	N/A	Competition limited to Greece Structuring activity for GR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2017	C220-044FM	Deployable high gain antenna structure for small spacecraft science missions	0	0	0	0	0	C	GR	N/A	Competition limited to Greece Structuring activity for GR
CTP	Y2018	C220-049FT	Verification of interface zones for uninterrupted pre-preg fibre placed lattice structures	0	0	0	0	0	DN	IE	N/A	Structuring activity for Ireland. DN with ATG Innovation (IE) and Eirecomposites (IE).
CTP	Y2012	C221-001MT	Detector cooling system including cryostat and active coolers down to 50mK	0	0	0	0	0	C	FR	N/A	TDA is running. CNES (FR) + subs. 2650 kEuro in 2016.
CTP	Y2018	C221-017FT	Graphene based thermal straps	0	0	0	0	0	C	FI	N/A	TDA is running with VTT (FI). Structuring activity for FI.
TDE	Y2018	T221-111MT	Integration simplification of capillary driven heat transport systems	0	0	0	0	0	C		N/A	
TDE	Y2015	T223-103QT	Investigation of additive manufacturing of improved ceramic packages for detectors.	0	0	0	0	0	C(1)		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2015	T224-004QT	Demonstration of an Additive Manufactured Metallic Optical Bench	0	0	0	0	0	C(1)	DE	N/A	TDA is running. Fraunhofer GmbH (DE) 1000 kEuro in 2016.
TDE	Y2014	T224-003QT	Adhesive bond behaviour in cryogenic environment	0	0	0	0	0	C(3)		N/A	TDA is running KRP Mechatec GmbH (DE)
CTP	Y2018	C226-001FM	Adaptation of small satellite technologies for deep space applications	0	0	0	0	0	DN	DK	N/A	Structuring activity for Denmark. Preparation activities for enabling small satellite planetary science missions (one of the selected themes for the New Science Ideas). DN with GOMspace (DK)
CTP	Y2018	C226-002FT	MEMS based nanoparticle storage and release system for Quantum Physics Platform	0	0	0	0	0	C	IE	N/A	Competition limited to Ireland. Structuring activity for Ireland.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2020	T220-056FT	Maturation of Additive Manufactured Metallic Optical Bench	0	0	0	0	0	DN/C	DE	N/A	Implemented as CCN to T224-004QT. (previous total price 1187 kEuro), bringing the total amount to 2187 kEuro. DN with Fraunhofer Institute for Material and Beam Technology (IWS)
TDE	N/A	T224-005QT	Adhesive bond behavior in cryogenic environment (CCN)	150	0	0	0	0	DN/S	DE	N/A	CCN to KRP(DE) contract (current running contract total price 300 kEuro)
TDE	Y2020	T203-114EP	Ultra-Stable Power System Architectures	500	0	0	0	0	C		N/A	Potential application for several future science missions including LISA
TDE	N/A	T207-063EP	Electro-Magnetic Shielding Effectiveness Optimization for Thermal Multi-Layer Insulation	300	0	0	0	0	C		N/A	
TDE	N/A	T203-113MT	Electro-chemical compressor for Joule Thomson Cooler	250	0	0	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2020	T221-021MT	Characterization of MLI materials and definition of MLI blanket for aerobraking environment	500	0	0	0	0	C		N/A	Relevant for several possible planetary missions, including EnVision
TDE	N/A	T219-003MP	Development of a low power cathode for scientific missions	200	0	0	0	0	C		N/A	
CTP	Y2020	C220-051FT	Verification of Interface Zones for Uninterrupted pre-preg fibre placed lattice structures - CCN	360	0	0	0	0	DN/C	IE	N/A	Recommended by Industrial Policy Task Force, ref: minutes of the Joint Ireland/ESA Industrial Policy Task Force meeting of 31 March 2020. Implemented as CCN to C220-049FT (total previous contract price 840 kEuro). DN with ATG (IE)
TDE	N/A	T205-125SA	Attitude Guidance Using On-Board Optimisation	300	0	0	0	0	C		N/A	
TDE	N/A	T212-061GS	Multiple frequency-shift keying modem	350	0	0	0	0	0		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2022	T216-174MM	Patterned Liquid-Crystal Retarders as Basis Optical Components for Exoplanet Direct Imaging	0	0	650	0	0	C		N/A	
CTP	Y2022	C216-179MM	Large area high-performance optical filters for X-ray detection in space based on CNT	0	500	0	0	0	DN/C	FI	N/A	
TDE	Y2022	T217-075MM	Improvement of radiation hardness of BSI SiPM detectors	0	0	800	0	0	C		N/A	Procurement policy changed to open competition.
TDE	Y2022	T207-068MM	Optical Vector Magnetometer Based on The Hanle Effect	0	0	750	0	0	DN/S	AT	N/A	Direct negotiation with Austrian Academy of Sciences -IWF – (AT) / Graz University of Technology (AT)
CTP	Y2022	C217-098FI	Optimised ASIC development for large format NIR/SWIR detector array	0	500	0	0	0	DN/C	BE	N/A	Direct negotiation with CAELESTE (BE) + subs
TDE	Y2022	T206-024EF	Broadband high power transmitter for future radar sounders	0	0	0	350	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	Y2022	T216-173MM	Hysteretic Deformable Mirrors for Next Generation Space Telescopes	0	0	350	0	0	C		N/A	
CTP	Y2022	C205-119SA	Coriolis Vibrating Gyroscope sensing element Space Qualification	0	1000	0	0	0	DN/C	IE	N/A	CCN to C205-114SA. Structuring measure for IE. Implemented as CCN to 4000123078. Total approved amount to 3600 kEuro.
TDE	Y2019	T205-124SA	Fine Guidance Sensor Feasibility Consolidation for SPICA mission	0	0	0	0	0	C		N/A	
TDE	Y2019	T217-070MM	CMOS Image Sensor for X-ray Applications	0	0	0	0	0	C		N/A	
Total - Technologies applicable to several Science Programme Missions				**CTP: 960 TDE: 3350**	**CTP: 7000 TDE: 4500**	**CTP: 4450 TDE: 3550**	**CTP: 0 TDE: 5850**	**0**	**29660 Total = 12410 CTP + 17250 TDE**			

8.1.11 Science Programme Missions in Implementation

8.1.11.1 L1-MISSION: JUICE

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2012	C204-108EE	Jovian Rad-Hard Electron Monitor Proto-Flight Model	0	0	0	0	0	C(R)	PT, CH, NO	N/A	TDA is running (current total price 4000 k in 2014). EFACEC (PT) + subs.Special Measure for CH, PT and NO. Activity approved in ESA/IPC(2012)81, rev. 1.
Total – L1-Mission: JUICE				**0**	**0**	**0**	**0**	**0**	**0 Total = 0 CTP + 0 TDE**			

8.1.11.2 M3-Mission: PLATO

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2018	C201-038FI	Pre-development of High Accuracy Heater Controller for PLATO	0	0	0	0	0	DN/S	IE	N/A	DN with Realtime Technoligies (IE)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2017	C205-114SA	Radiation Hard Gyroscope Development for Science Missions	0	0	0	0	0	DN/S	IE	N/A	Structuring activity for Ireland. TDA is running, Innalabs (IE)
CTP	Y2017	C205-115SA	High Accuracy Accelerometer for Space Applications	0	0	0	0	0	DN/S	IE	N/A	Structuring activity for Ireland. TDA is running. DN with Innalabs (IE)
CTP	Y2017	C215-131FM	Antenna Pointing Mechanism for PLATO	0	0	0	0	0	DN/S	NO	N/A	Direct negotiation with Kongsberg Defence & Aerospace (NO). TDA is running.
Total – M3-Mission: PLATO				**0**	**0**	**0**	**0**	**0**	**0 Total = 0 CTP + 0 TDE**			

8.1.11.3 M4-Mission: ARIEL

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
CTP	Y2015	C221-009FM	Neon Joule-Thomson Cooler for Ariel	0	0	0	0	0	DN/S	UK	N/A	TDA is running. DN with RAL (UK). CCN to C221-008FM (current total contract price 2400 kEuro).
CTP	Y2019	C221-018FT	V-grooves development for ARIEL	0	0	0	0	0	DN	CH	N/A	Structuring activity for Switzerland. DN with RUAG (CH)
CTP	Y2019	C216-169FE	Development of the optical test GSE for the ARIEL telescope	0	0	0	0	0	DN/C	BE	N/A	Implemented as a CCN to C216-159FM (price 1080 kEuro). DN with CSL (BE)
CTP	Y2020	C224-007FM	Development of the method of gluing glass elements with titanium holders in cryogenic temperature	460	0	0	0	0	DN/S	PL	N/A	DN with CBK, responsible for Ariel Fine Guidance Sensor. Structuring activity for Poland.
CTP	Y2020	C224-007EF	X-band Low Gain Antenna development	650	0	0	0	0	DN	FI	N/A	DN with DA-Group. Structuring activity for Finland as per recommendation of the Delegation.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Count ry	SW Clause	Remarks
				2021	2022	2023	2024	2025				
Total – M4-Mission: ARIEL				**CTP: 1110 TDE: 0**	**0**	**0**	**0**	**0**	**1110 Total = 1110 CTP + 0 TDE**			

8.1.11.4 F1-Mission: Comet Interceptor

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2021	2022	2023	2024	2025				
TDE	N/A	T204-134EP	Coma Model for Comet Interceptor	0	0	0	0	0	C		Open Source Code	
Total – F-Mission: COMET INTECEPTOR				**0**	**0**	**0**	**0**	**0**	**0**			

Annex II

9 Detailed Description of ESA Cosmic Vision Technology Development Activities

This annex contains a detailed description of those activities under ESA responsibility.

L1-MISSION: JUICE

Pre-qualification of integrated LILT solar cells					
Programme:	CTP		**Reference:**	C203-102EP	
Title:	Pre-qualification of integrated LILT solar cells				
Total Budget:	1000 kEuro				
Objectives					
Qualification of solar cells for low intensity and low temperature (LILT) applications such as missions to Jupiter.					
Description					
The qualification of the solar cell under LILT conditions, both on bare cell and solar cell assembly level is the objective of this activity. The qualification shall be performed according to the qualification test plan established in the preceding activity (C203-101EP) which is planned to end in 2012. As a baseline for the qualification it is foreseen to use the 30% cell product from AZUR SPACE Solar Power GmbH which is coming on the market in 2012. It can be expected that with the same modifications that are applied to the 28% cell, the 30% cell will give the same good performance predictability under LILT conditions as the 28% cell. Before qualification this will be validated by a dedicated test programme as a Phase 1 of this activity. In case this test programme is not successful the 28% cell can be used as a backup to enter qualification. A follow-on activity that is just about to be kicked-off (ITT Reference: AO/1-6449/10/NL/EK) is now dedicated to validate the positive findings by significantly increasing the number of tested solar cells under LILT conditions for improving the statistics. In the framework of that activity it is also requested that a qualification plan is established that is based on the ECSS E-ST-20-08C adapted to the Jupiter mission requirements. The qualification of the solar cell under LILT conditions, both on bare cell and solar cell assembly level is then the objective of this activity. The qualification shall be performed according to the qualification test plan established in the preceding activity which is planned to end in 2012. As a baseline for the qualification it is foreseen to use the 30% cell product from AZUR SPACE Solar Power GmbH which is coming on the market in 2012. It can be expected that with the same modifications that are applied to the 28% cell, the 30% cell will give the same good performance predictability under LILT conditions as the 28% cell. Before qualification this will be validated by a dedicated test programme as a Phase 1 of this activity. In case this test programme is not successful the 28% cell can be used as a backup to enter qualification.					
Deliverables					
Qualification test report					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	TRL 6 in 2015
Application Mission:	JUICE		**Contract Duration:**	18 months	

S/W Clause:	NA
Consistency with Harmonisation Roadmap and conclusion:	
Yes. See Harmonisation Technical Dossier A10 and A11	

Jovian Rad-Hard Electron Monitor Proto-Flight Model					
Programme:	CTP		**Reference:**	C204-108EE	
Title:	Jovian Rad-Hard Electron Monitor Proto-Flight Model				
Total Budget:	3500 kEuro				
Objectives					
Based on the design established in a previous activity (T204-043EE), the objective is to develop and qualify a Proto-Flight Model (PFM) of a radiation monitor tailored to the harsh radiation environment of the JUICE mission. A key aspect of the work involves the development of a new ASIC combining front-end signal processing and Analogue to Digital Conversion (ADC). The PFM performance will be extensively simulated, tested, and calibrated.					
Description					
The Radiation Hard Electron Monitor (RADEM) is a radiation monitor designed for very harsh radiation environments and optimized for the detection of high energy electrons as encountered in the Jovian system. A second sensor head is capable of proton and heavy ion detection. A recently completed activity has produced a prototype of the two sensor heads (HEP for proton detection, MSPEC for electron detection) and performed a preliminary calibration of RADEM under proton and electron beams. These tests have proven the measurement concept and highlighted the challenges. Major critical elements requiring development are the sensor readout ASICs and the processor. The current baseline RADEM design (PSI/RUAG (CH)) has separate front-end ASICs. The proposed RADEM PFM will benefit greatly from the development of a single ASIC which will combine the "traditional" front end functions and the ADC block. This ASIC will be qualified including full radiation hardness assurance and characterization for the Jovian environment. The design of the detection scheme and event processing will be supported through simulation and experimental verification/calibration leading to development of application software for the controller related to particle identification and physics processing. Full electrical and mechanical design and qualification will be performed, leading to construction of a PFM.					
Deliverables					
Rad-Hard Electron Monitor Proto-Flight Model, Technical Data Package					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	JUICE		**Contract Duration:**	24 months	
S/W Clause:	NA				

Consistency with Harmonisation Roadmap and conclusion:
N/A

Radiation testing of memories for the JUICE mission			
Programme:	CTP	**Reference:**	C223-056QE
Title:	Radiation testing of memories for the JUICE mission		
Total Budget:	500 kEuro		
Objectives			
This proposed activity aims at radiation testing two types of memory components: (1) the newly available low power dynamic memories LP-DDR2, and (2) NAND-Flash memories with an external rad-hard charge pump. These memory types are both important and complementary for JUICE mission: DDR2 is used in proximity with the microprocessor thanks to its fast access rate, while NAND-Flash are used as mass memory. Their radiation testing will be performed in parallel.			
Description			
1) LP-DDR2: Among the different dynamic memory types, low power DDR2 (LP-DDR2) SDRAM are attractive candidates for space applications. They provide lower power capability than standard DDR2 SDRAM and higher density, with for example four dies in the same package. Moreover, contrary to standard DDR2 SDRAM, low-power DDR2 SDRAMs can be operated over a large clock frequency range and can therefore easily adapt to different types of systems. They are presently used in the new generation mobile phones and laptop computers. LP-DD2 are commercially available from several manufacturers: Samsung, Elpida, Micron, Nanya, Hynix. For the JUICE mission, the high packaging density and low power consumption are significant advantages. This will facilitate the shielding that will be necessary in the Jupiter environment. However, the radiation sensitivity of these LP-DDR memories is still unknown. It is proposed to test LP-DDR2 SDRAM for both total ionizing dose (TID), and single event effects (SEE). The first step will be the analysis of the commercially available products, followed by the TID and SEE test preparation and performance. 2) NAND-Flash: These NAND-Flash memories provides non-volatility and the highest storage density of today's semiconductor memory technologies. However, they are more sensitive to radiation effects than conventional CMOS technologies. The TID hardness level of the present generation devices (34-nm single level cell NAND-Flash) is 60 krad. This is slightly better than for older generations (20-30 krad), but still insufficient for the JUICE mission. Moreover, single event dielectric ruptures have been observed at LET of 18 MeV-cm2/mg in the new NAND-Flash generation, compared to 35 MeV-cm2/mg for the previous generation (50-nm). The internal charge pump has been identified as the most sensitive part of the NAND-Flash for both TID and single-event destructive events. The			

charge pump locally withstands high voltages (>20V) with relatively thick oxide transistors, relatively sensitive to TID and gate rupture. One possible solution would consist in using an external rad-hard charge pump. New NAND-Flash permits such architecture. A space mass-memory system would use for example one external charge pump for several NAND-Flash memories. This proposal aim at testing and validating such new architecture under TID and destructive SEE.
Deliverables
T0 + 2 months: Analysis of the commercially available devices, procurement T0 + 6 months: Preparation of the tests, packaging, boards, software T0 + 12 months: TID testing at the ESTEC Co60 source T0 + 18 months: SEE testing at RADEF, focus on functional interrupts and destructive events T0 + 24 months: Final Report, analysis for the Juice environment

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2015
Application Mission:	JUICE		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

L2-Mission: NewAthena

Adaptation of the charged particle diverter system to the new configuration of Athena			
Programme:	CTP	**Reference:**	C204-134FT
Title:	Adaptation of the charged particle diverter system to the new configuration of Athena		
Total Budget:	150		
Objectives			
To adapt the design of the previously implemented chaged particle diverter system to the new configuration of Athena and implement the remaining qualificaiton tests identified to reach TRL 6			
Description			
The Athena mission requires a charged particle diverter system to prevent charged particles entering the Athena telescope through the mirror from reaching the focal planes with energies in the measurement band (0.2 - 15 keV). This element was previously identified as critical, since it would require deflecting soft protons, something that had not been done before. Therefore, an activity was set up to design, implement and test a demonstrator of this system in 2017. A design based on two assemblies frames populated with static magnets			

(one for each instrument) implementing a pseudo-Halbach design was targeted. It was sucessfully manufactured in 2020-2021 and structurally tested in 2021-2022. A Technology Readiness Assessement confirmed a maturity consistent with TRL 5-6 at the end of 2022 and identified the need to perform some additional work to completely reach TRL 6. During 2022, guided by an SPC decision, Athena entered a reformulation phase with the goal of lowering its cost at completion to ESA. This effort is ongoing with newly agreed performance requirements and is now converging onto a design exploiting passive cooling as much as possible (using v-grooves for one of the instruments) which leads to a completely different design for the Science Instruments Module. At the same time, there has been an agreement by all stakeholders that the absolute value non-x ray background is still critical and, therefore, the charged particle diverter system will need to be included in the reformulated Athena. This activity shall fund: (1) the necessary redesign of charged particle diverter system to be consistent with the new reformulated configuration of the Athena mission, and, (2) the necessary component/demonstrator testing to fully reach TRL6, namely: (2.1) TVAC testing of magnets and.or the full demontrator, (2.2) check possible delamination of surface treatment by posterior inspection, (2.3) design, manufacture of simplified model, vibration and possibly climatic test of conductive connection joint between Al part and magnet / Ti part with respect to galvanic corrosion occurrence
Deliverables
Report

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2023
Application Mission:	Athena		**Contract Duration:**	24	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Silicon Pore Optics process consolidation for reformulated Athena			
Programme:	CTP	**Reference:**	C216-181FT
Title:	Silicon Pore Optics process consolidation for reformulated Athena		
Total Budget:	8000		
Objectives			

<table>
<tr><td colspan="7">The activity shall ensure the continued evolution of the Silicon Pore Optics technology adjusting to the technical and programmatic requirements of the reformulated Athena.</td></tr>
<tr><th colspan="7">Description</th></tr>
<tr><td colspan="7">The Silicon Pore Optics (SPO) technology was developed by ESA as an enabling technology for the next generation high-energy astrophysics observatory. In support of the Athena mission significant investments have been made by the ESA Science Programme (CTP) and TDE covering all aspects of the SPO technology.

The core of the SPO technology is the SPO Mirror Module (MM), which allows the production of the large x-ray optics for Athena in a modular and cost-effective way.

With the programatic evolution of ESA's Science Programme and the associated postponement of the Athena adoption by about 4 years, a bridging phase is required to ensure the continuity of the necessary technology preparation for the mission adoption and implementation phase.

This activity shall focus on the following required tasks:
- Optimisation of the angular resolution of coated optics by balancing the mirror membrane thickness, the coating recipe and the stacking process,
- Development of optimised row-01 and row-15 geometries (potentially additional rows) to prepare for a future QM phase of the mission and to test switching production between rows,
- Lowering the cost of mirror plates,
- Simplification of the mirror module assembly process to speed up production, increase yield and reduce cost,
- Start using the second synchrotron facility (ALBA) to be able to balance the production load,
- Produce additional mirror modules and measure them in terms of performance and environmental compatibility,
- Validate the MM level x-ray facilities.

A representative number of MMs shall be produced for each radius to demonstrate the readiness for the mission adoption. Particular emphasis shall be given to the quality assurance aspects, production rate and cost efficiency.</td></tr>
<tr><th colspan="7">Deliverables</th></tr>
<tr><td colspan="7">Engineering/Qualification Model; Report</td></tr>
<tr><th>Current TRL:</th><td>5</td><th>Target TRL:</th><td>6</td><th>Application Need/Date:</th><td colspan="2">2023</td></tr>
<tr><th>Application Mission:</th><td colspan="2">Athena</td><th>Contract Duration:</th><td colspan="3">12</td></tr>
<tr><th>S/W Clause:</th><td colspan="2"></td><th></th><td colspan="3"></td></tr>
<tr><th colspan="7">Consistency with Harmonisation Roadmap and conclusion:</th></tr>
<tr><td colspan="7"></td></tr>
</table>

Implementation of the MAM MGSE for x-ray testing at XRCF					
Programme:	CTP		**Reference:**	C216-002MS	
Title:	Implementation of the MAM MGSE for x-ray testing at XRCF				
Total Budget:	600				
Objectives					
To implement the MGSE necessary for the x-ray testing foreseen to be done at the NASA XRCF facility					
Description					
ATHENA foresees the use of the NASA XRCF facility to verify the x-ray performance and calibrate the Mirror Assembly Module (MAM). This is a long vacuum facility where the x-ray sources are placed around 500 m away from the MAM. The MAM must be held in a vertical configuration which requires a purpose-built MGSE that can harness the existing positioning capabilities at XRCF (hexapod used for the JWST campaign) and minimises the negative impact of holding the MAM vertically (gravity sagging degradation). The design of the MGSE is maturing under an existing contract which will bring it to CDR level. The coordination with NASA is ongoing and the planning foresees early x-ray testing for the MAM demonstrators by 2024 requiring fit check verifications by 2023. This activity shall fund the implementation of the MGSE, guaranteeing that the schedule can be followed as planned. Particularly it should cover the manufacturing of all the elements (including gravity off-loading), integration in clean room conditions, vacuum bake-out and other cleanliness measures required by XRCF, and shipping (including shipping container).					
Deliverables					
MGSE and shipping container					
Current TRL:	3	**Target TRL:**		**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

ATHENA FMS demonstration					
Programme:	CTP		**Reference:**	C216-001MS	
Title:	ATHENA FMS demonstration				
Total Budget:	1700				
Objectives					
To design, manufacture and test a section of the ATHENA FMS as a demonstrator of capabilities for the future implementation phase					

Description					
An ITT was released for 1000 kEuro, bids above this value were received. Following assessment the proposals and of the work required the budget is increased to 1700kEuro in order allow placement of the contract. The ATHENA Fixed Metering Structure (FMS) is the large structural element of the spacecraft that ensures the required spacing between the Mirror Assembly Module (MAM) and the Science Instruments Module (SIM). It consists in a number of conic sections designed to achieve the 12 m focal length, optimised for the required structural performance (compatibility with the launcher stay-out zones and the minimisation of the loads). This activity shall fund the design, manufacture and test of a demonstrator of the FMS (potentially one of the conic sections) with the goal of building the necessary capability for its future implementation during the flight programme. The technological choice shall be compatible with at least one for the spacecraft prime solutions proposed during the ongoing phase B1 studies.					
Deliverables					
Demonstrator of the FMS, test results					
Current TRL:	3	**Target TRL:**		**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

SPO AIT facility implementation - CCN			
Programme:	CTP	**Reference:**	C216-009MM
Title:	SPO AIT facility implementation - CCN		
Total Budget:	355		
Objectives			
To support the robust implementation of the SPO AIT building that is currently ongoing. Ensuring a more resilient structural solution to cope with stricter requirements recently introduced			
Description			
The SPO AIT facility currently being implemented for ATHENA is a novel purpose-built facility that uses a a collimated UV beam to align the 600 MMs needed for the mission Mirror Assembly Module. The foundations of the building are currently being finalised and the detailed design of the rest of the facility evolved recently. The initial cost estimation was based on preliminary assumptions that were further refined and detailed throughout the execution of the contract with increasingly detailed designs and analyses. In many cases, the assumptions were confirmed throughout, in other cases new information that has become			

available in the course of the project has caused new revision of planning and costs. This activity shall fund the changes in the external building due to the request to expand the building to accommodate also the VERT-X facility in addition to the SPO AIT facility. This request led to the change of the building design from a single tower to a much larger rectangular building of 10 m x 20 m base, with increased height to 17 m. Due to this change and the need to comply with the wind and seismic rules, the structural design had to be updated, resulting in a stiffer, more expensive configuration. Moreover, there have been considerable changes in the design of the interfaces of the facility to the MAM, including the manufacturing of a simplified gravity release mechanism. This activity shall also fund the implementation of these changes.
Deliverables
SPO AIT building

Current TRL:	4	**Target TRL:**	**5**	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

Characterisation of thermal and mechanical performance of SIM cryostat straps			
Programme:	CTP	**Reference:**	C200-004MS
Title:	Characterisation of thermal and mechanical performance of SIM cryostat straps		
Total Budget:	300		
Objectives			
To perform thermal and mechanical properties characterization of potential candidates for Mechanical Straps to be used on the Athena SIM Cryostat, in order to find the candidate with the combining a high enough strength and low thermal conductivity, thus optimizing the Cryostat mechanical supports performance.			
Description			
The Athena SIM Cryostat is baselined on a russian-doll configuration using a large number of thermal shields, in a suspension structure based on Mechanical straps, in order to hold all the different shields at different temperatures from room temperature down to 2 K.			

These straps must be designed to provide sufficient stiffness to ensure a first frequency mode of the cryostat at 62 Hz, which comprises all the thermal shields and the 2K Core (Sub-Kelvin Cooler + FPA), while minimizing the conductive heat loads between each stage. Materials such as S2-Glass-Fibre Reinforced Plastic (for use between room temperature and roughly 30K) and T300 Carbon-Fibre Reinforced Plastic (for below 30 K) provide a good heritage from being used on previous cryogenics mission such as Herschel/Planck. However, alternative materials may constitute strong candidates with more promising thermal or mechanical characteristics. Unfortunately, there is a lack of data for the thermal characteristics of such materials in the cryogenic domain, namely in the wide range of the Athena Cryostat, from 300K down to 2K. This activity aims at identifying the best candidate materials, and subsequently performing thermal conductance measurement on a given amount of samples, in the wide temperature domain envisaged for Athena (300 K - 2K), and performing mechanical property tests at room temperature.
Deliverables
Technical Note including Test Procedure and Report with data and conclusions.

Current TRL:	2	**Target TRL:**	**4**	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

High performance microvibration isolation system (continuation)			
Programme:	TDE	**Reference:**	T215-017MS
Title:	High performance microvibration isolation system (continuation)		
Total Budget:	800 kEuro		
Objectives			
To continue the development of the semi-active isolation technology to meet the performance requirement up to 500Hz and introduce/derisk the critical hold down and release functionality.			
Description			
Microvibrations are a critical issue to more and more ESA missions and represent a significant technical challenge due to the stringent stability requirements of the payloads. The ongoing TDE activity ‘High performance microvibration isolation system’ is developing a very promising semi-active isolation technology based on electro-magnetic shunt damper, which can be			

used to isolate either noise sources or payloads. The current activity is in the process of testing the technology at breadboard level. Some improvements are required to ensure the required performance over the complete frequency range. It currently provides excellent results up to 300Hz. This activity encompasses the following tasks: - Upgrade the isolation system design to meet the functional requirements up to 500Hz. This includes material upgrades and a redesign of the magnetic design. - Complete the design with the critical hold down and release function: HDRMs and locking features in the struts - Assembly and testing of a new BB model. This includes full functional testing in ambient only and derisk environmental testing (thermal, vibration, shock, deployment, but not TVAC) - Functional testing at different temperatures, at sub-assembly level only.
Deliverables
Breadboard, report.

Current TRL:	TRL3	**Target TRL:**	TRL4	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena Radiation Environment Models and X-ray Background Effects Simulators			
Programme:	CTP	**Reference:**	C204-110EE
Title:	Athena Radiation Environment Models and X-ray Background Effects Simulators		
Total Budget:	600 kEuro		
Objectives			
Development of a tailored radiation environment model for L2, including low-energy protons and electrons; development of a Geant4-based comprehensive simulator to analyse the propagation of X-rays and charged particles in the pore optics and focal plane structures to allow accurate estimates of the instrument background and other radiation effects; evaluate relevant XMM-Newton experience, including quantitative comparisons with environment predictions and interaction simulations.			
Description			
The radiation background requirements for Athena are demanding and careful analysis will be necessary of background from particles penetrating			

the pores of the X-ray optics, the action of diverters, and background from secondary interactions in materials close to the payload. Electrons and low-energy protons propagate via low-angle processes (e.g. Firsov scattering) along the mirror surfaces to the focal plane. Such processes are still today not fully understood. This is combined with the more usual background induced by penetrating incident primary radiation environment and a broad range of secondary particles from the rest of the spacecraft. Previous X-ray missions (XMM-Newton and Chandra), experienced significant background and those experiences will be analysed in detail, including background sources, environments, exploitation of the XMM EPIC Radiation Monitor (ERM) and material & detector (EPIC, RGS) interactions, taking as a starting point the analyses already performed. Based on these experiences, physics models within Geant4 will be improved and a comprehensive particle and X-ray simulator developed, based where possible on existing prototypes. The tool will be stand-alone, user-friendly and will allow detailed analysis of all of the relevant radiation processes leading to instrument background for the full range of possible environmental scenarios. In addition to the usual radiation sources (solar particle events, galactic cosmic rays), of particular importance for Athena is the interplanetary (L2) low-energy (100s of KeV to few MeV) proton and electron environment. This population is poorly understood and includes electrons emitted from the Jovian magnetosphere. This activity will therefore also analyse data from the L2 SREM radiation monitors on Herschel and Planck and combine these with proton and electron measurements from other relevant near-Earth interplanetary spacecraft (including SOHO, ACE, ISEE-3 and Geotail), together with necessary extra- and interpolations over the energy range of interest and other analytical considerations. The local effect of the Earth's magnetotail and its temporal variations will be taken into account. The new model will be implemented in the ESA Space Environments Information System (Spenvis).
Deliverables
Software tool, documentation, validation outcome, analysis of results and experiences from previous missions

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2016
Application Mission:	Athena		**Contract Duration:**	21 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena High-Energy Particle Monitor (AHEPaM) Interface Definition			
Programme:	CTP	**Reference:**	C204-133EP
Title:	Athena High-Energy Particle Monitor (AHEPaM) Interface Definition		
Total Budget:	400 kEuro		

Objectives
The main objective of the activity is to design and prototype a high-energy charged particle monitor for supporting Athena radiation background measurements.
Description
Background and context: The Athena mission will experience a radiation background, an important contributor to which is the unconcentrated flux of high-energy particles from the incident Galactic Cosmic Rays (GCR) and their secondary particles generated in the spacecraft structures. This background is distinct from the concentrated flux of lower energy charged particles propagated along and focused by the Athena optics, and cannot be removed by sweeping magnets because of the high energy. Analyses showed that the most important contributors will be GCR protons in the energy range 0.1-2 GeV, Helium ions of 1-3 GeV and electrons of 0.05-1 GeV. Athena's science objectives require that the knowledge error on this background component is below 1%. Justification of the activity: Recent findings indicate that having an on-board instrument to track the high-energy particle fluxes is a key prerequisite for meeting the reproducibility requirement of the Athena background. This will be beneficial to improve the quality of the science data by enhancing the background noise reduction. Current radiation monitor instruments flown and planned by the Agency, such as NGRM, are not designed to specifically target the high-energy GCRs, hence calling for a tailored instrument. Description of the technology: The Athena High-Energy Particle Monitor (AHEPaM) shall be able to detect the most significant components of the Galactic Cosmic Ray radiation field. Its detection system shall be able to provide energy resolved spectra of protons of energies between 0.1 and 2 GeV, Helium ions between 1 and 3 GeV, and electrons between 0.05 and 1 GeV, at least in five energy bins each. Thus precise measurements of particle fluxes, through an onboard particle monitor, could be used to predict with high precision both the X-IFU and the WFI unconcentrated particle background components. Some technologies that could become part of the AHEPaM have been under development in the ESA R&D programme and other research projects in the Member States over the past decades. This activity encompasses the following tasks: - Critical review of AHEPaM requirements and of relevant available European technologies - Preliminary Design of comprehensive monitoring package including design justification - Radiation transport and detector response simulations/analysis - Prototyping and characterisation of sensor units - Demonstration Model of monitor package and interfaces
Deliverables
Demonstration Model; Simulations/Analytical Models; Prototype

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Design definition of AHEPaM for integration to Athena spacecraft in time for the launch of the mission.		**Contract Duration:**	24	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Focussing of Micrometeoroids in X-ray optics			
Programme:	TDE	**Reference:**	T204-120EE
Title:	Focussing of Micrometeoroids in X-ray optics		
Total Budget:	600 kEuro		
Objectives			
Micrometeoroid impacts have been observed in the focal planes of the XMM-Newton and Swift-XRT X-ray observatories. These impacts have resulted in considerable damages to focal-plane detectors. Particles entering an X-ray telescope aperture at grazing incidence are scattered from mirror shells and therefore focussed into a telescope's focal plane. This poses a considerable risk also for future X-ray missions like Athena. The underlying scattering process shall be investigated by performing tests and simulations. Based on the test results a scattering model shall be developed.			
Description			
This activity shall address the following key aspects: Investigate grazing-incidence hypervelocity impacts on X-ray mirror surfaces, observing the effects of incident angle, momentum, mirror material and coating on scattering angles and particle fragmentation (size and momentum). Study the relation between the properties of impacting particles and the failure and degradation of X-ray detectors. Assess the risk to Athena. Potential mitigation to avoid/reduce the risk of impact of micro-meteorites on focal plane instruments shall be investigated. The following specific tasks shall be performed: 1. Assess failure modes and potential impact damage for focal plane sensors (or representative mock-ups) by experimental hypervelocity impact tests (with at least: 2 incidence angles (near-vertical - TBC), 2 velocities within 5-30 km/s, 2 diameters within 0.1-10 micron, 2 densities (Al and Fe) and 50 shots per setting. 2. Study the scattering behaviour and degradation of X-ray mirrors by numerical simulations to identify compliant design configurations 3. Procure mirror test samples. Ideally this would be representative parts of			

the optics. Alternatively simplified geometries (flat plates) with representative mirror substrate and coating material could be used.
4. Study the scattering behaviour and degradation of X-ray mirrors by experimental hypervelocity impact tests on multiple configuration mock-ups (with at least: 5 incidence angles within 1-10 degrees, 2 velocities within 5-30 km/s, 2 diameters within 0.1-10 micron, 2 densities (Al and Fe) and 50 shots per setting).
5. Assess potential countermeasures to mitigate the micrometeoroid risk where two distinct approaches shall be investigated: mitigation by hardware design (shields/sinks) and by software logic (compensating the effects of impacts as e.g. bright pixels). The hardware countermeasures shall be at least evaluated by numerical simulations.
6. Assess the impact and failure probability for environment fluxes at L2 and instrument/sensor design.

Deliverables

Test report on the scattering behaviour of micrometeoroid-like particles on X-ray mirrors, corresponding mirror and sensor
degradation and performance of mitigation methods
Model for the funnelling of micrometeoroids
Risk analysis for Athena
Impact risk and mitigation guidelines for X-ray optics and sensors

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2017
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Athena - Magnetic Diverter

Programme:	CTP	**Reference:**	C204-119FM
Title:	Athena - Magnetic Diverter		
Total Budget:	500 kEuro		

Objectives

To design and realise a demonstrator model for the Athena magnetic diverter system, and verify performance, manufacturability, and environmental compliance.

Description

A magnetic diverter is needed to prevent charged particles entering the Athena telescope through the mirror from reaching the focal planes with energies in the measurement band (0.2 - 15 keV). Initial study of the magnetic diverter for Athena has resulted in selection of a twin Halbach array located ~1m<>1.6m from the focal planes, composed of high-strength neodymium magnets, totalling ~100 kg in mass.
This TDA will expand upon this initial design of the magnetic diverter, to include the following key tasks:

*DESIGN AND ANALYSIS - the current diverter design is a classic Halbach configuration providing a uniform field-strength across the aperture. Very significant mass-reductions are anticipated by taking advantage of (i) the non-uniform deflection requirements across the aperture to optimise the deflection, or (ii) placement of an additional magnet near the mirror to modify the sizing-case - these and other ideas should be explored within engineering constraints, and a baseline design selected. Experience of designing systems with very strong permanent magnets in close proximity is necessary at this step to ensure that coercivity and manufacturing aspects are properly anticipated: non-standard geometry/field combinations may represent a challenge to manufacturing individual magnets of the Halbach array; mounting in proximity with differing field-orientations implies management of large magnetic forces during the mounting process, while retaining the required alignment accuracies - this may require specialist jigs; fixation schemes (e.g. gluing) that are commonly used for terrestrial applications may be found unsuitable for the Athena environment (e.g. launch and magnetic forces acting in combination), and alternatives may need to be developed. The resulting design will be delivered also in mathematical model format for use in AREMBES background simulations. *DEMONSTRATOR MODEL - a partial or complete Halbach array will be manufactured and subjected to: 1. Partial environmental verification: Survivability of the array will be verified with a mechanical/thermal test campaign representing the Athena environment. 2. Performance verification: The achieved field-strength at relevant locations (supported by analysis in the case of a partial array) will be measured (pre/post environmental testing) to confirm that the array will provide the required deflection, and a sufficiently suppressed far-field at the instrument locations. In particular, this step will confirm that loss of magnetic-strength in the array due to coercivity effects is controlled.
Deliverables
Design justification and definition documentation, manufacturing plans, Halbach array mathematical model, physical demonstrator model, performance and environmental verification plans and test results.

Current TRL:	2	**Target TRL:**	4/5	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

SIM Structural Large Metallic Parts			
Programme:	CTP	**Reference:**	C204-129MS
Title:	SIM Structural Large Metallic Parts		
Total Budget:	380 kEuro		
Objectives			
Secure industrial manufacturing capabilities of large structural parts			

Description
The current ATHENA baseline design for the Science Instruments Module (SIM) includes a large truss structure to support several radiators and a central cylinder. In order to otpimise mass, thickenesses are challenged and minimised. This truss structure consists of large parts (around 2 meters long) with low thicknesses and specific section to reach stiffness requirements for panel junctions. These attach to a central cylinder. This TDA shall secure the particular manufacturing processes necessary to manufacture the SIM truss structure and its interfaces to the central cylinder. It will consist on a design iteration, development of the manufacturing process, manufacturing and material/processes qualification
Deliverables
Manufacturing files MPCB Breadboard of most critical parts

Current TRL:		**Target TRL:**		**Application Need/Date:**	2023
Application Mission:	ATHENA. WFI Instrument dark-current characterisation.	**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Characterisation of Micro-Meteoroid Induced Dark Current Increase in Silicon Detectors			
Programme:	CTP	**Reference:**	C204-123FT
Title:	Characterisation of Micro-Meteoroid Induced Dark Current Increase in Silicon Detectors		
Total Budget:	600 kEuro		
Objectives			
Si-based focal plane instruments on previous X-ray observatory missions like EPIC on XMM-Newton have observed sudden and localised dark current increase events, attributed to micro-meteoroid impacts into the detector surface. While experimental evidence exists supporting this damage mechanism, no quantitative data characterising the resulting dark increase is available. The objective of this activity is to characterise the dark current increase due to micro-meteoroid impacts in Silicon detectors.			
Description			
This activity shall characterise the dark current increase in Silicon detectors as a function of micro-meteoroid properties. The dark current increase shall be characterised with detectors representative in detector entrance window and Silicon bulk properties to the detectors used on the ATHENA WFI instrument. No further representativeness in terms of detector technology is anticipated.			

The following properties shall be characterised:
1) Dark current as function of temperature prior and post impact
2) Dark current generation as function of distance from impact site
3) Inspection and characterisation of physical extent of micro-meteoroid damage using electron microscopy

The aforementioned properties shall be characterised as a function of the following micro-meteoroid properties
A) Particle size (at least 4 TBD sizes)
B) Particle speed (at least 4 TBD speeds)
C) Particle composition (at least 2 TBD compositions)

Deliverables					
Report					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	ATHENA. WFI Instrument dark-current characterisation.	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Autonomous Targets of Opportunity for astronomy missions			
Programme:	TDE	**Reference:**	T209-001EC
Title:	Autonomous Targets of Opportunity for astronomy missions		
Total Budget:	300 kEuro		
Objectives			
The objective of the activity is to define on-board autonomous planning and execution of targets of opportunity (ToOs) observations. This includes, slew manoeuvres and developing of the related algorithms and logic, while operating under mission, system and pointing constraints of astronomy missions (in particular, XIPE and Athena).			
Description			
Many astronomy missions require the capability to perform observation of Targets of Opportunity such as supernovae or gamma ray bursts, where the quality of potential science data degrades rapidly with time. The execution of these unplanned observations can be very challenging, since the target must be reached quickly after the event (even within a few hours: Athena,XIPE), to collect data from the undergoing transient phenomena. The quick reaction time traditionally implies an increase in the workload of the ground segment; scientist notification/evaluation, target checking at the SOC, constraint checking at MOC, timeline re-planning, preparation and uplink of TCs. This typically requires a significant array of on-call staff in shifts and			

associated training costs. The minimum duration of this sequence, coupled with the final on-orbit reconfiguration and slew (e.g. potential instrument switch-out, memory handling, momentum management) , are the main contributors to the ToO response time and eventually increase the operational costs of the mission. An alternative is a concept where the scientist/SOC approves a ToO, the MOC uploads only the candidate inertial coordinates, and all the required SC operations and slews are performed autonomously on-board. This concept shall include slew strategy to ToO target, potential instrument reconfiguration, memory handling, momentum management and the automated return to the planned timeline. This activity shall propose and evaluate algorithms for target vetting & slew autonomy taking into account all the possible constraints both at S/C and mission level. The activity is intended to be implemented in two phases, consisting of the following main tasks: Phase 1 - Investigation of state-of-the-art autonomous slew capabilities and comparison with current practice for ToOs observation - Assessment of operational constraints: interruption of mission timeline, instrument management, field of regard bright object avoidance for instrument and/or star trackers, momentum management, actuator capabilities, communication to ground. - Identify the necessary high level architectural functionalities (On-Board SW, AOCS, FDIR) and requirements. - Development of algorithms for target vetting, spacecraft management, autonomous slew planning and execution, returning to planned timeline - Simulation and validation in MATLAB/Simulink environment. - Assess integration into the XMM (or Integral) operational simulators identifying the best approach for interfacing to the simulator emulators and/or simulator models. Phase 2 - Adaptation of the developed algorithms and logic for an existing astronomy mission e.g. XMM . - Implementation of the MATLAB/Simulinkof Phase 1 to be included in the XMM operational simulator at ESOC and associated simulation campaign					
Deliverables					
Simulink/MATLAB Models and scripts, Software for autonomous ToO management, Test Report of autonomous SW in XMM mission simulator					
Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena, XIPE		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Diamond like coating device					
Programme:	CTP		**Reference:**	C216-174FT	
Title:	Diamond like coating device				
Total Budget:	450 kEuro				
Objectives					
To investigate the DLC coating process applicability for the ATHENA Silicon Pore Optics Plates and to design and implement a coating device					
Description					
ATHENA is an x-ray observatory. The coatings are optimised for reflectivity for its energy range (0.2 - 12 keV). Until 2018 the baseline coating was a bilayer coating of Iridium (high Z with good high energy performance) and an overcoating of B4C (low Z). The low Z overcoat is very beneficial for the low energy performances as was learned from the experience in XMM-Newton. However, there are multiple unsorted issues with B4C. Diamond Like Coating is considered as an option with high potential to improve the low energy effective area of ATHENA. In the first phase the coating process using a Thermionic Vacuum Arc plasma source shall be investigated and the parameters shall be optimised. In the second phase, the coating device shall be designed and afterwards implemented. The installation and commissioning shall occur at the facilities of the SPO MM manufacturer."					
Deliverables					
Report.					
Current TRL:	TRL3	**Target TRL:**	TRL5	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena Hold Down Release Mechanism			
Programme:	CTP	**Reference:**	C215-128FM
Title:	Athena Hold Down Release Mechanism		

Total Budget:	800 kEuro				
Objectives					
The objective of this activity is to produce a Development Model (DM) of a Hold Down Release Mechanism (HDRM) for application on the Athena spacecraft.					
Description					
The Athena spacecraft has several locations where HDRM devices are required: * the sunshield, critical to protecting the telescope mirror during observations and achieving the required sky coverage; * the mirror cover, which will be ejected or deployed during transfer; * the HDRA which is located at the top of the HDRM bipods which hold the mirror during launch. This is a particularly interesting application as an OTS solution does not appear readily available with the current characteristics (high pre-load >100 kN and low shock <300g). This activity shall, in response to the selected application: * review the requirements of the HDRM; * produce a conceptual design of the HDRM; * manufacture and test a DM for performance and environmental aspects.					
Deliverables					
Requirements Review documentation; Design Definition and Justification Documentation; Manufacturing Plans; HDRM mathematical models; Performance and Environmental Verification Plans and test results.					
Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

ATHENA ISM hexapod based on linear actuators			
Programme:	CTP	**Reference:**	C215-037MS
Title:	ATHENA ISM hexapod based on linear actuators		
Total Budget:	800 kEuro		
Objectives			
To design and implement a bredboard model of an hexapod system based on linear actuators compatible with the requirements of the ATHENA mission to be used as its Instrument Switching Mechanism (ISM) - a critical element of the Mirror Assembly Module.			
Description			

The ATHENA ISM is a critical element of the Mirror Assembly Module that allows moving the mirror in 6 degrees of freedom once in orbit. This ability allows to place the focal point of the telescope in a large geometric range at the level of the instruments, making it possible to have the full effective area of the mirror at each one of the 2 instruments (or sub arrays) and even defocus or dither. The ISM needs to be verified in order to ensure (1) comptability with the structural loads during launch (although launch locks are foreseen), (2) the required accuracy and stability in the placement of the mirror node, (3) the ability to reach the required geometrical range foreseen for ATHENA, and (4) the effectiveness of its control system (open or closed loop using external metrology). The proposed scope of Work covers the development activities at hexapod level as well as activities that are complementary to the actuator's current activities which are raising actuator's TRL to TRL 5 and ensuring the critical ball-joint & actuator thermal design. In order to achieve the discussed system maturity, the main goals proposed are: 1. To build a full scale breadboard model of the Instrument Selection Mechanism based on the linear actuators. 2. To build control system breadboard. 3. To perform testing leading to completion of the activity at least at TRL 4 on ISM level. Then, the following tasks will be conducted: • Perform full scale testing campaign to measure pointing performance of the ISM. The tests will be performed in ambient conditions. • Kinematic/dynamic system modelling and correlation with test results. • Testing of motion control software, algorithms, and electronics. • Testing of different system operation modes, depending on actuator performance characterized in different speeds, w.r.t. motion stability, parasitic effects, power dissipation and vibrations. • Dynamic errors: study impact of elastic deformations, natural vibration and drive errors as sources of positioning errors. • Geometrical errors: study sensitivity to manufacturing tolerances as a source of positioning errors. • Structural damping verification, as an important input to system level structural dynamic analysis. • Study of modal response of the ISM as a relevant input to AOCS modelling, as the structure is not ideally stiff. • Demonstrate motion range up to ranges as defined in the table below with a level of accuracy kept across the whole range of the movement: o Rotation about yMA_PCS : ±4.27 deg o Rotation about xMA_PCS : ±0.73 deg o Translation along zMA_PCS: -36 mm/+1 mm o Translation along xMA_PCS/yMA_PCS: ±3.5 mm deg
Deliverables

Engineering Model					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2023
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena ISM launch vibration damper			
Programme:	CTP	**Reference:**	C215-138MS
Title:	Athena ISM launch vibration damper		
Total Budget:	300 kEuro		
Objectives			
1- Design and test a EM damper for the Athena Instrument Selection Mechanism (ISM) subsystem, or more in general, a damper for the Athena mirror; 2- conduct the studies and experimental tests on visco-elastic material, in order to fully understand their behavior in the specific application of the ISM; 3- Realize an optimized design of the damper, meeting at best the requirements of damping performance and robustness.			
Description			
The work shall be organized in the following tasks: 1- Update of the requirements with new mirror mass, structural behavior, vibration load levels, using also the ISM development experience; 2- Design and analysis aiming at maximizing the damping ratio (e.g. > 0.1) in the specified freq. range. Specific emphasis shall be placed on: - representative modelling via FEM of non-linear behavior; - thermal behavior; - outgassing, cleanliness; Possible trade offs: - type of material realizing the damping function; - optimized balance between the stiffness provided by the damper and the one provided by the rest of the HDRM: - implement or not a speed multiplication via compliant mechanism (as per actual ISM design); - implement or not a tuned mass damper; 3- Perform the visco-elastic material (VEM) characterization at BB level before PDR or CDR; 4- Perform the EM test campaign at damper units level, at different temperatures, including fatigue/life; 5- EM tests with ISM EM HDRM; 6- Provide the implementation roadmap to the flight model.			
Deliverables			
Engineering Model			

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

15 K Pulse Tube Cryocooler Unit Engineering Model developments phase 1			
Programme:	CTP	**Reference:**	C215-141MT
Title:	15 K Pulse Tube Cryocooler Unit Engineering Model developments phase 1		
Total Budget:	1500 kEuro		
Objectives			
Improve the design and performance mapping of the 15k EM cooler			
Description			
The activity will consist of the following tasks: 1 – improve the alignment procedure of the compressor assembly to guarantee friction free performance without the need to run in, required to achieve long-lifetime 2 – perform additional performance testing to support the Athena re-formulation study, including parasitic of a non-operating cooler in a representative configuration 3- perform some limited lifetime testing Phase 2 of the activity will be defined after the baseline configuration of the New Athena has been selected			
Deliverables			
Test Reports; Friction mitigation study reports			

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2026
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Silicon Pore Optics Ruggedisation and Testing - Phase 3			
Programme:	CTP	**Reference:**	C216-136MM
Title:	Silicon Pore Optics Ruggedisation and Testing - Phase 3		
Total Budget:	3000 kEuro		

Objectives
The activity shall develop and demonstrate Silicon Pore Optics with improved structural stability. Especially the robustness of mirror plate stacks, mirror modules and straylight baffles against vibration and shock loads shall be optimised and be demonstrated for optics covering the extreme radial positions (inner and outer radius) of the Athena optics.
Description
In past activities, Silicon Pore Optics mirror modules with 0.7m radial curvature have been tested under vibration, thermal and shock loads. The mounting system has achieved a high maturity and is fully compliant with the expected Athena load cases. The full mirror module was qualified against vibration and thermal loads but suffered plate debonding in first shock tests. In this activity, the plate bonding strength shall be further improved to increase the shock level survivability of Silicon Pore Optics as much as possible. Additionally, optics for 0.25m and for 1.5m radius shall also undergo a full test campaign to assure that mirror modules at all radial positions (having different internal stress and different bonding areas) are compliant with Athena environmental loads. Split into two phases, the activity shall: In phase 1 (1200 kEuro): 1) review the plate design, manufacturing and stacking process and identify possible measures to increase the robustness against vibration and shock loads. Especially thermal annealing and bonding with plasma activated surfaces shall be considered to reach the highest possible bond strengths. 2) perform component level tests to improve the understanding and statistical significance of the load limits of bonded mirror plates and to verify the progress of the stacking process upgrades. 3) perform FEM analysis on the present mirror module design to identify and implement design changes (for mirror plates, brackets and dowel pins) improving the robustness. 4) manufacture and test (vibration, shock, x-ray performance) at least 2 mirror stacks in order to experimentally determine the shock load limits In phase 2 (1800 kEuro): 5) further iterate the MM design and stacking process parameters based on the results of the first phase 6) review the straylight baffling properties and design and implement improvements to ruggedise the baffling structures. 7) manufacture and test (vibration, shock, x-ray performance) at least 10 mirror stacks in order to support the final optimization of the shock resistance,

to increase the statistical significance of the test results and to demonstrate that multiple stacks can be manufactured with a constant robustness 8) manufacture and test (vibrations, shock, x-ray performance) at least 3 mirror modules (inner, middle and outer radius)					
Deliverables					
Three mirror modules, 12 mirror stacks, TNs					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Silicon Pore Optics Engineering Qualification Model – A			
Programme:	CTP	**Reference:**	C216-149MM
Title:	Silicon Pore Optics Mirror Module Engineering Model		
Total Budget:	7000 kEuro		
Objectives			
The activity shall demonstrate and qualify the manufacturing processes of Silicon Pore Optics for Athena, by producing Engineering Qualification Models at three radial positions (12 m focal length, inner, mid-radial and outer position of Athena large mirror). At least one radius shall be representative for the baseline design configuration both in terms of external layout and internal parameters (e.g. rib spacing and membrane thickness) and performance (<5 arcseconds HEW). In addition, the manufacturing speed shall be demonstrated with the continuous production of 5 mirror modules (TBC) of the representative type.			
Description			
This activity shall fund: • the continuation of the improvements in the stacking process (improve sides, improve entry-exit effects, improve curvature), • the optimisation of plate manufacturing processes (lithography, spray coating resist deposition, TTV, etc..), • the procurement of critical long lead items to prepare mass manufacturing of coated plates, • the procurement of the upgrades for the stacking robot(s) to allow production of the middle radius baseline configuration, • the harmonisation of the stacking processes across different radii, • the establishment of the processes to allow the manufacturing of confocal mirror modules, • the manufacturing of a representative number of confocal mirror modules to verify the processes,			

• environmental testing at stack an mirror module, • x-ray testing validation, • documentation of the processes to guarantee QA requirements and future repeatability during implementation
Deliverables
All Mirror modules produced, technical data package

Current:	4	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

True Wolter Silicon Pore Optics and Improved Performance – CCN3			
Programme:	CTP	**Reference:**	C216-140MM
Title:	True Wolter Silicon Pore Optics and Improved Performance – CCN3		
Total Budget:	1800 kEuro		
Objectives			
This CCN shall extend the design maturity of the middle radius mirror module towards a prototype level. The main objective is to maximise the angular resolution while maintaining a large effective area and structural robustness. It shall also re-iterate the design decisions (e.g. stack height, pore width, multi stacks, straylight covers) taking into account the latest results of the technology developments and the system studies.			
Description			
The contractor shall iterate the design and manufacturing process of the middle radius mirror module to further optimise the angular resolution. In addition, the activity shall also update and demonstrate the design and process including those listed below: 1) Demonstrate an angular resolution of 4.3 arcsec or below 2) Demonstrate a MM having a focal point at the nominal position within the integration and alignment tolerances (500um lateral and axial position knowledge, values are TBC) 3) Increase the rib pitch (currently 1 mm for middle radius) to maximise off-axis effective area while maintaining optical performance and mechanical robustness 4) Increase the plate width to comply with the Athena mirror layout (approx. 100 mm width) 5) Evaluate the multi-stack approach vs. single stack and implement resulting changes (either larger stacks or multi stack co-alignment)			

6) Develop a straylight cover design to block open areas inside the mirror module and in between the mirror module and the structure (e.g. caused by base plates, gaps between stacks and brackets, gaps between brackets and mirror structure)
7) Implement a sufficiently fast mirror module assembly process (<4h) and demonstrate glue curing outside the x-ray facility vacuum chamber.
8) Elaborate a mirror layout (mirror module sizes and configuration) covering all radii required by the system study baseline design.

Deliverables

1 middle radius MM, TNs

Current TRL:	4	**Target TRL:**	4	**Application Need/Date:**	
Application Mission:	Athena		**Contract Duration:**	12 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Athena Outer SPO Mirror Module

Programme:	CTP	**Reference:**	C216-134MM
Title:	Athena Outer SPO Mirror Module		
Total Budget:	2000 kEuro		

Objectives

This activity will address the realisation of a SPO Mirror Module meeting the requirements of the outer radius of the mirror.

Description

Athena requires silicon pore optics mirror modules (SPO MM) at a number of radial positions. Previous activities have concentrate(d) on a middle/inner position, and this activity shall demonstrate the production of an outer mirror module (radius about 1.5 m TBC).

The construction of such outer mirror modules requires shorter mirror plates, a modified mounting system, etc., and includes specific mirror module assembly tools. An SPO MM baffling system shall be implemented as required.
The contractor shall perform pencil beam and full aperture X-ray tests of all produced stacks and SPO MM to characterise their performance. The design and processes shall be documented as required by ECSS standards for product and quality assurance.

Deliverables

Outer mirror module.
Technical Data Package.

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2016

Application Mission:	Athena	**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Silicon Pore Optics modelling and simulations					
Programme:	CTP		**Reference:**	C216-132FT	
Title:	Silicon Pore Optics modelling and simulations				
Total Budget:	500 kEuro				
Objectives					
Detailed modelling and simulations of Silicon Pore Optics.					
Description					
Accompanying the further development of the Silicon Pore Optics (SPO) as enabling technology for the L2 Science Theme (Hot Universe), detailed software modelling and simulations of the optics is required. The simulations will range from individual elements over modules to the complete telescope, and address the imaging performance including diffraction effects, straylight (visible and X-ray), deformations (thermal and mechanical), etc. Data obtained by X-ray and other metrology of optical elements will be considered and used to improve the modelling.					
Deliverables					
Computer models of the SPO optics Simulations results and reports					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2018
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Silicon Pore Optics modelling and simulations for telescope			
Programme:	CTP	**Reference:**	C216-160FT
Title:	Silicon Pore Optics modelling and simulations for telescope		
Total Budget:	300 kEuro		
Objectives			
Improvement of the modeling of the Silicon Pore Optics for Athena and simulations covering telescope level.			
Description			
In support of the verification of the Silicon Pore Optics (SPO) for the L2 Athena mission, detailed software modeling and simulations of the optics is			

required to continue until the mission adoption review. The simulations will continue from the work already done, and this activity will include simulations ranging from individual elements over modules to the complete telescope. The simulations will address the imaging performance including diffraction effects, straylight (visible and X-ray), deformations (thermal and mechanical), etc. Data obtained by X-ray and other metrology of optical elements will be considered and used to improve the modeling.
Deliverables
Report; Software

Current TRL:	5	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	Open Source				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

X-ray Mirror Module Assembly, Integration and Testing - CCN			
Programme:	CTP	**Reference:**	C216-141MM C216-141MM-B
Title:	X-ray Mirror Module Assembly, Integration and Testing - CCN		
Total Budget:	1300 kEuro		
Objectives			
This CCN shall extend the original contract to use Silicon Pore Optics mirror modules (instead of simplified dummies) for demonstrating the alignment and integration process. This shall also include using x-ray metrology tools for verification of the alignment.			
Description			
The original contracts proposed the use of dummy mirror modules to demonstrate the co-alignment and integration process. Based on the selected metrology and integration process, the use of dummies is possible, but results in a large risk that the alignment performance cannot be sufficiently evaluated for the real x-ray focal position. To mitigate this risk, real Silicon Pore Optics shall be procured and used for the breadboard. The contractor shall also adapt the proposed alignment, integration and performance verification process to take into account the use of real mirror modules. The integration facilities shall be upgraded to be suitable for Silicon Pore Optics mirror modules. The final alignment accuracy shall be verified using a large-beam x-ray facility to measure the actual x-ray focal position of at least two co-aligned mirror modules.			
Deliverables			

Integration breadboard as requested in the original contract but with real Silicon Pore Optics mirror modules					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	
Application Mission:	Athena		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Silicon Pore Optics consolidation during the transition period					
Programme:	CTP		**Reference:**	C216-177FT	
Title:	Silicon Pore Optics consolidation during the transition period towards the implementation phase				
Total Budget:	8000 kEuro				
Objectives					
The activity shall ensure the continuation of the maturation of the Silicon Pore Optics technology for the Athena mission during its transition to the implementation phase.					
Description					
The Silicon Pore Optics technology is the key technology for the ATHENA mission. It is at the core of the Mirror that shall deliver large effective area with exquisite angular resolution. The combination of these 2 performance parameters will allow science cases that until now have been unreachable.					
Deliverables					
Engineering/Qualification Model; Other; Other; Report					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	ATHENA		**Contract Duration:**	14 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Silicon Pore Optics Consolidation for the ATHENA Mission Adoption			
Programme:	CTP	**Reference:**	C216-164FT
Title:	Silicon Pore Optics Consolidation for the ATHENA Mission Adoption		
Total Budget:	8500 kEuro		
Objectives			
The activity shall ensure the continuation of the maturation of the Silicon Pore Optics technology for the Athena mission until its adoption. It shall allow the			

consolidation of all the steps of the currently developed process and allow the exploration and testing of a few alternatives that may have a significant impact in the improvement of the performance.
A representative number of Mirror Modules shall be manufactured with the agreed process steps that is fully compatible with the latest reference geometry for the mission.

Description

The Silicon Pore Optics technology is the enabling technology for the ATHENA mission. It is at the core of the Mirror that shall deliver large effective area with exquisite angular resolution. The combination of these 2 performance parameters will allow science cases that until now have been unreachable.

This technology has been supported by multiple previous activities to bring it to its current status, with a demonstrated performance of around 8 arcsec for a set of 20 plates in double reflection for a rib pitch of 1 mm. This activity shall fund the further development of the process steps known to have the greatest potential to further improve on this performance, namely:

- Introduction of Ion Beam Figuring into the production process to improve the thickness variation at plate level, replace the wet chemical wedging and potentially demonstrate the ability to correct for stack-up errors that are built up during stacking,
- Maturation of other improvements of the stacking recipe that have been identified to improve sides, entry-exit effects and excess meridional curvature,
- Maturation of plate production processes to improve performance, production rate and price for mass production (ensuring that 2 plate suppliers are capable of producing the mirror plates to the required specification)
- Improve the confocality during the assembly of the Mirror Modules,
- Exploration of a new wedging configuration and potential inclusion in the production process (with expected significant improvements on performance),
- Exploration of an ability to produce mirror modules with only 2 stacks (instead of the current 4), simplifying the assembly process and improving effective area,
- Exploration of the switch to thinner membranes and larger rib pitch (from 1 mm to 2.3 mm) for different rows.

