EUROPEAN SPACE AGENCY

INDUSTRIAL POLICY COMMITTEE

Science Programme Technology Development Plan: Programme of Work for 2020 and 2021, 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. The national initiatives activities of relevance to the Science programme are provided for information. Activities funded through the Industrial Policy Task Forces (IPTFs) and of relevance to the Science Programme are also provided for information.

June 2020

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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(2019)81.rev.1, approved by the IPC in November 2019.

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 2022; JUICE was selected as L1 and is also planned for launch in 2022. 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 2026.

The Call for the fourth M mission (M4) has led to the selection of the ARIEL mission in March 2018. ARIEL is currently within Phase B1. The mission adoption is planned late 2020 and launch is targeted in 2028, together with Comet Interceptor.

The Call for the fifth medium-sized mission opportunity (M5) was issued in April 2016 and resulted in selection of three candidate missions: EnVision (mission devoted to investigate the surface and subsurface of Venus, in collaboration with NASA); SPICA (mid- and far-infrared observatory using a 2.5 m cryogenic telescope following Herschel, in collaboration with JAXA); and THESEUS (mission devoted to Gamma Ray Burst measurements). Parallel Phase A studies for each of the candidate missions were initiated early 2019 and the selection of the M5 mission is planned mid-2021.

Additionally, a Call for a small mission took place in 2012. Following the Call, CHEOPS was adopted by the SPC as the S1 mission in February 2014 and the industrial implementation contract was kicked-off mid-2014. CHEOPS was launched on a Soyuz rocket from Kourou as a passenger to a main spacecraft in December 2019.

The Call for "Fast" mission was issued in July 2018 for a modest-sized mission to be launched as a passenger to ARIEL in 2028 on an Ariane 6.2 launcher. Following the scientific peer review of the proposals carried out in mid-2019, the Comet Interceptor mission was selected and is currently in Phase A/B, aiming at the mission adoption by 2022.

In March 2013 ESA issued a Call to define the scientific themes of the Large missions L2 and L3, with envisaged launches before 2035, resulting in the selection of "the hot and energetic Universe" theme (to be addressed by an X-ray observatory) for L2, and "the gravitational Universe" theme (to be addressed by a gravitational wave observatory) for L3.

The Call for mission proposals for the L2 launch opportunity was issued early 2014 and resulted in the selection in June 2014 of the Athena mission concept. 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 Phase A study was completed in 2019, and is currently in the Phase B1, aiming at the mission adoption by mid-2022 and launch in 2032/2033 timeframe.

The L3 Call for mission proposals was issued late 2016 and resulted in the selection of the LISA mission concept in June 2017, using laser interferometry for gravitational wave measurement, building on the successful demonstration achieved in orbit by LISA Pathfinder in 2016. The Phase A started in 2018, in parallel with the mission technology preparation, and is expected to be completed in 2021. The mission adoption date is planned in 2024. The overall implementation scheme for LISA and Athena will be discussed with the SPC at its July 2020 meeting.

In January 2015 a joint ESA/Chinese Academy of Sciences (CAS) call for a small joint mission led to the selection of the SMILE mission. SMILE will provide for the first time global imaging of the interaction between the solar wind and the magnetosphere of the Earth using innovative X-ray and UV instrumentation. Following the successful completion of Phase A/B, undertaken jointly by ESA and CAS, the mission was adopted in March 2019, with a planned launch in 2024.

The Figure 1 summarises the Science Programme plan as of March 2020. An update to the plan will be discussed with the SPC at its July 2020 meeting.

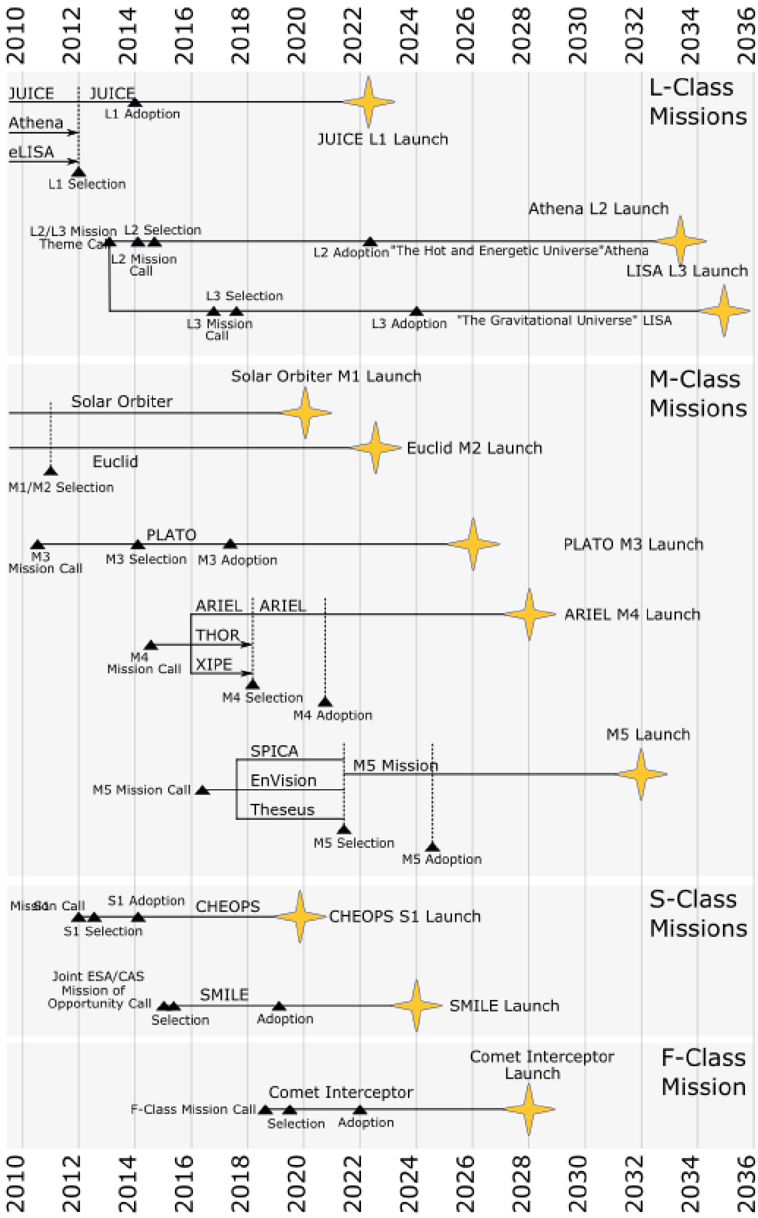

Figure 1: ESA Science Programme Mission Plan Timeline Summary

3 Science Programme Technology Development Plan

3.1 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.

The new activities are addressing the L missions Athena (L2) and LISA (L3), Ariel, Comet Interceptor and technologies applicable to several missions.

3.2 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 JAXA and NASA contributions)	X-ray telescope (Silicon Pore Optics) Cryogenic cooling chain for X-ray spectrometer (with possible contributions from partners)
LISA (L3 Mission)	C	Optical bench, Gravitational Reference Sensor, Phasemeter	Telescope, Laser system (with possible contributions from NASA)
ARIEL (M4 mission)	B	Complete payload complement, including cryogenic PLM and warm payload units.	V-grooves, AIRS detectors
SMILE (ESA-CAS mission)	C	Soft X-ray Imager (SXI), UV Imager (UVI led by Canada), MAG and LIA instruments are provided by CAS	PLM overall responsibility
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.

3.3 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 Council decisions contained in ESA/C(2017)119, 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 restricted 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.

3.4 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 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.

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

4.1 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: Athena

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 early 2030s.

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 around 2035.

4.1.3 M4 Mission: ARIEL

The ARIEL mission (Atmospheric Remote-Sensing Infrared Exoplanet Large-survey) has been selected for the M4 mission opportunity. The mission will study what exoplanets are made of and how they formed and evolved by surveying a diverse sample of about 1000 extrasolar planets simultaneously in visible and infrared wavelengths. It is the first mission dedicated to measuring the chemical composition and thermal structures of hundreds of transiting exoplanets, enabling planetary science far beyond the boundaries of the Solar System. Mission Adoption is planned in 2020 for a launch in 2028.

4.1.4 M5 Candidate: SPICA

SPICA is a Mid- and Far-IR observatory for studying the formation and evolution of galaxies, black holes and planetary systems. It will improve, by two orders of magnitude, the spectroscopic sensitivity compared to previous space telescopes such as Herschel, and resolve, for the first time, the far-infrared polarisation of galactic filaments. The payload consists of a 2.5 m Ritchey-Chretien telescope cooled to 8 K, with a high resolution Far-IR spectrometer (SAFARI), a Mid-IR spectrometer/camera (SMI) and a Far-Infrared Imager/Polarimeter (B-BOP). SPICA is proposed as a mission in cooperation with JAXA.

4.1.5 M5 Candidate: EnVision

Carrying 3 cutting-edge instruments: an S-band Synthetic Aperture Radar (VenSAR), a Subsurface Radar Sounder (SRS) and an emission mapper (VEM), 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 evidences 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.

4.1.6 M5 Candidate: THESEUS

The THESEUS mission will be dedicated to the observation of high-energy transient sky phenomena, in particular Gamma Ray Bursts (GRBs), over a wide range of red-shifts, allowing understanding of the evolution of the Early Universe. The payload comprises an X-Gamma ray Imaging Spectrometer (XGIS) covering an unprecedented energy range (2 keV – 20 MeV), a Soft X-ray Imager (SXI) and an InfraRed Telescope (IRT).

4.1.7 F-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.

4.2 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	Pulse Tube and Joule Thomson coolers, cryogenic harness
		End-to-end cooling chain for transition edge sensor based cryogenic x-ray spectrometer including cryostat

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 2 L2 and L3 Mission Critical Technologies.

M4 Mission		
Mission	Technology area	Technology Development Activities
ARIEL	Payload	HgCdTe detectors (various cut-off wavelengths) and associated read out electronics
		Ne JT cooler
		Cryogenic aluminium telescope mirror with silver coating
		Cryogenic M2 re-focussing mechanism
		Broadband Vis/NIR dichroic mirror

Table 3 M4 Mission Critical Technologies.

M5 Mission Candidates		
Mission	Technology area	Technology Development Activities
SPICA	Payload	SAFARI: Transition Edge Sensors (TES) cooled to 50mK, Half-Wave Plate
		SMI: large format (1k x 1k) detector array, free form mirror optics, MIR filters and gratings
	Spacecraft	AOCS, micro-vibration control (TBC)
EnVision	Payload	Large heritage for all instruments
	Spacecraft	No critical technology identified
THESEUS	Payload	XGIS: broad band detector (Silicon Drift Detector Photodiode and Cs(Tl) scintillator detector), very low noise ASIC
		IRT: detector cooling (miniature pulse tube cooler)

Table 4 M5 Mission Candidates: 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 500k€ and has had approval if applicable. A year entry e.g. “Y2008” indicates prior IPC/ approval of an activity.
Reference:	Unique ESA generated reference for TDA
Activity Title:	Title of the proposed TDA
Budget:	The total Contract Authorisation (CA) values are given in k€, 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 C(R) = Competition is restricted to a few companies, indicated in the "Remarks" column; (Ref. ESA Procurement Regulations) 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(2001)29, 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

New Activities Budget Summary Table

Mission	Programme	2020	2021
ATHENA	CTP	0	450
	TDE	0	500
	Total	**0**	**950**
LISA	CTP	0	1500
	TDE	0	800
	Total	**0**	**2300**
ARIEL	CTP	0	1110
	TDE	0	0
	Total	**0**	**1110**
SPICA	CTP	0	0
	TDE	0	0
	Total	**0**	**0**
EnVision	CTP	0	0
	TDE	0	0
	Total	**0**	**0**
THESEUS	CTP	0	0
	TDE	0	0
	Total	**0**	**0**
Comet Interceptor	CTP	**0**	**0**
	TDE	**250**	**0**
	Total	**250**	**0**
Technologies applicable to several Science Programme Missions	CTP	0	360
	TDE	1500	2750
	Total	1500	**3110**
Total CTP		**0**	**3420**
Total TDE		**1750**	**4050**
Total ESA		**1750**	**7470**

This table provides a summary of the budgets for new activities in 2020 and 2021 for missions in preparation.

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Annex I

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 AND MODIFIED ESA ACTIVITIES INCLUDING THOSE SEEKING APPROVAL FOR IMPLEMENTATION

L2-MISSION: ATHENA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
CTP	IPC	C215-141MT	15 K Pulse Tube Cryocooler Unit Engineering Model developments phase 1	0	3000	0	DN/C	FR	N/A	Already approved. Changed procurement policy to DN/C. DN/C with ALAT.
TDE	IPC	T215-017MS	High performance microvibration isolation system (continuation)	0	0	500	DN/C	UK	N/A	To be possibly implemented as CCN to contract (previous price 350 k initial contract + 56 k for first CCN). DN with Uni. of Surrey.
CTP	IPC	C216-174FT	Diamond like coating device	0	0	450	DN/S	RO	N/A	Structuring Activity for Romania. Unique capability confirmed with sample tests. DN with The Plasma Coatings Research Group of the National Institute for Laser, Plasma & Radiation Physics (INFLPR) in Romania.
Total – L2-Mission: Athena				**0**	**3000**	**950**	**950 Total new = 450 CTP + 500 TDE, 3000 Total updated PP**			

L3-MISSION: LISA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
CTP	IPC	C219-012MP	Delta-developments of heritage Cold Gas Micro-thruster for LISA	0	0	1500	DN/C	IT	N/A	To be possibly implemented as CCN to running activity with Leonardo (C219-011MP, total previous price 500 k). Activity intended to preserve and enhance cold gas micropropulsion for LISA needs
TDE	AC	T217-072MT	Optical fiber micro-Kelvin temperature sensor network for sensitive optical payloads	0	0	400	C		N/A	
IPTF	IPC	C217-091FI	Development of a master oscillator for the LISA laser system	0	600	0	C	IE	N/A	Already approved, funded through the Work Plan of the Industrial Policy Task Force with Ireland. PP changed to open competition limited to Ireland
TDE	AC	T207-064EP	Advanced DC and AC Magnetic Verification	0	0	400	C		N/A	
Total – L3-Mission: LISA				**0**	**600**	**2300**	**2300 Total new = 1500 CTP + 800 TDE, 600 Total updated PP**			

M4-MISSION: ARIEL

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
CTP	IPC	C224-007FM	Development of the method of gluing glass elements with titanium holders in cryogenic temperature	0	0	460	DN/S	PL	N/A	DN with CBK, responsible for Ariel Fine Guidance Sensor. Structuring activity for Poland.
CTP	IPC	C224-007EF	X-band Low Gain Antenna development	0	0	650	DN/S	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	Country	SW Clause	Remarks
				2019	2020	2021				
Total – M4-Mission: ARIEL				**0**	**0**	**1110**	**1110 Total = 1110 CTP**			

F-MISSION: COMET INTERCEPTOR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
TDE	AC	T204-134EP	Coma Model for Comet Interceptor	0	250	0	C		Open Source Code	
Total – F-Mission: Comet Interceptor				**0**	**250**	**0**	**250 Total = 250 TDE**			

TECHNOLOGIES APPLICABLE TO SEVERAL SCIENCE PROGRAMME MISSIONS

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
TDE	IPC	T220-056FT	Maturation of Additive Manufactured Metallic Optical Bench	0	1000	0	DN/C	DE	N/A	Possibly to be implemented as CCN to T224-004QT. (previous total price 1187 k). DN with Fraunhofer Institute for Material and Beam Technology (IWS)
TDE	AC	T224-005QT	Adhesive bond behavior in cryogenic environment (CCN)	0	0	150	DN/S	DE	N/A	CCN to KRP(DE) contract
TDE	IPC	T203-114EP	Ultra-Stable Power System Architectures	0	0	500	C		N/A	Potential application for several future science missions including LISA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget			PP	Country	SW Clause	Remarks
				2019	2020	2021				
TDE	-	T207-063EP	Electro-Magnetic Shielding Effectiveness Optimization for Thermal Multi-Layer Insulation	0	0	300	C		N/A	
TDE	-	T203-113MT	Electro-chemical compressor for Joule Thomson Cooler	0	0	250	C		N/A	
TDE	IPC	T221-021MT	Characterization of MLI materials and definition of MLI blanket for aerobraking environment	0	0	500	C		N/A	Relevant for several possible planetary missions, including EnVision
TDE	-	T219-003MP	Development of a low power cathode for scientific missions	0	0	200	C		N/A	
TDE	IPC	T201-052ED	High-Speed High Resolution Quad-ADC for Science Instruments	0	500	0	DN/S	IE	N/A	Potential application for several future science missions including LISA. DN with S3/Adesto. Majority of the funds to IE and PT
CTP	IPC	C220-051FT	Verification of Interface Zones for Uninterrupted pre-preg fibre placed lattice structures - CCN	0	0	360	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. Possibly to be implemented as CCN to C220-049FT (total previous price 840kEuro). DN with ATG (IE)
TDE	-	T205-125SA	Attitude Guidance Using On-Board Optimisation	0	0	300	C		N/A	
TDE	-	T212-061GS	Multiple frequency-shift keying modem	0	0	350	C		N/A	
Total – Technologies applicable to several science programme missions				**0**	**1500**	**2910**	**4410 Total = 360 CTP + 4050 TDE**			

COMPLETE LIST OF RUNNING AND PLANNED ACTIVITIES

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

- Running since 2017 i.e. activities for which contracts have been signed.
- In preparation for implementation.
- Foreseen to be implemented up to and including 2021.

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.

