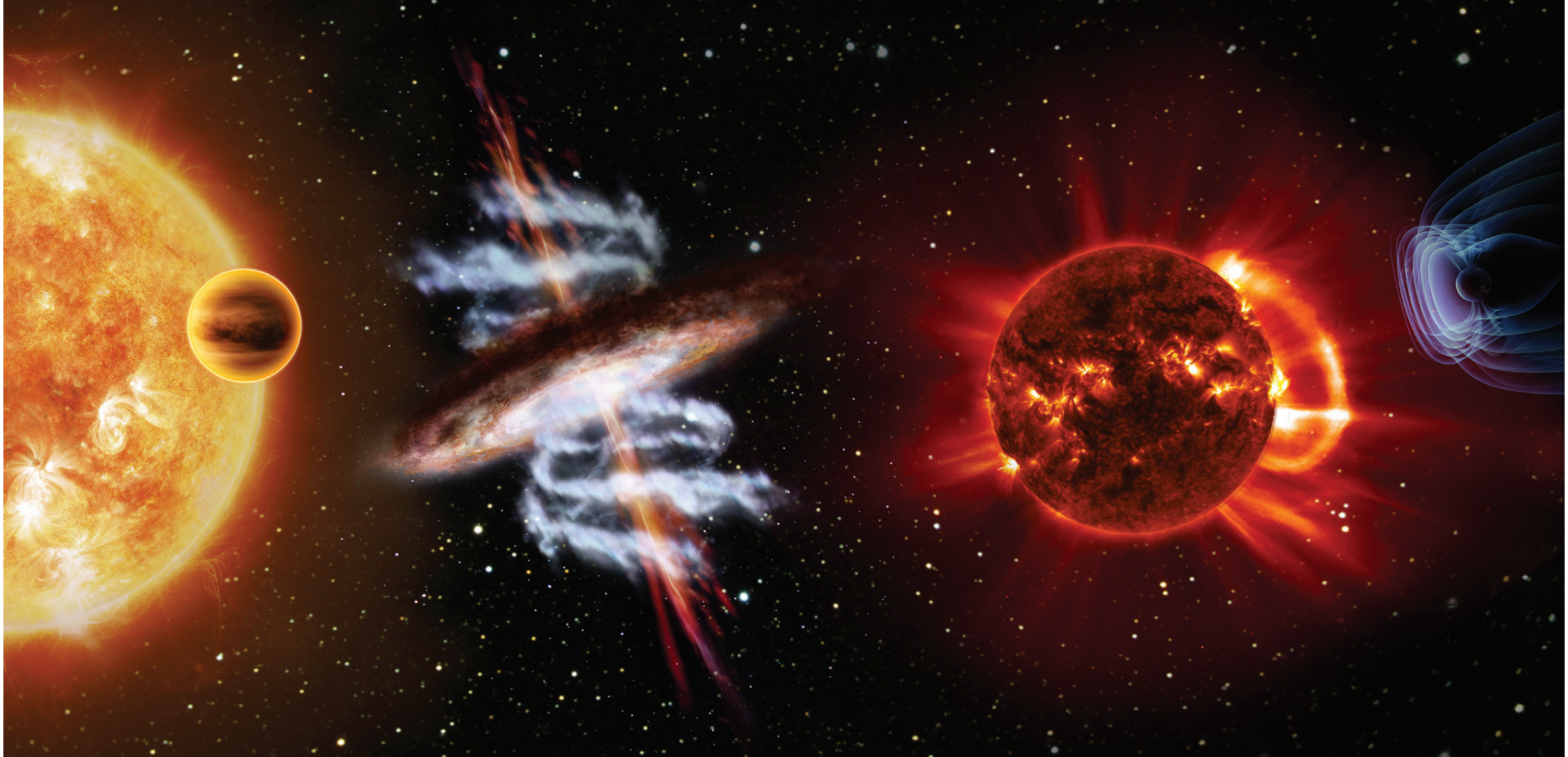
ESA'S CORE TECHNOLOGY PROGRAMME

→ PAVING THE WAY FOR ESA'S COSMIC VISION PLAN



ESA/AOES

European Space Agency

CCD 273 developed by e2v for Euclid. *ESA*

Author: Georgia Bladon, EJR-Quartz
Designer: Sarah Poletti, ATG medialab
Produced by: Communication, Outreach and Education Group
Directorate of Science and Robotic Exploration
European Space Agency

Available online: sci.esa.int/core-technology-programme-brochure

SRE-A-COEG-2015-001; September 2015

Cover image: Scientific themes for Cosmic Vision M4 candidate missions. *ESA/ATG medialab*