The maturation of the production steps above shall be done on a representative radius (row 8) whose mandrels have already been ordered, but these improvements shall be rolled out for the other selected radii as well.

A representative number of Mirror Modules (expected to be around 5) shall be manufactured with the agreed process steps that is fully compatible with the latest reference geometry for the mission (with 15 rows).
These Mirror Modules shall demonstrate the required performance for mission adoption (angular resolution and effective area) confirmed by x-ray measurements, and shall be compatible with the environmental conditions

(e.g. structural loads) confirmed by environmental tests. Their production shall allow the demonstration of a production rate capability comparable to the one required for the implementation of ATHENA (about 1 Mirror Module/day), with the required quality assurance to ensure process control and repeatability.
Deliverables
Delta-Development Plan, mirror plates, stacks and modules, Technical Notes

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2022
Application Mission:	ATHENA	**Contract Duration:**	14 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Implementation of the long lead items for the Ultraviolet Vertical Integration Facility for the Integration of the ATHENA Mirror Assembly			
Programme:	CTP	**Reference:**	C216-163FT
Title:	Implementation of the long lead items for the Ultraviolet Vertical Integration Facility for the Integration of the ATHENA Mirror Assembly		
Total Budget:	1500 kEuro		
Objectives			
The objective of the activity is to implement the long lead items for the Ultraviolet Vertical Integration Facility, including parts of the optical bench and the building, which are required for the integration of the SPO Mirror Modules onto the ATHENA Mirror Assembly.			
Description			
The modular design of the ATHENA mirror imposes tight accuracies in the allignment method for the its Mirror Modules in the order of a fraction of an arcsec. It is therefore critical to demonstrate the required allignment performance prior to mission adoption. The previous activities C216-127MM and C216-141MM have funded parallel contracts to demonstrate two distinct methods that could meet the tight accuracies required. This demonstration was done by co-alligning two Mirror Modules and measuring the performance in x-ray. As planned, an independent review was held to choose the baseline method for the continuation of the mission, which led to the choice of the method using Ultraviolet as a proxy for the x-ray performance and performing the allignment in air in a quasi-direct way. This activity shall fund the implementation of the long lead items of the Ultraviolet Vertical Optical Bench and building, in order to be able to validate the required allignment performance in an adequate larger scale model prior to mission adoption.			

It shall include the metrology tools needed for the AIT process, the quasi-static 1-g offloading devices, the integration tools and the building construction. It shall also use all of the knowledge gathered and the deliverables from the previous activities (e.g. detailed facility design, foundation work, and Ultraviolet mirror cell, allignment mechanism (HAD)) and follow a cost effective approach and focus only on the parts which are required prior to adoption. Costly items such as stable thermal control, increased number of allignment heads, or good contamination control shall be deferred to after the adoption date.					
Deliverables					
Other					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	ATHENA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Figuring of Large Precision UV-optics					
Programme:	CTP		**Reference:**	C216-162FT	
Title:	Figuring of Large Precision UV-optics				
Total Budget:	2500 kEuro				
Objectives					
Production of a large collimator mirror for the Athena X-ray optics AIT.					
Description					
Structuring activity building on the experience and heritage from previous ESA and other activities, including the manufacturing of the Herschel mirror. The core of this activity is the figuring and polishing of a high performance UV collimator mirror for the optical alignment of the Athena mirror modules into the optical bench. The detailed design of the optics, the procurement of the required blank, the figuring and polishing of the mirror surface, the provision of the coating, and the mirror cell and test equipment are part of this activity.					
Deliverables					
Collimator and support equipment, Technical data package.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Figuring of Large Precision UV optics - CCN					
Programme:	IPTF		**Reference:**	C216-173FT	
Title:	Figuring of Large Precision UV optics - CCN				
Total Budget:	480 kEuro				
Objectives					
To enhance the metrology of the UV collimator to be installed at the mirror AIT facility for ATHENA.					
Description					
As a follow on to the running C216-162FT the following additional tasks need to be performed and equipment needs to be procured/developed: • Design and implementation of a system to be able to determine the wave front error and focal position of the UV collimator during operation. A three pentaprism-based system with associated insertion devices and control system. • Alignment source with optical fiber and pinhole to feed three pentaprism system. • Laser tracker system and accessories to provide continuous monitoring capabilities of the focal position wrt. UV mirror. • 2 tiltmeters with associated electronics to monitor alignment of the UV collimator wrt. gravity vector. • UV mirror support plate with adjustment system for alignment of the UV collimator • Implementation of the above equipment and commissioning at the AIT UVOB facility.					
Deliverables					
Optical quality metrology tooling, position metrology tooling.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Implementation of the critical items to increase the robustness and extend the use of the BEATRIX facility to lower x-ray energies			
Programme:	CTP	**Reference:**	C216-176FT
Title:	Implementation of the critical items to increase the robustness and extend the use of the BEATRIX facility to lower x-ray energies		
Total Budget:	250 kEuro		
Objectives			

To procure a number of equipment that can increase the robustness of the use of the BEATRIX facility (Advanced and Compact X-ray Test Facility for the Athena SPO module), and the critical items that will allow its use to test the performance of Athena mirror modules at lower energies.					
Description					
The acceptance of the x-ray performance of the ATHENA Mirror Modules is planned to be done in a novel type of facility that has been developed over a series of previous activities called BEATRIX.					
Deliverables					
Optical quality metrology tooling, position metrology tooling.					
Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Preparation of coated X-ray mirror plate production					
Programme:	CTP		**Reference:**	C216-135MM	
Title:	Preparation of coated X-ray mirror plate production				
Total Budget:	2500 kEuro				
Objectives					
This activity shall address the development of a second source of coated X-ray mirror plates suitable for stacking.					
Description					
For the implementation phase of the Athena mission, it is anticipated that a second source of coated Silicon Pore Optic (SPO) mirror plates will be required. The aim of this activity is to develop a second source meeting the requirements of Athena. In this activity the required mirror plate production facilities will be set-up in dedicated clean-rooms, and the production of coated mirror plates fully meeting the requirements of the Athena mission will be demonstrated. The facilities shall include the equipment for dicing, wedging, laser marking identification, cleaning and coating. The associated infrastructure (provision of clean water, process chemicals etc.), containers, materials, etc. shall also be addressed.					
Deliverables					
Reports Coated mirror plates					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2017

Application Mission:	Athena	**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Telescope mirror structure and optics integration demonstrator			
Programme:	CTP	**Reference:**	C216-007MM C216-007MM-B
Title:	Telescope mirror structure and optics integration demonstrator		
Total Budget:	2500 kEuro		

Objectives

- To demonstrate the capability of manufacturing a full sized Athena mirror structure compatible with the functional and interface requirements of the mission.
- To perform environmental tests to:
- verify the compatibility of the Athena mirror assembly with the environment (mechanical and possibly thermal)
- validate the analysis done that led to the specification of interface requirements at mirror module level

Description

This activity shall consist of 2 phases:

- Phase 1: Manufacturing of a mirror structure with full size representation in order to demonstrate the capability to produce the complex geometry (with deep pockets with small radius corners) and the achievement of small tolerances in specific parts. The process and tooling specifically targeting the ATHENA Mirror Structure shall be defined and evolved.
  The quality shall be verified with respect to the ATHENA application, demonstrating geometry, surface treatment, repair methods, etc...

- Phase 2: Environmental testing of a mirror structure populated with a MTDs of mirror modules (and possibly some mirror modules – TBD). As a minimum representative sine, random and HDRM release tests (shock) shall be included as well as a thermal verification test of the subset of the structure.
  These tests can be extended to also include sine, random and acoustic as specified in the launcher user manual as well as clampband release tests (shock) with the use of a representative MGSE (also to be developed).

Deliverables

Analysis and modelling results.
Telescope mirror structure populated with TBD MTD and TBD mirror modules.

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Low-Energy X-ray Coating Development and plate production improvements for the ATHENA SPO plates			
Programme:	CTP	**Reference:**	C216-170FI
Title:	Low-Energy X-ray Coating Development and plate production improvements for the ATHENA SPO plates		
Total Budget:	1200 kEuro		
Objectives			
The objective of this activity is to further develop the plate production processes and the coatings for the ATHENA SPO plates with particular emphasis on the study of alternative plate configurations, coating recipes, control of the wedging angle, and lithography.			
Description			
The Athena SPO plates require specific production processes and reflectivity enhancing coatings in order to enable the grazing incidence optics to meet the telescope effective area requirements. This activity shall build on the work performed during previous CTP activities (C216-135MM and C216-166FT) and fund a number of identified improvements such as: - implementation of the processes necessary to produce oversized SPO plates whose sides can be sacrificed after stacking to improve the angular resolution, - implementation of a process to measure the total thickness variation of the plates directly at the plate supplier, allowing to very accurately control the wedging angle, - study/implementation of different Silicon crystal orientations, - implementation of SPO plate configurations with different rib spacing and plate membrane thickness, - study/implementation of mask-less lithography and/or spray resist deposition, - design optimisation of the coatings with recipe solutions for bilayer and multilayer building on the work performed in the context of the activity C216-144FT, - implementation of an additional magnetron and different targets in the ATHENA coating machine, - study/implementation of additional processes to improve the coating quality and stability (e.g. thermal annealing), - verification of the feasibility and performance of the coating design options by checking the low-energy coating reflectivity performance and the compatibility of the coating with the SPO manufacturing processes. The temporal and			

compositional stability shall be verified using coated samples or SPO plates subjected to all steps of the SPO processes. For that purpose, the contractor shall utilise appropriate analytical tools including low-energy XRR (developed and implemented with the activiy C216-157FI), AFM, XPS, TEM etc. - production of a representative TBD number of SPO plates to support the concurrent activities focussing on the stacking and mirror module level improvements until mission adoption (e.g. C216-149MM), - study and preliminary implementation of QA/PA processes in preparation of the ATHENA flight production.
Deliverables
Technical data package; Equipment purchased under this activity; Representative TBD number of SPO Plates (coated and uncoated)

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Coatings					

Carbon nanotube-based filters for x-ray applications			
Programme:	TDE (TRP)	**Reference:**	T216-171FT
Title:	Carbon nanotube-based filters for x-ray applications		
Total Budget:	500 kEuro		
Objectives			
Novel carbon nanotube-based foils have recently emerged in the semicon industry. These filters offer a promising path to producing high performance light blocking filters for x-ray instrumentation applications. In this activity, the technology shall be developed and demonstrators for the 2 instruments onboard ATHENA shall be produced.			
Description			
As required for the ATHENA mission, filters with high opacity for IR/Visible/UV light need to be developed to reduce the straylight in these spectra. At the same time, a high transmission in the x-ray band shall be maintained. The experience from recent developments in the semicon industry of producing suitable large size carbon nanotube-based foils, shall be utilized. These foils shall form the support membrane for the required x-ray filters. Alternative paths to close the porous structure of these foils shall be identified and explored. Suitable test filters shall be produced and evaluated allowing a down-selection of the most promising implementation architecture and production method. In the following phase, demonstrators for filters as required for ATHENA, shall be produced.			

The resulting filters shall be characterized with regards to their performance (x-ray transmission, blocking characteristics in the other bands, environmental compatibility).					
Deliverables					
Breadboard; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	ATHENA and other future x-ray missions	**Contract Duration:**	18		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Demonstration of critical items for x-ray scanning facility					
Programme:	CTP	**Reference:**	C216-172FT		
Title:	Demonstration of critical items for x-ray scanning facility				
Total Budget:	2500 kEuro				
Objectives					
In order to derisk the concept and maintain compatibility with the ATHENA schedule, critical items identified in the running activity T216-110FT shall be demonstrated. The x-ray testing facilities are critical items that need to be verified before adoption for ATHENA. This particularly includes the collimated x-ray source and associated equipment.					
Description					
This activity shall consist of the following tasks: - According to the design specified in the running T216-110FT activity, a micro-focus source shall be procured/developed. - The required Wolter collimator shall be produced and its performance suitably verified. - The connecting optical bench shall be implemented allowing the completed collimated source to be validated in a suitable x-ray facility. - The key elements of positioning system and associated metrology shall be refined and implemented as necessary to validate the control algorithm and system.					
Deliverables					
Engineering Model; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	ATHENA	**Contract Duration:**	18		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
N/A

Synchrotron beam time and monochromator beamline maintenance					
Programme:	CTP		**Reference:**	C216-129FT	
Title:	Synchrotron beam time and monochromator beamline maintenance				
Total Budget:	340 kEuro				
Objectives					
Provision of synchrotron beam time and maintenance of ESA beamline in the PTB laboratory at Bessy II.					
Description					
Continued provision of beam time to ESA for a further 3 to 4 years, including the prior customised set-up and support during the beam time, and unlimited access to and maintenance of the dedicated fixed-energy beamlines operated for ESA.					
Deliverables					
Beam time at the PTB beamlines at the Bessy II facility, and maintenance of the dedicated beamlines.					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2015
Application Mission:	Athena		**Contract Duration:**	48 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Synchrotron beam time and monochromator beamline maintenance - extension			
Programme:	CTP	**Reference:**	C216-178FT
Title:	Synchrotron beam time and monochromator beamline maintenance - extension		
Total Budget:	400 kEuro		
Objectives			
Provision of synchrotron beam time and maintenance of ESA beamline in the PTB laboratory at Bessy II for an additional 2 years.			
Description			
Continued provision of beam time to ESA for a further 2 years, including metrology support, the prior customized set-up and support during the beam time, and unlimited access to and maintenance of the dedicated fixed-energy.			
Deliverables			
Other			

Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	ATHENA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Synchrotron beam time and monochromator beamline maintenance continuation					
Programme:	CTP		**Reference:**	C216-161FT	
Title:	Synchrotron beam time and monochromator beamline maintenance - continuation				
Total Budget:	800 kEuro				
Objectives					
Provision of synchrotron beam time and maintenance of ESA beamline in the PTB laboratory at Bessy II for an additional 4 years.					
Description					
Continued provision of beam time to ESA for a further 4 years, including metrology support, the prior customised set-up and support during the beam time, and unlimited access to and maintenance of the dedicated fixed-energy beamlines operated for ESA.					
Deliverables					
Other					
Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	Beam time in support of Athena optics verification activities		**Contract Duration:**	48 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

X-ray facility design and verification for the Athena flight mirror performance testing and calibration.			
Programme:	CTP	**Reference:**	C216-142MM
Title:	X-ray facility design and verification for the Athena flight mirror performance testing and calibration.		
Total Budget:	500 kEuro		
Objectives			
The activity shall elaborate a detailed design for a new or extended facility suitable to test and calibrate the complete Athena X-ray mirror. Critical			

technologies and performance evaluations (e.g. impact on cleanliness, test durations, thermal conditions) shall be verified at existing facilities.
Description
The design activity shall cover the detailed design of the facility including: - Identification of the location - Full verification of the suitability of the location with respect to technical, legal and other formal requirements - Design of the building, vacuum equipment, x-ray source, clean rooms, thermal control, operational control system, handling (inside and outside the vacuum parts) and storage equipment. - Analysis of the suitability of the facility to do the performance tests and calibration of the Athena mirror - Detailed schedule for the setup of the facility. - Detailed cost analysis (setup and operations) Critical technologies and performance evaluations (e.g. impact on cleanliness, test durations, thermal conditions) shall be verified at existing facilities.
Deliverables
Detailed designs

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Advanced and Compact X-ray Test Facility for the Athena SPO module			
Programme:	CTP	**Reference:**	C216-153MM
Title:	Advanced and Compact X-ray Test Facility for the Athena SPO module		
Total Budget:	500 kEuro		
Objectives			
Design, assembly and verification of an advanced compact X-ray facility for testing the XOUs of the Athena SPO module			
Description			
X-ray tests of the Athena SPO module are today performed at large facilities that will not be able to process the high quantity of X-ray Optical Units (XOU) needed for the Athena mission. The objective of this activity is to design, assemble and verify the performance of a compact X-ray test facility that is capable to perform full-illumination testing of the XOUs of the Athena SPO			

module with a target process rate of several XOUs per day. The facility shall be designed to provide a broad, parallel, uniform, monochromatic and polarized X-ray beam that can fully illuminate the largest apertures of the XOUs, and have very low residual divergence to reliably characterise XOU PSFs. The facility shall be designed with the possibility to be replicated at the industrial production site of the XOUs. Following assembly of the facility, the beam collimation shall be measured using a calibrated test module and facility performances verified.					
Deliverables					
GSE					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Panter beam time provision					
Programme:	CTP		**Reference:**	C216-150FT	
Title:	Panter beam time provision				
Total Budget:	1000 kEuro				
Objectives					
Provision of beam time at the Panter facility					
Description					
The Panter facility provides a uniform large area X-ray beam of low divergence, as required for the verification and characterisation of high performance X-ray optics. Beam time at the Panter facility shall be provided to ESA in support of the Athena X-ray optics development, and for any other similar activities. The provision of beam time will be phased annually, covering the period 2017 to 2019. The beam time provision includes the prior customised set-up and support during the campaigns, and the processing, analysis and reporting of the measurement results and campaign progress/events.					
Deliverables					
Beam time at the Panter beamline, measurement data, analysis results and associated reports.					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2017
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

N/A

Panter beam time provision - continuation					
Programme:	CTP		**Reference:**	C216-180FT	
Title:	Panter beam time provision - continuation				
Total Budget:	1000 kEuro				
Objectives					
Continuation of provision of beam time at the Panter facility					
Description					
The Panter facility provides a uniform large area X-ray beam of low divergence, as required for the verification and characterisation of high performance X-ray optics. Beam time at the Panter facility shall be provided to ESA in support of the Athena X-ray optics development, and for any other similar activities. The provision of beam time will be phased annually, covering the period 2023-2025. The beam time provision includes the prior customised set-up (including manufacture of dedicated jigs and GSE), support during the campaigns, processing, analysis, reporting of the measurement results, and campaign progress/events.					
Deliverables					
Beam time at the Panter beamline, measurement data, analysis results and associated reports.					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2025
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

ALBA fixed energy beamline			
Programme:	CTP	**Reference:**	C216-168FT
Title:	ALBA fixed energy beamline		
Total Budget:	1000 kEuro		
Objectives			
Set up of beamline at the ALBA synchrotron facility for characterization of X-ray optics with 12m focal length.			
Description			
A dedicated beamline with good accessibility shall be designed, built and set-up at the ALBA synchrotron facility. The beamline shall be equivalent to the existing 12 m Fixed Energy Beamline at the Bessy-II facility and provide a well collimated beam with low divergence at a fixed energy (about 1.6 keV			

(TBC)). The facility shall be able to accommodate test optics with focal length of 12 m. A suitable sample chamber shall be included, with adequate windows and doors for loading and alignment of the sample, and be equipped with adequate pumps for fast pump-down to operational pressures. A hexapod sample positioner with associated controllers and autocollimators is required, integrated into a control environment permitting stable automatic metrology. The sample chamber area shall be protected by a clean tent in which also a sample preparation area shall be included. A sample loading station shall be designed and implemented, including the mechanism required for the transfer to the hexapod. High accuracy metrology shall be implemented, monitoring the exact position of the focal plane detector with respect to the beam and the optics sample (for example, using laser trackers).
Deliverables
Operational beamline at ALBA Technical data package including User Manual

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena On Board Metrology			
Programme:	CTP	**Reference:**	C217-067FM
Title:	Athena On Board Metrology		
Total Budget:	900 kEuro		
Objectives			
To study, design and develop a metrology system compatible with ATHENA telescope requirements measuring the relative lateral and longitudinal position over 12m focal length of the X-Ray telescope detector with respect to the mirror plane/axis (TRL 6 at the end of the study).			
Description			
Inputs: • Applicable pointing accuracy requirements (from ATHENA AKE and HEW budgets); • 15μm lateral position at 95% confidence level with temporal statistical interpretation; • 50μm longitudinal position at 95% confidence level with temporal statistical interpretation; • ATHENA Geometry and physical constraints (available volume/mass). The TDA shall provide the following outputs:			

• conceptual and detailed design of on-board metrology (OBM) system and related budgets: - OBM Receiver/Transmitter+Receiver (OBM-R/RT) composed by optical head/detector/transmitter (OBM-OH) and processing electronics (OBM-EL) to be positioned on the mirror plane - OBM Transmitter/Reflector (OBM-T/F) composed by fiducials to be positioned close to the telescope detectors and any control electronics for the fiducials * design and development of a representative metrology BB • performance test results • analysis of accommodation constraints (if any) for the OBM-R and the OBM-T/F including: relative position between OBM-R and OBM-T/F's for all the detectors; minimization of the mass, volume and thermal dissipation. * analysis of the need for on-board sensor calibration exploiting the needed accuracy and feasibility • analysis of induced straylight on ATHENA detectors * development of TRL 6 BB: full Engineering Model including OBM-R and OBM-T/F • development of representative validation facility to test and calibrate the sensor performance Definition of Technological limits in the sensor physical realization and calibration (if any) and their influence on the design • Redundancy concept for the metrology system considering the accommodation limitations • The closed loop control concept using the OBM and the ATHENA Instrument Switching Mechanism • Material characteristics, space qualification problems identification (if any) and proposed solutions • Implementation requirements; • Definition of main programmatic aspects such as Potential Supplier identification and preliminary cost estimate					
Deliverables					
Detailed design and budgets for on-board metrology system; on board accommodation constraints. Performance simulation results and performance test results; stray light simulation results. Metrology Breadboard. TRL 6 (OBM-R and OBM-T Engineering Model) Validation/calibration test facility and validation test report Potential supplier and cost estimate					
Current TRL:	3-4	**Target TRL:**	6	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Formation Flying – Optical Metrology (to be replaced with new dossier: RF and Optical Metrology)					

<table>
<tr><th colspan="6">Optimization of a European Transition Edge Sensor Array - Large Array Production and Testing</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C217-043FM</td></tr>
<tr><td>Title:</td><td colspan="5">Optimization of a European Transition Edge Sensor Array - Large Array Production and Testing</td></tr>
<tr><td>Total Budget:</td><td colspan="5">1000 kEuro</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">The objective of this activity is to further develop a European Transition Edge Sensor (TES) detector for X-Ray missions and which can be used as a backup for the X-ray Spectrometer instrument (X-IFU) on-board Athena.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">This activity will build on the results of the "Optimisation of a European Transition Edge Sensor Array" activity, which develops a small European TES array with a high energy resolution compatible with the needs of Athena.As part of this activity, a large Array (> 1000 Pixels) in line with the need of Athena shall be developed, manufactured and tested.

The work foreseen in this activity includes:
- Explore the maximum array sizes that could be manufactured with high reliability, of required performance, and with uniform performance
- Verify the wiring concept for these large arrays
- Fabricate large arrays with improved performance and full wiring
- Integrate and test these arrays with an appropriate SQUID multiplexing scheme
- manufacture and deliver a test cryostat operating at 50mK</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Transition edge sensor arrays, detailed design reports, test reports, test cryostat.</td></tr>
<tr><td>Current TRL:</td><td>3</td><td>Target TRL:</td><td>4</td><td>Application Need/Date:</td><td>2019</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Athena</td><td>Contract Duration:</td><td colspan="2">24 months</td></tr>
<tr><td>S/W Clause:</td><td colspan="5">N/A</td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6">N/A</td></tr>
</table>

<table>
<tr><th colspan="4">Large Area European Transition Edge Sensor Array for X-Ray missions</th></tr>
<tr><td>Programme:</td><td>CTP</td><td>Reference:</td><td>C217-044FM</td></tr>
<tr><td>Title:</td><td colspan="3">Large Area European Transition Edge Sensor Array for X-Ray missions</td></tr>
<tr><td>Total Budget:</td><td colspan="3">1400 kEuro</td></tr>
<tr><td colspan="4">Objectives</td></tr>
</table>

The Objective is to further develop a European TES detector for X-Ray missions and which can be used as a backup for the US detector currently foreseen on X-IFU

Description

There is a need to develop the European technology to be not critically dependent on a non-European partner as identified in the call for the L2 mission. In the baseline NASA will provide the TES array for the X-IFU instrument, but a European backup should be available at the time of the mission adoption. The activity will build on the results of the CTP activity of the Optimisation of a European Transition Edge Sensor Array, which develops a small Euroepan TES Array which should achieve the energy resolution required for Athena.
As part of this follow on activity, several large flight representative Array (> 1000 Pixels) meeting the following requirements shall be developed, manufactured and tested.
- the array should have > 1000 pixels with technology allowing the implementation of 3840 pixels (e.g. strip line wiring, etc) of which a subset (4 channels with 40 pixels each) need to be connected
- the performance of a single detection element should be < 3 eV
- the filling factor of the TES array should be > 0.9
- the pixels should allow > 15 counts/sec/pixel with 80% of the events with a resolution better than 3.5 eV
- the stopping power at 6 keV should be > 0.7
- the pixel size should be 250 x 250 micron2

The work foreseen in this activity include:
- production of TES arrays (at least 4 design iterations starting in 2018 and ending end of 2020 (2 iterations per year: pixel optimization round 1, array optimization round 1, pixel optimization round 2, and array optimization round 2.
- testing of the produced TES arrays, feedback into the production line and corresponding reporting.
- limited environmental testing to provide confidence that TRL 6 can be reached in < 1 year

Deliverables

Transition Edge Sensor arrays, detailed design reports, test reports.

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Athena Superconducting Quantum Interference Device Readout Development

Programme:	CTP	**Reference:**	C217-065FM

Title:	Athena Superconducting Quantum Interference Device Readout Development
Total Budget:	1000 kEuro

Objectives

The objective of this activity is to develop and guarantee European capability to produce the most sensitive cryogenic amplifiers needed to push sensitivity limits of future detectors. The development will focus on the SQUID (Superconducting Quantum Interference Device) required for the X-ray Spectrometer instrument (X-IFU) on-board Athena.

Description

During this activity, readout SQUIDs for a large Array of TES detectors (Transient Edge Sensor, > 1000 Pixels) and for the readout of cryogenic Anti-Coincidence (cryoAC) detectors shall be developed, manufactured and tested. The circuits will multiplex and amplify the signal from a TES array with a high energy resolution and from the cryoAC detectors compatible with the needs of Athena X-IFU instrument.

The work foreseen in this activity includes:
- Evaluate and design samples of various design options
- Iteratively fabricate three batches of circuits
- Prepare test and qualification plans for SQUID circuits and perform initial qualification for the most critical aspects
- Design and build a moderate scale testing environments for testing the circuits at room temperature, at liquid helium and in a cryostat at 0.05 K.
- Test of different design options
- Make demonstration test for an application on-board Athena.

Deliverables

SQUID chips, design reports, test and qualification plans, test reports, test environment.

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena		**Contract Duration:**	36 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Athena SQUID Amplifier Qualification

Programme:	CTP	**Reference:**	C217-097FM
Title:	Athena SQUID Amplifier Qualification		
Total Budget:	2000 kEuro		

Objectives
The objective of this activity is to develop and guarantee European capability to produce cryogenic amplifiers needed to enable the read-out and multiplexing of TES detectors. The development will focus on the SQUID (Superconducting Quantum Interference Device) required for the X-ray Spectrometer instrument (X-IFU) on-board Athena. This extension of C217-065FM will build on the output and progress of the previous activity and focus on implementing TDM compatible amplifier SQUIDs and qualification of the SQUID amplifiers.
Description
The cryogenic nature of the focal plane assembly of the ATHENA X-ray Integral Field Unit necessitates a low power cryogenic amplification chain. SQUID amplifiers developed in Finland are a key element of this chain. In order to qualify the SQUID amplifiers for a flight programme, several steps are foreseen: • Update the SQUID design to be compatible with TDM • Manufacture TDM compatible amplifier SQUIDs • Optimise quality and yield of production process in preparation of flight production. • Develop GSE for efficient qualification measurements of large number of samples • Close delta from currently ongoing pre-qualification to full flight qualification, e.g. homogeneity. • Manufacture first batch of proto-flight devices
Deliverables
SQUID chips, design reports, test and qualification plans, test reports, test environment.

Current TRL:	5	**Target TRL:**	7	**Application Need/Date:**	2023
Application Mission:	Athena		**Contract Duration:**	24	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
N/A

Athena Focal Plane Module Development Model			
Programme:	CTP	**Reference:**	C220-041FM
Title:	Athena Focal Plane Module Development Model		
Total Budget:	2000 kEuro		
Objectives			

The objective of this activity is to produce a structural Development Model (DM) of the Science Instrument Bench (SIB), that is carrying Athena science instruments. This DM will be used to pre-qualify the PL-accommodation and AIT procedures, and also be used in mechanical/thermal (TBD) pre-qualification activities.					
Description					
- The Athena SIM is a structure comparably large to an individual SC (2-3m dimensions), with an important role (primarily thermo-mechanical) to play in accommodating the two instruments (WFI and X-IFU). In the case of the X-IFU instrument, this entails the accommodation of the large main dewar assembly, and also a large number of individual electronics boxes. The SIB structure, subject of this activity is required to meet the requirements of both the instruments, most critically being: *Providing a benign mechanical load environment during launch. This in particular requires a 'centred' configuration where the CoM of the overall FPM is well-aligned with the centre-line of the SC Fixed Metering Structure (FMS), and suitable eigenfrequencies to be compatible with the SC/launcher (first mode ~33 Hz TBC) and instruments (first mode ~55 Hz TBC). *Providing the required radiator area (~12 m^2 TBC) and thermal-links (LHPs/HPs) to the radiator area (including heat-spreading capability) to the many thermal I/F points on both the instruments. Mechanical considerations related to (L)HP selection, and resulting AIT constraints, will need to be carefully considered. *Providing TBD additional EMC-shielding functionality, e.g. provision of mumetal enclosures etc. to the instruments. The work will cover the following: to refine the baseline SIB design; - The production of a DM of the FPM structure, excluding thermal H/W . The DM will be used to pre-qualify the PL-accommodation and AIT procedures, and also be used in mechanical/thermal(TBD) pre-qualification activities, using Mass-Thermal Dummies of the 2 instruments, which will also be produced as part of the activity.					
Deliverables					
SIB thermo-mechanical design consolidation, MRR report SIB DM and PL MTD manufacture, DM test-campaign reports					
Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena Instrument Selection Mechanism			
Programme:	CTP	**Reference:**	C220-038FM
Title:	Athena Instrument Selection Mechanism		
Total Budget:	1000 kEuro		
Objectives			
The baseline implementation of the Athena mission foresees the use of an instrument selection mechanism in order to correctly position the focal plane instruments at the focus of the telescope mirror. This activity will address the design and breadboarding of a mechanism meeting the Athena requirements for the instrument selection mechanism.			
Description			
The Athena spacecraft baseline carries two independent instruments; a spectrometer (X-IFU) and an imager (WFI) which will share a single focal point provided by a single x-ray telescope. The mission therefore requires a means of placing one of the instruments at a time at the telescope focus via an Instrument Selection Mechanism (ISM). Two possibilities are foreseen in order to meet this requirement (a) the Movable Mirror Assembly (MMA) approach where the telescope mirror assembly shall be rotated/translated whilst the focal plane instruments remain fixed with respect to the spacecraft structure and (b) the Movable Instrument Platform (MIP) approach where the instruments are translated and the telescope mirror assembly remains fixed with respect to the spacecraft structure. This activity is foreseen to be conducted in two phases. Phase 1 shall address the preliminary design of an ISM meeting the requirements of both the MMA and MIP approaches. Phase 2 shall address the detailed design and breadboarding of one of the two approaches which will be selected by the Agency			
Deliverables			
Technical data package, breadboard model, test data.			
Current TRL: 2	**Target TRL:** 4	**Application Need/Date:**	2017
Application Mission:	Athena	**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Cryogenic vibration isolators and thermal disconnects			
Programme:	CTP	**Reference:**	C221-005FI
Title:	Cryogenic vibration isolators and thermal disconnects		

Total Budget:	500 kEuro				

Objectives

To develop a cryogenic vibration isolator to minimise the sensitivity of the Focal Plane Array (FPA) to external exported vibrations. To survive the launch loads, a hold down release "mechanism" shall be incorporated, which will enable the minimisation of the conductive loads through allowing the sizing of the support structure to the minimum required for on-ground and in-orbit operations, and not to the launch loads as currently the case.

Description

Lessons learnt from Planck and Astro-H have shown that sub-Kelvin Bolometers are sensitive to self-heating caused by exported vibrations which are dissipated in the Kevlar support structure. In the past, this has been solved by reducing the exported vibration at the source. But with the number of active coolers foreseen at future missions like Athena+ and SPICA, this results in significantly increased complexity at system level and does not prevent any interactions with other mechanisms (e.g. reaction wheels) at system level which might only be discovered late in the programme.

For ground based detectors, compact vibration isolators have already been developed, which suppress the vibration to close to the background level. These systems consist of a spring-loaded system, acting as a filter for high frequency vibrations similar to what is under development for the room temperature damping system for MTG coolers. Due to the low eigenfrequencies of such systems, a locking mechanism is required during launch. Such a locking mechanism can take advantage of the warm launch configuration and being activated during cool down of the system (by e.g. using different CTE materials). As a side-effect, the support structure required during operation has then only to be sized to the loads for on-ground and in-orbit, but not for the launch loads as in current systems. This should allow to replace the Kevlar support systems with lower efficient, but more reproducible and reliable support structures.

During the initial phase of the activity, a vibration isolator compatible with a Transition Edge Sensor (TES) FPA and 50mK cooling stage shall be designed and analysed. This shall also include a passive locking mechanism using the cool-down from room temperature down to 2-4K. Trade-off's shall be performed on the final support structure materials looking into alternatives to Kevlar and assess the impact on the final cooling power required at low temperatures. In a second phase, the system shall be manufactured and the performance shall be verified at cryogenic conditions. Mechanical tests shall be included to verify that the system can withstand the loads during launch.

Deliverables

Hardware, test results , documentation

Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2017
Application Mission:	L2	**Contract Duration:**	24 months		

S/W Clause:	N/A
Consistency with Harmonisation Roadmap and conclusion:	
N/A	

Superconducting multilayer flex harness			
Programme:	CTP	**Reference:**	C221-006FI
Title:	Superconducting multilayer flex harness		
Total Budget:	300 kEuro		
Objectives			
To develop a multilayer flex harness to read out TES detectors operating below 1K, which can be manufactured in a reproducible way for future flight applications.			
Description			
Previous developments have shown that a single layer superconducting flex harness can be manufacture to read-out TES detectors operating at 50mK. The main advantage of this technology is that it allows to reduce significantly the heat load onto the detector, since the metallic lines (which are the main conductive loss) can be reduced to the bare minimum cross-section required. In addition, due to the flexibility of the harness a very compact Focal Plane Assembly can be obtained, minimising the volume/mass of the cryogenically cooled part. In the first phase of the activity, a multilayer superconducting harness shall be designed and manufactured. From previous experience it is known that the Nb layers obtained do not always become superconducting. It is therefore required to improve and verify the process of manufacturing to obtain a reliable product. In second phase the multilayer harness shall be tested in the relevant environment to verify the thermal, electrical and EMC performance required. This also includes the verification of suitable interconnections between the harness and the detector/read-out.			
Deliverables			
Multilayer harnesses, test results , documentation			

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2017
Application Mission:	L2	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Low vibration 15K Pulse Tube engineering model cooler including cooler drive electronics			
Programme:	CTP	**Reference:**	C221-007FM

Title:	Low vibration 15K Pulse Tube engineering model cooler including cooler drive electronics				
Total Budget:	2000 kEuro				
Objectives					
The aim of this activity is to develop a 15K Pulse Tube cooler to Engineering Model (EM) level. This will include a flight like configuration of the coolers (brackets, buffer volumes) and an optimisation of the active phase shifter to minimise the input power required. In addition, a suitable EM Cooler Drive Electronics shall be developed to operate the 15K Pulse Tube, minimising the exported vibrations. The complete system shall undergo performance, environmental and lifetime tests					
Description					
This activity shall develop a 15K Pulse Tube cooler to Engineering Model (EM) level. This will include a flight like configuration of the coolers (brackets, buffer volumes) and an optimisation of the active phase shifter to minimise the input power required. In addition, a suitable Cooler Drive Electronics (CDE) which allows to minimise the exported vibrations, shall be developed, manufactured and tested within this activity. This will then allow to verify not only the cryogenic performance but also to explore other critical cooler system parameters as exported vibrations, EMC/EMI in a flight representative configuration including an EM of the CDE. This cooler system shall then undergo an environmental test campaign in preparation for a lifetime test of the cooler.					
Deliverables					
Documentation, Cooler, Cooler Drive Electronics, lifetime test bench					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	Athena	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Industrialisation of the Joule Thomson cooler mechanical assembly			
Programme:	CTP	**Reference:**	C221-019MT
Title:	Industrialisation of the Joule Thomson cooler mechanical assembly		
Total Budget:	4500 kEuro		
Objectives			
To manufacture and test Engineering Model(s) of the full 4K Joule-Thomson Cooler Mechanical Assembly, comprised of the Compressor Assembly CPA , the Cold Finger Assembly CFA or Cold Plumbing, and the Cooler Ancillary			

Panel CAP, capable to be integrated into the cryostat EM on Athena SIM prime level. The design of the overall cooler will be based on the 2K JT compressor currently under development and which will be flight qualified for the Ne-JT cooler on Ariel. As part of this activity, the contractor shall raise an industrial setup capable of delivering space hardware within the ESA quality and engineering standards and showing reproducible performances as required by the Athena flight programme.					
Description					
The activity shall be split into 4 tasks: Task 1 will consist of the requirements definition for the JT 4K EM CMA, with special focus on transferring the Compressor Assemblies to an industrial partner, keeping the synergies with the Ariel cooler flight program. This shall consolidate the requirements set by ESA/ Athena SIM primes and also integrate lessons learned from previous JT development contracts. The supplier shall also clearly define the split in responsibilities within the industrial consortium, with regard to hardware manufacturing, product assurance and system performance verification. The main output of this task shall be the Requirements Definition Documents for the JT 4K. Long Lead Items and required GSE will also be identified and included in the documentation, in order to start procurement early. The task shall be closed by a Systems Requirements Review. Task 2 will consist of the detailed design of JT4K EM CMA, integrating any necessary changes to the design that stemmed from the previous task. The Test procedures shall also be defined, in terms of acceptance at unit level and performance verification at system level. The responsibilities in each test campaign shall be clearly defined. The task shall be concluded by a Detailed Design Review that will enable the start of the manufacturing. Task 3 will consist of the manufacturing and assembly of the JT4K EM CMA(s) required for the Athena SIM EM program, together with acceptance testing at unit level for each item, CMA, CFA and CAP. The task will be finished by a Test Readiness Review that will preclude the system testing for the full CMA. Task 4 will consist of the testing and exploitation of JT CMA. The expected performances shall be correlated and the results exploited for further work. In parallel the contractor shall support ESA in defining the IRD/URD for integrating the JT coolers in the design of the parallel Athena SIM cryostat during Phase B1 The activity shall be closed off with a final review, which will also include the delivery of the hardware to ESA. This activity is a direct continuation of the activity C221-008FM (2K Joule-Thomson engineering model cooler system including cooler drive electronics), implementation as a change notice to said contract is proposed					
Deliverables					
Engineering Models, Technical Data package					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2024

Application Mission:	Athena	**Contract Duration:**	36 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Cryogenics and Focal Plane Cooling, B04			

Athena Wide Field Imager Loop Heat Pipe Engineering Model Development					
Programme:	CTP		**Reference:**	C221-010MT	
Title:	Athena Wide Field Imager Loop Heat Pipe Engineering Model Development				
Total Budget:	950 kEuro				
Objectives					
Design, build and test an engineering model (EM) of a Loop Heat Pipe (LHP) to comply with the Athena Wide Field Imager (WFI) requirements with respect to thermal requirements (e.g. heat transport, temperature range), mechanical decoupling of sensor from heat sink, while respecting all relevant configuration aspects. In addition, the initial phase 1 of the activity will be followed by a qualification program (phase 2).					
Description					
Based on the available experience with Loop Heat Pipes (LHP's) with Ethane and Propylene as working fluid (which allows to cover the temperature range required by WFI), the most suitable working fluid (between the two) shall be selected in view of the WFI requirements. An EM design shall then be elaborated, taking into account all thermal, mechanical and configuration requirements coming from WFI. The EM shall then be designed in detail - making maximum use/heritage of existing LHP designs. In the Phase 1 of the activity, the EM shall be built and submitted to an exhaustive test program. All relevant (thermal and mechanical) WFI requirements shall be addressed by the test program. It is expected that at the end of the test program the EM LHP will have a TRL level of 5. At the end of the phase 1 and once the WFI and Focal Plane Module design and related environments are defined in detail, an evaluation of the EM test results shall be performed and any improvements/adaptations of the EM LHP that allow to meet the updated WFI instrument and system level requirements shall be described. In the second phase of this activity, a process and product qualification program shall be defined and implemented. The required TRL level at the end of Phase 2 shall be 7.					
Deliverables					
Design documentation, test and evaluation reports, EM hardware					
Current TRL:	3	**Target TRL:**	7	**Application Need/Date:**	2020

Application Mission:	Athena	**Contract Duration:**	36 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Two-Phase Heat Transport harmonisation			

Low temperature radiator panel with embedded heat pipes					
Programme:	CTP		**Reference:**	C221-012FT	
Title:	Low temperature radiator panel with embedded heat pipes				
Total Budget:	600 kEuro				
Objectives					
The objective of this activity is to design, develop and test a demonstrator of a radiator panel with ethane embedded heat pipes					
Description					
The WFI instrument which will be embarked on the Athena spacecraft requires heat rejection capabilities onto a low temperature interface. In its operational state, the camera head of WFI needs to dissipate around 40 W into at an interface with a temperature of 173 K. This heat needs to be transported through linking heat pipes to a set of radiator panels that need to be operating at even lower temperatures (less than 163 K). Due to the lower radiative power dissipation performance at these temperatures, it is envisaged to use panels with embedded heat pipes to improve the performance as much as possible. These embedded heat pipes are foreseen to use ethane as the working fluid (different than the standard ammonia). This activity shall focus on design and development of a demonstrator of a radiator panel with embedded ethane heat pipes capable of rejecting a representative power at a low temperature interface, and shall demonstrate the technology for a possible future application for the STM and FM of the WFI instrument. The design shall include the radiator panel and a thermally insulated mechanical interface capable of minimising conductive heat losses between the panels and any support structure. The design work shall focus on mechanical and thermal analysis of the different elements and on exploring different possibilities such as embedded geometry (vertical/horizontal), thicknesses, different materials, etc. The manufacturing processes and tolerances shall also be defined as well as the testing procedures. As a minimum quasistatic structural tests, CTE measurements and thermal performance tests shall be performed.					
Deliverables					
Demonstrator of radiator panel (including mechanical support); Detailed Design Reports, Test reports.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2020

Application Mission:	Athena	**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Low temperature radiator panel with embedded heat pipes - CCN					
Programme:	CTP		**Reference:**	C221-020MT	
Title:	Low temperature radiator panel with embedded heat pipes - CCN				
Total Budget:	300 kEuro				
Objectives					
The overall objective of this activity is to design, develop and test a demonstrator of a radiator panel with ethane embedded heat pipes					
Description					
The WFI instrument which will be embarked on the Athena spacecraft requires heat rejection capabilities onto a low temperature interface. In its operational state, the camera head of WFI needs to dissipate around 40 W into at an interface with a temperature of 173 K. This heat needs to be transported through linking heat pipes to a set of radiator panels that need to be operating at even lower temperatures (less than 163 K). Due to the lower radiative power dissipation performance at these temperatures, it is envisaged to use panels with embedded heat pipes to improve the performance as much as possible. These embedded heat pipes are foreseen to use ethane as the working fluid (different from the standard ammonia). The development of the radiator panel with embedded ethane heat pipes is ongoing under a previous ESA contract. Design trade-offs include investigation of different solutions, such as embedded geometry (vertical/horizontal), thicknesses, different materials, etc. This activity shall cover: - design optimization of the Radiator Isolation brackets, - design optimization of the Linking Heat Pipe brackets, - manufacturing of Engineering Models of the Linking and Radiator brackets, - mechanical testing of the EM brackets, - thermal cycling test of the Cold Radiator Breadboard Model, - static mechanical test of the Cold Radiator Breadboard Model following thermal cycling. Note: this activity will be implemented subject to satisfactory progress of activity C221-012FT.					
Deliverables					
EM brackets, Technical datapackage (e.g. detailed design reports, test plans, test reports)					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2023

Application Mission:	ATHENA	**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Feedthroughs with low thermal parasitic loads for cryogenic applications					
Programme:	TDE		**Reference:**	T221-113FT	
Title:	Feedthroughs with low thermal parasitic loads for cryogenic applications				
Total Budget:	250 kEuro				
Objectives					
This activity shall focus on the design, implementation and testing of (a) breadboard(s) of feedthrough(s) that can allow to reduce the thermal parasitic loads on cryogenic applications. The Dewar of the ATHENA X-IFU instrument shall be used as the representative application.					
Description					
The cryogenic chain of the X-IFU instrument on the ATHENA mission is extremely complex, needing a Dewar with a large number of shields in a "matrioska-like" configuration. Such a configuration requires a number of feedthroughs to route power and data cables to the inner components (such as the Focal Plane Array or the ADR cooler) and also to feed the cooler fluid into the internal shields of the Dewar. The feedthroughs are an important source of thermal parasitic loads that shall be minimised as much as possible. Also, for applications with strict EMC and microvibrations requirements such as the ATHENA X-IFU instrument, the feedthroughs shall also minimise any additional performance degradation in these aspects. The activity shall start by identifying different possibilities for the design of the different feedthroughs on the ATHENA X-IFU instrument and evaluate these options in view of the overall system-level aspects. Once baselines are established, the detailed design shall be performed and implemented in a(several) breadboard(s). The performance of the breadboard(s) shall afterwards be assessed by testing in a relevant environment. Thermal parameters such as thermal conductivity (and therefore parasitic loads) shall be measured in different configurations, as well as other electrical and mechanical properties such as microvibration damping or EM compatibility.					
Deliverables					
Breadboard, Reports					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
N/A

High Temperature Superconductor Harness for use in cryogenic applications			
Programme:	TDE	**Reference:**	T221-114FT
Title:	High Temperature Superconductor Harness for use in cryogenic applications		
Total Budget:	250 kEuro		
Objectives			
This activity shall focus on the design, implementation and testing of a breadboard of a harness based on High Temperature Superconductor (HTS) material(s) that can allow to reduce the thermal parasitics in missions with cryogenic needs.			
Description			
Science missions such as SPICA (with the Safari instrument) and ATHENA (with the X-IFU instrument) require a complex cryogenic chain to ensure thermal bath temperatures in the order of 50 mK at the level of their respective detectors. The last cooling stage in these complex chains includes an Adiabatic Demagnetization Refrigerator (ADR) that takes advantage of the fact that the entropy of paramagnetic materials in a magnetic field is lower than when no field is present. The ADR requires the ability to generate a variable magnetic field that can be used to cyclically align the atoms in a paramagnetic salt pill so that the change in entropy can be used to cool the system. A variable magnetic field with a maximum of around 3 T is generated by a coil that requires an electric current in the order of 2 A. Routing such high currents to the most internal part of the cryostat is a challenging endeavor and a big contributor to the parasitics in the cryogenic chain. We are dealing with conflicting requirements, ideally the harness should have high electrical conductivity (low electrical resistance and therefore low Joule losses) and low thermal conductivity. This is not possible with normal metallic materials, where the thermal and electrical conductance are correlated. Superconductors on the contrary have a low/zero electrical resistance and a low thermal conductance and are therefore used as a lead-in wire for superconducting magnets. Currently, MgB_2 wires, which have been developed for the NASA-JAXA Hitomi mission are used at the lower temperature stages as a lead-in wire. Due to the transition temperature of MgB_2, these can only be used safely at a temperature below 30K and therefore result in a still significant heatload onto the low temperature stages of the Pulse Tube pre-cooler. In recent years, High Temperature Superconducting cables for power grids have been developed, capable of operating up to 80K. Whereas these commercial cables are designed for power capacities well above the needs for space missions and typically operate in an iso-thermal requirement, they can be modified to act as a lead-in wire for magnets, reducing significantly the heat load on the low temperature stages of two-stage pre-cooler.			

During the activity, various commercial HTS power cables shall be investigated and the most promising (customized) candidates shall be procured. The cables shall then be sliced to the size required for the current capabilities required for the specific application and any excess metallic material (typically copper and stainless steel) used by the commercial supplier to thermalize and ruggedize the wire shall be removed if needed. Technologies to encapsulate the HTS material from air with a low thermal conductivity material shall be developed and applied to protect the wires. In addition, a low thermal conductivity support structure of the wire might be required to prevent mechanical damage of the wires during launch and integration Finally, an EM lead-in wire shall be created and tested to verify the critical functions of the design proposed in a cryogenic environment (as close as possible of to the most stringent environment of the two missions), verifying the long-term stability in air and survivability during launch.					
Deliverables					
Breadboard, Reports					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2021
Application Mission:	Athena, SPICA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Cryogenics and Focal Plane Cooling					

Characterisation of Helium Joule-Thomson Vapour Cooling with Return Line			
Programme:	TDE	**Reference:**	T221-020MT
Title:	Characterisation of Helium Joule-Thomson Vapour Cooling with Return Line		
Total Budget:	500 kEuro		
Objectives			
To demonstrate the feasibility of using the low pressure return line of a Helium-4 Joule-Thomson Cooler, as a cooling source for an intermediate temperature shield.			
Description			
In the context of the XIFU Cryostat, in order to remotely accommodate the JT pre-Coolers, a solution to provide shield cooling without resorting to a very long and massive thermal strap and a complex vacuum tightness continuity, is to use the enthalpy of the return gas to provide inner shield cooling at 25-40 K. In order to implement such a solution an additional length to the Low pressure line is added downstream of the last CounterFlow Heat Exchanger, that is thermally coupled with sufficient length to the shield to be cooled, and then re-routed back to the second CounterFlow Heat Exchanger which is warmer than the pre-cooling stage.			

Such a solution carries an added heat load on the last pre-cooling stage. As a result, the temperature of the vapor cooled shield will be determined by the balance of heat load in the inner shield and available cooling power at the JT pre-cooling stage, which is adding to the already existent JT pre-cooling heat load. Likewise, the vapor cooling capacity will be limited by the mass flow of JT loop which has a direct impact on the cooling capacity. A test setup will be laid out to find the limitations in vapor cooling capacity of the current 4KJT and the added heat load on the JT pre-cooling stage. A new set of cold plumbing downstream of the last pre-cooling stage will be manufactured for the purpose, which will be coupled to the JT test setup The vapor cooling shall be performed with a representative heat exchanger in a thermally decoupled plate, with a heating element to tune the vapor cooling capacity. The pre-cooling heat load will be measured by heat flowmeter on a GSE grade Cryocooler. The impacts on the overall JT cooler system will also be evaluated, such as effect on pressure drop, parameter optimisation such as mass flows and pressure, in order to optimise the JT performance as well as the vapor cooling as a global JT cooling system performance. The activity shall be phased in two tasks, an initial task for the design and definition of the vapor cooling and test setup, as well as analyses on the impact of the JT operation. The second task will consist of the testing and subsequent correlations.					
Deliverables					
Reports (Design Description, Test Procedures, Test Reports)					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2021
Application Mission:	Athena	**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Customisation of the qualification of components for science missions			
Programme:	CTP	**Reference:**	C223-057FI
Title:	Customisation of the qualification of components for science missions		
Total Budget:	1000 kEuro		
Objectives			
This activity shall focus on the development of processes and capabilities to be able to customise the qualification of components in a centralised and standardised way. A case study shall be performed focussing on the high performance DAC components needed for the ATHENA/X-IFU instrument.			
Description			
The early design phases of science missions usually require several demonstration models and/or technology development activities to			

demonstrate the critical functions of the mission that are executed by several independent stakeholders.
Depending on the required level of form/fit/function representativeness, these demonstration models and/or technology development activities may require the use of qualified components, which can be very demanding in terms of resources (cost/schedule). Frequently, a lower level/type of qualification consistent with the details of the mission would be sufficient. The customisation of the qualification can allow significant savings.

Different standardised tests shall be identified as services depending on: the type of component, level of qualification desired, etc.. In-house vs. test-house options shall be evaluated as well as effects from economy of scale (testing of multiple items).

The required support processes and capabilities shall be developed and demonstrated in a case study focussing on the qualification of COTS high performance DAC components to be used in the ATHENA/X-IFU instrument. A large number of these components is expected to be required (in the order of hundreds during the implementation).

These DAC components are used to perform Frequency Division Multiplexing of TES detectors in calorimetric applications, with very stringent demands on base-band generation, in particular in terms of feedback loop stability and spurious-free dynamic range. While Breadboard tests of the foreseen DAC components show adequate performance, they currently do not exist in a space-qualified version.

This case study shall pre-qualify existing COTS high-performance DAC components for this application. As a minimum, the Analog Devices AD9726 DAC shall be qualified, optionally one or several European alternatives.
At least, the following tests shall be performed: 1) Baseline performance characterisation, 2) Thermal cycling, 3) Burn-in test, 4) TID, 5) SEE, 6) SEU effects on feed-back loop operation.

Deliverables					
Process definition documents, Test reports, Test packages, Test devices					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Maturation of the ATHENA Charged Particle Diverter System			
Programme:	CTP	**Reference:**	C204-128FI
Title:	Maturation of the ATHENA Charged Particle Diverter System		

Total Budget:	200 kEuro

Objectives

To increase the maturity level of the Charged Particle Diverter System for the ATHENA mission by performing representative environmental tests and redesigning the concept to be consistent with the latest version of the ATHENA Science Instruments Module.

Description

In order to meet the tight background requirements of the ATHENA mission, a Charged Particle Diverter (CPD) system is needed. The CPD prevents charged particles entering the Athena telescope through the mirror from reaching the focal planes with energies in the measurement band (0.2 - 15 keV). The ATHENA CPD system is the first one of its kind to deflect soft protons.
This activity will build on the work performed in the scope of the precursor activity: "C204-119FM - ATHENA Magnetic Diverter" that led to the design and manufacture of a demonstrator consisting of two elements to be accommodated in the ATHENA Science Instruments Module (SIM) close to the X-IFU and WFI instruments.
The precursor activity will allow the functional verification of the critical requirements for the two elements (deflection efficiency, residual magnetic field, and mass) but will only include simplified environmental tests.
This activity shall allow a more thorough verification of the environmental compatibility by performing (1) structural tests with a fully representative CFRP sandwich panel consistent with the proposed design, (2) thermal compatibility tests.
Potentially, also proton scattering tests on surface materials of the CPD shall be performed to increase the confidence of the deflection efficiency for the particles that hit the CPD surfaces.
Finally, this activity shall ensure consistency of the CPD design with the ongoing SIM B1 activities, therefore a redesign of the CPD concept is envisaged prior to the finalisation of the activity in time for the ATHENA mission adoption

Deliverables

Environmentally tested CPD demonstrator. Test reports. Design Reports.

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	Athena		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

L3-Mission: LISA

<table>
<tr><th colspan="6">Delta-developments of heritage Cold Gas Micro-thruster for LISA - CCN</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C219-015MP</td></tr>
<tr><td>Title:</td><td colspan="5">Delta-developments of heritage Cold Gas Micro-thruster for LISA - CCN</td></tr>
<tr><td>Total Budget:</td><td colspan="5">1200</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">Technology consolidation and industrialization activities regarding the cold gas micro-thruster system for the LISA mission</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Due to the forward shifted adoption and subsequently earlier launch date of the proposed LISA mission an industrialization of the current manufacturing and assembly process of the cold gas micro-thruster system (CG MPS) is necessary in order to timely produce the required large amounts of micro-thrusters.

The LISA mission will require around 65 FM units, compared to a total production across all previous missions using CG (GAIA, LPF Microscope and Euclid) of only 40 FM units.

This activity adds to the already running activity (C219-012MP) the following tasks to specifically address the enabling elements for an increased production rate while securing reliability and performance:

- Development of MPS Industrialisation Plan fulfilling LISA mission needs
- Conduction of Process Risk Analysis (PFMEA)
- Review of components obsolescence risk and mitigations
- Risk/Benefits Assessment of Task Externalization (e.g. for LAT and acceptance tests)
- Design, manufacturing and verification of custom GSE equipment (e.g. for TVAC testing, thruster plunger and MFS calibration, TV MAIT, …)
- Procurement of LLI COTS GSE equipment where required
- E2E Production Test Run to verify quality and reliability of newly developed GSE and processes as well as training additional personnel
- Additional tasks to address design and testing for MFS regarding lifetime performance degradation risks</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Other: MT GSE TVAC, MFS calibration, MAIT 1,2
Report: Process Risk Analysis Report
Report: LISA MPS Industrialisation Plan</td></tr>
<tr><td>Current TRL:</td><td>4</td><td>Target TRL:</td><td>6</td><td>Application Need/Date:</td><td>2023</td></tr>
<tr><td>Application Mission:</td><td colspan="2">LISA</td><td>Contract Duration:</td><td colspan="2">18</td></tr>
<tr><td>S/W Clause:</td><td colspan="2">N/A</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6"></td></tr>
</table>

<table>
<tr><th colspan="6">In-situ detection and alert system for micron-sized particle contamination on laser optical surfaces during AIT</th></tr>
<tr><td>Programme:</td><td colspan="2">TDE</td><td>Reference:</td><td colspan="2">T217-076MM</td></tr>
<tr><td>Title:</td><td colspan="5">In-situ detection and alert system for micron-sized particle contamination on laser optical surfaces during AIT</td></tr>
<tr><td>Total Budget:</td><td colspan="5">500</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">To design, develop and test a detection system which can monitor with high sensitivity and alert to the presence of micron sized particle contamination on laser optical surfaces during AIT activities.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Particle contamination has been identified as one of the risks for the optical surfaces in the LISA laser (ESA-LISA-EST-PA-TN-001). It is well known that even very small micron sized particles can cause degradation of the laser beam quality or even damage to the optical surfaces.

Particulate contamination monitoring is well established in space projects. However, the most common and/or traditional techniques such as air-borne monitors and fall out plates are either: not real-time or cannot be used within confined cavities or lacking the capability of providing particulate size distribution. A number of techniques are available for in-situ monitoring of particle contamination (some are given in the references below).

This activity would involve a trade-off and test of different techniques and development of a monitoring system which would be compatible with the LISA system configuration.

This activity encompasses the following tasks:

- Requirement consolidation for LISA;
- Research of different particle detection techniques;
- trade-off study;
- development of concept for in situ particle detection;
- development of a breadboard demonstrator for an alert system.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Breadboard; Report</td></tr>
<tr><td>Current TRL:</td><td>2</td><td>Target TRL:</td><td>4</td><td>Application Need/Date:</td><td>2024</td></tr>
<tr><td>Application Mission:</td><td colspan="2">LISA</td><td>Contract Duration:</td><td colspan="2">24</td></tr>
<tr><td>S/W Clause:</td><td colspan="5">N/A</td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6"></td></tr>
</table>

Novel Manufacturing Technologies for Low-Noise Pressure Regulators			
Programme:	CTP	**Reference:**	C219-014FT
Title:	Novel Manufacturing Technologies for Low-Noise Pressure Regulators		
Total Budget:	1000		
Objectives			
Assess, develop and test new designs for low-noise pressure regulators for micro-propulsion cold gas systems using novel design and manufacturing approaches			
Description			
High precision micro-propulsion systems (MPS) using Cold Gas are a key enabling technology for a multitude of current and future Science missions such as GAIA, LISA Pathfinder, Euclid, Microscope and LISA. A key component is the high pressure regulator that reduces the pressure from the gas tanks from about 300 bars down to ~1 bar to supply the downstream cold gas thrusters with a very low mass flow of nitrogen while fulfilling very stringed noise requirements. As there is only a single Non-European manufacturing source the future availability of this regulator might be at risk, directly endangering the for several past and future science missions crucial MPS system. Considering the stringent requirements especially regarding thrust noise, there is currently no alternative technological solution available. This activity aims to explore alternative options for pressure regulation potentially using novel design and manufacturing approaches such micro-channels and additive manufacturing to meet or even significantly improve the noise requirements while potentially also reducing manufacturing cost and time. Priority should be given to the usage of European products and components where feasible. The activity is forseen to be divided in two contractual phases. Phase 1 aims to raise the TRL to 4, and phase two will aim to reach TRL 6 via the development and test of an EM. The following tasks are foreseen for Phase1 - Literature review/update and requirements specification - (Delta-) Design of test facilities with a focus on thrust noise verification - Preliminary design of pressure regulation breadboards - Selection, assessment, testing and trade-off of sub-components - Analyze and optimize design for noise contributions - Design, Development and test a prototype breadboard for performance verification, including the pressure/thrust noise test - Definition of a development plan capturing qualification and fast-track flight production - PA and Quality Assessment of additive manufacturing for space			

applications (were applicable) The following tasks are foreseen for Phase2 - Review and lessons learnt from Phase1 - Review/update of requirements considering LISA mission needs and TRL6 development target - Subsequent (Delta-) Design of test facilities and pressure regulator - Update of analytical performance estimations of the design - Design, Development and test of an EM, again with a special focus on pressure/thrust noise compliance - As an option plan for a coupled E2E test (pressure regulator + CFI thruster, TBC) - Update of the development plan capturing qualification and fast-track flight production - Update of PA and Quality Assessment of additive manufacturing for space applications (were applicable)   The Phase 2 EM results shall aim to support the decision regarding the usage of the novel pressure regulator in the LISA mission, either as a backup or baseline.
Deliverables
Breadboard; Report

Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2023
Application Mission:	Future Science Missions, LISA, Voyage 2050		**Contract Duration:**	30	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Delta-developments of heritage Cold Gas Micro-thruster for LISA			
Programme:	CTP	**Reference:**	C219-012MP
Title:	Delta-developments of heritage Cold Gas Micro-thruster for LISA		
Total Budget:	1500 kEuro		
Objectives			
Technology consolidation and industrialization activities regarding the cold gas micro-thruster system for the LISA mission			
Description			

This activity aims to consolidate the technology activities regarding the cold micropropulsion system needed for LISA. During the previous activity (C219-011MP) an EM thruster valve underwent an 8 month endurance test which at this point in time showed no degradation, anomalies and/or failures. Wearing and fatigue elements of the current thruster design are understood and currently assessed compliant with LISA lifetime requirements. The thrusters piezo elements are also deemed capable to sustain the full number of cycles including the extended mission period. The continuation of this previous activity now foresees the following new tasks: 1) Continuation of TV test (e.g. accelerated test of full piezo stack) 2) Industrialisation of Mass Flow Sensor (MFS) Manufacturing Processes 3) Modification of Micro Propulsion Electronics Unit to LISA specific needs 4) Investigate a mechanical regulator back-up solution The first tasks is the direct continuation of the currently running endurance test on the EM to reach as close as possible the stringent LISA mission life time requirement of the valve. The second tasks aims to bring in-house the mass flow sensor (MFS) manufacturing processes (e.g. bonding and gluing) previously under the responsibility of external suppliers and to requalify the MFS according ECSS standards. The third task shall cover required modifications of the Micro Propulsion Electronics Unit (MPE) and the relevant software to match LISA needs (e.g. commanding frequency, cluster size). The forth task shall investigate a potential backup solution for the mechanical regulator, including suitable tests (for example noise charaterisation). The tests should be performed in a flight representative environment with adequate instrumentation and facilities.					
Deliverables					
EM Thruster Valve System (endurance tested) MFS Industrialisation Data Package MPE Design and Test Data Package MPE Hardware Pressure Regulator Investigation Report					
Current TRL:	TRL4	**Target TRL:**	TRL6	**Application Need/Date:**	2024
Application Mission:	LISA		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

N/A

High-Speed High Resolution Quad-ADC for Science Instruments			
Programme:	TDE	**Reference:**	T201-052ED
Title:	High-Speed High Resolution Quad-ADC for Science Instruments		
Total Budget:	700 kEuro		
Objectives			
Design, manufacture, validation, irradiation, and characterization of an integrated circuit to implement a 4-channel analogue-to-digital converter component.			
Description			
High Speed and High Performance Analog to Digital Converters (ADC) are a key component for scientific payloads, especially for multi-channel instruments with challenging requirements regarding thermal stability, power consumption, electronic noise, volume and mass such as the LISA mission. In particular the LISA phasemeter requires a large amount of channels and respective ADC (~80). Currently on the market available ADC with adequate performance requirements (required: 300 Mhz analogue bandwidth, > 80 Mhz sampling rate) such as for example the AD9246S or the RHF1401 do however not comply with the stringent power dissipation (thermal) requirements (e.g. 20/100 mW target/goal) of the LISA phasemeter. The usage of this 4channel ADC would lead to an estimated reduction of power and mass of the LISA payload by 40 W respectively 12 kg compared to the existing single channel options and greatly simplify the already complex phasemeter design. Additionally this 4channel ADC is a very generic component that will be available and useful for many other payloads. This activity continues a successful previous development (20263/06/NL/LvH) of a proof-of concept Single-ADC which reached prototype level at TRL3 and aims to expand the design to quad-channel layout and further expanding interface options matching generic instrument requirements. The resulting Quad-ADC EM's performance shall be tested and verified. The activity shall also include a definition of a potential follow-on characterization campaign, which is however not part of this activity. Tasks ===== - Definition and consolidation of requirements specification - Architectural Design - Detailed Design - Layout - Prototype Implementation - Design Validation - Radiation Testing			

Deliverables					
- ADC component prototypes, packaged and tested - ADC component dies, untested, unpackaged - Related design documentation					
Current TRL:	TRL3	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	LISA / Several Science Programme missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Microelectronics - ASIC & FPGA- Partially consistent: This activity follows the same path as Ref C16 in Aim C (Analogue and mixed-signal ASICs, ADC/DAC) but with different specification parameters.					