CANDIDATE MISSIONS IN PREPARATION:

L2-MISSION: ATHENA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
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 k€ in 2016.
TDE	Y2015	T204-117EE	Experimental evaluation of Athena charged particle background from secondary radiation and scattering in optics	600	0	0	0	0	C(3)	IT	N/A	TDA is running. INAF (IT)
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 k€ in 2016.
CTP	Y2017	C204-119FM	Athena - Magnetic Diverter	500	0	0	0	0	C	CZ	N/A	TDA is running. Frentech Aerospace S.R.O. (CZ)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2019	C204-128FI	Maturation of the ATHENA Charged Particle Diverter System	0	0	0	200	0	DN/C	CZ	N/A	To be possibly implemented as a CCN to C204-119FM (previous total price 500 k). DN with Frentech Aerospace S.R.O. (CZ).
CTP	Y2018	C204-123FT	Characterisation of micro-meteoroid induced dark current increase in silicon detectors	0	0	600	0	0	C		N/A	
TDE	Y2016	T209-001EC	Autonomous Targets of Opportunity for astronomy missions	0	300	0	0	0	C	ES	N/A	TDA is running. GMV (ES) + subs
CTP	Y2016	C215-128FM	Athena Hold Down Release Mechanism	800	0	0	0	0	C	PL	N/A	TDA is running. Sener (PL) Competition limited to Poland Structuring activity for PL
CTP	Y2019	C215-138MS	Athena ISM launch vibration damper	0	0	300	0	0	DN/C	PL	N/A	TDA is running .CCN to C220-038FM and follow-up. DN with Sener (PL) (previous total price 1200 k).
CTP	IPC	C215-141MT	15 K Pulse Tube Cryocooler Unit Engineering Model developments phase 1	0	0	0	3000	0	DN/C		N/A	Already approved. Changed procurement policy to DN/C. DN/C with ALAT.
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 k€ in 2016. This activity is implemented as a CCN to C216-006MM, price 1000 k€. Phased activity with Phase 1 1200 k€ and Phase II 1800 k€ (total current price 4200 k).
CTP	Y2018	C216-160FT	Silicon Pore Optics modelling and simulations for telescope	0	300	0	0	0	DN/C	IT	Open Source	TDA is running. CCN to C216-132FT, (total current price 800 k). DN with INAF/OAB (IT)
CTP	Y2016	C216-148MM	Silicon Pore Optics Engineering Qualification Model - Preparation	0	6000	0	0	0	DN/S	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
				2017	2018	2019	2020	2021				
CTP	Y2019	C216-149MM	Silicon Pore Optics Engineering Qualification Model	0	0	0	7000	0	DN/C	NL	N/A	TDA is running. DN with Cosine (NL) led consortium
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	1850	0	DN/C	IT	N/A	TDA is running. Implemented as a CCN to C216-127MM and C216-141MM (total 2730 k€). DN with Media Lario (IT). Contract placed for 1850 k€.
CTP	Y2018	C216-162FT	Figuring of Large Precision UV Optics	0	2500	0	0	0	DN	FI	N/A	TDA is running. Structuring activity for Finland. DN with Opteon Oy (FI)
TDE	Y2018	T216-110FT	X-ray raster scan facility for the Athena Mirror Assembly	0	300	0	0	0	C	IT	N/A	TDA is running. INAF (IT) + subs.
CTP	Y2019	C216-007MM	Telescope mirror structure and optics integration demonstrator	0	0	0	2500	0	C		N/A	TDA under procurement
CTP	Y2019	C216-007MM-B	Telescope mirror structure and optics integration demonstrator	0	0	0	2500	0	C		N/A	TDA under procurement
CTP	N/A	C216-128MM	Silicon Pore Optics Manufacturing Facility Design	0	0	0	0	0	C		N/A	For information, 400k considered in 2021/22
CTP	Y2019	C216-166FT	Improvement of the ATHENA SPO Plate Production and Coating Processes	0	0	0	600	0	DN/C	NL, UK, DK	N/A	To be possibly implemented as a CCN to C216-135MM (3000 k€). DN with Cosine (NL) with the majority of CCN funds to subs: Teledyne e2v (UK) + DTU Space (DK)
CTP	Y2016	C216-144FT	Athena Coating Process Optimisation	450	0	0	0	0	DN/C	DK	N/A	TDA is competed.
CTP	Y2018	C216-157FI	Low-Energy X-ray Coating Development for Athena	0	1000	0	0	0	DN/C	DK	N/A	TDA is running. CCN to C216-144FT and C216-116PA, total previous price 880 k€. DN with DTU Space (DK).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	IPC	C216-174FT	Diamond like coating device	0	0	0	0	450	DN/S	RO	N/A	Structuring Activity for Romania. Unique capability confirmed with sample tests. DN with The Plasma Coatings Research Group of the National Institute for Laser, Plasma & Radiation Physics (INFLPR) in Romania.
CTP	Y2018	C216-161FT	Synchrotron beam time and monochromator beamline maintenance continuation	0	800	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 price 2440 k).
CTP	Y2014	C216-131FT	Thermal equipment and large optics accommodation at existing Panter facility	0	0	0	0	0	DN/C	DE	N/A	TDA is completed.
CTP	Y2016	C216-142MM	X-ray facility design and verification for the Athena flight mirror performance testing and calibration	500	0	0	0	0	DN/C	DE	N/A	TDA is running. DN with MPE (DE) CCN to C216-131FT (total current price 2150 k).
CTP	Y2017	C216-153MM	Advanced and Compact X-ray Test Facility for the Athena SPO module	500	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	1000	0	0	0	0	DN/C	DE	N/A	TDA is running. DN with MPE (DE) CCN to C216-131FT (total current price 2150 k).
CTP	Y2019	C216-168FT	ALBA fixed energy beamline	0	0	0	1000	0	DN/S	ES	N/A	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	1200	0	DN/C	NL,DK, UK	N/A	To be possibly implemented as a CCN to C216-135MM and C216-166FT (previous total price 3600 k). DN with Cosine (NL), with an anticipated majority of CCN funds to subs: Teledyne e2v (UK) and DTU Space (DK). Subject to

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
												Athena proceeding to phase B1, currently planned end 2019.
TDE	Y2019	T216-171FT	Carbon nanotube-based filters for x-ray applications	0	0	0	500	0	DN/C	FI	N/A	To be possibly implemented as a CCN to T217-061MM (previous total 1500 k)
TDE/ CTP	Y2019	C216-172FT	Demonstration of critical items for x-ray scanning facility	0	0	0	2500	0	DN/C	IT	N/A	To be possibly implemented as a CCN to T216-110FT (300 k). TDE (500 k) contribution to CTP (2000 k). Subject to Athena proceeding to phase B1, currently planned end 2019.
CTP	Y2019	C217-067FM	Athena On Board Metrology	0	0	900	0	0	C	PT	N/A	TDA is running. Contract with FCUL Structuring activity for Portugal. Competition limited to Portugal.
TDE/ CTP	Y2016	T217-061MM	Large area high-performance optical filter for X-ray instrumentation	0	0	0	0	0	C	FI	N/A	TDA is running. Joint funding with 500 k€ TDE and 1000 k€ CTP. (1500 k€ in 2016)
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 k€ in 2016.
CTP	Y2018	C217-044FM	Large Area European Transition Edge Sensor Array for X-Ray missions	0	0	1400	0	0	DN/S	NL	N/A	To be possibly implemented as a CCN to C217-043FM, C217-031FI, (total price 1672 k€). DN with SRON (NL).
CTP	Y2016	C217-065FM	Athena Superconducting Quantum Interference Device Readout Development	1000	0	0	0	0	DN/S	FI	N/A	TDA is running. DN with University of Helsinki (FI)
CTP	Y2019	C217-094FT	Development of high count rate energy-resolving x-ray camera for ATHENA calibration	0	0	0	300	0	C	CZ	N/A	Competition limited to CZ. Structuring activity for CZ.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2016	C220-041FM	Athena Focal Plane Module Development Model	2000	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 k€ in 2016.
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 k€ in 2014.
TDE	IPC	T215-017MS	High performance microvibration isolation system (continuation)	0	0	0	0	500	DN/C	UK	N/A	To be possibly implemented as CCN to T215-011MS (total previous price 350 k). DN with Uni. of Surrey.
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 k€ 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 k€ in 2016.
CTP	Y2014	C221-008FM	2K Joule-Thomson engineering model cooler system including cooler drive electronics	0	0	0	0	0	C	UK	N/A	TDA is completed.
CTP	Y2019	C221-019MT	Industrialization of the Joule Thomson cooler mechanical assembly	0	0	0	4500	0	DN/S	UK	N/A	Implementation under consideration due to evolution of responsibilities in the ATHENA mission. To be possibly implemented as a CCN to C221-008FM, C221-009FM (previous total price 2400 k). 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	950	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	600	0	0	0	DN	LU	N/A	Direct negotiation with Eurocomposites (LU)

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
												Structuring activity for Luxembourg.
CTP	Y2019	C221-020MT	Low temperature radiator panel with embedded heat pipes - CCN	0	0	0	300	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	250	0	C		N/A	Targeting Athena, but relevant for other cryogenic missions.
TDE	Y2019	T221-114FT	High Temperature Superconductor Harness for use in cryogenic applications	0	0	0	250	0	C		N/A	Targeting Athena, but also relevant for SPICA
TDE	Y2019	T221-020MT	Characterisation of Helium Joule-Thomson Vapour Cooling with Return Line	0	0	0	500	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	1000	0	0	DN	FI	N/A	TDA is running. Structuring activity for Finland. DN with RUAG (FI)
Total – L2-Mission: Athena				**8300**	**11800**	**4200**	**28950**	**950**	**53285 Total = 49585 CTP + 3700 TDE**			

L3-Mission: LISA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2018	C201-037FT	LISA Phasemeter Unit Development	0	1500	0	0	0	DN	DK	N/A	TDA is running. Structuring activity for Denmark. DN with DTU Space (DK)
TDE	Y2019	T204-125EP	Test mass charging toolkit and LPF lessons learned	0	0	400	0	0	C		Open Source	
CTP	Y2017	C204-120EP	Development and validation of a contamination package in SPIS for Liquid based Electrical Propulsion systems for LISA	0	200	0	0	0	C	FR	Open Source	TDA is running. ONERA (FR) + subs

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2016	T205-033EC	Assessment and Preliminary Prototyping of a Drag Free Control System for the L3 Gravity Wave Observatory	0	300	0	0	0	C(1)	IT	N/A	TDA is running. Politecnico di Torino (IT) & subs.
TDE	Y2017	T205-038EP	Micro-particle impact related attitude disturbances	0	300	0	0	0	C(3)	DE	Operational Software	TDA is running. HTG GmbH (DE)
TDE	Y2019	T208-022MM	Straylight LIDAR OGSE verification tool, hardware pre-development	0	0	0	500	0	C		N/A	
TDE	Y2019	T215-016FT	Development of prototype Active Aperture Mechanism for LISA	0	0	0	500	0	C		N/A	
CTP	Y2019	C215-137FT	LISA Optical Assembly Tracking Mechanism Development	0	0	1500	0	0	C		N/A	
CTP	Y2019	C215-136FT	Antenna Pointing Mechanism for the LISA High-Gain Antenna - Concept and Verification	0	0	0	400	0	C		N/A	
CTP	Y2018	C216-164MM	Molecular contamination de-risking activities for LISA	0	0	200	0	0	C(3)		N/A	
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 k€ in 2014
CTP	Y2018	C217-084FT	Photonic components analysis in support of the LISA laser system development	0	0	400	0	0	DN/S	IE	N/A	TDA is running. Structuring activity for Ireland. DN with Tyndall (IE)
CTP	Y2015	C217-046FM	Gravitational Wave Observatory Metrology Laser	0	0	0	0	0	C	CH, DE	N/A	Phased activity with two parallel contracts. Phase I contracts of 600 k€ and one Phase II contract of 2300 k€ .TDA Phase I is completed: CSEM (CH) and SpaceTech GmbH (DE)
CTP	Y2019	C217-088FI	Gravitational Wave Observatory Metrology Laser - CCN	0	0	0	1500	0	DN/C	DE	N/A	Continuation of C217-046FM

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2019	C217-095FI	LISA Laser System Performance Metrology	0	0	0	1500	0	DN/S	CH	N/A	
CTP	Y2016	C217-068MM	Fine-structure of laser radiation in the far-field	150	0	0	0	0	C(3)	IE	N/A	TDA is running (NUI Galway)
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 (DE) 1200 k€ in 2016.
TDE	Y2017	T217-066MM	Hollow core fibre gas cell for laser frequency stabilisation (I2 and C2HD)	0	1000	0	0	0	C	DK	N/A	TDA is running. Structuring activity for Denmark. Direct negotiation with DMU (DK).
CTP	Y2019	C217-089FI	Laser Pre-stabilisation System for the LISA Mission	0	0	750	0	0	DN/S	UK	N/A	DN with NPL (UK)
CTP	Y2018	C219-009MP	Preliminary Qualification Status Assessment of Heritage Cold Gas Micro-thruster for LISA	0	250	0	0	0	DN/S	IT	N/A	TDA is running. DN with Leonardo (IT) Total Budget incl CCN 500k
CTP	Y2019	C219-011MP	Preliminary Qualification Status Assessment of Heritage Cold Gas Micro-thruster for LISA - CCN	0	0	250	0	0	DN/C	IT	N/A	To be implemented as a CCN to C219-009MP (250 k€). DN with Leonardo (IT)
CTP	IPC	C219-012MP	Delta-developments of heritage Cold Gas Micro-thruster for LISA	0	0	0	0	1500	DN/C	IT	N/A	To be possibly implemented as CCN to running activity with Leonardo (C219-011MP, total previous price 500 k). Activity intended to 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	0	0	0	0	400	C			
IPTF	IPC	C217-091FI	Development of a master oscillator for the LISA laser system	0	0	0	600	0	C	IE	N/A	Already approved, funded through the Work Plan of the Industrial Policy Task Force with Ireland. PP changed to open competition restricted to Ireland

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2017	C221-016MT	Enhanced temperature measurement for LISA	0	400	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	400	0	0	0	C	DK	N/A	TDA is running, TERMA (DK) parallel contracts
TDE	N/A	T207-064EP	Advanced DC and AC Magnetic Verification	0	0	0	0	400	C		N/A	
Total – L3-Mission: LISA				**150**	**4350**	**3500**	**5000**	**2300**	**15300 Total = 12000 CTP + 3300 TDE**			

M4-MISSION: ARIEL

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2018	C216-159FM	Cryotesting of ARIEL M1 mirror and coating process qualification for de-risking ARIEL schedule	0	960	0	0	0	DN/S	BE	N/A	TDA is running. DN with CSL (BE)
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 price 2400 k).
CTP	Y2019	C221-018FT	V-grooves development for ARIEL	0	0	2000	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	850	0	0	DN/C	BE	N/A	To be possibly implemented as a CCN to C216-159FM (price 1080 k€). DN with CSL (BE)
CTP	IPC	C224-007FM	Development of the method of gluing glass elements with titanium holders in cryogenic temperature	0	0	0	0	460	DN/S	PL	N/A	DN with CBK, responsible for Ariel Fine Guidance Sensor. Structuring activity for Poland.
CTP	IPC	C224-007EF	X-band Low Gain Antenna development	0	0	0	0	650	DN	FI	N/A	DN with DA-Group. Structuring activity for Finland as per recommendation of the Delegation.
Total – M4-Mission: ARIEL				**0**	**960**	**2850**	**0**	**1110**	**5120 Total = 5120 CTP**			

M5-Mission Candidate: SPICA

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2019	T205-124SA	Fine Guidance Sensor Feasibility Consolidation for SPICA mission	0	0	200	0	0	C		N/A	
CTP	Y2019	C206-016FI	Polarization-sensitive submillimeter bolometer technology for the B-BOP instrument on SPICA	0	0	1000	0	0	DN/S	FR	N/A	DN with CEA SACLAY (FR)
CTP	Y2019	C217-082FI	Far-infrared superconducting imaging technology for the SAFARI instrument on SPICA	0	0	1400	0	0	DN/S	UK	N/A	DN with Uni. Cardiff (UK) and Uni. Cambridge (UK)
Total – M5-Mission Candidate: SPICA				**0**	**0**	**2600**	**0**	**0**	**2600 Total = 2400 CTP + 200 TDE**			

M5-Mission Candidate: EnVision

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2019	T204-129EP	Neutral atmosphere model for future science missions	0	0	150	0	0	C		Open Source	
TDE	Y2019	T205-121SA	Control/structure co-design for planetary spacecraft with large flexible appendages	0	0	300	0	0	C		N/A	
TDE	Y2019	T205-123SA	GNC and FDIR design for robust autonomous Aerobraking corridor control	0	0	300	0	0	C		N/A	
TDE	Y2018	T206-011EF	External calibration method for the VenSAR instrument	0	0	250	0	0	C		N/A	
TDE	Y2018	T206-018FI	Analysis and bradboarding of sub-surface radar boom for EnVision M5 candidate mission	0	0	650	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2019	T206-021GS	Very high rate TM downlink using GMSK with simultaneous pseudo noise ranging	0	0	800	0	0	C		N/A	
TDE	Y2019	T206-015ES	120 W, 32 GHz TWT for Payload Data Transmitter	0	0	750	0	0	C		N/A	
TDE	Y2018	T207-054EF	Broadband Dipole Antenna for Multi-Mode Sub-Surface Radar	0	0	450	0	0	C		N/A	
TDE	Y2019	T212-005GS	Very High Rate Turbo Decoder with interleaver in the TTCP	0	0	300	0	0	C		N/A	
Total – M5-Mission Candidate: EnVision				**0**	**0**	**3950**	**0**	**0**	**3950 Total = 3950 TDE**			

M5-MISSION CANDIDATE: THESEUS

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2019	T217-070MM	CMOS Image Sensor for X-ray Applications	0	0	1000	0	0	C		N/A	
CTP	Y2019	C216-018PA	Further development of the ALFA-N detector (VIS/NIR/SWIR) in view of upcoming Science missions	0	0	3000	0	0	DN/C	FR	N/A	To be possibly implemented as a CCN to T216-048PA (2000 k€). DN with Sofradir (FR) For information, moved from 'Several Missions'- title and scope changed to target application for Theseus.
Total – M5-Mission Candidate: THESEUS				**0**	**0**	**4000**	**0**	**0**	**4000 Total = 3000 CTP + 1000 TDE**			

F-MISSION: COMET INTERCEPTOR

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	N/A	T204-134EP	Coma Model for Comet Interceptor	0	0	0	250	0	C		Open Source Code	
Total – F-Mission: COMET INTECEPTOR				**0**	**0**	**0**	**250**	**0**	**250 Total = 0 CTP + 250 TDE**			

TECHNOLOGIES APPLICABLE TO SEVERAL SCIENCE PROGRAMME MISSIONS

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2014	T201-033ED	Platform and Payload Sensor/Actuator Bus Nodes	0	0	0	0	0	C	UK	N/A	TDA is running. TAS (UK) + sub. 500 k€ in 2016.
CTP	Y2018	C201-036ED	Contribution to High Density European Rad-Hard SRAM-based FPGA	0	300	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	3500	0	0	DN	FI	N/A	Structuring activity for Finland. DN with RUAG (FI). Co-funded by TDE (500k) and CTP (3000k).
CTP	Y2018	C203-112FM	SMILE SXI PSU de-risking activity	0	0	1250	0	0	DN	DK	N/A	Structuring activity for Denmark. DN with Terma (DK) To be possibly implemented as a CCN.
CTP	Y2018	C204-122EP	European contribution to International Radiation Environment Near Earth modelling system	0	800	0	0	0	DN	GR	Open Source	Structuring activity for Greece. DN with SPARC (GR).
TDE	Y2016	T204-124EE	Mini Ion emitter for Spacecraft Potential Mitigation on Science Missions	0	400	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 k€ in 2016
TDE	Y2015	T204-119EE	Radiation environment at extremely low altitude and latitude	0	0	0	0	0	C(3)	UK	N/A	TDA is running, RadMod Research Ltd. (UK) 300 k€ 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

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget 2017	2018	2019	2020	2021	PP	Country	SW Clause	Remarks
												500 k€ in 2016
CTP	Y2012	C205-106EC	High Accuracy Star Tracker	0	0	0	0	0	C(1)	DE	N/A	TDA is completed. Jena Optronik (DE) + subs. 500 k€ in 2014
CTP	Y2018	C205-118SA	High Accuracy Star Tracker Engineering Model Development	0	400	0	0	0	DN/C	DE	N/A	TDA is running. CCN to C205-106EC, total price 575 k€. DN with Jena Optronik (DE) CTP contribution to GSTP activity GT17-102SA (1000 k€).
TDE	Y2014	T205-032EC	Robust Attitude Guidance and Control for Flexible Spacecraft	0	400	0	0	0	C	UK	N/A	TDA is running. Airbus Defence and Space (UK)
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 k€. Approved in ESA/IPC(2013)81. 1500 k€ in 2015
TDE	Y2018	T205-053SA	Adaptive control for fast acquisition and re-acquisition of precise scientific constellations	0	0	250	0	0	C(3)		N/A	
TDE	Y2018	T205-119SA	Star Tracker Based Generic Safe Mode for Science Missions	0	0	400	0	0	C		N/A	
TDE	Y2019	T205-122SA	Pulsar Navigation for Science Missions	0	0	200	0	0	C		N/A	
CTP	Y2019	C205-127SA	3-axis high accuracy accelerometer unit	0	0	0	2000	0	DN			
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 k€ in 2015
TDE	Y2014	T206-002ET	System Study of Optical Communications with a Hybridised Optical/RF Payload Data Transmitter (PDT)System Design	0	0	0	0	0	C	AT	N/A	TDA is running. Joanneum Research (AT) + subs. 750 k€ in 2015