ESA'S CORE TECHNOLOGY PROGRAMME

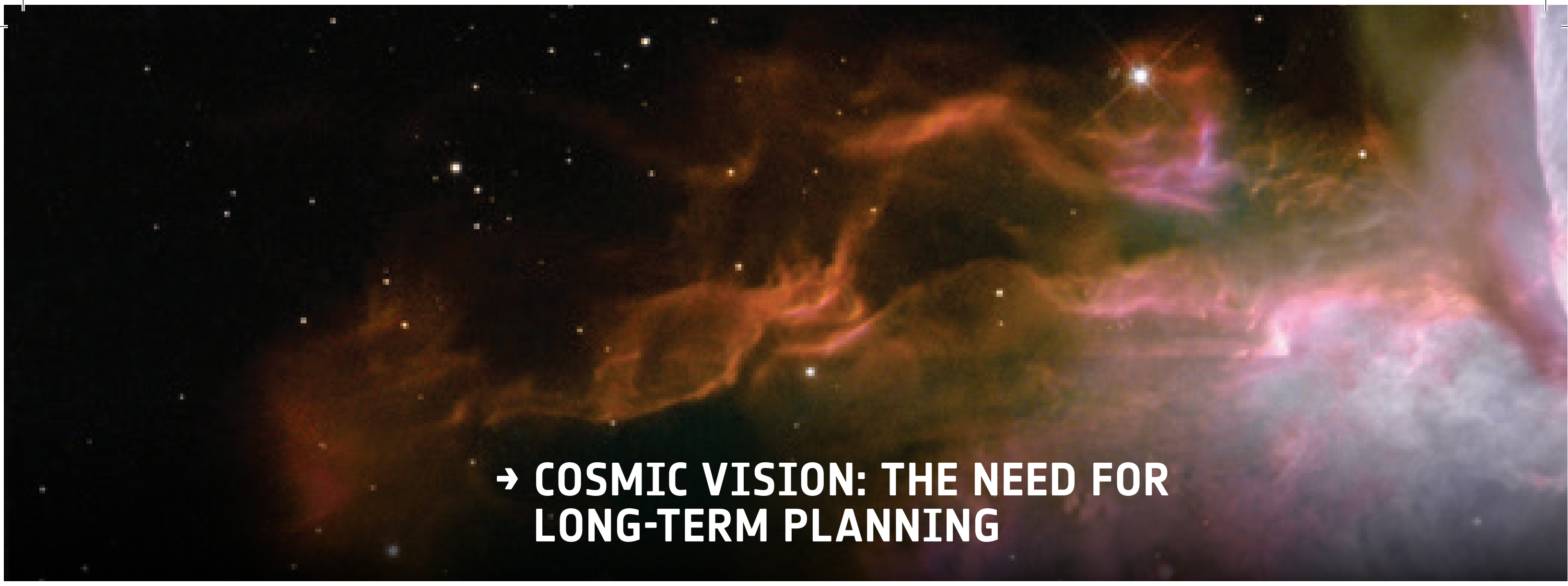
→ PAVING THE WAY FOR ESA'S COSMIC VISION PLAN

→ CONTENTS

→ INTRODUCTION

This brochure acts as a guide to ESA's Core Technology Programme and how it supports the Cosmic Vision Plan – ESA's mechanism for the long-term planning of space science missions.

The information featured here describes how the science directorate ensures that the technology needed to make these ground-breaking missions a reality is ready when needed. It also outlines the work the Core Technology Programme has already done toward some of the most ambitious missions in ESA's history.



→ COSMIC VISION: THE NEED FOR LONG-TERM PLANNING

In order to achieve the goals of a broad scientific community, and ensure ESA is at the forefront of space exploration, long-term planning of space science missions is essential.

In previous periods this long-term planning was led by the Horizon 2000 programme, which was conceived in 1984 and oversaw long-term mission planning from 1985 to 2005. The programme allowed for large-scale missions such as SOHO (launched in 1995), XMM-Newton (1999), Cluster (2000), Rosetta (2004), and Herschel (2009), as well as Huygens — the ESA contribution to the Cassini mission to Saturn (1997), INTEGRAL (2002), SMART-1 (2003), the Mars Express (2003) and Venus Express (2005) missions, and Planck (2009). This was followed by the Horizon 2000 Plus Programme, which extended the scope by a decade, oversaw the launch of Gaia in 2013, LISA Pathfinder in 2015, and set the stage for BepiColombo and the European contribution to the NASA-led James Webb Space Telescope.

ESA's Cosmic Vision Plan has now taken over and is responsible for cultivating ESA's long-term vision for space science missions. The plan works towards addressing four very broad and inclusive key questions that have been identified by the scientific community and selected by ESA's Science Programme Committee. The questions are:

1. **What are the conditions for planet formation and the emergence of life?**
2. **How does the Solar System work?**
3. **What are the fundamental physical laws of the Universe?**
4. **How did the Universe originate and what is it made of?**

The Cosmic Vision Plan's core objective is to ensure a quasi-regular sequence of missions that address these questions and reflect the Science Programme needs. This is only achievable if the development of new missions is under control and the Science Programme budget is stable.

New missions are proposed by the science community and follow a thorough competitive process before being proposed for selection by the Science Programme Committee. The current approach to mission selection and implementation can be summarised as follows, with a timeline that depends on the size of the mission in question:

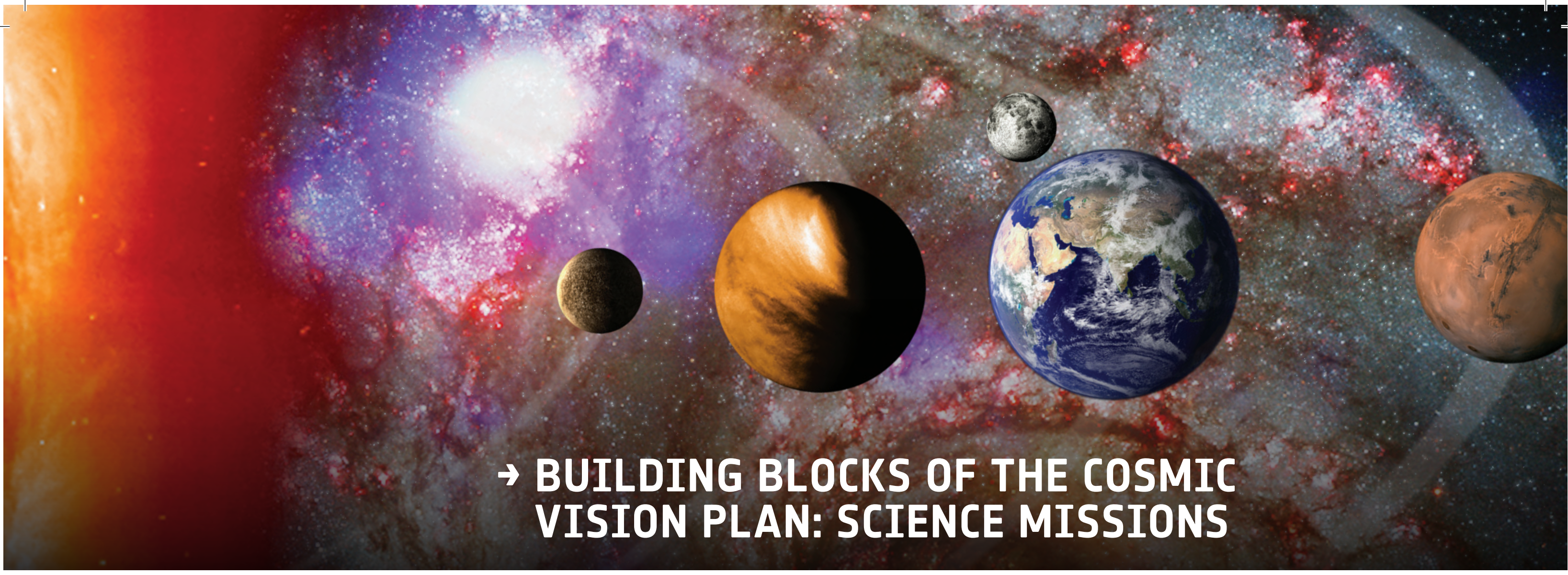
Planetary nebula, NGC 6302. *NASA/ESA/Hubble SM4 ERO Team*