Optical fiber micro-Kelvin temperature sensor network for sensitive optical payloads			
Programme:	TDE	**Reference:**	T217-072MT
Title:	Optical fiber micro-Kelvin temperature sensor network for sensitive optical payloads		
Total Budget:	400 kEuro		
Objectives			
Demonstrate a multipoint temperature sensor network based on optical fiber sensor techniques suitable to achieve micro kelvin resolution temperature measurements that would be suitable for science missions such as LISA.			
Description			
An increasing number of scientific missions are relying on the extreme levels of thermal control in order to perform their scientific goals. For example LISA requires micro-Kelvin resolution temperature knowledge of the space craft in order for the payload to achieve its primary mission. This level of performance is currently not possible with existing electrical gauges. Fibre optic techniques can offer some substantial benefits not only offering a means to achieve these levels of performance but also providing additional benefits such as electromagnetic interference (EMI) immunity, galvanic isolation and the possibilities in some configurations to offer multiplexing of sensors along the sensing fiber, either in a truly distributed approach or quasi distributed, using elements such as Bragg gratings. 1) To design and manufacture an Elegant Breadboard Model of the Measurement System as well as a Test Bench for performance testing achieving Technology Readiness Level (TRL) 4. 2) To carry out performance testing of the developed Measurement System and exploit the results,			

3) To define the necessary steps in order to take the Elegant Breadboard Model to a TRL 6.
Deliverables
Breadboard Model, Report

Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	LISA		**Contract Duration:**	12 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
Photonics – Partially consistent. While there are no activities that directly cover this topic of micro Kelvin precision sensors for Science missions, the photonics harmonisation dossier clearly covers the need for the development of fiber optic sensors for harness reduction and for distributed sensing which falls under AIM D.					

Development of a master oscillator for the LISA laser system			
Programme:	IPTF	**Reference:**	C217-091FI
Title:	Development of a master oscillator for the LISA laser system		
Total Budget:	600 kEuro		
Objectives			
The aims of this activity are to further develop a master oscillator for the LISA laser system, to develop space suitable packaging, and submit prototypes to environmental testing.			
Description			
The LISA space-borne interferometric gravitational wave observatory mission requires a laser system operating at 1064 nm with exceptional performance requirements which must be met over the entire mission lifetime. The output power, frequency and power noise as well as sideband phase fidelity are of the particular criticality. The master oscillator which is the source of the laser system light is a critical aspect of the system. ESA is investigating a number of technologies for use as the master oscillator of the LISA laser system. One candidate technology is based on a novel miniaturised semiconductor and whispering gallery mode technology. This technology has been subject to preliminary performance testing in the context of the LISA mission and has demonstrated excellent performance in the laboratory environment. This activity will further develop this technology yielding prototype devices which will be space packaged and subjected to environmental testing. The main activity tasks will be:			

Design second generation laser units with separated hermetic laser heads and driver packages meeting the LISA laser system performance requirements - Produce packaged second generation 1064nm master oscillator prototypes with improved frequency and power noise - Perform optimization of the electronic modules for long term locking and build improved electronic driver - Assemble two units and perform preliminary testing - Support full metrological characterisation - Support preliminary environmental testing of the prototypes - temperature cycling, temperature shock, vibration, shock, gamma & proton radiation, etc.
Deliverables
Prototypes, Technical Data Package

Current TRL:	TRL4	**Target TRL:**	TRL5	**Application Need/Date:**	2023
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Advanced DC and AC Magnetic Verification			
Programme:	TDE	**Reference:**	T207-064EP
Title:	Advanced DC and AC Magnetic Verification		
Total Budget:	400 kEuro		
Objectives			
To develop efficient verification methods for DC and AC magnetic emissions at unit level with intrinsic rejection of ambient noise			
Description			
Payloads sensitive magnetic fields require low magnetic field emission levels from other payload instruments or platform equipment, or at least the characterization of them. Payloads can be sensitive to constant (""DC"") or time-varying (""AC"") magnetic fields itself, both periodic and aperiodic, or especially to the spatial field gradients, i.e. the rate of change in magnetic field with distance. Verification and characterization of payload instrument and platform equipment units allows to establish bottom-up magnetic models at sub-assembly and system levels for prediction magnetic fields and their gradients at the location of sensitive payloads. State-of-the-art test equipment will reduce testing time and help to reduce measurement uncertainty. DC and AC magnetic verification methods with advanced ambient noise rejection need to be combined for efficient testing. The use of spherical harmonics expansion and Gaussian separation into inner and outer sources			

for both AC and DC magnetic verification of platform equipment and payload instruments will allow to relax requirements on the ambient environment during test or to target more stringent requirements. To verify functionality, the existing concepts need to be integrated in a proto-type multi-magnetometer facility and combined with a low-noise ambient field compensation system. A special focus will be the measurement and verification of spatial magnetic field gradients and their temporal evolution at relevant time scales, e.g. 1000 s, i.e. equivalent to 1 mHz. This activity encompasses the following tasks: - Assessment of existing methods and facilities and identify hardware modifications for multi-magnetometer facility to combine them. - Study of existing data acquisition and dipole modelling software suites to include Gaussian separation for DC and AC fields and gradients. - Implementation of hardware elements for AC/DC multi-magnetometer facility, e.g. alignment/calibration, low-noise ambient field compensation system, gradiometer configuration, extended data acquisition system - Upgrade of software with necessary modifications for operation of AC/DC multi-magnetometer facility, e.g. to interface with extended data acquisition system, to facilitate gradient measurements/modelling, to support alignment and calibration, and to operate ambient field compensation system. - Initial design validation on a test item with known characteristics A validated ""breadboard"" facility (TRL4) will be needed as a deliverable to ESA as reference implementation and to serve as input and starting point for follow-on activities to develop engineering and qualification models.

Deliverables					
Breadboard facility					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

LISA Phasemeter Unit Development			
Programme:	CTP	**Reference:**	C201-037FT
Title:	LISA Phasemeter Unit Development		
Total Budget:	1500 kEuro		
Objectives			
Further development of the LISA Phasemeter unit from TRL4 to TRL6			
Description			
In June 2017 the LISA mission was selected as ESA's third L-mission with a launch date currently planned for 2034. The LISA mission is based on the			

principle of laser interferometry between free-falling test masses housed onboard three identical heliocentric spacecraft flying in a triangular constellation. The configuration of the spacecraft forms a three arm Michelson interferometer with a mean inter-spacecraft distance of 2.5 million kilometers. Laser interferometers will measure with pico-meter accuracy the distance changes between the test masses and the optical bench inside each spacecraft. Long-baseline interferometers using optical telescopes will measure the inter-spacecraft distances between the optical benches of different spacecraft. Such accuracies can only be achieved by precision metrology. The frequency distribution and phase measurement system (phasemeter) is a critical element of the LISA metrology system. A breadboard of the LISA phasemeter was developed under previous ESA contract achieving a Technology Readiness Level of TRL 4. This activity shall further develop the phasemeter to TRL 6, by designing, manufacturing and testing an EM using MIL-spec components, with the goal to verify the phasemeter critical functions with respect to LISA requirements in a relevant environment. The work shall include at least: - Review and update of the requirements - EM design and analyses, including: adapting the form factor of the existing breadboard design to one capable of being integrated into an electronics box; designing the electronics box to accommodate the electronics; designing the phasemeter thermal control system able to maintain the critical parts thermally stable. - Definition of verification plan including GSE - Performing verification testing in the relevant environment
Deliverables
Technical data package, phase meter engineering model validated in relevant environment

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	TRL 6 by 2024
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Test mass charging toolkit and LPF lessons learned			
Programme:	TDE	**Reference:**	T204-125EP
Title:	Test mass charging toolkit and LPF lessons learned		
Total Budget:	400 kEuro		
Objectives			
Develop capabilities to accurately calculate the charging of test masses of arbitrary size and chemical composition on gravitational wave missions and other free-fall experiments with test masses. Both environmental input			

definition and 3D simulation of penetration and interactions will be implemented. Evaluate the charging behaviour of the LPF masses and compare with predictions.
Description
One of the key disturbances to the test masses in space gravitational wave detectors and other free-fall experiments is the electrostatic charge induced in them through interactions with penetrating charged particles and their secondaries. The masses are normally behind heavy shielding and as charged particles penetrate, they slow, scatter and create a range of secondary particles through a variety of physical processes. As a consequence, the accurate tallying of the net charge is a complex and difficult problem. The final effect also depends on the size and chemical composition of the test mass employed. An open toolkit will be developed to make 3D simulations of the penetration of cosmic ray ions, solar energetic particles and interplanetary electrons using full description of the geometry and materials surrounding the test masses, including the spacecraft. A rigorous investigation will be made of the completeness of the relevant interaction physics implemented in Geant4 which will be used as the basis for the development. Expected improvements include, for example, the low energy electron-photon cascade physics resulting from very high energy CR proton atomic and nuclear interactions. The test mass size and composition effects shall be considered such that test masses of arbitrary dimensions can be analysed. Estimates of the charging were made for LISA Pathfinder based on Geant4 and Fluka. The operation of the LPF charge management system provides information on the nature and extent of the charging, and the on-board radiation monitor measures the penetrating particle flux, allowing comparison with the predictions. This evaluation of the in-space behaviour will provide a partial validation of improved tools. The toolkit will also allow for input of LPF radiation monitor and other space radiation environment data or models, and provide as an output test mass charges and internal particle fluxes.
Deliverables
Geant4 based toolkit; software documentation; validation reports

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development and validation of a contamination package in SPIS for Liquid based Electrical Propulsion systems for LISA			
Programme:	CTP	**Reference:**	C204-120EP
Title:	Development and validation of a contamination package in SPIS for Liquid based Electrical Propulsion systems for LISA		

Total Budget:	200 kEuro
Objectives	
1 - To review the physics of emission of droplets from Liquid based Electrical Thrusters (such as FEEPS and colloidal thrusters), the physics of droplets interactions within the environment, as well as processes of deposition and contamination on spacecraft surfaces. 2 - To implement corresponding emission and contamination models in the Spacecraft Plasma Simulation System and validate them with available measurements. 3 - To enhance the numerical performances of the software in order to allow multiple thruster simulations and contamination diagnostics on a full scale LISA model	
Description	
This activity will build upon the existing Spacecraft Plasma Interaction System developed since more than 10 years under ESA and CNES funding and especially the latest development allowing the modelling of plasma plumes / spacecraft interactions. This activity will target the modelling of droplets generated from liquid based electrical thrusters, droplet evolution after emission (e.g. charge state, evaporation), interaction processes with the environment (ambient ionisation), deposition and interaction with s/c surfaces in order to provide a full diagnostic package for mission preparation and in-flight analysis. In addition molecular contamination models will be tested against actual data and refined such as to incorporate droplet generated materials. An analysis of numerical performances for multiple thrusters and contamination simulations on full scale spacecraft will be carried out and an improved numerical scheme proposed and possibly implemented in order to increase the code usability towards full scale / complex systems.	
Deliverables	
Software, technical documentation	

Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	LISA	**Contract Duration:**	18 months		
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Response Time Improvement of Micro-Propulsion Thrusters for Precise Science Missions			
Programme:	TDE (TRP)	**Reference:**	T205-126NA
Title:	Response Time Improvement of Micro-Propulsion Thrusters for Precise Science Missions		
Total Budget:	400		
Objectives			

To study if the response-time characteristics of Cold Gas Micro-Propulsion System thrusters currently used in precise scientific missions can be improved, without sacrificing their noise performance, by modelling the physics and re-designing the internal control system using novel advanced control approaches.
Description
High precision micro-propulsion systems (MPS) using Cold Gas (CG) are a key enabling technology for a multitude of current and future Science missions such as GAIA, LISA Pathfinder, Euclid, Microscope and LISA. Cold Gas Thrusters provide micro-Newton control with very low noise, which is required to achieve the challenging science objectives of these missions. In addition Voyage 2050 also features several missions (e.g. GAIA-NIR) requiring an MPS. However, the current CG thrusters have a poor response-time, which imposes a limit on the platform's overall control bandwidth. Improving this performance aspect would enable higher bandwidth and more responsive science controllers for these types of missions, increasing science performance at higher frequencies and improving overall mission robustness to micro-meteorites. Due to the extensive flight heritage of these thrusters, there are several factors currently limiting their response time, which cannot be modified or improved without embarking in costly and lengthy developments and resulting in significant loss of heritage. This is specifically the case for the mechanical components and the physical design of the thrusters, such as their internal volumes, valve springs, actuators, etc. Therefore, a novel higher order internal controller, designed using advance control techniques, has the potential to improve upon the present trade-off limit between response time and overshoot imposed by the current controller. Such a novel controller would boost the overall thruster response time, requiring little to no hardware modifications and thus preserving as much as possible the significant heritage of the CG MPS. Lessons learnt from LPF also point towards a gap in the analytical understanding of the behaviour of the MPS system, which would be addressed by this activity as a required step in the advanced control design. Additionally, the ability to easily customize the tuning of the MPS optimal controller for the frequency band of various science missions would be a major asset for future missions. This would be possible through a structured advance control design approach. The proposed activity would consist of the following main tasks: - Mathematical modelling: dynamic modelling of the relevant components using available design documentation and test data. In particular, modelling of the thruster dynamic response including the Mass Flow Sensor (MFS), thruster valve and gas-dynamic response (transfer function from valve to thrust force). This step may require using the design details of the current

controller in conjunction with test data to de-tangle the open-loop response of the system from the closed loop test data. In addition, during this task the contractor shall identify any additional tests, which may be proposed to improve the modelling, if required. - Control system trade-off and design: survey and selection of the most appropriate advance control technique to employ for the controller design in order to improve the response time without compromising the noise performance of the thrusters. Design and prototyping of the proposed control solution. - Simulation campaign: dynamic simulations to assess the resulting performance with the new controller and comparison to the legacy controller. This campaign should also assess the robustness and performance sensitivity of the new controller with respect to key modelling parameters, to be decided before the campaign. - Controller prototype implementation in the MPE software. - Performance test campaign: validate the new controller on representative MPS hardware, including comparison to the legacy controller. - Proposed Development plan towards QM and FM implementation, especially highlighting implication on qualification status vs performance improvements.
Deliverables
Report; Software; Software

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Future Science Missions, LISA, Voyage 2050. The MPS thruster response time is currently the limiting bottleneck preventing the design of higher bandwidth controllers to improve science performance and robustness to micro-meteorite impacts which severely affect scientific availability time.	**Contract Duration:**	18		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Optimal actuation algorithm for test mass suspension control in drag-free missions			
Programme:	TDE	**Reference:**	T205-127SA
Title:	Optimal actuation algorithm for test mass suspension control in drag-free missions		

Total Budget:	250 kEuro
Objectives	
To design a flexible force/torque actuation algorithm that maximally uses the available actuation envelope for suspension control of test masses in drag free missions.	
Description	
Heritage test mass control systems such as the one implemented on Lisa Pathfinder provide a hard 50/50 force/torque actuation authority allocation in Wide Range mode, regardless of the control system request. This inflexible allocation implies a fixed limit for both forces and torque channels, even if the request is small on the other channels. A simple design change, as will be implemented on the LISA Gravity Reference Sensor (GRS) Front End Electronics (FEE), enables this allocation to be flexible, allowing the Drag-Free Control System (DFACS) to choose the split by commanding each electrode individually. This implies that there is a need to design a new optimal actuation algorithm to provide maximum force/torque authority based on the DFACS needs. Traditional actuator allocation algorithms, such as thruster actuation algorithms, rely on sub-optimal simplifications on-board in order to reduce the computational load. These sub-optimal simplifications must be designed on a case by case basis, depending on the nature of the allocation problem and the required constraints. As an example, the Thruster Actuation Algorithm (TAA) of Lisa pathfinder was developed by the mathematical institute ZARM in Germany, due to its heavy reliance on mathematical techniques to guarantee an algorithm that yields a solution that is as close as possible to the optimal, but computationally simpler and with guaranteed convergence. For these reasons, in order to design a flexible test mass actuation algorithm which can make use of the full authority envelope, a detailed evaluation of different methods for computationally efficient sub-optimal techniques applicable to this problem is required. This should also include a detailed evaluation of the computational load of the proposed algorithms, in order to define an almost optimal algorithm that can work on-board. Tasks: - Detailed modelling of the LISA Gravity Refernce Sensor (GRS) electrostatic actuation system as a reference mission case, including geometric test mass state dependencies. - Survey of actuation allocation methods - Trade-off of different methods for selection of a suitable subset to be implemented - Implementation of several actuation allocation solutions including the optimal one as the baseline - Characterization of achievable force/torque envelopes (6-dimensional) for the different allocation schemes	

- Processor in the loop assessment of the different on-board feasible implementations					
Deliverables					
Study report					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2023
Application Mission:	LISA		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Assessment and Preliminary Prototyping of a Drag Free Control System for the L3 Gravity Wave Observatory			
Programme:	TDE	**Reference:**	T205-033EC
Title:	Assessment and Preliminary Prototyping of a Drag Free Control System for the L3 Gravity Wave Observatory		
Total Budget:	300 kEuro		
Objectives			
This activity shall investigate, trade-off, and preliminary prototype a control system for the upcoming L3 mission, taking advantage of the results and lessons learnt from the Lisa Pathfinder mission. The study shall trade-off different control system architectures and design methodologies to satisfy the challenging requirements of this mission. Preliminary prototyping using a representative simulation environment shall also be implemented. This activity will allow to lower the development risk of this expensive and complex control system before phases A/B1.			
Description			
It is expected that the control system for the L3 mission will need to control several degrees of freedom with different actuators at different frequencies, yielding a tightly coupled, multiple-input multiple-output system. Even though the Lisa Pathfinder (LPF) mission has proven some of the control system technologies required to achieve this, the architecture of the LPF Drag Free Attitude Control System (DFACS) has been designed to best fit the motion equations and requirements of LPF, which are less challenging than those for L3. For this reason, an in depth theoretical investigation of the possible control system architectures and control design methodologies for L3 is required. The drag free control architecture for this mission is key for its performance and therefore an in depth trade-off at mathematical-theory level, aided by simulations shall be prototyped. This activity is proposed as a bridging phase between the activities executed for the design, development, and early operations of the control system of the LPF mission and those for L3. It will allow to gather the results and lessons learnt from LPF project and inject this knowledge quickly into the early			

phases of the design and development of the control system for the L3 mission. The software final product of the activity will serve as a framework for ESA to test case any changes in the evolution of requirements of the L3 mission during its early phases. Tasks: 1) State of the art and definition of the elementary equations of motion for the L3 mission, including a de-coupling analysis to identify possible control system design simplifications. 2) Trade-off different control system architectures and advanced, robust control system design methodologies to preliminary prototype the drag free control system. 3) Implement the different proposed options into a representative simulation environment and analyse the different proposed solutions to find the best candidate. 4) Provide conclusions a and identify way forward for phases A/B1.
Deliverables
Study report

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2018
Application Mission:	LISA		**Contract Duration:**	12 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Activity not subject to harmonisation

Straylight LIDAR OGSE verification tool, hardware pre-development			
Programme:	TDE	**Reference:**	T208-022MM
Title:	Straylight LIDAR OGSE verification tool, hardware pre-development		
Total Budget:	500 kEuro		

Objectives
To breadboard, test and verify a novel stray light verification tool based on pulsed laser time of flight techniques.
Description
Background and context: The aim of this activity is to breadboard the Straylight LIDAR instrument concept and to verify its performance experimentally. This activity aims to raise the TRL to 4 and follows the TDE activity (T216-104MM Verification of straylight rejection of optical science payloads using a pulsed laser source). The aim of this smooth follow-on is to verify the concept experimentally using an available flight spare space telescope baffle as a representative test object.

Description of the concept: The technique is called “straylight LIDAR” and the concept is based on recent research results of a number of groups working in differing fields. The range gating technique at macro (m to cm) scales using a ps laser has been shown to achieve 1 mm range resolutions. It enables very short photon pulses to be identified and resolved in x, y and t. By doing a "temporal analysis" of the straylight performance model of an optical instrument it seems feasible to identify the time gating needed to actually measure the critical straylight paths. By sweeping the time gate over the full range of response of the system, previously unidentified paths can also be detected. This is the real power of the technique. Furthermore, by varying the angle of incidence of the (pulsed laser) source with respect to the entrance aperture/baffle, and by setting the time gate and imager integration time, it seems feasible to achieve spatially and temporally resolved images of the straylight characteristics of the system under test. The principle measurable parameter used to quantify straylight performance is the Point Source Transmittance - PST. This is typically measured vs angle of incidence at the instrument entrance aperture and is the most commonly used straylight performance requirement specification for astronomical telescopes and can be derived readily from straylight models. Task list: - Assess LISA straylight verification OGSE needs vs LIDAR instrument concept performance - Use the output of the concept study to produce a Straylight LIDAR breadboard design ready for manufacture with a view of the LISA requirements - Construct and test the Straylight LIDAR breadboard - Use the Straylight LIDAR breadboard to verify and confirm the measurement of Point Source Transmittance using a piece of flight representative hardware - Evaluate the results, draw conclusions and make recommendations for developing an operational Straylight LIDAR instrument
Deliverables
Breadboard, Technical Data Package

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development of prototype Active Aperture Mechanism for LISA			
Programme:	TDE	**Reference:**	T215-016FT
Title:	Development of prototype Active Aperture Mechanism for LISA		
Total Budget:	500 kEuro		
Objectives			
Develop and demonstrate a concept of the Active Aperture Mechanism for the LISA Optical Bench.			
Description			

The Active Aperture Mechanism (AAM) is a key element of the Optical Bench of the LISA Gravitational Wave Obervatory. It allows adjustment of the key pupil locations of the long-arm interferometer and therefore allows control over the overall tilt-to-length coupling, and greatly increases the feasibility of the overall OB/Telescope mounting and alignment. The activity shall involve the concept design of a suitable AAM against the requirements developed in the LISA Phase A study, followed by the build and demonstration of a suitable prototype. The demonstration shall include: • The stability of the clipping aperture both in the LISA measurement band and over longer timescales between the envisaged re-calibration points • The range, repeatability and accuracy of the mechanism adjustment against requirements • The optical properties of the aperture
Deliverables
Design Report, Prototype of the AAM

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2020
Application Mission:	LISA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

LISA Optical Assembly Tracking Mechanism Development			
Programme:	CTP	**Reference:**	C215-137FT
Title:	LISA Optical Assembly Tracking Mechanism Development		
Total Budget:	1500 kEuro		
Objectives			
Design, manufacturing and test of a Breadboard of the Optical Assembly Tracking Mechanism providing angular articulation between the two Moving Optical Sub-Assemblies in each LISA spacecraft.			
Description			
The LISA Core Assembly (LCA) consists of two Moving Optical Sub-Assemblies (MOSAs) and the mounting structure which supports them and interfaces to the main structure of the spacecraft. The Optical Assembly Tracking Mechanism (OATM) articulates the MOSAs by allowing a rotation of up to ±1.5° around the Z-axis of the spacecraft with an average tracking speed of 1.1 nrad/s and a maximum speed up to 5 nrad/s. The OATM is attached to the LCA structure and acts on the MOSA supporting structures. Over the course of a year, celestial mechanics causes the vertex angle between two arms of the LISA constellation to fluctuate by 60°¿1°. This ‘breathing’ must be compensated in order to maintain the optical links. The OATM accommodates the instantaneous evolution of the breathing angle by steering each MOSA independently. The amplitude of ±1.5° ensures full			

redundancy, i.e. should one articulation fail in any point of the angular range, the other can supply the full extent of the breathing angle.
The main performance driver of the OATM is the required angular resolution of about 1 nrad coupled to the large stroke (3° = 5.2E7 nrad) and the total jitter of the system of 10nrad/sqrt(Hz).
The OATM electronics concurs in the performance via the very high stroke-to-resolution ratio and it shall be part of the development. The control approach (open or closed loop) shall be part of the development and will be linked to the available position sensing signals (either coming from the payload DWS or encoder integrated in the OATM). Indeed the encoder will need to be defined in the frame of this activity, as a resolution of at least 0.5 ¿rad will be required for constellation acquisition.
Most suitable actuators identified so far are piezo electric actuators (walking stack actuators and inertia operated actuators) but its final characterisation, contamination issues, lifetime, redundancy concept and space qualification shall be stablished accurately, as well as the final performances of the full system, hence the need for a dedicated development including all the system elements (actuator, electronica, hinge, harness dummy, MOSA dummy)
The objective of the activity is selection of a design and validation of critical performance requirements by a breadboard model in a laboratory environment. A successive TDA is envisaged targeting TRL 6 by 2023.
Mechanism performance
Stroke: +/-1.5°
Resolution: 1 nrad
Angular noise around the rotation axis: <10 nrad/vHz·v(1+(0.8 mHz/f)^4)
Average tracking speed: 1.1 nrad/s
Maximum tracking speed: 5 nrad/s
Encoder resolution: < 0.5 urad

Environment
Any magnetic field generated by the OATM shall not exceed:
• DC field <1 μT
• field gradient <5 μT/m
• field gradient noise <25 nT/m/sqrt(Hz) at a location 0.2 m away from the OATM.

Interface
• Mass allocation: 12 kg (actuator + MOSA hinges + electronics)
• Power allocation: 8 W
• MOSA mass: 140 kg
• MOSA moment of inertia around pivot axis: 20 kg·m² •
Command update rate towards the OATM: 1 – 20 Hz (a variation of the rotation angle is commanded to OATM by the DFACS). Note: The commanded delta angle must be almost continuously distributed along over the 1s interval; this implies that the OATM low-level control shall operate at a frequency >> 1 Hz.

Tasks
• Preliminary engineering to freeze design driving requirements and preliminary dimensioning of the mechanism and allocation of budgets for the

main components, with special focus on actuator performance, flexural hinge stiffness and command strategy and control. • Selection, procurement and characterisation of actuator(s) • Definition of test plan, associated tooling, instrumentation • Development plan, agreement on TRLs of elements • Element breadboard development (mechanism characterisation, electronics, position sensors) • Detailed design, operation and control definition • Breadboard model manufacturing and test: o Mechanical joints, damping and filtering mechanism o Electrical and RF elements o Flexible hinge manufacturing stiffness tests, unit lifetime (at component level) o Functional tests at laboratory ambient for: mechanism performances (position, resolution, repeatability, jitter, lifetime, contamination…), electronics (actuation command), noise. o Correlation activities, definition of functional performance requirements, updated design. o Driving electronics (lab standard) • Test result analysis and model correlation • Updated detailed design • Development plan
Deliverables
Design Report, Mathematical Model, OATM breadboard including electronics and low-level control, test plan, test reports

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2021
Application Mission:	LISA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Molecular contamination derisking activities for LISA			
Programme:	CTP	**Reference:**	C216-164MM
Title:	Molecular contamination derisking activities for LISA		
Total Budget:	200 kEuro		
Objectives			
The main objective of the proposed activity is to assess the impact of molecular contamination on a surface, exposed to short and long term CW laser irradiation at 1064nm, specifically as it pertains to the following parameters: -wavefront deformation, -transmission of optical component, -depolarisation (which will be dependent on contamination species) -cosmetic aspect of coating/surface before and after irradiation. Additionally if the impact of molecular contamination is confirmed to be a potential issue for the mission, a design of a portable, in-situ verification system will be proposed.			
Description			

-LIC testing at 1064nm, in CW regime for known contaminants. The contaminants to be chosen to evaluate impact of CW regime and impact of wavelength. To be tested: *Contaminants having failed LIC, at other wavelengths (e.g. naphthalene) *Impacts
Deliverables
Report; Report; Report

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2019
Application Mission:	LISA		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High-power fibre-coupled optical switch for space applications			
Programme:	TDE (TRP)	**Reference:**	T217-074NA
Title:	High-power fibre-coupled optical switch for space applications		
Total Budget:	500		
Objectives			
To design and develop an optical switch capable of switching a high power single-mode and linearly polarized laser beam on/off, with low insertion loss and fibre-optical interfaces in a package suitable for space applications.			
Description			
Laser based instruments are increasingly at the heart of new space missions, unlocking new measurement capability but at the same time adding unique technological challenges. The photonic components, which are typically used to construct these instruments, are generally not custom-made for space, but rather selected from readily-available high performance parts designed for terrestrial applications. One key challenge for photonic components in space applications is the vacuum environment; combined with high power laser beams there is a runaway effect caused by trace quantities of volatile organic molecules being trapped and deposited by the laser beam which can lead to 'laser induced contamination' and ultimately catastrophic device failure. The importance of considering this failure mode is evident by the complications experienced in the Aeolus mission development. The presence of oxygen helps to prevent laser induced contamination, and therefore there is a strong requirement for hermetic packages for any photonics components having free-space beam paths and high optical power densities. In addition, the use of outgassing materials in the construction of such a device should be minimized. As an example, the LISA laser system includes an optical switch at the output of the laser system, with a throughput of ~5W laser light at 1064nm. Such a high power optical switch has free-space beam propagation inside the			

package. This component is essential in the system to fulfill the requirement to switch on/off the laser without perturbation of the thermal environment, meaning the switch must be at the output of the laser and not earlier in the system. This functionality is necessary during the constellation acquisition phase, where the laser links between the three spacecraft of the LISA mission are established so that the interferometric measurements for the science experiment can be initiated.

A hermetic packaged, high-power optical switch, suitable for this space application, is not available. This activity addresses the need for a high-power optical switch capable of reliable operation in space for ~12 years, having a high power-handling capacity, while maintaining the beam's single mode and polarization properties with high fidelity. Furthermore, insertion losses should be minimized, and the packaging robust enough to withstand launch.

The tasks foreseen include;
- review of the performance and package requirements for the high-power optical switch
- preliminary design
- trials and breadboarding of hermetic sealing and assembly aspects and final design
- manufacture of a batch of devices (~10 parts)
- test campaign including for example: long duration vacuum operation at maximum power rating, mechanical shock and vibration, thermal cycling, corona discharge test
- conclusions and technology development roadmap towards TRL6 and path to qualification

Deliverables

Prototype; Report

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Mission Need: LISA and also future space-based gravity-wave observatory in Voyage 2050 plan	**Contract Duration:**	18		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

Consistent with Harmonisation Roadmap: %

High-power laser system for eLISA			
Programme:	CTP	**Reference:**	C217-030MM
Title:	High-power laser system for eLISA		
Total Budget:	3000 kEuro		

Objectives

To develop a high-power laser system for the eLISA mission.
Description
In this activity the prime-contractor is asked to form a consortium of expert companies with the aim to develop the high-power laser system (>2W) of eLISA to engineering qualification model (EQM) standard (TRL 5/6). The activity will be split in two phases of which phase 1 will start with an assessment of the optimum laser technology and a survey of best suited components, which shall include space qualifiability and radiation tolerance. After the definition of the optimum technology, all laser sub-systems will be breadboarded in order to verify compliance with the performance requirements of the eLISA mission. Special attention will be paid to laser relative intensity noise (RIN) and laser frequency noise in the presence of a low index phase modulation (10%) and the stability and performance of the laser system over the eLISA specified temperature range. After approval of the phase 1 results, the consortium will develop in phase 2 the engineering model of the eLISA laser system. Should components be identified that are already commercially available at a sufficiently high TRL level those components can be omitted from the qualification and can be replaced by commercial off the shelf (COTS) components with sufficient proof that a delta-qualification for eLISA can be accomplished. After verification of its functional performance the engineering model (EM) will undergo a full environmental testing campaign including thermal vacuum (TV) testing, vibration and radiation testing to achieve TRL 6 level. The activity will be split into two phases: Phase 1 shall last 12 months and end with the performance testing of the breadboards. Phase 2 shall last 15 months and shall end with the delivery of an EQM of the eLISA laser system.
Deliverables
EQM of the laser system performance tested and qualified for the eLISA mission. Test specifications, test plans and test reports as well as accelerated test results.

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	LISA		**Contract Duration:**	27 months	
S/W Clause:	NA				

Consistency with Harmonisation Roadmap and conclusion:
N/A

Photonic components analysis in support of the LISA laser system development			
Programme:	CTP	**Reference:**	C217-084FT
Title:	Photonic components analysis in support of the LISA laser system development		
Total Budget:	400 kEuro		

Objectives

Perform an in depth analysis on the photonic components baselined in the LISA laser system development activities.

Description

The laser system is identified as one of the critical elements of the LISA mission.
The preparation of the system is being addressed through a number of activities being funded through the Science Programme Core Technology Programme. These activities are targeting the development of the laser system to TRL 6 by 2022, in time for mission adoption. EM hardware is being developed and will be tested under representative conditions to demonstrate the functional and performance requirements.

The laser system relies on COTS photonic components (e.g. active optical fibres, electro-optic modulators, laser diodes, optical isolators). An essential part of achieving the required TRL is to understand the construction and materials of each of the selected components in order to ascertain their suitability for the mission. This is achieved by performing a Constructional Analysis (CA) of the components.

The CA is essential to assess the suitability of selected components for this application, ensuring that;
- the materials used in the component are suitable,
- the general construction quality is high,
- and allowing to assess the risk for catastrophic optical damage for parts with a free-space beam path in the internal cavity, including an accurate measurement of the leak rate.

In addition to the usual CA sequence, a unique focus of this particular activity is to precisely measure the leak rate from the component package allowing for an accurate estimate of the end-of-life internal cavity pressure. This is critical for the laser diodes, and for other parts having a free-space beam path. Since this is not typically the focus of a CA, this activity may include developments of appropriate test methods.

For some components additional analysis and tests may be required (e.g. temperature cycling, humidity testing) if deemed critical during the initial assessment of the components.

Deliverables

Components Analysis Reports

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2020
Application Mission:	LISA		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Photonic components analysis in support of the LISA laser system development					
Programme:	IPTF		**Reference:**	C217-092FI	
Title:	Photonic components analysis in support of the LISA laser system development				
Total Budget:	200 kEuro				
Objectives					
The objective of this activity is to perform an in depth analysis on the photonics components pre-identified in the LISA laser head development activities. This analysis will assess the component suitability in fulfilling its function considering the LISA mission environment and lifetime.					
Description					
The LISA space-borne interferometric gravitational wave observatory mission requires a laser system operating at 1064 nm with exceptional performance requirements which must be met over the entire mission lifetime. The output power, frequency and power noise as well as sideband phase fidelity are of the particular criticality. ESA is implementing a number of activities addressing the development of the LISA laser system. These activities focus on the overall performance and some system level environmental aspects and target to reach TRL 6 before adoption. An essential part of achieving this TRL is to understand the quality, parts, materials and processes used in each of the laser system constituent components (e.g. fibre splitters, EOM, optical isolators ...) to ascertain their suitability for the mission. This activity will assess the component quality through environmental testing supporting by appropriate inspection e.g. Constructional Analysis (CA). An ESA provided component list will be procured, tested and inspected by the Contractor.					
Deliverables					
Technical Data Package					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2021
Application Mission:	LISA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Phase Reference Distribution for Laser Interferometry			
Programme:	CTP	**Reference:**	C217-045FM
Title:	Phase Reference Distribution for Laser Interferometry		

Total Budget:	1200 kEuro
Objectives	
Development and Verification of an optical phase reference distribution system for gravitational wave applications.	
Description	

A gravitational wave detector compares the phase-delay of laser light caused by a gravitational wave in one interferometric 'arm' of the detector with the phase delay in the other arm of the detector. To do so, both arms need to have a common phase reference that is usually derived from a local oscillator and that is passed between the optical benches of each respective arm via an optical link usually called the 'backlink' or Phase Reference Distribution (PRD) system.

As the backlink is an integral part of the overall interferometric system, it has to adhere to similar stability (i.e. picometer stability) and scattered light requirements as the rest of the interferometric system. In addition, the backlink performance has to be fulfilled in two scenarios related to how the relative movement of the spacecraft constellation is addressed: 1) two separate moving optical benches (telescope translation) and 2) a single fixed optical bench (fixed telescope).

Several possible implementations of the back link have been breadboarded e.g. optical fibre, free-space optics with beam steering. Within this activity, at least those two candidate implementations shall be traded-off, while also assessing the option of adding an additional laser for phase referencing, and assessing the foreseen performance as well as manufacturing and implementation aspects, environmental compatibility (radiation especially), etc.

The overall aim of the activity is to produce an engineering model (EM) of the most promising PRD that can be integrated with the optical bench to form part of the overall optical system of a gravitational wave detector.

The activity will be conducted in two phases:
Phase I
- Trade-off of the architectures for the PRD
- Preliminary design of all the considered options
- Assessment of expected performance, environmental compliance, manufacturability and implementation issues
- PRD baseline selection

Phase II
- Design the PRD
- Implement the PRD to EM level
- Test the PRD for function and performance, in relevant environment

A second goal of this activity will address the further development of the ground support equipment test bench required for verification of the phase

fidelity of the laser system. This test bench shall be made available to entities working under contract to the Agency.					
Deliverables					
Phase1: Trade-off and PRD design document Phase 2: PRD EM and supporting documentation					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2017
Application Mission:	LISA	**Contract Duration:**	16 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Hollow core fibre gas cell for laser frequency stabilization (I2 and C2HD)					
Programme:	TDE	**Reference:**	T217-066MM		
Title:	Hollow core fibre gas cell for laser frequency stabilization (I2 and C2HD)				
Total Budget:	1000 kEuro				
Objectives					
-Verify feasibility using different types of hollow core fibres to create a gas cell suitable for frequency stabilization at the LISA level of performances. -Simulate behaviour of the gas cell. -Manufacture a fibre gas cell -Test gas cell absorption and frequency stabilise a Nd:YAG laser to a molecular line.					
Description					
The study shall evaluate the feasibility of using Iodine (I2) and mono-deuterated Acetylene (C2HD) fibre cells as absolute frequency references to stabilize a laser emitting at 1064nm. Iodine has the disadvantage of requiring frequency doubling, while C2HD has very narrow but feebly absorbing lines at 1064nm. Other gasses may also be proposed, provided their absorption line could be proven to be compatible with the LISA stability. In particular the expected losses of the fibre gas cell including splicing to standard PM fibres shall be evaluated. The required fibre length and optimized pressure to obtain absorption for the two gasses shall be determined and evaluated against fibre-induced losses. In this first phase of the study, the behaviour of the gas cell/s in a saturated absorption configuration shall be evaluated and a demonstrator bread-board fibre using the most promising gas developed and tested by frequency stabilizing a Nd:YAG laser to a molecular line.					
Deliverables					
Prototype, Technical Documentation					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2022 TRL 6

Application Mission:	LISA	**Contract Duration:**	18 months
S/W Clause:	Operational Software		
Consistency with Harmonisation Roadmap and conclusion:			
Frequency and Time Generation and Distribution - Space (2013)			

Laser Pre-stabilisation System for the LISA Mission					
Programme:	CTP		**Reference:**	C217-089FI	
Title:	Laser Pre-stabilisation System for the LISA Mission				
Total Budget:	750 kEuro				
Objectives					
This activity addresses the development of a Laser Pre-stabilisation System (LPS) Breadboard (BB) model meeting the requirements of the LISA laser system.					
Description					
The LISA laser system requires a reference system, the LPS, against which the individual Laser Heads can be frequency stabilised. To date the ESA funded LISA laser system development activities have not addressed the LPS for LISA. This activity will address the development of a LPS BB meeting the requirements of LISA. This activity will develop the LPS to BB level. The LPS BB will be provided by ESA as a Customer Furnished Item (CFI) to the Laser System Contractors for system level testing and performance demonstration. A following activity is foreseen to further develop the LPS to EM/EQM level for performance demonstration in the relevant/operational environment and environmental testing. This activity is proposed to be implemented with NPL (UK) based on their cubic cavity development which has demonstrated performance in line with the LISA mission requirements. Two BB LPS systems shall be delivered supported by a technical data package. A work package addressing the follow-on EM/EQM development is foreseen.					
Deliverables					
Breadboard, Technical Documentation					
Current TRL:	5	**Target TRL:**	5	**Application Need/Date:**	2024 TRL 6
Application Mission:	LISA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Assessment and Breadboarding of Pressure Regulator Alternatives for Micropropulsion Systems			
Programme:	TDE (TRP)	**Reference:**	T219-004NA

Title:	Assessment and Breadboarding of Pressure Regulator Alternatives for Micropropulsion Systems
Total Budget:	400

Objectives

Assess, develop and test novel approaches for pressure regulators for micro-propulsion cold gas systems

Description

High precision micro-propulsion systems (MPS) using Cold Gas are a key enabling technology for a multitude of current and future Science missions such as GAIA, LISA Pathfinder, Euclid, Microscope and LISA.

A key component is the high pressure mechanical regulator that reduces the pressure from the gas tanks.
Gaseous Nitrogen stored at high pressure (MEOP 310). must be regulated in the range 1,8-1 bar with very low mass flow (up to14 mg/s GN2) with a stringent pressure noise requirements to supply the cold gas system .

As there is only a single Non-European manufacturing source the future availability of this regulator might be at risk.

Considering the stringent requirements especially regarding thrust noise, there is currently no alternative technological solution available.

This activity aims to explore alternative options for pressure regulation either mechanical, either electronic, which are currently not suitable for science missions due to their high thrust noise.

Priority is given to the development of European products.

The following tasks are foreseen

- Assess MPS requirements (e. g. next implementing mission LISA as baseline)
- Trade-Off of novel and existing technologies for pressure regulation (i.e. mechanical/electronic)
- Analyse noise contributions
- Design, Development and test a prototype (either mechanical either electronic) for performance verification, including the pressure/ thrust noise test
- Definition of a development plan

Deliverables

Breadboard; Other

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022

Application Mission:	Future Science Missions, LISA, Voyage 2050	**Contract Duration:**	24
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Enhanced temperature measurement for LISA			
Programme:	CTP	**Reference:**	C221-016MT
Title:	Enhanced temperature measurement for LISA		
Total Budget:	400 kEuro		
Objectives			
- Investigate temperature measurement methods for LISA - Develop a breadboard of the chosen approach and demonstrate in lab. conditions.			
Description			
The LISA mission requires temperature stability of the order 1x10-3 K/vHz for equipment such as laser sources and 1x10-5 K/vHz for the optical bench. Currently available temperature measurement techniques - typically thermistors for flight and thermocouples for testing - are limited in their resolution. For previous missions, such as GAIA and LISA Pathfinder, this limitation led to a reliance on numerical analysis for the verification of stability requirements. Moreover, for flight operations, the knowledge of temperature was inadequate, leading to difficulties to understand certain phenomena. The proposed study aims to develop enhanced temperature measurement techniques for the LISA mission. The requirements will target flight hardware, but with a view to using the same hardware for verification of requirements during ground testing. The study shall start with a survey of currently available temperature measurement techniques and identify the best candidate to be developed further. The requirements for LISA are challenging, however, they are expressed in the frequency domain (i.e. it is about stability of temperature over time, and not absolute temperature measurement). So the direct measurement of temperature variation over time may be possible using, for example, high precision bridges or differential measurements. Part of the activity shall be to define what is the best temperature measurement performance that can practically be achieved, and to assess if this performance is adequate to verify requirements. Based on the chosen concept then a breadboard shall be developed to demonstrate a working system in laboratory conditions. The scope of the breadboard shall include the sensor(s) and well as the required drive circuitry and signal conditioning etc. The interfacing with a spacecraft data handling			

system will not be part of the breadboard, but shall be considered in the requirements.

Deliverables

Breadboard, Technical documentation

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	LISA	**Contract Duration:**	24 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

High Performance Time-Domain based Temperature Diagnostics for Science Missions

Programme:	TDE	**Reference:**	T221-017MT
Title:	High Performance Time-Domain based Temperature Diagnostics for Science Missions		
Total Budget:	500 kEuro		

Objectives

Design, manufacturing and test of a time-domain based temperature measurement system Breadboard.

Description

High thermal stability is a key requirement for several Science missions. For example the LISA mission requires temperature stability of the order 1x10-3 K/vHz for equipment such as laser sources and 1x10-5 K/vHz for the optical bench.

Currently available temperature measurement techniques - typically thermistors for flight and thermocouples for testing - are limited in their resolution. For previous missions, such as GAIA and LISA Pathfinder, this limitation led to a reliance on numerical analysis for the verification of stability requirements. Moreover, for flight operations, the knowledge of temperature was inadequate, leading to difficulties to understand certain phenomena.

This study builds on the outcome of C221-016MT-B (Enhanced temperature measurement for LISA) which successfull demonstrated the novel approach of a time-domain based temperature measurement system with microkelvin resolution (1x10-4 at 10-4 Hz to 1x10-6 K/vHz at 10 Hz). This approach uses the temperature-sensitive variations of an oscillator crystal compared with an ultra-stable reference clock (which is already on-board e.g. the LISA mission) to derive a temperature measurement.

Key advantages of this approach are:

• Provides a direct digital output without the need for high resolution/high precision analog to digital converter.

• One sensor can cover the whole measurement range
• Compared to conventional ADC based systems, the measurement electronics of a time domain ETMS has the potential of providing a much lower sensitivity to changes in ambient temperature, simplifying
• Very long cable lengths of several meters possible (additional GSE applications)

This follow-up activity shall address at a minimum the following tasks:

- Further Noise Performance Improvements (considering e.g. temperature sensitivity of ocscillator, reference clock and counter instabilities)
- Standalone Frequency Measurement via a dedicated BB
- Temperature Measurement Verification
- Charaterisation over a large continuous temperature measurement range

Additionally, a technology development plan including an assessment of suitable space and terrestrial applications of the technology shall be delivered.

Deliverables

Breadboard; Other; Report

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	LISA, Voyage 2050, science missions with high thermal stability	**Contract Duration:**	12 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Antenna Pointing Mechanism for the LISA High-Gain Antenna - Concept and Verification

Programme:	CTP	**Reference:**	C215-136FT
Title:	Antenna Pointing Mechanism for the LISA High-Gain Antenna - Concept and Verification		
Total Budget:	400 kEuro		

Objectives

Design of the Antenna Pointing Mechanism driving the LISA High Gain Antenna including verification GSE and performance model.

Description

Each of the three LISA spacecraft includes an X-band High-Gain Antenna (HGA) equipped with an Antenna Pointing Mechanism (APM).

For the LISA mission, the operation of the scientific instrument is incompatible with the uvibration perturbations induced by a conventional Antenna Pointing Mechanism. Therefor this activity shall conceptualise an APM design that fulfills the stringent LISA uvibration requirements. Due to the challenging nature of uvibration regarding design and specifically verification the activity shall in parallel also lead to the design of an appropriate verification GSE and associated analytical and/or numerical models that allow the simulation of the performance of the proposed design solution and associated verfication GSE. If required by the proposed design and solution trade-off, the performance of identified critical elements and components shall be evaluated and tested. A successive TDA is envisaged, further developing the selected design targeting TRL 6 by 2023.
Deliverables
Tradeoff and Design report; Mathematical model; Simulation report; Development roadmap; Critical items and components HW

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2021
Application Mission:	Required for SCI LISA mission. Mechanical Antenna is baselined. Very low uvibration requirements which are not met with current technologies.	**Contract Duration:**	10 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Gravitational Wave Observatory Metrology Laser CCN			
Programme:	CTP	**Reference:**	C217-088FI
Title:	Gravitational Wave Observatory Metrology Laser CCN		
Total Budget:	1500 kEuro		
Objectives			
This activity shall address the development of a laser system meeting the requirements of a Gravitational Wave Observatory mission.			
Description			
The LISA space-borne interferometric gravitational wave observatory mission requires a laser system with exceptional performance requirements which must be met over the entire mission lifetime. Of particular criticality are the output power, frequency and power stability and sideband phase fidelity. In			

addition the mission lifetime places stringent demands on the laser system reliability. The goal of this activity is the development and test of an engineering model (EM) of a laser system meeting the requirements thereby demonstrating TRL 6 (model demonstrating the critical functions in a relevant environment). The activity is split in two contractual phases. The completed Phase I has yielded breadboard demonstration of the performance requirements in a laboratory environment. Phase II shall begin with the completion of the detailed laser system design and related technology development and component qualification status assessment. The laser system EM shall be manufactured and subjected to functional and performance testing in a relevant environment. Phase II shall address any component level testing required for demonstrating compliance with the LISA mission environment i.e. the demonstration of TRL6, including where possible lifetime. This CCN proposal intends to expand the scope of the Phase II activities to include additional technical activities reflecting the lessons learned of phase 1, in particular with respect to the master oscillator (affecting the consortium composition) and additional derisking PA/QA activities.
Deliverables
Engineering Model; Report

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	LISA Laser System		**Contract Duration:**	30 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
No					

LISA Laser System Performance Metrology			
Programme:	CTP	**Reference:**	C217-095FI
Title:	LISA Laser System Performance Metrology		
Total Budget:	1500 kEuro		
Objectives			
This activity will address a number of tasks related to the performance metrology of the LISA laser system			
Description			
The LISA space-borne interferometric gravitational wave observatory mission requires a laser system with exceptional performance requirements which must be met over the entire mission lifetime. Of particular criticality are the output power, frequency and power stability and sideband phase fidelity. The goal of this activity is the further development of metrology techniques			

and hardware and the application of such to the performance characterisation of candidate technologies for the LISA laser system.

The following five tasks are included within this activity:
Task 1: Study of implementation phase (B2CD) metrology approach
Task 2: Metrology test bench upgrade
Task 3: NASA BB LS performance testing
Task 4: OEwaves MO performance testing
Task 5: NASA EM LS performance testing

Deliverables

Technical data package, upgraded LISA metrology hardware

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2022
Application Mission:	LISA		**Contract Duration:**	30 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Delta Development Assessment of the LISA GRS GPR mechanism

Programme:	CTP	**Reference:**	C217-076MM
Title:	Delta Development Assessment of the LISA GRS GPR mechanism		
Total Budget:	450 kEuro		

Objectives

The objective of this activity is to assess the needed delta Developments of the LISA GRS GPRM subsystem from the preceding LISA Pathfinder mission in order to improve and safe-guard the performance and reliability of the GRS for the LISA mission.

Description

The LISA Gravity Reference Sensor (GRS) is a key subsystem of the LISA payload, directly linked to the main scientific goal of the LISA mission, the detection and observation of gravitational waves.

The GRS has already been successfully tested on board the preceding LISA Pathfinder Mission (LPF). Lessons learnt from this technology demonstrator regarding the GRS performance and reliability now need to be assessed wrt to the Grabbing, Positioning, Release Mechanism (GPRM) for the LISA mission, which poses additional challenges due to its much longer life time.

The following tasks are foreseen to be included to fulfil the objective of this activity:

- Review and adaptation of existing CAD models
- Review and adaptation of mathematical models
- Verify design analyses predicted performance

- Verify mathematical models consistency wrt as-built - Review of custom made items procurement specification - Assess qualification program - Assess technology obsolescence risks - Assess verification plans and procedures - Definition of a Delta-Development plan The key output of this activity will be a detailed delta-development plan covering the conclusions of the above tasks, as well as the necessary documentation to initiate bread-boarding activities on changed parts.
Deliverables
Delta-Development Plan, Technical Notes.

Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	LISA		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Delta Development Assessment of the LISA GRS GPR mechanism - CCN			
Programme:	CTP	**Reference:**	C215-143FT
Title:	Delta Development Assessment of the LISA GRS GPR mechanism - CCN		
Total Budget:	490 kEuro		
Objectives			
Develop and test design improvements as required by the LISA mission based on the previous assessment of needed delta-developments via dedicated breadboarding.			
Description			
The LISA Gravity Reference Sensor (GRS) is a key subsystem of the LISA payload, directly linked to the main scientific goal of the LISA mission, the detection and observation of gravitational waves. The previous TDA (C217-076MM) assessed necessary design changes, this CCN is now extending the scope towards evaluating the advantages of these design improvements via breadboarding addressing the following identified design improvements: 1. Plunger linear guide / bearings upgrade 2. Piezo stack length increasing 3. Position sensor upgrade 4. Force position upgrade 5. TM-plunger interface profile modification 6. Hot redundancy implementation in release pins			

7. Refinement of plunger design Goals of the breadboard evaluation: - To verify the minimization of rotations of the test mass occurring when plunger is extended/retracted and at the motion inversion - To verify the compliance of the lateral constraint contributes to lateral vibrations of the plunger at the TM release - To implement a longer release tip piezo stack implementing fast and slow actuation strategies
Deliverables
Breadboard; Report.

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	LISA		**Contract Duration:**	8 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

L4-Mission: Moons of the Giant Planets

Spin in of Terrestrial Solid Oxide Fuel Cell (SOFC) Technology for Outer Planet Exploration Power Generation			
Programme:	TDE	**Reference:**	T203-122FM
Title:	Spin in of Terrestrial Solid Oxide Fuel Cell (SOFC) Technology for Outer Planet Exploration Power Generation		
Total Budget:	700		
Objectives			
To adapt a terrestrial mobile Solid Oxide Fuel Cell system for power generation for outer planets exploration as an alternative to solar and nuclear power energy.			
Description			
Future exploration missions, including missions to the outer planets such as Jupiter, Saturn, Uranus and Neptune as well as their Moons, would benefit from the study of alternative energy generation solutions. Generating electrical power at far distance from the Sun, as well as maintaining the required thermal environment required for a specific mission, are both critical capabilities needed for such missions. Different technologies already exist to provide power in different operating conditions, and in different types of space missions, including Batteries, Solar Arrays and Nuclear Systems but the large distances from the Sun and the unavailability of European RTGs suggest to explore alternative solutions. In particular, the hydrocarbon (e.g. methane, butane) O_2 reaction is high in mass-specific energy, and would be potentially manageable over long timescales with pressurised storage			

compared to the very low boiling point of hydrogen (providing the highest mass-specific energy) for which storage for many years would not be easily achievable without major boil-off loss. A fuel cell system is well suited for this purpose since the efficiency is high, and it is a static, vibration-free device; successful space heritage of fuel cells exists from Apollo and STS.
In order to use high energy density hydrocarbons as reactants, the concept must be based on existing Solid Oxide Fuel Cell (SOFC) technology. As compared to other fuel cell technologies, which require pure hydrogen as reactant, SOFC is tolerant to hydrocarbon derived fuels and can even operate directly on hydrocarbons and carbon monoxide, which are poisons for other fuel cells. SOFC technology has been flown on the Perserverance rover to generate O_2 from the Martian CO_2 atmosphere this year. The concept was successfully demonstrated.
In order for the SOFC subsystem to be versatile for multiple functionalities and/or mission scenarios, it must be designed with the following basic features:
- The SOFC should be capable to provide low power delivery (< 150 W) suitable for multi-year reliable space operation
- The SOFC should be capable of throttleability and re-startability (thermal cycling) during the operational lifetime
- The SOFC should require low quiescent power consumption for e.g. control and monitoring.

This activity shall be focused at verification of the functional performance by breadboard testing in laboratory environment. The activity will need to include the following activities:
-System architecture design by spinning in existing terrestrial SOFC mobile system technology
-materials and reactants trade-off and selection, fuel storage and fluidic chain design
-Establishing a mathematical model to design and validate the system
-Adapt the existing terrestrial system to the space requirements
-Build the breadboard
-Experimental demonstration of the breadboard including the main elements, i.e. the SOFC stack, reactant storage, fluid handling, gas pre-processing reactor, heat exchangers, thermal management for cycleability, electrical performance and lifetime.
The demonstration of flight worthy CH_4 and O_2 tanks shall not be included in this activity, however, the testing of the breadboard shall be done based on real reactants. Furthermore, a preliminary sizing of a later flight application of the full system shall be made and related high-level requirements for a tank and fluidic chain development activity shall be derived.

Deliverables

Breadboard; Report

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2023
Application Mission:	L4 mission of the Voyage 2050	**Contract Duration:**	18		

S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Harmonisation Roadmap Reference: E10 Harmonisation Comments: Some changes to the details but the overall description fits very well to the spirit of this activiy Harmonisation Roadmap: Electrochemical Energy Storage			

Lightweight Thrust Mechanism for Large Engines Configurations (LiTMEC)					
Programme:	TDE		**Reference:**	T215-019MP	
Title:	Lightweight Thrust Mechanism for Large Engines Configurations (LiTMEC)				
Total Budget:	600 kEuro				
Objectives					
To design and demonstrate a very lightweight Thrust Orientation mechanism for large electrical engine configuration for future Science missions					
Description					
To reduce mass, an activity to design a lightweight SEP thruster pointing system (using hold down bolts for the launch, and then very low mass and slow moving devices to point the thrusters) would be very beneficial for future science missions. The mechanism should be able to support at least three 20kW class EP thrusters (of roughly 150kg in combined payload mass). Minimising the number of degrees of freedom is one objective (gimbaling canted thrusters may require more than 2 angular axes to point at CoG...); minimize the combined mass and cost; utilization of advanced technologies (e.g. additive manufacturing) and rapid prototyping can be an asset; Tasks: - Establish and consolidate technical requirements - perform a tradeoff between solutions against TRL, mass and cost - select 2 promising concepts - preliminary design the concept critical aspects - build necessary breadboards and prototype of the critical technologies to demonstrate feasibility - Refine technical requirements and technical constraints - Pave the way forward for a further development					
Deliverables					
Prototype					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Mission need: science exploration		**Contract Duration:**	24 months	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

E06: Electric Propulsion Pointing Mechanisms (EPPMs)

Heat Recovery and Thermal Management Sub-System for Deep Space Missions			
Programme:	TDE	**Reference:**	T221-115MT
Title:	Heat Recovery and Thermal Management Sub-System for Deep Space Missions		
Total Budget:	500 kEuro		
Objectives			
To develop a heat recovery and thermal management architecture using passive or active means to recover the waste heat and redistribute to equipment and propulsion sub-system in order to reduce the electrical heating power need and to reduce/eliminate the need of Radioisotope Heating Units.			
Description			
The typical approach when designing thermal sub-systems is to bias towards the heat rejection and to compensate with electrical heating to account for various spacecraft modes and mission scenarios. For deep space missions such as Saturn or ice giants planets, the cost and mass of the electrical sub-system becomes an important driver in the mission and any heat loss to space becomes a precious commodity. Substituting this loss heat with electrical power or radioisotope heating units or even radioisotope thermal generator increases the complexity of other sub-systems and even can increase the complexity and safety aspects of the integration and launch of the mission. Given the lead time and the restrictions of launching of RHUs, these components may be mission enablers but their handling, late integration and thermal management remains complex and costly. Therefore, developing a thermal architecture that can recover waste heat and able to redistribute to equipment and to the propulsion systems efficiently in terms of power and mass can become a mission enabling technology. As well as if the thermal subsystem can accommodate and manage the heat dissipation of RHUs, this would allow to achieve a large flexibility in the design able to cope to new mission scenarios and architectural changes. There are several possible thermal architectures that needs to be traded-off in order to evaluate the mass and complexity of the sub-system and compared it to the resulting mass of the electrical power generation. The possible thermal architectures that could be use in the trade-off are JUICE-Rosetta Design using electrical power and RHUs, a Hybrid JUICE-Rosetta Design with a Passive Heat recovery system (such as loop heat pipes) to heat up the propulsion system and to minimize the amount of RHUs, or a NASA Europa Clipper type design, with a Mechanical pump system for heat recovery and redistribution system with a Plug-in for RHUs if needed. The following tasks shall expected to be performed within this activity			

- A trade-off study of various Heat recovery and thermal management architectures - A preliminary design and analysis of the thermal sub-system shall be performed - Breadboarding of key components or assemblies in order to validate part of concept - Breadboarding of the overall architecture concept in order to validate key assumptions made in the analyses - A development roadmap of the overall thermal sub-system for deep space missions shall be provided.