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2016	T206-004ET	Miniaturisation of the Deep Space Transponder	0	250	0	0	0	C	IT	N/A	TDA is running. TAS (IT)
CTP	Y2016	C206-008FM	TT&C Subsystem Capability Development	8630	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	350	0	0	C		N/A	
TDE	Y2018	T206-012EF	K/Ka-band antenna technology development for future science missions	0	0	450	0	0	C		N/A	
TDE	Y2018	T206-009EF	Verification and calibration techniques for low frequency antennas	0	500	0	0	0	C		N/A	
CTP	Y2018	C206-011FV	Cryogenic Polarisation Modulator for CMB science missions	0	0	500	0	0	DN/S	UK, IT	N/A	To be possibly implemented as a CCN to C207-022FI and T207-035EE, (total price 379 k€) 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	600	0	0	C		N/A	
CTP	Y2017	C207-022FI	Large radii Half-Wave Plate (HWP) development - CCN	200	0	0	0	0	DN/C	UK	N/A	TDA is running. Uni. Cardiff (UK), implemented as CCN to T207-035EE (600k€).
CTP	Y2016	C207-021EE	Design and development of an electrically steerable antenna for science missions	0	0	0	0	0	DN/S	IE	N/A	DN with Arralis (IE). Approved in ESA/IPC(2016)81 (current total price 2000 k).
TDE	Y2018	T207-051EF	Compact HF-VHF tubular deployable antenna	0	450	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	450	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 k€ in 2016.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2018	C208-001FI	Assessment of Assembly, Integration and Testing Software Support System for ESA Science Missions	0	950	0	0	0	DN/S	IE	N/A	DN with Skytek Ltd. (IE). This activity will be contractually phased: 250 k€ phase I, 700 k€ phase II
TDE	Y2018	T208-003SY	End-to-End Performance Simulator Modelling Tool (E2ES Tool)	0	0	350	0	0	C		N/A	
CTP	Y2018	C209-002OP	Contribution to Machine Learning Science Operations Virtual Assistants	0	0	100	0	0	C	EE	N/A	For information, Science Programme CTP contribution (100 k€) to activity ERM-01 Estonia Incentive Scheme (total price 200 k€)
TDE	Y2014	T212-002GS	Photon-Counting Ground-based Optical Communications Detector	0	0	0	0	0	C(1)	FR	N/A	TDA is running. CEA Leti (FR) 400 k€ in 2016.
TDE	Y2014	T212-052GS	Prototype of off-line correlator for arraying of large aperture antennas	0	0	0	0	0	C(1)	IT	N/A	TDA is running. Arpsoft (IT) + subs. 350 k€ in 2016.
TDE	Y2014	T212-053GS	X-Band 80 kW amplifier pre-development	0	0	0	0	0	C(1)	IT	N/A	TDA is running. Rheinmetall Italia SpA (IT). 350 k€ in 2016.
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 k€ in 2016.
TDE	Y2018	T212-059GS	High power (80 kW) X-band uplink for Deep Space missions – development of critical waveguide components	0	500	0	0	0	C		N/A	
TDE	Y2018	T212-057GS	High rate flexible high-order SCCC communications system for Science X-band	0	450	0	0	0	C	IT	N/A	TDA is running TAS (IT)
CTP	Y2013	C215-119MS	ECHO telescope secondary mirror mechanism	0	0	0	0	0	C(1)	AT	N/A	TDA is running, RUAG (AT), 1500 k€ in 2014.
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.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
												1250 k€ 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 k€ in 2014
TDE	Y2016	T215-011MS	Development of a high performance microvibration isolation system	0	350	0	0	0	C	UK	N/A	TDA is running. Uni. of Surrey (UK) + subs.
CTP	Y2017	C215-132SA	Wheel with local speed control loop	700	0	0	0	0	C	NL	N/A	TDA is running (Bradford)
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) 750 k€ in 2016.
TDE	Y2018	T215-014MS	Piezoelectric motors tribology for space science application	0	0	350	0	0	C(3)		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 k€ 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 k€ 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 k€ in 2016.
TDE	Y2016	T216-104MM	Verification of straylight rejection of optical science payloads using a pulsed laser source	0	150	0	0	0	C		N/A	TDA is running CSEM (CH)
TDE	Y2018	T216-111MM	Joining process for manufacturing of large aluminium-based optical mirrors	0	0	250	0	0	C		N/A	TDA is running Media Lario (IT)
TDE	Y2018	T216-112MM	Design and Testing of Far and Medium Ultraviolet Coatings	0	0	400	0	0	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2016	C217-064FV	Delta-development of PLATO CCD detector for SMILE Soft X-ray Imager	1900	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
TDE	Y2011	T217-055PA	Development of low dark current MWIR/LWIR detectors	0	0	0	0	0	C(1)	DE	N/A	TDA is running. AIM (DE). Parallel contract. In line with recommendations of ESA/SPC(2011)27. 1700 k€ in 2015
TDE	Y2011	T217-055PA-B	Development of low dark current MWIR/LWIR detectors	0	0	0	0	0	C(1)	FR	N/A	TDA is running. Sofradir (FR). Parallel contract 1700 k€ in 2015
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 from C(3) to C(1) in ESA/IPC(2016)81. 1000 k€ in 2016.
TDE	Y2011	T217-054MM	European Low-Flux CIS Development and Optimisation	0	0	0	0	0	C(1)	BE	N/A	TDA is running. Caeleste (BE) + subs. 750 k€ in 2016. SD2 contribution to CMOS APS development activity T717-301MM in ESA/IPC(2011)3, add.2. Note total activity budget 1650 k€ - see ESA/IPC(2015)3,add.1
CTP	Y2019	C217-072MM	European Low-Flux CIS Development and Optimisation - CCN	0	0	800	0	0	DN/C	BE	N/A	To be possibly implemented as a CCN to T217-054MM (750 k€), which is SD2 contribution to T717-301MM in ESA/IPC(2011)3.add.2. (note total activity budget 1650 k€ - 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	640	0	0	0	DN/S	UK	N/A	DN with Open University (UK) + subs. To be possibly implemented as a CCN.

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	Y2019	T217-069MM	Large-format NIR Avalanche Photodiode Array for Scientific Imaging	0	0	0	1300	0	C		N/A	
CTP	Y2018	C217-080FI	Development of a space grade package for Electron Multiplying CCDs	0	450	0	0	0	DN/S	UK	N/A	TDA is completed.
CTP	Y2017	C217-076FV	Gamma-ray detector prototype module development	230	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 k€.
CTP	Y2018	C217-081FI	Performance testing of gamma-ray detector prototype module	0	250	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 k€). DN with UCD (IE).
CTP	Y2017	C217-066FI	Prototype ASIC for silicon photomultiplier based gamma-ray detector CCN	250	0	0	0	0	DN/C	NO	N/A	TDA is running. IDEAS (NO) Follow on to C217-034FT (500 k€) to complete radiation hardness assessment.
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 k€ in 2010.
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 k€ in 2015
CTP	Y2018	C219-010FT	Delta-development of electric micropropulsion subsystem for deep space scientific missions	0	2000	0	0	0	DN	AT	N/A	TDA is running. Structuring activity for Austria. DN with FOTEC (AT)
TDE	Y2008	T220-053MC	Advanced 2K JT cooler	0	0	0	0	0	DN/S	UK	N/A	TDA is running. RAL (UK). 700 k€ in 2009
CTP	Y2017	C220-042FM	Consolidation of high performance CFRP struts	0	1100	0	0	0	DN	DK	N/A	Structuring activity for Denmark. DN with Space Structures Denmark (DK).

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
CTP	Y2017	C220-043FM	Advanced optical benches using nano-enabled CFRP	0	600	0	0	0	C	GR	N/A	Competition limited to Greece Structuring activity for GR
CTP	Y2017	C220-044FM	Deployable high gain antenna structure for small spacecraft science missions	0	1000	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	700	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 k€ in 2016.
CTP	Y2018	C221-017FT	Graphene based thermal straps	0	500	0	0	0	C	FI	N/A	Competition limited to Finland. Structuring activity for FI.
TDE	Y2018	T221-111MT	Integration simplification of capillary driven heat transport systems	0	500	0	0	0	C		N/A	
TDE	Y2015	T223-103QT	Investigation of additive manufacturing of improved ceramic packages for detectors.	0	400	0	0	0	C(1)		N/A	
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 k€ in 2016.
TDE	Y2014	T224-003QT	Adhesive bond behaviour in cryogenic environment	0	300	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	3900	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	400	0	0	C	IE	N/A	Competition limited to Ireland. Structuring activity for Ireland.
TDE	IPC	T201-052ED	High-Speed High Resolution Quad-ADC for Science Instruments	0	0	0	500	0	DN/S	IE/PT	N/A	Potential application for several future science missions including

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
												LISA. DN with S3/Adesto. Majority of the funds to IE and PT
TDE	IPC	T220-056FT	Maturation of Additive Manufactured Metallic Optical Bench	0	0	0	1000	0	DN/C	DE	N/A	Possibly to be implemented as CCN to T224-004QT. (previous total price 1187 k). DN with Fraunhofer Institute for Material and Beam Technology (IWS)
TDE	N/A	T224-005QT	Adhesive bond behavior in cryogenic environment (CCN)	0	0	0	0	150	DN/S	DE	N/A	CCN to KRP(DE) contract (current running contract total price 300k)
TDE	IPC	T203-114EP	Ultra-Stable Power System Architectures	0	0	0	0	500	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	0	0	0	0	300	C		N/A	
TDE	N/A	T203-113MT	Electro-chemical compressor for Joule Thomson Cooler	0	0	0	0	250	C		N/A	
TDE	IPC	T221-021MT	Characterization of MLI materials and definition of MLI blanket for aerobraking environment	0	0	0	0	500	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	0	0	0	0	200	C		N/A	
CTP	IPC	C220-051FT	Verification of Interface Zones for Uninterrupted pre-preg fibre placed lattice structures - CCN	0	0	0	0	360	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. Possibly to be implemented as CCN to C220-049FT (total previous price 840kEuro). DN with ATG (IE)
TDE	N/A	T205-125SA	Attitude Guidance Using On-Board Optimisation	0	0	0	0	300	C		N/A	

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2017	2018	2019	2020	2021				
TDE	N/A	T212-061GS	Multiple frequency-shift keying modem	0	0	0	0	350	C		N/A	
Total - Technologies applicable to several Science Programme Missions				**11910**	**17540**	**10850**	**5250**	**2910**	**48460 Total = 33910 CTP + 14550 TDE**			

SCIENCE PROGRAMME MISSIONS IN IMPLEMENTATION:

L1-MISSION: JUICE

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2016	2017	2018	2019	2020				
CTP	Y2013	C201-032ED	Scalable Sensor Data Processor Flight Model Development	0	0	0	0	0	DN/C	ES, BE, NL	N/A	(1200 k in 2015). DN with TAS (ES), IMEC (BE) RECORE (NL) and Arquimea (ES).Special Measure for BE. This activity is implemented as a CCN to C201-031ED, price 1430 k. Approved in ESA/IPC(2013)81.
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.
CTP	Y2014	C205-110EC-B	Closed-loop attitude guidance on-board approach for JUICE	0	0	0	0	0	C	FR	N/A	TDA is running (400 k€ in 2015). TAS (FR) + subs.
CTP	Y2018	C215-133PR	Development of the Boom GSE for JUICE RPWI instrument	0	0	650	0	0	DN	FI	N/A	TDA is running. DN with Rejlers Oy (FI).
CTP	Y2013	C220-037MS	Qualification of MAG boom for JUICE	0	0	0	0	0	C	CZ	N/A	TDA is running (1500 k€ in 2015). Frentech Aerospace (CZ).
Total – L1-Mission: JUICE				**0**	**0**	**650**	**0**	**0**	**650 Total = 650 CTP**			

M3-MISSION: PLATO

Prog.	IPC Appr.	ESA Ref.	Activity Title	Budget					PP	Country	SW Clause	Remarks
				2016	2017	2018	2019	2020				
CTP	Y2018	C201-038FI	Pre-development of High Accuracy Heater Controller for PLATO	0	0	650	0	0	DN/S	IE	N/A	DN with Realtime Technoligies (IE)
CTP	Y2017	C205-114SA	Radiation Hard Gyroscope Development for Science Missions	0	2600	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	900	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	2000	0	0	0	DN/S	NO	N/A	Direct negotiation with Kongsberg Defence & Aerospace (NO). TDA is running.
CTP	Y2017	C220-048PL	Manufacturing process for CFRP sandwich (prepreg M55J UD / EX1515 + aluminium honeycomb core)	0	0	320	0	0	DN/S	GR	N/A	Structuring activity for Greece. DN with INASCO (GR)
Total – M3-Mission: PLATO				**0**	**5500**	**970**	**0**	**0**	**6470 Total = 6470 CTP**			

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Annex II

Detailed Description of ESA Cosmic Vision Technology Development Activities

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

L2-MISSION: ATHENA – ESA ACTIVITIES

High performance microvibration isolation system (continuation)			
Programme:	TDE	**Reference:**	T215-017MS
Title:	High performance microvibration isolation system (continuation)		
Total Budget:	500 k€		
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					

Diamond like coating device			
Programme:	CTP	**Reference:**	C216-174FT
Title:	Diamond like coating device		
Total Budget:	450 k€		
Objectives			
To investigate the DLC coating process applicability for the ATHENA Silicon Pore Optics Plates and to design and implement a coating device			
Description			
"As you know 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 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 k€				
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					

Experimental evaluation of Athena charged particle background from secondary radiation and scattering in optics			
Programme:	TDE	**Reference:**	T204-117EE
Title:	Experimental evaluation of Athena charged particle background from secondary radiation and scattering in optics		
Total Budget:	600 k€		
Objectives			

The objective of this activity is to use accelerator facilities to quantify the physical models and cross sections for high-energy charged particle secondary production (in particular delta rays) in representative spacecraft and instrument materials, together with evaluation of low-energy charged particle forward scattering in the silicon pore optics of the Athena mirror. This shall allow improved evaluation of radiation-induced background on Athena science data.
Description
Due to the Athena sensitivity to charged particle induced background from Galactic Cosmic Rays and Solar Energetic Particles, it is vital that the physics models and cross sections that are used as a basis of simulators such as Geant4 are accurate and up-to-date. There are certain areas, notably high-energy particle delta electron production and low-energy particle forward scattering from the Athena silicon pore optics, where lack of experimental data currently leads to a degree of uncertainty on the accuracy of the existing models for such processes in Geant4.This activity will remedy this situation by experimental campaigns in particle accelerator facilities, taking into account the relevant particle species and energies and the materials and configurations to be employed in Athena. The secondary electron experimental plan shall involve the characterization of the emitted secondary electrons in terms of spectrum, flux and angular distribution, as function of the relevant parameters (i.e., energy and angle of the incident protons, target composition and thickness). The proton forward scattering experimental campaign shall produce similar spectrometry data for protons from representative silicon pore optics mirror plates. The proposed activity will be broken down into the following steps: - Definition of the requirements: proton and ion beam facilities (e.g. CERN PS, J-PARC, PSI HIPA), detectors to be used (e.g. Si/B photodiodes), targets to be characterized (e.g. materials for space applications, such as Copper and Niobium, materials with low secondary electrons yield, such as Kapton and Carbon-based compounds, Si-pore optics modules), secondary electrons and low- energy scattered proton selection mechanism, silicon pore optics samples - Implementation of the experimental setup - Reproduction of the experimental setup inside Geant4 - Testing (at least 3 campaigns) and reporting
Deliverables
New experimental data for high-energy delta ray and low-energy forward scattering physics cross sections and improved models in Geant4; comparison to existing models; new models and documentation to be proposed to Geant4

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					

Focussing of Micrometeoroids in X-ray optics			
Programme:	TDE	**Reference:**	T204-120EE
Title:	Focussing of Micrometeoroids in X-ray optics		
Total Budget:	600 k€		
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 k€		
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					

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 k€				
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 k€		
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					

Athena Hold Down Release Mechanism			
Programme:	CTP	**Reference:**	C215-128FM
Title:	Athena Hold Down Release Mechanism		
Total Budget:	800 k€		
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 launch vibration damper			
Programme:	CTP	**Reference:**	C215-138MS
Title:	Athena ISM launch vibration damper		
Total Budget:	300 k€		

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:	3000 k€		

Objectives

To design and develop the Engineering Models of the PT15K CCU for the XIFU instrument.
To further enhance the Cryocooler Control Electronics to EM level. Characterisation of exported micro-vibration using passive dampers based on existing designs for Earth Observation applications

Description

The activity will consist of the following tasks:

1 – Design of the Athena 15K PT Flight Cooler system up to PDR level to release the manufacturing files for the iEM required for the FM development, incorporating the interface requirements for the EM of the XIFU instrument
2 – Design of the CMA STM’s
3 – Long lead item procurement for at least 2 EM coolers and STM’s, guaranteeing in time delivery of the coolers and STM’s to the X-IFU instrument after adoption
4- Modify existing passive dampers developed for the LPTC in ongoing Earth Observation missions (e.g. MTG) for the 15K cooler and characterise the exported micro-vibrations

The intermediate EM (CMA only - excluding electronics) will serve as the industrialisation step, handed over from the R&D department to the projects team. It will also allow to implement the lessons learned on the previously developed EM.