1. A Call for Mission Proposals is issued by ESA with specific boundaries in place, including budget and launch date.
2. Mission proposals are submitted by the scientific community.
3. Proposals are screened for feasibility.
4. Feasible proposals are scientifically assessed through a peer review process, and one or more candidate missions are identified and initial feasibility studies take place.
5. A final down-selection to one mission is performed through a peer review process followed by a decision by the Science Programme Committee.
6. The mission is subject to a detailed study phase to demonstrate its technical and programmatic feasibility, including technology readiness.
7. The mission is adopted by the Science Programme Committee for implementation.
8. The space and ground segments are developed.
9. The spacecraft is launched.
10. The spacecraft is operated in orbit and science data are delivered.

This bottom-up selection process aims at reaching both 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 plan for the Science Programme not only provides mechanisms for selecting and implementing missions, it also ensures the stability needed for these activities. Stability is essential for ESA's science missions, with larger missions taking decades to progress from initial concept to scientific results. This requires years of development time and perseverance from scientists, as well as extended periods of preparation and ingenuity from industry partners. The existence of long-term support from ESA builds confidence in the success of these large-scale projects, which is important to national funding agencies, space industry and international partners. Furthermore, long-term planning and stability allow for mission proposals that require the development and preparation of technology and ground infrastructures that do not exist at the time of conception.

Long-term planning not only makes larger missions more feasible, it also enhances what ESA, and the scientific community, can achieve more generally. Long-term planning enables better coordination with other agencies and national programmes and ensures that expertise is maintained within ESA's member states.



→ BUILDING BLOCKS OF THE COSMIC VISION PLAN: SCIENCE MISSIONS

There is a necessity in space science to remain flexible and respond to the evolving development of science and technology. The bottom-up model of the Science Programme works toward this aim by reflecting the needs of the community and so too do the building blocks of the plan, consisting of missions of varying size and development time.

LARGE-CLASS MISSIONS

The Large-Class (L-Class) missions are ESA flagship missions and are required to yield major scientific results. They are ESA-led but typically with limited international participation.

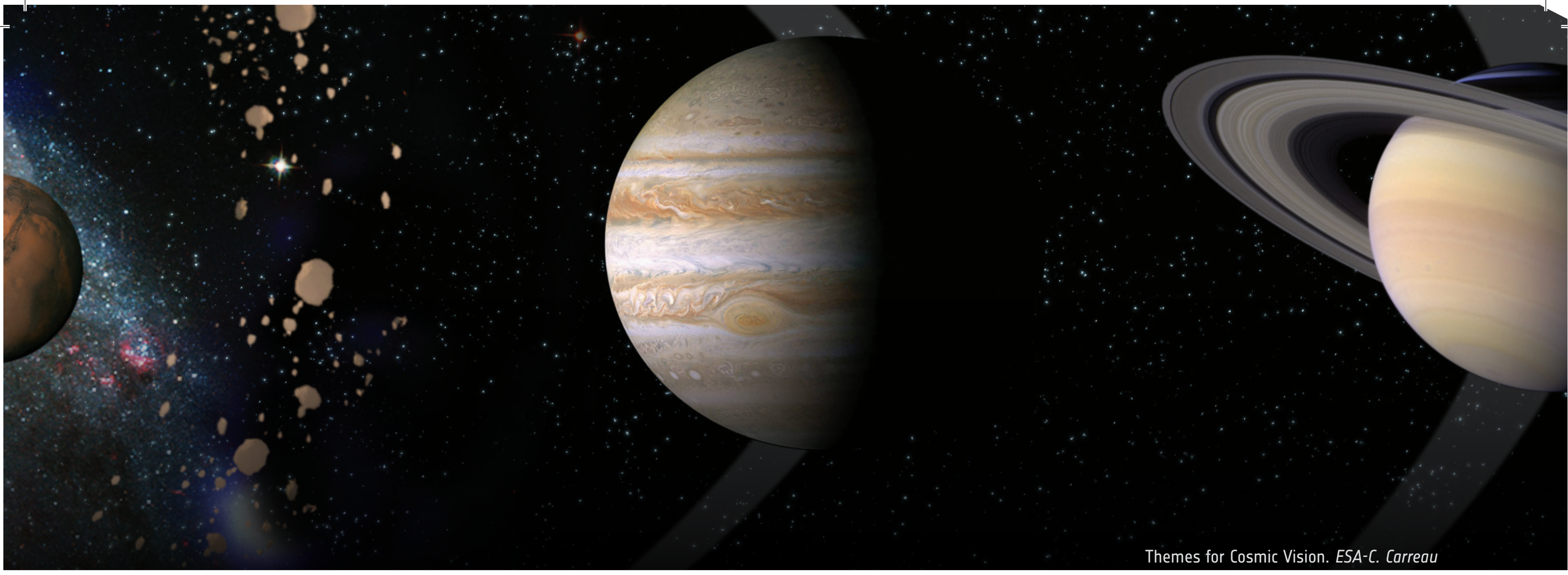
These missions require substantial technological advancements in order to become a reality and both rely upon and instigate innovative technology development across Europe. The missions must be identified well in advance of their launch – typically between fifteen and eighteen years – in order for the concept to mature and, on average, enabling seven or eight years for the technology required to be developed before the mission is adopted.