Deliverables					
Breadboard					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:		**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Two-Phase Heat Transport Equipment					

Adaptation of Existing Solar Arrays for Missions to Saturn			
Programme:	TDE	**Reference:**	T203-121EP
Title:	Adaptation of Existing Solar Arrays for Missions to Saturn		
Total Budget:	300 kEuro		
Objectives			
To investigate if an existing solar array design or product can be adapted for use in deep space missions to Saturn.			
Description			
Large solar arrays are currently being developed for telecommunication and scientific missions. Recent examples include the semi-rigid ENEO array, the fully flexible SolarFlex array of the Novacom 2 telecommunications satellite and the rigid array of the JUICE mission to Jupiter. With a high specific power, such arrays lend themselves for use in exploration missions. Recent feasibility studies have demonstrated that missions to Saturn, fully powered by solar arrays, are indeed feasible. However, the total area needed would be between 150 - 200 m2. This places demanding requirements on the solar array design. Apart from high specific power (W/kg) and low areal mass (kg/m2), other important parameters include the eigenfrequencies in stowed and deployed configurations, as well as the ability to retract and to re-deploy, to protect the array from damage, should the satellite pass through the dust rings of Saturn.			

The activity therefore encompasses the following tasks:

- Scalability of an existing array design to 100 m2 cell area.
- Adaptation of deployment mechanisms to include a retraction capability.
- Assessment of areal mass, using latest LILT solar cell technology, potentially modified with reduced thickness.
- Assessment of eigenfrequencies for arrays of up to 100 m2 area.
- Demonstration of multiple retractions and re-deployments of the solar array by means of test at low temperature of a representative design mock-up.
- Identification of development needs.
- Preparation of a roadmap.

Deliverables					
Breadboard					
Current TRL:	TRL2	**Target TRL:**	TRL3	**Application Need/Date:**	2022
Application Mission:		**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Solar Generators and Solar Cells					

De-risking active damping of large flexible appendages in the AOCS loop for planetary missions			
Programme:		**Reference:**	T205-128SA
Title:	De-risking active damping of large flexible appendages in the AOCS loop for planetary missions		
Total Budget:	300 kEuro		
Objectives			
To mature and de-risk active damping control in the AOCS loop for large flexible appendages, in order to implement a generalised strategy for low-frequency flexible modes rejection.			
Description			
Large flexible appendages such as solar arrays are becoming more and more common for planetary mission, particularly for destinations in the outer solar system. To minimize the mass of these large components, stiffness is always compromised, resulting in highly flexible appendages. Large flexible appendages have a huge impact in the control performance of space missions. Once excited, the flexible modes induce attitude and position oscillations onto the body of the spacecraft, affecting pointing performance;			

minimizing agility; and imposing long convergence periods to allow for damping of the oscillations.

Fortunately, when the flexible modes are within the attitude control bandwidth, they can be accounted for in the design to be actively damped by the AOCS, without the need for any additional actuators. This can enable a more agile and better performing AOCS without much additional complexity.

Nevertheless, such inclusion of the flexible modes in the controller design is not standard practice on space missions. Traditional AOCS systems are only designed to not excite flexible modes by applying filters to prevent actuation at resonant frequencies. This prevents catastrophic failure of the flexible appendages, but does not improve agility nor performance of the AOCS.

An example of this type of non-traditional AOCS systems is the "Emergency Damping Loop" (EDL) mode on JUICE. This mode, however, is only effective in damping symmetric cantilever deflections of the arrays. It does not operate on attitude disturbances caused by anti-symmetric motion of the first cantilever mode, nor the effects of any other flexible (sub)-mode nor torsional flexible modes.

For these reasons, this study is aimed at maturing and de-risking the implementation of such an AOCS damping loop, in order have it operate on several flexible modes and sub-modes and minimize their effects on the spacecraft attitude.

Task list:
- Trade-off and select a suitable control strategy to actively damp flexible modes from multiple appendages inside the control loop
- Prototype and implement a suitable control solution based on a generic candidate mission for simulation, formal verification and testing
- Implement system identification techniques and define an effective re-tuning procedure after flexible modes identification in flight
- Define a generic procedure for active damping control design
- Perform a parametric analysis as input to the design of flexible appendages

Deliverables

Report; Software

Current TRL:	TRL3	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:			**Contract Duration:**	15 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Particle radiation modelling for interplanetary missions extending to low energies			
Programme:	TDE	**Reference:**	T204-138EP
Title:	Particle radiation modelling for interplanetary missions extending to low energies		
Total Budget:	300 kEuro		

Objectives

To develop solar particle radiation modelling capabilities for distances away from 1 AU, to lower energies for thin films and coatings and incorporate electron populations.

Description

Solar particle radiation is a key contributor to dose and single event effects for many Earth orbits especially where the strength of geomagnetic shielding is weaker. Once spacecraft leave the Earth's magnetosphere the pre-eminence of these populations increases as all protection is removed and the trapped particle populations are no longer present. Low energy solar particles are now able to reach spacecraft with very high fluences impacting solar arrays, thin films and coatings. In addition solar electrons become the driving population for internal charging effects.

At present the ECSS Standard on Space Environment takes a very conservative approach for scaling interplanetary populations has no way to extend modelling down to lower energy particles eroding surface materials and references an incomplete model of the solar electron environment which is not readily available.

This activity shall:
1) Exploit physics-based modelling of solar energetic particle events to prescribe new scaling factors for missions in the heliosphere reducing excess conservatism (indicated to reduce dose levels by a factor of 50% during cruise phases for a mission to Saturn)
2) Elaborate solar electron modelling for interplanetary space using latest data calibration and modelling techniques.
3) Elaborate extensions of environments down to low energies
4) Create time series for single event effects and spacecraft internal charging analyses
Outputs will be incorporated into engineering tools to evaluate effects.

The activity encompasses the following tasks:
- Review state of the art for probabilistic modelling of solar particle radiation in the heliosphere
- High- and low-level software design for implementation of algorithms to be interfaced to other tools
- Development of prototype/alpha version of software including user manual
- Verification and Validation of software

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.					
Deliverables					
Report; Software					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:			**Contract Duration:**	12 months	
S/W Clause:	S/W				
Consistency with Harmonisation Roadmap and conclusion:					
A10: Radiation Environments & Effects					

Dust Model for the Saturnian System			
Programme:	TDE	**Reference:**	T204-139EP
Title:	Dust Model for the Saturnian System		
Total Budget:	300 kEuro		
Objectives			
Develop a dust model and an engineering tool to evaluate the dust impacting on satellites in the Saturnian System.			
Description			
Micrometeoroids pose a relevant risk to spacecraft on interplanetary missions. This risk is further enhanced by local dust populations in planetary systems. Knowledge on these local populations is very limited, building in the low size range on in-situ dust impact detection in instruments as the Cassini Dust Analyser and in the high size range on optical remote measurements as the opaqueness of Saturnian Rings. The objective of this activity is the development of a meteoroid population model for the Saturnian system that covers the size range from microns to centimeters that can be used for impact risk assessments for space missions. Note that within the dust rings larges particle sizes of up to meter may need to be modeled to ensure safe spacecraft passage. The model shall provide as a minimum the number density, velocity and directional distribution as a function of the particle mass and it shall allow to derive the impact velocity, impact flux and impact directional distribution relative to a spacecraft with defined trajectory within the Saturnian system. The model shall give special attention to the neighbourhood of the Saturnian moons, in particular Titan and Enceladus. The dust belts should also be included in the model to allow impact risk assessments for potential spacecraft belt crossings.			

Deliverables					
Report; Software;					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Voyage 2050 Ocean Worlds and other missions to Saturnian system	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

M3-Mission: PLATO

Pre-development of High Accuracy Heater Controller for PLATO					
Programme:	CTP		**Reference:**	C201-038FI	
Title:	Pre-development of High Accuracy Heater Controller for PLATO				
Total Budget:	650 kEuro				
Objectives					
Development of a functional breadboard of a highly accurate heater controller with application in PLATO thermal payload camera thermal control.					
Description					
The breadboard will validate the performance of a high accuracy heater controller for up to eight Resistance Temperature Detector (RTD) inputs and a single heater output. The activity will include designing the RTD measurement and heater interfaces, implementing them in breadboard hardware, creating VHDL code for the controller and testing to verify that the required performance characteristics are met in relation to the requirements for the PLIU (PayLoad Interface Unit) on PLATO. The following tasks shall be addressed: - Design and validation of a highly accurate Resistence RTD temperature sensing circuit compatible with space-grade equivalent components - Design and validation of a highly reliable heater actuator / driver circuit - Implementation of an FPGA based PID controller and characterization of the FPGA resources required per heater channel - Verification of electrical accuracy and performance meeting PLATO PLIU requirements.					
Deliverables					
Functioning breadboard hardware of RTD sensor/heater controller and controller functions, design verification report characterizing the performance, roadmap with schedule and cost estimate for finalizarion of design and realization of qualification for PLATO					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2019

Application Mission:	PLATO	**Contract Duration:**	12 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

FM pre-development of the AEU power supply for PLATO			
Programme:	CTP	**Reference:**	C203-105PL
Title:	FM pre-development of the AEU power supply for PLATO		
Total Budget:	500 kEuro		
Objectives			
The Objective of this activity is to design, and manufacture the development model(s) of the AEU power supply for PLATO, including functional verification to ensure robustness of the design.			
Description			
The AEU power supply has been specifically selected to provide the stringent power requirements to the (24+2) Cameras of the PLATO Payload. There are two types of AEU, Fast and Nominal. Each nominal AEU is designed to provide power to 12 Front End Electronics for the cameras, and the Fast AEU provides power to the Two Fast Cameras that are also an integral part of the spacecraft fine guidance as part of the AOCS. This activity to consolidate the AEU design architecture and to manufacture & test development model(s) that will demonstrate that the power requirements of the PLATO Payload can be fulfilled. This activity is critical for the further development of the camera and to ensure that there are no unforeseen EMC issues with the payload. The Main tasks during this development activity are comprised of the following: 1) Consolidation of the design and architecture to be inline with the PLATO Mission definition. 2) Finalise all open technical requirements and ensure that the design is robust enough to accommodate any further changes. 3) Selection of components and definition of all activities related to any qualification/delta qualification or radiation needs. 4) Manufacture of the secondary voltage and camera synchronisation modules 5) Manufacture of the House Keeping and Data handling Module. 6) Integration of the Power supplies and House Keeping modules and the backplane together to form a AEU development model. 7) Test Plan Definition and preparation of the relevant procedures. 8) Testing of the development model(s). 9) Finalisation of the design of the Flight Units and update of the relevant documentation. 10) Demonstration that manufacturing and PA processes reflect flight standard. 11) The development will be used within the remaining project development			

Deliverables					
Trade-off and detailed design reports that reflect the most recent design and payload requirements Design definition (manufacture of the secondary power supplies and House Keeping Telemetry) AEU Development Model Manufacture and test of the DM Test report(s) Updates to all relevant design documentation.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	PLATO		**Contract Duration:**	10 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Radiation Hard Gyroscope Development for Science Missions			
Programme:	CTP	**Reference:**	C205-114SA
Title:	Radiation Hard Gyroscope Development for Science Missions		
Total Budget:	2600 kEuro		
Objectives			
The objective of this activity is to develop, manufacture and test to TRL6 an Engineering Qualification Model (EQM) of the Arietis medium accuracy 3-axis gyroscope for application in ESA Science missions, with PLATO identified as the first use case.			
Description			
Innalabs (Ireland) has manufactured and is successfully selling Coriolis gyroscopes for terrestrial applications and non-rad-hard space applications. The next step in the development of this technology is to develop high reliability radiation hardened electronics and further improve the performance of the gyroscope for high reliability Science mission application. The ESA Science mission PLATO has been identified as the first application of this 3-axis gyroscope. This activity will build upon previous ESA led development and address the further activities required to improve the TRL, namely : - Maturation of the electronics design with all supporting analyses - Breadboarding activities resulting in an EBB supporting a CDR - Demonstration of the improvements of the sensing element - Manufacturing of an EQM to de-risk a future qualification, targeted for late 2018 - Appropriate testing to reach TRL6 The target specifications for this 3-axis gyro are the following : - ARW < 0.006 deg/sqrt(hr) - Bias sensitivity over temperature : 1 to 5 deg/hr (-30 to +65 degC)			

- Bias stability over 1h (steady conditions) : < 0.1 deg/h - 1.5 kg (3 axis) - Power consumption below 5W - Full performance after 10s - Radiation hardened While the driving requirements are derived from Science mission application it should be noted that such a development can serve a large spectrum of space applications (Science, Earth Observation, Telecoms, Navigation...).					
Deliverables					
EQM, Full CDR datapackage					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	TRL6 by 2019
Application Mission:	PLATO		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
AOCS SENSORS AND ACTUATORS: STAR TRACKERS, APS, GYROS, ACCELEROS, WHEELS (Aim A05)					

High Accurary Accelerometer for Space Applications			
Programme:	CTP	**Reference:**	C205-115SA
Title:	High Accurary Accelerometer for Space Applications		
Total Budget:	900 kEuro		
Objectives			
The objective of this activity is to develop and test to TRL6 a high accuracy accelerometer meeting the requirements of Science missions. The first targeted application is the PLATO mission.			
Description			
In ESA missions, high accuracy accelerometers are used for two types of applications. Science missions require accelerometers for delta-V monitoring, while exploration missions require accelerometers to be embedded in IMUs for landing applications. This development is targeting increasing the TRL for the accelerometer used in the delta-V monitoring application on Science missions with PLATO being the first targeted application. In the two use cases, accelerometers are currently procured from the US. In order to maintain a performance not degraded with respect to US accelerometers, the MEMS accelerometers considered in previous activities to equip future European high accuracy IMUs need to be replaced in favour of a higher performing design, either a Vibrating Beam accelerometer or a Quartz Pendulous accelerometer. A Quartz Pendulous accelerometer has been developed by Innalabs (Ireland). The performance has been demonstrated and is a suitable candidate for PLATO. Adequate radiation hardening of the accelerometers, both sensor and electronics, and the testing in relevant environment will be performed to de-risk future qualification. The following tasks will be performed			

in this activity: - Review of Science mission performance requirements, with PLATO being the reference application - Liaise with the manufacturer of the European 1090A IMU to provide guidance and specifications for the testing and radiation hardness to be achieved - Implement the radiation hardening of the accelerometer electronics and confirm performance at breadboard level. - Manufacture and test five Engineering Model accelerometers (form/fit like Flight Model, including the new space grade high reliability proximity electronics if fully fitting within the accelerometer volume), confirm survivability to environments (vacuum, mechanical, radiations) and achieved performance with respect to applicable requirements. Target specifications: - Accelerometer measurement range +/- 20 g (at least) - Accelerometer bias repeatability <40 ?g (20 g range) - Accelerometer scale factor error <300 ppm (including stability, thermal residuals and radiation effects) - Accelerometer Bias Stability, Short Term < 3 ?g (possible on a reduced range) - Accelerometer Bias Stability, Thermal Sensitivity (before compensation) < 15 ?g/?C - Accelerometer noise <5 micro g /sqrt-Hz - Power consumption < 250 mW
Deliverables
Engineering Model

Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	TRL6 by 2019
Application Mission:	PLATO		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensors and Actuators: II - Specific Sensors and Actuators (incl. IMU) (2015)					

Antenna Pointing Mechanism for PLATO			
Programme:	CTP	**Reference:**	C215-131FM
Title:	Antenna Pointing Mechanism for PLATO		
Total Budget:	2000 kEuro		
Objectives			
Development to EQM level of elements of the Antenna Pointing Mechanism (APM) for PLATO			
Description			
The activity shall entail the following tasks: 1. design of the APM for PLATO based on existing heritage but including the mission specific requirements (e.g. dual band X/K, micro-vibration control, etc.) 2. development at E(Q)M level of the coax feed for the X-band in addition to the K-band waveguide			

3.development of Rotary Actuator for high pointing accuracy and characterisation with respect to micro-vibrations 4. dynamic modeling of the APM system to assess microvibration transmission to the system
Deliverables
Coax feed Rotary actuator Design, analysis and testing documentation

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	Jan 2019
Application Mission:	PLATO		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Validation of large format CCDs for PLATO: environmental test phase			
Programme:	CTP	**Reference:**	C217-042FA
Title:	Validation of large format CCDs for PLATO: environmental test phase		
Total Budget:	1500 kEuro		
Objectives			
The objective of this activity is to prepare the flight model production of PLATO CCDs by validating the PLATO CCD design and verifying that its build standard is appropriate for the anticipated PLATO environment condition.			
Description			
PLATO is one of the five candidates for the third ESA M-class mission, M3, planned for launch in 2024. Its payload includes 32 cameras, each including 4 large format CCDs. During a first phase of manufacturing and screening phase with ESA, e2v will manufacture and screen sufficient devices to yield 24 CCD270 and 8 CCD280 devices, so called qualification lot. An electro-optical test camera with two cryostats dedicated to PLATO CCDs will also be developed. In a second phase, object of the present activity, environmental tests of the qualification lot are required to confirm that: - to verify that its build standard is appropriate for the anticipated PLATO environmental conditions, the CCD280 device is sufficiently representative of the CCD270 as a radiation test vehicle for PLATO CCDs during the FM production phase.			
Deliverables			
The objectives of this environmental test phase are to submit 24 CCD270 and 8 CCD280 devices to a complete set of tests including mechanical, thermal, electro-optical, and radiation tests. A qualification report will be delivered. The			

qualification devices will be kept at E2V for reference during the PLATO flight model production phase.					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2017
Application Mission:	PLATO		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

M4-Mission: ARIEL

Development of the method of gluing glass elements with titanium holders in cryogenic temperature			
Programme:	CTP	**Reference:**	C224-007FM
Title:	Development of the method of gluing glass elements with titanium holders in cryogenic temperature		
Total Budget:	460 kEuro		
Objectives			
Gluing is one of the preferred options for optical element mounting in space. However, for cryogenic applications the mismatch of the coefficient of thermal expansion (CTE) between glass/metal creates major problems. In this activity a process shall be developed and qualified to glue small glass/metal optical elements for cryogenic applications. The process shall include procedures for gluing BK7 and SF6 glasses to titanium frames. The selected environment is based on the Fine Guidance System instrument for the ARIEL mission with temperatures as low as 30K.			
Description			
The project takes advantage of the experience gained in the current project (STAT 2460 - TRP Adhesive bond behavior in cryogenic environment). The FEM structural and thermal analysis were performed for selected adhesives, different geometries and materials. As was shown the results are highly dependent on CTE and stiffness (E) values of the glue. However, for cryogenic temperatures these values are not available for many materials. Thus, experimental methods must be applied to develop and qualify the gluing process. Having these results the method of gluing glass elements with titanium holders in cryogenic temperature will be developed. In frame of the proposal following activities are planned: 1. Upgrade of the glue procedure from samples to holders incl: Glue surface cleaning, mixing approach, de-gassing approach (micro-bubble removal) , glue pad application method , glue pad application monitoring,			

glue pad size control , glue residual removal method, glue curing method (ambient vs. heated) 2. Ground support equipment for holders: Holder position device, Glue application device , Glue pad monitoring system (camera) Glue mixing machine procurement 3. Test equipment development/ improvement - Upgrade of thermal vacuum chamber (currently 80K) with CryoCooler (Cold head with Compressor) (enable 30K) - Upgrade of temperature measurement system to cryogenic temperatures 30K 4. Application of glue procedures for FGS type optical elements holders - manufacturing and assembling of the holders with optical elements 5. Glued holder tests Thermal shock (dip test) , Thermal cycling (8 x 30 K to 60°C) , 6. Supporting/Shadowing FEM analyses Glue modelling/meshing approach development , Analysis method development (linear vs. non-linear) , Margin of safety calculations
Deliverables
Glue bread-board report describing above mentioned points, Final glue selection, Gluing procedure, Gluing FEM analysis report, test report of FGS optical elements holders

Current TRL:	TRL3	**Target TRL:**	TRL7	**Application Need/Date:**	2023
Application Mission:	ARIEL		**Contract Duration:**	24 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

X-band Low Gain Antenna development			
Programme:	CTP	**Reference:**	C224-007EF
Title:	**X-band Low Gain Antenna development**		
Total Budget:	650 kEuro		
Objectives			
The objective of this activity is to develop an Engineering Model of a X-band Low Gain Antenna for application to ARIEL and other future science missions. This Engineering Model will be fully representative in form, fit and functions of the flight unit.			
Description			
This activity shall encompass:			

1. Specifications, design and overall engineering of the antenna 2. PA implementation in preparation of flight programme (parts, processes) 3. Procurement of components 4. Manufacturing of an Engineering Model 5. Performance (electromagnetic) Testing 6. Some Environmental Testing based on ARIEL specifications (thermal cycling, random vibrations)
Deliverables
Antenna specifications and design documentation PA documentation Engineering Model HW Engineering Model Test Plans and Reports

Current TRL:	3	**Target TRL:**	5-6	**Application Need/Date:**	Q4 2022- Q1 2023
Application Mission:	ARIEL and other science future missions	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Neon Joule-Thomson Cooler for Ariel			
Programme:	CTP	**Reference:**	C221-009FM
Title:	Neon Joule-Thomson Cooler for Ariel		
Total Budget:	400 kEuro		
Objectives			
The objective of this activity is to design and manufacture a Neon Joule-Thomson (JT) engineering model cooler re-using the small scale compressor, optimise the performance considering the Ariel specific environment and verify the performance by tests.			
Description			
Ariel requires cooling down to 35K for the Mid Infra-Red (MIR) detector. The ESA CDF study has identified a Ne JT cooler, based on the small scale compressor and the Planck 4K JT cooler, as the preferred solution. This is using a similar architecture as Planck, but replacing the 50-80K Stirling compressors with a more modern, smaller compressor, which is commercially available. Contrary to other cooling cycles, this approach allows to pre-cool the gas via the V-Groove radiators and does not require to transport the "cooling" from the Service Module (SVM) to the payload through the passive V-Groove system. Replacing Helium by Neon in a JT cooler allows to re-use the same compressor technology, since both fluids are inert noble gases. Nevertheless, since the viscosity and density of Neon is different from Helium, adaptations to the compressors (e.g. piston diameter, number of			

flexure springs) are required to operate the system near resonance conditions to minimise the input power required. The counter-flow heat exchanger designed for the 4K JT has been optimised for Helium and the Planck cooling chain and needs to be re-optimised for the Ariel passive pre-cooling with Neon as a working fluid. The design of the cold-end requires modifications to consider the difference in density, heat of vaporisation and viscosity of Neon to enable a stable operation in 0-gravity.

In the first part of the activity, the small scale compressor will be modified to work as a JT compressor and with Neon as an operating fluid. The design of the counter-flow heat exchanger needs to be optimised for the Ariel configuration. A suitable cold-end for Neon will be designed, based on the exiting Helium JT cold-ends. In the second part, an Ariel engineering model cooler will be assembled and tested to verify that the performance (cryogenic, micro-vibration etc.) matches the requirements. Environmental testing (i.e. vibration, shock) shall be conducted.

Deliverables					
Documentation, test results, EM cooler hardware					
Current TRL:	2	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	ARIEL		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

V-grooves development for ARIEL			
Programme:	CTP	**Reference:**	C221-018FT
Title:	V-grooves development for ARIEL		
Total Budget:	2000 kEuro		
Objectives			
To develop the V-groove system for the ARIEL mission.			
Description			

ARIEL detectors require cooling < 50 K. This is achieved by a combination of passive and active cooling. Passive cooling is achieved by a system of three V-grooves similar to the one flown in Planck. This guarantees a good thermal isolation between the warm SVM and cold Payload Module.
This activity will comprise:
1. Detailed design and analysis of the V-groove system for ARIEL, including the relevant interfaces to the SVM, PLM, harness and cooler piping.
2. TRL assessment and identification of eventual delta-qualification needs with respect to the Planck heritage.
3. Define, manufacture and test breadboard(s) for the critical elements of the V-groove system (e.g. struts interface, coatings etc.).

Deliverables					
Breadboard, Technical Data Package					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	ARIEL		**Contract Duration:**	30 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

ARIEL telescope: development of the GSE and associated metrology for optical test in cryogenic conditions			
Programme:	CTP	**Reference:**	C216-169FE
Title:	ARIEL telescope optical test GSE		
Total Budget:	850 kEuro		
Objectives			
To design, manufacture and characterise the GSE and associated metrology necessary for the ARIEL telescope optical testing in cryogenic conditions.			
Description			
The ARIEL mission is dedicated to the atmospheric characterisation of exoplanets. The ARIEL telescope is composed of a primary mirror, secondary mirror and a collimating mirror feeding common optics and two main instruments (Fine Guidance System - FGS - and Ariel InfraRed Spectrometer - AIRS). The optical and straylight design of the ARIEL telescope is performed in Belgium at the Centre Spatial de Liege (CSL) under the Belgian ESA PRODEX Programme and funded by BELSPO. As part of the AIT/AIV program at telescope level, the Wave Front Error (WFE) must be verified in cryogenic conditions (40K) in one test facility of the CSL on both the PVM and the PFM units. This measurement requires the development of a specific Ground Support Equipment composed of a thermal tent, an isostatic interface mounting and handling system of the ARIEL telescope, and of WFE measurement setup. These parts of the test setup need de-risking: - Design, including: o Overall test set-up (thermal and mechanical analysis, hardware identification) o Thermal tent (including supporting structure, MLI, sensors and heaters) o Telescope mechanical interface (isostatic fixation and brackets), with TE stability analysis o Handling tools (specific to handle the test set-up)			

o Wave Front Sensor (WFS) setup (including support, motorisation, canister and barrels, laser, feedthroughs, optics and relays, cabling), with TE stability analysis o Performance predictions (accuracy predictions of WFS set-up) - Manufacturing drawings (thermal tent and structure, WFS parts, handling tools, isostatic interfaces) - Procurement specifications (thermal tent and structure, WFS parts, handling tools, isostatic interfaces) - Assembly and handling procedures - Manufacturing and reception of the hardware Note: This activity concerns Flight Hardware development.
Deliverables
1 complete GSE, commissioned, with all its metrology and command/control equipment

Current TRL:	2/3	**Target TRL:**	5/6	**Application Need/Date:**	2022 TRL 6
Application Mission:	ARIEL		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

M5-Mission: EnVision

Solar Cells for EnVision - Life test extension			
Programme:	CTP	**Reference:**	C203-117EP
Title:	Solar Cells for EnVision - Life test extension		
Total Budget:	600		
Objectives			
Complement life test of potential solar cell assembly technologies for EnVision to reach TRL 5.			
Description			
With expected qualification temperatures of around 160°C and sun intensities of 2 suns, EnVision falls into the category of high temperature high intensity missions for the solar generator and as such require dedicated attention on solar array technology. For BepiColombo, detrimental effects on solar cell assembly level have been identified at elevated temperatures and under high UV exposure. Even if the EnVision environment is more benign than the BepiColombo one, in order to avoid unexpected anomalies and to benefit from the experience gained in BepiColombo, it is important to submit the current newest solar cell technology - the 4G32C-advanced solar cell from AZUR Space - and as a back up the 3G30 cell from AZUR to conditions representative of the expected EnVision environment. Both, a UV test campaign and a life test campaign have been started in a predecessor activity "Solar Cells for EnVision - de-risking activity under			

representative environment, Part 2". However, the budget earmarked for that activity was not sufficient to cover a sufficient amount of test hours in order to exclude any showstoppers. Therefore, this activity is meant to complement the life test and complete what is considered the minimum amount of test hours in order to claim TRL 5 for the different solar cell assembly technologies tested.					
Deliverables					
Report					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2023
Application Mission:	TRL 5 by 2023/24 for EnVision	**Contract Duration:**	6		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Harmonisation Roadmap Reference: E16 Harmonisation Roadmap: Solar Generators and Solar Cells					

MRO EM test campaign and critical process / parts qualification					
Programme:	CTP		**Reference:**	C217-099FM	
Title:	MRO EM test campaign and critical process / parts qualification				
Total Budget:	1000				
Objectives					
To ensure MRO design has TRL 6 at EnVision mission adoption					
Description					
The activity will consist of the following tasks: 1 – Integrate EM and perform functional testing 2 – Perform MRO EM test campaign including environmental testing (thermal-vac, mechanical vibration) and analyses to ensure MRO design will reach TRL6. 3 – Perform performance testing to ensure MRO design fulfills main performance requirements with respect to all kinds of effects affecting frequency stability of the output of the MRO. 4 – Assess critical processes and parts and ensure both are qualified for EnVision mission 5 – Perform some limited lifetime testing, long term frequency stability. 6 – Update design as needed					
Deliverables					
Test Reports; Friction mitigation study reports					
Current TRL:	4-5	**Target TRL:**	6	**Application Need/Date:**	2024
Application Mission:	EnVision		**Contract Duration:**	12	

S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
N/A			

Solar Cells for EnVision - de-risking activity under representative environment, Part 2			
Programme:	CTP	**Reference:**	C203-115EP
Title:	Solar Cells for EnVision - de-risking activity under representative environment, Part 2		
Total Budget:	800		
Objectives			
Reach TRL 5 on solar cell assembly level for the EnVision mission.			
Description			
With expected qualification temperatures of around 160°C and sun intensities of 2 suns, EnVision falls into the category of high temperature high intensity missions for the solar generator and as such require dedicated attention on solar array technology. For BepiColombo, detrimental effects on solar cell assembly level have been identified at elevated temperatures and under high UV exposure. Even if the EnVision environment is more benign than the BepiColombo one, in order to avoid unexpected anomalies and to benefit from the experience gained in BepiColombo, it is important to submit the current newest solar cell technology – the 4G32C-advanced solar cell from AZUR Space – and as a back up the 3G30 cell from AZUR to conditions representative of the expected EnVision environment. These tests shall comprise as a minimum a UV test campaign and a life test under representative conditions. The activity shall be seen as the complementary step to reach TRL 5 covering then all aspects of the environmental conditions of the EnVision mission. The following tasks are expected to be performed: - Definition of solar cell assembly technology - manufacturing of samples - Preparation of test plan - Test execution - Evaluation Test samples shall comprise the following solar cell types: • 4G32C advanced cell • 3G30 cell Both variants shall be fully equipped with interconnectors and coverglasses. Samples shall be procured from the main SCA manufacturers in Europe potentially involved in the solar array procurement (e.g. AIRBUS GmbH, AZUR SPACE and Leonardo).			

Only if all environmental aspects of the EnVision mission are successfully covered by test, TRL 5 at SCA level can be claimed for EnVision.
Deliverables
Report

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2022
Application Mission:	TRL 5 by 2023 for EnVision		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
E16: Solar Generators and Solar Cells					

Solar Cells for EnVision - de-risking activity under representative environment			
Programme:	CTP	**Reference:**	C203-114NA
Title:	Solar Cells for EnVision - de-risking activity under representative environment		
Total Budget:	200		
Objectives			
Reach TRL 5 on solar cell assembly level for the EnVision mission. A successor activity will be needed to reach this objective.			
Description			
With expected qualification temperatures of around 160°C and sun intensities of 2 suns, EnVision falls into the category of high temperature high intensity missions for the solar generator and as such require dedicated attention on solar array technology. For BepiColombo, detrimental effects on solar cell assembly level have been identified at elevated temperatures and under high UV exposure. Even if the EnVision environment is more benign than the BepiColombo one, in order to avoid unexpected anomalies and to benefit from the experience gained in BepiColombo, it is important to submit the current newest solar cell technology – the 4G32C-advanced solar cell from AZUR Space – and as a back up the 3G30 cell from AZUR to conditions representative of the expected EnVision environment. These tests could comprise e.g. a UV test campaign, temperature coefficient characteristion and a life test under representative conditions. The activity shall be seen as a first step to reach TRL 5 covering as a minimum one aspect of the environmental conditions of the EnVision mission. The following tasks are expected to be performed: - Definition of solar cell assembly technology - manufacturing of samples - Preparation of test plan - Test execution			

- Evaluation Test samples shall comprise the following solar cell types: * 4G32C advanced cell * 3G30 cell Both variants shall be fully equipped with interconnectors and coverglasses. Samples shall be procured from the main SCA manufacturers in Europe potentially involved in the solar array procurement (e.g. AIRBUS GmbH, AZUR SPACE and Leonardo). Only if all environmental aspects of the EnVision mission are successfully covered by test, TRL 5 at SCA level can be claimed for EnVision.
Deliverables
Engineering Model; Report

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2022
Application Mission:	TRL 5 by 2023 for EnVision		**Contract Duration:**	18	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Consistent with Harmonisation Roadmap: No Harmonisation Roadmap: Solar Generators and Solar Cells Harmonisation Comments: Activity is included in updated roadmap (E16 "Development and qualification of solar cells for near sun missions")

Update of the Venus Climate Database for Improved Atmospheric Predictability			
Programme:	TDE (TRP)	**Reference:**	T204-135NA
Title:	Update of the Venus Climate Database for Improved Atmospheric Predictability		
Total Budget:	130		
Objectives			
To improve the very first version of the Venus Climate Database which provides a mean to extract atmospheric parameters of interest (density, pressure, temperature...), their spatial and temporal variabilities at different scales useful for mission design and especially to constrain EnVision aerobraking phases.			
Description			
Since 2018, ESA has been studying the next mission to Venus, the EnVision mission. EnVision, proposed as a joint mission with NASA, is an orbital mission which will essentially study the planet geological activity by carrying high resolution surface observations, using a set of synthetic aperture radar, radar sounders and emissivity mappers and spectrometers.			

The mission profile with a baseline launch in 2032, includes a 135 day transfer phase (or extended transfer of 543 days) followed by an extensive 2-year aero-braking phase. The nominal mission duration for science collection is 2.66 years (four Venus cycles), with a possible extension of 1.4 years. Its science orbit will be 220-470km, nearly polar orbit.xa0The EnVision mission scenario also foresees orbit perigee lowering down to about 140km using aerobraking. Mission analysis, atmospheric probes design as well as in-flight operationsxa0rely on existing atmospheric modelsxa0to produce the needed constrains such as densities, temperatures and associated variabilities. However, uncertainties on atmospheric parameters are driving margins but are also major risk drivers for the success of manoeuvres such as atmospheric entry, descent and landing as well as fuel saving manoeuvers such as aerobraking or aerocapture, thus directly affecting system design in a number of critical areas such as attitude control, spacecraft volume and mass, thermal control and power. This activity encompasses the following tasks: - the improvement of the production of atomic Oxygen in Venus atmosphere as captured by the Global Circulation Model used to produce the Venus Climate Database which is not consistent - a comprehensive cross - comparison campaign between existing Venus GCMs (FR, US, UK, Japan..) in order to capture models variabilities especially in the region of interest for aerobraking - the development of a new scheme to combine existing Venus GCM atmospheric fields outputs to produce a comprehensive Venus Climate Database - the creation of new relevant forcing scenarios combining EUV inputs and clouds properties (e.g. albedo) inputs to allow users to capture in a refined way Venus atmospheric variability accounting for missions timeline and constrains - a validated and user transparent parametrization of atmospheric gravity waves which strongly impact atmospheric density variability scenarios - a statistical analyses of atmospheric densities variability at different timescales to be used as inputs for EnVision aerobraking corridor sizing - the maintenance of the existing Venus Climate Database accounting for users feedback
Deliverables
Report; Report; Report; Report; Report; Report; Report; Report; Software

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	The EnVision mission has been selected as one of the next M5 missions to be further studied in Phase B starting end of 2021. Of critical importance is the	**Contract Duration:**	18		

	sizing of the aerobraking corridor which has a strong impact on platform performance (e.g. mass) and cost.		
S/W Clause:	Open source code		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Neutral atmosphere models for future science missions					
Programme:	TDE		**Reference:**	T204-129EP	
Title:	Neutral atmosphere models for future science missions				
Total Budget:	150 kEuro				
Objectives					
To develop neutral atmospheres engineering models in Europe for future missions to Venus (EnVision), useful to the design of mission phases involving e.g. aerobraking, atmospheric entry, descent and landing.					
Description					
Uncertainties on atmospheric densities and temperatures are major risk drivers for atmospheric entry and orbital maneuvers such as aerobraking or aerocapture. The EnVision mission scenario foresees orbit perigee lowering down to about 140km using aerobraking. Europe has gained a good expertise during the Venus Express mission, however there is no easily accessible model not to say engineering model to rely on for mission design at Venus. In comparison the Venus - GRAM model is developed and maintained by NASA MSFC. This study will target the development of an engineering model from at least the cloud top at 70km to the exosphere at Venus based on the combination of existing Global Circulation Model(s) and exospheric models developed in Europe. This shall be validated using Venus Express data (in particular densities and temperatures where available) during aerobraking.					
Deliverables					
Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	EnVision		**Contract Duration:**	24 months	
S/W Clause:	Open Source				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Control/structure co-design for planetary spacecraft with large flexible appendages			
Programme:	TDE	**Reference:**	T205-121SA

Title:	Control/structure co-design for planetary spacecraft with large flexible appendages
Total Budget:	300 kEuro

Objectives

The main objective of this activity is to address the control-structure interaction problem using an integrated structure control co-design framework, aiming at reducing the typical conservatism in control and structural design and, as a consequence, reduce the structural mass of flexible appendages. EnVision is used as application mission, because of the particular relevance of the control-structure interaction problem to such mission, due to the presence of large flexible appendages (solar arrays, SAR array, subsurface radar antenna) together with tight agility requirements.
Detailed objectives are the following:
1 - Review the EnVision mission requirements and spacecraft architecture in order to establish the perimeter of the control/structure co-design and the required performance. Special focus shall be devoted to the agility requirements and the implications in terms of flexible modes damping following slews on the pointing performance requirements.
2 - Using the latest developments in multi-physics modelling and robust control tools, establish a model of the EnVision spacecraft that will serve as reference for control/structure co-design.
3 - Establish an integrated optimisation process that allows optimising the structural mass while at the same time robustly achieving all pointing performance requirements. This process shall encompass the analysis and synthesis of the attitude control system in a robust multi-variable control fashion as well as an iterative reduction of the structual mass of flexible appendages to streamline the stiffening elements of such appendages as far as possible in compliance with the stability and performance requirements.
4 - Using the tools and optimisation process mentioned above, perform a co-design of the EnVision attitude controller and stiffening elements of the flexible appendages with the objective of achieving a mass efficient spacecraft design.

Description

Classical control design techniques used for flexible spacecraft are based on single axis design approaches to control the rigid-body motion complemented by low-pass and notch filters to suppress the resonant peaks of the low-frequency flexible modes.
These techniques are inherently relying on a priori knowledge of the structural flexible modes and introduce significant conservatism in the control and structural design, dictated by the need to separate the controller bandwidth from the flexible modes frequency.
The present activity aims at addressing the conservatism of the classical approaches by exploiting robust control techniques that allow to avoid the strict separation between controller bandwidth and flexible modes frequency and, therefore, reduce the structural mass of flexible appendages.
This activity builds on a previous study completed in 2012, which was targeting Earth Observation missions and specifically an application to the BIOMASS mission. The perimeter of such activity was restricted by the limited number of structural parameters that could be modified. Despite this

limitation, mass savings on the structural appendages in the order of 20% were achieved. This new activity aims at taking advantage of the recent developments in multi-physics modelling tools and robust control tools which are expected to increase fidelity and reliability of the methodology and, ultimately, improve the efficiency of mass reduction. Timely execution of this activity will provide valuable inputs for the EnVision mission implementation, given the importance of achieving a mass efficient spacecraft design for a mission that is mass critical.
Deliverables
Report, software (optimisation software tailored to EnVision application)

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	EnVision		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Dipole Antenna for EnVison			
Programme:	TDE (TRP)	**Reference:**	T206-022NA
Title:	Dipole Antenna for EnVison		
Total Budget:	150		
Objectives			
To modify an existing dipole antenna design for use on the EnVison mission			
Description			
There is an ongoing activity for designing a broadband dipole, with the aim to enable additional science for future sub-surface radar instruments. For this activity, Envision was taken as a possible mission where such a concept could be used. While the development has so far been successful, the use of an enhanced dipole is deemed not feasible at this stage by the project. In order to be compatible with the mission requirements the design needs to be modified and corresponding matching circuit adapted. The overall achievable performance needs to be determined, and a roadmap for bringing this to flight hardware needs to be established. By doing this, a second possible supplier will be available to the instrument team. Tasks: Update RF design for the dipole and matching network for the new frequency band. Update mechanical design of the dipole. Further mechanical and thermal analysis of key components ensure compliance with Venus environment			

Determine overall performance Determine a roadmap for bringing this to flight hardware.					
Deliverables					
Report					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	To enable a second possible supplier for the EnVision SRS dipole.		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Relevant environmental testing for Envision Dipole					
Programme:	CTP		**Reference:**	C206-023NA	
Title:	Relevant environmental testing for Envision Dipole				
Total Budget:	150				
Objectives					
To enhance the qualification level of the EnVision SRS dipole.					
Description					
A representative RF and mechanical breadboard of the Envision SRS dipoles is currently being developed and tested. While some environmental testing is being performed as part of the activity, it's clear that further thermal and mechanical tests will need to be performed to ensure TRL6 is reached. This is required due to the challenging environment the dipole will face in the Venus orbit, compared to previous dipole antennas. Tasks: Perform additional thermal and mechanical tests.					
Deliverables					
Report					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	This is currently the baseline breadboard design for EnVision.		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

External calibration method for the VenSAR instrument			
Programme:	TDE	**Reference:**	T206-011EF

Title:	External calibration method for the VenSAR instrument				
Total Budget:	250 kEuro				
Objectives					
Study and design of an external calibration method for the VenSAR instrument					
Description					
The M5 future science candidate mission EnVision foresees an S-Band interferometric synthetic aperture radar (InSAR) instrument. An internal calibration loop as used in the heritage EO mission NOVASAR-S is current baseline. However, an additional external calibration loop, i.e. including the SAR antenna, is currently not foreseen. An external calibration requires reference objects in the antenna field-of-view. Earth observation SAR instruments use reference objects such as corner reflectors and/or active signal sources for this purpose. Such devices are not available on Venus. However, the absence of an external calibration would be a major mission risk as for once the internal calibration could then not be verified. Second, a degradation of antenna charactersitics during the mission lifetime cannot be detected. At the beginning of this activity, calibration reference objects on Venus shall be investigated such as the Veneras, Vegas, Pioneer Venus Large Probe landers as well as potential natural reference objects which are sufficiently stable in S-Band throughout all six EnVision mission cycles. VenSAR-specific InSAR end-to-end error sources over lifetime shall be determined. Based on this, an external calibration method for antenna correction based on delta-measurements shall be developed. In this respect, a comparison of measurements in mission cycles two to six to a reference measurement in the first mission cycle shall be used for characterisation of antenna degradation. A corresponding antenna calibration error model shall be developed. An optimum VenSAR signalling for this calibration shall be identified considering optimum SAR modes, potential phase centre sequencing, signalling, etc. A final model considering propagation effects (affecting calibration uncertainty) shall be developed. The capability of the developed method shall be proven in a final demonstration.					
Deliverables					
Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	ENVision	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Analysis and breadboarding of sub-surface radar boom for EnVision M5 candidate mission			
Programme:	TDE	**Reference:**	T206-018FI

Title:	Analysis and breadboarding of sub-surface radar boom for EnVision M5 candidate mission				
Total Budget:	650 kEuro				
Objectives					
Analyse the thermal and structural compatibility of the RIME boom (subsurface radar on JUICE) for the same application on EnVision. A possible adaptation to the hotter Venus environment and larger mechanical stress (aerobraking) may require a design adaptation followed by a breadboard to demonstrate compatibility.					
Description					
The JUICE mission carries a subsurface radar (RIME) of which the deployment boom has been developed under ESA responsibility as a project/spacecraft contributed item to the payload. With the exception during the early deployment and a Venus flyby the JUICE mission experiences a rather cold environment. The antenna length of RIME is around 16 m corresponding to a centre frequency of 9 MHz. The proposed subsurface radar of EnVision (SRS) will have a similar working frequency (subject to analysis). The RIME boom will preliminary act as the design case for the EnVision study. However, there are severe doubts that the current design will be appropriate to work in the Venus environment with the given constraints of the EnVision mission. The activity shall compare and analyse the different mission requirements and the deduced boom requirements with the existing design. Any non-compatibilities shall be addressed by an improved design solution. In a second phase the new design approach shall be built into a breadboard and tested under relevant conditions.					
Deliverables					
Report, breadboard					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	EnVision	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Very high rate TM downlink GMSK Transmitter with pseudo noise ranging upgrade to EM IDST			
Programme:	CTP	**Reference:**	C206-024NA
Title:	Very high rate TM downlink GMSK Transmitter with pseudo noise ranging upgrade to EM IDST		
Total Budget:	190		
Objectives			

Develop and integrate in the Integrated Deep Space Transponder (IDST) EM model the transmitter for simultaneous transmission of very high rate (up to ~300 Msps) GMSK (Gaussian Minimum Shift Keying) telemetry (TM) signal together with Pseudo Noise (PN) ranging component in Ka band.
Description
Future science missions (e.g. EnVision) will require very high telemetry downlink bitrates, up to 300 Msps, with possibly the simultaneous transmission of a dual PN (pseudo noise) ranging in both X- and Ka-band to perform radio science experiments. Today more than one high data rate missions to Venus is planned (EnVision + 2 NASA missions + 1 potential ISRO mission), thus the allocation of the 500 MHz bandwidth in Ka for the high data rate return link might become challenging. The same will be applicable in the future for the Mars scenario. GMSK (Gaussian Minimum Shift Keying) telemetry (TM) provides the best performance in terms of efficient spectrum occupation, so reduction/optimisation of the occupied bandwidth is achieved without compromising the data return. The objective of this activity is to develop, integrate and test in a EM unit the simultaneous transmission of a very high rate (up to ~300 Msps) GMSK telemetry (TM) signal with Pseudo Noise (PN) ranging component in Ka band. A dedicated TRP activity (T206-021GS; contract 4000129320/19/NL/FE) is ongoing, increasing the TRL level of both spacecraft transponders/transmitters and ground station modems to support this application. In the mentioned TRP, the techniques are analysed and implemented in two separate breadboards (one for the on-board transmitter and one for the ground receiver), targeting to TRL 5. The on-board development is being carried out in a breadboard with the future goal of integrating the transmitter into the iDST platform. It is hence proposed to perform the required delta development from TRL5 to TRL6 of the onboard part by integrating the transmitter being developed in the currently running activity, inside the iDST EM platform that is in turn currently being developed in the frame of the GSTP contract 4000125957/18/NL/FE. The work would cover the following main tasks: - migrating the Very High TM + PN ranging transmitter from the breadboard currently in development into the IDST platform - performing a validation test @ ambient, hot and cold of such transmitter (potentially re-using the receiver breadboard of the parallel activity) The activity is performed after the completion of the baseline IDST schedule, in order to avoid impact on the current activities (foreseen to finish by end 2021).
Deliverables

Engineering Model					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	Missions like EnVision, that in addition to the high data rate TM, require to perform radio science experiments, with dual ranging downlink in X/Ka-band; Missions that require very high rate TM in Ka-band.		**Contract Duration:**	6	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: A07 Harmonisation Roadmap: TT&C Transponders and Payload Data Transmission Harmonisation Comments: This activity is a step to further increase the TRL from 5 to 6. TRL 5 is to be reached by previous activity. This activity can be the starting point for the proposed one in the roadmap, starting with higher TRL.					

120 W 32 GHz TWT EM for Payload Data Transmitter			
Programme:	CTP	**Reference:**	C206-026NA
Title:	150 W 32 GHz TWT EM for Payload Data Transmitter		
Total Budget:	1500		
Objectives			
Enable an European source/supplier for high power Ka-band TWT EM, operating at 32GHz with 120W minimum saturated output power, 500MHz instantaneous bandwidth and 65% efficiency.			
Description			
Background and justification: The EnVision mission, officially endorsed in June 2021, is ESA's most recent medium (M-class) mission to study Venus. For the data return link, the spacecraft will make use of Ka-band possibly combined with X-band. The high science data return requirement (200 Tbits) is achieved by an optimization at mission level between ground segment (9hours daily usage of ESA's 35m antennas with cryocooling capability) and space segment (large fixed HGA with high RF power). To ensure reliable communication and fulfil the specification on the minimum required downlink data rate, despite the large SC to Earth distance, the spacecraft has to make use of a high power RF transmitter. At present, there is no off-the-shelf, space qualified TWT(A) in the allocated frequency band (31800-32300 MHz) in Europe with 120W saturated output			

power. To address this, a TDE activity was launched in Q1 2020 to start pre-developments on a Ka-band TWT for this mission. With the good progress of this activity, there is confidence that a European supplier can deliver a tube with the required performance. Description: The goal of this project is to further raise the TRL of the high-power Ka-band TWT that is currently in pre-development. The TWT that is currently being developed will reach TRL 4 by Q4 2022. To have the TWT at TRL 6 by Q4 2024 and enable the selection of this tube for the EnVision mission, a follow-up activity is required. TWTs are used for a broad range of applications in space and have been demonstrated at this frequency as well. What has not been demonstrated before at this frequency is the high power output (at least 120 W). The design efforts during this project will therefore have to be focused on reaching the desired output power, keeping a good efficiency and at the same time maintain a very high reliability of the TWT to meet the environmental and lifetime requirements.
Deliverables
Engineering Model

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	For EnVision IceGiant and other future science missions implementing 32 GHz Ka-Band for the data return, a 120W TWT(A) is considered as mission enabling equipment.	**Contract Duration:**	24		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Very high rate TM downlink using GMSK with simultaneous pseudo noise ranging			
Programme:	TDE	**Reference:**	T206-021GS
Title:	Very high rate TM downlink using GMSK with simultaneous pseudo noise ranging		
Total Budget:	800 kEuro		
Objectives			
To study and breadboard (in relevant environment) the simultaneous transmission and reception of a very high rate (up to ~300 Msps) GMSK (Gaussian Minimum Shift Keying) telemetry (TM) signal with Pseudo Noise			

(PN) ranging and to analyze and prepare the technological readiness for using this signal modulation in future very high rate on-board and ground downlink systems (especially in Ka-Band).
Description
Future science mission (e.g., EnVision) will require very high TM downlink bitrates, up to 300 Msps, with possibly the simultaneous transmission of a dual PN (pseudo noise) ranging in both X- and Ka-band to perform radio science experiments. As an example, in the frame of EnVision, it has been proposed the usage of OQPSK modulation to reach the high telemetry rates required in Ka band (from 16 Msps up to ~300 Msps). However, CCSDS (rec. 2.4.20B) only foresees GMSK modulation for Deep Space missions when symbol rates are greater than 20 Msps, because GMSK needs less bandwidth allocation compared to other modulation schemes like OQPSK. Furthermore, CCSDS foresees the simultaneous transmission of TM + PN ranging only when using GMSK as modulation scheme also in Ka band (CCSDS 401 - 2.4.22B P-1.0 in publication). GMSK modulation would therefore be recommended, even though at these rates it has not been used on ESA missions yet. GMSK plus simultaneous PN ranging, with lower TM rates, has already been achieved for the Solar Orbiter X/X mission. However, at present the on board transponder and the ground station processors have limited capabilities in terms of respectively transmitting and receiving GMSK at very high symbol rates, reaching only 10 to 20 Msps. In addition, the combination of the very high rate GMSK telemetry with PN ranging at much lower chip rate value is not foreseen in the current CCSDS standard. As a consequence, to support future missions (as EnVision), requiring very high rate telemetry simultaneously with radio science experiment, it is necessary to increase the TRL level of this technology both for on-board and on-ground applications. For this purpose the needed steps are: - to analyze and prepare the technological readiness for using very high rate GMSK modulation on satellite transponders (Ka-band). - to study the possible combination in the downlink of the very high rate TM with a simultaneous pseudo noise ranging (PN RG) and establish the end-to-end performances. - to implement the on-board modulator (TM GMSK + PN RG) and ground demodulator (TM GMSK + PN RG) at breadboard level for E2E test. A more detailed overview of the required activity will be: 1. Analyze the technological limitations (mainly relevant to the processing speed) that constrain the achievable GMSK TM rate (at on-board level); 2. Identify and trade off different solutions that overcomes the existing limitations (at on-board level); 3. Analyze the impact of adding the lower PN chip rate range component to the very high rate GMSK signal (both at on-board level and at ground level); 4. Analyze the end-to-end performance of very high rate GMSK + PN ranging; 5. Breadboard the proposed solutions; 6. Test the proposed implementations standalone (in relevant environment e.g. temperature for the on-board breadboard); 7. Test the end to end

performances using the on-board modulator and ground demodulator breadboards together. For the on-board modulator, it is of outmost importance to remark that any proposed solution shall be suitable for implementation in the current space qualified technology. A suitable roadmap for the implementation in the Flight Model shall be identified. It shall also be noted that the coherency of the ranging and carrier signal of the downlink signal to the uplink, has to be maintained. For the ground demodulator, the study shall analyze the potential benefits of using the new CCSDS recommendation for ranging cancellation. Ranging cancellation of the combined PN ranging and GMSK signal, allows for better TM performance and could be important in a scenario with large differences between the ranging and TM rates. The following criticalities shall be undertaken from the beginning: • Assess the feasibility from analysis and/or/ simulation results; • Define architectures suitable for implementation in the current space qualified technology (for the on-board part). The activity will accordingly foresee two phases: T0 to T0+1 year (1st milestone): a first phase with the objective of confirming the feasibility, defining the architecture and describing the chosen implementation suitable to the current space qualified technology; T0+1 year to T0+18 months: an implementation phase (breadboard) that will include the environmental tests (for the on-board breadboard).
Deliverables
Breadboard (ground demodulator + set up items, on-board modulator + set up items), Reports

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2024 TRL 6
Application Mission:	EnVision		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
TT&C Transponders and Payload Data Transmitters, A3 This activity is also an extension of the roadmap Ground Station Technology, activity references F04, F05, G03					

120 W, 32 GHz TWT for Payload Data Transmitter			
Programme:	TDE	**Reference:**	T206-015ES
Title:	120 W, 32 GHz TWT for Payload Data Transmitter		
Total Budget:	750 kEuro		
Objectives			
Enable an European source/supplier for high power Ka-band TWT, operating at 32GHz with 120W minimum saturated output power, 500MHz instantaneous bandwidth and 65% efficiency.			
Description			
New scientific missions require Ka-Band high power sources for the data return. Limitation on maximum antenna size and minimum required data rate			

can be overcome by increasing the transmitted power. At present, there is no off the shelf TWT(A) in the allocated frequency band (31800-32300 MHz) in Europe with 120W saturated output power. Instead, a 250W TWT in the range 17700 - 20200 MHz is under qualification and the feasibility of 100W TWT in the range 37500 - 42500 MHz has been recently demonstrated by test in a breadboard. These two TWTs represent the starting point for the new development. The new TWT shall consider the use of EPCs at TRL 5-6 or higher.					
Deliverables					
Breadboard; Report					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	EnVision, IceGiant (M*) and other future science mission implementing Ka-Band	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Broadband Dipole Antenna for Multi-Mode Sub-Surface Radar			
Programme:	TDE	**Reference:**	T207-054EF
Title:	Broadband Dipole Antenna for Multi-Mode Sub-Surface Radar		
Total Budget:	450 kEuro		
Objectives			
The objective of this activity is to develop a dipole antenna that can be utilised for sub surface radar instruments at various centre frequencies and bandwidths, allowing multi-mode operation of the instrument and thus enabling true flexibility on the resolution and penetration depth throughout the mission.			
Description			
Most of the sub-surface planetary radars operate in the frequency band between 6 and 50 MHz. At these frequencies, and due to the large size of the antennas, a trade-off is made on the centre frequency and bandwidth of operation based on the science requirements of depth and resolution. The reason for this is that a resonant dipole antenna operating at a higher frequency out of resonance will generate nulls in the nadir direction, yielding a great loss in dynamic range and thus in penetration depth. The only alternative available today would be to accommodate multiple antennas for various frequency bands, with the direct consequence of risky deployment schemes and significant increase of cost and mass. This activity is focussed on the development of a single dipole antenna that			

can be used in a large frequency band (e.g. 9-30 MHz) for EnVision. Several techniques have been identified that can be used to achieve these results: a design based on lumped elements (inductances and capacitances) that at higher frequencies become high impedances and thus electrically reducing the size of the dipole, generating this way the wanted smooth pattern towards nadir, without loss of dynamic range. The same lumped element at low frequencies lets the current pass and the whole length of the dipole is used, to obtain the same type of radiation pattern. Alternatively, a telescopic boom can also be used as antenna arm, and through the change of the length of the dipole during flight, observation at different centre frequencies throughout the mission becomes possible. The mechanism and deployment of telescopic CFRP boom is already available in Europe with flight heritage. The existing transmitter and receiver units have already the capability to operate in multi-mode (including changing the centre frequency of the chirp and its bandwidth), but no antenna is available to enable such operation. This activity will start with a trade-off of the available techniques to achieve multi-band operation of the dipole and after selection of the most suitable methodology, design, manufacture and test a working breadboard of the selected concept.
Deliverables
Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	EnVision and all sub surface radar instruments	**Contract Duration:**	20 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Leros-4 Qualification Hot Firing for EnVision Mission Needs			
Programme:	CTP	**Reference:**	C210-002NA
Title:	Leros-4 Qualification Hot Firing for EnVision Mission Needs		
Total Budget:	2000		
Objectives			
The aim of the activity is to perform dedicated qualification hot firing tests, to ensure that the engine's operational envelop matches the mission needs of EnVision.			
Description			
To satisfy EnVision mission needs, a bipropellant engine capable of delivering 320 s Isp and a thrust of 1000 N is required. The mission profile includes burn durations and timing between firings, which			

is different to the planned and performed qualification hot firing campaign of the Leros-4 engine, which is currently under development. In order to make this engine usable for the EnVision mission and available when needed a two step apprach is proposed, 1) First mission specific dedicated tests will be added to the currently ongoing EM programme, which will bring the engine from TRL 5 to TRL 6. 2) Following the test campaign performed on the engineering model, a full qualification (including mechanical, electrical and hot fire testing) for the engine is to be performed. To achieve the latter, mission objectives, operational environment and the operational performance requirements will be established and agreed with industry via ongoing studies taking into account the engine integration in the final system. After this step a QM engine model, fully reflecting all aspects of the flight model design, will be subjected to a test programme which replicates all of the necessary conditions of the actual operational environment including the relevant qualification margins to demonstrate that it will perform in the defined operational environment. The data sets for the EM and QM testing will be used to build the unit to unit comparison. Objectives of the activity are: 1) Analysis of mission profile to define a reasonable test envelope, which covers the mission needs of EnVision and is compatible with test infrastructure (size of run tanks, etc.). 2) If needed adapt flow control orifices or other engine components according to selected operational points. 3) Perform hot fire testing and evaluate test results. 4) Perform testing of the identical available engine unit to reach full qualification and make the engine usable for EnVision					
Deliverables					
Qualification Model; Report					
Current TRL:	6	**Target TRL:**	7	**Application Need/Date:**	2021
Application Mission:	Due to constraints on spacecraft mass and mission duration, a large engine of 1000 N class is required (mainly due to gravity losses for the Venus orbit insertion). Currently no member state engine fulfils the mission needs. The Leros-4 engine, currently undergoing qualification testing, could be suitable.	**Contract Duration:**	18		

S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Offline antenna arraying for EnVision			
Programme:	TDE (TRP)	**Reference:**	T212-063NA
Title:	Offline antenna arraying for EnVision		
Total Budget:	400		
Objectives			
To demonstrate in an operational environment offline antenna arraying between Cebreros and Malargüe with timely delivery of science products (within one day from signal reception at receiving antennas) with 40MHz acquisition bandwidth and 2 or 4-bits signal amplitude quantisation (per complex component), suitable for data rates up to 10Mbps with turbo 1/4 or 20Mbps with turbo 1/2, when using GMSK BT=0.5 or filtered O-QPSK. Optionally to demonstrate the same operational capability with a pair of ground stations from ESA and NASA sites (e.g. Cebreros and Robledo, or New Norcia and Canberra, or Malargüe and Goldstone).			
Description			
During its science phase EnVision will use ESTRACK antennas located at the three ESA deep space sites in New Norcia (Western Australia), Cebreros (Spain) and Malargüe (Argentina), and optionally the DSN antennas located at the NASA sites of Canberra (Australia), Robledo (Spain) and Goldstone (United States of America). In order to increase the flexibility in the selection of the ground stations, or alternatively to increase the data volume, offline arraying between distant antennas is proposed during overlapping visibility slots. In particular the activity focuses on visibility overlap between Cebreros and Malargüe, which offer the greatest potential. During such time slots the data rate can be increased by around a factor two with respect to the reception from a single antenna. Offline arraying implies a significant delay between reception of the signal at the antennas and delivery of the final products to the user, as well as a channel bandwidth limitation, both due to the need to record and transfer digital raw samples between remote locations across the wide area network. Whereas a significant delay can be acceptable for science data, it is not tolerable for satellite housekeeping data. For the above reason offline arraying is only proposed for Ka-Band downlink which will be devoted to transmission of science data only. There are essentially two main use cases in this proposal: in the first, the arraying passes are defined in order to ensure that the same aggregate effective tracking time (out of planetary occultations) is achieved with arraying as in the case of no-arraying. The interest in the arraying option is justified in this case by the fact that the data volume is still compliant with the mission requirements, and at the same time the transmission time is reduced. This is the use case that introduces flexibility in the selection of ESTRACK stations and, by reducing the duration of the transmission to Earth (normally "stolen"			

to the production of science data), is beneficial to spacecraft and payload operations. In the second use case the transmission time is left unchanged with respect to the no-arraying baseline, with the simple aim of increasing the data rate and therefore the data volume.