Phase 2 of the activity, which will start after adoption of the Athena mission and funded by the Athena project, will then include the manufacturing of the iEM and at least two deliverable EM's of the full CCU, including electronics.
Deliverables
Breadboard; Report; PDR datapack; Test results

Current TRL:	5	**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					

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 k€		
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 k€): 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 k€): 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 k€		

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 k€		

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					

Silicon Pore Optics Half Energy Width Optimisation					
Programme:	CTP		**Reference:**	C216-154MM	
Title:	Silicon Pore Optics Half Energy Width Optimisation				
Total Budget:	2500				
Objectives					
To demonstrate an angular resolution of 4.3 arcsec half energy width of mirror modules as required by the Athena telescope.					
Description					
The Athena telescope has an angular resolution requirement of 5 arcsec half energy width (HEW) of which a contribution of 4.3 arcsec is allocated to the silicon pore optics (SPO) mirror modules (MM). Past developments have demonstrated the feasibility of reaching 4.3 arcsec on a limited aperture part of the MM. HEW performance of the complete MM aperture has improved over time (down to 13.9 arcsec), but further optimisation of the plate manufacturing, stacking robot hardware and operation parameters are required to achieved 4.3 arcsec HEW over the complete MM aperture. This activity shall execute the continuous iteration of SPO manufacturing hardware and parameters in order to improve the HEW of the SPO MMs for Athena. This shall include the identification of problem areas and the contration of efforts to demonstrate 4.3 arcsec HEW for the MM at the most relevant radius. Especially, the stacking parameters and design of the stacking tools shall be reviewed and iterated. SPO stacks shall be manufactured to identify HEW improvements. Short term modifications shall be tried out continuously, while long term improvements (limited by long lead items) shall be implemented in parallel. The HEW improvements of the resulting SPO stacks shall be measured regularly with x-ray metrology in order to verify the stacking metrology results					
Deliverables					
Improved plate manufacturing and stacking equipment, SPO stacks and MMs manufactured during the activity					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	9 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Athena Inner SPO Mirror Module			
Programme:	CTP	**Reference:**	C216-008MM
Title:	Athena Inner SPO Mirror Module		
Total Budget:	2600 k€		
Objectives			
Development of an inner mirror module for the Athena telescope			

Description					
Athena requires silicon pore optics mirror modules (SPO MM) at a number of radial positions. The other main developments concentrate(d) on a middle/outer position, and this activity shall demonstrate the production of an inner mirror module (r about 0.25m TBC). The construction of such inner mirror modules require longer mirror plates, a modified mounting system, etc, and includes specifically a new dedicated robotic stacking system. Furthermore the manufacturing of inner mirror plates required the extension of the current mirror plate production processes. Within this activity, the contractor shall: 1) Analyse the present SPO manufacturing process and identify modifications required to produce SPO MM for inner radii. 2) Elaborate the detailed design for the required inner SPO MMs including the mounting system (brackets and dowel pins) 3) Perform optical modelling of inner radius mirror modules and identify performance limitations. 4) Perform mechanical and thermal modelling of inner radius mirror modules and identify performance limitations. The compatibility with the environmental requirements shall be analysed and assessed. 5) Elaborate the detailed design for the required stacking robot for manufacturing inner SPO MMs. This robot shall allow re-tooling for larger radii. 6) Elaborate the detailed design for upgrading the plate manufacturing process and equipment for the production of mirror plates suited for inner SPO MMs 7) Procure components, assemble and commission new stacking robot 8) Upgrade the mirror plate manufacturing process as required for the inner SPO MM 9) Manufacture mirror plates and SPO MM for inner radii 10) Perform pencil beam and full aperture X-ray tests of all produced stacks and SPO MM to characterise their performance.					
Deliverables					
Inner mirror module. Stacking robot. Technical Data Package.					
Current TRL:	4	**Target TRL:**	5	**Application Need/Date:**	2014
Application Mission:	L2		**Contract Duration:**	24 months	
S/W Clause:	NA				
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 k€				
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 k€				
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 k€				
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					

Silicon Pore Optics Engineering Qualification Model - Preparation			
Programme:	CTP	**Reference:**	C216-148MM
Title:	Silicon Pore Optics Engineering Qualification Model - Preparation		
Total Budget:	6000 k€		
Objectives			
The activity shall prepare the Silicon Pore Optics (SPO) Engineering Qualification Model (EQM) development by further maturing the Silicon Pore Optics technology. Both, the environmental qualification and X-ray performance shall be addressed for three radial positions for the Athena telescope (about 12 m focal length, inner, mid-radial and outer position).			
Description			

Achieving the angular resolution requirement (<5 arcsec HEW) shall be demonstrated on at least 3 MMs (one for each radius) with the goal of reaching 3 arcsec. This shall include upgrades of the plate manufacturing and stacking equipment and processes in order to produce highest resolution optics under a high throughput environment as required for the flight production. The stacking height and use of multi stack mirror modules shall be reviewed in order to identify and implement the best solution for the flight models (achieving the best angular resolution and manufacturing throughput). These model mirror modules shall include brackets and mounting pins compliant with the relevant radial positions and mirror plate size for 12 m focal length. Designs for brackets and mounting pins shall be iterated to be compliant with the requirements derived from the current system studies and mirror module integration activities. Brackets and Silicon Pore Optics stacks shall be aligned and assembled at an x-ray facility. The assembly process shall be critically reviewed before execution. Limitations with respect to achieving a process speed of about one mirror module per 24h (as needed for future flight production) shall be identified, semi-automated solutions shall be proposed and demonstrated. Performance measurements of angular resolution and effective area at different energies shall be executed at an x-ray facility. The robots produced in this activity will nominally be used for the EQM follow-on activity and in principle for Athena flight optics, subject to successful EQM campaign.
Deliverables
3 mirror modules, 36 mirror stacks, industrial stacking robots, industrial assembly jigs, technical data package

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	Athena		**Contract Duration:**	14 months	
S/W Clause:	N/A				
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 k€		
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					

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 k€
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 k€		
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					

X-ray raster scan facility for the Athena Mirror Assembly			
Programme:	CTP	**Reference:**	T216-110FT
Title:	X-ray raster scan facility for the Athena Mirror Assembly		

Total Budget:	300 k€
Objectives	
The objective of this activity is to design a raster scan facility that would allow the check in x-ray of the partially or fully integrated ATHENA Mirror Assembly as well as the final calibration.	
Description	
The alignment check and the calibration of the fully or partially integrated ATHENA Mirror Assembly will require the check in X-ray of the overall mirror performance. The current baseline for this is to use a Long Beam Facility (LBF) to allow the illumination of a large part of the mirror (ideally full beam illumination) without a large divergence at the edge of the beam. However, such a configuration has a large cost impact on the mission since it would require building a new facility large facility in Europe. The low divergence of the beam is needed to guarantee that the HEW errors introduced by the divergence of the beam are kept to a low value. And the beam size needs to be large enough to guarantee that the calibration plan can be achieved within the allocated 6 months. Another possibility would be to use a configuration creating a small collimated beam that can be moved to cover the whole Mirror Assembly. Such a configuration would require x-ray optics to generate a highly collimated beam (divergence at arcsec level), and highly accurate translation and metrology systems to be able to effectively produce a raster scan of the Mirror Assembly. In addition to the lower cost and lower divergence, such a configuration would have the advantages of allowing local measurements of some of the MMs and could potentially allow E2E testing of the Mirror + Payload since the Mirror Assembly can be placed with the optical axis in a vertical configuration. However, it has several challenges such as the potentially small beam size and the required accuracy for the translation and metrology systems. This TDA shall investigate/trade-off different optical and mechanical designs for such a facility. Issues such as beam size, energy dependency, throughput and count stability shall be investigated. The activity shall end with design blueprints for such a facility and programmatic information including cost for its implementation.	
Deliverables	
Technical datapackage	

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

Silicon Pore Optics Manufacturing Facility Design			
Programme:	CTP	**Reference:**	C216-128MM
Title:	Silicon Pore Optics Manufacturing Facility Design		
Total Budget:	2500 k€		
Objectives			
The flight model manufacturing facility shall be designed, including plate production, coating, stacking, assembly and testing. The design and analysis of the manufacturing capacities shall demonstrate that the flight production of about 1000 mirror modules is feasible within time and cost. Major process modifications deviating from the present baseline shall be verified experimentally. Detailed designs for the flight model mirror module configuration at all radial positions shall be performed.			
Description			
The flight production for Athena will require manufacturing of about 1000 mirror modules within a few years. This requires about 140000 mirror plates including coatings, 4000 Silicon Pore Optics stacks and the related alignment and testing efforts. The individual manufacturing steps are already performed with processes and machines suitable for a future mass production. But handling the manufacturing of about one mirror module per day requires an optimized setup of machining capabilities and interfacing. This activity shall elaborate a design and process analysis covering the following aspects: A detailed design of the Athena mirror modules for all radii shall be performed in order to define designs and requirements down to component level. The design and models shall also be suitable to perform complex mechanical and thermal modelling of the mirror in the context of other activities (eg. system studies). A detailed manufacturing flow of all components and processes up to mirror module level assembly and testing shall be elaborated. This shall include all steps, procedures, materials, machines, times and manpower needed, also in dependence of the mirror module radius (i.e. different plate sizes). The required number and performance requirements of all machines and processes shall be specified. Commercially available products shall be identified. Margins for			

regular or unexpected maintenance time shall be considered. A design layout of the manufacturing facility shall be elaborated. This shall include the conceptual floor placement of machines in the cleanroom, storage capacity and procedures for materials, mirror plates and modules, procedures for transport (of plates or stacks) between different machines, packaging and shipping. Different options for colocation of sub elements (e.g. plate production, coating, stacking, assembly) shall be investigated and compared to locating sub elements in different ESA member states. Cleanliness and infrastructure requirements for rooms and machining areas shall be elaborated. Major process modifications deviating from the present baseline shall be verified experimentally. A work plan and schedule for procurements, setup, commissioning, operation and closing the facility shall be elaborated. The manufacturing sequence and schedule of all mirror modules for the complete aperture (plus spare modules) shall be discussed, especially covering recommendations for the order of manufacturing of different radii, the impact of times for tooling changes, planned or unplanned maintenances (also covering x-ray facilities). Major and minor schedule risks shall be identified, discussed and mitigations shall be proposed. Critical process steps shall be demonstrated experimentally. The facility design shall be reviewed by an independent third party which is experiences with operating facilities of similar size and complexity (e.g. optics or semiconductor industry). An independent assessment shall be performed, including recommendations, risk assessment and an independent cost analysis.

Deliverables					
Technical Data Package, 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					

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 k€				
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					

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 k€

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

<table>
<tr><th colspan="6">Carbon nanotube-based filters for x-ray applications</th></tr>
<tr><td>Programme:</td><td colspan="2">TDE (TRP)</td><td>Reference:</td><td colspan="2">T216-171FT</td></tr>
<tr><td>Title:</td><td colspan="5">Carbon nanotube-based filters for x-ray applications</td></tr>
<tr><td>Total Budget:</td><td colspan="5">500 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">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).</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>2020</td></tr>
<tr><td>Application Mission:</td><td colspan="2">ATHENA and other future x-ray missions</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">N/A</td></tr>
</table>

<table>
<tr><th colspan="6">Demonstration of critical items for x-ray scanning facility</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C216-172FT</td></tr>
<tr><td>Title:</td><td colspan="5">Demonstration of critical items for x-ray scanning facility</td></tr>
<tr><td>Total Budget:</td><td colspan="5">2500 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Engineering Model; Report</td></tr>
<tr><td>Current TRL:</td><td>2</td><td>Target TRL:</td><td>4</td><td>Application Need/Date:</td><td>2020</td></tr>
<tr><td>Application Mission:</td><td colspan="2">ATHENA</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">N/A</td></tr>
</table>

Improvement of the Athena SPO Plate Production and Coating Processes			
Programme:	CTP	**Reference:**	C216-166FT
Title:	Improvement of the Athena SPO Plate Production and Coating Processes		
Total Budget:	600 k€		

Objectives

This activity shall focus on the improvement of the quality of the plates for the SPO (Silicon Pore Optics) Mirror Modules of the ATHENA mission, particularly on the processes related with the production and coating of the plates that have an impact on the required performance.

Description

The quality of the SPO plates for the ATHENA mission is critical for the overall mirror performance which is measured in terms of angular resolution and effective area. Plate thickness variations with respect to the desired wedge angle and plate contamination have a direct impact on the angular resolution. Plate coating thickness and plate coating roughness effects have a direct impact on the effective area. In addition to these direct impacts, the quality of the plates also influences the stacking process due to e.g. entry-exit effects that create undesired curvatures.
This activity shall focus on the previously identified areas that can lead to significant increases in performance, namely:
- implementation of a custom dicing saw,
- evaluation of impact of different crystals orientations on the quality of the dicing and on the mechanical behavior of the plates,
- implementation of a mother plate approach (i.e. dicing after wedging) that will reduce the entry-exit effects,
- develop the capability to introduce an additional chromium layer into the coating recipes being studied (Ir, Ir/SiC, and others) to allow stress release,
- further study of the plasma cleaning recipes as a replacement of the current RCA based lift-off process that degrades the coating,
- design optimization of the plate carriers in view of throughput for the flight program,
- implementation of the capabilities to check plate dimensions upon at the acceptance by the Mirror Module supplier

Deliverables

Reports (Study scale up/design optimisation for scaling up of carriers for the flight program, Plasma cleaning recipes)
Custom dicing saw

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:

Coatings

Athena Coating Process Optimisation			
Programme:	CTP	**Reference:**	C216-144FT
Title:	Athena Coating Process Optimisation		
Total Budget:	450 k€		

Objectives

This activity will address a number of required improvements aiming at optimising the Athena X-ray mirror coating process.

Description

The Athena mirrors require reflectivity enhancing coatings in order to allow the grazing incidence optics meet the telescope effective area requirements. Previous activities have looked at the theoretical design optimisation of such coatings with recipe solutions for bilayer and multilayer having been evolved. In addition a programme of experimental work has addressed the coatings process including critical photolithographic steps required for realising patterned coatings as required for the Silicon Pore Optics.

Based on this previous experimental work, a number of areas of improvement and optimisation have been identified and these shall be addressed within this activity.

The areas to be conclusively addressed include:
- Coating stress determination and reduction techniques e.g. Cr layer effectiveness on coating stress and roughness reduction
- Conclusive study on Nitrogen reactive sputtering to improve surface roughness
- Photolithography process improvements e.g. lift-off step
- Coating contamination level determination and associated performance effects

- Determination of optical constants of coatings produced by optimised process over the energy range of Athena - Implementation of low energy (target 1 keV) X-ray coating metrology capability
Deliverables
Technical data package, coated SPO samples, low energy metrology capability

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

Low-Energy X-ray Coating development for Athena			
Programme:	CTP	**Reference:**	C216-157FI
Title:	Low-Energy X-ray Coating Development for Athena		
Total Budget:	1000 k€		
Objectives			
The objective of this activity is to further develop the Athena mirror coatings by characterizing and validating the low-energy reflectivity using an X-ray Reflectometer (XRR).			
Description			
The Athena mirrors require reflectivity enhancing coatings in order to allow the grazing incidence optics to meet the telescope effective area requirements. Previous activities have looked at the theoretical design optimisation of such coatings with recipe solutions for bilayer and multilayer having been evolved. In addition a programme of experimental work has addressed the coating process including critical photolithographic steps required for realising patterned coatings as required for the Silicon Pore Optics (SPO). In the context of CTP activity C216-144FT, several coating design options for ATHENA mirrors have been investigated on samples and a number of areas requiring further developments on the short/medium term have been identified to secure the coating feasibility and performance. One area of particular concern is the low-energy coating reflectivity performance, and the compatibility of the layer deposition with the Silicon Pore Optics manufacturing process. The low-energy response is achieved by a low-index top-coat material and the optimisation of this top-coat material requires multiple trials of coating deposition, SPO process steps (e.g. photolithography, cleaning, thermal annealing etc.) and ultimately performance metrology including XRR. Building on the C216-144FT activity results, the purpose of this activity is to define the coating process (layer definition and deposition) by taking into account the SPO manufacturing constraints, and quantifying/validating the achievable reflectivity performance in the low-energy band. For that purpose, Contractor is expected to procure a low-energy X-Ray Reflectometer for supporting the experimental trials and a suitable plasma cleaning equipment to ensure that the coating substrate cleanliness is representative of the SPO mirror plates.			
Deliverables			
Definition and characterization of coating options applicable to Athena Silicon Pore Optics, supported by reflectivity performance demonstration including the low-energy band (1 eV)			

Current TRL:	6	**Target TRL:**	6	**Application Need/Date:**	2020
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					
Programme:	CTP		**Reference:**	C216-129FT	
Title:	Synchrotron beam time and monochromator beamline maintenance				
Total Budget:	340 k€				
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 continuation					
Programme:	CTP		**Reference:**	C216-161FT	
Title:	Synchrotron beam time and monochromator beamline maintenance - continuation				
Total Budget:	800 k€				
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					

Thermal equipment and large optics accommodation at existing Panter facility			
Programme:	CTP	**Reference:**	C216-131FT
Title:	Thermal equipment and large optics accommodation at existing Panter facility		
Total Budget:	350 k€		
Objectives			
Addition of thermal control equipment and evaluation of large optics accommodation in the Panter facility.			
Description			
Firstly, equipment to provide the thermal environment expected during operation of X-ray optics shall be designed, procured, installed and calibrated, including the required control equipment. This equipment will be operational during simultaneous X-ray testing of X-ray optics, allowing the study of thermal effects on the imaging performance of the optics. Secondly, the accommodation of large X-ray optics in the Panter facility's main vacuum chamber shall be evaluated. Corresponding detailed designs for the required modifications and equipment shall be made, following the completion of the necessary trade-offs. Support equipment for sample handling and loading, vacuum chamber extensions and provision of new doors and accessories, as well as beam conditioning and monitoring upgrades shall be addressed.			
Deliverables			

Thermal test equipment at Panter User manual and detailed technical documentation Large X-ray optics accommodation report					
Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2016
Application Mission:	Athena		**Contract Duration:**	18 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 k€				
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 k€		
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 k€				
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					

ALBA fixed energy beamline					
Programme:	CTP		**Reference:**	C216-168FT	
Title:	ALBA fixed energy beamline				
Total Budget:	1000 k€				
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 k€				
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)					

Large area high-performance optical filter for X-ray instrumentation			
Programme:	TDE/CTP	**Reference:**	T217-061MM
Title:	Large area high-performance optical filter for X-ray instrumentation		
Total Budget:	1500 k€		
Objectives			

The main aim of the activity is to develop and test large area optical filters for future soft X-ray instrumentation. The activity shall demonstrate TRL 6 for the filters through the development of Engineering Model (EM) filters which will subjected to a full performance and space environment test programme.					
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, hitherto not available in Europe, combined with visible light attenuation of several orders of magnitude, excellent infra-red blocking performance, compatibility with cryogenic temperature operation and environmentally robustness. The activity shall: - Design, manufacture and characterise filter(s) (more than one diameter shall be demonstrated). - Demonstrate the feasibility of the reproducible production of high performance filters suitable for future space applications. - Demonstrate the critical qualification aspects considering the relevant environments (vibration, thermal cycling, acoustic test, etc.) and critical process steps.					
Deliverables					
EM filters, design report, test reports					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	Athena, Generic		**Contract Duration:**	27 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Optimization of a European Transition Edge Sensor Array - Large Array Production and Testing					
Programme:	CTP		**Reference:**	C217-043FM	
Title:	Optimization of a European Transition Edge Sensor Array - Large Array Production and Testing				
Total Budget:	1000 k€				
Objectives					
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.					
Description					
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					
Deliverables					
Transition edge sensor arrays, detailed design reports, test reports, test cryostat.					
Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Athena		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Large Area European Transition Edge Sensor Array for X-Ray missions			
Programme:	CTP	**Reference:**	C217-044FM
Title:	Large Area European Transition Edge Sensor Array for X-Ray missions		
Total Budget:	1400 k€		
Objectives			

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 k€				
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			

Development of high count rate energy-resolving x-ray camera for ATHENA calibration					
Programme:	CTP		**Reference:**	C217-094FT	
Title:	Development of high count rate energy-resolving x-ray camera for ATHENA calibration				
Total Budget:	300 k€				
Objectives					
To develop a x-ray camera that can be used for the calibration of the ATHENA Mirror in the allocated 6 months and with the required energy resolution. High count rate capability shall be combined with good energy resolution and position resolution. This capability was not identified in Europe as a commercial unit and shall be developed under this activity.					
Description					
The foreseen tasks for this activity are: 1) Assess the critical requirements such as the necessary pixel size (30 microns), energy range (0.2 - 12 keV), energy resolution (250 eV at 12 keV), readout rate (8 frames/s), vacuum compatibility, interfaces with facility, etc... 2) Design of not only the detector but the complete camera, including the mechanical, thermal and electronic design. Available commercial technologies and products shall be considered and utilized in this development. 3) Manufacture of the camera. 3) Test the performance of the camera with suitable x-ray facilities.					
Deliverables					
Prototype; Report					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2020
Application Mission:	ATHENA		**Contract Duration:**	18	
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 k€		
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 k€				
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					

<table>
<tr><th colspan="6">Cryogenic vibration isolators and thermal disconnects</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C221-005FI</td></tr>
<tr><td>Title:</td><td colspan="5">Cryogenic vibration isolators and thermal disconnects</td></tr>
<tr><td>Total Budget:</td><td colspan="5">500 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Hardware, test results , documentation</td></tr>
<tr><td>Current TRL:</td><td>2</td><td>Target TRL:</td><td>5</td><td>Application Need/Date:</td><td>2017</td></tr>
<tr><td>Application Mission:</td><td colspan="2">L2</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">Superconducting multilayer flex harness</th></tr>
<tr><td>Programme:</td><td>CTP</td><td>Reference:</td><td>C221-006FI</td></tr>
<tr><td>Title:</td><td colspan="3">Superconducting multilayer flex harness</td></tr>
<tr><td>Total Budget:</td><td colspan="3">300 k€</td></tr>
<tr><td colspan="4">Objectives</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">Deliverables</td></tr>
<tr><td colspan="4">Multilayer harnesses, test results , documentation</td></tr>
</table>

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 k€		
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					

2K Joule-Thomson engineering model cooler system including cooler drive electronics			
Programme:	CTP	**Reference:**	C221-008FM
Title:	2K Joule-Thomson engineering model cooler system including cooler drive electronics		
Total Budget:	2000 k€		
Objectives			
The aim of this activity is the development of a 2K Joule-Thomson engineering model cooler system including low vibration drive electronics capable of driving the 2K JT and a pre-cooler.			
Description			
This activity shall address the development of a 2K Joule-Thomson engineering model cooler system including low vibration drive electronics. Cooler Drive Electronics (CDE) driving the 2K JT and pre-cooler and minimising 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 such 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	