Three L-Class missions are planned in the Cosmic Vision Plan: The JUpiter ICy moons Explorer (JUICE, L1) which has started its implementation phase and is expected to launch in 2022; the Advanced Telescope for High-ENergy Astrophysics (ATHENA, L2), directly addressing the Hot and Energetic Universe theme and currently in its preparation phase, with expected launch in 2028; and a mission (L3) directly addressing the Gravitational Universe theme which will build upon the LISA Pathfinder in-orbit demonstration, with expected launch in 2034.

Jupiter's moon, Ganymede
NASA/JPL/DLR

Galactic Centre in X-rays
ESA/XMM-Newton/G. Ponti et al. 2015

Merging galaxies, NGC 6050 and IC 1179
NASA, ESA, the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration and K. Noll



Themes for Cosmic Vision. *ESA-C. Carreau*

MEDIUM-CLASS MISSIONS

The Medium-Class (M-Class) missions are ambitious missions addressing key scientific questions. These missions can be ESA-only, ESA-led with international participation, or they may be in the form of participation in missions led by other partners.

M-Class missions have a much shorter preparation time than their L-class counterparts, typically around twelve years, giving them the flexibility to react to changes in the science landscape. Due to this shorter lead time the missions must make use of technologies which are almost available, with two or three years of technological preparation allowed at most.

In the Cosmic Vision Plan, three M-Class missions have already been identified: Solar Orbiter (M1), under development, with launch in 2018; the dark energy mission Euclid (M2), under development, with launch in 2020; and the exoplanet detection mission PLATO (M3), in preparation, with launch in 2024. Three more M-class missions are planned to be launched before 2035.

SMALL-CLASS MISSIONS

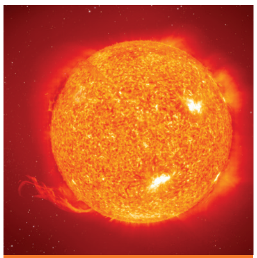
Over ninety percent of the Cosmic Vision budget is assigned to the L- and M-Class missions. The Small-Class (S-Class) missions are therefore, as their name suggests, much smaller in scale. The missions rely on existing technology and are designed with rapid implementation in mind, typically going from mission adoption to launch in less than four years.

S-Class missions are not yet a confirmed Programme element. The first S-Class mission, the CHaracterizing ExOPlanet Satellite (CHEOPS), was adopted in 2014 and is targeted for launch in 2018.

MISSIONS OF OPPORTUNITY

Missions of Opportunity are those led by an international partner or member state, in which ESA participates as a junior partner.

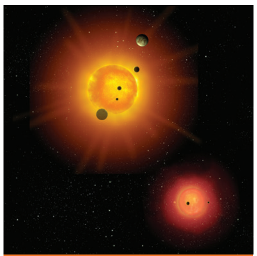
These missions play a valuable role in increasing flight opportunities for European scientists and giving access to world-wide science.



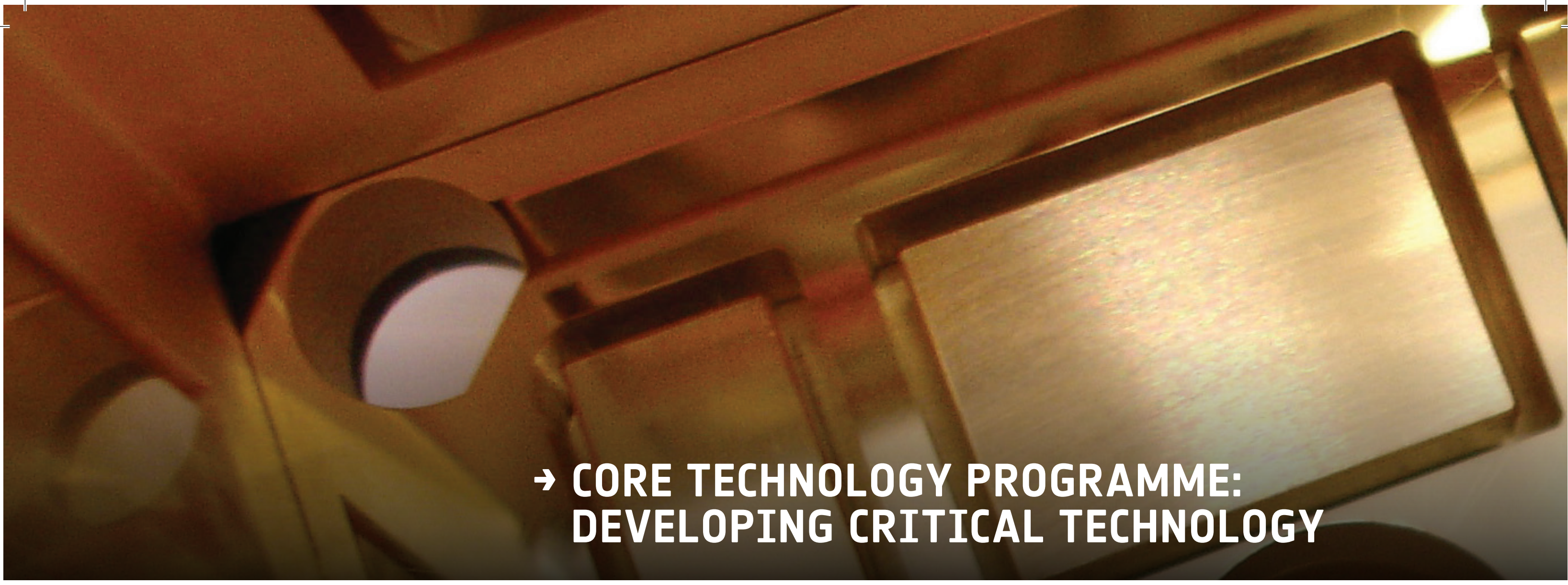
Impression of active Sun
ESA - C. Carreau

Impression of extrasolar planetary systems
ESA - C. Carreau

Galaxy cluster MACS J0717
NASA, ESA, CXC, C. Ma, H. Ebeling, E. Barrett (U. Hawaii/IfA), et al. and STScI



Impression of exoplanets
ESA - C. Carreau



→ CORE TECHNOLOGY PROGRAMME: DEVELOPING CRITICAL TECHNOLOGY

In order for the Cosmic Vision Plan to be successful, missions must be selected for their scientific excellence and must be feasible within the defined timeline and budget. It is important, therefore, that before a mission is adopted it can be shown that the critical technologies needed for it to fulfil its scientific aims can be developed in the timeframe given.