The activity is structured according to the following tasks

1. System requirements review and consolidation: the driving system (level 0) requirements applicable to the activity have been established in [RD-1] which is attached to this proposal, based on the EnVision Science Operations Reference Scenario, and can be summarized in the capability of combining two data streams, representing 40MHz wide signals, at a processing speed of around 1.6 Tbits per hour, allowing to comply with an overall latency in the delivery of science products of up to one day, including the data transfer through the wide area network, and with small combining loss due to adoption of Full Spectrum Combining (FSC). For data rates exceeding the above bandwidth, alternative scenarios may be conceived where Symbol Stream Combining (SSC) or Complex Stream Combining (CSC) or Baseband Combining (BC) are used instead of FSC. Additional system requirements will be defined related to the operability (integration in ESTRACK operations including monitor and control aspects) and availability of the arraying combining function. Furthermore the capacity, latency and availability requirements to be posed to the wide area network services will be expressed (to be used for costing), and scalability requirements will be formulated, related to the possibility of combining more than two antennas, as well as to the potential use of the arraying/combiner in quasi real time, when arraying collocated terminals. The output of this tasks is a set of level 1 requirements to be used for the subsequent phases of the activity.

2. System design: starting from the level 1 system requirements, and based on the previous bread-board implementation (TRP activity T212-052GS), the system architecture of the arraying/combiner will be defined, executing key trade off, primarily about the selection of the combining method (FSC, SSC, CSC, BC), selection of either hardware/firmware or software implementation for the core processing tasks, as well as inclusion of demodulation/decoding tasks vs. RF or basband interface with existing modems. Furthermore the use of processing over the Cloud will be explored. Inputs and output interfaces will be defined. Key algorithms will be reviewed from the previous TRP activity and scrutinized for performance enhancement, in particular identifying any need for code parallelization. The validity of the system design will be confirmed by simulations addressing the key performance aspects. The output of this tasks will be a complete system design subject to ESA critical review and approval.

3. Breadboard implementation: this task will include all required hardware procurement and firmware/software development, as defined in the previous task. The implementation will be confined to a non redundant bread-board arraying/combiner, however compliant with the key identified functional and performance requirements. In parallel with the breadboard arraying/combiner, an array data generator will be implemented, able to produce simulated data

streams with different scenarios in terms of data rate, modulation, coding, focused on EnVision as well as on flying Ka-Band mission (e.g. BepiColombo).

4. Testing and validation: the testing will proceed incrementally, by addressing individual components, internal interfaces, external interfaces and overall system. At every layer, functional and performance tests will be performed to verify full compliance with the requirements. The system tests will be performed first by using the array data generator, then by tests executed in ESOC ground segment facilities (GSRF), and finally with a flying spacecraft. In particular, for the final test session, it is envisaged to use BepiColombo Ka-Band passes, however retaining the full signal acquisition setup suitable for EnvVision (and oversized for BepiColombo), and optionally to aim at the inclusion of a temporary wide area setup compatible with EnVision needs.

RD-1 Offline arraying for EnVision, OPS-GS/2756/ML, 27/7/2020

Deliverables

Breadboard; Report

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	EnVision has shown an interest in the proposed activity as a risk mitigation in case the science operations plan becomes too loaded (due to the beneficial reduction of transmission time), and in order to increase the flexibility in selection of ESTRACK stations. Due to the nature of the activity (involving a distributed system, with problematics related to the transfer of large of amount of data through wide area network) the achievement of TRL 4 requires, on top of the verification in laboratory environment (ESOC reference station), testing with the real antennas, which will hence lead to TRL between 4 and 5	**Contract Duration:**	20		

S/W Clause:	Operational S/W		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: C02 Harmonisation Roadmap: Ground Station Technology Harmonisation Comments: The activity is consistent with the Theme-12-1: Data return via RF, bullet: Antenna arrays for deep space application with associated correlation techniques, listed in the approved IPC paper "European Space Technology harmonisation - proposed workplan for 2021 and list of technologies earmarked for 2022 and 2023"			

Very High Rate Turbo Decoder with interleaver in the TTCP			
Programme:	TDE	**Reference:**	T212-005GS
Title:	Very High Rate Turbo Decoder with interleaver in the TTCP		
Total Budget:	300 kEuro		
Objectives			
Explore the different options and select the most efficient one to implement a very high data rate Turbo decoder and test encoder for Turbo rates 1/2, 1/4 and 1/6 working up to 80 Mbps in the TTCP, including the new CCSDS interleaver . Breadboard the selected option in an economic platform and demonstrate its scalability up to the required 80 Mbps in the TTCP.			
Description			
The Envision CDF exercise has concluded that a bit rate of 75 Mbps is required to comply with the data return strategy, mainly due to big quantity of data produced by the proposed SAR instrument. At the Venus distances the received power on earth is quite limited, requiring a very efficient modulation and coding system. Turbo rate 1/4 is a very efficient coding mode, allowing to go down to Eb/No of 0 to 0.25 dB, which is around 1 dB better than the LDPC 1/2 codes, which is the current solution used in EUCLID at these high data rates. However the current implementation of the Turbo rate 1/4 decoder in ESA ground stations TTCP only reaches 3 Mbps. Also Turbo rates 1/2 and 1/6 only reach 3 Mbps at present. Moreover Turbo codes do not perform well in a bursty channel, as can be the case of Solar conjunctions, due to the scintillation effects. The incorporation of the channel interleaver recommended in CCSDS would improve substantially the behaviour of Turbo codes (see presentation SLS-CS_17-13_V2 from K. Andrews- CCSDS-The Hague. Nov. 2017. AI_17_03) In order to achieve the required 80 Mbps, a new architecture for the on ground Turbo decoder in the TTCP has to be studied and designed, together with the interleaver. A parallelisation of the decoder is possible, and would allow reaching the required rates, but to fit it in the TTCP available resources is a difficult task that requires optimisation. The optimisation of the TTCP Turbo rate 1/4 (and rates 1/2 and 1/6) to reach 80 Mbps and the inclusion of the new interleaver are the goals of this activity. The development of the Turbo encoders for rate 1/2, 1/4 and 1/6 to support testing and validation is also part of the tasks of this activity. The activity will be divided in 4 tasks:			

1- Explore the different options and select the most efficient one to implement a very high data rate Turbo decoder and test encoder for Turbo rates 1/2, 1/4 and 1/6, working up to 80 Mbps in the TTCP. Study the interleaver recommended in CCSDS. 2-Design the breadboard of the selected option in an economic platform and demonstrate its scalability up to the required 80 Mbps in the TTCP. 3- Develop and test the breadboard. 4- Produce the Test reports and Final report.
Deliverables
Breadboard; Report; Software

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	EnVision		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Ground Station Technology, G03, AIM G – New receivers for High Data rate reception – High rate telemetry TTCP					

EnVision VenSpec-H IDCA			
Programme:	CTP	**Reference:**	C216-175NA
Title:	EnVision VenSpec-H IDCA		
Total Budget:	1000		
Objectives			
The baseline detector for VenSpec-H instrument on EnVision is the AIM SWIR 384x288 detector with an integrated cooler (Integrated Cooler Detector Assembly, IDCA), developed for military applications. The objective of this activity is to raise the TRL of the unit to TRL5/6 by submitting it to the relevant thermal/mechanical environment and performing radiation tests. Part of these tests will be performed by ESA/VenSpec-H. In addition, this activity will also ensure that the IDCA meets the performance and I/F requirements of the VenSPEC-H instrument under memberstate responsibility by providing additional units to the instrument team for additional tests/BB tests at instrument level			
Description			
The purpose of the activity is to increase the TRL of the integrated cooler/detector assembly for the VenSpec-H instrument onboard EnVision to TLR6. This requires that the IDCA is tested and proved to be functioning correctly in the EnVision thermal, mechanical and radiation environment. The following activities shall be carried out: - Confirmation of baseline selection cooler / detector assembly with respect to the requirements of the VenSpec-H instrument. Agreement required by all parties (ESA/AIM/VenSpec-H team) with respect to complete requirement definition for the IDCA.			

- Manufacturing of 3 EMs of the IDCA - Functional/acceptance testing (including opto-electrical performance) of the IDCA EMs - One EM will be subjected to (1,2,3) 1 thermal vacuum testing with temperatures and durations defined by ESA 2 mechanical testing (vibration) with levels and durations in line with EnVision mission 3 radiation testing (TID, SEL/SEU and TNID) with levels predicted for the EnVision mission - Two EMs will only be functionally (including electro-optical performance) tested. - Manufacturing of 3 laboratory electronics to control/drive the IDCA - Delivery of 3 EMs and associated electronics to ESA. - Engineering support to the VenSpec-H instrument - Design and Development plan for FM provision - ROM cost					
Deliverables					
Engineering Model					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2021
Application Mission:	EnVision VenSpec-H instrument baseline detector		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: C07 Harmonisation Roadmap: Optical Detectors, IR Range Harmonisation Comments: The TRL target for the EnVision IDCA tests are TRL of 6 to prove that the detector performances under the EnVision environment meet the science requirements.					

EnVision Aerobraking Flap Assembly			
Programme:	CTP	**Reference:**	C218-006MP
Title:	EnVision Aerobraking Flap Assembly		
Total Budget:	600		
Objectives			
To develop the Aerobraking Flap Assembly for the EnVision satellite up to TRL6.			
Description			
The EnVision satellite will perform an extensive aerobraking campaign after Venus orbital insertion to reach the science orbit. To meet the aerobraking duration requirement of the mission, additional drag surface areas are accommodated on the satellite in the form of flaps.			

This activity follows on from the previous breadboard-scale development activity and will deliver a full-scale engineering model which is tested in a relevant environment in line with the requirement to achieve TRL6 by the end of 2024. Foreseen tests include thermal vacuum testing and mechanical testing with levels and durations in line with EnVision mission requirements. The preliminary definition of the relevant environment, which drives the test plan for this activity, will be provided by the precursor activity 'Design and Characterisation of Aerobraking Flap Assembly' (currently in ITT phase). The following tasks are foreseen: o Engineering model development o Manufacturing of a flap EM o Testing of the EM at full scale in relevant environment (TRL6) o Updating the DDVP and ROM cost estimate

Deliverables					
Breadboard; Other; Other; Report; Report					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2024
Application Mission:	Mission need: EnVision TRL6 by the end of 2024.		**Contract Duration:**	12	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Design and Characterisation of Aerobraking Flap Assembly			
Programme:	CTP	**Reference:**	C218-005NA
Title:	Design and Characterisation of Aerobraking Flap Assembly		
Total Budget:	400		
Objectives			
To develop an aerobraking flap assembly for the EnVision satellite up to TRL5.			
Description			
The EnVision satellite will perform an extensive aerobraking campaign after Venus orbital insertion to reach the science orbit. To meet the aerobraking duration requirement of the mission, additional drag surface areas can be included on the satellite in the form of flaps. Flaps can benefit the aerobraking strategy by decreasing the ballistic coefficient of the spacecraft, e.g. as an extension of the solar arrays or of the Spacecraft main bus but with very low mass density to minimise the dry mass penalty on the vehicle. The design needs to be suitable to the Venus aerothermal-mechanical environment, with special attention to the effects of atomic oxygen environment and mechanical fatigue over the several			

thousand passes during the aerobraking phase. The activity is targeting TRL5 by the end of 2023. The activity will analyse the applicable relevant environment, perform the trade-off and baseline selection of the aerobraking flap assembly in terms of material selection and flap assembly design, supported by breadboarding and testing in relevant environment (including at least thermal cycling and atomic oxygen exposure) to reach the target TRL level of 5. Note: The activity could be coordinated with an internal ATOX sample testing campaign running at ESTEC in 2022/2023 with the possibility to test candidate flap materials. The activity foresees the following tasks: o Aerobraking Flap Design (6m duration) : - Preliminary design and trade-offs - Material evaluation and research - Thermal, structural, fatigue and ATOX analysis - Selection of baseline design - Development and qualification test plan - Development plan and ROM cost, including qualification o Breadboard development (12m duration): - Material characterisation - Breadboard verification test in relevant environment (TRL5)
Deliverables
Breadboard; Other; Other; Report; Report

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2022
Application Mission:	Mission need: EnVision (TRL5 by the end of 2023, TRL6 by the end of 2025).		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

M7-Mission Candidates: CALICO, HAYDN, M-MATISSE, Plasma Observatory, and THESEUS

CIS300 Detector Radiation and Performance Testing			
Programme:	CTP	**Reference:**	C217-102FI
Title:	CIS300 Detector Radiation and Performance Testing		
Total Budget:	1000		
Objectives			

The primary aim of this activity is to assess the radiation tolerance of the new large format CIS300 visible image sensor, in particular the NIR sensitivity enhanced CIS302 version.					
Description					
Significant progress has been made towards the development of a very large format CIS image sensor product with performance meeting the requirements of space science applications. A critical aspect of assessing the suitability of an image sensor for a science application is it's radiation tolerance. This activity will conduct a thorough radiation tolerance assessment of the CIS302 image sensor. Image sensors will be subjected to single event effect (SEE) testing via heavy ion exposure, non-ionising dose testing via proton exposure, and ionising dose testing via gamma exposure. The electro optical performance of the sensors will be testing under representative conditions of vacuum and low operational temperature before and after radiation testing. Separate sensors will be used for each stream of the radiation testing. In addition to radiation, operating life testing will be performed. If successful the activity will raise the TRL of the CIS302 die to TRL6. TRL6 at product level requires mission specific package and environmental specification.					
Deliverables					
Prototype; Report					
Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	2023
Application Mission:	CIS302 sensor is proposed as part of M7 selected candidate Haydn.		**Contract Duration:**	18	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

CMOS Image Sensor for X-ray Applications - CCN			
Programme:	CTP	**Reference:**	C217-101FI
Title:	CMOS Image Sensor for X-ray Applications - CCN		
Total Budget:	1000		
Objectives			
The activity shall take the best performing pixel variant in the CIS221-X soft X-ray test device and implement this in the new large-format CIS300 image sensor platform. The resultant devices will be subjected to detailed electro optical and radiation characterisation.			
Description			
A previous TDE funded activity (T217-070MM) has developed CIS technology for soft X-ray detection applications, with the driving requirements coming from the THESEUS M class mission candidate. Whilst significant			

progress was made in the original activity, further development of this technology is required, in particular with regards to detector read out noise improvement. In this proposed follow on activity, the following shall be addressed: * Design update to the 40 micron pixel, including latest amplifier design for low noise * Incorporation of pixel design into the CIS301/302 digital architecture and tape out * Manufacture of 12 (TBC) wafers with a mix of sensor splits from full sized 9x9cm2 and quarter height for better yield and more thorough characterisation sized 9x2.25cm2 * Package devices for delivery with preliminary test * Detailed electro-optic testing including X-ray characterisation * Radiation damage assessment using gammas and protons to representative mission levels
Deliverables
Prototype; Report

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2023
Application Mission:	THESEUS M7 candidate mission baselines this CIS pixel technology in the SXI instrument.		**Contract Duration:**	18	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

F1-Mission: Comet Interceptor

Coma Model for Comet Interceptor			
Programme:	TDE	**Reference:**	T204-134EP
Title:	Coma Model for Comet Interceptor		
Total Budget:	250 kEuro		
Objectives			
To develop a consistent and documented engineering rated cometary coma model describing cometary dust emission, number densities and fluxes in the coma, including interactions with a model spacecraft during fly by trajectories.			
Description			

During Comet Interceptor Cocurrent Design Facility (CDF) studies 1 and 2, a simplified, spherically symmetric coma model based on first principles was used to assess cometary dust fluences and fluxes as function of mass impinging on spacecraft walls accounting for s/c attitude. However the lack of physics such as radiation pressure and drag forces in the model, together with limited capabilities to account for dust mass and velocities distribution (alpha) have proven to lead to inconsistencies when trying to benchmark the model outputs to actual data gathered during the GIOTTO and Rosetta flybys. The uncertainty associated with such discrepancies is an issue to ensure reliable design margins regarding particle impact risk, which given Comet Interceptor very large relative velocity range is a major design driver for platform and instruments.

The coma model developed in this activity shall be parametrized and allow for some flexibility in allowing to account for:
- cometary activity (dust mass rate and dust number rate), as related to Afp parameter (for quantifying optical photometry)
- dust mass, size, velocity, and density distributions
- spatial inhomogeneities in the surface emission rate (due to cometary surface illumination conditions or other relevant processes)

The model shall also allow the user to define a simplified s/c geometry (walls surface areas and orientation in e.g. the comet reference frame) as well as fly by trajectories with attitude parameters (orientation change as a function of time and position).

This activity encompasses the following tasks:
- review the current state of cometary coma modelling and assess the applicability of existing modelling approaches to be used as baseline for an engineering rated coma model
- review existing coma data allowing to validate the end developed model
- define the model user requirements with ESA and the relevant community (incl. coma interaction with s/c surfaces)
- define coma model and s/c interaction software requirements and a model architecture
- perform model implementation
- perform model verification and validation using relevant coma data identified
- perform model gap analysis and in case needed and relevant propose a roadmap for future model improvements

The expected deliverables shall include the model which can be used in the estimation of risk for near-comet operations and associated documentation to use the model and interface it to other tools.

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.

By developing such a tool during mission Phase 0/A inputs can be given in a timely fashion to avoid the need for redesign of affected elements thus improving overall spacecraft development time.					
Deliverables					
Prototype; Report; Software					
Current TRL:	TRL1	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Comet Interceptor	**Contract Duration:**	18 months		
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Technologies Applicable to Several Science Programme Missions

Evaluation of infrared linear mode avalanche photodiode arrays for time delay integration type operation			
Programme:	CTP	**Reference:**	C217-103FT
Title:	Evaluation of infrared linear mode avalanche photodiode arrays for time delay integration type operation		
Total Budget:	550		
Objectives			
Evaluate single-photon response of Leonardo SAPHIRA APD array variations. Investigate the optimum configuration of custom APD detector modules and front-end electronics to form large arrays necessary for GaiaNIR operation. Develop a parameter-based performance model to study focal plane array options and data handling optimisation.			
Description			
The Gaia mission uses Time-Delay Integration (TDI) to significantly improve the signal to noise ratio (SNR) of the detectors in very low flux conditions. Gaia operates in the visible waveband and uses charge coupled device detectors (CCD) which inherently support TDI. GaiaNIR, a potential large mission concept within the ESA Science Programme Voyage 2050 plan, aims to perform similar measurements in the near infrared waveband where CCDs are not available. One possible solution is to emulate TDI operation with a pixelated CMOS image sensor (CIS) by reading at a high frame rate to reduce the photons per frame to a very low level, and then adding offset images to counter the scanning of the source and hence improve the SNR. However, this can only be achieved if the CIS is capable of operating in or close to photon counting mode. This mode of operation has been demonstrated by linear mode avalanche photodiode (APD) arrays, opening up the possibility to emulate TDI in the NIR waveband. This activity aims to evaluate the performance of the Leonardo SAPHIRA infrared linear mode APD array when operating as pseudo-TDI detectors. The targeted objectives of the activity are:			

Evaluation of single-photon response of Leonardo SAPHIRA APD array variations. Investigation of the optimum configuration of custom APD detector modules and front-end electronics to form large arrays necessary for GaiaNIR operation. Development of a parameter-based performance model to study focal plane array options and data handling optimisation. The work shall be organised into the following tasks: -Task 1: Requirements review -Task 2: Detector array procurement and preparation -Task 3: Detector array characterisation -Task 4: Evaluation and optimisation of large-scale array configurations -Task5 : System performance parametric model development -Task 6: Conclusions, recommendations and focal-plane roadmap preparation
Deliverables
Report

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2023
Application Mission:	Voyage 2050		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

Saturn Moons Environment Models and their effects on spacecraft			
Programme:	TDE	**Reference:**	T204-141EP
Title:	Saturn Moons Environment Models and their effects on spacecraft		
Total Budget:	200		
Objectives			
To develop and validate environment models for Saturn moons Enceladus and Titan capturing plasma, charged dust/aerosols and neutral atmospheric populations and their interaction with Saturn's magnetosphere including radiation (shielding).			
Description			
As Saturn Moons Enceladus and Titan will be targeted by future missions, no Moons environment models have yet been established in order to systemativally describe the (dusty) plasmas, (radiation tbc) and exospheric / atmospheric neutrals environments, The current activity primarily aims at developing close environment models for Enceladus and Titan moons addressing plasma, dusty plasma and			

neutrals to prepare future missions flybys. In addition effects models in dusty plasma environment (Enceladus) such as charge dust triggered EMC (ESD) interferences shall be investigated, resulting in a model design and implementation.
Deliverables
Report, Software models

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Voyage 2050	**Contract Duration:**	18		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

Delta-qualification of CFRP and Aluminium skin Panels			
Programme:	CTP	**Reference:**	C220-054FT
Title:	Delta-qualification of CFRP and Aluminium skin Panels		
Total Budget:	800		
Objectives			
To complete the full qualification of the processes necessary for the manufacture of CFRP Panels with OSR, SSM and/or Heat pipe integration			
Description			
This activity shall build on previously qualified processes to manufacture CFRP panels (including bonding inserts and ancilliary equipment) and implement the required work needed to extend the qualification to the integration of OSMs (Optical Solar Reflectors), SSMs (Secondary Surface Mirrors) and Heat Pipes onto the panels. In terms of the OSR qualification, the following shall be covered: - implementation of a new workshop for the qualified glueing of OSRs in a dedicated controlled environment, - determination of optical and electrical properties before thermal and irradiation testing at coupon level, - post testing qualification testing (mechanical etc.) at panel level. In terms of the SSM and Heat Pipes, the focus shall be on the mounting on these components. The details on the qualificaiton processes shall be consistent with the validation required by a system prime integrator and shall be agreed by the Agency.			
Deliverables			
Qualification reports, Coupons and Representative size CFRP panel.			

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2025
Application Mission:	Voyage 2050	**Contract Duration:**	18		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

High performance x-ray source for compact x-ray facility					
Programme:	CTP		**Reference:**	C217-100FT	
Title:	High performance x-ray source for compact x-ray facility				
Total Budget:	350				
Objectives					
Design, manufacture a prototype, and deliver a robust micro focus x-ray source system with high flux for 1.49 keV					
Description					
This activity shall fund the design of a specific x-ray source system for the soft x-ray aluminium line (1.49 keV) that can be used for the verification and acceptance of x-ray optics for space applications such as the SPO Mirror Modules for Athena. This specific source shall be placed in the novel compact facility called BEATRIX that was commissioned during 2022 and developed under the activity C216-153MM. The BEATRIX facility generates a large size x-ray collimated beam with a divergence less than 1.5 arcsec in a very compact way. This is an alternative facility to the typical synchrotron beamlines which generate very small highly collimated beams, or the large x-ray facilities like Panter that require very long vacuum tubes (around 120 m long) and have a divergent x-ray beam. It was specifically designed to be the acceptance facility for the large number of SPO Mirror Modules foreseen for the Athena mission and it can be used for other missions. The BEATRIX facility uses a set optical elements to monochromate the x-ray beam coming from a small size source, and then expands the beam by using the diffraction in an assymetrically cut crystal. Because of this, it requires an x-ray source with small dimensions (30-35 micron size) and high flux (at least 5e11 ph/s/sr) which does not exist commercially for the 1.49 keV line (Aluminium line). This activity shall cover the design, trade-off of the different elements (including possible additional optical elements like elliptical mirrors), prototyping, and delivery of one (or several) x-ray sources compatible with the requirements mentioned above.					
Deliverables					
Prototype; Report					
Current TRL:	4	**Target TRL:**	7	**Application Need/Date:**	2023
Application Mission:	Athena or several		**Contract Duration:**	18	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

X-band transponder qualification finalisation					
Programme:	CTP		**Reference:**	C206-027FM	
Title:	X-band transponder qualification finalisation				
Total Budget:	2650				
Objectives					
1. to manufacture and test an X-band Transponder Model achieving TRL7. 2. to fully validate the FPGA design of the transponder (till successful Qualification Review)					
Description					
The Agency has initiated the development of an X-band transponder for Science mission as part of an overall TT&C subsystem development activity with Kongsberg Space Electronics. Design and development of this Transponder till TRL6 has been performed in the past two years. The present CCN aims to carry this development further to reach TRL 7.					
Deliverables					
Engineering/Qualification Model; Report					
Current TRL:	6	**Target TRL:**	7	**Application Need/Date:**	2023
Application Mission:	This development targets science missions in general but the activity will be based on the requirements of the LISA mission		**Contract Duration:**	18	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Advanced demagnetisation methods			
Programme:	TDE	**Reference:**	T204-140EP
Title:	Advanced demagnetisation methods		
Total Budget:	250		
Objectives			
To develop advanced deep demagnetisation techniques, as enabling technologies for next generation in-situ space plasma sensing missions and gravitational sensors missions.			
Description			
For spacecraft projects requiring magnetic cleanliness, flight units are demagnetised via a standard procedure using an homogeneous field of 3 to 5 Hz, slowly exponentially increasing up to 5 mT, then slowly decreasing. This demagnetisation field profile comes from a procedure applied to military			

submarines many decades ago, and was never justified for being optimal for space equipment.
It involves dedicated expensive equipment: Helmholtz coils sufficiently large and capable of withstanding the high currents involved, high power audio or 4-quadrant amplifier, and a waveform generator with high dynamic range.
According to existing practice, this is supposed to be preferably performed in a compensated Earth field environment, so two more pairs of Helmholtz coils are needed, and two adjustable high-stability current supplies to compensate the horizontal and vertical components of the Earth's field.
The procedure has to be performed 3 times, once along each main axis of the unit under test.
In spite of the sophistication of the method, which can provide some spectacular results, the outcome can also be disappointing, meaning that equivalent or better results can sometimes be obtained with more rudimentary methods.
Magnetic cleanliness is a necessary design and verification activity for missions flying experiments inherently sensitive to on-board magnetic field.
Ferromagnetic materials are used in many parts for very good technology reasons. One limitation to the reduction of the spurious magnetic field at the experiment sensors location is how deep and how systematically the ferromagnetic materials can be demagnetised.

Re-visitation of the demagnetisation procedures used for science missions, through a double approach: review of the methods used in other industrial sectors and of the physical background of demagnetisation procedures, so as to spin-in or develop techniques either permitting a deeper demagnetisation, or easier / faster to implement than the current ones.

Task list:
1) Review of the demagnetisation procedures used in the various industrial fields;
2) Review of the physical background of demagnetisation;
3) Theoretical assessment of the procedure used for space equipment: frequency, dynamic range, peak amplitude progressiveness, etc.
4) Experimental comparison of the results obtained with various demagnetisation methods and parameters;
5) Recommendations for space equipment.

Deliverables

Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:		**Contract Duration:**	18		
S/W Clause:					

Consistency with Harmonisation Roadmap and conclusion:

Electromagnetic Compatibility

Development of an in orbit cleaning tool for optical instruments

Programme:	TDE	**Reference:**	T224-012QE
Title:	Development of an in orbit cleaning tool for optical instruments		
Total Budget:	350		

Objectives

To develop an atomic hydrogen generator as in orbit cleaning tool for optical systems contaminated by high volatiles organic outgassing products, UV induced sticking / carbonization of molecular contamination, or radiation induced contamination.

Description

Molecular contamination onto optical systems, which reduce the performance of instruments, is a phenomenon, which is known and as well observed on past and current missions.

The available current method to "clean" optical systems during mission is decontamination via heating systems. The cleaning efficiency of this method is limited and not sufficient for molecular contamination sticking to a surface, polymerized or carbonized by UV light or by radiation induced contamination (RIC effect). The use of atomic hydrogen for cleaning of optical systems is a known and used method within the e.g. EUV lithography.

The usage of industry available cleaning process for space missions is due to our stringed mass, power and volume requirements not feasible. But the use of quantum dot technology (in particular quantum dot pulse laser systems) could enable the usage of this established for space missions / application alleviating on-ground and in orbit cleanliness requirements.

The proposed quantum dot base atomic hydrogen generator allows to build / implement an in orbit cleaning method under consideration of mass, power and volume.

The principle of this method is to generating atomic hydrogen via photolysis of hydrogen with UV light (270 nm – 300 nm). The photolysis is a "cold" cracking process with much less heat transfer to the optical system than the already used decontamination mode cleaning method. The cleaning tool is built by a hydrogen reservoir connected with a dedicated high precision low temperature compatible valve which allows to adjust the needed hydrogen flux trough a UV transparent tube were the atomic hydrogen will be generated. The flow of atomic hydrogen is optimized onto the optical system /surface to reach high cleaning efficacy.

This activity encompasses the following tasks:
- requirement consolidation
- selection of a dedicated UV transparent material (e.g. Suprasil – quartz glass)
- adaptation of available quantum dot UV light systems
- cleaning efficiency study of various contaminated optical surfaces

Deliverables

Breadboard; Report					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	All science missions	**Contract Duration:**	24		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Germanium on Silicon CCD structure development			
Programme:	TDE	**Reference:**	T217-077MM
Title:	Germanium on Silicon CCD structure development		
Total Budget:	500		
Objectives			
Design, manufacture and characterise germanium (Ge) diodes at cryogenic temperatures. Model the incorporation of Ge diodes into charge-coupled device (CCD) detector designs. Characterise the performance of existing CCD detectors at cryogenic temperatures. Evaluate surface treatment processes in the context of electro-optical performance enhancement.			
Description			
Charge coupled device (CCD) detectors are mature technology and have provided unparalleled imaging performance for visible wavelength space applications for several decades. An extension of CCD sensitivity into the near infrared (NIR) waveband would open up the use of this technology to many more applications. Inherent to CCD design is the ability to perform Time-delay integration which provides the ability to increase the measured signal without penalty of noise. This technique was fundamental to the success of the Gaia mission. Extending CCD waveband into the NIR would offer the potential of similar missions in the infrared. This activity aims to investigate two areas that were identified in the preceding study as necessary for the future development of a functional detector, along with a third objective aimed at improving the overall performance: 1. Verify if the dark current of Ge can be reduced enough through cooling to enable the required mode of operation. 2. Determine the lowest temperature at which a silicon CCD can effectively transfer charge and consequent compatibility with required Ge operating temperature. 3. Evaluate the application of thin Ge epitaxial layer processing (e.g. nanostructure surface formation, induced junction formation, ALD surface passivation) for electro-optical performance enhancement. The targeted objectives are:			

Design, manufacture and characterisation of Ge diodes. Modeling the integration of Ge photodiodes into CCD detector designs. Characterisation of the performance of existing silicon CCD detectors at cryogenic temperatures necessary for Ge photodiode operation. Evaluation of thin Ge epi surface treatments in the context of electro-optical performance improvement. The work shall be organised into the following tasks: -Task 1: Requirements review -Task 2: Photodiode design and manufacture -Task 3: Photodiode/CCD modelling -Task 4: Photodiode characterisation -Task 5: CCD cryogenic characterisation -Task 6: Thin Ge epi surface treatment evaluation -Task 7: Evaluation, conclusions and detector roadmap preparation.					
Deliverables					
Breadboard; Report					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	Voyage 2050, GAIA-NIR	**Contract Duration:**	24		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
C03 Harmonisation Roadmap: Optical Detectors, Visible Range					

Optical element to focus soft gamma rays			
Programme:	TDE	**Reference:**	T216-175FT
Title:	Optical element to focus soft gamma rays		
Total Budget:	300		
Objectives			
Design and build an optical module which focuses optical beams in the range of about 80-200 keV with a small on-axis PSF (10" target) with the goal to do spectral imaging and polarimetry of solar and/or astronomical sources.			
Description			
The imaging with gamma rays, even for soft energies, still faces the limitation of the available optical elements. Essentially Laue lenses are required and so far, only balloon flights were done with first generation optics. A number of ground-based demonstrators were developed, but have not been pursued further, mainly due to the limited optical quality achieved and the difficulty of mass producing the required crystals in a cost-effective manner.This activity shall undertake to develop a novel soft gamma ray optical element suitable for mass production with a repeatable performance with the potential of achieving an angular resolution of 10", which can be used to assemble large optical systems delivering several 100 cm2 of effective area in the bandpass of about 80-200 keV. In particular the following shall be performed: (1) design an optical system to image solar and astronomical sources and evaluate the performance in a potential space mission application.			

(2) design a demonstrator optical element (mirror module) (3) fabricate this demonstrator optical element (4) test with gamma rays in a suitable test facility the performance of the optical element (5) evaluate the potential performance of a telescope using such optical elements, and determine the programmatic aspects (cost, schedule)					
Deliverables					
Breadboard; Report					
Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Future gamma-ray missions		**Contract Duration:**	24	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Improved TT&C Sub-System Architecture			
Programme:	TDE	**Reference:**	T206-026EF
Title:	Improved TT&C Sub-System Architecture		
Total Budget:	650		
Objectives			
To consolidate alternative solutions for on-board loss minimization. To develop the prototypes of the most relevant solutions identified, to confirm the predicted performance. To provide road-map to flight models.			
Description			
The state of art TT&C Sub-System architectures for Science and Exploration missions are nowadays quite complex. In order to allow communications during all mission phases, several antennas are needed in combination with redundant High Power Amplifiers (HPA) and transponders (DST). The interconnection among these components is accomplished by the RF Distribution Unit (RFDU), which has to guarantee the maximum degree of reconfigurability and reliability to failures. In addition, it has also to implement the necessary filtering action, to allow full duplex communications. Its design is therefore quite complex encompassing the use of several switches, Diplexers, Filters and interconnecting waveguides (WG) runs. The latter can be quite long as they have to reach antennas which are typically far from the location of the rest of the TT&C subsystem. All this results in high losses with RF power reduction in transmission and increased noise figure in reception. The design solutions used so far in the frame of ESA projects are quite recurrent with no major improvements in the last decades. As shown in a TT&C Sub-Sytem architecture survey carried out in 2017, different approaches exist, as identified for example by other agencies and already flown successfully in the past years. For a complex RFDU as used in Deep Space missions, we can consider RF			

path losses in the order of 1 to 3 dB in X-band and 3 to 4 dB in Ka-band, with significant impacts in terms of data return (up to 50% reduction) and in terms of spacecraft recovery possibilities in case of anomalies (increased operations complexity and limitation on maximum achievable distance). Therefore, there is a clear need for loss reduction in the RFDU paths, through the implementation of novel solutions.
A study is on-going to consolidate the possible alternative subsystem architectures, and define relevant requirements. This will be completed in early 2024, but its conclusions need to be consolidated by experimental results.

The activity shall focus on the specification, detailed design, development and tests of prototypes of the components which will have the most significant impact on the TT&C subsystem performance and whose feasibility has to be demonstrated. Three main items have been already identified, which may need to be completed by additional technologies as an outcome of the on-going study:
- Receiving only antenna with integrated low-noise-amplifier (LNA) and downconverter (D/C), with a possible alternative for a receiving and transmitting solution
- High-gain-antenna dual-band feed including receiving LNA and D/C, and with direct interface to power amplifier
- Transponder front-end to manage the interfaces with new antennas designs

Tasks:
1. Consolidation of requirements and design
2. Design and manufacturing of bread-boards
3. Testing of bread-boards
4. Development plan for flight models.

Deliverables					
Breadboard					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	All Deep Space future missions	**Contract Duration:**	24		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
B01 Harmonisation Roadmap: TT&C Transponders and Payload Data Transmission					

In-flight adaptive pre-distortion techniques for TT&C subsystems with high-order modulations			
Programme:	TDE	**Reference:**	T206-025ES
Title:	In-flight adaptive pre-distortion techniques for TT&C subsystems with high-order modulations		

Total Budget:	400				
Objectives					
The objective of this activity is to study in-flight adaptive techniques for TT&C subsystems that employ high-order modulations. The activity will define mitigation methods for the nonlinear effects of the TT&C transmitter power amplifier, that will be able to follow also the variations along the satellite mission lifetime. As part of the activity, a breadboard will be developed as proof of concept (TRL 3).					
Description					
Future near-Earth F-class and M-class SCI missions will require high-rate links in X-Band, for either maximizing the data return or decreasing the ground station usage (especially in case of 35-m DSN antennas). Clear examples are THESEUS and HAYDN that are targetting 15-20 Mbps and, for achieving this, their TT&C subsystems will need to resort to high-order modulations that fully exploit the 10 MHz X-Band allocation. ESA already performed several activities for the development of X-Band transponders and ground stations receivers that can support the high-order modulations foreseen in the standard CCSDS 131.2, known also as SCCC. However, the performance of these modulations is highly impaired by the nonlinear effects of the X-Band power amplifier, the TWTA or SSPA. For tackling this, currently, transponders adopt predistortion algorithms based on a training performed on ground that uses as reference the power amplifier nonlinear characteristic measured at beginning of life. On the other hand, the aging of components makes the nonlinear characteristic changing overtime, thus diminishing the benefits of predistortion along the lifetime of the satellite missions. For tackling this, in-flight adaptive pre-distortion techniques, able to track the nonlinear variations over time, becomes mandatory. Thus, this activity will first study and define possible techniques that can be adopted in TT&C subsystem of SCI missions, by defining the changes to be performed in the transponder digital board, and its interface with the power amplifier. Then, a HW breadboard will be implemented as proof of concept.					
Deliverables					
Breadboard; Report					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	Near Earth and Lagrangian missions		**Contract Duration:**	24	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
F05 Harmonisation Comments: TT&C Transponders and Payload Data Transmission					

Ultra-High performance gyroscope for future X-ray Interferometer missions			
Programme:	TDE	**Reference:**	T205-129SA
Title:	Payload-grade gyroscope for future X-ray Interferometer missions		
Total Budget:	300		
Objectives			
Analyze and refine performance needs for AOCS sensors of future X-ray interferometers. Determine a preliminary feasibility to reach these performance metrics (gyroscopes, very high accuracy Star Trackers) and list the most suitable technologies.			
Description			
Future XRI mission will require a very significantly enhanced sensing performance compared to anything considered before. As an X-ray mission, the payload cannot be used in the control loop (Fine Guidance Sensor), and therefore, other sensors are envisaged. The scientific community considers an extremely high accuracy gyroscope as an enabler. The performance specification is preliminary but is between 1 and 2 orders of magnitude better than what is available today (with Astrix 200 from Airbus Defense and Space). In 2022 were concluded two TDE activities, both analyzing the landscape for the future of high performance gyroscopes. The objective of these activities was to look at next-generation replacements or complement to the existing portfolio, fitting within similar mass/volume/power consumption. Within the usual envelope, the studies have not identified performance improvements (mostly ARW and bias stability) of this magnitude. For this particular activity, the gyroscope is to be seen as part of the payload. A parallel to be considered to understand the scope is for instance the class of accelerometers used for orbit control and navigation, in comparison to what is used for gravity missions. Ground gyroscopes have reached the level of performance required, however they are designed to measure Earth rotation. One critical aspect to address is the performance of the technology around the zero (absolute inertial pointing) as a number of technologies can be blind or non linear around the zero. A proposed preliminary set of tasks could be the following : 1. Requirement analysis in the frequency domain for the mission 2. Possible sensors suite (single gyroscope, high frequency and low frequency gyroscope, very high accuracy Star Tracker) 3. Detailed analysis of the existing gyroscope technologies and their key limitations 4. Preliminary sizing, scaling and feasibility			
Deliverables			
Report			

Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	2024

Application Mission:	Voyage 2050	**Contract Duration:**	12
S/W Clause:			
Consistency with Harmonisation Roadmap and conclusion:			

Magnetically clean rotary actuator for optical bench application						
Programme:	TDE		**Reference:**	T215-020EP		
Title:	Magnetically clean rotary actuator for optical bench application					
Total Budget:	400					
Objectives						
To develop and test a magnetically clean rotary actuator with inherent self-locking capabilities.						
Description						
Spacecraft on-board science optical instruments and payloads require on specific missions magnetically clean components. The future gravitational wave sensors for example requires magnetically clean mechanism on the optical bench. Conventional actuators are usually based on the electromagnetic functional principle with coils, permanent magnets and ferromagnetic components. The strength of residual magnetic field makes them unsuitable for applications sensitive in this respect. Task: Review state of the art of nonmagnetic actuator principle. Trade off at least magnetic cleanliness, commercial access, mass, speed, torque, life time and particle contamination against each other for selection of the actuator principle. Design a self-locking rotary actuator capable to rotate a centrally mounted optical element by 360deg or ±180deg. Include a contact-less feedback sensor in the design (secondary objective) that support the test activities only. Review proposed design with similar current design used in gravitational wave sensors - especially with respect to magnetic cleanliness. Build the proposed design as breadboard. Perform hardware test campaign - with respect to function, performance and limited environment. Test compliance to magnetic cleanliness requirements .						
Deliverables						
Breadboard; Report						
Current TRL:	**3**	**Target TRL:**	**4**	**Application Need/Date:**	2024	
Application Mission:			**Contract Duration:**	18		
S/W Clause:	N/A					
Consistency with Harmonisation Roadmap and conclusion:						

Lab-on-a-Chip Instrument for Future Planetary Missions

Programme:	TDE	**Reference:**	T214-003FI
Title:	Lab-on-a-Chip Instrument for Future Planetary Missions		
Total Budget:	200		

Objectives

To investigate the state-of-the-art and capabilities of the lab-on-a-chip (LoC), a microfluidics based device, for future in-situ planetary missions and assess the adaptations needed for harsh environment.

Description

Future lander missions will target planetary bodies of astrobiological relevance such as those proposed in the frame of the Voyage 2050 programme (e.g., ocean worlds and dwarf planets). Lab-on-a-chip technologies are already known since a while and are established in the meantime on the market, using sophisticated microfluidic sample handling, together with very sensitive detection techniques using fluorophore immunoassays specific for molecules/functional groups. this enables the detection of organics and biomarkers down to the ppt level. The advantage is the high specificity and the benign sample handling allowing for the non destructive detection of complex molecules. Although proposed and planned in teh past, a microfluidic detection system has not yet been flown or baselined for upcoming missions.
Targeting for example icy/ocean worlds on the Iovian moons, lab-on-a-chip devices can perform in situ (bio)chemical analyses Its light-weight and miniaturised design forms a compelling technology for future deep space missions, given the limited resources. The challenge is here to adapt the htechnology such that it can operate in this harsh envrionment (temperature, radiation

This activity shall focus on assessing the following:
- Existing LoC instruments relevant for in-situ measurements in space (incl. sample handling).
- The behaviour/performance of the LoC under cryogenic conditions (i.e., required adaptations w.r.t. typical LoC).
- The susceptibility of the devices and reagents to the radiation environment
- Any potential dependencies and synergies with other instruments (e.g., sample handling and preparation of the surface sample).

Deliverables

Report

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	Voyage 2050 planetary missions	**Contract Duration:**	12		

S/W Clause:			
Consistency with Harmonisation Roadmap and conclusion:			

Enhancements of Radiation Hard Gyroscope for Science Missions					
Programme:	CTP		**Reference:**	C205-129SA	
Title:	Enhancements of Radiation Hard Gyroscope for Science Missions				
Total Budget:	400				
Objectives					
Improve the performance, the repeatability and the yield of the 3-axis Coriolis Gyroscope developed by Innalabs.					
Description					
Previous CTP activities (C205-114SA and C205-119SA) have led to the development of a 3-axis medium performance gyroscope in Ireland at Innalabs, called Arietis. This gyroscope has been selected in a number of ESA missions, and qualification is planned for 2023. As the development initiated in 2017, several elements can be improved to better support serial manufacturing in the future, improving the yield and the overall performance of the gyroscope. These include the characterization of new materials and processes. In addition, an assessment of a simplified architecture, considering the significant progress made in the field of re-programmable FPGAs shall be performed to evaluate the interest of a larger design upgrade in the future.					
Deliverables					
Report					
Current TRL:	6	**Target TRL:**	7	**Application Need/Date:**	2023
Application Mission:	Voyage 2050		**Contract Duration:**	9	
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					

Modelling and Prediction of Magnetic Field Perturbations by Thermo-Electric Effects			
Programme:	TDE	**Reference:**	T207-070EP
Title:	Modelling and Prediction of Magnetic Field Perturbations by Thermo-Electric Effects		
Total Budget:	350		
Objectives			
To develop and validate modelling capabilities and tools to predict magnetic field perturbations due to thermo-electric effects caused by thermal gradients.			
Description			

Thermal gradients in electrically conductive materials move electrons and thus create electric potentials, which in turn drive currents for equalization of these potentials. Such currents are the source of magnetic fields, which influence sensitive magnetic sensors in close vicinity to such thermal gradients. To minimize and mitigate these effects, the path of the current flow needs to be understood. In a pre-cursor GSP activity, the fundamental physical effects have been identified and simplified simulation models have been developed to describe observed effects on the Swarm spacecrafts.

With generalized models, this know-how could be utilized also for other missions with different designs and in different thermal environments.
These existing models should become flexible in terms of geometry that can be analyzed and address a variety of typical (electrically conductive) spacecraft materials. Modelling the spacecraft elements in the vicinity of sensitive magnetic sensors during the design process would then allow to compare different design options and implement features to avoid or minimize perturbations. Tools for such models can be based on the capabilities of general modelling platforms or multi-physics tools/solvers or complement them, and should interface with other tools or modules using existing data formats, e.g. to get temperature distributions. The tools and modelling methods then need to be validated on basic shapes (plates/sheets, blocks,/cubes, rods, etc.) of different materials and their combinations when exposed to different thermal gradients while monitoring the magnetic field with an thermally isolated magnetic sensor.

Task List:
- Review existing simulation models and latest literature
- Expand on materials usable in the simulations models to cover most typical, electrically conductive spacecraft materials (>10)
- Generalize existing simulation models for arbitrary, parametric geometries
- Study and simulate magnetic fields due thermo-electric effects including time variation on representative basic geometries
- Validate in laboratory tests on representative basic physical models

Deliverables					
Report; Software					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Missions with sensitive magnetic payload	**Contract Duration:**	12		
S/W Clause:	Open source code				
Consistency with Harmonisation Roadmap and conclusion:					
C06 Harmonisation Roadmap: Electromagnetic Compatibility					

Electrically Conducting Thermal Insulators			
Programme:	TDE	**Reference:**	T207-069EP
Title:	Electrically Conducting Thermal Insulators		

Total Budget:	250

Objectives
To identify and develop candidates for functional materials with high electrical conductivity as well as high thermal isolation.
Description
Electrical grounding is a mandatory per-requisite to control electromagnetic interference (EMI), from direct current (DC) over alternating current (AC) up to radio-frequency disturbances. In missions requiring stringent thermal control however high thermal insulation may be necessary, for example in hot environments and/or for cold instrument detectors like on ATHENA, infra-red observatories (L5), or cosmic microwave background mission (L6). But electrical conductivity and thermal insulation are typically mutually exclusive, because the high mobility of electrons in electric conductors allows those electrons also to increase their temperature and thus transport heat when moving in the electrical current flow. Functional materials like structured composites or meta-materials with engineered material properties could combine these usually exclusive properties. As a first step, candidate materials need to be identified and pre-screened for space applications. To serve as efficient electrical grounding path, the electrical conductivity is important over a wide frequency range. This activity encompasses the following tasks: - Review existing functional materials like structured composites and meta-materials regarding electrical conductivity and thermal insulation properties - Design a group of 5 functional materials which maximize electrical and minimize thermal conductivity - Implement and manufacture 10 samples of 2 designed materials - Characterize o their effective electrical conductivity (both real and imaginary part, to limit reactive contributions like inductive or capacitive), and o thermal insulation, also regarding relation with applied voltage and current, AC current frequency , and temperatures.
Deliverables
Report; Samples

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	All scientific missions	**Contract Duration:**	24		
S/W Clause:					

Consistency with Harmonisation Roadmap and conclusion:
Electromagnetic Compatibility

Augmented inertial navigation solutions for medium-accuracy landing			
Programme:	TDE	**Reference:**	T205-130SA
Title:	Augmented inertial navigation solutions for medium-accuracy landing		

Total Budget:	350				
Objectives					
To trade-off, design, test, and demonstrate the landing accuracy limits of a low-complexity navigation system for landing relying on inertial sensors with potential application to CALICO and L4					
Description					
Medium-performance landing accuracy such as foreseen for CALICO (1km) and possibly for the L4 mission may be reachable by a low-complexity hybrid navigation solution without resorting to terrain-relative navigation (TRN) and advanced vision-based navigation. The activity aims at demonstrating the feasibility of landing on a dwarf planet and/or moon of a giant planet with a low-complexity navigation system devoid of TRN. Following orbit determination (OD) of a cruiser spacecraft, a lander is released, and a typical fuel-optimal descent trajectory is tracked by a hybrid navigation system, object of this activity, relying on: - Inertial sensors (Star-tracker(s), Inertial Measurement Units - IMU(s)) that limit knowledge drift error following separation with the cruiser - A possible radiofrequency (RF) signal when available with the cruiser, which further reduces knowledge drift error - Slant range and/or range-rate measurements to finely track vertical velocity in the vicinity of touchdown The activity consist in trading-off, designing, implementing, testing, and demonstrating the landing accuracy of the hybrid navigation system as a function of sizing input parameters such as OD performance, characteristics of the RF signal and sensor performance class. The technology shall be demonstrated up to TRL4 considering a Ceres landing scenario as well as relevant use-cases addressing different potential target destinations for the L4 mission. The activity entails the following tasks: - Derivation of optimal descent trajectories for the selected scenarios - Trade-off and detailed design of a navigation system fusing inertial sensors and to-be-defined pseudorange measurements provided by a cruiser-lander RF signal. - Functional and sensitivity analyses of the navigation system performance depending on the variable input parameters and uncertainties: o Orbit determination accuracy at separation o Gravity and ephemeris knowledge errors o Availability, characteristics of the RF link and performance class of sensors, notably IMU - Test of the on-board navigation software on a space-graded processor, incl. demonstration of result equivalence and execution times (schedulability)					
Deliverables					
Report; Software					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024

Application Mission:	CALICO and L4 mission	**Contract Duration:**	15
S/W Clause:			
Consistency with Harmonisation Roadmap and conclusion:			

Reliability of electronic assemblies in cryogenic environment			
Programme:	TDE	**Reference:**	T223-104ED
Title:	Reliability of electronic assemblies in cryogenic environment		
Total Budget:	400		
Objectives			
The objective of the activity is to evaluate materials and processes (solder alloys, PCB, adhesive and EEE devices) suitable for manufacturing of electronics operating or exposed to very low temperatures (-80/-270°C).			
Description			
The use of electronics at very low temperatures (<-80°C) poses a challenge for the reliability of the assemblies. The materials and processes currently used for electronic assembly manufacturing are typically tested and qualified for operation in the range -55/+85°C. Applications at temperatures <-80°C can trigger different failure mechanisms. The materials experience an increase in strength and reduction in ductility whilst creep and stress relaxation do not any longer occur, limiting the ability of the solder to act as stress relief element. The change in stress distribution in the assembly of a device can move the failure from the solder joint to the component or to the PCB. Other phenomena as change of phases can take place with dramatic effect on performance, for example the change of phase of Sn which can lead to the Tin pest. The knowledge and experience in reliability of electronic assembly in extreme low temperatures is limited and even the definition of requirements and test conditions to evaluate electronic assemblies for these conditions is a complex task. The characterization of the materials and evaluation of assemblies at extreme low temperature will provide data to aid designers and manufacturers to make an educated choice of the materials/design for a specific environment and to define suitable test approaches for verification of processes The development of this knowledge is the base to enable the development and manufacturing of electronic units suitable for landers to the surface of planets, moons (Earth moon, giant planets moons), samples return missions, units located on the outside of spacecrafts (booms) for missions in the outer solar system or electronics located in cryostats. Tasks to be implemented: - Literature survey of state of the art for low temperature electronics and selection of candidate materials (e.g. PCB, solder alloy, EEE parts) - Test plan definition for basic characterization at elemental level at low temperature (incl. modulus, CTE, strength, phase changes, fatigue)			

- Test plan definition for testing of assemblies in thermal cycling and long term exposure at low temperatures - Modelling and test implementation - Result evaluation, definition of recommendations and identification of future development needs Future activities will be defined on the basis of the outcome of this campaign.
Deliverables
Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Voyage2050 L mission, CALICO	**Contract Duration:**	36		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
G04 Harmonisation Roadmap: Printed Circuit Boards and Electronic Assembly Technologies					

Consolidation of CFRP Anisogrid Tubes and Booms for Science Missions			
Programme:	TDE	**Reference:**	T220-057MS
Title:	Consolidation of CFRP Anisogrid Tubes and Booms for Science Missions		
Total Budget:	600		
Objectives			
To develop lightweight and stiff Anisogrid structural booms including inserts and attachments for science payload support.			
Description			
Structural booms are often used in the support of science payloads. Key requirements are stiffness, strength and mass, but also in some cases the need to provide multiple attachment points through inserts. In those cases, the classical technology is not appropriate, Anisogrid booms offer the potential to be highly efficient. However one of the greatest barriers to application for ANISOGRID structure is the cost of manufacturing parts with high quality, in particular managing interface locations for other components and high fixed tooling costs that multiply when the design changes. A new manufacturing technique has been proposed which could mitigate those issues. The activity proposed will demonstrate the design of ANISOGRID tubes with inserts and end fittings appropriate for a target application to be chosen (e.g. M7 candidate missions PLASMA OBS or CALICO where Payload descriptions require ESA to provide multiple 2 metre long solid booms for instruments or a robot arm with tubes of 1 meter long with 3 joints.			

This activity encompasses the following tasks: - Requirements definition for a anisogrid boom of 2 metres long with appropriate end fittings and attachments, to satisfy mission requirements for the envisaged M7 mission environments. - Design and analysis of the anisogrid solution, considering the manufacturing technique - Manufacturing of coupons, including insert locations - Test of the samples, typically strength characterisation after thermal cycling - Manufacture and test multiple instances of Anisogrid tube samples under mechanical load before and after environmental conditioning to demonstrate the mass and stiffness performance. - Design the Final Structure breadboard demonstrator (scaled or 1:1 depending on application) of the target product. - Manufacture and test of the structure demonstrator breadboard. - Assessment of Final breadboard demonstrator performance and final report					
Deliverables					
Breadboard					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	M7 Mission Need - TRL 6 by 2027	**Contract Duration:**	24		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
Harmonisation Comments: This topic is for qualification of fixed boom products that may be deployed by hinges, but it does not directly relate to in-orbit manufacturing or deployable boom for (large) reflector arrays which are activities noted inside the roadmap document. Harmonisation Roadmap: Deployable Booms & Inflatable Structures					

Manufacturing and AIT processes for equipped CFRP/Aluminium sandwich panels			
Programme:	CTP	**Reference:**	C220-052FT
Title:	Manufacturing and AIT processes for equipped CFRP/Aluminium sandwich panels		
Total Budget:	500 kEuro		
Objectives			

Development of manufacturing and AIT processes for the production of equipped CFRP and/or aluminium sandwich panels with embedded elements (inserts).
The subject activity is proposed as further developments of the successfully completed CTP ref. C220-048PL (Manufacturing process for CFRP (prepreg M55J UD / EX1515 + aluminium honeycomb core).

Specifically, the objectives of the proposed activity are:
Holder position device, Glue application device , Glue pad monitoring system (camera)
Glue mixing machine procurement
Test equipment development/ improvement
- Upgrade of thermal vacuum chamber (currently 80K) with CryoCooler (Cold head with Compressor) (enable 30K)
- Upgrade of temperature measurement system to cryogenic temperatures 30K
Application of glue procedures for FGS type optical elements holders
- manufacturing and assembling of the holders with optical elements
Glued holder tests
Thermal shock (dip test) , Thermal cycling (8 x 30 K to 60°C) ,
Supporting/Shadowing FEM analyses
Glue modelling/meshing approach development , Analysis method development (linear vs. non-linear) ,
Margin of safety calculations
(a) to develop and establish manufacturing and AIT processes for the production of “equipped” CFRP sandwich panels (with EX1515/M55JUD facesheets and aluminum honeycomb core) and Al skin/aluminum honeycomb core, with embedded elements (hot-bonded or cold-bonded);
(b) to develop and establish an inserts design database aiming at the manufacturing and assembly of a fully equipped CFRP or Aluminum sandwich panel that can be used in various sizes and for various platforms.

Description

To complete this objective, the following activities are considered necessary:
- Creation of an inserts database including, although not limited to:
  - Design of insert configurations;
  - Mechanical (pull-out, shear and bending) and thermal qualification of the above configurations according to ECSS standards;
  - Determination of electrical characteristics (in-plane and through thickness);
  - Determination of running torques for all the proposed configurations

The proposed database will include configurations covering various needs, i.e. assembly of individual panels and mounting of equipment/instruments (e.g. edge inserts, equipment mounting inserts partially potted, fully-potted, through-thickness).

- Consolidation of procedures for:
  - Definition of requirements;
  - Selection and implementation of materials and processes;

- Definition of manufacturing flows;
- Identification and qualification of surface treatments and inspection methods;
- Qualification of testing procedures.

• Production of manufacturing demonstrators covering the selected configurations and functional to the verification/qualification of the above procedures, materials and processes according to ECSS standards. This will include:
  - Procurement, inspection, testing and acceptance of raw materials (aluminium sheets, CFRP pre-pregs, aluminum honeycomb core, potting compounds, COTs)
  - Manufacturing of:
    - inserts and panels embedded elements;
    - assembled sandwich panels with embedded elements, including in-process testing (mechanical testing) and parts acceptance testing (NDI, dimensional and physical controls);
• Assembly trials (demonstrators).
• Implementation of ECSS PA standards for all the described activities.

Deliverables					
Technical Documentation; Demonstrators.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2024
Application Mission:	Several		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Titanium reinforced radiation absorbent metal matrix composite casing produced with additive manufacturing for deep space satellite missions			
Programme:	CTP	**Reference:**	C224-008FT
Title:	Titanium reinforced radiation absorbent metal matrix composite casing produced with additive manufacturing for deep space satellite missions		
Total Budget:	500 kEuro		
Objectives			
To design and demonstrate a lightweight metal matrix composite multi-layer panel with titanium skeleton made using additive manufacturing for future Science missions.			
Description			
To build satellites used in deep space scientific missions has many things to consider. A good balance must be found in the design of the structural,			

thermal and radiation absorbing shielding layer, taking into account the launch, deep space environment and mission requirements. All of them have great importance when missions to e.g. Jupiter or Saturn are planned. These three elements are usually decoupled in current satellites. The aim of this work is to lay the foundations of a Structural-Thermal-Radiation absorbent integrated multi-layer panel design to save space, weight without sacrificing functionality. The activity encompasses the following tasks: • Investigate the impact of different radiation environments, analyse the impact of different energies and fluences to shield. • Design, test and manufacture min 85x85 mm of AM Ti skeleton as a structural element reinforcement with integrated interface points. • Integrate the Ti skeleton with doped ceramic and Al (with eutectic and/or intermetallic transition) • Mechanical tests • Irradiation measurements. To test absorption levels for dedicated radiations based upon the state of art • Identify limitations for larger samples and prototype possible solutions • Study/roadmap for upscaling possibilities
Deliverables
Technical Documentation; Samples/demonstrators.

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2024
Application Mission:	Several		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Ultra Low Power Consumption Unit and Instrument Interface			
Programme:	TDE (TRP)	**Reference:**	T201-053NA
Title:	Ultra Low Power Consumption Unit and Instrument Interface		
Total Budget:	250		
Objectives			
To develop an interface for avionics and instruments that is able to keep the units in a very low power consumption mode. The objective is to reduce the overall platform consumption to the minimum and only consume power when needed.			
Description			
The usual concept in units and instruments is to keep the unit on all the time. Even when the unit is in idle mode, or not doing anything in particular, the power consumption is quite high compared to the power consumed in full			

operation. In missions going far away from the Sun, like the Ice Giants, power is one of the key enablers for the mission. There are two ways of taking action: improve the power generation when the Sun illumination is low or reduce the power consumtion of the units. This activity is devoted to the second concept. Developing an interface with the power bus and the communication bus that is able to consume extremely low power (<1W) while it is not operating (idle mode). To do this, the activity should be carried out having in mind both the avionics needs and the power needs. The goal is to develop concepts that could work overall at platform level in all units and instruments. A breadboard will be developed as a proof of concept showing ultra low power consumption in stand by mode.
Deliverables
Breadboard; Report

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	Ice Giants missions or missions in general going far away from the Sun will benefit from this development enabling more power available for the instruments.	**Contract Duration:**	24		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: C01 Harmonisation Roadmap: Power Management and Distribution Harmonisation Comments: The concept is the same but in the Roadmap it was focusing on EOP missions. It can also be applied in SCI missions.

Contribution to High Density European RAD-HARD SRAM-based FPGA			
Programme:	CTP	**Reference:**	C201-036ED
Title:	Contribution to High Density European RAD-HARD SRAM-based FPGA		
Total Budget:	300 kEuro		
Objectives			
Development and validation of the NG-LARGE FPGA.			
Description			
The Next Generation FPGA (NG-FPGA) has the goal to provide a high capacity (i.e. 2.5 million equivalent gates), raditation-hardened reprogrammable European FPGA to the Space Industry. The NG-FPGA project, known as BRAVE, is co-funded by ESA, CNES and the European Commission.			

This activity shall contribute to the definition, design, manufacturing and validation of the NG-LARGE (65 nm) FPGA. The activity shall cover the following tasks: - NG-LARGE development from PDR to CDR - Manufacturing - Package development and prototype assembly - Functional validation and electrical characterisation.					
Deliverables					
Technical datapackage					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	Several science missions		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Low Resource Reconfigurable Mission Controller for Future Science Missions			
Programme:	CTP	**Reference:**	C201-039FT
Title:	Low Resource Reconfigurable Mission Controller for Future Science Missions		
Total Budget:	3500 kEuro		
Objectives			
Design, develop and test a novel controller architecture, which flexibly combines various S/C platform and payload subsystems and functionalities into one or several controller nodes with the goal to reduce overall resource needs and thus increase science return.			
Description			
In this activity the contractor shall critically analyse the existing S/C and payload architectures, and with a view of the above objectives derive one ore multiple novel controller architecture based on one or several generic science mission profiles. As an example, the integration and fusion of the following functions (modular, optional, SW based) could be considered: - Star tracker computation - In-Flight reconfiguration (FPGA) - Data processing - Thermal control - Power - AOCS - Interface conversion (MILbus, SpW)			

- C/C, power and science data transport fusion

A clear comparison of the benefits of the proposed new architectures (e.g. resource reduction, schedule improvements, cost reduction) versus the additional risks (single point of failure, low TRL) shall be presented and discussed.

One or several architectures shall be implemented tested and verified, leading to the development and delivery of a Demonstrator Model, followed by the development of an EM.