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 k€				
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 k€		
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 k€		
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 k€		
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 k€		
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, MgB2 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 MgB2, 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 k€				
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 k€		

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

L3-MISSION: LISA – ESA ACTIVITIES

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 k€				
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:	500 k€		
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
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- 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 k€		

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 k€				
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 k€		
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:	Open Source Code				
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 k€		
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 k€		
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 k€		

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

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 k€		

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					

Microparticle impact related attitude disturbances					
Programme:	TDE		**Reference:**	T205-038EP	
Title:	Microparticle impact related attitude disturbances				
Total Budget:	300 k€				
Objectives					
Develop an engineering tool to derive the momentum transfer and attitude response of a s/c impacted by microparticles. Predict the attitude responce of a s/c model to a given microparticle flux and conversely reconstruct micrometeoroid flux based on attitude data. Apply tool to missions to identify potential issues on sensitive high-accuracy pointing missions.					
Description					
Microparticles pose a significant threat to space missions. Due to their high velocity of up to the order of several tens of kilometres per second even small particles can cause damage to s/c. In addition, challenging attitude stability requirements for some missions require to consider attitude disturbances caused by impacting particles. Thus, a vital step for designing such missions is to understand the impact of microparticle fluxes on the s/c attitude. The microparticle population can be separated into man-made debris in Earth orbits and to the natural micrometeoroid environment in the solar system. The populations are quite distinct in terms of particles sizes, directionality and velocities. Impacting particles will transfer momentum and torque to a s/c. This is relevant for scientific missions as esp. drag-free control concepts because of the required compensation of torques but also for high-accuracy Earth observation missions or any other mission with high pointing stability requirements. The LISA mission for example requires to maintain a link over 1.5 million km. As of today there is no tool available to determine attitude disturbances from microparticle impacts. Several ESA science missions will be operated beyond Earth orbits and be exposed to the interplanetary meteoroid environment, e.g. JUICE, Athena, SolO, Euclid, Plato. It has been shown by dedicated assessments, e.g. for Hipparcos, GAIA and LISA PF, that the meteoroid flux can be deduced from AOCS data. This methodology is based on the momentum transferred in impacts to stabilized s/c which needs to be compensated by the AOCS system. Thus, science missions could systematically support the validation of interplanetary meteoroid models by providing additional measurements and thereby reduce the uncertainties for future missions. This study aims to develop an engineering tool to predict the attitude disturbance to s/c based on a impacting flux of microparticles and to reconstruct the micrometeoroid flux based on attitude disturbance data. It is expected that external s/c surfaces and mass properties of the s/c need to be modelled in the tool. Then, the momentum transfer by impacting particles needs to be simulated, presumably by Adaptive Smooth Particle Hydrodynamics (AHPS) and the AOCS response modelled. The main drivers, uncertainties and potential key enablers shall be determined for both intended applications, derivation of attitude disturbances for future missions and derivation of microparticle fluxes from in-orbit data. For example, it is anticipated that additional sensors might be required on s/c in order to determine the location of microparticle impacts and thus to allow for reconstruction of momentum transfer and respective micrparticle flux derivation. To the extent possible the tool should be applied to operating and upcoming science missions (LISA) in order to validate the tool, assess disturbances on mission designs and determine microparticle fluxes from data.					
Deliverables					
Engineering tool to assess attitude disturbances from micrometeoroid fluxes and vice versa					
Current TRL:	1	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	large and/or pointing sensitive missions (e.g.LISA)		**Contract Duration:**	18 months	
S/W Clause:	Operational Software				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

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 k€		
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 k€		
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 k€

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

Gravitational Wave Observatory Metrology Laser					
Programme:	CTP	**Reference:**	C217-046FM		
Title:	Gravitational Wave Observatory Metrology Laser				
Total Budget:	3500 k€				
Objectives					
This activity shall address the development of a laser system meeting the requirements of a Gravitational Wave Observatory mission.					
Description					
A 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 development and test of an engineering model (EM) of a laser system meeting the requirements thereby demonstrating TRL 6. The activity shall be split in two contractual phases, with two parallel Phase I contracts being followed by a single Phase II contract. A third intended phase, not covered under this activity, shall be addressed as an option in the proposals submitted. Phase I shall begin with the assessment of currently available optoelectronics technology and identify the modifications, if required, for the technology to be used in a laser system for a gravitational wave observatory mission. The identified modifications shall be implemented in this phase and the results integrated into the laser system design. The laser system design shall be supported by appropriate trade-offs and analysis. As far as possible a breadboard demonstration of the chosen design shall be conducted in order to demonstrate compliance with the performance requirements in a laboratory environment. The qualification status of all components of the proposed system shall be reviewed with respect to the operational environment e.g. vacuum, radiation, lifetime and a test plan to be implemented in Phase II shall be developed. Phase I shall also deliver a design and development plan for Phase II and Phase III, as well as towards the full flight system. Phase II shall begin with the completion of the detailed laser system design. 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 L3 mission environment i.e. the demonstration of component TRL 7 Phase III shall demonstrate the lifetime of the proposed system on a second EM in a relevant environment.					
Deliverables					
Phase I: Documentation - trade-off report, baseline preliminary design, performance assessment, Phase II, III, flight implementation plan Phase II: EM HW, EM and component level testing and reports					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	LISA	**Contract Duration:**	36 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:	CTP		**Reference:**	C217-084FT	
Title:	Photonic components analysis in support of the LISA laser system development				
Total Budget:	400 k€				
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					

Fine-structure of laser radiation in the far-field					
Programme:	CTP		**Reference:**	C217-068MM	
Title:	Fine-structure of laser radiation in the far-field				
Total Budget:	150 k€				
Objectives					
The Gravitational Waves Observatory (L3) will measure distance fluctuations with picometric accuracy over millions of km. The purpose of this activity is to investigate the fine-structure of a laser wave-front in the far field and determine to which extend pointing and other instabilities modulate (or otherwise influence) the interferometric signal.					
Description					
The Gravitational Waves Observatory consists of three satellites in an equal triangular arrangement connected via laser beams for the scientific measurements as well as for mutual pointing and tracking. To detect and distinguish a gravitational wave component in the interferometric signal, measurement accuracies at picometer level are necessary. Beam pointing and tracking corrections, required to maintain perfect alignment of the laser beams between the satellites in the constellation, can potentially translate into a similar kind of distance modulation if the far-field wave-front exhibits a fine structure component. As an example, a 1 picometer change in the fine-structure of a wavefront received by a 200 mm diameter telescope translates into a 10 mm lateral shift (or wavefront disturbance) over 2 Mio km. The activity will therefore perform a theoretical investigation into potential sources of wave-front aberrations in the far field and will analyse potential solutions for their avoidance. It will establish corresponding telescope and system requirements to mitigate their contribution to the interferometer signal.					
Deliverables					
Detailed analysis of potential causes of fine-structure wavefront aberrations in the far-field.					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	

Application Mission:	LISA	**Contract Duration:**	12 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 k€				
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 k€				
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 k€				
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					

Preliminary qualification status assessment of heritage Cold Gas Micro-thruster for LISA			
Programme:	CTP	**Reference:**	C219-009MP
Title:	Preliminary qualification status assessment of heritage Cold Gas Micro-thruster for LISA		
Total Budget:	250 k€		
Objectives			
Preliminary assessment of the compatibility of the heritage cold gas micro-thruster (GAIA, LISA Pathfinder, Euclid) for the LISA mission.			
Description			

The LISA Pathfinder mission utilised cold gas microthrusters as actuators of the control system to compensate for disturbances on the spacecraft, such as solar radiation pressure. The LISA mission will also utilise micropropulsion for disturbance free attitude control during science operations. Due to requirements of the (DFACS) control system, the command update rate of the micropropulsion subsystem during science mode shall be ≥ 10 Hz. The mission will consider a nominal science phase of 4 years, with a possible extension to 10 years of science observations. The aim of this activity is to complete a preliminary qualification status review of critical elements of the Micro Propulsion Assembly (heritage from GAIA, LISA Pathfinder, Microscope, Euclid) with respect to the micropropulsion needs of LISA. The main objectives are to: • capture a summary of the micropropulsion requirements of the different heritage programmes, along with an initial assessment of the preliminary micropropulsion requirements for LISA; • capture a summary of all design and operational differences between the MPAs embarked on the heritage missions; • perform a fatigue analysis of the mechanical components of the Thruster Valve, and assess any wear and ageing effects of the Micro-Thruster that may affect lifetime; • propose any design modifications to the Micro-Thruster for achieving the preliminary LISA requirements, and provide an updated preliminary FMEA, Reliability Analysis, Worst Case Analysis and Derating Analysis for the proposed unit; • commence a test on a representative Micro-Thruster for LISA with the aim to demonstrate the capability to sustain life requirements;
Deliverables
Technical datapackage

Current TRL:	4	**Target TRL:**	5/6	**Application Need/Date:**	2022 TRL 5/6
Application Mission:	LISA		**Contract Duration:**	9 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Preliminary qualification status assessment of heritage Cold Gas Micro-thruster for LISA - CCN			
Programme:	CTP	**Reference:**	C219-011MP
Title:	Preliminary qualification status assessment of heritage Cold Gas Micro-thruster for LISA - CCN		
Total Budget:	250 k€		
Objectives			
A preliminary assessment of the compatibility of the heritage cold gas micro-thruster (heritage from GAIA, LISA Pathfinder, Microscope, Euclid) has been undertaken with respect to preliminary requirements of the LISA mission. A test was initiated on a Thruster Valve (heritage design) under previous ESA contract to support analytical assessments of wear and fatigue effects when considering LISA lifetime requirements. This activity shall cover the continuation of the Thruster Valve cycle test campaign to further increase the number of valve actuations towards the LISA requirements. An accelerated test shall also be implemented on a stand-alone piezo-actuator at high frequency in order to demonstrate capability (at piezo level) to accumulate the full amount of actuations required for 4 years of nominal science operations and that required for a total duration of 10 years of science operations.			
Description			
'Drag-free flying' was successfully demonstrated on LISA Pathfinder utilising cold gas microthrusters as actuators of the control system to compensate for disturbances on the spacecraft. The LISA mission will also utilise micropropulsion for disturbance free attitude control during science operations. Due to requirements of the (DFACS) control system, the command rate of the micropropulsion subsystem during science mode shall be ≥10 Hz. The mission will consider a nominal science duration of 4 years, with the possibility to extend the science operations up to a total of 10 years. A preliminary assessment of the compatibility of the heritage cold gas micro-thruster (heritage from GAIA, LISA Pathfinder, Microscope, Euclid) has been undertaken under previous ESA contract with respect to the preliminary requirements of the LISA mission. To support analytical assessment of wear and ageing effects, an EM Thruster Valve (heritage design) has been manufactured and has started a cycle test campaign with the aim to reach a sensible amount of actuations to support the analytical assessments (since the frequency for this test is limited by the mass flow sensor capability). This activity shall cover the continuation of the Thruster Valve (TV) cycle test campaign, running TV actuations without interruption until the end of 2019. Additionally, an accelerated test on stand-alone piezo-actuator shall be implemented. Due to the intrinsic ability of the piezo (stack) element to react in a time domain of tens of kHz, cycles shall be performed at high frequency to demonstrate the capability of the piezo-actuator to accumulate the full amount of actuations required for the 4 years nominal science operations and for the goal to cover 10 years of science operations.			
Deliverables			
EM Thruster Valve; Piezo stacks (piezo-actuator); Technical Data Package			

Current TRL:	4	**Target TRL:**	5/6	**Application Need/Date:**	2022 TRL 5/6
Application Mission:	LISA		**Contract Duration:**	6 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
Chemical Propulsion – Micro Propulsion and Related Technologies

Enhanced temperature measurement for LISA					
Programme:	CTP		**Reference:**	C221-016MT	
Title:	Enhanced temperature measurement for LISA				
Total Budget:	400 k€				
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					

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 k€		
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 k€		
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 k€		
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					

M4-MISSION: ARIEL – ESA ACTIVITIES

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 k€				
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 k€		
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

Cryotesting of ARIEL M1 mirror and coating process qualification for de-risking ARIEL schedule

Programme:	CTP	**Reference:**	C216-159FM
Title:	Cryotesting of ARIEL M1 mirror and coating process qualification for de-risking ARIEL schedule		
Total Budget:	960 k€		

Objectives

Demonstrate opto-mechanical stability and optical quality of large-scale Silver coated Aluminium mirrors at cryogenic temperature for ARIEL mission and qualification of Silver coating process

Description

This activity shall verify the opto-mechanical stability and optical quality of the ARIEL PTM M1 mirror (full scale pathfinder 1.1 x 0.7m elliptical mirror) at cryogenic temperature and qualify the baseline mirror Silver coating process. The PTM M1 mirror has been developed by the ARIEL Payload consortium in phase A.

The end-to-end qualification of the silver coating process shall start from the basis of existing processes and related available technology. The process verification shall be achieved using a space product and quality assurance approach, which involves, amongst other things, definition of coating process flow, quality verification at raw material level, definition of relevant test sample types and tests with acceptance/success criteria. Test samples of aluminium mirror for the coating process verification shall be manufactured and finished to specifications consistent with ARIEL requirements. Characteristics such as coating thickness uniformity and roughness shall be evaluated. Environmental testing (including thermal cycling between qualification temperatures approx. 30K – 393K) and humidity exposure tests followed by optical measurements on the coating surface and reflectivity shall be performed on a sub-set of samples.

The fully completed PTM M1 mirror shall be provided by the ARIEL Payload consortium. Cryogenic testing of the PTM M1 mirror shall be performed down to a temperature of at least approx. 90K to ensure ≥95% of the expected thermal contraction / deformation of the mirror has occurred compared with the expected state at a nominal operating temperature of approx. 50K (with 10K margins). At least one thermal cycle shall be performed. The mounting scheme of the mirror for the tests shall be as representative as possible to the expected flight design/configuration using the wiffle tree support system. The WFE shall be monitored and a relative measurement from ambient to cryogenic temperature recorded.

The activity shall also include the design, manufacture, assembly and calibration of any required GSE to facilitate the test, although the test set up shall utilise as much as possible existing hardware.

Deliverables

Technical datapackage

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2019
Application Mission:	ARIEL	**Contract Duration:**	15 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 k€				
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 k€				
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 k€		

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:
  - Overall test set-up (thermal and mechanical analysis, hardware identification)
  - Thermal tent (including supporting structure, MLI, sensors and heaters)
  - Telescope mechanical interface (isostatic fixation and brackets), with TE stability analysis
  - Handling tools (specific to handle the test set-up)
  - Wave Front Sensor (WFS) setup (including support, motorisation, canister and barrels, laser, feedthroughs, optics and relays, cabling), with TE stability analysis
  - 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-CANDIDATE MISSION: SPICA – ESA ACTIVITIES

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 k€				
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					

Polarization-sensitive submillimeter bolometer technology for the B-BOP instrument on SPICA			
Programme:	CTP	**Reference:**	C206-016FI
Title:	Polarization-sensitive submillimeter bolometer technology for the B-BOP instrument on SPICA		
Total Budget:	1000 k€		
Objectives			
Manufacture a series of B-BOP prototype detectors to establish experimentally the performances that have been simulated up to now. These batches implement technical options that need to be validated and will be used to identify the suitable compromises for operation in flight context.			
Description			
Detectors that enable the B-BOP instrument to perform polarization sub-millimetric measurements inherit from the Herschel/PACS imaging detectors but implement a significant number of technological innovations. The two principal innovations are (1) that the detection part of the pixel is grown directly on the readout circuit (ASIC) instead of hybridized to it "above IC" technology, and (2) that the detection layer is polarization sensitive through the inclusion of two series of orthogonal absorbing dipoles per pixel. The detector design has been completed, with several options, both in the detection layer and in the readout layer, and detailed physical simulations of the expected performances have been run to predict the sensitivity of the detector. The manufacturing program will proceed through three production runs of detectors in the course of 1.5 yr during the phase A program. The production runs are spaced by 4-6 months to minimize risks by creating "return on experience" channels from the potentially challenging manufacturing steps. In each production run, all design options will be produced to explore and characterize a range of possible implementations that will allow future trade-off at instrument level. The proposed program will cover: - Kick-off meetings at the start of each production run to validate all technical options that will be put in place. Relevant run documentation review will occur at this stage. - Manufacturing of the detector according to the validated design and			

procedures. - Regular progress meetings along each of the tree production run to inform successive runs, as well as capture of each of the manufacturing stages diagnostics in data package for delivery. - Assessment of the resulting production at the end of the manufacturing process and preparation for delivery to the test site. Final review of the associated data package that will accompany the delivery. All readout circuits necessary for the three production runs are considered an input to this work-package and will be delivered to the manufacturer at the start of the activity. Note: design validation and characterization of the detector performances, following their delivery, is planned in the overall Phase A schedule but is not part of this activity. Those tasks will be covered as part of the CEA/CNES phase A work packages.
Deliverables
Prototypes (3 batches of detector prototypes, with full traceability of the manufacturing process)

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2024 TRL 6
Application Mission:	SPICA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Optical Detectors					

Far-infrared superconducting imaging technology for the SAFARI instrument on SPICA			
Programme:	CTP	**Reference:**	C217-082FI
Title:	Far-infrared superconducting imaging technology for the SAFARI instrument on SPICA		
Total Budget:	1400 k€		
Objectives			
The objectives of this activity are: - demonstrate multiplexed transition edge sensor (TES) modules that are fully compatible with the layout, constraints and interfaces of SPICA-SAFARI; - develop rugged packaging and operating techniques, including manufacture and metrology, ensuring science-grade performance in the relevant space environment (magnetic & EMI shielding, resilience to energetic particles, performance uniformity, ruggedness, space-readiness compatibility); - establish a 50-mK test facility for developing and verifying SAFARI detector technology and control software.			
Description			
The SAFARI instrument on the cold-aperture space telescope SPICA will use ultra-low-noise TES detectors, SQUID-based frequency domain multiplexers (FDM), and grating spectrometers to achieve unprecedented sensitivity over the wavelength range 34-230 µm. A total of 3500 TESs are needed, which must be cooled to 50 mK to achieve NEPs better than 2×10-19 WHz-1/2, response times of < 10 ms, and saturation powers of ~ 20 fW. The core technology with the required sensitivity, speed and saturation power has been demonstrated for all bands in the laboratory, but now critical functions and performances must be verified in a relevant environment to demonstrate a technology readiness level of TRL 6. This activity shall include: - device development and production - imaging array module development and assembly - optical coupling development - detailed performance characterization with respect to SAFARI requirements. This shall involve verification testing within a dedicated 50 mK test facility including remote computer access.			
Deliverables			
Engineering Model, Dedicated 50 mK test facility, Technical Data Package			

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2024 TRL 6
Application Mission:	SPICA		**Contract Duration:**	36 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Optical Detectors, IR range					

M5-CANDIDATE MISSION: ENVISION – ESA ACTIVITIES

Neutral atmosphere models for future science missions					
Programme:	TDE		**Reference:**	T204-129EP	
Title:	Neutral atmosphere models for future science missions				
Total Budget:	150 k€				
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 k€		
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					

GNC and FDIR design for robust autonomous aerobraking corridor control					
Programme:	TDE		**Reference:**	T205-123SA	
Title:	GNC and FDIR design for robust autonomous aerobraking corridor control				
Total Budget:	300 k€				
Objectives					
The main objective of the activity is to investigate, trade-off and design the GNC and FDIR algorithms needed to extend the autonomy of the aerobraking phase for EnVision and future planetary missions. In more detail, the following lower-level objectives are in order: 1 - To study and trade-off autonomous corridor control strategies (reactive strategies, predictive strategies, mixed reactive/predictive strategies, etc.) and to identify, for the selected options, the implications at system, GNC and operations level. 2 – To derive the associated system, GNC and FDIR requirements, including requirements for sensors (e.g. accelerometers, thermistors, heat flux sensors, etc.) and avionics (on-board processing and memory) that arise from the need to enhance the spacecraft state estimation in view of increased autonomy. 3 – For the selected best strategy (or strategies), to define an associated robust safe mode and aerobraking contingency manoeuvres (e.g. pop-up manoeuvres). 4 - For the selected best strategy (or strategies), to design and validate on a numerical simulator the GNC and FDIR algorithms that implement the autonomous corridor control, the safe mode and the aerobraking contingency manoeuvres. 5 - To assess the benefits of the proposed solutions from an operational point of view (reduction of ground effort) and mission point of view (increased robustness, reduced fuel consumption, etc.)					
Description					
Recent planetary missions, including notably ESA's ExoMars Trace Gas Orbiter, have implemented state-of-the-art semi-autonomous techniques to update a pre-loaded command sequence for aerobraking that increases the efficiency of aerobraking thanks to the safety features implemented on-board. However, the effort of the ground segment for planning, commanding and monitoring aerobraking operations remains high. The present activity is intended to address the above, by providing a systematic assessment of autonomous corridor control techniques, highlighting the operational risks and benefits as well as the design implications at system, GNC and FDIR level. Prototyping and validation of the most promising technique (or techniques) will increase the confidence in the effectives of such techniques as well as a consolidation of the requirements on system, GNC and FDIR, with special focus on implications for sensors and avionics. In addition, the required on-board navigation functionalities and on-board models (e.g. atmospheric model) as well as the interfaces with the ground segment (e.g. periodic update of spacecraft navigation with radiometric data from ground) will be identified. An assessment of the operational benefits of autonomous corridor control will provide a quantitative assessment of the reduction of ground segment effort that can be expected, together with the associated saving in the cost of operations.					
Deliverables					
Report, software (prototype for GNC and FDIR algorithms that implement autonomous corridor control, the safe mode and the Aerobraking contingency manoeuvres together with numerical simulator used for verification)					
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					

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

Total Budget:	250 k€				
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 k€				
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 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 k€		

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 k€		
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 k€				
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					

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 k€				
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					

M5-CANDIDATE MISSION: THESEUS – ESA ACTIVITIES

CMOS Image Sensor for X-Ray Applications			
Programme:	TDE	**Reference:**	T217-070MM
Title:	CMOS Image Sensor for X-Ray Applications		
Total Budget:	1000 k€		
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.					