This is where the Core Technology Programme plays a crucial role. This programme is devoted to developing the critical technologies required for successful implementation of future science missions and ensuring the milestones needed prior to mission adoption are reached. It exists to take new technologies, on a case-by-case basis, to higher stages of technological maturity and demonstrate their feasibility by testing models at full scale and in environments relevant to the given mission. By mastering the technologies in this way the Core Technology Programme demonstrates that they are ready for inclusion in the design phase of the spacecraft construction, should that mission be adopted, and that the mission can be shown to be achievable with a well-defined development schedule.

A guiding principle of the Cosmic Vision Plan is that a mission must have reached a Technology Readiness Level (TRL) of 5-6 to be adopted, which means that the critical base technology developments of the spacecraft and science instruments must be completed by this time. The effective time available for these technology developments to take place varies with the mission's type. For L-Class missions dozens of critical technology activities might be needed and these activities may take place over a period of seven or eight years. For M-Class missions this is closer to two or three years.

The Core Technology Programme is key to ensuring this period of technology development is successful, allowing for timely mission implementation. In addition, for L-Class missions, intermediate results obtained through technology developments may also feed into the mission definition studies and support major design trade-offs.


LISA Pathfinder electrode housing box. *CGS SpA*

The Core Technology Programme focuses on both platform and payload technologies, and addresses all elements that are to be developed by ESA. For the science instrumentation elements that are provided by ESA member states, critical technologies are developed by the respective lead funding agencies, in close coordination with ESA. The Core Technology Programme also works in close conjunction with ESA's Technology Research Programme, which focuses on the initial stages of new technology development, bringing them to proof-of-concept stage (TRL 3-4) before transferring them to the Core Technology Programme to increase the TRL level (TRL 5-6), by taking into account mission specific requirements.

Taking technologies from the concept stage and tailoring them to specific mission requirements which are technically, financially and programmatically feasible, is a treacherous stage of ESA's Technology Readiness Levels. The Core Technology Programme has shown great success in overcoming this stage and making ambitious missions possible.

The programme of work for the Core Technology Programme is revised annually – sometimes twice a year – to allow the work plan content to be continuously adapted for future missions. The programme of work includes detailed information on the technology activities, providing full visibility to ESA member states and the space industry on new development opportunities. The programme is fully funded by the ESA Science Programme and is one of its mandatory activities.

European Space Agency
Cosmic Vision
Technology Development Plan
Programme of Work and Related Procurement Plan
sci.esa.int/cosmic-vision-tdp

➔ L-CLASS MISSIONS

L-CLASS MISSION 1 – JUICE

Radiation hardened star tracker
Sodern

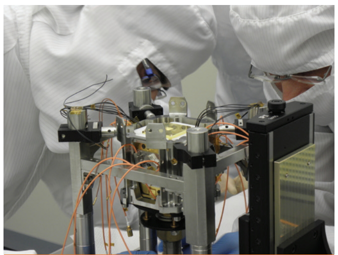
The JUpiter ICy moons Explorer (JUICE) mission will spend at least three years making detailed observations of Jupiter and three of its largest moons: Ganymede, Callisto and Europa. The spacecraft will undertake multiple flybys of these objects before entering into orbit around Ganymede to study the icy surface and internal structure of the moon, including its subsurface ocean. JUICE will be the first spacecraft to orbit a moon of an outer planet.

Before the mission could be adopted there were several technological challenges to overcome. Whilst ESA have operated spacecraft that pass through the radiation belts of Earth, the radiation levels in Jupiter's environment are five times greater. To ensure the mission was viable in these conditions the Core Technology Programme completed a radiation assessment of all components and materials to be used and made improvements to the tools used to model the effect of radiation on these.

The programme also developed a star tracker resistant to malfunctions caused by radiation and a radiation monitor, which will gather information on the charged particle environment of the Jovian system and its effects. In addition, the programme achieved key steps in the qualification of solar cells for this mission, which have to work in Jupiter's harsh radiation environment and in a low intensity, low temperature regime.

These technology advancements increased confidence in the mission and led to its adoption as the first L-Class mission in 2014, with a targeted launch date of 2022.