Deliverables					
Controller Architecture Description Report, Demonstrator Model, EM					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024
Application Mission:	Small Planetary Platform (SPP) SCI mission concept	**Contract Duration:**	48 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High efficient, ultra light weight solar cells for deep space missions			
Programme:	TDE (TRP)	**Reference:**	T203-117NA
Title:	High efficient, ultra light weight solar cells for deep space missions		
Total Budget:	500		
Objectives			
Design a high efficient ultra-light weight solar cell that does not show any deficiencies when operated at LILT conditions as they are applicable at Saturn or even beyond (Uranus, Neptune). Furthermore, a TBD radiation dose shall be taken into account.			
Description			
So far, with missions like Juno, JUICE and Europa Clipper it is demonstrated that solar cells can still provide the required power for missions to Jupiter although the input power from the sun is reduced to only 3.7% of its value around Earth. It was assumed that Jupiter represents the ultimate limit for the use of solar cell powered satellites. However, in the meantime also missions to Saturn and beyond are considered to be powered with solar cells although sun intensities are further reduced to only around 1% compared to Earth. It is obvious that very large areas will be needed for those missions. Considering the typical mass constraints, this asks for solar arrays with very high specific power. As a main important element of the solar array, the solar cell therefore needs to achieve highest possible efficiencies at very low mass. Furthermore, low intensity, low temperature (LILT) specific features need to be taken into account.			

The solar cell used for JUICE (3G28) was at that time not the latest solar array product. However, newer products (3G30) showed deficiencies at LILT conditions. These deficiencies could be understood to be directly connected with design modifications that made the 3G30 superior compared to the 3G28 with respect to radiation hardness under standard operating conditions (> -50°C). However, the same design modifications lead to performance loss when these cells are operated under very low temperatures (< -100°C). Thus, a cell designed specifically for LILT conditions shall be developed that represents the best compromise between high performance under LILT conditions and still good radiation hardness. At the same time, the solar cell shall be made as light weight as possible to arrive at highest specific power (W/kg and W/m2). Task list: - identify solar cell architecture based on past experience (JUICE) with high potential to reach highest efficiencies under LILT conditions with still good radiation stability - manufacture first prototypes of solar cells characterize under AM0 and LILT conditions - identify any shortcomings if any and reiterate the previous tasks - perform irradiation tests under room temperature conditions with subsequent LILT characterisation - prepare a development roadmap (also in terms of test facilities that might need to be built) LILT conditions are considered here in a first instance conditions at Saturn. As a second step also conditions under Uranus and Neptune shall be considered as well.
Deliverables
Prototype; Report

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	TRL 5 by 2026 / Technology Push		**Contract Duration:**	24	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: E10 Harmonisation Roadmap: Solar Generators and Solar Cells					

Concentrator systems as mission enablers for deep space missions			
Programme:	TDE (TRP)	**Reference:**	T203-116NA
Title:	Concentrator systems as mission enablers for deep space missions		
Total Budget:	500		
Objectives			

Develop a concentrator system with a concentration in the range of up to 10x (TBC) with a high acceptance angle and optical elements that shall be robust towards the space environment (including outgassing of satellite and solar array components as well as thrust).

Description

Concentration of sunlight typically increases the conversion efficiency of solar cells. The drawback of such systems in space - apart from the sensitivity of the optics - are the fact that solar cell might operate at too high temperatures (which then reduces again efficiency) and losses that are coming into play when sun pointing cannot be granted. For deep space missions, however, concentrator systems might become mission enablers. The low intensity impinging on the solar cells would reveal any even small imperfections, such as little shunts, in the solar cell with detrimental effects on the performance. With for example a 10x concentration of sunlight, one would boost the intensity on the cells to values even higher than for current Jupiter missions. With well-designed optics that also offer a decent acceptance angle, concentrator systems could be a very interesting way to support missions to Saturn and beyond.
Also temperature could be increased with such optical systems. Although conversion efficiencies increase with decreasing temperature, it is known that for a given solar cells design there are limits beyond which performance starts dropping again when temperature is further decreased. That's why it could be important to have temperatures no dropping below a certain threshold.
Tasks:
- Literature review of concentrator systems for space
- design and prototyping of concentrator system
- evaluation of concentration factor under lab (or outdoor) conditions with appropriate high efficiency solar cell
- evaluation of acceptance angle
- Preparation of test plan to cover aspects like outgassing, degradation due to thruster plume impingement
- Assessment of concentrator system performance compared to non-concentration
- Development roadmap (including facilities that are required to support full LILT characterisation/qualification of such a concentrator system)

Deliverables

Prototype; Report

Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	TRL 5 2026 / Technology push		**Contract Duration:**	24	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: E10 Harmonisation Roadmap: Solar Generators and Solar Cells

Power Transfer via Optical Links with reduced Electromagnetic Harness Emissions					
Programme:	TDE (TRP)		**Reference:**	T203-115NA	
Title:	Power Transfer via Optical Links with reduced Electromagnetic Harness Emissions				
Total Budget:	100				
Objectives					
To study and develop technology concepts of efficient optical power transfer to minimize electromagnetic emissions for next generation instruments with increased sensitivity.					
Description					
Efficiency of both emitter diodes (transmitting) and photosensors (receiving) has substantially improved in the recent past and is still continuing. Optimizing such building blocks for power distribution applications to use optical links and integrating them in power converters comes with reduced power efficiency but has the potential for novel solutions for scientific missions with ultra-sensitive payloads, which would be sensitive to residual electromagnetic emissions from conventional electrical harnesses. Scientific missions that explore the solar wind, monitor plasma environment or have optical detectors as payload would benefit from such technology. This seeding activity is to study possible implementations concepts, explore their potentials and identify possible challenges for developing such technology further. The goal will be to develop a first optical power transfer breadboard as a proof-of-concept with substantial power. Such demonstrator would better allow to assess the order of magnitude of power that can be transmitted via an optical link and which are necessary developments for further power increase, And it will provide an indication of the overall reduction of electromagnetic emissions, including transmitter and receiver electronics. The activity encompasses the following tasks: - to perform a technology and application study, - to design a technology demonstrator with existing components, - to perform an analytical and experimental proof-of-concept, - identify technological challenges and summarize the findings and results.					
Deliverables					
Breadboard; Report					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	All scientific missions with stringent electromagnetic requirements.		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Solide Oxide Fuel Cell (SOFC) technology for outer planet exploration power generation			
Programme:	TDE (TRP)	**Reference:**	T203-120NA
Title:	Solide Oxide Fuel Cell (SOFC) technology for outer planet exploration power generation		
Total Budget:	800		

Objectives

To design, develop and test the main elements of a Solid Oxide Fuel Cell system based on Hydrocarbon & Oxygen as reactants intended for energy generation on space exploration missions, particularly for outer planets exploration as an alternative to solar and nuclear power energy.

Supported by SCI-FMP (Solar System Missions Section)

Description

Future exploration missions, including missions to the outer planets such as Jupiter, Saturn, Uranus and Neptune as well as their Moons, would benefit from the study of alternative energy generation solutions. Generating electrical power at far distance from the Sun, as well as maintaining the required thermal environment required for a specific mission, are both critical capabilities needed for such missions. Different technologies already exist to provide power in different operating conditions, and in different types of space missions, including Batteries, Solar Arrays and Nuclear Systems but the large distances from the Sun and the unavailability of European RTGs suggest to explore alternative solutions. In particular, the hydrocarbon (e.g. methane, butane) ¿ O_2 reaction is high in mass-specific energy, and would be potentially manageable over long timescales with pressurised storage compared to the very low boiling point of hydrogen (providing the highest mass-specific energy) for which storage for many years would not be easily achievable without major boil-off loss. A fuel cell system is well suited for this purpose since the efficiency is high, and it is a static, vibration-free device; successful space heritage of fuel cells exists from Apollo and STS.
In order to use high energy density hydrocarbons as reactants, the concept must be based on existing Solid Oxide Fuel Cell (SOFC) technology. As compared to other fuel cell technologies, which require pure hydrogen as reactant, SOFC is tolerant to hydrocarbon derived fuels and can even operate directly on hydrocarbons and carbon monoxide, which are poisons for other fuel cells. SOFC technology has been flown on the Perserverance rover to generate O_2 from the Martian CO_2 atmosphere this year. The concept was successfully demonstrated.
In order for the SOFC subsystem to be versatile for multiple functionalities and/or mission scenarios, it must be designed with the following basic features:
- The SOFC should be capable to provide low power delivery (< 150 W) suitable for multi-year reliable space operation
- The SOFC should be capable of throttleability and re-startability (thermal cycling) during the operational lifetime

- The SOFC should require low quiescent power consumption for e.g. control and monitoring.

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- The SOFC should require low quiescent power consumption for e.g. control and monitoring.

This activity shall be focused at validating the functional performance by breadboard testing in laboratory environment. The activity will need to include the following activities:
- System architecture design including SOFC technologies, materials and reactants trade-off and selection, fuel storage and fluidic chain design
-Establishing a mathematical model to design and validate the system
-Design the breadboard
-Build the breadboard
-Experimental demonstration of the breadboard including the main elements, i.e. the SOFC stack, reactant storage, fluid handling, gas pre-processing reactor, heat exchangers, thermal management for cycleability, electrical performance and lifetime.

The demonstration of flight worthy cryogenic CH4 and O2 tanks shall not be included in this activity, however, the testing of the breadboard shall be done based on cryogenic reactants. Furthermore, a preliminary sizing of a later flight application of the full system shall be made and related high-level requirements for a tank and fluidic chain development activity shall be derived.					
Deliverables					
Breadboard; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2023
Application Mission:	L4 mission of the Voyage 2050 Programme: Mission to the Moons of the Giant Planets (i.e. Jovian or Saturnian system).		**Contract Duration:**	24	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

SMILE SXI PSU de-risking activity			
Programme:	CTP	**Reference:**	C203-112FM
Title:	SMILE SXI PSU de-risking activity		
Total Budget:	1250 kEuro		
Objectives			
Design, manufacture and test the development model(s) of the SMILE SXI power supply unit (PSU), including board level flight qualification. The activity must be completed by 2020 for de-risking SMILE PLM development schedule			
Description			
The SXI power supply unit (PSU) has been specifically selected to provide the stringent power requirements to the front end electronics of the SMILE Soft X-ray Instrument (SXI). Each nominal PSU is designed to provide power to the front end electronics, data processing unit, the radiation shutter electronics and mechanism and the focal plane heaters. This activity covers the PSU design and manufacture & test of the development model(s) to verify the feasibility of the SXI PSU and that its power and electrical interfaces requirements can be met, including redundancy. This activity is critical to ensure that there are no unforeseen electrical interfaces or EMC issues with the SXI instrument and the payload module and to de-risk the PSU from the SMILE mission schedule. The main tasks during this development activity are comprised of the following: 1) The design of the SMILE SXI PSU.			

2) Finalise all open technical requirements and ensure that the design is robust. 3) Manufacture of a pre-development Model (Breadboard) for testing with the SXI electronics breadboard units. 4) Selection of components and definition of all activities related to any qualification/delta qualification or radiation needs. 5) Manufacture of an EQM unit. 6) Test Plan definition and preparation of the relevant procedures. 7) Qualification of the PSU board. 8) Finalisation of the design of the Qualification Units (Flight standard) and update of the relevant documentation. 9) Manufacture of two fully representative qualification model boards. 10) Testing of all the development model(s). 11) Demonstration that manufacturing and PA/QA processes reflect adequate standard. 12) EQM refurbishment. 13) The development is expected to directly feed into and be used within the remaining SXI development.
Deliverables
Detailed design reports that reflect the most recent design and payload module requirements for all models Pre-development model (Breadboard) EQM Board Two flight representative Boards (nominally used as FMs) EQM Board Refurbishment Test report(s) Updates to all relevant design documentation

Current TRL:	4	**Target TRL:**	7	**Application Need/Date:**	TRL 7 by 2020
Application Mission:	SMILE		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Comprehensive Environment Model Catalogue for for Systems Moons of Giant Planets			
Programme:	TDE (TRP)	**Reference:**	T204-136NA
Title:	Comprehensive Environment Model Catalogue for Systems Moons of Giant Planets		
Total Budget:	300		
Objectives			
To develop European models for the radiation, plasma, microparticle, plume and atmosphere environments of Saturn and its moons within an extensible model framework applicable to all gas giant systems.			

Description
Background and context: Missions are being studied to the systems and moons of outer planets, including extended observation periods by local orbiters or possible landers, that require careful evaluation of the local radiation, plasma, microparticle, atmospheric and plume environment for design of both platform and science payload. Radiation impact potentially includes total cumulative doses, single event effects from short term enhancements and internal charging risk whilst plasma environments present risks of surface charging. Behaviour of the plasma environment and mechanisms for trapping, acceleration, losses for electrons and protons in the outer planet radiation belts are not very well known. Highly tilted global magnetic fields with respect to the planet rotation axis are believed to induce complex interactions with heliosphere. Of those planets in the solar system which possess significant magnetospheres, the Saturnian system is not as well characterised as Earth or Jupiter whilst not being described by models at all for Uranus and Neptune. Local (natural) microparticle environments are also important due to the large gravitational attraction of the gas giants and the potential for impact damage posing a risk to spacecraft. Justification of the activity: The Saturnian system and its moons each have their local and variable environments. These environments have been experimentally studied by missions such as Cassini, Pioneer 11 and Voyager 2. A dedicated NASA model (SATRAD) exists for the Saturnian system as well as similar models for Uranus (UMOD) and Neptune (NMOD). Relevant European model developments (such as JOSE, Salammbo, BAS project, JMEM) exist for the Earth an Jovian systems only. Thus far there is no coherent and complete European set of engineering models for the environments of the moons of these planets for future mission analysis purposes. Description of the technology to be developed: This activity will develop a flexible and easy-to-use environment model framework and related software for gas giant planet moon systems based on the wealth of data from visiting missions. The resulting model catalogue will be targeted at deriving specifications for future science mission engineering purposes. Within this activity, derived specific models shall be focused on the Saturnian system. This activity encompasses the following tasks: - Literature study, including scientific analyses and reports from other modelling activities. - Review of existing datasets and possible need for data (re) analysis (target engineering models). - Development of a comprehensive set of model framework for the systems and moons of the outer planets. - Validation of the model output against existing in situ and remote data, and comparison to other models. - Application of framework to derive models for mission scenarios to the

Saturnian system and possible extension to other exploration scenarios from current ESA studies. - Integration of the new models in the ESA Space Environment Information System (SPENVIS) Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.					
Deliverables					
Report; Software					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Mission to the moon systems of Saturn or other outer planets (Jupiter, Uranus and Neptune). Platform and payload dimensioning against radiation, plasma and microparticles for orbiters need engineering models based on sound review of local environments. For some of the possible destinations (Titan, Europa, Enceladus) local atmosphere and plume models are required.		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Mini Ion emitter for Spacecraft Potential Mitigation on Science Missions			
Programme:	TDE	**Reference:**	T204-124EE
Title:	Mini Ion emitter for Spacecraft Potential Mitigation on Science Missions		
Total Budget:	400 kEuro		
Objectives			
To develop a miniaturised version of an ion emitter to mitigate spacecraft charging effects on plasma measurements for science missions.			
Description			

Spacecraft potentials in the outer Earth magnetosphere may reach a few tens of volts positive and therefore severely perturb plasma particle and electric field measurements. Therefore, magnetospheric missions from ESA such as Cluster, but also from international partners such as Double Stars and MMS have relied on an ion emitting instrument, ASPOC (Active Spacecraft Potential Control), developed by IWF in Austria for lowering the positive potential down to a few Volts positive. The latter version of ASPOC flown on MMS consists of 2 pairs of instruments (to ensure symmetric emission) of 2.9 kg each and consuming up to 3.7 W. Future magnetospheric missions such would also benefit from such a device. A miniaturised version of an ion emitter (<1 kg) for scientific missions is foreseen to reduce embarkation constraints and allow more mass allocation to payload sensors and their electronics and maintain European leadership for such an instrument.					
Deliverables					
New design of a mini-ion emitter and a laboratory prototype developed and tested.					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Future magnetospheric mission		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Modelling of Electrostatic Environment of Ion Emitting Spacecraft			
Programme:	TDE	**Reference:**	T204-118EE
Title:	Modelling of Electrostatic Environment of Ion Emitting Spacecraft		
Total Budget:	250 kEuro		
Objectives			
The activity objective is to improve the simulation tools for spacecraft-plasma interactions in order to cope with effects of operation of an ion emitter and demonstrate electrostatic cleanliness down to the sub-volt level.			
Description			
Magnetospheric missions such as Cluster, DoubleStar and MMS flew Active Spacecraft Potential Control (ASPOC) systems to control and stabilise the spacecraft surface potential to a few volts positive. This is required in regions where photoemission would result in larger and unstable positive potential, preventing to measure the entire distribution functions of plasma populations which future missions, e.g. THOR, must measure down to the 1eV level. As the Debye length is generally much larger than the spacecraft, the spacecraft electrostatic potential influence extends over a volume much larger than the spacecraft. Mitigation of the effect of the spacecraft potential is part of the electrostatic cleanliness requirements for particle and field			

measurements, and implemented through a number of measures (conductive surfaces, long booms, use of ASPOC system, etc.). The operations of ion emitters introduces a perturbation due to the positive space charge in the beams, which disturbs particle trajectories and electric field measurements. This space charge is inherent to the system and its influence can only be minimized by a careful estimate of the needed current and optimal distribution of the beams with respect to the fields probes and particle sensors. Interpretation of data taking into account the influence of a positive space charge has to rely on a numerical model which allows to accurately represent the dynamical aspects of the system: platform spin, emitter operations, variable solar illumination, etc. giving rise to an asymmetric time varying photoelectron cloud. At the same time low energy particles are affected by the potential barrier in the ion beam and overall spacecraft charging, while ions drifts and wakes also affect the field measurement. This activity will address the improvement of the SPIS spacecraft plasma interaction simulation toolkit in order to model the low-level electrostatic environment of an ion emitting spacecraft. Critical analyses will be performed of the requirements with respect to spinning emitting spacecraft, the beam, photoelectron and space-charge conditions, and the associated numerical simulation challenges. The system will be improved to accurately model the environment and provide capabilities to aid the ASPOC accommodation, characteristics and operation, and interpret instrument measurements in such an environment.
Deliverables
Updates to SPIS toolkit. Analysis reports, software documentation

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2018
Application Mission:	Future magnetospheric mission		**Contract Duration:**	15 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Geant4-based Particle Simulation Facility for Future Science Mission Support			
Programme:	CTP	**Reference:**	C204-116EE
Title:	Geant4-based Particle Simulation Facility for Future Science Mission Support		
Total Budget:	500 kEuro		
Objectives			

The objective is to establish a strategic, complementary, long-term capability as a key resource for space science-related simulation of particle radiation interactions with the payloads and systems, both for future missions and to aid data analysis from past and operating missions. This should be based on the Geant4 simulation toolkit - which can simulate in detail particle propagation and interactions in complex geometries - implemented on a suitably powerful computing infrastructure. The activity should exploit ("spin-in") expertise and products from High Energy Physics and medical physics domains, and should be coordinated with the Geant4 collaboration.

Description

Science missions are demanding progressively more detailed simulation of particle radiation interactions with the payloads and systems. This is because detectors are becoming more complex and sensitive, but also because some missions will be operating in space environments with high particle radiation levels. Therefore, each mission and detector require tailored analysis. The workhorse for this type of analysis is the Geant4 Monte Carlo simulation toolkit. ESA has been a signatory to the Geant4 collaboration for nearly 20 years, and has driven many of its developments using a special space users group. Geant4 simulates in great detail particle propagation and interactions in complex geometries.

This activity shall develop strategic capacity and the associated infrastructure facility required for space-related Geant4 in-depth developments such as detailed physics improvements, advanced simulation techniques, geometry modelling, etc. The capability shall establish responsive support for ESA Geant4 activities and delivery of key capabilities needed in support of the development and operation of ESA science missions.

The project shall model in detail a series of future ESA missions and (preliminary) payloads and provide detailed radiation assessments for them, in terms of traditional concerns (dose, SEE), but also complex background and disturbance phenomena. The initial test cases shall be JUICE, Athena and LISA Pathfinder. Physics and simulation developments will be undertaken, focussing on completion and validation of reverse Monte Carlo techniques (for efficiency improvement), radioactive decay, test mass charging, and internal charging in the Jovian environment.

Activities shall include:
- Detailed code review of ESA Geant4 code/models
- Reverse Monte-Carlo improvements and validation for simulation speed-up
- Radioactive decay updates
- Hadronic physics for secondary particle generation and interactions
- Interface to sensor physics
- Improvements to GREET / Planetocosmics codes for planetary and lunar analyses
- Re-evaluation of low-energy electromagnetic interactions
- Experimental validation

- Demonstrator of Graphics Processing Unit for space science applications (as done in the medical domain) - Further Geant4 applications in SPENVIS - Development of space-specific advanced examples for the Geant4 release - Characterization and modelling of relevant space radiation environments as reference for the Geant4 code/models As starting points, the ESA developments GRAS, MULASSIS and CIRSOS shall be used. The analyses shall be performed within a well-structured service with good attention to documentation and communication/outreach to maximise the impact of the service in the European space community. The facility shall be supported by computing infrastructure with a large number of cores, as well as GPUs and other advanced architectures that might be beneficial.
Deliverables
Updated Geant4 simulation tools and documentation, updates to Geant4 physics, validation files, simulation facility, technical documentation, workshops.

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2018
Application Mission:	Generic		**Contract Duration:**	30 months	
S/W Clause:	Open Source				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High Accuracy Star Tracker			
Programme:	CTP	**Reference:**	C205-106EC
Title:	High Accuracy Star Tracker		
Total Budget:	500 kEuro		
Objectives			
To develop a bespoke high accuracy star tracker for demanding missions which cannot take advantage of a fine guidance system (FGS) in the instrument focal plane.			
Description			
High pointing accuracy missions require a high accuracy inertially referenced sensor e.g. star tracker. This should be of very low power dissipation and mountable on the optical bench of the payload. The requirements of such a star tracker are seen as: Separate optical head (OH) and electronics < 0.5 Watt OH dissipation 5 to 8 degree full cone field of view (FoV) 0.1 to 0.2 sec update rate			

Autonomous quaternion out operation < 1.5Kg OH and baffle 40 deg SEA baffle ~ 0.1 arcsec performance The proposed activity will design and develop an optical breadboard based on new APS detector developments together with new algorithms and test equipment to demonstrate the target performance.					
Deliverables					
Optical breadboard and test equipment. Design and justification file.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2016
Application Mission:	Generic	**Contract Duration:**	18 months		
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High Accuracy Star Tracker Engineering Model (EM) Development			
Programme:	CTP	**Reference:**	C205-118SA
Title:	High Accuracy Star Tracker Engineering Model (EM) Development		
Total Budget:	400 kEuro		
Objectives			
Complete and demonstrate the end to end performance, functionality and properties of a high accuracy star tracker (0.1 arcsec class - one order of magnitude better than state of the art) such that it be ready for consideration by future science missions.			
Description			
A currently running activity is demonstrating the feasibility of a compact, low power, very high accuracy star tracker suitable for supporting missions where payload in the loop operation is either not feasible or not desirable. At the end of that activity, the optics and algorithms will have been de-risked via 'component level' testing and a baseline design, sufficient to assess feasibility, has been developed. This activity shall complete the design of both the optical head (OH) and the remote electronics unit (EU), together with the software and embedded algorithms required to achieve such performances, including all lessons learnt from the pre-cursor activity. All relevant design analyses shall be performed and the performance predicted using detailed simulations. A full Engineering Model (OH+ EU+ S/W) shall be produced and shall be			

tested for launch and environmental compatibility, performance, sun survivability and straylight. All relevant design analyses shall be performed and the performance predicted using detailed simulations.
Design solutions for any issues found during testing shall be proposed and their feasibility demonstrated.

This activity bringing the very high accuracy Star Tracker from TRL3 to TRL5 aims to reach the required TRL in due time for ATHENA mission. The funding is completed by activity GT17-102SA in GSTP E1, supported by the delegation.

Target specifications :
- Mass of the optical head < 2.5 kg
- Mass of the electrical unit < 2.5 kg
- Nominal Power consumption of the Optical Head < 0.5 W
- 0.1 arcsec class (Low Frequency errors)
- 10 Hz update rate

Deliverables					
Engineering Model					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Enabling Star Tracker for Athena. Also considered as a back-up on PLATO.	**Contract Duration:**	18 months		
S/W Clause:	Operational S/W				
Consistency with Harmonisation Roadmap and conclusion:					
Harmonisation Roadmap Reference: A02 Harmonisation Roadmap: AOCS Sensors and Actuators: I - Star Trackers, APS, IMU's and Wheels Harmonisation Comments: Fully consistent with Harmonization Roadmap. AIM STR_A (STR) Very High Accuracy APS STR Consistent with Harmonisation Roadmap: Yes					

Future AOCS Enabling Technologies			
Programme:	TDE	**Reference:**	T205-031EC
Title:	Future AOCS Enabling Technologies		
Total Budget:	700 kEuro		
Objectives			
Future science missions will require very demanding pointing stability and/or accuracy. This activity intends to study several AOCS technologies to enable such future missions: 1) improvement of gyro performance; 2) Fine Guidance Sensor design guidelines derivation (handbook); 3) friction torque compensation.			

Description
1) Improvement of gyro performance for very-high accuracy pointing missions. In several on-going mission (e.g. EUCLID) and next generation ones (e.g. ECHO), the limitation on FGS sampling frequency and delays in processing don't permit to achieve the optimal attitude determination accuracy. Since the FGS sampling frequency is mainly limited by the telescope aperture and by the detector readout noise, improvements could be achieved having a more accurate gyroscope. The objective of the study is to address which improvements and/or design changes have to be performed, in the current state of the art gyroscopes, to increase by a factor 5-10 the performance (ARW in the order of 0.02-0.04 10-3 deg/sqrt(h)). 2) Fine Guidance Sensor for high-pointing stability/accuracy missions Science mission with high-pointing stability/accuracy require the use of Fine Guidance Sensor (FGS) to recover the gyroscope bias and drifts, thermo-mechanical deformation between gyroscope and FGS/instrument. The FGS is an almost application specific equipment due to the required performance, accommodation and environmental constraints. Nevertheless, there are FGS design steps, technologies and problematic that are quite common between all applications. The objective of this activity is to derive the guidelines for the design (detector selection, image quality and SNR, front-end-electronics, readout schemes, with and/or without reference star-catalogue, thermo-mechanical interfaces, electro-magnetic compatibility, etc.), the development and integration processes of an FGS. This helps to address properly all the FGS aspects (several disciplines are involved) since the early phases of mission definition and design, reducing the risks for later additional costs and/or mission de-scoping. This set of guidelines should be collected in a sort of handbook, to be used as input/reference to the instrument PI responsible and AOCS engineer as well. 3) Friction torque compensation for science missions Wheel based AOCS represents a cheap solution for several science mission (e.g. PLATO). However, there are some wheel intrinsic characteristics that could be detrimental factors for the pointing performance in the wheel based AOCS. The sudden change of the wheel friction torque due to oil jogs or cage instability is a major one. The objective of this activity is to review the current considered solution, and to design an integrated robust attitude and wheel controller, based on state-variable approach and disturbance observer. Another major outcomes of this activity will be the definition of clear design guidelines at sub-system level.
Deliverables
Technical Reports FGS design handbook S/W simulator and algorithms code

Current TRL:	1/2	**Target TRL:**	3/4	**Application Need/Date:**	2020
Application Mission:	Generic		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
AOCS Sensors and Actuators roadmap - Gyros Aim D- New Technology Investigations (relevant for part 1).					

Radar Planetary Altimeter Engineering Model			
Programme:	CTP	**Reference:**	C205-002EC
Title:	Planetary Altimeter Engineering Model		
Total Budget:	1500 kEuro		
Objectives			
The goal of this activity is to develop an Engineering Model of a compact altimeter to be used during the landing sequence of science and robotic exploration missions e.g. MarcoPolo-R, Mars. Both radar and laser altimeters will be addressed.			
Description			
The need for small, low-power altimeters for small planetary landers (such as network landers) has been previously identified. In a Martian scenario, an altimeter is required after the parachute opening phase to trigger various altitude-dependent events (e.g. parachute release, airbag inflation) leading to landing. Use of the same altimeter for asteroid landing mission is also envisioned. Following up on the Assessment and Breadboarding of a Planetary Altimeter (ABPA) activity (T905-003EC), which will produce by 2014 a field-tested breadboard of a radar and a LIDAR altimeter (for each, mass is less than 1Kg, power less than 5W), this activity shall develop the breadboards into an Engineering Model to be tested in a relevant environment. The main tasks shall include: - incorporation of the conclusions of the ABPA study, including the breadboard itself - update of mission requirements taking into account those of Mars and asteroid mission in development or proposed at the start of this activity - design of the Engineering Model - development, procurement of parts and integration - testing, verification and validation, including the use of space environment simulator, and outdoor test campaigns, including dynamic testing to be performed with a suitable flying platform (e.g. drone, helicopter) reproducing the kinematics conditions of Mars/asteroid descent trajectories. At least in the case of Mars (a) terrestrial analogue terrain(s) shall be selected for its (their) radar return properties.			

This activity will be implemented as a CCN.
Deliverables
EM, technical data package

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2016
Application Mission:	Planetary, asteroid missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Pulsar Navigation for Science Missions			
Programme:	TDE	**Reference:**	T205-122SA
Title:	Pulsar Navigation for Science Missions		
Total Budget:	200 kEuro		
Objectives			
Design at concept level, size and preliminarily estimate the performance of Pulsar Navigation solutions to support orbit determination for planetary science missions. Provide a development plan for future work for most promising solution including the manufacturing of an EM.			
Description			
State-of-the-art planetary science missions have demanding requirements regarding orbit knowledge prediction ; for example, for ExoMars TGO, the prediction requirement is around 100m (cross track) and 10s (along track) 2 weeks in advance during the science phase. EnVision M5 candidate mission has similar requirement with a 300 m cross-track and 10s along-track orbit knowledge prediction up to 2 weeks in advance of a given pass. Aerobraking operations also require accurate orbit determination e.g. to estimate the achieved pericenter altitude and plan for the next pericenter correction manoeuvres. This requires very long ground pass durations for ranging / doppler tracking. For ExoMars TGO aerobraking which lasted 1 year, up to 16 hours daily ESTRACK support were required when the orbital period was greater than 6 hours, and even 24 hours when the orbital period was smaller. For Envision, a similar ground stations load is envisaged, but over even longer duration (2 years), making the aerobraking one of the cost driver for the mission. In this context, solutions allowing to increase on-board autonomy to alleviate the operations cost / complexity could be of interest if affordable ressources-wise (mass, power). Orbit determination currently relies solely on Ground Stations. When the distance from the Earth increases, the ground station performance for orbit determination deteriorates, on top of providing bad GDOP for the measurements. There has been very recent and numerous important developments in the field of Pulsar Navigation. Most important was the Station Explorer for X-ray Timing and Navigation Technology (NASA / SEXTANT) demonstration on the ISS late 2017, demonstrating the feasibility of the concept. Today, many			

NASA missions are envisaging this as an alternative or complement to ground-based orbit determination. The combination of a pulsar signal receiver with a precise Star Tracker enables to reduce the field of view of the X-Ray cameras gathering the signal. The SNR is improved by a lower background noise, when a small FoV is considered. It has been demonstrated that position measurement can be envisaged in the order of 2 km, where-ever in the solar system. In comparison, 2 km is what can be achieved by ground stations up to the vicinity of L2. When determining the orbit using these individual measurements, an orbit determination significantly better than the kilometer can be achieved, for a largely relaxed ground involvement. Therefore, for missions further than L2 (planetary missions), Pulsar Navigation can outperform Ground Stations, on top of requiring less ground intervention. For the particular case of EnVision, particular benefits are possible : - Frequent updates of on-board orbit determination during the aerobreaking, reducing the operational burden, - Improvement of the orbit knowledge during the science phase, in particular along track, improving science operations efficiency The activity shall review and trade-off Pulsar Navigation concepts (X-Ray, RF) for a use in planetary missions, considering EnVision as application case. The receiver features (mass, volume, power, accommodation constraints, testability) will be part of the trade off against orbit determination performance achievable. The most promising traded solution will be defined and analysed, and a plan for next study and development steps will be provided.
Deliverables
Report;

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	TRL 6 by 2024
Application Mission:	Several science missions (e.g. EnVision)		**Contract Duration:**	15 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

GaN MMIC based solid state amplifier for X band for long range high capacity communication			
Programme:	CTP	**Reference:**	C206-006ET
Title:	GaN MMIC based solid state amplifier for X band for long range high capacity communication		
Total Budget:	900 kEuro		
Objectives			

The aim of this activity is the development of an Engineering Model of an X band Gallium nitride (GaN) monolithic microwave integrated circuit (MMIC) based high power Solid State Power Amplifier (SSPA).
Description
GaN is an emerging technology for SSPAs with 5 times higher power density (as compared to the currently used GaAs), very high breakdown and operating voltages, very high junction temperatures and high radiation tolerance. These key properties make GaN based SSPAs an ideal replacement for bulky travelling wave tube (TWT) amplifiers in space applications where mass and footprint are of critical importance. A reduction of 40% for both mass and footprint, is expected for SSPAs based on GaN MMICs. This activity will develop an Engineering Model of an X band Gallium nitride (GaN) monolithic microwave integrated circuit (MMIC) based high power Solid State Power Amplifier (SSPA). The activity will be consist of three technical phases: Phase 1: Literature survey, Technology evaluation and Modelling activity. Phase 2: Detailed Design for 20W MMIC and 50/80W MMIC, Circuit manufacturing and test. Phase 3: SSPA Engineering Model built-up, Environment and performance testing.
Deliverables
Technical Notes and Reports EM of a 50/80 W CW SSPA

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	Several		**Contract Duration:**	24 months	
S/W Clause:	NA				

Consistency with Harmonisation Roadmap and conclusion:
Harmonization Dossier "TT&C Transponders and Payload Data Transmitters", Issue 3, Rev 1, Sect. 4.7.

Miniaturisation of the Deep Space Transponder			
Programme:	TDE	**Reference:**	T206-004ET
Title:	Miniaturisation of the Deep Space Transponder		
Total Budget:	250 kEuro		
Objectives			
The objective of this activity is to reengineer the communication subsystem typical architecture for Deep Space missions targeting mass reduction, power efficiency, modularity and scalability to achieve miniaturisation, whilst maintaining high reliability and provide the design of a high performance miniaturised version of the Deep Space transponder. The innovative design			

shall make use of state-of-the-art technologies needed to achieve miniaturisation for future implementation.					
Description					
There are currently on going mission studies in ESA which consider the use of medium size platforms for Deep Space investigations. These missions are restricted in mass and power and would benefit from lighter and more compact Telemetry, Tracking and Command (TT&C) architectures. In this activity, the contractor shall study the state of the art techniques and technologies available for providing a miniaturised TT&C transponder; evaluating system on chip technologies, MMIC, ASIC and power efficient architectures. In addition to the transponder design, any required hardware developments/qualification shall be identified and included in a roadmap to flight development.					
Deliverables					
Technical Notes					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2020
Application Mission:	Generic		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Yes - outlined in TDE plan for TT&C transponder and payload data transmitters					

TT&C Subsystem Capability Development			
Programme:	CTP	**Reference:**	C206-008FM
Title:	TT&C Subsystem Capability Development		
Total Budget:	8630 kEuro		
Objectives			
The objective of this activity is the development of a TT&C subsystem prime capability including the development of specific subsystem equipment's.			
Description			
This activity shall address three key areas: 1. The development of a TT&C subsystem prime capability: - develop firm understanding of subsystem design, analysis and technical budgets and derive a preliminary subsystem design for Plato - perform evaluation of subcontractors and finalise Make/Buy strategy for Plato - develop evaluation, selection and control structure for subcontracts for what regards technical, PA management and contractual aspects. 2. The development to Engineering Model level of an X-band transponder meeting the requirements of future science missions			

3. The development to Engineering Model level of a Ka-band payload data modulator meeting the requirements of future science missions The activity will be implemented with contractual phasing.
Deliverables
TT&C subsystem design and equipment specifications X-band transponder Engineering Model Ka-band payload data modulator Engineering Model

Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	Plato, Generic		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Breadboard for telemetry ranging (CCSDS 401, 2.4.24)			
Programme:	TDE	**Reference:**	T206-017ES
Title:	Breadboard for telemetry ranging (CCSDS 401,2.4.24)		
Total Budget:	350 kEuro		
Objectives			
The objective of this activity is to study and implement (at breadboard level) a telemetry ranging system (CCSDS 401.0-B,2.4.24) that allows the simultaneous transmission of high data rate telemetry and high-accuracy ranging. The activity will analyse if the new ranging scheme is suitable for future ESA satellite missions, the impact of potential cross support requests from NASA and what would be required to prepare them.			
Description			
Current ranging technologies (e.g. ESA standard code ranging and PN ranging) rely on the transmission of a ranging signal that can be coupled only with a residual carrier (with low data rate) telemetry signal or, in the case of PN ranging, with a suppressed carrier using GMSK modulation, with bitrate limited by the PN ranging chiprate. In alternative, NASA has proposed a system based on telemetry ranging, and currently the corresponding recommendation (CCSDS 401, 2.4.24) is now out for agency approval. ESA has not yet studied this NASA led development, but the telemetry ranging approach could become interesting for future ESA satellite missions and for cross support. In particular, telemetry ranging allows to downlink the ranging information as part of the telemetry stream, therefore eliminating the need for separate sessions and simplifying significantly operations. Additionally, the approach is compatible with any telemetry modulation format and relies on latching the received ranging phase in the spacecraft, via the telemetry channel to the downlink. The organisation of this activity is in two steps. First step is to perform an			

end-to-end system simulation, to analyse the performance of the telemetry ranging approach. Second step is to build up a hardware demonstrator (breadboard) to further analyse the system performance and identify possible problems with the suggested scheme and its implementation into operational hardware. Special importance is given to study the ranging accuracy in dependency of the data rate, and in presence of link adaption (i.e., variable data rate). The output of the activity would allow ESA to better evaluate if the telemetry ranging approach is suitable for the needs of future ESA satellite missions and to analyse the potential cross support requests from NASA					
Deliverables					
Breadboard; Report					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2020
Application Mission:	Several missions (EnVision)	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Ground Station Technology, F04					

K/Ka-band antenna technology development for future science missions			
Programme:	TDE	**Reference:**	T206-012EF
Title:	K/Ka-band antenna technology development for future science missions		
Total Budget:	450 kEuro		
Objectives			
Design and breadboarding of K/Ka communication antenna for future science missions			
Description			
For future science missions, communication antennas with full azimuth field-of-view are needed. In previous missions, X-band phased array antennae (PAA), with an aperture conformal to a cone surface, have been employed. Although such conformal geometries are still very promising candidates for future missions, X-band will phase limitations. For one, the tendency towards increased data rates drives the need for increased bandwidth and increased gain. Second, X-band is more and more occupied by terrestrial services so that its availability for future science space missions is at risk. More promising would be a K/Ka-band PAA, but the K/Ka band technology readiness is currently too low for space application. For this purpose, an activity is proposed on a deep-space K/Ka band communication antenna development suited for future science missions. An antenna architecture and layout shall be elaborated and justified by future mission needs. Radiating elements, subarray structuring and all active beam-forming network elements shall be assessed (SSPAs, LNAs, amplitude phase actuators etc.). A breadboard shall be designed, RF measured and			

manufactured. As a minimum, the breadboard shall contain all critical elements identified in the design phase and one fully operational subarray. A technology roadmap shall be presented at the end of the activity.					
Deliverables					
Breadboard; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	Several science missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Cryogenic Polarisation Modulator for CMB Science Missions					
Programme:	CTP	**Reference:**	C206-011FV		
Title:	Cryogenic Polarisation Modulator for CMB Science Missions				
Total Budget:	500 kEuro				
Objectives					
The aim of this activity is to continue the development of a Half Wave Plate (HWP) based cryogenic polarisation modulator including its rotation mechanism with the aim of reaching TRL 5.					
Description					
ESA has for the past number of years funded the development of a Half Wave Plate (HWP) based cryogenic polarisation modulator for application in a potential future Cosmic Microwave Background (CMB) space science mission aiming to detect the B-mode component of the CMB. These previous activities have successfully demonstrated high efficiency broadband electromagnetic performance meeting the mission needs. The purpose of this proposal is to build upon these previous activities and raise the TRL to 5 for both the HWP element and its supporting rotation mechanism.. Breadboard hardware shall be manufactured and tested in representative environment demonstrating TRL5.					
Deliverables					
Breadboard; Report					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	CMB B mode mission	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development of Large Anti-Reflection Coated Lenses for Passive (Sub)Millimeter-Wave Science Instruments

Programme:	TDE	**Reference:**	T206-014EF
Title:	Development of Large Anti-Reflection Coated Lenses for Passive (Sub)Millimeter-Wave Science Instruments		
Total Budget:	600 kEuro		

Objectives

To demonstrate the feasibility of manufacturing large low RF-loss lenses, including anti-reflection coating, for refractive telescope optics. The design and performance of the mounting structure of the lenses shall be included as well in the activity

Description

Over past decades scientists built millimeter-wave sensitive instruments to characterise the Cosmic Microwave Background (CMB) from the ground, balloon, and satellite. For these telescopes, designs have been considered that are either based on reflecting or refracting optics.

Previous instrument trade-offs have shown that refractive telescope designs can have some benefits over reflective optics designs for polarized CMB instruments, i.e. potential removal of the complex rotating half-wave plate and a more compact design as compared to off-axis Dragone telescope designs.

Missions, such as LiteBird, need to make observations over large frequency bandwidths and require a large focal plane detector array to improve the sensitivity. To meet the requirements of these refractive optic designs, broadband antireflection (AR) coated (e.g. made of silicon, alumina or any other low loss material) lenses are required. For small silicon lenses such ARCs have already been demonstrated and this now needs to be proven for large (300 mm) lenses covering frequencies over an octave bandwidth and operation at cryo temperatures of 4K. The design and performance of the structure supporting the various lenses needs also to be included in the activity as this is critical for the alignment and performance of the telescope.

The activity shall cover the design, manufacturing and testing of the AR coated lenses to demonstrate the compliance against the requirements.

Deliverables

Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	LiteBird	**Contract Duration:**	18 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Innovative Materials and Designs for Magnetic Shielding

Programme:	TDE (TRP)	Reference:	T207-065NA
Title:	Innovative Materials and Designs for Magnetic Shielding		
Total Budget:	300		

Objectives

To utilize innovative magnetic materials in magnetic shielding applications and to develop novel design concepts for magnetic shielding of payloads and experiments sensitive to magnetic fields.

Description

Substantial performance improvements in the next generation of various scientific payloads and experiments are increasingly depending also on minimizing energy or forces due to magnetic fields.

This applies especially to payloads and experiments involving cold-atom interferometry, e.g. fundamental physics experiments and precision atomic clocks, but extends also over a large variety of detectors types (microwaves, infrared, visible, ultra-violet, X- and gamma-rays) up test masses or ultra-stable oscillators.

Magnetic field instruments cannot be shielded themselves as this would also shield-off the magnetic fields of the space environment to be measured. They can however benefit indirectly, if sources of magnetic disturbances can be efficiently suppressed.

The utilization of novel materials, e.g. soft magnetic nanocrystalline alloys, nanoparticles or nanotubes, and their adaptation of passive and active shielding designs has the potential to substantially improve shielding performance and/or improve mass, volume and power efficiency.

The activity aims at developing the needed design concepts and proofing them in breadboard setups.

The tasks include:
- study and ranking of magnetic materials for shielding applications
- establishing virtual models capturing relevant properties (magnetic, geometric, etc), including nonlinear effects like hysteresis
- verification of datasheet magnetic properties by test and validation of virtual models
- implementation of breadboard setups for selected application cases

Deliverables

Breadboard; Report

Current TRL:	2	Target TRL:	3	Application Need/Date:	2022
Application Mission:	Scientific missions with next-generation payloads or experiments	Contract Duration:	24		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Consistent with Harmonisation Roadmap: %

Development of a multi-chroic, dual polarization, wide-band on-chip array for CMB spectroscopy			
Programme:	TDE (TRP)	**Reference:**	T207-066NA
Title:	Development of a multi-chroic, dual polarization, wide-band on-chip array for CMB spectroscopy		
Total Budget:	350		
Objectives			
To develop a dual polarization focal plane array with spectroscopy capability for CMB applications. Technologies based on Kinetic Inductance Detector (KID) pixels in combination with an Ultra Wide Band (UWB) antenna and on-chip filtering or bolometers with Fabry-Perot filter bank superstrate shall be considered.			
Description			
Background and Justification Instruments for Cosmic Microwave Background (CMB) observations consist of a Focal Plane Array (FPA) with microwave detectors covering the different frequency bands. In order to include spectroscopy capability, some short of filtering has to be added to the FPA. Different technologies have been considered in the literature, each of them with their limitations. For example, single polarization wide band antennas in combination with Kinetic Inductance Detectors (KIDs) and band defining filters have already been demonstrated. However, in order to enable spectral-polarimetric spectroscopic imaging of the CMB, dual polarization capability would be needed. On the other hand, dual polarized bolometers with a Silicon superstrate have been demonstrated. In order to add the spectral-polarimetric capability, Fabry-Perot filter banks (fixed or movable) as a superstrate of the detectors would be needed. Description The focus of this activity is in the overview of the different technologies and implementation of the most promising one. In the case of the KIDs detectors, the focus would be in the design of the dual polarization wide band antenna, in combination with the Anti Reflection (AR) coating, where on-chip superconducting circuits are used to spectroscopically detect the radiated power in each independent polarization. In the case of bolometers, the design would benefit from the dual polarized bolometers developed for the B-BOP instrument of SPICA. The focus would be in the design of the Fabry-Perot filter bank, paying attention to the filtering capability, losses of the superstrate and frequency coverage. In the scope of this activity, a focal plane array containing ~10 spatial pixels would be envisaged. Each spatial pixel would consist off an AR coated lens			

with underneath the rest of the detection chain including an antenna, filters and KIDs. In the case of bolometers, the selectivity of 10 different frequencies shall be demonstrated. In order to allow the Focal plane filling, the whole detector chain shall be compact enough to fit under the lens/superstrate. Considering the current CMB channels with typical 20% bandwidth, 4-5 spectral channels could be connected to the feed of a single 1:2 bandwidth lens-antenna. This would allow the implementation of the full FPA with only three kinds of pixels. This would mean a simplification of the FPA by a factor of 2 with respect to the typically considered FPA. Task list: - Requirements consolidation and architecture trade-off - Preliminary design and critical breadboarding - Detailed design and analysis - Manufacturing and integration - Testing - Conclusions and recommendations
Deliverables
Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Voyage2050 - CMB spectroscopy / Technology Push		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: A46 Harmonisation Roadmap: Technologies for Passive Millimetre & Submillimetre Wave Instruments					

Large radii Half-Wave Plate (HWP) development CCN			
Programme:	CTP	**Reference:**	C207-022FI
Title:	Large radii Half-Wave Plate (HWP) development		
Total Budget:	200 kEuro		
Objectives			
To ensure availability of half-wave plates of sufficient dimension to fulfil the requirements of future Cosmic Microwave Background (CMB) polarization missions.			
Description			
The Halve-Wave plate proposed as a polarization modulation element in future CMB missions plays a critical role in the overall system performance.			

This plate is a polarizer modulator which rotates in front of the instruments focal plane. detectors. This component allows to measure the B-mode polarization of the cosmic microwave background radiation. This activity will be targeted to the following main areas: - Study and design of Half Wave Plate (HWP) architectures. - Address critical technological areas identifying potential solutions. - Perform critical breadboard development The activity will start with a careful assessment on the requirements. This activity will identify and select the mechanical, thermal and technological solutions and HWP architectures required to achieve the necessary accuracy and stability for a future CMB mission. These solutions/architectures will have to be demonstrated by critical breadboarding (as a minimum at electro and thermo-mechanical representative sample level). Specific attention will need to be given to: Capability to recover the Stokes parameters, capability for foreground removal, cryo operation (if applicable), cooling, power dissipation, noise, wear/tear, diameter, diameter/thickness ratio, anti-reflection coating. A technology roadmap to bring the technology to flight level shall be provided.
Deliverables
HWP breadboard at sample level, technical data backage

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	CMB Polarisation		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Next generation sub-millimetre wave focal plane array coupling concepts			
Programme:	TDE	**Reference:**	T207-036EE
Title:	Next generation sub-millimetre wave focal plane array coupling concepts		
Total Budget:	400 kEuro		
Objectives			
To develop methods to ensure efficient coupling to large format focal plane arrays.			
Description			
Observation of celestial features by space telescopes benefits from simultaneous data acquisition by co-located multi-frequency focal plane detector arrays. The benefit comes from the ability to use this co-located data to characterise with low systematic errors the foreground signals of celestial bodies, which is useful to extrapolate their signature at other frequencies, and therefore facilitate their removal when searching for background bodies.			

Therefore, focal plane elements that are able to operate in various spectral bands are required. At sub-millimetre wave bands, coupling of incoming radiation onto these focal plane elements is achieved by means of either horns or lenses. However, the relatively large size and number of these elements leads to large focal plane array sizes. A potential future B-mode Cosmic Microwave Background mission could be based for example on a dual-reflector telescope system. However, it is not obvious that dual-reflector systems are able to compensate for all aberrations at large offset positions with respect to the telescope's focal point, therefore making it very difficult to achieve homogeneity of beam patterns across all focal plane detectors. This homogeneity is required to reduce the effect of systematic effects in the combined image obtained by the focal plane array. Therefore techniques to reduce the size of the focal plane are seen as very important enabling technologies. To solve this issue this activity will address the fabrication of multi-frequency/multi-polarization detecting elements. Consequently, the activity shall focus on: - the design of arrays of detecting elements able to operate at various (sub)mm-wave bands and dual polarizations. Methods to interleave several arrays working at different frequencies shall also be investigated. A technology roadmap to bring the technology to flight level shall be provided.
Deliverables
Optimum array layout to reduce size of the focal plane array. Results of the simulations run during the study. Breadboard of representative multi-frequency/dual polarization focal plane array.

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2013
Application Mission:	CMB Polarisation		**Contract Duration:**	18 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
Fully consistent with the following Dossier: Technologies for (sub) millimeter wave passive instruments					

Design and development of an electrically steerable antenna for science missions			
Programme:	CTP	**Reference:**	C207-021EE
Title:	Design and development of an electrically steerable antenna for science missions		
Total Budget:	2000 kEuro		

Objectives
To design, manufacture and characterise a low resource, high performance flat, electrically steerable antenna for science missions.
Description
Meeting the increasing data return requirements of science missions has seen the implementation of dual band communications systems (Euclid, Plato (TBC)) with X-band used for spacecraft telecommand and housekeeping data and K-band being used for science data download. The two downlink channels are fed to a dual frequency antenna which requires articulation via a pointing mechanism. An alternative approach to a standard articulated high gain antenna dish approach is the use of a phased-array antenna which can be hard mounted on the spacecraft body. Such an approach has several potential spacecraft resource advantages, namely low power, low mass, low volume and no moving parts or need for hold down release mechanisms. The approach can be particularly interesting for the case of rotating spacecraft (e.g. Gaia, Planck, L3 mission) This activity will address the design and development of such an antenna tailored to the needs of future science missions. A number of technology approaches will be studied with three solutions taken to component level testing. The two most promising options will be breadboarded. Finally, one antenna design will be further developed and tested to engineering model level achieving TRL 5.
Deliverables
2 breadboard antennas, 1 engineering model antenna, technical data package

Current TRL:	2/3	**Target TRL:**	5	**Application Need/Date:**	2022
Application Mission:	Generic	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Compact HF-VHF tubular deployable antenna			
Programme:	TDE	**Reference:**	T207-051EF
Title:	Compact HF-VHF tubular deployable antenna		
Total Budget:	450 kEuro		
Objectives			
The objective is to develop up to breadboard level a deployable UH-VHF antenna for ground penetrating radar for small planetary missions.			
Description			

Low frequency radar instruments are under study in the framework of a small planetary science missions making use of nanosatellites. The goal is to achieve a global signal penetration for various different penetration depths and measurement positions for Near Earth Asteroid (NEA) of 260-600 m diameter from a few kilometres. A set of identical nanosatellites is deployed and hover around the target providing bistatic measurements with high signal-to-noise ratio for the covered 2MHz bandwidth. The radar centre frequency is 20 MHz. A ground penetrating radar can be embarked within a few units cubesat (about 6U) with an allocation of 1U. The relevant payload makes use of a tubular antenna in a lambda/2 dipole configuration at 20MHz realised by two deployable monopoles of about 3.75 m length. Mass and volume constrains call for compact antenna with reduced stowed volume and reliable deploying mechanism. While the deploying mechanism and the mechanical implementation of a reliable solution for such an antenna have been studied in the last years, the RF implementation including feeding chain is still missing or lack maturity. Moreover, the antenna test presents a set of challenges related to the very low frequency which require large antenna test facility and dedicated set-ups. The activity will include an initial phase aimed at studying the state of the art of deployable tubular antennas focusing on low mass and stowed volume. Antennas RF requirements will be then elaborated and integrated with the mechanical ones. Different concepts will be compared in terms of volume and mass in deployed and stowed configuration taking into account the deploying mechanism reliability and the RF aspect of all the deploying phases with particular focus on the feeding strategy. Performance of the antenna will be simulated and a verification and validation strategy put in place. A fully representative breadboard will be developed to validate the design from both the RF and mechanical point of view. Full test campaign will be performed at the end of the activity.					
Deliverables					
Breadboard					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Ground penetrating radar for small planetary missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Miniaturised antennas for planetary mission probes			
Programme:	TDE	**Reference:**	T207-058EF
Title:	Miniaturised antennas for planetary mission probes		

Total Budget:	450 kEuro
Objectives	
To develop a miniaturised antenna for Entry, Descent and Landing phases of planetary mission probes	
Description	
After Beagle 2 failure, one of the recommendations from the Commission of Inquiry concluded that future planetary entry missions should include a minimum telemetry of critical performance measurements and spacecraft health status during mission critical phases such as entry and descent. In case a relay satellite would be available, the data would be transferred to it, which will act as an Orbiter. Alternatively, a Direct-to-Earth (DTE) link would be required. The Entry Descent and Landing (EDL) is a very specific scenario for communications limited by several constraints: plasma formation, aerodynamic disturbances due to protrusion from probe external mechanical profile, antenna exposure to high temperature, probe attitude, Earth angle coverage, etc. and the antenna has to be able to cope with any possible angular movement of the landing probe. The communication link using conventional omnidirectional antennas is often marginally capable of the required bit rate in the baseline scenarios. Furthermore, the pattern could be strongly affected by the body of the probe and possible shadowing can occur in case only one element is used. Wrap-around conformal antennas are considered a very good alternative in order to fulfil the aerodynamic and RF requirements. They will be integrated on the surface of the backshell and on the surface of the Lander after the backshell is released. This type of antenna will also allow to be highly performing independently of the attitude of the descent landing probe. UHF wraparound conformal antennas have been successfully used on the Phoenix lander during EDL and proposed for Mars Sample Laboratory (MSL). Typically UHF frequency has been considered for the communication with the orbiter, but possible upcoming missions might consider S-band. This activity will start with a critical look at the requirements of the past and upcoming planetary missions and will carefully consider the attitude of the Descent module and lander and its impact on the view angle of the antenna. A trade-off analysis on the optimum communication frequency and antenna performance shall be performed. A preliminary design of a conformal antenna considering a realistic representation of the entry probe and lander shall be performed. The critical components will be identified and critical breadboarding activities carried out. Using these results, a detailed design will be performed, followed by the manufacturing of the full conformal antenna. A full test campaign on a mock-up will be performed and conclusions drawn. A development plan will be established to bring the technology to flight readiness. This activity encompasses the following tasks: - System Requirements - Preliminary design - Critical breadboarding activities - Detailed design - Manufacturing and testing	

- Conclusions and development plan					
Deliverables					
Breadboard, Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022 TRL 6
Application Mission:	Several science missions	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Array Antennas					

Pre-Verification of THOR Electro Magnetic Cleanliness Approach					
Programme:	CTP		**Reference:**	C207-020FM	
Title:	Pre-Verification of THOR Electro Magnetic Cleanliness Approach				
Total Budget:	700 kEuro				
Objectives					
This activity shall address the pre-verification of the electromagnetic cleanliness approach for THOR.					
Description					
The THOR mission has stringent AC electro-magnetic cleanliness requirements that push beyond the JUICE levels. This activity shall address the verification of the requirements and demonstrate a credible pre-verification method to support the down selection process. This may include characterisation of existing equipment, simulations (especially with respect to equipment placement), and definition of specific procedures.					
Deliverables					
Documentation, Simulation Tools/Results					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2018
Application Mission:	THOR		**Contract Duration:**	14 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Assessment of Assembly, Integration and Testing Software Support System for ESA Science Missions			
Programme:	CTP	**Reference:**	C208-001FI
Title:	Assessment of Assembly, Integration and Testing Software Support System for ESA Science Missions		

Total Budget:	950 kEuro				
Objectives					
The ultimate goal of this two phase activity is to develop a feature complete demonstrator of the software support system for spacecraft AIT using the EGS-CC standard and interfacing to the currently used AIT software management systems					
Description					
The International Procedure Viewer (IPV) system has originally been developed for ESA in order to manage and support the performing of daily operational procedures and the recording of manual data by astronauts on board the International Space Station (ISS). The system provides a complete end to end suite of tools for the authoring, distribution and execution of these operational procedures. This activity consisting of two phases will assess the potential use of the IPV system in spacecraft AIT activities. Phase 1 shall address the initial requirements analysis and architecture design/definition of the AIT system. The user/system requirements analysis and architectural design will focus on the key elements of the proposed system. Phase 1 will be executed in close cooperation with the spacecraft prime contractors: TAS, ADS and OHB. Pending a successful Phase 1 the activity shall proceed to Phase 2. Phase 2 shall address the development of a demonstrator system including the appropriate interfaces to existing AIT software management systems.					
Deliverables					
Phase 1: user/system requirements documents, architectural design, interface control document, design justification, design review documentation. Phase 2: demonstrator prototype, supporting technical documentation					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2021
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

End-to-End Performance Simulator Modelling Tool (E2ES Tool)

Programme:	TDE	**Reference:**	T208-003SY
Title:	End-to-End Performance Simulator Modelling Tool (E2ES Tool)		
Total Budget:	350 kEuro		
Objectives			

Provide a generalized simulation framework that enables quick composition and adaptation of building blocks in order to improve the efficiency and effectiveness of the development, adaptation and maintenance of end to end simulators for space science missions.					
Description					
End-To-End mission performance simulators (E2ES) in Space Science have been typically ad-hoc developments to support phase 0/A studies and are usually not maintained throughout mission lifetime. Data processing pipelines are then a separate development started from scratch. The availability of a standard E2ES architecture implemented in a tool, which enables generation of a simulation framework and access to libraries of models, would allow the development of standardized mission E2E simulators, which can evolve from Phase A/B1 to later phases. This concept, E2ES reference architecture and requirements, has been studied in the GSP activity "MISSION PERFORMANCE ASSESSMENT FOR SPACE SCIENCE MISSIONS, CN4000120662) ACTIVITIES - Consolidate tool requirements and architecture, adapting model-based systems engineering (MBSE) tools capabilities for model architecture, configuration and interfaces, key performance indicators at mission level, and exploiting code generation capability - Trade-off and selection between existing technologies (e.g. Capella, Enterprise Architect / SysML, Cameo Systems Modeler, Eclipse EMF based tools, Phoenix Model Center, Matlab/Simulink, IDL, Anaconda Python / R, EcosimPro, Modelica based tools, ...) - Implement the E2E Performance Simulator Modelling Tool - Select, implement and validate a preliminary set of generic building blocks (BB) (e.g. geometry BB) - Implement demo E2ES by integrating in the E2E Simulation Framework (generated by the E2E Performance Simulator Modelling Tool) and the BB developed within this activity OUTPUT The output of this activity will be an editable model, to be provided to the users (scientists), with the capability to generate source code (the E2E Simulation Framework) to jump start development activities. This framework, once populated with Building Blocks (BB), will constitute the E2E performance Simulator (E2ES). The SW shall be distributed under a ESA permissive Community Software License (ECSL Type 3)					
Deliverables					
Prototype; Report; Software; Software					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2019

Application Mission:	Several missions	**Contract Duration:**	12 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Harmonisation Roadmap: System Modelling and Simulation Tools Harmonisation Comments: It will be consistent with the latest version of the System M&S Roadmap, under preparation Consistent with Harmonisation Roadmap: Yes			

Giant planets tour design tools for orbiter/lander applications			
Programme:	TDE (TRP)	**Reference:**	T209-004NA
Title:	Giant planets tour design tools for orbiter/lander applications		
Total Budget:	400		
Objectives			
Research and implement prototype building blocks for giant planets moon tours trajectory design, with a focus on Saturn			
Description			
ESA is involved in giant planets tour design for different mission development levels: it ranges from CDF study (e.g. Ice giants, Io Orbiter) to Phase C/D (JUICE). The program Voyage 2050 proposes fly-by/orbiter/lander missions for giant planets Jupiter and Saturn. Even a sample return mission is being considered. For Voyage 2050, the mission goals and the dynamical environment are different from JUICE. They require research on specific algorithms and the associated software building blocks for the mission analysis software, which do not exist yet at ESA. The different building blocks required for the tour design depend on the mission objectives. In the frame JUICE, some of them have been developed: the planet capture including single moon fly-by, the pseudo-orbiter technique to perform moon coverage, the ladder technique between two moons to save DeltaV, the low energy endgame to minimize the propellant consumption to capture around a moon. Extension of these blocks or development of new blocks will be useful if not mission enabling for other missions, especially to Saturn. As examples, one can cite the planet capture including double moon fly-bys, the retrograde capture around the planet, the non-tangent fly-bys for moons with low gravitational constants, the mixing of low and high energy regime for the endgame. These extension or creation can serve multiple applications, e.g. DeltaV efficient tours with moons of low gravitational constant [Saturn], mixing high and low energy endgames [Saturn/Jupiter] or fast routes -due to radiations - for moon landing [Jupiter]. A lot of research has been invested to develop the abovementioned building-			

blocks and related tools for the specific case of JUICE. It is interesting to note that research for this mission is still on-going, one year before launch: tour design is still a domain on the edge of research. Some tools could be reused for a Saturnian moon, but there is a clear research/development gap to fil in order to design optimal tours for Saturn. The activity would focus on the research connected to the required extension or creation of building blocks. A bibliographical work should be performed, the algorithms documented; the activity should also lead to the creation of prototype software. Example tools sets related to the Voyage 2050 mission goals, especially missions to Saturn, would be assembled for demonstration.
Deliverables
Report; Software

Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Voyage 2050 - Recommendations for Large Mission Science Themes: - Moons of the Giant Planets	**Contract Duration:**	18		
S/W Clause:	Operational S/W				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Contribution to Machine Learning for Science Operations Virtual Assistants			
Programme:	CTP	**Reference:**	C209-002OP
Title:	Contribution to Machine Learning for Science Operations Virtual Assistants		
Total Budget:	100 kEuro		
Objectives			
The main objective of this activity is the development of intelligent agents (based on Artificial Intelligence) able to process natural language and able to automate tasks in some of the Science Operations (SCI-O) portals.			
Description			
This activity shall develop intelligent agents able to process natural language and to automate tasks in some of the SCI-O portals. The agents shall be trained with machine learning techniques so that the agents contain the knowledge of the tasks for which they have been trained for. The agents will then have the capability to assist current users of the SCI-O portals to perform the desired portal tasks or act as an e-learning platform for new portal users. The work shall include: system concept and technology selection; design; implementation; preliminary verification			

Deliverables					
Report (technical data package including User Manual for alpha version).					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Several science missions	**Contract Duration:**	14 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Optical communications for Voyage 2050 missions			
Programme:	TDE (TRP)	**Reference:**	T212-062NA
Title:	Optical communications for Voyage 2050 missions		
Total Budget:	300		
Objectives			
a) Addressing and demonstrating the benefits of optical communication for a Saturn mission scenario by deriving space and ground systems as well as operational scenarios. b) Prototyping one technical building block for the derived system. c) Establishing a technology roadmap to implement such a communication system for a Voyage 2050 mission and estimate its associated cost.			
Description			
The Agency and specifically its science directorate have announced the selected themes for Voyage 2050 in the SPC paper ESA/SPC(2021)20. This proposal focuses on the future large missions, whose selection is more defined and conclusive in the above paper. The three future large missions will comprise a mission to one of the Giant planets like Saturn, located at ~11AU. From a communications point of view, the Saturn scenario offers a unique opportunity to introduce optical communications beneficially. Optical communication could ensure substantial scientific data return of larger magnitude than achievable with radio frequency (RF) communications. - Task 1 will focus on addressing technical analysis for a Saturn mission scenario based on high-level link budget considerations and initial but sound considerations about power consumption, mass, and accommodation for the onboard optical terminal. A set of prominent design characteristics of the optical link (space and ground) shall be addressed. The output of this first task is a technical design note detailing the implementation of an optimal optical communications subsystem in charge of science data return, with a sound description of all related interfaces and budgets. All required layers of the communications protocols stack are designed and described. The inclusion of optical uplink capabilities is explored in terms of aid to concept of operations (CONOPS) and concerns potential use for telecommands and			

two-way ranging. - Task 2 focuses on breadboarding one critical technology building block, as identified in the first task. The following critical building blocks have already been identified by the Agency: a) Precision pointing system relative to the optical ground beacon b) Safe implementation of telecommands via the optical uplink c) TBC (to be finalized at preTEB). The contractor shall select one building block, either from the list of the Agency or one proposed and justified in their proposal. - Task 3 defines a technology and investment roadmap of the onboard and ground systems identified in task 1. In particular, all missing elements and gaps enabling the adoption of the technology for the Saturn mission scenario and the required investments allowing the build-up of a European operational capability. The output of this task is a technology and investments roadmap tailored to the Saturn mission scenario.
Deliverables
Breadboard; Report; Report; Report; Report

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	The identified themes from Voyage 2050 indicate a potential benefit from the use of optical communications in terms of achievable data rate and data volume transfer as well as of reduced size, weight and power of the on-board terminal, compared to traditional RF solutions.		**Contract Duration:**	12	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: D10 Harmonisation Roadmap: Optical Communication for Space Harmonisation Comments: Second harmonisation dossier to be referenced: ground station technology harmonisation Dossier

Photon-Counting Ground-based Optical Communications Detector			
Programme:	CTP	**Reference:**	C212-002GS
Title:	Photon-Counting Ground-based Optical Communications Detector		
Total Budget:	400 kEuro		

Objectives
The objective is the development of a European very high-bandwidth, single photon-counting detector for deep-space optical communications at 1550nm.
Description
Future missions are currently being proposed / designed with existing (or moderately improved) Space-to-Earth communication capabilities in mind. Optical communications technology offers the potential of a dramatic increase in data-rates, specifically in the down-link of science data, thereby allowing for a substantial increase in science return. Direct detection technology using pulse position modulation (PPM) is regarded as the preferred solution for "deep space" optical links. The two primary wavelengths being considered are 1064nm and 1550nm. Among the challenges to be addressed prior to any implementation of an operational Deep-Space optical terminal is a highly sensitive, high-bandwidth optical detector. Single-photon counting detection capability is required for distances of several AU, and offers the best link efficiency even for much shorter distances (e.g. Moon). Such a detector reduces the resource (power) requirements of the on-board terminal making it an attractive alternative to its RF counter-part. The aim of this activity is to develop such a detector based on super-conducting nano-wire technology for optical communications at 1550 nm with a bandwidth of at least 2 GHz (10 GHz goal, TBC). Critical areas to address are: - stable production process and reproducibility - electro-optical and electrical performance (QE / detection probability, false-alarm probability / dark counts, high band-width etc.) - operational and life-time considerations (operating temperature, stability, etc.)
Deliverables
Breadboard detectors, technical data package including test results.