Further development of the ALFA-N detector (VIS/NIR/SWIR) in view of upcoming Science missions					
Programme:	CTP		**Reference:**	C216-018PA	
Title:	Further development of the ALFA-N detector (VIS/NIR/SWIR) in view of upcoming Science missions				
Total Budget:	3000 k€				
Objectives					
The main objectives of this activity are to (i) demonstrate ALFA-N detector optoelectronic performance meeting the requirement specifications of ESA Science missions (e.g.THESEUS M5 candidate IRT detectors) and (ii) increase the detector TRL to 6 in line with mission programmatic requirements (2024 for THESEUS). This requires addressing the following points: #1 sensitivity in the visible i.e. down to 400 nm #2 space qualified package including flex cable #3 radiation testing of the detectors					
Description					
The development of a European NIR/SWIR MCT detector (ALFA-N) meeting the needs of ESA Science missions is being funded under a multi-phase roadmap funded through the TDE and CTP Programmes. In an earlier phase of the ALFA-N detector development Sofradir and CEA Leti (FR) have demonstrated very good electro-optical performance. The current phase - "Prototype NIR/SWIR large format array detector development" - addresses reaching the same performance for a larger format detector: 2k x 2k with 15 micrometer pixel pitch, based upon the complete redesign of the ROIC (readout integrated circuit). After verification of the functionality of the newly-designed rad-hard ROIC, three objectives shall be addressed in this activity to meet the needs of upcoming Science missions: #1 sensitivity in the visible i.e. down to 400 nm #2 space qualified package including flex cable #3 radiation testing of the detectors					
Deliverables					
Engineering/Qualification Model					
Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2024 TRL 6
Application Mission:	Theseus		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

TECHNOLOGIES APPLICABLE TO SEVERAL COSMIC VISION MISSIONS – ESA ACTIVITIES

Platform and Payload Sensor/Actuator Bus Nodes			
Programme:	TDE	**Reference:**	T201-033ED
Title:	Platform and Payload Sensor/Actuator Bus Nodes		
Total Budget:	500 k€		

Objectives

Objectives of the activity include requirements analysis, architectural design, detailed design and manufacturing of sensor/actuator bus nodes for application on the Athena spacecraft platform and for the Athena payload. Hardware and software for bus nodes and the platform backend shall be developed, tested, and validated. Performance, versatility and flexibility of the concept shall be demonstrated. Savings in RTU and harness mass, power consumption, AIV time, cost, as well as improvements in data quality and FDIR capabilities shall be quantified. FM development plans shall be defined.

Description

The proposed sensor/actuator bus nodes will allow to replace or complement a traditional centralized Remote Terminal Unit (RTU) based architecture with decentralized sensor data acquisition (temperature and other parameters) and actuator control (heaters, etc.). These miniaturized bus nodes (~4x4x3cm, 70g TBC for basic node) will be based on standardized technology such as CAN bus and use highly integrated latest generation chips like the ESA microcontroller or equivalent chips. A modular and scalable design will support localized sensor data acquisition and actuator control in order to enable significant reductions in harness complexity, length and mass. It will also increase sensor signal quality, enable new modes for Failure Detection Isolation and Recovery (FDIR) and autonomy, and enable significant AIV/AIT time and cost reductions. Synergies with ongoing ESA technology developments will be exploited wherever possible. A previously completed study ("Smart Microsystems for Space Applications",) has indicated that on a spacecraft with a complexity similar to the Rosetta orbiter about 4 km of harness, and >60% / ~65kg of related mass could be saved by using sensor/actuator bus nodes. Similar or higher complexities are expected for the Athena spacecraft, and achievement of similar savings is the design goal.

Deliverables

Consolidated requirements and tradeoffs for Sensor Bus Nodes
Sensor Bus Node EMs with flight-like form, fit and function, including corresponding sensors and harness
Sensor Bus Node software and platform backend software
Test and validation data, impact analysis and EQM/FM development plan
Documentation

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	Generic	**Contract Duration:**	20 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

The proposal is consistent with on-going developments (interfaces, sensor buses, microcontroller).

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 k€		

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 k€				
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					

SMILE SXI PSU de-risking activity			
Programme:	CTP	**Reference:**	C203-112FM
Title:	SMILE SXI PSU de-risking activity		
Total Budget:	1250 k€		
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					

European contribution to International Radiation Environment Near Earth modelling system			
Programme:	CTP	**Reference:**	C204-122EP
Title:	European contribution to International Radiation Environment Near Earth modelling system		
Total Budget:	800 k€		
Objectives			
This activity shall address the development of an international space radiation environment modelling system that couples advanced radiation models previously developed under ESA contract with other leading international models, and which allows flexible interfacing with different environment and effects tools. The solar energetic particle model shall be updated for the system with increased energy range and an interplanetary environment component in order to better support science missions. Following validation of the models, the functionality of the system shall be demonstrated for science mission scenarios.			
Description			
Detailed understanding of the radiation and plasma environment is important for all space missions. Radiation effects result in internal charging, dose and single event effects, whereas plasma effects result in surface charging and instrument interference. A prototype European Space Radiation Environment Modelling system has been previously developed under ESA contract to connect statistical models of the solar, trapped and galactic cosmic ray energetic particle environments. Additionally, prototype effects tools to determine internal charging, ionising and non-ionising dose and single event effects were included. This system has been developed with a flexible python architecture which can be utilised for interfacing with other models, such as the US developed AE9/AP9 models of trapped electrons and protons. However, the system must be further expanded with new datasets and functionality before it can be utilised by European industry. The main objective of this activity is to build on the backbone architecture of this existing system to develop an international tool (IRENE: International Radiation Environment Near Earth) coupling models of all radiation environments with flexible interfacing to different environment and effects tools. The tool shall be proposed to be adopted as an international standard. Compatibility of the tool with ESA's Space Environment Information System (SPENVIS) shall be considered. Of specific importance to science missions are solar energetic particles (SEP); however the existing SEP model is limited in terms of energy and spatial coverage restricting the usefulness for science missions such as Athena, BepiColombo, Solar Orbiter, JUICE, JWST, Euclid, PLATO and LISA. This activity shall integrate new models into the global solar particle			

model to expand ranges, and the tool shall include functionality to output interplanetary propagation models to support science missions. Additionally, trapped energetic particle models are needed for ESA missions such as CHEOPS. The tool shall therefore allow interfacing with the US-led AE9/AP9 models permitting continued exploitation of these models and visibility of on-going international developments. In the 2018-2021 timeframe new European radiation monitor data will become available which can be used to update and validate the Radiation Belt and SEP models of the tool. Following validation efforts of the models, the system functionality shall then be demonstrated for science mission scenarios.
Deliverables
Radiation environment modelling system: alpha version and beta version. Technical Reports. User manual for alpha and beta version.

Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2021
Application Mission:	All		**Contract Duration:**	36 months	
S/W Clause:	Open Source Code				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

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 k€		
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 k€		

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

Radiation environment at extremely low altitude and latitude			
Programme:	TDE	**Reference:**	T204-119EE
Title:	Radiation environment at extremely low altitude and latitude		
Total Budget:	300 k€		

Objectives

The activity aim is to assess the variability and evolution of the radiation environment very near the terrestrial equator at low altitude and hence to improve the modelling of the environment in this region. As a result, risks to the performance of spacecraft like XIPE would be reduced and safety margins driven by current levels of uncertainty could be reduced.

Description

Low-altitude near-equatorial orbits are increasingly being proposed for missions such as XIPE as a means of minimising exposure to radiation that causes damage and interference to instrument sensors. These orbits are selected because they allow a spacecraft, according to standard models, to stay just outside the high radiation environment of the South Atlantic anomaly (SAA). However, the characteristics of the edges of the SAA are not nearly as well understood as its peak and the environment predicted to be actually experienced by a satellite in this kind of orbit is very sensitive to the details of steep flux gradients in terms of latitude and altitude. Hence it is not surprising that the AP8 and AP9 models can give widely different mission fluences in this region. These models are based on data from different spacecraft and a different modelling coordinate system in this region. Apart from the SAA, satellites in this orbit encounter a population of charge exchange produced, trapped, lower-energy protons very close to the equator. Changes to the radiation fluxes due to space-weather related and seasonal atmospheric heating, as well as the drift motion of the SAA itself due to changes in the Earth's internal magnetic field, mean that the radiation environment will experience significant variability and evolution. An apparent long-term decline of solar magnetic flux would also imply an increase in the flux of cosmic rays that create the SAA via albedo neutron decay. Significant east-west anisotropies are also found in this region, leading to effects that depend on sensor orientation.

This study will examine the data and models relating to ions from around to 100's MeV. Data from SREM on Proba-1, EPT on Proba-V, other recent relevant data, and older data sets such as AZUR will be examined and results correlated with space weather indices and season. Historical information on the SAA drift and magnetic field models will be used to predict its evolution and the divergence of possible future states. Models that are driven by solar activity/cosmic ray flux and magnetic and atmospheric interactions will be constructed.

The main deliverable will be a models of proton spectra in this region as a function of altitude and latitude, including functions describing quasi-random, cyclical and evolving variations. A trade-off of orbital options for a XIPE-like spacecraft will also be delivered.

Deliverables

Technical data package, software models

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2018
Application Mission:	XIPE, Generic		**Contract Duration:**	18 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 k€		

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 k€				
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					

<table>
<tr><th colspan="6">High Accuracy Star Tracker Engineering Model (EM) Development</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C205-118SA</td></tr>
<tr><td>Title:</td><td colspan="5">High Accuracy Star Tracker Engineering Model (EM) Development</td></tr>
<tr><td>Total Budget:</td><td colspan="5">400 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Engineering Model</td></tr>
<tr><td>Current TRL:</td><td>3</td><td>Target TRL: 5</td><td></td><td>Application Need/Date:</td><td>2018</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Enabling Star Tracker for Athena. Also considered as a back-up on PLATO.</td><td>Contract Duration:</td><td colspan="2">18 months</td></tr>
<tr><td>S/W Clause:</td><td colspan="5">Operational S/W</td></tr>
<tr><td colspan="6">Consistency with Harmonisation Roadmap and conclusion:</td></tr>
<tr><td colspan="6">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</td></tr>
</table>

<table>
<tr><th colspan="4">Future AOCS Enabling Technologies</th></tr>
<tr><td>Programme:</td><td>TDE</td><td>Reference:</td><td>T205-031EC</td></tr>
<tr><td>Title:</td><td colspan="3">Future AOCS Enabling Technologies</td></tr>
<tr><td>Total Budget:</td><td colspan="3">700 k€</td></tr>
<tr><td colspan="4">Objectives</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">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</td></tr>
</table>

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).					

Robust Attitude Guidance and Control for Flexible Spacecraft			
Programme:	TDE	**Reference:**	T205-032EC
Title:	Robust Attitude Guidance and Control for Flexible Spacecraft		
Total Budget:	400 k€		
Objectives			
The objective of this activity is twofold: the first objective is to investigate the applicability of two different modern robust techniques for attitude control of flexible spacecraft. The second objective is to create a software framework that allows analysis, modelling, and design of the Attitude Guidance and Control system for flexible spacecraft. This activity shall specifically address potential new scientific missions where large appendages and sloshing effects need to be controlled with demanding pointing accuracy.			
Description			
The two techniques to be investigated are the following: 1) combining optimal feed-forward and robust feedback by means of open/closed-loop input shaping, optimal command and state space design techniques with disturbance observer, in order to minimize the impact of flexible appendage or fuel sloshing on pointing accuracy and manoeuvrability capability of a spacecraft. The major proposed innovations are: a) the use of input shaping filters in close-loop, and b) the design based on state space techniques. 2) an integrated Modelling Control framework which incorporates uncertainty modelling via LFTs (linear fractional transformations), robustness analysis via the structured singular value ?, and various Hinfinity control synthesis techniques, including structured Hinfinity control. It is expected that this activity will bring improvements in the control solution leading to improved and more robust pointing performance for missions with dynamic disturbances from larger appendages and propellant sloshing effects. It is also expected that applying modern control techniques will also improve the mission science availability in case of slews and settling effects as well as optimising the control effort/cost. This will help enable future spacecraft configurations with larger flexible appendages and propellant sloshing.			

Deliverables					
Technical Reports SW Simulator Algorithms code					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2020
Application Mission:	Generic		**Contract Duration:**	12 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Radar Planetary Altimeter Engineering Model					
Programme:	CTP		**Reference:**	C205-002EC	
Title:	Planetary Altimeter Engineering Model				
Total Budget:	1500 k€				
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					

Adaptive control for fast acquisition and re-acquisition of precise scientific constellations			
Programme:	TDE	**Reference:**	T205-053SA
Title:	Adaptive control for fast acquisition and re-acquisition of precise scientific constellations		
Total Budget:	250 k€		

Objectives

To develop a unified estimation and control system for precise scientific constellations that can dynamically adapt to cope with the range of disturbance rejection levels required from constellation acquisition/re-acquisition up to science, including the rejection of dynamic events such as micro-meteorite impacts.
Scientific availability of science constellations (such as for the LISA mission) is highly dependent on the recovery time from high dynamic events such as micro-meteorite impacts or failures, which could cause laser link loss. Recovery from such events is traditionally a lengthy process involving numerous operational modes required to use different sensor inputs to acquire the links and gradually reduce the dynamics using progressively lower bandwidth controllers, each of which impose minimum convergence times.
This activity would investigate cutting edge advanced control techniques for the development of a unified estimation and control system that can seamlessly utilize all available sensor information and dynamically adapt to cope with the range of disturbance rejection levels required from constellation acquisition/re-acquisition up to science, including the rejection of dynamic events such as micro-meteorite impacts. Such a seamless control system would reduce the required number of mode transitions and thus the time to achieve science, significantly increasing science availability time and thus science yield.
Note that the intention of this activity is not necessarily to employ 'adaptive control' techniques to solve this problem. Instead, the goal is to research cutting edge control techniques that can be used to design a control system that can adapt dynamically to cover the entire range of disturbances while avoiding discrete operational stages and complex switching behavior with their associated large transients.

Description

Current control designs for acquisition of precision science modes and constellations require several operational modes that are stepped through in order to deal with the different sensor inputs, scan the instruments, acquire the constellation links, and progressively reduce the residual motion in order to achieve the required performance levels for science. Even if such controllers might typically be designed using robust control methods, such as H-infinity, a cascade of control modes cannot be avoided in order to cover the range of bandwidths required from instrument scanning and constellation link acquisition up to the high fidelity science modes. This implies that several mode transitions are required, including minimum wait times for controller convergence. Therefore, the time required for entering and subsequently re-acquiring science mode is generally significant, reducing the overall science availability and scientific yield. For this reason, a novel estimation and control system that could adapt to control the different levels of disturbances using different sensors, without requiring mode transitions between different operational modes, would significantly reduce the recovery time and increase science availability. Such a system would also be inherently robust to dynamic events such as micro-meteorite impacts or some failures, avoiding the need for triggering a safe mode in the first place.
This activity would tackle the use of highly advanced control techniques for the development of an estimation and control system for science constellation missions that can dynamically adapt to cope with the range of disturbance rejection levels required from constellation acquisition/re-acquisition up to science, including the rejection of dynamic events such as micro-meteorite impacts. This would also include the development of any required estimation techniques to deal with the different sensors and/or sensor modes to implement such an adaptive system and allow recovery of science even after loss of the constellation links.
The activity is applicable to any mission requiring a high degree of precision stabilization of the scientific platform. However, it is especially appealing for science constellations where all spacecraft are required to yield the scientific output, and the total science outage time is proportional to the number of spacecraft. For this reason, the LISA mission would serve as a benchmark application example for the techniques developed during this project.

Tasks:
1) Explore cutting edge control and estimation techniques currently not used for space systems focused on non-linear, adaptive, gain scheduled, and failure tolerant control.
2) Trade-off and select the most promising and feasible technique to design a unified estimation and control system that cope with a wide range of disturbance rejection levels required from constellation acquisition/re-acquisition up to science.
3) Design and implementation of the estimation and control system.
4) Implementation of a simplified LISA simulation environment for preliminary testing of the algorithms.
5) Characterization and testing of the proposed algorithms in the simplified LISA simulation environment.
6) Model-in-the-loop testing of the new algorithms in the LISA DFACS simulator developed under a previous contract at ESA.