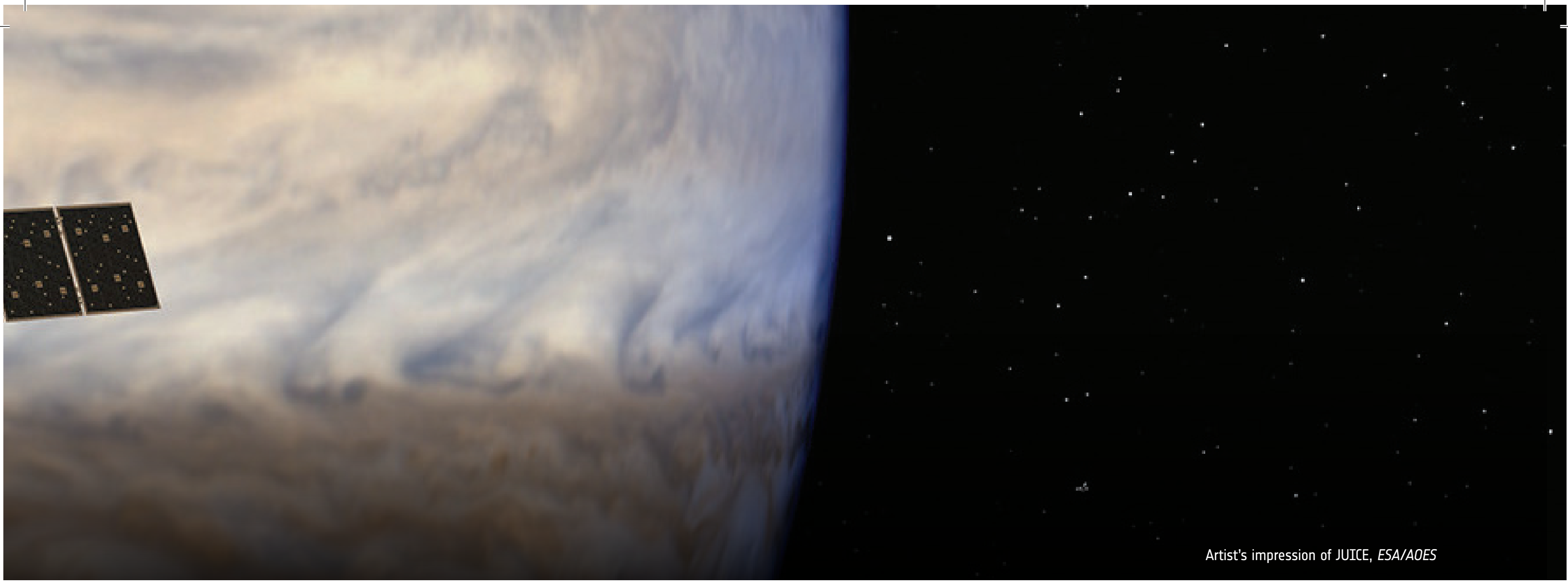
L-CLASS MISSION 3



Inertial Sensor Head on the
LISA Technology Package - *CGS SpA*

The third L-Class mission will be chosen to address the selected L3 theme: The Gravitational Universe. The yet-to-be-selected mission, with a launch date of 2034, will be the first observatory in space to observe gravitational waves emitted by compact sources – giving us an entirely new view of the Universe.

This unique mission will require multiple technology developments, which are being defined by the Core Technology Programme. In addition, some of the key technologies will be tested by the LISA Pathfinder mission, which will launch in 2015.



Artist's impression of JUICE, *ESA/AOES*

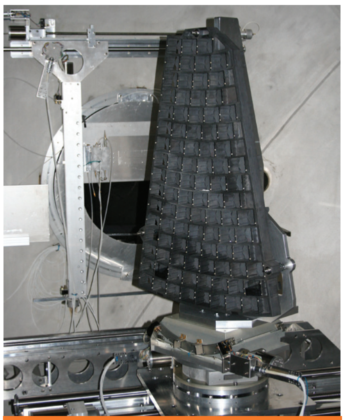
L-CLASS MISSION 2 – ATHENA

The Advanced Telescope for High-ENergy Astrophysics (ATHENA) mission was selected in 2014 to address the Cosmic Vision 'Hot and Energetic Universe' theme. The X-ray observatory has two primary objectives. The first, to map hot gas structures with the aim of discovering how ordinary matter in the Universe assembles into the large-scale structures we see today. The second, to search for supermassive black holes to further knowledge of how they grow and shape the Universe.

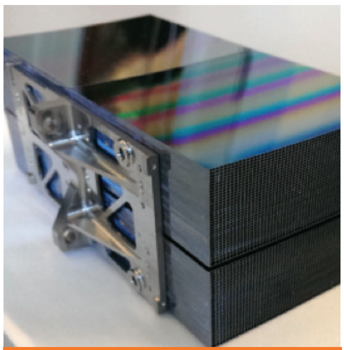
Fulfilling these scientific objectives requires an X-ray telescope with a focal length of twelve metres and an effective area at one keV of two square metres, along with excellent angular resolution (5 arcseconds) and a wide field of view (about 40 arcminutes square). A space observatory with an X-ray telescope of this size has never been launched before, nor is one planned in the short term.

For over a decade, ESA have been researching what is known as Silicon Pore Optics (SPO) technology to make such a telescope possible. Now, the Core Technology Programme is running activities to develop and test this technology in order to meet the mission's needs. If successful, SPO will provide a unique combination of a large collecting area and high angular resolution across a large field of view while also falling within the mass budget needed for the spacecraft. It is projected that critical performance and feasibility of this vital technology will be reached by 2020, with an expected launch date of 2028.

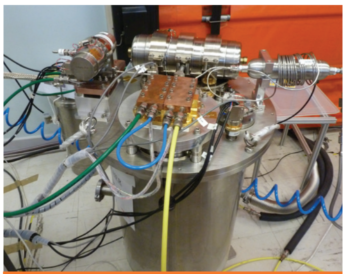
ESA member states will provide the two science instruments located at the telescope's focal plane: the XIFU spectrometer using Transition Edge Sensors, and the Wide Field Imager (WFI). Contributions from NASA and JAXA are envisaged for this mission, in particular for the XIFU detector, the cooling chain and the testing facilities. ESA will provide some of the instrument coolers and, through the Core Technology Programme, is initiating activities dedicated to the cooler developments and to the pre-qualification of the cooling chain.