Current TRL:	2	Target TRL:	4	Application Need/Date:	2020
Application Mission:	Several		Contract Duration:	30 months	
S/W Clause:	NA				

Consistency with Harmonisation Roadmap and conclusion:
AIM-D "Deep Space Data Return" in harmonization theme "Optical Communication for Space"

X-Band Feed 80 kW Breadboard for ESA Deep Space Antennas			
Programme:	TDE	Reference:	T212-054GS
Title:	X-Band Feed 80 kW Breadboard for ESA Deep Space Antennas		

Total Budget:	250 kEuro
Objectives	
To perform a preliminary RF, thermal and mechanical design of the new uplink feed system to transmit 80 kW continuous wave in X- Band and to manufacture and test a breadboard of critical feed components, reusing results from T912-005GS and T212-050GS.	
Description	
The ESA Deep Space Network consists of three 35m beam waveguide antennas located around the globe. The 35m beam waveguide antennas employ an X-Band feed covering the Deep Space uplink band near 7.2 GHz and down-link band near 8.45 GHz. Simultaneous uplink commanding at 20 kW and low noise reception (Generation #2) is supported. In order to increase the transmit power capability of ESA Deep Space antennas it is currently considered to add a new high power feed and associated 80 kW High Power Amplifier. The following activities are envisaged: - Trade off between two different feed topologies (traditional versus turnstyle) - Preliminary design of the selected feed topology - Manufacturing and testing of critical components - Documentation (design documents, test procedures and test reports) The activity shall consider the integration of a) X-Band cryo feed prototype receive section (from T912-005GS) b) Standard existing X-Band feed receive section with cryo LNA generation #2	
Deliverables	
Breadboard of critical components of the X-Band 80 kW feed Documentation	

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	Generic, Deep space missions	**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Yes, activity K02 of the Ground Stations Technology Harmonisation Dossier, presently under discussion in the 2015 cycle					

High power (80 kW) X-band Uplink for DS Missions - Development of critical waveguide components			
Programme:	TDE	**Reference:**	T212-059GS
Title:	High power (80 kW) X-band Uplink for DS Missions - Development of critical waveguide components		
Total Budget:	500 kEuro		

Objectives					
To develop critical waveguide components required to transport high power in RF (80 kW) from the High Power Amplifier (HPA) to the feed system. Waveguide components shall operate over the full 7145 - 7235 MHz X-Band uplink band.					
Description					
Present ESA Deep Space Stations are equipped with a 20 kW X-Band High Power Amplifier (HPA). Future missions will demand larger uplink power levels, for distant spacecraft or for critical phases like entry descending and landing or for emergency situations. Previous GSP activities concluded that the only viable way to increase the Uplink performances is providing the Deep Space Terminals with an 80 kW transmitter. Critical waveguide components have been identified in a previous TDE activity requiring dedicated development: power loads, waveguide switches, waveguide couplers and waveguide runs. This activity shall start with the consolidation of the requirements, followed by a preliminary and a detailed design phase. Prototypes shall be built and tested against requirements and results summarized in test reports.					
Deliverables					
Breadboard, technical datapackage					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	TRL 9 by 2022 (JUICE)	**Contract Duration:**	18 months		
S/W Clause:					
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

High rate flexible high-order SCCC communications system for Science X-band			
Programme:	TDE	**Reference:**	T212-057GS
Title:	High rate flexible high-order SCCC communications system for Science X-band		
Total Budget:	450 kEuro		
Objectives			
To develop a High Order SCCC communications system (SCCC modem) in the spacecraft transponder and in the ESTRACK TTCP modem to support missions incorporating the ACM modes of the CCSDS-131.2-B recommendation thus increasing data return.			
Description			
ESA missions with downlink in X-band are limited to 10 MHz of bandwidth and 8.75 Mbps of data, using the current GAIA modulation. GAIA-NIR is requiring higher data rates and it is pushing the limits at X-band. The CCSDS-131.2-B standard defines 27 Adaptive Coding and Modulation (ACM) modes that are intended to allow fine control of information rate in a			

given bandwidth to optimise data throughput by minimising the required link margin. A variable rate (0.36 to 0.90) Serial Concatenated Convolutional Code (SCCC) encoder is followed by a transmitter which maps 2 (QPSK), 3 (8 PSK), 4 (16 APSK), 5 (32 APSK) or 6 (64 APSK) bits onto each modulation symbol to accommodate steps of the order of 1 dB in link performance whilst maintaining a constant FER over a range of around 20dB. The high spectral efficiency modulations are having up to ~5 Mbps per MHz of available bandwidth that will allow to extend the capability and meet the GAIA-NIR needs. CCSDS spring meeting will analyse a modification of Rec 2.4.17.A to add ACM modes up to to ACM 17 (16 APSK) of coding and modulation in the X-band Space Research portfolio of selectable modulations. This study will: 1) produce and refine the requirements for the SCCC modem in the spacecraft transponder and in the ground station receiver, taking into account the complete communications system and the roadmap of the on-board transponder development plan. 2) prepare a transmitter breadboard from existing blocks of previous on-board transponder developments. 3) design the different elements in the ground receiver modem (i.e. synchronisation chain, channel equalizer, APSK demodulator, SCCC decoder and auxiliary elements) and implement them in a ground receiver prototype. The prototype of the ground receiver will be designed to allow smooth incorporation of the SW and FW in the TTCP. 4) perform end-to-end validation between SCCC transmitter and the ground prototype, tested against the requirements refined in the first task.					
Deliverables					
Ground station receiver prototype, breadboard of the transmitter, technical datapackage,					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	Several science missions, missions with limited data rate capability of X Band and those that would benefit of an enlarged capability without the penalty of a 26 GHz payload (like Euclid or Plato).	**Contract Duration:**	24 months		
S/W Clause:	Operational S/W				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Pre-development of de-spin mechanism of IR astrometry mission			
Programme:	TDE (TRP)	**Reference:**	T215-018NA

Title:	Pre-development of de-spin mechanism of IR astrometry mission				
Total Budget:	500				
Objectives					
To design and develop at breadboard level a mechanism allowing to maintain a steady image on the focal plane of a spinning IR astrometry satellite and reproducing the behaviour of a detector working in TDI (Time Delay and Integration) mode.					
Description					
Astrometry in the near-IR is mentioned in the Voyage 2050 recommendations from the Senior Committee as one of the techniques to fulfil the science theme: "From Temperate Exoplanets to the Milky Way". A study on Astrometry in Near-IR (named GAIA NIR) has been performed in 2017 in the ESTEC Concurrent Design Facility as part of the call for new science ideas in the SCI directorate . For such mission, there are basically two mission options: 1. Similar to GAIA but requiring the availability of IR detector that can work in TDI (time delay and integration) mode, 2. Based on standard IR detectors but with the use of a de-spin mechanism to keep the image steady in the focal plane while the SC scans the sky. The preliminary requirements of such mechanism point to the need of a new development which is the subject of this proposed activity. In particular, this activity shall encompass: 1. Specifications, design and overall engineering of the mechanism 2. Design Manufacturing of Breadboard 3. Functional and low temperature (140 K) testing of the breadboard The activity will allow assessing the feasibility and performance of such concept for IR astrometry					
Deliverables					
Breadboard; Report					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Voyage 2050 theme: "From Temperate Exoplanets to the Milky Way"	**Contract Duration:**	18		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Large stable deployable structures for future science missions			
Programme:	CTP	**Reference:**	C215-121MS C215-121MS-B
Title:	Large stable deployable structures for future science missions		

Total Budget:	1500 kEuro

Objectives

The objective of this activity is to develop and test a breadboard of an ultra-stable deployable structure.

Description

In the case of X- and Gamma-ray telescopes, the energetic nature of such photons means that focussing can only be done at grazing incidence angles, hence requiring focal lengths of the order of several meters to tens of meters, well beyond the size of existing launcher fairings. A deployable mast would therefore allow, once in orbit, to achieve the required focal length by deploying either the focal plane instruments or the optics (e.g. JAXA's Astro-H).

There is a growing need for a European deployable mast system, adaptable for potential use on different applications. Deployable masts already have a flight heritage outside Europe (e.g. the ADAM mast in the USA or the HALCA mast in Japan). The objective of the proposed TDA is to reach TRL 5 by 2015 with a flexible and scalable design solution, for which the range of requirements is described below.

Requirement Range: Deployment capability L 10 - 20 m (goal of 10 to 50 m)
Packaging ratio < 0.1 (goal of <0.05)
Mast diameter D 0.3 to 1 m (goal of 0.3 to 3 m)
Mast mass < (LxD) x 12 kg.m-2 (goal of < (LxD) x 8 kg.m-2)
Platform to-be-deployed mass 50 to 1000 kg
Deployment accuracy < L x 10E-4 (goal of < L x 10E-5)
First eigen frequency of deployed s/c > 1 Hz
Deployed mast system structural damping ratio > 2%
Operating temperature (including deployment) -10 to +30 C (goal of -60 to + 60 C)
Linear coefficient of thermal expansion < 5.10E-6 / C (goal of < 1.10E-6 / C).

The objective of the activity is:
- Phase 1: trade-off the possible technologies and to pre-design the ultra-stable deployable structure
- Phase 2: detailed design, manufacture and test in a relevant environment, a 1-to-1 scale breadboard model of the ultra-stable deployable structure

Phase 1 will consist of 2 competitive parallel contracts of 250 kEuro each.
Phase 2 will consist of a single contract of 1000 kEuro.

Deliverables

Phase 1: Review of the state of the art, technology trade-off, preliminary design
Phase 2: Reports including design report, breadboard procurement plan, manufacturing drawings, validation and test plan, test data and assessment of the results, breadboard, simulation/test videos.

Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	Several		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development of a high performance microvibration isolation system			
Programme:	TDE	**Reference:**	T215-011MS
Title:	Development of a high performance microvibration isolation system		
Total Budget:	350 kEuro		
Objectives			
Mechanical disturbances drive system level choices on science missions. Drastic reduction of microdisturbances can simplify the spacecraft design and enable missions with more sensitive payloads. For example, high performance isolation systems for reaction wheels could avoid the need for hybrid AOCS system using expensive cold gas propulsion systems (ARIEL). The proposed technology should be suitable for all noise sources, or to isolate the sensitive payload itself. The isolation system should be high performance, low mass, low cost, low power, low complexity and versatile (tuneable/scalable).			
Description			
Typical isolation systems currently used are limited to passive isolators, based on viscoelastic elements. Other passive existing technologies include eddy-current dampers, the so-called D-struts and shunted piezo electric transducers. Active systems include voicecoil and piezo actuators and active eddy current dampers. This proposal is prompted by recent developments in the frame of TEC Technology Assessment supported work on electromagnetic shunt dampers connected to a negative resistance circuit showing promising performances. However, multiple promising competing technologies are under development in Europe and the TDA is open to all technologies fulfilling the following criteria: - Limited amplification of system resonances (~3dB) - 20 dB attenuation @ 20Hz, 50-60dB attenuation @ 100Hz, 80-90dB attenuation @ 200Hz . (Best existing systems provide 40dB @ 100Hz, but have not been flown.) - Low/predictable temperature dependence of isolation performance - Low complexity/ high reliability - Low mass, 25-75% of mass of isolated equipment - Low power consumption - Magnetically clean - Tuneable/scalable (to avoid complete system redesign as is currently the case for passive isolators)			

This activity aims to take the newest technologies demonstrated in the laboratory or via analysis and develop a full scale breadboard for one application (e.g. reaction wheel isolation). A typical configuration for these isolation systems is in the form of a hexapod, using 6 struts. The following tasks will be performed: - Selection of the application (e.g. reaction wheels, cryo coolers, payload isolation) - Design of a full-scale breadboard - Modelling and simulation/analysis of isolation system performance - Functional validation at strut level - Functional validation at hexapod level, including assessment of tunability
Deliverables
Functional breadboard model including electronics (if applicable)

Current TRL:	2-3	**Target TRL:**	4	**Application Need/Date:**	
Application Mission:	ARIEL, others		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
The ESA Technical Dossier on AOCS Sensors and Actuators covers microdisturbances in the following development aim: RW - Development Aim A02: Micro-disturbance sources and characterisation					

Development of a Large Angle Flexible Pivot for Science Applications			
Programme:	CTP	**Reference:**	C215-127FT
Title:	Development of a Large Angle Flexible Pivot for Science Applications		
Total Budget:	750 kEuro		
Objectives			
The objective of this activity is to develop a Large Angle Flexible Pivot (LAFP) meeting the needs of future science mission applications.			
Description			
Frictionless rotational bearings or "pivots" were developed in the 1950's and have been since widely used as key engineering components for multiple applications, including in space (e.g. on Sentinel-3, MTG, Hershel, etc). Their working principle relies on the material elasticity of the internal blades to offer a limited rotational oscillatory motion without any sliding contact. The absence of friction and wear allowed the device to be lubrication-free which led to numerous advantages such as an extended service life and no particle generation. Current flexible pivots commercially-available for space applications are uniquely sourced from the US and are ITAR-classified. Notwithstanding the advantages, the currently available pivot technology has a number of limitations, including limited angular movement range, launch			

load survivability requiring oversizing, significant pivot centre shift limiting positional resolution, etc. The first task of this activity is to study a number of reference science applications e.g. filter wheels, scanning mechanisms, mirror positioning and derive the requirements on a flexible pivot based system. This shall include a detailed trade-off on the advantages of using pivot technology. Based on the results of the first task a flexible pivot engineering model shall be designed, manufactured and tested with the goal of demonstrating TRL 6. The pivot shall address the limitations of the current technology and shall aim to have large angular range (at least 45 degrees), life expectancy of at least 50 million cycles, centre shift of less than 10 microns, integrated launch load protection, linear motion over full range. The third task shall address the development of a roadmap for production of a flight model LAFP.					
Deliverables					
EM LAFP, test results, technical data package.					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Piezoelectric motors tribology for space scientific applications			
Programme:	TDE	**Reference:**	T215-014MS
Title:	Piezoelectric motors tribology for space scientific applications		
Total Budget:	350 kEuro		
Objectives			
To identify and characterize piezo motors tribological solutions suitable for usage in space scientific environmental conditions (e.g. Thermal Vacuum).			
Description			
Piezoelectric motors usage in space applications is currently very seldom despite their attractiveness in terms of performances. Main disadvantage of linear and rotative piezo motors lies in their intrinsic use of friction for the achievement of their performances, which is of concern in terms of repeatability, reliability and sensitiveness to space environmental conditions. The major benefit deriving from this activity would be to raise the confidence in piezo motors technology performances when considered for space scientific applications. The project shall cover the design, manufacturing and test of piezoelectric motor breadboards with special attention to tribological surfaces behavior			

characterization when exposed to different working conditions in terms of environment (e.g. vacuum, thermal range or radiation) and loads. This activity encompasses the following tasks: - Identify existing piezoelectric motors for terrestrial and space applications. - Identify technology limitations in terms of functional performances and reliability of the tribological surfaces - Trade off and downselection of the most promising solutions (minimum 2) considering a generic application for scientific instrument. Scalability and modularity of the solution shall also be taken into account. - Design and manufacturing of chosen piezo motors BBs - Extensive test campaign on BBs under thermal vacuum and radiative environment for different loading and frequency conditions. Expected deliverables from this activity are breadboards models tested in representative environment with comprehensive reporting of the outcome of the activity and recommendation for future activity in this field, targeting a specific solution
Deliverables
Breadboard, Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Several science missions		**Contract Duration:**	18 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
Yes, Electrical Motors and Rotary Actuators, D5, D6					

Nulling interferometry techniques with single telescope			
Programme:	TDE (TRP)	**Reference:**	T216-172NA
Title:	Nulling interferometry techniques with single telescope		
Total Budget:	250		
Objectives			
To explore alternative nulling interferometry techniques with a single mid-Infrared telescope, providing preliminary optomechanical designs and performance assessments as well as technological roadmaps for potential implementation in a L-Class Temperate Exoplanet Characterisation in line with the corresponding Voyage 2050 theme.			
Description			
The level of contrast needed for the imaging and characterisation of Earth-like exoplanets is out of reach of current technologies. Most prominent architectures for future high-contrast imaging/characterisation of exo-Earths are either based on coronagraphy (e.g. LUVOIR, HABEX, EUVO) or multimirror nulling interferometry. A potential solution is the use of a coronagraph including internal active			

optics with high number of actuators (e.g. LUVOIR). A promising alternative is nulling interferometry using either 2 spacecrafts or 2 mirrors deployed at large distance. A presentation on such a concept (LIFE) was given at the latest WITSO workshop 2019.

However, nulling interferometry techniques also exist for a single telescope either with single aperture (e.g. common path shear interferometers in sagnac or mach-zehnder configurations, point diffraction) or deployed dual apertures. This single-telescope approach has been less present in recent literature and its study would allow to open the range of possible mid-infrared implementations of L-class missions dedicated to temperate exoplanet characterisation, possible decreasing the complexity presented by the current 2 most prominent approaches.

This activity would assess the feasibility of such a concept, with a preliminary design and performance assessment, maturity analysis of the main payload bricks and technological roadmap towards TRL 6.

The study would encompass:
- optomechanical preliminary design
- performance assessment with analytical demonstration of suitability to the need.
- technological roadmap towards implementation in a L-Class mission

Deliverables					
Report					
Current TRL:	1	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	Mission need: Voyage 2050 L-class theme "Characterisation of Temperate Exoplanets"		**Contract Duration:**	18	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: %					

Prototype NIR/SWIR large format array detector development.			
Programme:	TDE	**Reference:**	T216-048PA
Title:	Prototype NIR/SWIR large format array detector development.		
Total Budget:	2000 kEuro		
Objectives			
Development of a prototype large area NIR/SWIR detector array using hybrid technology.			
Description			
Both dark energy missions propose the use of the Teledyne Imaging Systems Hawaii-2RG detector and SIDECAR ASIC. These activities would			

lead to a European supply of NIR/SWIR detector technology for both these and future science missions. This programme aims at developing a prototype large area hybrid array comprising silicon read-out integrated circuit and HgCdTe photovoltaic sensing layer.
Deliverables
Laboratory prototype of hybridised HgCdTe/CMOS ROIC detector.

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2013
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Optimised ASIC development for large format NIR/SWIR detector array.			
Programme:	CTP	**Reference:**	C216-017PA
Title:	Optimised ASIC development for large format NIR/SWIR detector array.		
Total Budget:	1000 kEuro		
Objectives			
Further development of a cryogenic, control and digitisation application specific integrated circuit predominantly for optimised large area NIR/SWIR detector hybrid.			
Description			
Following on from the prototype development programme this project would be to develop an optimised and characterised control and digitisation ASIC to match the optimised hybrid array development.			
Deliverables			
Optimised and characterised control and digitisation ASIC for NIR/SWIR detector array.			

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Novel In-Vacuum Alignment and Assembly Technologies for Optical Assemblies			
Programme:	TDE	**Reference:**	T216-103MM

<table>
<tr><td>Title:</td><td colspan="5">Novel In-Vacuum Alignment and Assembly Technologies for Optical Assemblies</td></tr>
<tr><td>Total Budget:</td><td colspan="5">400 kEuro</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">The activity shall develop and test novel technologies for the alignment, assembly and integration of optical assemblies under vacuum.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Many astronomical space missions observe at wavelengths which are absorbed by the atmosphere, as for example some infrared, ultraviolet or x-ray bands. Especially UV and x-ray optics have very stringent alignment tolerances due to the small wavelengths. Consequently, telescopes and instruments can only be tested at their operational wavelengths under vacuum conditions. Traditional methods for fixing optical elements and subassemblies (e.g. gluing, soldering, welding, laser based methods) are executed under atmospheric conditions and by using reference interfaces or other wavelengths to ensure their correct alignment. Being able to perform critical alignment steps under vacuum conditions at the design wavelengths would be the most direct and accurate way and reduce risks associated with indirect alignment methods or using in-flight mechanisms for alignment corrections.
The activity shall:

(1) Review existing alignment and bonding technologies for optical elements and subassemblies and evaluate their suitability for being used under vacuum conditions including an assessment of the mechanical, thermal and contamination properties of the methods. This shall include a wide range of optics and subassemblies (e.g. size, wavelengths, materials) and technologies (e.g. gluing, soldering, welding, laser based methods).

(2) Design test setups and samples for different technologies and perform alignment and assembly tests on different optical samples under vacuum (and under atmosphere as references). This shall include the measurement of the alignment accuracy, the interface strengths, contamination of optical surfaces and their effects at the design wavelength.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">TNs, test samples</td></tr>
<tr><td>Current TRL:</td><td>2</td><td>Target TRL:</td><td>4</td><td>Application Need/Date:</td><td>2018</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Generic</td><td>Contract Duration:</td><td colspan="2">18 months</td></tr>
<tr><td>S/W Clause:</td><td colspan="5">N/A</td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6">N/A</td></tr>
</table>

Joining process for manufacturing of large Aluminum-based optical mirrors			
Programme:	TDE	**Reference:**	T216-111MM
Title:	Joining process for manufacturing of large Aluminum-based optical mirrors		
Total Budget:	250 kEuro		
Objectives			
To develop a joining process for manufacturing large, low roughness optical mirrors in Aluminium-based alloys.			
Description			
Aluminum-based alloys obtained by a rapid solidification process have been successfully used for manufacturing optical mirrors. The maximum size of this type of aluminum mirrors is limited by the size of the billet, i.e. currently considered to be approximately 500 mm with and homogenenous microstructure. Consequently, the current manufacturing processes allow to produce mirrors with an effective area limited to a maximum dimension of 400 mm. The need for larger Aluminum-based mirrors is coming from scientific missions that require a large collecting area. The mirrors manufactured with rapidly solidified aluminum alloys are easy to polish down to nm scale roughness, possible due to their fine grain size. In addition, such mirrors have high thermal conductivity, good specific stiffness, and relatively low cost compared to optical ceramics. Furthermore, aluminum-based mirrors can easy match the CTE of scientific instruments, often manufactured in aluminum alloys. A possible way of increasing the attainable size of aluminum mirrors is to join together multiple mirror segments and to polish the mirror to the required surface roughness. Conventional fusion welding techniques applied on aluminum alloys would melt the parent metals and remove the fine-grained structure of rapidly solidified alloys. As a consequence, the polishing of the mirror will result in non-homogenenous surface roughness in the weld areas. Recent developments have made processes available which limit the impact on the parent materials microstructure and the residual stresses in the joint e.g. solid state joining processes. The objective of this activity is to develop a process for joining segments of optical mirrors in aluminium-based alloys. The selected process shall give the possibility to achieve nm scale roughness while minimizing thermal stresses in the mirror structure. The activity shall encompass the following tasks: - Trade-off to identify suitable Al-based alloys and joining methods.			

- Joining trails at specimen level for parameter optimization - Manufacturing of Al-based mirror demonstrator by joining a minimum of 3 segments. - Polishing of the demonstrator Al-based mirror. The mirror shall have an useful area corresponding to a diameter of at least 300mm and a shape representative of a telescope mirror, e.g. parabolic, spherical. - Testing and characterization of a demonstrator Al-based mirror. Test shall include surface roughness, shape accuracy (below 40 nm), thermal stability, CTE, specific stiffness, mechanical properties.
Deliverables
Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Low temperature space telescope for Exoplanet observation.	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Design and testing of Far and Medium Ultraviolet coatings			
Programme:	TDE	**Reference:**	T216-112MM
Title:	Design and testing of Far and Medium Ultraviolet coatings		
Total Budget:	400 kEuro		
Objectives			
The goal of this study is to extend the current European capabilities for space-qualified coatings for Medium UV (120-220nm) down to Far UV (90-120nm). The objectives are: - a thorough state-of-the-art survey of European capabilities for coating and characterization in the MUV and FUV, - to design, produce and characterise coating samples in MUV and FUV. This would enable the development of future Science FUV/MUV instruments, incl. reflective coatings, dichroic, AR.			
Description			
The availability of European-sourced Space-qualified coatings for the Medium and Far UV bands is a potential issue for future Science projects involving those wavelength range. This activity will first perform a comprehensive survey of the European capabilities in terms of MUV and FUV (manufacturing & characterisation). Furthermore, after identification of typical performance needs for such coatings, the activity will contain the design, manufacturing (samples) and characterisation of coating samples (typically, reflective, anti-reflection, and potentially dichroic)			
Deliverables			

Breadboard; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	Future Science FUV/MUV instruments (also EO), incl. reflective coatings, dichoics, AR	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Yes, Coatings Harmonisation Roadmap					

Miniaturised frequency comb for science mission applications					
Programme:	CTP		**Reference:**	C217-058MM	
Title:	Miniaturised frequency comb for science mission applications				
Total Budget:	600 kEuro				
Objectives					
The primary objective of the project is to develop a new micro-comb technology based on the integration of micro-resonator and gain switched combs, and to explore it's potential as a technology for future space science applications.					
Description					
Optical frequency combs are becoming an increasingly important tool for many scientific experiments because they link the optical and microwave domains, allowing coherent phase locking of signals from each domain. Such phase-locking allows light cycles to be counted using microwaves in high-frequency metrology applications such as atomic clocks, and allows precise optical frequencies to be generated from microwaves in optical synthesisers. Other applications of frequency combs include astronomical spectrometer calibration, dual comb spectroscopy and imaging, atom interferometry, and coherent telecommunications. In this activity, a survey of science mission applications will be conducted with space instrument calibration, fundamental physics payloads and THz carrier generation being included. Following initial technology concept validation, the building blocks will be integrated into a prototype breadboard. The performance of this breadboard will be validated against the application case requirements. Finally a roadmap for further development will be developed.					
Deliverables					
BB, Technical Data Package					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2030

Application Mission:	Several	**Contract Duration:**	24
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			

TRL and Performance enhancement of Large-format NIR APD Arrays for Astronomy					
Programme:	TDE (TRP)		**Reference:**	T217-073NA	
Title:	TRL and Performance enhancement of Large-format NIR APD Arrays for Astronomy				
Total Budget:	1000				
Objectives					
Performance extension, ROIC optimisation and TRL enhancement of large-format NIR avalanche photodiode array.					
Description					
Mercury cadmium telluride (MCT) detectors have established themselves as the main sensor choice for space applications in the infrared, in particular in the SWIR waveband. For low-signal and photon starved applications, the sensitivity baseline is typically set by noise limit of the readout integrated circuit. This limit can be overcome through the implementation of avalanche photodiodes (instead of standard photodiode) which have an in-built, effectively noiseless gain mechanism which boosts the signal above the ROIC baseline. The APD array development is the subject of an on-going activity, due to complete in Q2 2022. At the end of the on-going activity, there will be a decision on the exact strategy of TRL and performance enhancement, which is the subject of this follow-on activity. Currently, the targeted objectives that are envisaged are the following: 1. ROIC optimisation. 2. TRL enhancement through the development of a flight-type package and subsequent environmental validation. The work shall be organised into the following tasks: Task 1: Detector specification review. Task 2: Preliminary detector design. Task 3: Detailed detector design. Task 4: Detector manufacture. Task 5: Detector characterization including radiation testing Task 6: Evaluation, conclusions and recommendations.					
Deliverables					
Engineering Model					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2023
Application Mission:	Photon-limited astronomy missions requiring high-performance imaging in		**Contract Duration:**	24	

	the Visible-SWIR wavebands.		
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: Yes Harmonisation Roadmap Reference: A18 Harmonisation Roadmap: Optical Detectors, IR Range			

Delta-development of PLATO CCD detector for SMILE Soft X-ray Imager			
Programme:	CTP	**Reference:**	C217-064FV
Title:	Delta-development of PLATO CCD detector for SMILE Soft X-ray Imager		
Total Budget:	1900 kEuro		
Objectives			
The SMILE CCD detector for the X-ray imager is derived from PLATO CCD with a few modifications. The objective is to implement the design modifications and perform the minimum delta-qualification tests that are required for the SMILE mission. The activity must be completed by Q4 2019 for enabling SMILE implementation schedule			
Description			
The SMILE SXI CCD (CCD370) will be a modified version of the CCD270 currently baselined for the PLATO mission and working in the visible wavelength range. The CCD370 has the same format as for PLATO CCD270 with identical mechanical package and flexi. A few low-risk modifications are needed for enhancing SMILE X-ray imager detection performance in the expected radiation environment, among which are: implementation of a high responsivity output amplifier, reduced channel width of the serial read-out register, implementation of a supplementary burried channel and the removal of the anti-reflection coating. The CCD380 (defined as the equivalent of the CCD280 for PLATO, i.e. small version of the CCD270 with identical electro-optical performances) will have the same electro-optical performances as the CCD370 and will be used essentially for the Lot Acceptance Tests and early performance evaluation by ESA and the SMILE consortium. The activity aims at designing the CCD370 and CCD380 , respectively from the 270 and 280, manufacturing test devices as well as performing a reduced lot acceptance test. The CCD370 will directly benefit from the on-going CCD270 qualification and therefore will see no specific validation. The development and tests are streamlined to the minimum need and simplified where possible by taking full benefit of PLATO CCD270 extensive qualification tests. As a result, the activity is expected to naturally deliver 6 CCD370, which can be directly used for SMILE development (nominally 2 FM, 1 FS, 3 EM) and 7 CCD380.			

Deliverables					
6 CCD370: 2 FM, 1 FS, 3 EM, 7 CCD380					
Current TRL:	4	**Target TRL:**	7	**Application Need/Date:**	2019
Application Mission:	SMILE		**Contract Duration:**	29 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development and cryogenic testing of MWIR detectors					
Programme:	CTP		**Reference:**	C217-063MM	
Title:	Development and cryogenic testing of MWIR detectors				
Total Budget:	1000 kEuro				
Objectives					
The main objective of the activity is to develop and characterise detectors in the Mid Wave Infrared (MWIR - 2 to 8 um) wavelength range, operating at 40 K with performances meeting the requirements of potential future science missions.					
Description					
Potential future science missions (e.g. Ariel) require high-performance detectors operating at 40 K in the MWIR wavelength range (2 to 8 um). Previous investigations have demonstrated that the quantum efficiency and dark current of existing Mercury Cadmium Telluride (MCT) detectors do not meet the necessary performance requirements at the required operating temperature. The aim of this activity is to: - examine possible solutions to design a detector matching Ariel requirements (quantum efficiency, readout noise, dark current) and perform modelling of performances and degradation under irradiations. - develop or adapt one (or more) associated detectors with its Read Out Integrated Circuit (ROIC). - test and characterise the developed detectors at the required operating temperature, using the results to improve the detector performance model.					
Deliverables					
One (or more) developed detector(s),study reports, test reports.					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					

N/A

European Low-Flux CIS Development and Optimisation - CCN					
Programme:	CTP		**Reference:**	C217-072MM	
Title:	European Low-Flux CIS Development and Optimisation - CCN				
Total Budget:	800 kEuro				
Objectives					
Design iteration of the European low-flux CMOS image sensor to improve the performance and correct read-out mode related issues. Manufacture, test and characterize new iteration of the CMOS detector, including radiation testing.					
Description					
The European low-flux CMOS image sensor development is part of ESA's strategy to make visible detectors for space application which are entirely designed, built, tested and qualified within Europe. This activity is currently under the final characterization and will be soon completed successfully. However, detectors from the current iteration show some reduced performance as the global shutter read-out mode is not fully functional. The causes for the reduced performance have been investigated and the necessary design and process improvements identified. The aim of this activity is to undertake the design and process changes, re-manufacture the detectors followed by test and characterization.					
Deliverables					
Breadboard					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	Several future science missions		**Contract Duration:**	12 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
Optical Detectors, Visible Range, A01					

Development of a large format science-grade p-channel CCD			
Programme:	CTP	**Reference:**	C217-079MM
Title:	Development of a large format science-grade p-channel CCD		
Total Budget:	640 kEuro		
Objectives			
The aim of the activity is to develop and characterize (including radiation tests) a new large format science-grade p-channel CCD building on the acquired know-how during the previous activities, including the investigation of several designs variants			
Description			

The results of the previous study (ESA Contract No. 4000108704/13/NL/CBi) highlight an improvement to End of Life (EoL) Charge Transfer Inefficiency (CTI) over a comparable n-channel device of up to a factor 10x under certain operating conditions (clock speed, temperature) that would provide a significant advantage to future missions through either extension of the nominal mission lifetime and/or reduced levels of shielding, hence mass. The proposed study would involve the design and manufacture of new p-channel technology development CCDs incorporating 4 design variants on a wafer to enable independent study of the performance of each variant, as per the illustration (right, image areas blue, serial registers purple). This new p-channel CCD would be based on the Euclid 4k x 4k CCD273 with the following proposed variants: 1. Euclid CCD273 device manufactured in p-channel material 2. Same as 1 but with a doped 'notch' in the clocked channel to reduce the electron cloud size and hence radiation damage effects for small signal sizes 3. Same as 1 but with an extended dump gate into the pre-scan register elements to reduce Clock-Induced Charge 4. Same as 1 but with a modified design to both the transfer gate and output gate structure to reduce the impact of potential pockets Once manufactured the devices would undergo in-depth pre- and post-irradiation characterisation concentrating on comparing the performance of the design variants with each other and an n-channel Euclid CCD273 (to be supplied by ESA). The irradiations will be performed with the CCDs operating cryogenically to simulate flight representative operation. The outputs of the study will be a report detailing the advantages and disadvantages of each p-channel device variant compared with the equivalent n-channel Euclid CCD273 and recommendations on the design of a flight-ready p-channel device for future applications.
Deliverables
Prototype; Report

Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Plato/Euclid/ SMILE missions type		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Large-format NIR Avalanche Photodiode Array for Scientific Imaging			
Programme:	TDE	**Reference:**	T217-069MM
Title:	Large-format NIR Avalanche Photodiode Array for Scientific Imaging		
Total Budget:	1300 kEuro		

Objectives					
The objectives of this activity are to design, manufacture and characterise a large-format MCT APD array optimised for low dark current and low photon-flux detection.					
Description					
In recent years, the traditional MCT (Mercury Cadmium Telluride) technology for near-infrared (NIR) sensing has been developed further to manufacture APD (Avalanche Photo-Diode) arrays, which enables sub-electron readout noise measurements. This technology is now routinely used for wave-front sensing on ground-based telescopes using small format devices. Further effort to increase the size of NIR APD sensors as well as improving the MCT material properties (e.g. lower dark current) is needed such that they can be used for future ground and space-based scientific instrumentation. The IRT instrument (Infra-Red Telescope), onboard the ESA Cosmic Vision M5 candidate mission THESEUS, would greatly benefit from such a development as its scientific performance will be readout noise limited using the standard MCT technology. The goal of this activity is to develop a 2k x 2k MCT APD array with a radiation-hard ROIC and dark current performance compatible with imaging for Astronomy while preserving sub-electron readout noise capability and high quantum efficiency in the NIR and - as a goal - in the visible wavelength ranges.					
Deliverables					
Breadboard					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	Several future science missions (e.g. Theseus)	**Contract Duration:**	24 months		
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
Optical Detectors, IR Range, A18					

Gamma-ray detector prototype module development			
Programme:	CTP	**Reference:**	C217-076FV
Title:	Gamma-ray detector prototype module development		
Total Budget:	230 kEuro		
Objectives			
Development and demonstration of Gamma-ray detector prototype module			
Description			
The purpose of this activity is to integrate the Silicon Photomultiplier (SiPM) and ASIC readout technological building blocks that have been previously developed, into a single, end-to-end prototype gamma-ray detector module. The module will undergo performance and environmental testing.			
Deliverables			

Prototype module, technical data package					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2020
Application Mission:	Several Missions		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Performance testing of gamma-ray detector prototype module					
Programme:	CTP		**Reference:**	C217-081FI	
Title:	Performance testing of gamma-ray detector prototype module				
Total Budget:	250 kEuro				
Objectives					
Performance and environmental testing of gamma-ray detector prototype module					
Description					
The purpose of this activity is to integrate the Silicon Photomultiplier (SiPM) and ASIC readout technology building blocks that have been previously developed under ESA contract into a single, end-to-end prototype gamma-ray detector module. The module will undergo extensive performance and environmental testing. This CCN shall cover more extensive testing of the module.					
Deliverables					
Prototype module, technical data package					
Current TRL:	4	**Target TRL:**	5/6	**Application Need/Date:**	2020
Application Mission:	Gamma-ray physics payloads		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Kinetic shock tube for radiation data base for planetary exploration			
Programme:	TDE	**Reference:**	T217-052MP
Title:	Kinetic shock tube for radiation data base for planetary exploration		
Total Budget:	1000 kEuro		
Objectives			

Development of a European shock tube dedicated to kinetic studies for high temperatures (more than 6000K). At present there is no facility available in Europe.
Description
Shock and expansion tubes are important elements for the investigation of chemical kinetics and radiation associated with planetary entry. Facilities exist in the US, in Russia, Japan, Korea, Australia etc... In Europe, the only facility useful though not optimised for this task (TCM2) was developed for the Hermes program, was used for Huygens and Aurora studies, but it has closed. There is a need for a new facility, allowing to perform investigations at a moderate cost, for the conditions foreseen in our future Earth entry missions and Mars entry missions, including aerocapture and aerobraking. A dedicated shock tube shall be specified, developed and instrumented. Tests will be performed for various gas mixtures, to provide spectrally resolved emission and absorption spectra, as a minimum. More advanced techniques shall also be assessed, and demonstrated. The obtained results will be compared with documented results.
Deliverables
EM and Technical notes (incl. executive summary)

Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2012
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	NA				

Consistency with Harmonisation Roadmap and conclusion:
Yes

Development an Entry and Descent Instrument Sensors Suite for Ice Giant Entries			
Programme:	TDE (TRP)	**Reference:**	T218-009NA
Title:	Development an Entry and Descent Instrument Sensors Suite for Ice Giant Entries		
Total Budget:	300		

Objectives
This activity will pre-develop of a modern, state of the art, highly miniaturized instruments set and their corresponding data acquisition functions for efficient in-flight measurement of aerothermodynamic processes for very high-speed entry.
Description
The outer gas planets Saturn, Jupiter, and in particular the ice giants Neptune and Uranus have broad interest in the planetary science community and are the last major planetary bodies to be explored in the Solar system. Their atmosphere consists mainly of hydrogen (H2) and helium (He) with traces of CH4 (Methane).

The scientific interest is highlighted through their selection for study in the next Planetary Sciences Decadal Studies. Furthermore, two ESA CDF studies have examined potential contributions to a NASA led mission from ESA (and other European countries). This has led to the formation of an international working group to investigate the aerothermal environment of ice giant entry. The timeline of the work is enhanced by a potential launch opportunity, with a Jupiter swing-by, in the early 2030s, which would allow access to both planets, Uranus and Neptune.

This activity will pre-develop a set of aerothermodynamics instruments for the real-time detection of the entry scenario with respect to convective and radiative fluxes as well as the plasma composition, pressure, density, and temperature within the hydrogen/Helium Methane atmospheric gases. A miniaturized system shall be investigated and eventually designed and tested in this study in the relevant aerothermodynamics environment.

The Task foreseen are:
1. Review of current aerothermodynamics instrumentation systems applicable for the ice Giants gas planets as well as their potential pre-development. This shall include the trade-off of instruments in terms of weight and parameters influencing the measurements, and integration procedure for securing the measurement in flight.
2. Analysis of the aerothermodynamics instrumentation wavelength intervals and detectors instruments sensitivities for the various entry atmospheric conditions.
3. Layout development and electronics and miniaturized detectors. The possibility of different intelligent power supply strategies shall be investigated too.
4. Design consideration for the long duration flight to the planet (radiation hardening and aging) and final entry.
5. Design of a high-speed digital data onboard processing unit. This includes the development of an algorithm for data analysis, trade-off of advanced processing algorithm like neural networks, clustering and simulation methods, anomaly detection and data transfer to the orbiter.
6. Fabricate a bread board of a selected most representative part of the aerothermodynamics instrumentation
7. Propose future activities for an engineering model (EM) of the complete aerothermodynamics instrumentation.

Deliverables

Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Technology push to prepare the development of new generation miniaturized sensor and data acquisition system for	**Contract Duration:**	12		

	efficient in-flight measurement of aerothermal loads for future gas giant entry flights. The sensor suits are exposed to very long travel time and radiation.		
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Development of a state-to-state CFD code for the characterization the aerothermal environment of Ice Giants planets entry capsules			
Programme:	TDE (TRP)	**Reference:**	T218-008NA
Title:	Development of a state-to-state CFD code for the characterization the aerothermal environment of Ice Giants planets entry capsules		
Total Budget:	300		
Objectives			
The goal of this research activity is the development of a high fidelity, high-speed state-to-state, numerical tool for the reliable determination of the aerothermal environment during the entry into the ice giant's atmosphere. The numerical tools shall implement the most recent and accurate dynamical data for elementary processes and exploit the efficiency of modern computing systems.			
Description			
Background Planetary re-entry missions have broad interest in the science community in the Solar system, namely Mars, Titan, Venus, etc. Moreover, in June 2017 NASA published the Ice Giants Pre-Decadal Survey Mission Study Report, which focused at science priorities and mission concept for missions to those planets. More recently, interest has grown within ESA for outer planet exploration. In support of this objective, ESA has performed two CDF studies (January and July 2019) which analyzed the feasibility of stand-alone elements (orbiter and probes) provided by ESA as a part of a NASA led mission to the Uranus or Neptune systems. Justification Today the aerothermodynamic convective and radiative heat flux predictions are based on the Galileo mission to Jupiter, severely extrapolated to other planetary bodies. Large discrepancies exist in the prediction of the radiative heat fluxes. In particular, the system needs a state-to-state description because of non-Boltzmann internal distributions causing deviations from multi-temperature approach (electronic states and vibrational levels). Furthermore, trace species from the atmosphere and ablative products might			

impact the radiative flux and need to be assessed. The model shall consider Hydrogen/Helium with impurities (Argon, Methane) and provide reference of heat fluxes for aerothermodynamics design of planetary entry missions. The chemical and thermal processes acting in the hostile environment inside the shock wave play a fundamental role in determining the interaction between the flow and the vehicle, particularly concerning the correct prediction of the shock stand-off distance, of the trim angle of attack and of the temperature and heat flux at the vehicle surface.

In recent years, the necessity of using state-to-state kinetics as the proper aero-thermodynamic model in conjunction with fluid dynamics conservation laws has been widely proved: the common assumption made in multi-temperature approaches of considering a Boltzmann distribution fails because the population of very high energy levels (the most important for chemical processes) are not correlated with the vibrational temperature.

Coupling vibrational kinetics with fluid dynamic codes is a complex problem, due to the large dimension of the chemical variables. The number of virtual species is of the order of 100 and the number of processes of the order of 10000. These numbers limit the applicability of the state-to-state model to simple 1D/2D geometries.

These problems could be overcome by using high-efficient processing units recently adapted for scientific calculations. New programming tools can be executed efficiently code on specialized computers.

The main goal of this research activity is the construction of numerical tools for the reliable determination of the heat fluxes during entry into outer gas planets atmospheres with ionizing shock layer, implementing the most recent and accurate dynamical data for elementary processes and exploiting the efficiency of new computing systems.

Activities:
The numerical tool (code) shall implement the most recent and accurate dynamical data for elementary processes and exploiting the efficiency of modern computing systems. The activity shall build a tool based on Navier-Stokes equations with state-to-state kinetics allowing massively parallel calculation. The activity shall validate the data with experimental results from ground facilities.

The fluid dynamic code, equipped with state-to-state non-equilibrium models, shall be built to simulate 2D axisymmetric and three-dimensional flow fields. Also, the effective time-dependent entry problem could be faced with the vehicle being moved while interacting with the flow without the need for expensive mesh re-generation.

An existing code for radiation modeling shall be used to estimate the radiative heat flux, updating, when necessary, the database of emission properties and collisional data.

The following detailed tasks are foreseen: T0 - Literature review of the state of the art modeling. T1 - Implementation of the code the ionization kinetics for H2/He plasmas. T2 - Implementation of discretization routines, based on multi-block body-fitted structured grid and immersed-boundary technique, in the CFD code T3 - Refinement of state-to-state chemical model for H2/He plasmas with impurities. T4 - Construction of a database of collision integrals for binary interactions involving the species relevant to a contaminated hydrogen/helium plasmas with impurities (Ar, methane), and species originating from carbon-phenolic ablators. T5 - Calculation of thermodynamic and transport properties of outer planet atmospheres contaminated by ablated species. T6 - Construction of macroscopic model for outer planet atmospheres high temperature kinetics. T7 - Construction of an efficient numerical tool for the reliable simulation of the super-orbital entry conditions, estimating macroscopic quantities, such as the standoff distance, the ionization degree and surface heat flux, including the radiative one, starting from an accurate description of the reactive chemistry and the ionization mechanisms. T8 - Development of physical-based macroscopic models from accurate state-to-state (STS) models, including the effects of non-equilibrium distributions. T9 - Computation of front and back convective and radiative heat flux on typical probe configurations T10 - Analyze available tube test data (ESTHER, T6 and EAST). T11. Propose further developments to reach TRL 6.					
Deliverables					
Report; Software					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2022
Application Mission:	Entry missions in to Giant planet atmosphere will need an accurate prediction of the aerothermal environment to support heat shield design. The shock layer characterization is not well known nowadays, especially for the very high entry speeds. The novel state-to-state approach is needed because the standard multi-temperature model is not adequate for strong non-equilibrium	**Contract Duration:**	18		

	flows the required accuracy for the heat shield design. New paradigms are needed also for ionizing systems, where radiative heating can play a fundamental role. Thermal ionization in the shock wave can follow non-traditional paths, driven by chemi-ionization channels. Efficient parallelization techniques in the CFD code are necessary to cope with complexity of the high fidelity models.		
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Characterisation of radiation for high speed entry			
Programme:	CTP	**Reference:**	C218-001MP
Title:	Characterisation of radiation for high speed entry		
Total Budget:	750 kEuro		
Objectives			
Development of accurate models for radiation related to high speed Earth and planetary entry. Development of validation data bases, from measurement in the Vacuum Ultra Violet (VUV) range in particular. Development of recommended kinetic schemes, and assessment of uncertainties. This activity end product is the capability to accurately model the radiative environment of capsules during high speed Earth entry.			
Description			
Earth and planetary entries at high velocity (typically above 11 km/s) are associated with a large emission of radiation in VUV range. This radiation is subject to absorption by various species in the flow field boundary layer near the vehicle, and the corresponding energy is transported and distributed along the heat shield of the capsule. It is therefore important to improve the knowledge of this specific component of radiation, to prepare the design of future entry vehicles. This activity shall be performed in representative conditions (shock tube), and shall focus on the qualification and calibration of the ESA shock tube facility for the relevant regimes, the development of measurement techniques and the validation of models. The determination of uncertainties shall also be an			

important target. In the frame of this activity, suitable optical windows, spectrometers and calibration lamps shall be identified and procured for the wavelength range of interest (at least 110 nm - 200 nm, possibly down to 80 nm). COTS and ESA material shall be also considered, provided they offer the required performance in terms of sensitivity, wavelength range and speed, for their application to a shock tube flow (few hundreds of microseconds flow measurement time). This activity end product is the capability to accurately model the radiative environment of capsules during high speed Earth entry. This capability will provide extremely valuable input to future mission design (heatshield sizing, material choice etc.) and technology development activities.
Deliverables
Measurement technique reports and hardware, databases, numerical modules, recommendations on methodologies for radiation characterisation, for numerical models and for experimental techniques.

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2015
Application Mission:	Marco Polo-R but also all other hypervelocity entry missions	**Contract Duration:**	24 months		
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Delta-development of Electric Micropropulsion Subsystem for Deep Space Scientific Missions			
Programme:	CTP	**Reference:**	C219-010FT
Title:	Delta-development of Electric Micropropulsion Subsystem for Deep Space Scientific Missions		
Total Budget:	2000 kEuro		
Objectives			
The activity shall undertake the required delta-developments of Indium-fed FEEP propulsion modules, developed to date for LEO applications, in order demonstrate critical functions and performances required for deep space scientific missions, such as primary propulsion for small satellite planetary missions.			
Description			
Electric micropropulsion providing high delta-v capability will be enabling for small satellite planetary missions. Following successful in-orbit demonstration of the technology, Indium-fed FEEP micropropulsion modules are undergoing development and qualification for various LEO and MEO applications. FEEP propulsion offers low thrust and			

high specific impulse in a modular form allowing tailoring of subsystem performances in line with the needs of deep space scientific missions. This activity shall cover development and verification activities including the following: Equipment level: 1) Delta-development of neutraliser assembly including component trade-offs, performance characterization and endurance testing. 2) Delta-development of rad-hard PPU for required operational range applicable for small satellite planetary missions. 3) Delta-development of Thruster Assembly, including improvement of crown pre-selection process for high performance emitters. Design and manufacture of a Thruster Module DM, followed by thruster module DM verification testing which shall involve: 4) Upgrade of diagnostics (thrust balance, mass efficiency verification system and plasma diagnostics) 5) Module performance characterization and endurance testing of at least 2000 hrs. Additionally, the activity shall include a review of PA/QA aspects and adaptations necessary for small ESA science missions. A preliminary PA/QA plan shall be provided.
Deliverables
DM of Thruster Module; technical datapackage

Current TRL:	3/4	**Target TRL:**	5-6	**Application Need/Date:**	TRL 5/6 by Q1 2020
Application Mission:	Small Planetary Platform missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Consolidation of high performance CFRP struts			
Programme:	CTP	**Reference:**	C220-042FM
Title:	Consolidation of high performance CFRP struts		
Total Budget:	1100 kEuro		
Objectives			
Further development of high performance Carbon Fibre structural elements to offer the following benefits to strut solutions compared with metallic end fittings: - 60% mass saving - CTE and CME = 0 - No cost increase - Larger confidence in the solution (no bonding of dissimilar materials) - Off the shelf sizing - Qualified to TRL=7			
Description			

Previous developments of CFRP struts were successful in demonstrating the performance of these new struts. Low CTE and CME was achieved, along with the required mass saving, with no impact on the mechanical performance of the strut. This activity aims to complete the qualification of the struts to TRL=7. Consistent quality of the struts needs to be demonstrated with proper statistics (more struts) and good predictability of test results, which requires to consolidate the manufacturing process (e.g. de-moulding of the CFRP threads). Additional effects will also be investigated (creep and radiation). Finally, to bring this technology to the market, a specific task will be dedicated to a market survey of needs and requirements (science, EOP, telecom and also spin-off applications), the results of which will be used to develop a modular solution (different strut sizes all qualified and available off-the-shelf). All the sizes selected will be fully developed and qualified, including detailed FEM analysis, as well as manufacturing and testing.					
Deliverables					
Qualification Model					
Current TRL:	5	**Target TRL:**	7	**Application Need/Date:**	2020 TRL 7
Application Mission:	Several Missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Composite Materials (2014)					

Advanced optical benches using nano-enabled CFRP			
Programme:	CTP	**Reference:**	C220-043FM
Title:	Advanced optical benches using nano-enabled CFRP		
Total Budget:	600 kEuro		
Objectives			
Development, validation and demonstration of thermally enhanced CFRPs through nano-enabling approaches for stable optical benches.			
Description			
Studies are currently being carried out by ESA for the development and validation of advanced technologies for nano-enabling CFRP components. These activities aim at introducing the use of nanostructured materials (e.g. carbon nanotubes) and other highly conductive materials together with traditional CFRP materials, in order to obtain structural elements with higher performances, w.r.t. traditional technologies. Envisaged improvements are in terms of conductivity, toughness, stiffness, mass etc. Methodologies have been developed for creating Made-to-Measure Material formulations based on nano-materials for specific improvements. Also, processing techniques have been developed to integrate such formulations in the CFRP. These developments have brought significant enhancements in electrical, thermal and fracture properties of CFRP, as reported in previous projects. Industrial Processing and Manufacturing maturity has been demonstrated through production and testing of representative satellite structural and housing			

elements; CFRP sandwich panel, curved monocoque parts. However, limited works have dealt with the potential benefits offered for optical assemblies, especially in view of the latest enhancements reported in thermal conductivity. The scope of this activity will be to investigate the thermal benefits that such technologies can bring to optical systems which are core to Science missions. The framework of the proposed activity shall include the following Tasks: 1) Identification of existing OB designs from past missions and OB in development 2) OB Design Definition 3) Made-to-Measure Thermal Material development and validation 4) Sample Manufacturing & Material Validation Campaign 5) OB Demonstrator Development & Test Planning 6) Demonstrator Test Campaign 7) Synthesis of results and Future developments Existing OB designs shall be employed along with requirements from Science missions. Thermal formulations will be studied and validated. All the thermal characteristics (thermal conductivity, CTE, etc.) of the nano-enabled CFRP shall be addressed and validated w.r.t. mission operational conditions. Baseline tests will be performed for non-thermal properties critical to the application. Testing will cover different levels: Material level, Laminate level and Sandwich Panel level. Extension of testing for relevant mission requirements will be considered (e.g. conductivity at cryogenic temperature). The effects of the material enhancements have to be considered in order to assess and validate the final implementation and benefit at (sub)system level. Except for the nano-enabled OB, an OB design shall be reproduced with traditional materials. The validity of the proposed materials and implementations on PB level shall then be demonstrated by test in the relevant mechanical and thermal environment, including thermal vacuum					
Deliverables					
Prototype, technical documentation					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	Several Missions		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Composite Materials (2014)					

Deployable high gain antenna (HGA) structure for small S/C science missions			
Programme:	CTP	**Reference:**	C220-044FM
Title:	Deployable high gain antenna (HGA) structure for small S/C science missions		
Total Budget:	1000 kEuro		
Objectives			

Increase the aperture of antenna reflectors available to small S/C science missions by developing a deployable structure capable of supporting a reflective surface to be used as a high gain antenna. The size of the S/C targeted is 1m cube while the diameter of the reflector aimed is 1.5 to 2m.
Description
Small S/C capabilities have been steadily increasing, mainly due to electronics miniaturization, advances in optics quality and high efficiency electric propulsion options, coupled with deployable high efficiency solar arrays. One of the limiting factors for the employment of small S/C in high data generating interplanetary science missions, is RF communication data and link budgets. For a given frequency range, increasing the data rate requires higher gain, achievable by increasing the antenna aperture. Small S/C platforms with apertures larger than one of the major dimensions of the S/C can only be achieved through deployable reflector architectures. This activity will aim at developing a reliable, stable deployable structure that can provide the support for a reflective surface which can be used as an antenna reflector. The activity will consist of the following tasks: 1. Literature survey on deployable reflectors and related technologies 2. Definition of application case requirements for science missions 3. Preliminary design and analysis 4. Breadboard manufacturing testing 5. EQM manufacture and testing 6. Overall activity assessment and roadmap for IOD
Deliverables
Engineering/Qualification Model, technical documentation

Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2020 TRL 5
Application Mission:	Several Missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Composite Materials (2014)					

TRL maturation of interface zones for uninterrupted prepreg fibre placed lattice structures			
Programme:	CTP	**Reference:**	C220-049FT
Title:	Verification of interface zones for uninterrupted prepreg fibre placed lattice structures		
Total Budget:	700 kEuro		
Objectives			
Uninterrupted Pre-preg Fibre Placed Lattice Structures (UPFPLS) offer unique strength and stiffness characteristics and potentially significant mass reductions over sandwich structures. Standard structural solutions for			

interfacing UPFPLS with other structures requires further development. The objectives of this activity are:

- to identify and design a comprehensive portfolio of interface zones for UPFPLS
- to establish, verify and validate critical processes for the manufacture of different interface zones in UPFPLS.
- establish methods for the analytical verification of the interface zones, generate simulation models to be validated through correlation of the test results.
- perform testing, including mechanical and TVAC tests with relevant envelope load levels and environmental conditions, to demonstrate suitability for a range of structural applications for the Athena spacecraft and other future science missions.

Description

UPFPLS is the only composite lattice structures technology capable of outperforming CFRP sandwich structures. The benefits of using a lattice architecture over sandwich structures include: lower product mass; lower cost and shorter lead time; an open architecture which can facilitate component integration; easy accommodation of last minute changes in interface position (cable and pipe routing, etc.), along with multiple other merits.

A structures optimisation study for the Athena spacecraft indicated that for a blank shell (excluding load introduction points and attachment zones) the lattice architecture could provide a 20% reduction in mass compared with a sandwich architecture. This reduction did not include the benefits of a lower ancillary mass (additional mass related to reinforcing various attachment zones) linked with lattice structures. Accounting also for this lower ancillary mass, the total mass reduction of using the lattice architecture for Athena could be upward of 30%.

The manufacture of lattice structures for space applications has matured significantly in recent years; however, standard structural solutions for interfacing lattice structures with other structures still requires considerable development and characterisation effort.