Deliverables

Report; Software

Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2018
Application Mission:	Several missions	**Contract Duration:**	12 months		
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

N/A

Star Tracker Based Generic Safe Mode for Science Missions			
Programme:	TDE	**Reference:**	T205-119SA
Title:	Star Tracker Based Generic Safe Mode for Science Missions		
Total Budget:	400 k€		

Objectives

To perform the detailed design and analysis of a star tracker based safe mode applied to Cost Effective Science Missions

Description

A previous study (TDE Star sensing based safe mode) confirmed the interest of using star tracker as primary sensor in a generic safe mode: versatility, suitability to complex requirements and constraints (e.g. TTC from long distance to Earth such as Mars, Jupiter, Deep Space), cumulative maturity/reliability across missions, reduced development effort (genericity), and operational errors mitigation.
The commonality of sensor and reduction of the sensor suite is particularly attractive for cost-effective space missions, since commonality of sensors between several modes relaxes the sensor procurement, integration, verification and testing effort.
Additional activities are required in order to implement this attractive solution on a science mission. This activity will perform detailed analysis and design, assess the robustness of star tracker based safe mode to worst case conditions using flight data and simulations. Flight data will consist in star tracker measurements out of normal mode such as sun acquisition, safe mode, star tracker reconfigurations, as retrieved from previous and current mission telemetry.
This activity encompasses the following tasks:
- Task1/ Science mission (small planetary missions) study cases section and requirements definition considering at least Cost Effectiveness, Operations, Safety, TTC and payload constraints (e.g. TTC pointing requirements, payload attitude constraints, initial conditions).
- Task2/ Assessment of Star tracker acquisition and tracking robustness to worst-case conditions including dynamic conditions and end of life conditions considering proton damage to the detector: Solar Flares, Non-Stellar objects in the field of view (Moon, planets, other satellites, dust), high angular rates, stray light, SEUs
- Task 3 / Assessment of the suitability and robustness of state-of-the-art European manufacturers? star tracker products
- Task4/ Safe mode detailed design taking into consideration cost effectiveness: define the AOCS sensors and actuators, the avionics architecture including standard interfaces, and the FDIR strategy.
- Task5/ Safe mode detailed analysis including FMECA (including for example parameters errors such as star tracker matrix error)
- Task6/ Acquisition and Safe mode Simulator development, Test plan definition, Robustness, FDIR, and performance assessment
- Task7/ Definition of a test plan, aiming at robustness and performance testing on a representative AOCS (preferably closed loop) testbench including RT aspects, STR model, as well as STR optical stimulation.
- Task8/ Preliminary assessment of complementary cost-effective attitude determination solution, such as Doppler attitude determination (see Ulysses spacecraft for example)
- Task9/ Conclusion and way forward
The expected deliverables are related documentation and study simulator. AOCS testbench and STR physical model and optical stimulation are considered out of scope of the deliverables.

Deliverables

Breadboard; Report; Software

Current TRL:	3	**Target TRL:**	4	**Application Need/Date:**	TRL 6 by 2022
Application Mission:	Several science missions		**Contract Duration:**	21 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 k€		

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 k€		
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.

System Study of Optical Communications with a Hybridised Optical/RF Payload Data Transmitter (PDT)					
Programme:	TDE		**Reference:**	T206-002ET	
Title:	System Study of Optical Communications with a Hybridised Optical/RF Payload Data Transmitter (PDT)				
Total Budget:	750 k€				
Objectives					
Taking advantage of results from earlier optical communications studies and trade-offs this activity shall define and consolidate an end-to-end system for a pathfinder mission that can demonstrate the enhancements enabled by optical links for payload data transmission on future deep space missions. Regarding the space segment the activity shall investigate the potential of on-board PDT's that use optical/RF hybridised concepts to maximize commonality of RF and optical functionalities and hardware in backend and front-end equipment.					
Description					
The activity shall take an end-to-end system engineering approach to examine the potential of an optical communications system that combines on the spacecraft some elements of a deep-space RF and optical payload data transmission system, for the purpose of reducing the size, weight and power burden on the spacecraft. Another objective for such demonstrator mission is to avoid a complex ground segment of several optical terminals. Figures of merit and analytical methodologies shall be developed to conduct system trade studies, and several potential technology integration strategies shall be established. In order to achieve a 20-fold (or even higher) increase in telemetry rates on future (deep space) science missions a promising (initial) concept is to hybridise the PDT that uses RF technology as backbone and optical technology to augment significantly the RF based capacity when optical link circumstances allow so. The telemetry capacity of the demonstrator system may be limited such that an uplink laser beacon (otherwise needed for acquisition and tracking) is avoided and by relying on spacecraft sensors instead. A complex network of distributed optical ground terminals is not necessary because a high operational availability of the optical telemetry link in a pathfinder mission is considered not essential. The goals are to let RF-based PDT communications not constrain the science data return when optical sky conditions are favourable, and to minimise on-board and ground resources while optimising throughput and operations. A hybridised approach is perceived as extendable and an enabling response to the ever-increasing requirements for higher data rate. It is also a responsible programmatic approach that reduces mission risk on the way forward to optical communication technology for missions in future. A system concept can be based primarily upon a combined RF/Optical teletenna and integrated, shared digital processing in backend equipment such as for formatting, channel coding, modulation, subsystem control and the interfaces with the spacecraft. The hybridised approach aims at significant savings in resources if compared with completely independent RF and optical terminals and respective antenna apertures on-board. It combines the best features of RF and optical communication elements into one integrated system without compromising upon the reliability of the primary RF-based TT&C and PDT subsystem as the backbone.					
Deliverables					
Technical data package					
Current TRL:	2	**Target TRL:**	3	**Application Need/Date:**	2020
Application Mission:	Generic		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
Yes, European Space Technology Master Plan 2012, p. 210, Optical PDT Systems (AIM E), Activity E01.					

Miniaturisation of the Deep Space Transponder					
Programme:	TDE		**Reference:**	T206-004ET	
Title:	Miniaturisation of the Deep Space Transponder				
Total Budget:	250 k€				
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 k€				
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 k€				
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 k€		
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					

Verification and Calibration Techniques for Low Frequency Antennas					
Programme:	TDE		**Reference:**	T206-009EF	
Title:	Verification and Calibration Techniques for Low Frequency Antennas				
Total Budget:	500 k€				
Objectives					
The objective of this activity is to develop and demonstrate, through the manufacturing and testing of a breadboard, the methodologies for testing and verification of space based low frequency antenna sensors such as low frequency radars. A representative dipole antenna breadboard operating at 20 MHz assembled on a 6U cubesat mockup will be manufactured and tested.					
Description					
Antenna based space science sensors operating under 400 MHz rely on simulation tools for the estimation of their in-flight performance. This is mostly due to the fact that the verification of the antenna radiating characteristics below these frequencies requires very large testing rooms with volumous and expensive absorbers that provide an anechoic environment to suppress multiple reflections within the testing area. At these low frequencies the functionality of these absorbers is much reduced and the testing facilities behave as large cavities, yielding very inaccurate results. Consequently, these antenna sensors are launched with a relatively limited knowledge of their actual performance in space. This activity shall investigate, and demonstrate through the manufacturing and testing of a bread board, novel techniques of testing and verifying low frequency antennas typically used as sensors (e.g. ground penetrating radars) in Science missions. These techniques can be based on Spherical Wave Expansion Mode Filtering or other mathematical post processing mechanisms combined with Spherical Near Field testing. Suitable probes for Spherical Near Field testing at 20 MHz shall be investigated and developed. Within this activity a simplified, but electrically representative, satellite mockup (e.g. 6U cubesat) and dipole antenna that operates at 20 MHz shall be developed and its performance verified against an electromagnetic model using the developed methodologies. In addition, the combined uncertainty of the measured antenna performance shall be determined shall be evaluated.					
Deliverables					
Breadboard; Other; Report					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2019
Application Mission:	Any science mission that makes use of an antenna operating at frequencies below 400 MHz		**Contract Duration:**	18 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 k€		
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 k€				
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					

Large radii Half-Wave Plate (HWP) development CCN			
Programme:	CTP	**Reference:**	C207-022FI
Title:	Large radii Half-Wave Plate (HWP) development		
Total Budget:	200 k€		
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 k€		
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 k€				
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 k€		
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 k€		
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 k€				
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 k€				
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 k€				
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					

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 k€		
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					

Photon-Counting Ground-based Optical Communications Detector					
Programme:	CTP		**Reference:**	C212-002GS	
Title:	Photon-Counting Ground-based Optical Communications Detector				
Total Budget:	400 k€				
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"					

Prototype of off-line correlator for arraying of large aperture antennas			
Programme:	TDE	**Reference:**	T212-052GS
Title:	Prototype of off-line correlator for arraying of large aperture antennas		
Total Budget:	350 k€		

Objectives

ESA Deep Space Antennas provide state of the art performances. To yield further performance improvement, as will be required by future missions, it will be necessary to array several large aperture antennas. As the physical colocation of Deep Space Antennas does not currently exist, a simultaneous track from Cebreros and Malarg?e can be recorded and later (off-line) processed to validate the correlator characteristics, discover the problems of arraying large antennas and validate the final implementation of a future real-time operational correlator yielding higher data download rates.

Description

The outcome of the GSP study "Future Architecture of ESA Deep Space Stations for Enhanced Mission Support" showed that the most effective way to increase the Ground Station sensitivity to get a higher TM downlink rate or better emergency coverage is via arraying of large aperture antennas.

The use of arrays introduces the need of a correlator, a new software component that shall combine adequately the individual signals coming from the different antennas of the array. The function of the Array correlator is to adequately phase and combine the received signals maximising the S/N and to compensate for the different instabilities of the system. Presently ESA has no location with two large antennas to validate a correlator, but the received signal can be recorded open loop from two stations (Cebreros and Malarg?e) and later processed in an off-line correlator. This off-line correlator will allow to learn on the operations of arraying, find the problems present when arraying large antennas, the ways to solve them and trade-off the different solutions or approaches using real data. Also, the application of such prototype to actual S/C signal acquired at two Deep Space Antennas is foreseen, in order to practically demonstrate the feasibility of the concept and characterise the system performance.

The proposed study phase are as follows:
- Study and definition of the most suitable algorithms for signal combination (e.g. Simple, Sumple, Eigen, LSfits). In this phase, the applicability of the combination method to the actual use-case shall be taken into account and be part of the trade-off. - A software simulator of the array correlator with special emphasis on the modelling of the different phase instability sources (atmospheric effects, interferences, electronic/mechanical antenna equipment and satellite movement)
- Implementation of a correlator prototype (HW or SW) compatible with the open loop data interface currently used at ESTRACK antennas
- Demonstration of the feasibility of the proposed concept by data analysis of a dedicated tracking campaign on an interplanetary probe from ESA Deep Space Antennas
- Identification of critical requirements and steps for the evolution to a real-time system for co-located antennas.

Deliverables

- Design Documentation and technical notes
- Simulator and simulation results
- Array correlator suitable to be used for ESA Deep Space missions
- Execution of the test campaign with real mission signals and delivery of test reports

Current TRL:	2	**Target TRL:**	5	**Application Need/Date:**	2018
Application Mission:	Generic, interplanetary missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:

To be included in TD12 Harmonization dossier under elaboration.

X Band 80 kW amplifier pre-development			
Programme:	TDE	**Reference:**	T212-053GS
Title:	X Band 80 kW amplifier pre-development		
Total Budget:	350 k€		

Objectives

The activity objective is to provide better uplink performances by increasing the uplink power of the ESA Ground Stations by a factor of 4 (6 dB) up to a transmitted power of 80 kW at X Band. This will enable improved uplink performances for distant spacecraft or for critical phases like entry descending and Landing or for emergency situations of missions. This activity shall cover the first phases and pre-design activities to validate concepts and solutions.

Description

Present ESA Deep Space Stations are equipped with a 20 kW X Band High Power Amplifier (HPA). Future missions will demand improved uplink performance and as such it is required to increase the uplink power. A previous GSP activity has concluded that an increase in the uplink performances can be achieved with an 80 kW transmitter. A second

GSP activity has analysed the viability of a European alternative to US Klystron tubes (100 kW, X band) and considered the viability of European tubes at 25 and 100 kW. This activity shall design the complete High Power Amplifier around the existing tube (or a new European one), including all the different HPA subsystems (power supplies, protection, preamplifiers, internal cooling, ...) and ancillary systems (mains distribution, de-ionised cooling system). At the conclusion of the activity, a detailed and complete Design Data Package will be available allowing to start the manufacturing phase minimising the risk of the development. The activity will cover the first steps of the amplifier design and development, from the analysis of customer needs and requirements, through the architecture definition, trade-offs, performance analysis and budgets, and finalising with the detailed design of the unit and complete definition of each subsystem of the amplifier (including the de-ionised cooling system).

Deliverables					
- Requirements definition - Analysis of different architectures and trade-off - Detailed design of the system - Performance analysis and budgets - Detailed definition of all the subsystems - Critical Design Data Package including all the analysis, budgets, simulations and drawings					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2017
Application Mission:	Generic, interplanetary missions		**Contract Duration:**	9 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
To be included in TD12 Harmonization dossier under elaboration.					

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 k€				
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 k€				
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 k€		
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					

Echo telescope secondary mirror mechanism					
Programme:	CTP		**Reference:**	C215-119MS	
Title:	Echo telescope secondary mirror mechanism				
Total Budget:	1500 k€				
Objectives					
To develop and test an engineering model of the EChO telescope secondary mirror mechanism.					
Description					
The demanding wave front error (WFE) requirements and the cryogenic operating temperature (30K) applicable to the EChO telescope require the adoption of a 5 degree of freedom (DoF) secondary mirror (M2) focusing mechanism to mitigate the risks associated to thermoelastic/manufacturing/ageing effects. The main functions of the M2 mechanism are: - Support and secure M2 during launch (without power), - Provide 5 DoF correction (3 translations and tip/tilt) on ground and in orbit, - Maintain stable position without need for power when in orbit. The activity is structured in two phases: phase 1 up to TRL 3 (2 x parallel contracts, duration 6 months), phase 2 up to TRL 5 (1 contract, duration 18 months) The main tasks of phase 1 are: - Review of technical specification based on ESA functional specification (for both EChO and SPICA). - Linear actuator trade-off, definition, and preliminary design and analyses - Mechanism trade-off, definition, preliminary design and analyses. The main tasks of phase 2 are: - Bread-boarding of key technologies. - Preliminary characterisation of the actuator as stand alone unit. - Manufacturing, Assembly and Integration of the mechanism EM. - Testing: o Performance tests: (at ambient conditions and under thermal vacuum (TV) at 30K) including resolution, accuracy, precision, motorisation margins, power dissipation, life test-under 1g and with zero g off-loading device. o Environmental tests: vibration at ambient and TV cycling) with a dummy mirror. o Inspections. - Lessons learnt, implementation plan for QM and FM programmes.					
Deliverables					
M2 mechanism EM, technical data package					
Current TRL:	3	**Target TRL:**	5	**Application Need/Date:**	2015
Application Mission:	EChO, SPICA		**Contract Duration:**	24 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

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 k€		
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 k€ each. Phase 2 will consist of a single contract of 1000 k€.

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 k€		

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					

Characterisation of actuator behaviour for a fine steering tip/tilt mechanism - CCN			
Programme:	CTP	**Reference:**	C215-126MS
Title:	Characterisation of actuator behaviour for a fine steering tip/tilt mechanism - CCN		
Total Budget:	300 k€		
Objectives			
The three main objectives of this activity are: a) Characterise the piezo-electric material by measuring its deformation in vacuum and cryogenic conditions (this will include out-gassing effects, thermo-elastic deformation, pre-load variation and piezo-electric effect). b) Upgrade the Cryogenic Fine Steering Mechanism (CFSM) design from the needs of EChO to the needs of ARIEL, and improve design features (isostatic mount for the mirror to allow different mirror materials, and increased resistance to shock). c)Test the CFSM in a closed control loop			
Description			
The following five tasks will be addressed in this activity: 1.Piezo-electric material characterisation (vacuum and cryogenic). Temperatures required are = 100 K, resolution required is < 1 micron. At least 4 pre-stressed piezos are to be characterised, with a possible addition of un-stressed piezos as well. The aim is to understand how the CTE, out-gassing, pre-load and piezo-electric effect evolve/vary under these conditions. 2. Design of an upgraded CFSM. Range is to be increased from 1.5 arcsec to 5-10 arcsec to cover the reaction wheel spikes. An isostatic mirror mount is to be included. Shock capacity is to be increased from 700 g to = 1500 g. 3. MAIT of the upgraded CFSM engineering model with a dummy Al mirror. To include LAT 3 level testing of piezos and basic functional tests at room temperature. 4. Test the updated CFSM EM. This is to include performance in cryogenic / vacuum conditions (piston + tip/tilt with a 1 mas resolution) and mechanical environment (vibrations and shock). Drift measurement during initial vacuum and cooling process is also to be measured and correlated with results of Task 1. 5. Test the CFSM in a closed control loop with a secondary sensor for real-time sensing of the CFSM position. The error should remain < 1 mas of the command amplitude. Two reference signals will be tested: 1) reaction wheel spike (~2-3 arcsec over 2-3 seconds) and reaction wheel micro-vibrations (~100 mas at 1-100 Hz frequency).			
Deliverables			
Design reports Test reports Upgraded CFSM EM			

Current TRL:	4	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	ARIEL, Generic		**Contract Duration:**	18 months	
S/W Clause:	N/A				

Consistency with Harmonisation Roadmap and conclusion:
N/A

Wheel with local speed control loop					
Programme:	CTP		**Reference:**	C215-132SA	
Title:	Wheel with local speed control loop				
Total Budget:	700 k€				
Objectives					
The objectives of the activity is to develop a local wheel speed control loop					
Description					
Wheel friction torque variations (so called wheel spikes) can be detrimental to high accuracy pointing performance missions. Together with micro-vibrations, this effect is a major contributor to the global pointing budget (e.g. on ARIEL about 100 mas on RPE for a 200mas requirement with current AOCS controller). A first mitigation solution consists in increasing the AOCS bandwidth; but this solution is limited by the sensor noise and by closed loop delays. Another solution consists in implementing an additional control loop in parallel to the AOCS loop using a Fast Steering Mirror(FSM); this solution allows at the same time to relax the AOCS control bandwidth, and to improve the pointing performances; but it is limited by the sensor delay. The objective of the current activity is to address another solution implementing a wheel speed control loop at AOCS level or at equipment (wheel) level, for wheels capacity covering ARIEL needs (currently up to 45 Nms) and other fine pointing missions. The proposed steps for this activity are the following: a/ Trade-off between implementations of a wheel speed control loop at AOCS level or at wheel level. b/ Design of the wheel control loop taking into account ARIEL requirements and constraints (e.g. low wheel rate): which sensors (tacho, optical encoder,…), controller characteristics (bandwidth, delays …) c/ Development of an AOCS simulator implementing the wheel model including spikes and wheel speed control loop d/ Performance assessment based on simulations e/ Development of the hardware wheel control loop - EM level (sensors, electronics). This EM design and development shall cover the RW models baselined for ARIEL needs and be modular enough to cover the RW family composed by the RW having similar interfaces so that it can be used for other missions as well. f/ Integration of the electronics within an existing wheel EQM [fitting with ARIEL anticipated needs] g/ Performance assessment based on hardware tests (EM) in a relevant environment to reach TRL6					
Deliverables					
Wheel Control Loop hardware + Final Report + various technical notes					
Current TRL:	2	**Target TRL:**	6	**Application Need/Date:**	2018
Application Mission:	Ariel and similar inertially pointed/ high accuracy missions		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

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 k€				
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 k€		
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					

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 k€				
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 k€				
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	
Title:	Novel In-Vacuum Alignment and Assembly Technologies for Optical Assemblies				
Total Budget:	400 k€				
Objectives					
The activity shall develop and test novel technologies for the alignment, assembly and integration of optical assemblies under vacuum.					
Description					
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.					
Deliverables					
TNs, test samples					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	Generic		**Contract Duration:**	18 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Verification of straylight rejection of optical science payloads using a pulsed laser source			
Programme:	TDE	**Reference:**	T216-104MM
Title:	Verification of straylight rejection of optical science payloads using a pulsed laser source		
Total Budget:	150 k€		
Objectives			
One of the major challenges in space optics and straylight management is measurement verification of performance at subsystem, instrument, payload or spacecraft level. The purpose of this activity is to assess the feasibility of using very short pulse length (ps or fs) lasers with time gating of fast synchronous detectors to perform a type of internal path length ranging of an optical system, in a process that could be considered as "straylight LIDAR".			
Description			
Currently, experimental straylight verification is not commonly done for space optical systems, relying instead on the fidelity of modelling and/or measurements in flight. By making a "temporal analysis" of the straylight performance model of an optical instrument it should be feasible to measure the critical paths in astronomical payloads. By sweeping a time gate over the full range of response of the system, additional paths could also be detected. Furthermore, by varying the angle of incidence of the source with respect to the entrance aperture/baffle and setting the time gate and imager integration time, it should be feasible to achieve spatially and temporally resolved images of the straylight characteristics of the system under test. These measurements can in turn be used to derive the Point Source Transmittance (PST), which is the standard straylight performance requirement specification for astronomical telescopes. This activity will study the possibility of implementing this technique for typical Science spacecraft instrument applications e.g. the CHEOPS telescope. Pending a successful outcome of this activity, the Agency intends to have a second activity with hardware demonstration of the approach. The following tasks are foreseen:			

Task 1: Literature review of proposed methodology, to include identification of technologies to enable concept to be tested, and the feasibility of proposed methodology Task 2: Preliminary design (block diagram and first iteration of parts list) supported by simulations of optical test-setup to verify test concept, to be based around the use of the CHEOPS optical telescope baffle as a test case Task 3: Preparation of test plan, schedule and ROM cost for executing proposed tests (including costs of refurbishment of CHEOPS spares) It is proposed to use the CHEOPS Telescope as a reference case to test the technique. Detailed comparison of the experimentally determined PST will be made with extensive existing straylight simulations (including PST analyses). This will be combined with in-flight measurements (foreseen 2018), enabling a detailed evaluation and an efficient test of this promising technique to be made in the near future.