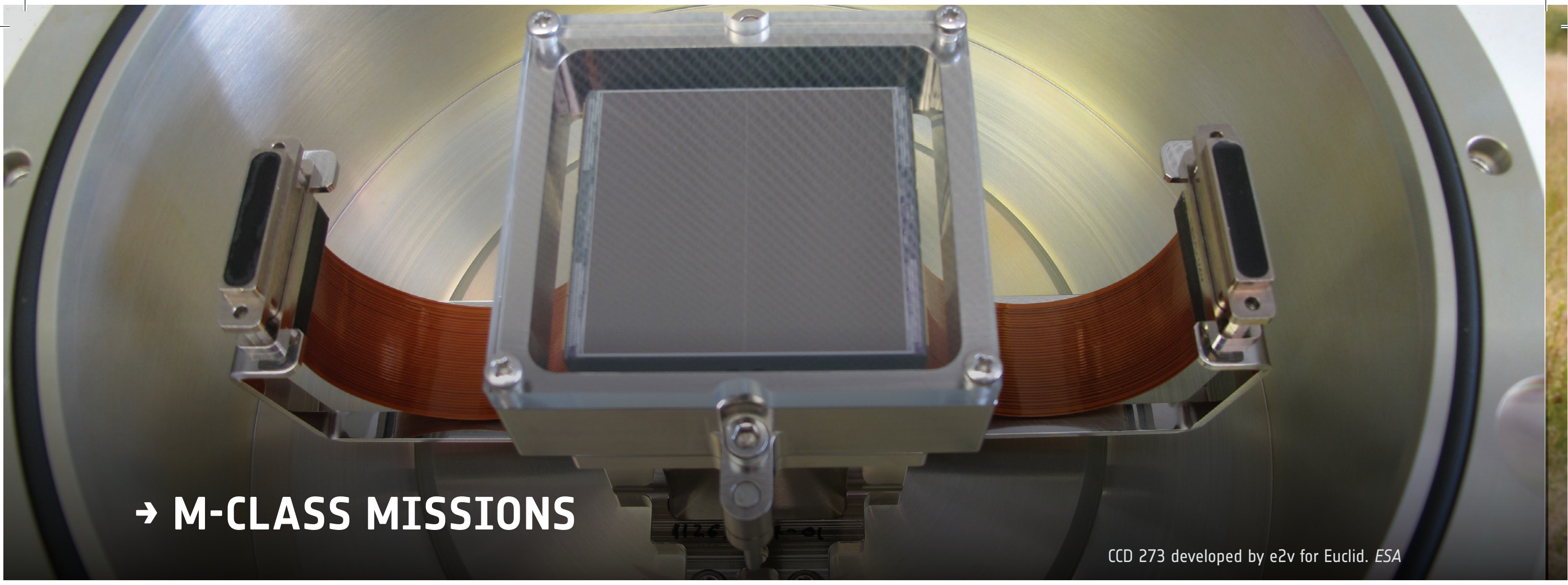
Silicon Pore Optics mirror structure (breadboard)
ESA/Max Planck Institute for Extraterrestrial Physics/Kayser-Threde/cosine Research



Silicon Pore Optics mirror module
ESA/cosine Research



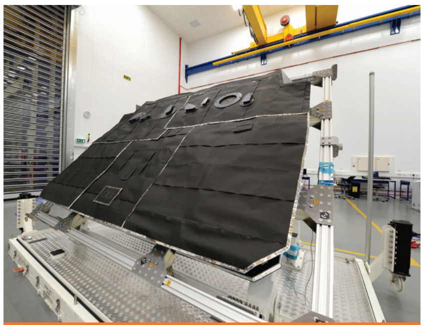
15K pulse tube cooler (breadboard)
Air Liquide Advanced Technologies



→ M-CLASS MISSIONS

CCD 273 developed by e2v for Euclid. *ESA*

M1: SOLAR ORBITER



Structural and thermal model of heat shield for Solar Orbiter
Airbus Defence and Space 2015

The Solar Orbiter mission, projected for launch in 2018, aims to discover more about the changes to the Sun's surface, the solar winds ejected from it, and the relationship between the Sun's activity and the magnetic bubble that encompasses and defines the Solar System – known as the heliosphere.

To achieve the desired observations, parts of the spacecraft's orbit will take it to within 43 million kilometres of the Sun. To protect the observatory's ten state-of-the-art instruments during its close-encounter a heat-shield was created using a specialised thermo-optical coating which was developed partially through funding by the Core Technology Programme.

The Solar Orbiter mission is led by ESA with important contributions by NASA.

M2: EUCLID

Euclid cold gas thruster, engineering model
Selex ES

The primary aim of the Euclid mission, projected for launch in 2020, is to investigate the evolution of cosmic structure. It will do so by measuring the shapes, positions and redshifts of galaxies and galaxy clusters up to redshifts of 2.

One of the primary technology developments needed for Euclid to become viable was an augmented version of the cold gas propulsion system used on the Gaia spacecraft. The Core Technology Programme funded a model of this system demonstrating that the thrust range required for the Euclid mission was possible.

The mission also requires large numbers of high performance and large format CCDs. The programme funded activities to address this need, through a pre-development of Euclid detectors that enabled the mission implementation to proceed in a good state.

M3: PLATO

CCD 270 developed by e2v for PLATO
ESA

The most recently selected M-Class mission is the PLAnetary Transits and Oscillations of stars (PLATO) mission, which is projected for adoption in 2016 and launch in 2024.

PLATO's objective is to detect and study extrasolar planets, focussing on studying the properties of terrestrial planets in the habitable zone around Sun-like stars. PLATO will also investigate the properties of the stars that play host to these planets by measuring their seismic activity.

The Core Technology Programme is funding activities that address the design, manufacturing and validation of the high performance and very large format CCDs, which are needed for this mission.

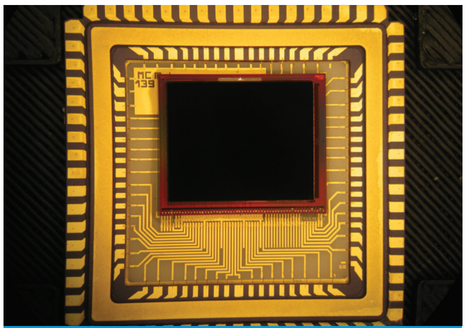
→ GENERIC TECHNOLOGY DEVELOPMENT

Planetary penetrator. *QinetiQ*

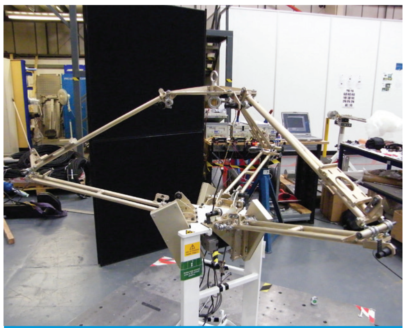
Whilst most of the Core Technology Programme budget is used for mission-specific technology developments there are also resources invested for generic technology development. Up to twenty percent of the Core Technology Programme budget can be allocated to these generic developments, which are decided by ESA in consultation with its science advisory groups. These developments are generally building blocks that are applicable to a large variety of missions, but can also be intended to enable a high priority science mission theme, for which severe technology gaps are preventing the mission's selection.