This activity shall include:
- the identification and and state-of-the art review of typical central tube structural interface types applicable to Athena and other future science missions;
- design of representative interface zones for UPFPLS (including primary and secondary load introduction zones, hoisting points, electrical grounding points, etc.) including definition of manufacturing processes;
- analytical verification of the interface zones, performance prediction and correlation of the test results;
- evaluation and verification of critical manufacturing processes for the different interface zones in UPFPLS by use of representative test samples (the fabrication of attachment points in required positions may necessitate the need for dedicated machining positioning jigs);

- following verification of critical manufacturing processes, the design and manufacture of a UPFPLS Development Model (test cylinder of a representative dimension for application to Athena and other future science missions, for example, approx. 1.5 m diameter and 1 m length) that will include a high number of interface zones representative of a variety of attachment types and load levels. The interface zones of the Development Model shall be extensively characterised and DM tests shall include thermal vacuum cycling and mechanical tests with relevant environmental conditions and with relevant envelope load levels.
Deliverables
Test Samples, Development Model, Report (technical datapack)

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	Athena, PLATO, several science missions	**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Detector cooling system including cryostat and active coolers down to 50mK			
Programme:	CTP	**Reference:**	C221-001MT
Title:	Detector cooling system including cryostat and active coolers down to 50mK		
Total Budget:	2650 kEuro		
Objectives			
In order to reach the sensitivity levels required by future scientific investigations, next generation astrophysics missions (X-ray observatories or Far-IR/sub-mm missions) will use detectors made of superconducting materials that operate at sub-K temperatures. For reaching these low temperatures, previous missions (e.g. Herschel) were relying on cryogen consumables, limiting the missions lifetime while others (e.g. Planck) worked with a combination of large and complex passive cooling system with active coolers. The cooling systems required for future astrophysics missions need to be compact and integrated into a cryostat to allow testing in a laboratory while also allowing lifetimes of up to 10 years. Such cooling systems rely on the cascading of various cooler types (e.g. Stirling, JT, Sorption, ADR). ESA has initiated technology development activities for each of the cooler technologies required. The outcomes of those activities will need to be integrated into a complete cooling chain providing a 50mK interface. The objective of this activity is therefore to develop a flight-like cryostat			

including active cryocoolers for cooling of sub-Kelvin detectors to 50 mK and to test its compatibility with a representative sensor.
Description
In a first phase, a flight like cryostat breadboard compatible with European coolers and future astrophysics mission focal plane array (FPA) requirements shall be developed and manufactured, simulating the various cooling stages down to 2K with ground segment equipment/mass thermal dummies, with the main purpose being to achieve a highly efficient insulation. To minimise costs, mass optimisation of classical structural elements (e.g. vacuum vessel) will not be required. Parasitic loads from science harness and non-operating coolers will only be simulated by heaters and/or thermal dummies. After successful verification of the cryogenic performance, a mechanical test campaign shall be performed to increase the TRL of the cryostat to 5. In a second phase, the cryostat will be equipped with the actual engineering model coolers, developed in currently running or previous activities to verify the overall performance of the cryochain, test the dynamic behaviour (e.g cooldown, T-stability) and verify the compliance with the I/F requirements from the FPA (e.g. magnetic stray-field, exported vibrations ...). Since it is assumed, that all the coolers are already at TRL5, mechanical testing of the complete assembly is not deemed necessary. In a last phase a representative TES sensor and multiplexer will be integrated and tested together with the cooling chain. The emphasis shall be on the verification of the compatibility of the coolers with the detector assembly in terms of cooling power, intermediate stages intercepts, temperature profiles during cool-down/warm-up and cycling, temperature stability, micro-vibrations, EMC and magnetic fields.
Deliverables
Design documentation, Integrated cryostat with cryogenic coolers and sensor; Test report.

Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	Future astrophysics missions e.g. Athena		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
2007					

Graphene based thermal straps			
Programme:	CTP	**Reference:**	C221-017FT
Title:	Graphene based thermal straps		
Total Budget:	500 kEuro		
Objectives			

The objective of the activity is to design and develop a demonstrator model of graphene-based thermal straps for the DEPFET detector and front end electronics cooling of the WFI instrument that will embark on the Athena spacecraft.
Description
With five times the thermal conductivity of copper and two times the thermal conductivity of graphite, thermal straps made of nanostructured graphene layers have the potential to have much better performance than any existing thermal straps. The same heat dissipation can be achieved with much lower thicknesses that do not compromise the flexibility of the configuration, preventing undesired distortions due to thermo-mechanical loads. The baseline for the internal heat dissipation of the WFI instrument is to use ethane heat pipes to accomplish the heat transport from the DEPFET detector and front end electronics to a thermal interface. A thermal strap alternative can help reduce the expected thermo-mechanical distortions and will also simplify the AIV/T procedures by effectively removing 1-g testing constraints. The activity shall start with the review of the state of the art regarding graphene-based thermal applications, continue with the identification and trade-off of candidate graphene-based solutions, preliminary design (in chosen configuration), detailed design, manufacturing and end with the testing of a breadboard in a relevant environment. Particular emphasis shall be given to: - the definition of the thermal-strap based configuration (with the instrument provider), - design and characterisation of the end fittings to chosen metallic interfaces, - encapsulation of the graphene layers to minimise thermal losses and contamination, - evaluation of thermal performance of the complete system including end fittings, - evaluation of changes in performance before and after sine/random vibration tests.
Deliverables
Engineering Model

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2019
Application Mission:	Athena. WFI Instrument Thermal Control System.	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Integration Simplification of Capillary Driven Heat Transport Systems			
Programme:	TDE	**Reference:**	T221-111MT
Title:	Integration Simplification of Capillary Driven Heat Transport Systems		
Total Budget:	500 kEuro		
Objectives			

Develop and validate new technologies and methods to simplify the integration of capillary driven heat transport systems.					
Description					
Capillary Driven Loops, as Loop Heat Pipes (LHP) are currently assembled and filled at the loop heat pipe manufacturer premises. LHPs are used to transport heat from dissipative units where sometimes these units could be in an area that is difficult to access. In these cases, the LHP tubing routing could be very complex which makes the task of inserting these two-phase devices very challenging. Furthermore, the radiators used by LHPs could be an access panel which would need to be opened and closed multiple times. Flex lines could allow the panel to be opened but typically, more than one LHPs would share the same radiator increasing the number of flex lines. In addition, flex line has a negative impact in demanding additional volume of working fluid to be added in the LHP. This demand causes the compensation chamber volume to be increased which increases the overall mass of the system. Design and integration of LHP would be improved if the LHP could be dismantled at the LHP manufacturer and assembled within the spacecraft, then purged and filled on the integration floor while guaranteed the performance, the life time and safety In order to address such issues, new technologies and techniques, similar to the ones currently used for propulsion systems, shall be developed for Two-Phase heat transport systems. The activity covers the developments of connectors for ground and flight equipement valves, ground support equipment for emptying, purging, filling with ammonia, etc. as well as the safety aspects of performing such operations. The requirement of the qualification needed on flight hardware, shall be taken into account in the development phase but the qualification testing will be considered in a follow-up activity.. However, the repeatability and reliability of the filling process will be assessed. This activity encompasses the following tasks : - requirements consolidation - technology trade off review - integration process definition - design and manufacturing of prototype and breadboard - validation testing on functional LHP - way forward for industrialisation					
Deliverables					
Breadboard					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	TRL 6 by 2024
Application Mission:	Athena, several EO & Science missions		**Contract Duration:**	28 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Investigation of additive manufacturing of improved ceramic packages for detectors.			
Programme:	TDE	**Reference:**	T223-103QT
Title:	Investigation of additive manufacturing of improved ceramic packages for detectors.		
Total Budget:	400 kEuro		

Objectives

The aim of this activity is to explore the use of additive manufacturing techniques to produce Silicon Carbide (SiC) packages with similar features to Aluminium Nitride (AlN) or Aluminium Oxide (Al2O3). The two major aspects to be explored are firstly the ability to create a ceramic package with additive manufacturing processes and explore more complicated shaped designs, and secondly the possibility of incorporating electrical routing.

Description

The current materials used for high performance detector packaging are typically ceramics with high thermal conductivity. To preserve the flatness of the focal plane array, their coefficients of thermal expansion (CTE) closely match that of the hosted silicon sensor. AlN remains a popular choice due to its high manufacturing quality, and the processes for co-firing multilayers are well established.

However, for Science mission such as GAIA, EUCLID or PLATO, the detector package is constituted of SiC, to match to the focal plane array material and to provide a very accurate thermal control of the CCDs in the order of 10's of mK. There are currently no processes for integrating internal routing in this material and so the electrical connections are implemented via additional elements such as direct bonding between the chip and flexible PCB.

The activity will start with the study of SiC manufacturing via additive manufacturing. This shall include investigation of methods for internal electrical routing (e.g. how to introduce metallic pathways through ceramic, what materials to use, quality of metal-ceramic interfaces, cross-contamination etc.). The output shall be a suitable process for fabrication of both the SiC and the integrated electrical connections. Subsequently, prototypes shall be designed and manufactured prototypes. The developed package shall go through performances assessment followed by an evaluation testing (thermal cycling, etc.).

Deliverables

Technical data package, prototype package with integrated electrical connections

Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Generic	**Contract Duration:**	24 months		

S/W Clause:	N/A
Consistency with Harmonisation Roadmap and conclusion:	
N/A	

Demonstration of an Additive Manufactured Metallic Optical Bench			
Programme:	TDE	**Reference:**	T224-004QT
Title:	Demonstration of an Additive Manufactured Metallic Optical Bench		
Total Budget:	1000 kEuro		
Objectives			
Development of a large Additive Manufactured optical bench using metallic materials (e.g. titanium alloys) with the aim to: 1. Increase performance through enabling geometrical complexity of the optical bench 2. Reduce costs and lead time			
Description			
Cladding methods using for example lasers, electron beams or plasma arcs as energy source, were developed in the past in order to protect a certain base metal from e.g. corrosive or abrasive degradation. Since the need for more and more complex, large components for e.g. Aerospace industries is steadily increasing, cladding techniques were further developed to produce 3 dimensional, near net shape objects. Large geometrical complex structures, exceeding overall dimensions of 1 m, are nowadays possible to be manufactured using additive manufacturing. Since powder bed based methods cannot meet these dimensional requirements, laser cladding methods are typically employed. The benefits of additive manufacturing for future science missions is clear with applications identified in areas such as deployable structures and optical benches, the Athena mission optical bench being one such example. The Athena mission requires an optical bench with a diameter of about 3 m and a height of roughly 30 cm. Conventional machining of such large titanium structures is affected by issues like long lead times for the billet material, low cutting speeds, massive material waste, and therefore high costs. Additive Manufacturing using direct metal deposition techniques is proposed to replace the conventional subtractive manufacturing processes. In the proposed activity, the following will be performed: 1. Review and definition of optical, thermal, mechanical, and dimensional requirements 2. Review of available, state of the art end-to-end manufacturing processes and materials meeting the above requirements 3. Identification of weak points within the end-to-end manufacturing process and implementation of improvements 4. Definition, manufacture, and testing of representative material samples, based on input of design and FE analysis 5. Manufacture of the breadboard:			

1 unit cell of the optical bench 6. Testing of the breadboard and assessment of the performance					
Deliverables					
Study report, test samples, breadboard					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2016
Application Mission:	Generic		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Adhesive bond behaviour in cryogenic environment			
Programme:	TDE	**Reference:**	T224-003QT
Title:	Adhesive bond behaviour in cryogenic environment		
Total Budget:	300 kEuro		
Objectives			
To test a representative panel of adhesive bonds in cryogenic condition in order to gain quantitative data and for a better prediction of their behaviour and properties evolution.			
Description			
Adhesives to bond different component are widely used within Science missions. These adhesives are required to maintain a certain level of reliability with respect to the environmental factors that have an influence on their properties and thus functionality. The behaviour of such adhesives in cryogenic condition needs to be clearly understood and quantified to increase design reliability and optimize their use. The commonly used approach of extrapolation of room temperature performance measurement is not necessarily valid and moreover, the available data of adhesive behaviour in cryogenic conditions is limited. In view of long term operation in cryogenic condition like for deep space missions, L2 missions or other specific missions (i.e. JUICE), a better prediction and understanding of adhesive bond properties is needed. The following activity will consist of the following: 1)Literature review: - related to the type of adhesive/substrate combination used in space and/or for cryogenic application - related to the existing data for adhesive bond behaviour in cryogenic environment 2)Selection/Trade-off of the most representative adhesive/substrate combination that can be used in cryogenic condition for space missions.			

3)Definition of a test plan to evaluate, quantify and predict the change in the adhesive bond property in cryogenic condition. This test plan should focus on the characterization of relevant parameters.

4)Carry out the agreed test plan

5)Produce a test report that compile all quantified data as function of the adhesive/substrate type and the chosen investigated parameter. This document shall be used as reliable database (i.e. Handbook) for future application.

6)Propose a model to evaluate adhesive bond reliability in time in cryogenic condition as function of the adhesive/substrate combination.

Deliverables

Test Report / Study report / Database

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2016
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Adaptation of Small Satellite Technologies for Deep Space Applications

Programme:	CTP	**Reference:**	C226-001FM
Title:	Adaptation of Small Satellite Technologies for Deep Space Applications		
Total Budget:	3900 kEuro		

Objectives

The objective of this activity is to advance the development of small satellite (20-40kg range) technologies requiring adaptation from their typical LEO applications for use in deep space scientific missions.

Description

Interplanetary missions making use of small satellites for multi-point & multi-target science observations around bodies (asteroids and planets) are currently under study within ESA in preparation of a possible F-class mission call.
Small satellites have traditionally been used for LEO applications, typically with limited performance and lifetime requirements. Extending their use to interplanetary scientific missions requires adaptation and improvement of the technologies on system- and subsystem level. This TDA is intended to tackle the most urgent technology areas to enable a potential F-class mission launch in 2028:

1. Propulsion: to evolve the existing small satellite cold gas systems to increase reliability by integrating redundancy or added FDIR functionality as well as the integration within the AOCS system. The assessment phase will perform a gap analysis to detail the extent of the required adaptation and will be followed by a testing campaign against the specified requirements (within this TDA) and in relevant environment.
2. Communications:
   - an Inter Satellite Link (ISL) system for the communication between a network of small satellites and a mother spacecraft shall be further developed from the existing system in industry in order to improve navigation and time synchronisation performances and provide flexibility on the network topology and data rate adaptability.
3. AOCS:
   - introduction of fine pointing capability and rework of the currently used algorithms to remove Earth-orbiting dependencies, include wheel desaturation based on RCS propulsion, develop interfaces to additional required sensors and augment the simulation fidelity for the deep space environment. The activity will conclude with a full software simulation and validation testing;
   - Introduction of high precision timing and clock synchronization and perform testing in a relevant environment.
   - requirements definition to increase the level of spacecraft autonomy and proximity operations around the target body.
4. Command and data handling system: assessment of the applicability of the existing cubesat computing platforms and required design upgrades and modifications like memory architecture with inclusion of higher-capacity and increased robustness. The activity shall provide a system validation test.
5. Assessment of any other potentially critical technologies (thermal, power, etc) based on the findings of the ongoing system level studies.

Additionally, the activity shall include a review of PA/QA aspects and adaptations necessary for small ESA science missions, identify the required steps to arrive to an acceptable risk and mission assurance level and develop a first draft of the PA/QA plan including the necessary ECSS tailoring. The activity shall include a RAMS analysis and address potential means for verification and validation (test benches, simulators, etc) at system level. The integration and production aspects of the small satellites shall also be addressed.

The activity detailed description may be re-visited following consolidation of mission needs.

Deliverables

Hardware and technical datapackage.

Current TRL:	2-4	**Target TRL:**	5-6	**Application Need/Date:**	TRL 5/6 by Q1 2020
Application Mission:	Small Planetary Platform missions	**Contract Duration:**	18 months		

S/W Clause:	N/A
Consistency with Harmonisation Roadmap and conclusion:	
N/A	

MEMS based nanoparticle storage and release system for Quantum Physics Platform			
Programme:	CTP	**Reference:**	C226-002FT
Title:	MEMS based nanoparticle storage and release system for Quantum Physics Platform		
Total Budget:	400 kEuro		

Objectives

The objective of this activity is to develop a means to store and release on-demand nanoparticles which are then delivered to an optical bench and are the subject of experiments to test quantum physics principles at the mesoscopic scale. The need for this device was an outcome of the CDF study on the Quantum Physics Platform (QPPF). Existing solutions for terrestrial experiments are not applicable in a space environment, therefore this would be a mission enabling technology. A range of potential solutions were considered during the CDF study, and the most promising concept was based on a MEMS device.

The MEMS device concept consists of a large scale array of nanoparticles, where each particle is located in the center of a micro-membrane or bendable micro-plate (eg. cantilever, bridge, suspended plate, beam). Each micro-membrane/plate acts as a spring to launch the particle and can be actuated individually. By selective actuation (eg. electrostatic, magnetic, and piezoelectric) of the array elements of the MEMS, a sufficient acceleration is reached such that the nanoparticle can detach and be ejected from the surface. The top level objectives are;
- to demonstrate feasibility at a strongly reduced MEMS array (1x3, TBC) level, including surface engineering to reduce the attraction force of the particle to the membrane/plate if necessary
- to characterize the velocity, direction and charge of the nanoparticles (and statistical distributions) after they are ejected

Description

This activity is phased in two parts.

Phase A is to demonstrate feasibility of the concept for the mission needs of QPPF. The contractor shall propose a test device, which may be an existing MEMS device, and concentrate on aspects such as;
- vacuum operation
- positioning a nanoparticle in the desired location
- characterization of the adsorption forces and potentially surface treatment/engineering to reduce it
- developing of diagnostics to image the system, and to verify the particle was ejected and where it went.

Following on from a successful phase A, phase B will consist of further refining the device and optimizing the processes. This may include - device survival, and functional stability after typical launch shock and vibration levels - survey across different size nanoparticles (and potentially different types of materials) - developing a concept for a scalable loading method that would also be appropriate for loading the order of 100,000 nanoparticles - precise measurement of velocity and directional dispersion of the nanoparticles - measurement of charge and statistics of the distribution after many trials - requirement definition for a device fulfilling the mission need (array size, loading approach etc)
Deliverables
Breadboard; Report

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Quantum Physics Platform		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

3-axis high accuracy accelerometer unit			
Programme:	CTP	**Reference:**	C205-127SA
Title:	3-axis high accuracy accelerometer unit		
Total Budget:	2000 kEuro		
Objectives			
The objectives of the activity are two-fold : 1. Qualify the sensing element (1-axis accelerometer) developed in the frame of C205-115SA (High Accuracy Accelerometer for Space Applications) 2. Develop, manufacture and qualify a 3-axis accelerometer unit using the qualified sensing element to support future science and exploration missions.			
Description			
A currently running activity is designing a radiation hardened 1-axis accelerometer, based on a terrestrial accelerometer developed for high accuracy applications (delta V monitoring). The quartz sensing element is unchanged, while the electronics of the control loops are being upgraded to use space EEE components. This activity ends with the testing of engineering models. A follow-on activity is required to qualify the 1-axis accelerometer. The main difference between the EMs and the QMs to be manufactured is the necessity to fit within the enclosure of the component (25 mm diameter and 15 mm height) and to implement all necessary design changes identified as per the EM test campaign.			

This 1-axis accelerometer remains a component to be integrated in an equipment. The accelerometer needs several very stable power supplies and it outputs analog current proportional to the linear acceleration. To be used on a spacecraft, a 3-axis unit shall be developed, to be supplied by the main satellite bus, and using digital interface (for instance RS422) for the communication with the OBC. An engineering model of the 3-axis unit can be based on terrestrial accelerometers to de-risk the main new functions (raw acceleration compensation for scale factor, bias and misalignment against temperature, as well as acceleration integration to compute deltaV). A PDR and CDR shall be conducted for the 3-axis unit. The qualification model of the 3-axis unit shall use the space accelerometer and use flight EEE components. Target specifications : - Mass of the 3-axis accelerometer unit < 1.5 kg - Settable input range (starting from a few mg input range) - Settable acceleration integration frequency in delta V - Acceleration measurement better than 1"g / hour at stable temperature.
Deliverables
Engineering Model; Qualification Model

Current TRL:	3	**Target TRL:**	7	**Application Need/Date:**	2023
Application Mission:	Several Cosmic Vision Missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Harmonisation Roadmap Reference: B02 Harmonisation Roadmap: AOCS Sensors and Actuators: I - Star Trackers, APS, IMU's and Wheels Consistent with Harmonisation Roadmap: Yes					

X band Transponder Qualification Development			
Programme:	CTP	**Reference:**	C206-025NA
Title:	X band Transponder Qualification Development		
Total Budget:	4500		
Objectives			
Starting from the work performed in a previous technology development activity, the objectives of this activity are: 1. to complete the design of a X-band transponder for SCI mission (taking as reference ARIEL and ATHENA requirements) 2. to develop and test a breadboard fully representative of the digital part of the transponder 3. to develop and test a transponder model allowing to achieve TRL6			
Description			

This activity is a CCN to an existing contract (TT&C Subsystem Capability Development) with Kongsberg Space Electronics and it aims to the development of a model of a X-band transponder for SCI missions. This model will allow to achieve TRL 6.					
Deliverables					
Breadboard; Engineering/Qualification Model; Report					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2022
Application Mission:	The target of this development is future SCI missions starting from ARIEL, which is taken as reference for the need date of this development (end 2023).		**Contract Duration:**	24	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with Harmonisation Roadmap: No Harmonisation Roadmap Reference: A09 Harmonisation Roadmap: TT&C Transponders and Payload Data Transmission Harmonisation Comments: The budget proposed is higher due broaded TRL range (3-6). Development is targeted to Science missions thus, implementation via CTP is proposed.					

Fractionated sub-surface sounder configurations for Giant Planets satellites exploration			
Programme:	TDE (TRP)	**Reference:**	T206-023NA
Title:	Fractionated sub-surface sounder configurations for Giant Planets satellites exploration		
Total Budget:	150		
Objectives			
The objective of the proposed study is, through a multistatic radar configuration to enable Single-Pass interferometry capabilities with the objective of removing the residual clutter and DSM(Digital surface Model)/DEM(Digital Elevation Model) generation or Tomography for 3D reconstruction The study aims to investigate the feasibility of a fractionated surface/sub-surface sounder (radar) configuration capable to provide new fundamental data that have not been acquired by previous remote sensing missions on Solar Systems Planet and their satellites. In particular the objective is to obtain these results taking advantage of a small array of at least three satellites deployed in an orbital formation flying for synthesizing a very large antenna aperture in a SIMO- Single Input Multiple Output configuration,			

where only the "mother" master platform transmits and receives the signal , while the other satellites would work in a Rx only mode.					
Description					
An investigation shall be done of the feasibility of a fractionated (multi-static) surface/sub-surface sounder configuration that fulfils the needs of the key application of interest i.e. remote sensing of the planets or moons of planets. This type of configuration allows to increase the SNR (having more than one receiver) and together with the use of advanced radar processing strategies enables the clutter removal or feature extraction. In fact the clutter can be mitigated due to the fact of having a synthesized across-pattern, since it has clearly lower sidelobe levels and main-lobe width with respect to a single platform configuration.. A clutter free acquisition together with a higher SNR guarantees a much deeper penetration depth and good ambiguity rejection. There are different payload simplifications possibilities that can be adopted and shall be analysed during the study e.g. Mirror SAR approach, according to which the "children" satellites do not embark storage or processing means, but simply receive the backscattered echo, and then after an up-conversion (operated in analog domain) , transmit it to the "mother" satellite. The possible frequencies to be used can vary from the VHF 20 / 45 MHz up to 2/3 GHz, clearly depending on the type of application assumed as priority First of all the selection of the frequency shall be the main driver, as it will have impact most of all on the antenna size and overall on mass and volume. Different conceptual configurations shall be traded-off shall in order to define the one(s) that guarantees the best compromise in terms of performances and needed resources. TASK lists: - Survey of state-of-the-art SIMO radar concepts for sub-surface sounding - Trade-off analysis and definition of different conceptual multi-static sounder configurations (drivers are cost, system complexity and corresponding benefits) - Selection of the best candidates for which a further refinement shall be performed - Baseline selection and relative definition of preliminary conceptual architecture and performance analysis, including the design and analysis of the various antennas. - Conclusion and possible technology development roadmap					
Deliverables					
Report					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2022
Application Mission:	Potential supporting mission concepts need in the framework of Voyage 2050, Large Missions Science Theme for the discovery and initial exploration of		**Contract Duration:**	12	

	Moon of the Giant Planets (e.g. Habitability: characterise interior and subsurface oceans)		
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Consistent with Harmonisation Roadmap: %			

Maturation of Additive Manufactured Metallic Optical Bench					
Programme:	TDE		**Reference:**	T220-056FT	
Title:	Maturation of Additive Manufactured Metallic Optical Bench				
Total Budget:	1000 kEuro				
Objectives					
To manufactured a large size titanium optical bench. The ATHENA optical bench shall be used as an example.					
Description					
In the preceding activity T224-004QT facilities and manufacturing processes are being developed for the production of large scale monolithic titanium structures. In order to demonstrate the full capability of this technology a 2.6 m diameter structure shall be manufactured. The ATHENA optical bench supporting the SPO Mirror Modules is a suitable test case. The structure requires high rigidity and stability while featuring a complex and elaborate geometry. The hybrid manufacturing method, combining additivite and substractive elements shall be elaborated as required to fabricate the required bench. The qualification of the processes and materials shall be evolved coherent with the ECSS guidelines for additive manufacturing."					
Deliverables					
Engineering/Qualification Model; Report					
Current TRL:	TRL4	**Target TRL:**	TRL5	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Multiple frequency-shift keying modem			
Programme:	TDE	**Reference:**	T224-005QT
Title:	Adhesive bond behavior in cryogenic environment (CCN)		

Total Budget:	150 kEuro				
Objectives					
To test a representative panel of adhesive bonds in cryogenic condition in order to gain quantitative data and for a better prediction of their behaviour and properties evolution. This is activity is a CCN to T225-003QT.					
Description					
A requested CCN on the TRP contract, Adhesive bond behavior in cryogenic environment, with KRP (Germany). The CCN will allow additional materials and adhesives to be tested in cryo by KRP, in addition to the ones already included in the contract. CBK will provide the samples.					
Deliverables					
Test Report / Study report / Database					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Ultra-Stable Power System Architectures			
Programme:	TDE	**Reference:**	T203-114EP
Title:	Ultra-Stable Power System Architectures		
Total Budget:	500 kEuro		
Objectives			
To study and trade-off design implementations for power quality and frequency stability of intentional output on user outlets and unintentional spurious emissions on input and output interfaces.			
Description			
Many science missions require very stable conditions to allow very precise measurements, e.g. voltage ripple as low as 1 ppm and frequency stability below 50 ppm. Moreover both thermal and electrical stability are closely linked, as e.g. voltage variations will subsequently create temperature variations through the heaters. Temperature stability in the order of mK for example is expected to require voltage stability in the order 1/10^5 or 1/10^6. To accommodate these needs they need to be considered in the fundamental design of power systems. Studying and trading-off design implementations for power quality and frequency stability of intentional output on user outlets and unintentional spurious emissions on input and output interfaces will allow to identify and define the building blocks required. This will enable innovated power systems with improve stability performance and reduce future development time for specific applications.			

Apart from the identification and selection of suitable components, and the bread-boarding and proto-typing of an ultra-stable converter design, also the definition of an efficient verification technique is important. With an existing and verified converter proto-type as a basic building block, it will then become possible to define an extremely stable electrical architecture consisting of the power sub-system and the various power users or even voltage reference sources. This activity encompasses the following tasks: - Identification and selection of components for ultra-stable DC/DC converters - Identification and design of converter topologies for ultra-stable converter - Bread-boarding of a ultra-stable converter - Definition and implementation of efficient stability verification techniques - Definition of electrical architecture using developed converter bread-board as basic building block Breadboard converter (TRL4) will be needed as technology demonstrator and to serve as building block for specific applications.
Deliverables
Breadboard

Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Power Management and Distribution – not consistent; Specific need for SCI is described in dossier but was not translated in any specific activity in the roadmap

Electro-Magnetic Shielding Effectiveness Optimization for Thermal Multi-Layer Insulation			
Programme:	TDE	**Reference:**	T207-063EP
Title:	Electro-Magnetic Shielding Effectiveness Optimization for Thermal Multi-Layer Insulation		
Total Budget:	300 kEuro		
Objectives			
-identify and optimize the design parameters of MLI which are relevant to shielding effectiveness. -design a MLI with multi-domain (thermal and electrical) optimization, targeting similar thermal performance, with minimised mass impact and improved EM shi			
Description			

In many science missions, there are sensitive instruments doing precise and crucial measurement onboard. They are susceptible to emission from transmitter and disturbance from other units. Most spacecraft flown today are covered with MLI (Multilayer Insulation) blanket, which is one of the key items used for the spacecraft thermal insulation. One of its additive functions is EM shielding, due to its conductive layers, which is very helpful to protect sensitive units from EM (Electro-Magnetic) disturbance. The EM shielding effectiveness of the MLI was found in the range of 20-40 dB. Recently, some modern MLIs was tested, and the shielding effectiveness was found to be 8 dB lower than its predecessor, which add stress to maintain sufficient margin to ensure EMC.

Modern MLI focusses increasingly on thermal properties, while shielding effectiveness degrades. With multi-domain (thermal and electrical) optimization, MLIs could target thermal performance and EM shielding effectiveness in parallel.

This study fits very well with the technology strategy of improving the cost efficiency. MLI were originally used only for limiting the heat flow to and from a spacecraft. Today they may also be used to protect against micrometeoroids, atomic oxygen, electron charge accumulation, and rocket plume impingement. However, the inherent functionality of EM shielding is overlooked or neglected, which will be enhanced in this study. With the optimized design, without increasing the amount of component, sufficient EMC margin can be achieved.

The study will include the following activities:
- identify the design parameters (number, material and thickness of interior layers, thickness of vapour deposited aluminium VDA coating, perforation density, hole size, hole alignment, embossed configuration, spacer material and thickness, outer and inner cover material and thickness, etc.) of MLI which are relevant to shielding effectiveness. The number of MLI types (mainly in terms of materials selected) to be studied will be determined during SoW.
- develop a model to predict the shielding effectiveness and thermal performance of MLI based on the identified relevant design parameters. A 2D model (i.e. flat MLI) or a 3D model (e.g. MLI cube) will be specified during SoW.
- validate the model by experiment. In case a 3D model is considered necessary, or both a 2D and 3D model will be specified during SoW.
- develop a software with user-friendly interface which helps the user to evaluate the shielding effectiveness and thermal performance based on the developed model.
- design a MLI with multi-domain (thermal and electrical) optimization, targeting similar thermal performance, with minimised mass impact and improved EM shielding effectiveness (> 20 dB@2GHz)
- disseminate the result, include shielding effectiveness test in the product qualification and include shielding effectiveness in product specification.

This study could be a collaborative work between TEC-EPE and TEC-MT

Deliverables

Engineering Model; Report; Software

Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions	**Contract Duration:**	24 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Electro-chemical compressor for Joule Thomson Cooler

Programme:	TDE	**Reference:**	T203-113MT
Title:	Electro-chemical compressor for Joule Thomson Cooler		
Total Budget:	250 kEuro		

Objectives

To demonstrate that an electrochemical compressor can provide the compression and mass flow required for a Hydrogen Hydrogen (H2) Joule Thomson loop within a defined envelope, including an integrated system to lower the Hydrogen water content to an acceptable value and avoid clogging in the JT flow at lower temperatures.

Description

Vibration-free solutions for cryocoolers present significant advantages for stability sensitive applications.

Electrochemical compression would present an elegant, scalable solution without moving parts.
Currently Electrochemical compressors require a given water content in the flow in order to produce the compression, which is incompatible with a Joule-Thomson Cryocooler. A space compatible and optimized water management system - capturing the water and re-circulating it - is required as essential equipment to render this technology feasible for JT cryocoolers reaching from 15K to 80 K (Hydrogen Hydrogen H2 and Oxygen Oxygen O2). Similar technology exists for fuel cells.

This activity encompasses the following tasks:
- requirements consolidation
- technology trade off review
- design and manufacturing of the electrochemical compressor
- Design and manufacturing of the water management system
- validation testing of the setup
- way forward for industrialisation

Deliverables

Breadboard; Report

Current TRL:	TRL2	**Target TRL:**	TRL3	**Application Need/Date:**	2023

Application Mission:	Several Science Programme missions	**Contract Duration:**	12 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
Cryogenics and Focal Plane Cooling – consistent to activity A18 in the roadmap.			

Characterization of MLI materials and definition of MLI blanket for aerobraking environment			
Programme:	TDE	**Reference:**	T221-021MT
Title:	Characterization of MLI materials and definition of MLI blanket for aerobraking environment		
Total Budget:	500 kEuro		
Objectives			
To define and test a MLI for Envision's aerobraking thermal environment allowing a more aggressive aerobraking regime.			
Description			
Aerobraking phase of ENVISION is critical in terms of duration and required operations. One limitation during aerobraking is the temperature reached on Multi Layer Insulation (MLI) due to the aerothermal heat flux. MLIs can withstand during short durations (intermittent exposure) higher temperatures than their steady state qualification temperature. Using intermittent temperature limit instead of steady state limit would allow to drastically reduce the duration of the aerobraking phase, resulting in significant cost savings on the operations, without re-design of the existing materials. This requires characterization of materials in conditions representative of the whole aerobraking phase in terms of heat flux, duration (heat load) and thermal cycles (several thousands of atmospheric passes are expected). This activity encompasses the following tasks: - requirements consolidation, including specific Venus environment - selection of candidate materials suitable for MLI under Venus environment - test the materials according to Envision mission requirements in terms of thermal cycling, radiation environment and aerobraking (aerothermal flux and heat load) - Assess MLI performance degradation under realistic aero fluxes conditions, including impact of Venus atmosphere (e.g. degradation due to erosion) - Define, manufacture and test a MLI blanket, in line with EnVision mission requirements. Outcome is a definition of a MLI blanket optimized for ENVISION, including thorough characterization of the materials including the reachable intermittent			

temperature as a function of relevant parameters such as atmospheric pass duration and total number of atmospheric passes.					
Deliverables					
Breadboard; Report					
Current TRL:	TRL4	**Target TRL:**	TRL5	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development of a low power cathode for scientific missions			
Programme:	TDE	**Reference:**	T219-003MP
Title:	Development of a low power cathode for scientific missions		
Total Budget:	200 kEuro		
Objectives			
Design and analysis of a low power, long lifetime neutraliser suitable for electric micropropulsion for future scientific missions.			
Description			
Electric micropropulsion technologies providing precise, low thrust levels in the micro-Newton to milli-Newton range with high specific impulse are under development within Europe to meet the challenging propulsion requirements for scientific missions (such as for drag-free control of spacecraft or for high delta-v small satellite missions). These technologies often require an electron source for space-charge neutralisation of the ion beam and to mitigate spacecraft charging effects. In order to maximise the efficiency of the overall micropropulsion subsystem, the consumption (power, and mass flow if applicable) of the neutraliser should be minimised. Developments have been undertaken in the past on different types of neutraliser technology for electric micropropulsion, such as plasma based devices, low power thermionic cathodes and also field emission cold cathodes. Promising performances have been demonstrated in previous decades for the latter cathode devices, such as power consumption ~ 0.1 W/mA and current levels ~7 mA. Some of these devices have been tested up to several 1000 hours, but extending the operational lifetime of these devices towards 10,000 hours or more (as might be needed for some future scientific missions) remains a challenge considering the local plasma environment expected on orbit. However, in recent years advances have been made in novel cathode materials and devices (e.g. for microscopy applications or for THz devices) that could prove beneficial for low power, long lifetime neutralisers for electric micropropulsion.			

The main objective of this activity is to assess the state-of-art in novel cathode materials and devices (such as novel electride materials, diamond or graphene based cathodes) and to design a low power neutraliser suitable for electric micropropulsion subsystems for future scientific missions. The activity shall cover: - State-of-art review of low power neutralisers previously developed for electric micropropulsion; - Survey of novel cathode materials and devices to identify one or more that could improve performances beyond the state-of-art; - Requirements definition for a long lifetime (>several 1000 hours), low power neutraliser for future scientific missions; - Preliminary design of a neutraliser in accordance with the requirements, and necessary analyses to support justification of predicted performances; - Identification of lifetime limiting factors and a lifetime assessment report. - Definition of a roadmap for future neutraliser development, and assessment on additional applications for space (such as for spacecraft potential control or scaling to higher current applications).
Deliverables
Report

Current TRL:	TRL2	**Target TRL:**	TRL3	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions	**Contract Duration:**	12 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Electric Propulsion Technologies – related to activity D02 in the roadmap but here the goal is to assess novel cathode materials along with the state-of-art in (existing) EP neutralizer technologies, and therefore, the TRL starts lower.					

Multiple frequency-shift keying modem			
Programme:	TDE	**Reference:**	C220-051FT
Title:	Verification of Interface Zones for Uninterrupted pre-preg fibre placed lattice structures - CCN		
Total Budget:	360 kEuro		
Objectives			
Uninterrupted Pre-preg Fibre Placed Lattice Structures (UPFPLS) offer unique strength and stiffness characteristics and potentially significant mass reductions over sandwich structures. Standard structural solutions for interfacing UPFPLS with other structures requires further development. This is activity is a CCN to C220-049FT.			
Description			
UPFPLS is the only composite lattice structures technology capable of outperforming CFRP sandwich panel structures. The benefits of using a lattice architecture over sandwich panel structures include: lower product mass; lower cost and shorter lead time; an open architecture which can			

facilitate component integration; easy accommodation of last minute changes in interface position (cable and pipe routing, etc.), along with multiple other merits. This activity will continue the mechanical and thermal testing of samples.					
Deliverables					
Test Samples, Development Model, Report (technical datapack)					
Current TRL:	5	**Target TRL:**	6-7	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions	**Contract Duration:**	18 months		
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Attitude Guidance Using On-Board Optimisation			
Programme:	TDE	**Reference:**	T205-125SA
Title:	Attitude Guidance Using On-Board Optimisation		
Total Budget:	300 kEuro		
Objectives			
Demonstrate on-board real-time fuel, power or time optimal and robust attitude guidance using optimisation techniques in presence of exclusion zone constraints and non-uniform actuator authority envelopes.			
Description			
Recent developments in optimisation formulation and software design have allowed multi-criteria optimisation problems to be solved in real-time on typical space-grade processors. An important potential application is slew attitude guidance in the presence of actuator limitations and star tracker or instrument exclusion zones, particularly when slew time is critical. The optimisation problem can be formulated as time, fuel or pointing error (during slew) minimisation with constraints of exclusion zones and actuator authority envelopes. The non-convex problem can then be convexified with certain assumptions, and compiled into a convex optimisation solver. This would then be integrated into flight software and solved either at slew start time, as a path planner making use of state knowledge just prior to the slew, or continuously during the slew, as in model predictive control. Real-time optimisation solvers will bring robustness to time-critical missions such as comet fly-by (ESA's Comet Interceptor mission), where actuator authority, managed by standard algorithms, may be insufficient due to design constraints, unexpected actuator failure or impacts of large dust particles. With on-board guidance optimisation, the attitude profile can be altered in real-time to minimise the visual/IR science outage within the constraints of the wheel initial conditions, actuator authority limits and instrument sun exclusion zones.			

These same solvers, with different costs and constraints, could reduce time-to-target in Gamma-ray burst tracking missions (like ESA's Theseus), where slew-duration reduction can significantly benefit the science return or provide extra agility without extending the actuator capacity. Potential benefits are greater for large slew angles where simple ad-hoc planning algorithms may select sub-optimal slew paths. These are some examples of types of missions that may benefit from this technology, but the total set of possible applications is far more widespread. A first stepping stone for industry could be to use convex optimisation as a reference solution for evaluating classical algorithms during phase A/B design and for actuator sizing exercises for complex problems where analytical solutions are not available. For adoption on future ESA science missions, it is important that the technology be demonstrated on a flight-like processor for flight-like problems. Several example cases will be defined for the study which will assess the best convex optimisation solutions and demonstrate adequate performance on a flight-like processor, compared with heritage techniques. Verification and validation will also be addressed. Task List: Task 1/ Literature Review (Convex Optimization and associated Verification & Validation approaches) Task 2a/ Requirements Definition for several example cases (targets: THESEUS and COMET INTERCEPTOR missions) Task 2b/ Mathematical Optimisation Problems Definition Task 3/ Convexification Methodology Selection Task 4/ Algorithm Tuning & Preliminary Simulation Results Task 5a/ Test case definition Task 5b/ Verification & Validation by Analysis Task 6/ Demonstration on Flight Processor

Deliverables					
Prototype; Report					
Current TRL:	TRL3	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Avionics Embedded Systems – consistent with activity B02.					

Multiple frequency-shift keying modem			
Programme:	TDE	**Reference:**	T212-061GS
Title:	Multiple frequency-shift keying modem		
Total Budget:	350 kEuro		
Objectives			

To develop a receiver breadboard for ground stations that supports: - Safe/survival mode communications via low gain antennas of deep space spacecraft (outer solar system or inner solar system farther than 1 AU). - Direct-to-Earth (D2E) communications of deep space vehicles during Entry Descent and Landing (EDL).
Description
A previous ESA study on Entry Descent and Landing communications technologies (ECOMTEC) identified MFSK (Multiple Frequency Shift Keying) as the the best signal for direct transmission to Earth of very low bit rate telemetry in deep space during EDL. However, other deep space scenarios where reliable low rate transmission of telemetry during critical phases might be needed could benefit of using MFSK. In fact, every deep space mission facing a safe/survival situation where the high or medium gain antenna cannot be pointed to Earth with sufficient accuracy (i.e. a tumbling spacecraft that has lost control of its attitude actuators) has the last resort to communicate to Earth via low gain antenna/s. In this emergency condition, and considering state-of-art communications technology, a robust deep space link budget via low gain antenna/s is hard to achieve at very low bit rates with residual carrier-based phase modulation schemes, being the residual carrier power in the ground station loop bandwidth the limiting factor in most of the cases. As a result, ESTRACK's 35 m-diameter Deep Space Antennas (DSA) have limited capability to receive data from spacecrafts (in emergency conditions) farther than 0.5 - 1 AU. This results in a need for baselining the usage of NASA's 70 m-diameter Deep Space Network (DSN) of ground stations for the spacecraft recovery. One of the objectives of this activity prior to breadboard implementation would be to find the minimum TM bit rate (in the order of a few bits per second) that an MFSK signal (or even a phase modulated signal) would be able to support either in safe/survival mode or during an EDL phase, taking into account the particular conditions of both scenarios (i.e., higher Doppler dynamics during EDL, and low C/No). The study should also include an analysis of the existing coding schemes considering the limitations imposed by the very low rates and other conditions of the link. Currently, MFSK transmission capabilities are being developed for a deep space transponder (as part of other ESA activities); however, a ground station receiver with such capabilities has not been developed yet. The activity shall hence cover the following points: 1) Identification of safe/survival mode scenarios, reference link budgets and frequency band/s, using ESOC 35 m-diameter ground stations. 2) Identification of Entry, Descent and Landing target scenarios, reference link budgets and frequency band/s (from the ECOMTEC study), using ESOC 35 m-diameter ground stations.

3) Selection of the modulation schemes that would best support very low bit rate TM for the safe/survival mode, among the ones existing or that are being developed at deep space transponder level. 4) Investigation and selection of the coding schemes that would best support the selected modulation schemes, among the ones existing or that are being developed at deep space transponder level. 5) Provision of input (document) to support the standardisation of MFSK for these scenarios (to enable inter-agency cross-support.) Design, implementation and testing of a ground receiver breadboard. This breadboard shall include the following capabilities: - An MFSK demodulator (in both the so-called ""special"" and ""classical"" variants), capable of detecting the MFSK tones from an EDL vehicle or a spacecraft in safe/survival mode. - Decoder. - SBI processor for accurate EDL trajectory tracking. - Other relevant techniques identified during the study. A definition of the ground segment architecture capable of meeting the end-to-end performance of these scenarios shall precede the implementation of the receiver breadboard. The architecture defined in the ECOMTEC study shall be used as a reference. During the development of the breadboard, the analysis carried out in the ECOMTEC R&D activity shall be taken into consideration (ESA contract number xx). The MSFK transmission capabilities implemented in the activity ""Design and Development of the Integrated Deep Space & Radio-science Transponder (IDST)"" (ESA contract number xxs shall also be taken into consideration.
Deliverables
Breadboard; Report; Software

Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Several Science Programme missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Ground Station Technology - This proposal is not fully consistent with any activity from the Ground Station Technology Harmonisation Roadmap because result of previous studies recommend to de-scope the initially foreseen activities F07 and F10 and concentrate the effort on the MFSK demodulation, like presented in this proposal. It is also in line with the development in TEC-ES in the Flexible Autonomous Transponder FAT and the IDST

Patterned Liquid-Crystal Retarders as Basis Optical Components for Exoplanet Direct Imaging			
Programme:	TDE	**Reference:**	T216-174MM

Title:	Patterned Liquid-Crystal Retarders as Basis Optical Components for Exoplanet Direct Imaging
Total Budget:	650 kEuro

Objectives

Explore and validate novel designs and implementation of patterned liquid-crystal optical components for next-generation space-based coronagraphs for direct imaging exoplanet missions.

Description

As described in the Voyage 2050 white paper by I. Snellen, the characterization of temperate rocky exoplanets around solar-type stars using direct imaging can only be achieved with space-based telescopes. In ground-based astronomy, Europe has a leading expertise in novel focal plane and pupil plane coronagraphs based on patterned liquid-crystal static optical elements already implemented in the largest ground-based telescopes. Currently there is a growing interest in applying this technology to the next generation exoplanet mission concepts like LUVOIR and HabEx (e.g. as part of an ESA instrument or an ESA contribution to a NASA instrument) aiming for orders of magnitude higher contrast compared to what was achieved on ground.

The custom patterned liquid-crystals in question are very thin static optical components behaving as polarization retarders. The elaborate patterns are permanently solidified during the manufacturing stage with an ultraviolet laser fixing the orientation of the liquid crystal polymers and enabling the printing of any geometric phase pattern. These components are achromatic meaning that they maintain the same efficiency over a very large spectral range making them applicable for a variety of science instruments.

For the purpose of this activity, the patterned-liquid crystals will be developed specifically for high contrast imaging in space, but the technology itself is very versatile and its development will enable other space applications involving holographic elements such as wavefront sensors, aperture masking, polarization gratings, and spatial modulators. The latter two are in fact the basic building blocks for future life-detecting spectropolarimeters. Such components already exist for ground-based astronomy however their requirements are much less stringent and the environment in which they operate is not representative for space application.

To develop high performance and robust components for the space environment the following aspects need to be researched and optimized:

- Pattern design and printing accuracy
- Integration of the printed pattern into an optical component
- Testing at component level within a representative environment
- Implementation at a system level (breadboard demonstration) and performance testing

Deliverables

Breadboard; Report					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:			**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Large area high-performance optical filters for X-ray detection in space based on CNT			
Programme:	CTP	**Reference:**	C216-179MM
Title:	Large area high-performance optical filters for X-ray detection in space based on CNT		
Total Budget:	500 kEuro		
Objectives			
The main aim of the activity is to develop and test, in the relevant environment, large area optical filters for future soft X-ray instrumentation based on the use of carbon nano tubes (CNT) both for the thin pellicles and for the supporting meshes.			
Description			
Future X-ray astronomy missions have identified a need for large area, optical filters with very high transmission in the soft X-ray portion of the electromagnetic spectrum. The filters require a large diameter of order of 130 mm or larger with visible and IR light attenuation of several orders of magnitude, while operating at cryogenic temperatures and being strong enough to resist launch stresses. The use of CNT pellicles and C yarns supporting meshes has been investigated in a previous contract (CCN1 to ESA contract 4000120250 and De-risk activity to be implemented). Preliminary encouraging results have been obtained demonstrating the feasibility of manufacturing large area very thin CNT based filters and the higher soft x-ray transparency with respect to continuous polyimide films. The use of C yarn meshes, which become fully transparent at E > 5 keV, can provide higher transparency also at high energies with respect to the use of thick metal meshes. Finally, C yarn meshes can improve the thermal conductivity of the filter which is needed for de-contamination temperature control. A dedicated technology development program would be needed to fully demonstrate the competitiveness of the new technology with respect to previous adopted technologies in space. The main objectives of the activity are: - Design, manufacture and characterise small/medium size filters (diam. < 60 mm) aiming at optimizing the CNT pellicle manufacturing process and the Al deposition;			

- Demonstrate the high X-ray transmission and UV/Vis/IR attenuation performances; - Demonstrate the feasibility and reproducible production of high performance filters suitable for future space applications with large diameters (more then one possible diameter shall be demonstrated in the range 30-130 mm); - Demonstrate the critical qualification of form fit and function breadboards in the relevant environments (vibration, thermal cycling, etc); - Raise the Technology Readiness Level to 5 according to ECSS standards.					
Deliverables					
Breadboard; Report					
Current TRL:	TRL3	**Target TRL:**	TRL5	**Application Need/Date:**	20
Application Mission:	ATHENA		**Contract Duration:**	21 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Consistent with on-going "Optical Detectors" (2022.1, not yet IPC agreed) - D02 "ATHENA : Large area high-performance optical filter for X-ray instrumentation"					

Improvement of radiation hardness of BSI SiPM detectors			
Programme:	TDE	**Reference:**	T217-075MM
Title:	Improvement of radiation hardness of BSI SiPM detectors		
Total Budget:	800 kEuro		
Objectives			
Enhance the performance in radiation environment of Silicon Photo Multiplier (SiPM) detectors by designing them for backside illumination.			
Description			
SiPM detectors are currently explored as promising technology in a large number of fields: photon counting, medical application, gamma- ray spectroscopy, etc. Thanks to Single Photon Time Resolution, high frequency read-out, low dark count rate, this technology is also investigated for automotive LIDAR purposes. All those application are pushing the design and the limits of the technology to very high level for on ground application. The aim is to implement rad-hard elements to SiPM detectors to increase the radiation hardness. The activity will consist on: - simulation, - design, - process definition and - manufacturing of SiPM detectors - characterization before and after radiation campaigns The design of the new SiPMs shall be based on backside thinning, in order to enhance the quantum efficiency. Multiple batches will need to be manufactured, each taking in consideration the feedback from radiation			

campaigns conducted on the samples produced in the previous batch. Electro-optical testing will be performed after each campaign, to assess performances and improvements. Possible target applications could be atmospheric LIDAR mission or gamma-ray instrumentation.					
Deliverables					
Breadboard; Report					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2023
Application Mission:	Technology push		**Contract Duration:**	30 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
AIM B Develop high-end CIS and SPADs, Activity B11					

Programme:	TDE		**Reference:**	T207-068MM	
Title:	Optical Vector Magnetometer Based on The Hanle Effect				
Total Budget:	750 kEuro				
Objectives					
To build and characterise a breadboard of an optical Vector Magnetometer covering the range from 0 nT to several 1000 nT with a resolution better than 200fT.					
Description					
Demonstration first of a single axis micro cell magnetometer. Reduce the size of single sensor cell (l x d: 25mm x 10mm) to enable a competitive 3D sensor The expansion of this concept to a three-axis magnetometer. Including the development of the appropriate drive electronics. Characterisation of the magnetometer cell over temperature and over its full sensing range - 0 nT to several 1000 nT					
Deliverables					
Breadboard					
Current TRL:	TRL2	**Target TRL:**	TRL3	**Application Need/Date:**	20
Application Mission:	Generic mission needs can apply to multiple science missions.		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Optimised ASIC development for large format NIR/SWIR detector array

Programme:	CTP		**Reference:**	C217-098FI	
Title:	Optimised ASIC development for large format NIR/SWIR detector array				
Total Budget:	500 kEuro				
Objectives					
The objective of this activity is to implement further improvements of the universal optimised ASIC for readout and control of CMOS-ROIC based detectors in line with the roadmap for a European near infra-red detection and readout chain.					
Description					
This activity shall address further improvements identified during the development of the ASIC. The ASIC has demonstrated good analog and digital performance. However, some areas of improvement were identified which require additional design, manufacturing and test activities.					
Deliverables					
Prototype; Report					
Current TRL:	TRL5	**Target TRL:**	TRL5	**Application Need/Date:**	2022
Application Mission:			**Contract Duration:**	14 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Broadband high power transmitter for future radar sounders			
Programme:	TDE	**Reference:**	T206-024EF
Title:	Broadband high power transmitter for future radar sounders		
Total Budget:	350 kEuro		
Objectives			
The objective of this activity is to design, manufacture and test a broadband high power amplifier for future subsurface radars in science missions.			
Description			
RIME is a radar sounder instrument optimized for the penetration of the Galilean icy moons up to a depth of 9 km. The instrument is unique as it is the first one to be deployed in Jupiter and the outer Solar System capable of performing direct subsurface measurements. Throughout the development of RIME, few technological challenges had to be faced due to the complexity of such low frequency radar, the length of its dipole antenna and the multinational industrial set up. At present, only a broadband dipole for multi-mode subsurface radars is being developed though an ESA contract, while the rest of the radar			

elements rely on non-EU suppliers. This activity proposes to develop a broadband transmitter that fits to the dipole and matching network under development. The broadband nature of the transmitter will enable multi centre-frequency chirps to exploit the broadbandness of the dipole antenna. The activity will also focus on designing and manufacturing an amplifier with higher RF power (>200W) in order to improve the radar performance such as its penetration depth. Finally, this development will enable an overall performance enhancement due to the co-design of the different constituents with same radar performance goals in mind. These predevelopments shall constitute the basis for future subsurface radars in future planetary missions e.g. JUICE follow-on. The activity shall start with the review of the current subsurface radar as used in Juice. In synergy with the dipole and matching network development already in place, the activity shall focus on means to increase the power of the transmitter attending to technological options for the transmitter chain, including power handling of the dipole. Following the detailed design, the activity shall continue with the design, manufacturing and testing of the high power transmitter. Testing of the complete transmitter chain including the antenna shall be also foreseen. The activity shall conclude with an assessment of results and the feasibility of such radar concept based on the obtained results.

Deliverables					
Breadboard; Report					
Current TRL:	TRL2	**Target TRL:**	TRL4	**Application Need/Date:**	2024
Application Mission:	Juice follow-on type of science missions having a fully European transmitter for subsurface radars.		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Critical Active RF Technologies. This activity intends to use the products developed under A03					

Hysteretic Deformable Mirrors for Next Generation Space Telescopes			
Programme:	TDE	**Reference:**	T216-173MM
Title:	Hysteretic Deformable Mirrors for Next Generation Space Telescopes		
Total Budget:	350 kEuro		
Objectives			
Develop and scale up the piezo nano layer technology for Hysteretic Deformable Mirrors to reach a high number of actuators for post-launch fine			

corrections in telescopes and instrumentation for astronomy. Study compatibility of candidate materials for cryogenic applications.					
Description					
In the context of the Voyage 2050 astronomy missions (GaiaNIR, Exoplanet Characterization, ESA/NASA collaboration for LUVOIR/HabEx), there will be a need for very fine control and correction inside the main science instruments (eg. coronagraph) or potentially the front telescope. Additionally, the components used for post-launch adjustments need to be compatible with a cryogenic environment as expected for the upcoming infrared missions. Current generations of deformable mirrors for space applications are aiming at correcting lower order aberrations in front telescopes for instruments dedicated to general physics. However, for application requiring much higher image and wavefront quality as well as stability, the number of actuators have to be increased by 1 or 2 orders of magnitude which calls for a specific concept of deformable mirrors. Additionally, such deformable mirrors with a high number of actuators can also be used to correct for mid-spatial frequencies of optics therefore easing and speeding up the manufacturing process of large mirrors. Hysteretic Deformable Mirrors could be a very compact solution for correcting post-launch higher order thermo-elastic deformations and residual aberrations. These devices consist of thin piezo layers combined with a matrix of electrodes. A low voltage is applied at the electrode nodes creating a persistent reconfigurable local deformation allowing for wavefront corrections up to mid-spatial frequencies. There is near-zero power dissipation once the mirror has been deformed and remains static (set-and-forget) which makes it a promising application for cryogenic environments. Moreover, this technology is scalable and could relax the requirements on the other optics in the system enabling cheaper telescopes. A development at a component level is required to scale the technology to a high number of actuators and further material science research is needed to pave the way towards full adaptation to cryogenic environments. This activity will improve on the current limitations of the technology and demonstrate its performance. Task list: - Improve the nano-fabrication process and polishing - Develop the stacking of the piezo layers and the integration with the electrodes including a prototype with a high number of actuators - Research candidate materials for cryogenic application - Establish a technological roadmap to reach maturity (TRL5) of the mirror design and manufacturing process, including for cryogenic use.					
Deliverables					
Breadboard; Report					
Current TRL:	TRL1	**Target TRL:**	TRL3	**Application Need/Date:**	2023

Application Mission:		**Contract Duration:**	24 months
S/W Clause:	N/A		
Consistency with Harmonisation Roadmap and conclusion:			
B20: Technologies for Optical Passive Instruments – Mirrors.			

Coriolis Vibrating Gyroscope Sensing Element Space Qualification			
Programme:	CTP	**Reference:**	C205-119SA
Title:	Coriolis Vibrating Gyroscope sensing element Space Qualification		
Total Budget:	1000 kEuro		
Objectives			
The objective of this activity is to qualify the manufacturing processes of the gyroscope sensing element and implement screening processes to guarantee the repeatability of the production for Space Applications.			
Description			
Innalabs (Ireland) has manufactured and is selling Coriolis Vibratory Gyroscopes (CVGs) for terrestrial applications and non-rad-hard commercial space. The objective and focus of C205-114SA (Radiation Hard Gyroscope Development for Science Missions) is to design, manufacture and qualify a 3-axis gyroscope, using rad-hard and high-reliability components. The ESA Science mission PLATO has selected this 3-axis Gyroscope as first application. The heritage sensing element is a cylindrical metallic resonator, driven by piezoelectric sensors and actuators. A smaller and lighter sensing element – CVG2 has been designed and early batches have been manufactured. To be used in a high reliability mission, the individual qualification of all manufacturing processes is required. Nine processes have been identified, for which RFAs (Request for Approval) have been submitted. The space environment considered is covering wider applications (Temperature range, Thermal Cycles, Ageing) than the Scientific mission L2, granting flexibility in its use. In addition, the space environment differs from terrestrial use cases and detailed characterisation at component level is required as part of the sensing element qualification, focussing on mechanical environment and ageing, to cover a wide range of missions. In addition, C205-114SA has demonstrated the capability to reach high performance - ARW below 0.002 deg/sqrt(hr) - however proper screening requiring industrialisation of the test and calibration equipment are needed to achieve the goal regularly for Flight Models.			
Deliverables			
Qualification Report, Screening Plan and results			

Current TRL:	5	**Target TRL:**	6	**Application Need/Date:**	TRL6 by 2023
Application Mission:	PLATO, ARIEL		**Contract Duration:**	15 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
AOCS SENSORS AND ACTUATORS: STAR TRACKERS, APS, GYROS, ACCELEROS, WHEELS (Aim A05)					

Fine Guidance Sensor Feasibility Consolidation for SPICA mission			
Programme:	TDE	**Reference:**	T205-124SA
Title:	Fine Guidance Sensor Feasibility Consolidation for SPICA mission		
Total Budget:	200 kEuro		
Objectives			
To consolidate the SPICA Fine Guidance Sensor feasibility, looking at its performance in terms of absolute pointing accuracy, in particular regarding the catalogue accuracy; while considering it is accommodated in an infrared payload with stringent temperature and dissipation requirements			
Description			
Background and context: SPICA mission requires an unprecedented attitude estimation performance for an infrared (IR) mission. The requirements are 10 times more stringent than the performance obtained on the Herschel mission during the In Orbit Verification, and these requirements are closed to the feasibility limit even using a Fine Guidance Sensor (FGS) accommodated inside the payload. From the Concurrent Design Facility study, the required SPICA performance should be achievable but the Technology Readiness Level (TRL) of the design solution is very low (at FGS level) and the compliance may be at a huge cost on the attitude control settling time and so on the mission agility and availability. Therefore this activity aims at consolidating the feasibility of the attitude estimation performance. The technology to be developed utlimately for SPICA mission is a Fine Guidance Sensor (FGS) accommodated inside an infrared payload with a reduced FOV, which implies highly stringent power dissipation and temperature requirements. While complying to these interface requirements the FGS will also have to demonstrate a fine accurate absolute pointing performance of the whole system (0.21 arcsec which is already below the accuracy of the available Star catalogues in the IR), a good availability over the Sky sphere (aiming also at working while pointing towards the North galactic pole), and with a low integration time (4s which is challenging wrt the detection limit with the infrared payload, as low star magnitudes have to be considered to meet the Sky availability). This activity encompasses the following tasks: - FGS design trade-off and optimization: to assess the system feasibility and trade the possible options against system performances (delay and accuracy), costs and risks			

- IR Star catalogue development: to achieve the required accuracy (depending on the design solution selected, maybe 0.07arcsec)					
Deliverables					
Report, star catalogue in the infrared					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2024 TRL 6
Application Mission:	SPICA		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

CMOS Image Sensor for X-Ray Applications					
Programme:	TDE		**Reference:**	T217-070MM	
Title:	CMOS Image Sensor for X-Ray Applications				
Total Budget:	1000 kEuro				
Objectives					
The objectives of this activity are to design, manufacture and characterise a large-format CMOS image sensor optimised for soft X-ray detection.					
Description					
CCD technology with its low readout noise, noise-less binning capability, and high soft X-ray quantum efficiency (QE) has been the workhorse for low-energy X-ray detection in the last decades (e.g. XMM, Chandra). However CMOS technology can offer significant advantages at system level e.g., lower power consumption, higher temperature of operation, and flexible operation. For these reasons CMOS image sensors (CIS) are now being considered for several future X-ray instruments; in particular the SXI (Soft X-ray Imager) instrument onboard THESEUS - one of the ESA's three Cosmic Vision M5 candidates. For CIS to reach the level of performance satisfying the scientific needs its X-ray capabilities need to be improved; to reach this goal the proposed activity shall demonstrate a large format, buttable device: efficient charge collection for large pixels, improved X-ray QE for a thick fully depleted device and low readout noise. The CIS improved X-ray performance shall be demonstrated.					
Deliverables					
Breadboard; Report					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2024 TRL 6
Application Mission:	Theseus		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Optical Detectors, Visible Range – the activity is targeting X-rays but can be potentially covering visible range.					

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