Deliverables					
Technical Data Package					
Current TRL:	1	**Target TRL:**	2	**Application Need/Date:**	2018
Application Mission:	Generic		**Contract Duration:**	9 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

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 k€		
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 k€				
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					

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 k€		
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 of low dark current MWIR/LWIR detectors					
Programme:	TDE		**Reference:**	T217-055PA T217-055PA-B	
Title:	Development of low dark current MWIR/LWIR detectors				
Total Budget:	1700 k€				
Objectives					
Future science missions (astrophysics in particular) require IR detectors with dark current levels several orders of magnitude lower than existing HgCdTe technology. New fabrication technologies (e.g. p-on-n structures) are being developed in the Near-IR range that should prove beneficial also at longer wavelengths and will be highly beneficial to future science missions. The objective of this activity is to design, develop and test new HgCdTe MWIR/LWIR detectors optimized for low dark currents. These detectors shall exhibit a dark current several orders of magnitude lower than existing European technology, which will be applicable to future science missions in general. It is foreseen to initiate 2 competitive contracts for the total activity.					
Description					
Future science (astrophysics) missions require detectors in the wave range between 5 and 11 microns with dark current levels several orders of magnitude lower than what has been shown with existing HgCdTe technology. The goal of this activity is hence to: Design, develop and test new HgCdTe detectors: - investigate fabrication and design solutions which would allow meeting such requirements - develop one (or more) detector(s) filling the required wavelength range while implementing the identified design solutions - test this detector(s) at the necessary cryogenic temperature to demonstrate compliancy with requirements					
Deliverables					
1) One (or more) novel detectors in the MWIR/LWIR wave range with a high QE, low dark current, low noise and a high dynamic range 2) Design reports 3) Test reports					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	Q4 2014
Application Mission:	Astrophysics missions e.g. EChO		**Contract Duration:**	24 months	
S/W Clause:	NA				
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 k€		
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					
Programme:	TDE		**Reference:**	T217-054MM	
Title:	European Low-Flux CIS Development and Optimisation				
Total Budget:	750 k€				
Objectives					
Optimisation and validation of CMOS APS integration, control and read-out operation.					
Description					
This activity forms a part of the wider strategic programme to develop and stabilise European capability in providing high-performance and practical CMOS APS detectors for space and related applications. CMOS APS detectors can be designed to operate in a wide variety of ways while the CMOS process allows the integration of increasing levels of on-chip functionality. The aim of this activity is to consolidate the operational and on-chip design functionality and develop the building blocks necessary for the construction of practical CMOS APS devices that can be matched to a wide variety of mission applications.					
Deliverables					
Technology demonstrator breadboard					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2015
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	NA				
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 k€				
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 k€		
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 k€		
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 k€				
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 k€				
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			

Prototype ASIC for silicon photomultiplier based gamma-ray detector					
Programme:	CTP		**Reference:**	C217-066FT	
Title:	Prototype ASIC for silicon photomultiplier based gamma-ray detector				
Total Budget:	500 k€				
Objectives					
Design, manufacture and characterisation of a multi-channel ASIC for silicon photomultiplier based gamma-ray detector modules.					
Description					
Future high-energy astrophysics missions will have demanding requirements in terms of spectral, temporal and spatial resolution and will require hundreds or even thousands of individual detector arrays. Lanthanum bromide (LaBr3) scintillators coupled to silicon photo-multipliers (SPM) have been identified as capable candidates for meeting the necessary large detection volumes while providing simplicity of operation and solid-state reliability. Various development activities are already pursuing targeted improvements in SPM performance and SPM-Scintillator detector module optimisation. To complement these activities and to cope with the processing of large numbers of detector outputs present in future gamma-ray missions, a custom, multi-channel ASIC development is necessary.					
Deliverables					
Prototype ASIC, technical data package					
Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2015
Application Mission:	High-energy astrophysics missions e.g. GRIPS		**Contract Duration:**	18 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 k€				
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					

<table>
<tr><th colspan="6">Characterisation of radiation for high speed entry</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C218-001MP</td></tr>
<tr><td>Title:</td><td colspan="5">Characterisation of radiation for high speed entry</td></tr>
<tr><td>Total Budget:</td><td colspan="5">750 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Measurement technique reports and hardware, databases, numerical modules, recommendations on methodologies for radiation characterisation, for numerical models and for experimental techniques.</td></tr>
<tr><td>Current TRL:</td><td>N/A</td><td>Target TRL:</td><td>N/A</td><td>Application Need/Date:</td><td>2015</td></tr>
<tr><td>Application Mission:</td><td colspan="2">Marco Polo-R but also all other hypervelocity entry missions</td><td>Contract Duration:</td><td colspan="2">24 months</td></tr>
<tr><td>S/W Clause:</td><td colspan="5">NA</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">Delta-development of Electric Micropropulsion Subsystem for Deep Space Scientific Missions</th></tr>
<tr><td>Programme:</td><td>CTP</td><td>Reference:</td><td>C219-010FT</td></tr>
<tr><td>Title:</td><td colspan="3">Delta-development of Electric Micropropulsion Subsystem for Deep Space Scientific Missions</td></tr>
<tr><td>Total Budget:</td><td colspan="3">2000 k€</td></tr>
<tr><td colspan="4">Objectives</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">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:</td></tr>
</table>

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					

Advanced 2K JT cooler					
Programme:	TDE		**Reference:**	T220-053MC	
Title:	Advanced 2K JT cooler				
Total Budget:	700 k€				
Objectives					
The objective is to develop a high cooling power Joule Thompson cooler with an operating temperature below 2K					
Description					
The current 4K cooler developed for Planck is currently based on the first generation of linear compressors. Currently, new linear compressors under development offer the possibility to achieve high cooling powers at temperatures below 2K, offering the capability to use more compact sub-Kelvin cooler and minimising the heat load at the low temperature stages at a comparable mass compared to today's 4K systems. Based on the new generation of long-life linear compressors currently under development, a high power, low temperature Joule Thompson cooler shall be developed, assembled and tested.					
Deliverables					
Fully tested EM cooler, documentation					
Current TRL:	2	**Target TRL:**	6	**Application Need/Date:**	2012
Application Mission:	Generic		**Contract Duration:**	24 months	
S/W Clause:	NA				
Consistency with Harmonisation Roadmap and conclusion:					
Cryogenic and Focal Plane cooling (2007)					

Consolidation of high performance CFRP struts			
Programme:	CTP	**Reference:**	C220-042FM
Title:	Consolidation of high performance CFRP struts		
Total Budget:	1100 k€		
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 k€		

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 k€		

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 k€		

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 k€		

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 k€				
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 k€		
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 k€				
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 k€		
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 k€		
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 k€		

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 k€				
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					

L1-MISSION: JUICE – ESA ACTIVITIES

<table>
<tr><th colspan="6">Scalable Sensor Data Processor Flight Model Development</th></tr>
<tr><td>Programme:</td><td colspan="2">CTP</td><td>Reference:</td><td colspan="2">C201-032ED</td></tr>
<tr><td>Title:</td><td colspan="5">Scalable Sensor Data Processor Flight Model Development</td></tr>
<tr><td>Total Budget:</td><td colspan="5">1430 k€</td></tr>
<tr><td colspan="6">Objectives</td></tr>
<tr><td colspan="6">In this activity Flight Models (FMs) of the Scalable Sensor Data Processor (SSDP) ASIC shall be developed, tested with respect to functionality, performance and radiation hardness, characterized in both analogue and digital domain, and space qualified according to ESCC. Supporting software and hardware shall be developed and implemented, and initial support to early users shall be provided.</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">SSDP is a highly rad-hard, mixed signal, fast and versatile data processing ASIC implemented on IMEC's rad-hard DARE180 mixed signal technology with application cases in JUICE and other Science/Exploration missions for instruments and payload data processing units. It contains multiple processing cores and provides on-chip analogue functions such as ADCs and associated circuitry. Based on the test results of functional SSDP prototypes developed in the SSDP activity started in 2013, the following work shall be performed by the contractor:

• The design for the FM chips shall be optimized based on prototype chip test results.
• A dedicated FM ASIC production run in DARE180 technology shall be performed.
• A flight package shall be developed and FM chips shall be packaged, functionally tested, characterized and benchmarked.
• Test hardware and software shall be developed and radiation tests shall be performed.
• The full sequence of test activities required for ESCC flight qualification.
• Support to initial users shall be provided.

This activity will be implemented as a CCN to ESA activity # C201-031ED which will deliver functional SSDP prototypes.</td></tr>
<tr><td colspan="6">Deliverables</td></tr>
<tr><td colspan="6">Test hardware and software incl. IP- and S/W licenses and rights of use
ESCC qualified SSDP ASICs
Qualification documentation, test reports</td></tr>
<tr><td>Current TRL:</td><td>3</td><td>Target TRL:</td><td>6</td><td>Application Need/Date:</td><td>2015</td></tr>
<tr><td>Application Mission:</td><td colspan="2">JUICE, 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>

<table>
<tr><th colspan="4">Pre-qualification of integrated LILT solar cells</th></tr>
<tr><td>Programme:</td><td>CTP</td><td>Reference:</td><td>C203-102EP</td></tr>
<tr><td>Title:</td><td colspan="3">Pre-qualification of integrated LILT solar cells</td></tr>
<tr><td>Total Budget:</td><td colspan="3">1000 k€</td></tr>
<tr><td colspan="4">Objectives</td></tr>
<tr><td colspan="4">Qualification of solar cells for low intensity and low temperature (LILT) applications such as missions to Jupiter.</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">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</td></tr>
</table>

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 k€		
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					

Closed-loop attitude guidance on-board approach for JUICE			
Programme:	CTP	**Reference:**	C205-110EC C205-110EC-B
Title:	Closed-loop attitude guidance on-board approach for JUICE		
Total Budget:	400 k€		
Objectives			
To overcome the large discrepancy on pointing between Science requirements and JUICE design capability, a closed-loop attitude guidance on-board approach is studied using the navigation camera for close approach limb tracking, surface feature tracking, autonomous, semi-autonomous versus the current baseline ground based approach.			
Description			

During Jovian moons' science observations, the spacecraft pointing will be affected by a combination of two main contributors: the attitude guidance error and the spacecraft inertial pointing capabilities. During moons' Close Approach (C/A) and Ganymede low orbital phases, the guidance error is the largest contributor. This is linked to the fact that the last relative optical measurement, used by Ground to compute the attitude guidance profile, will be taken up to 72 hours before C/A. In order to address the large discrepancy on pointing between Science requirements and JUICE design capability, a closed loop guidance on-board approach would allow reducing the guidance error of at least one order of magnitude. In particular this will be beneficial in case of a sequence of fly-bys or Ganymede orbits. The following tasks will be performed: 1.Study of a closed loop guidance on-board approach and proof of concept. 2.Trade-off and performance assessment shall at least cover limb tracking, surface feature tracking, autonomous, semi-autonomous techniques versus the ground based approach. 3.Preliminary design of the algorithms, system architecture and possible impact to system level. 4.Preliminary validation of the algorithms on the base of a representative simulation environment (image generation, camera model, …) and real images of the Jovian moons: Ganymede, Callisto and Europa.
Deliverables
- Final Report - Trade-off analysis - Preliminary architecture and algorithms design and justification - Preliminary verification and validation plan - Software Simulator Tool

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2014
Application Mission:	JUICE		**Contract Duration:**	14 months	
S/W Clause:	N/A				
Consistency with Harmonisation Roadmap and conclusion:					
N/A					

Development of the Boom GSE for JUICE RPWI instrument			
Programme:	CTP	**Reference:**	C215-133PR
Title:	Development of the Boom GSE for JUICE RPWI instrument		
Total Budget:	650 k€		
Objectives			
To design, manufacture and characterise the GSE (lifting device and associated metrology) necessary for the JUICE LP-RPWI Boom.			
Description			
The RPWI instrument (Radio Plasma Wave Instrument) is one of the instruments of the Juice mission, aimed at characterizing the radio emission and plasma environment of Jupiter and its icy moons. The instrument includes four deployable booms (4 LP-PWI booms), developed in Poland under the Polish slice of the ESA PRODEX Programme. The LP-PWI booms are mounted on the JUICE S/C at 4 different locations. As part of the AIT/AIV program at S/C level the 4 LP-PWI booms need to be deployed and their alignments and performance measured after their integration to the S/C through an end-to-end test. This operation requires the development of a specific RPWI boom Ground Support Equipment, including a lifting device and metrology equipment, hereafter designated as GSE, object of the present procurement that also includes the operations for test and commissioning. This activity addresses the design, development, manufacturing, test and commissioning of the RPWI GSE comprising: • the so-called lift table and related sub-systems, the command/control sub-systems and the metrology equipment (in addition to boom lifting, the lift table shall provide the fine adjustment for the 2 rotations adjusting the vector gravity orientation of the slip table, on which the deployment takes place); • the Metrology instrumentation that shall allow performing a series of measurements including: - gravity vector error prior to deployment, - differential gravity vector between: 1) the S/C (& stowed boom), (linked to floor via MPT), 2) the slip table (linked to floor via Lift table); 3) the differential altimetry between the S/C (& stowed boom) and the slip table (linked to floor via Lift table). • commissioning of the Lift table including metrology is part of the procurement.			
Deliverables			
1 GSE, commissioned, with all its metrology and command/control equipment			

Current TRL:	N/A	**Target TRL:**	N/A	**Application Need/Date:**	2019
Application Mission:	JUICE		**Contract Duration:**	18 months	

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

Qualification of MAG boom for JUICE					
Programme:	CTP		**Reference:**	C220-037MS	
Title:	Qualification of MAG boom for JUICE				
Total Budget:	1500 k€				
Objectives					
Design and qualification of a MAG boom for JUICE magnetometer experiment.					
Description					
A magnetometer boom for JUICE needs to have maximum length (about 6 m) with 2 hinges. The material shall be lightweight, stiff, non-magnetic, and needs to withstand the environment and Jupiter (intense electron radiation and low temperatures up to –240°C) and during the Venus gravity assist during higher solar intensity. The material should also have a non-zero conductivity so as to avoid charging. The activity shall include the selection of the material, and design of the mechanisms. The deployment shall be demonstrated on a prototype. A full scale model shall be manufactured and environment qualifications be carried out. The activity is proposed to be phased, with phase 1 (600 k) including the activities leading to a design, including deployment demonstration, and phase 2 (900 k) demonstrating the qualification.					
Deliverables					
Design and interface documentation Mathematical models (FEM, CAD, multi-body) Prototype Qualification model					
Current TRL:	3	**Target TRL:**	6	**Application Need/Date:**	2015
Application Mission:	JUICE		**Contract Duration:**	24 months	
S/W Clause:	N/A				
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 k€		
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					

M3-MISSION: PLATO – ESA ACTIVITIES

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 k€				
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 k€		
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 k€				
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 k€				
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 k€				
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 k€				
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					

Manufacturing process for CFRP sandwich (prepreg M55J UD / EX1515 + aluminium honeycomb core)			
Programme:	CTP	**Reference:**	C220-048PL
Title:	Manufacturing process for CFRP (prepreg M55J UD / EX1515 + aluminium honeycomb core)		
Total Budget:	320 k€		
Objectives			
In order to achieve the scientific objectives of several scientific missions, CFRP structural items are mission critical H/W elements in terms of stiffness, geometrical accuracy as well as dimensional stability. This applies, in particular, to optical missions, where the deformations induced by thermal effects have to be minimized and, at the same time, the available resources in terms of mass and volume are critical, so that the use of CFRP elements represents the best technical solution. The objective of the activity is to improve manufacturing processes in order to qualify the production of CFRP sandwich panels with carbon fibre prepreg material M55J UD / cyanate ester resin + aluminium honeycomb core.			
Description			
The contractor shall perform following activities: a) Procurement of the material, including: - Clearing of all formal aspects (e.g. export licences) - Material storage conditions - Incoming inspection - Handling precautions b) Coupon test samples at ply level: - All the below activities shall be performed in accordance with ECSS rulesand commonly accepted test standards such as ASTM - Manufacturing of test samples - Thermal cycling of test samples (temperature limits TBD at KO) - Testing of samples to determine as a minimum following parameters: - Ultimate strength in tension and compression in both principal directions - Stiffness in tension and compression in both principal directions			

- In-plane shear modulus - Poisson’s ratio - CTE in all 3 principal directions, at 3 temperatures (minimum -100°C TBC, ambient, maximum, +100°C TBC) - CME in all 3 principal directions - Fibre volume content - Porosity - Tg - Reporting of the results c) Manufacturing of coupon test samples at laminate level: - All the below activities shall be performed in accordance with ECSS rules and commonly accepted test standards such as ASTM - Manufacturing of test samples (laminate lay-up and thickness TBD at KO) - Ultrasonic inspection before thermal cycling - Thermal cycling of test samples (temperature limits TBD at KO) - Ultrasonic inspection after thermal cycling - Testing of samples to determine as a minimum following parameters: - Ultimate strength in tension and compression in both principal directions - Stiffness in tension and compression in both principal directions - Poisson’s ratio - ILS strength - CTE in all 3 principal directions - CME - Fibre volume content - Porosity - Tg - Reporting of the results d) Manufacturing of coupon test samples at sandwich level: - All the below activities shall be performed in accordance with ECSS rules and commonly accepted test standards such as ASTM - Manufacturing of test samples (laminate lay-up and thickness TBD at KO) - Ultrasonic inspection before thermal cycling - Thermal cycling of test samples (temperature limits TBD at KO) - Ultrasonic inspection after thermal cycling - Testing of samples to determine as a minimum following parameters: - 4-point bending test - Reporting of the results e) Establishment of lesson-learnt / process improvement
Deliverables
Technical Notes Test samples

Current TRL:	2	**Target TRL:**	4	**Application Need/Date:**	2018
Application Mission:	PLATO		**Contract Duration:**	12 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 k€		
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					

F MISSION: COMET INTERCEPTOR

Coma Model for Comet Interceptor			
Programme:	TDE	**Reference:**	T204-134EP
Title:	Coma Model for Comet Interceptor		
Total Budget:	250 k€		
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

3-axis high accuracy accelerometer unit			
Programme:	CTP	**Reference:**	C205-127SA
Title:	3-axis high accuracy accelerometer unit		
Total Budget:	2000 k€		
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

Maturation of Additive Manufactured Metallic Optical Bench					
Programme:	TDE		**Reference:**	T220-056FT	
Title:	Maturation of Additive Manufactured Metallic Optical Bench				
Total Budget:	1000 k€				
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 k€				
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 k€		

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 k€		

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 k€

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 k€				
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 k€		
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 k€				
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 k€		

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 k€		

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