For example, in 2014 the technologies identified as critical to enabling long-term planning included, though not exclusively:

- Development of a space qualified end-to-end cooling chain in Europe, down to 50 milliKelvin;
- Development of cryogenic micro-bolometer detectors known as Transition Edge Sensors for use in astronomical observation instruments;
- Development of large deployable masts that can be used to increase the focal length of a telescope in orbit;
- Evolution of novel optics technologies for collimators, coatings, and filters applicable to sub-millimetre/far-infrared observatories;
- Investigation of the limitations of existing HgCdTe infrared detectors and readout technology;
- Design of guidance, navigation and control technology for low gravity landing and sampling.



Near-infrared detector (breadboard)
ESA/CEA-LETI (Fr)



Deployable mast (breadboard)
Airbus Defence and Space Limited

→ PROGRAMME BENEFITS AND PARTICIPATION

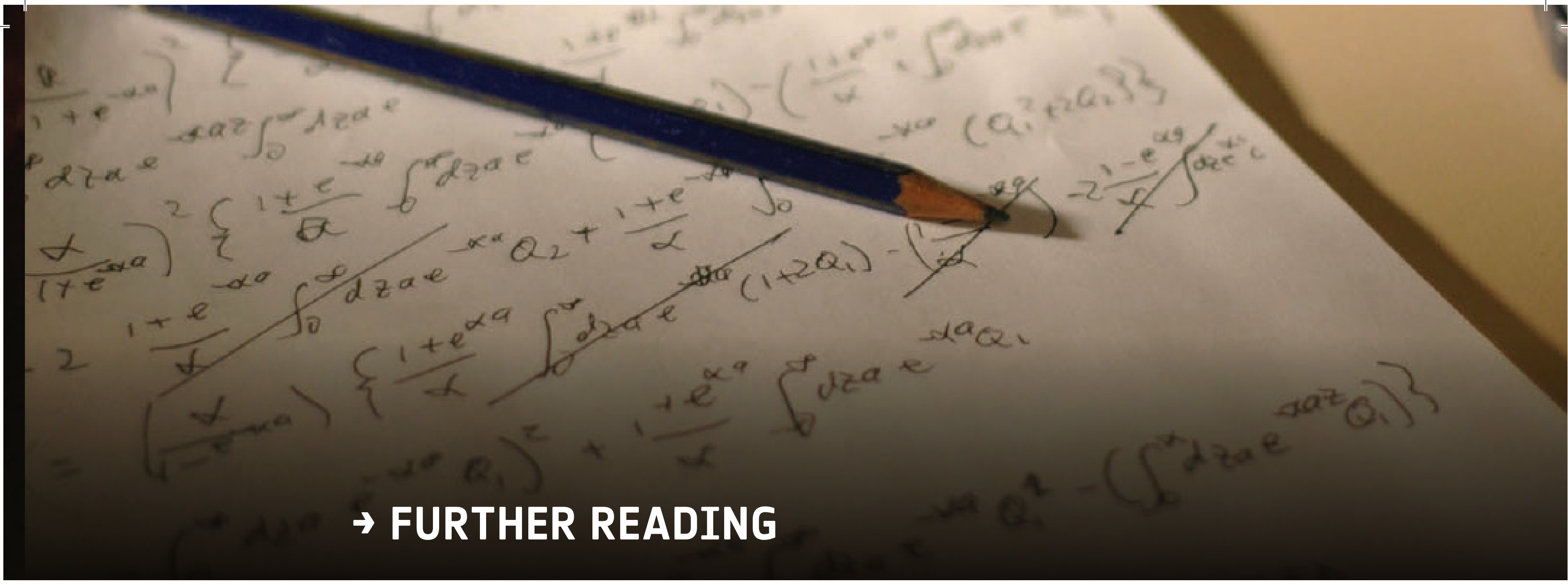
Evaporation of Helium. *ESA*

Approaching technology development using the case-by-case method of the Core Technology Programme has a range of benefits, the primary one being reducing the risk of key technologies being unavailable during a mission's actual project development phase. The programme has also prevented technology setbacks, which can cause substantial delays and cost increases when encountered in the project development phase.

The activities of the Core Technology Programme are mainly contracted out to industry, which has the benefit of strengthening industrial competitiveness and positioning industry for preparing the implementation stage should the mission be carried forward.

The search for science excellence often involves using cutting-edge innovative technologies, particularly in the case of the flagship Large-Class missions where very demanding requirements must be achieved with limited resources. Therefore, the Core Technology Programme is naturally and continuously promoting technical excellence, innovation and new capabilities in the European space industry and contributes to enhancing and balancing industrial capabilities with a goal of achieving a fair distribution of industrial contracts in the Science Programme. The technology matured by the Science Programme for one mission also often has the benefit of being of use to many other missions beyond the Science Programme.

Core Technology Programme Invitations To Tender are issued continuously throughout the year on ESA's EMITS website, available to all European firms on a 100 percent funding basis. For some activities, small to medium-sized enterprises (SMEs) or large companies outside the Primes can be favoured, while the general implementation guideline is to maximise industrial competition.



→ FURTHER READING

Cosmic Vision:
sci.esa.int/cosmic-vision

Future Missions Office:
sci.esa.int/future-missions-office

Technology Preparation Section:
sci.esa.int/technology-preparation

Cosmic Vision technology development plan:
sci.esa.int/cosmic-vision-tdp

EMITS (Electronic Mail invitation to Tender System):
emits.esa.int

Cosmic Vision – Space Science for Europe (brochure):
sci.esa.int/cosmic-vision-brochure

This brochure online:
sci.esa.int/core-technology-programme-brochure

CONTACT

ESA HQ
France
+33 1 53 69 76 54

ESTEC
The Netherlands
+31 71 565 6565

ESOC
Germany
+49 6151 900

ESRIN
Italy
+39 06 941 801

ESAC
Spain
+34 91 813 1100

EAC
Germany
+49 2203 6001 111

ECSAT
United Kingdom
+44 1235 567900

ESA REDU
Belgium
+32 61 229512