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CENTRE NATIONAL D'ÉTUDES SPATIALES

French Report to COSPAR 2026

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CONTENTS

Editorial

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Space continues to have a profound impact on France's scientific community, technological leadership and economy. Through CNES, France actively contributes to observing and understanding our planet, exploring the solar system, probing the Sun and heliosphere, advancing fundamental physics and pushing the boundaries of astrophysics. Space data are essential not only for knowledge, scientific discoveries and for public services—such as weather forecasting, emergency response and civil protection—but also for economic sectors including agriculture, transport, fisheries and aviation, as well as in citizens' daily lives through applications like geolocation, pollution alerts and disaster management.

This report highlights CNES's contributions to space science over the past two years, reflecting a longstanding partnership with the French scientific community. For more than half a century, CNES has supported research through funding, instrument development, mission coordination and data exploitation. Today, the agency faces new challenges: instruments are more sophisticated than ever, generating unprecedented volumes of complex data, while the national research landscape has evolved with greater autonomy for universities, new laboratories and a growing emphasis on interdisciplinarity. In this context, CNES's role continues to expand, not only in enabling innovative space instrumentation but also in ensuring that data are processed, archived and accessible for scientific research, operational applications and societal benefit.

In line with the scientific structure of COSPAR, this report presents CNES's recent achievements in Earth observation, planetary science, heliophysics and space plasmas, astrophysics, life sciences, material research and fundamental physics. The period under review has been particularly rich and dynamic, showcasing both national excellence and strong international collaboration.

Over the past two years, French space science has produced remarkable results across all major domains. In **Earth observation and climate studies**, the SWOT mission, co-led by CNES and NASA, has delivered the first global, high-resolution map of land surface waters, offering new insights into river dynamics, ocean-land interactions and coastal ecosystems. In the coming years, the TRISHNA mission, developed in partnership with India, is expected to begin delivering frequent multispectral observations of land and ocean surfaces following its calibration and commissioning phase. These missions highlight CNES's pivotal role in contributing to innovative scientific missions that support scientific understanding and practical applications alike.

In **planetary science**, French teams have made significant contributions to Mars exploration through the DORN, SuperCam, and ChemCam instruments, which continue to provide detailed analyses of Martian rocks and surface chemistry. Preparations for the EnVision mission to Venus are progressing, promising new observations of the planet's atmosphere and interior dynamics, while France is playing a central role in the ESA-led JUICE mission to study Jupiter and its icy moons and gain new insights into giant planet systems and potential habitability.

In **solar and heliospheric science**, the Parker Solar Probe and Solar Orbiter missions, with significant French involvement, are providing unprecedented data on the solar corona, solar wind, and magnetic field fluctuations. These measurements are transforming our understanding of solar activity, space weather and their impact on Earth's environment.

France has also played a central role in **astrophysics,** contributing to Gaia's ongoing survey of the Milky Way, Euclid's exploration of dark matter and dark energy, and SVOM's monitoring of high-energy cosmic transients. XMM-Newton remains a cornerstone of X-ray astronomy, while the James Webb Space Telescope (JWST) continues to revolutionize observational cosmology and exoplanet characterization, with strong French participation. Together, these missions highlight France's contributions to mapping, understanding and interpreting the universe at local and cosmological scales.

Life and material sciences in microgravity have advanced significantly. Parabolic flight campaigns have tested novel medical procedures to improve astronaut care, while experiments aboard the ISS are investigating fluid dynamics, combustion and material properties in reduced gravity using instruments such as FLUIDICS and DECLIC. These studies are critical not only for future human space exploration, but also for terrestrial applications in materials science and fluid mechanics.

In **fundamental physics**, work in 2024 on future quantum tests of the weak equivalence principle (WEP) demonstrated that the completed Microscope mission is a benchmark for more ambitious experiments aiming to test the WEP to 10^{-17}, highlighting its lasting impact on the planning of next-generation fundamental physics missions. Since being integrated with the ACES payload aboard the International Space Station in 2025, PHARAO has delivered its first in-orbit measurements, including the initial Ramsey fringes, thus demonstrating the successful operation of CNES's ultra-precise cold-atom caesium clock. Work towards LISA, the space-based gravitational-wave observatory, continues, promising transformative insights into gravitational physics.

The development of space science research in France relies on CNES's strategic support and its partnership with public research organizations. Guided by its Scientific Programmes Committee (CPS), CNES prioritizes projects, coordinates missions and ensures the quality and long-term accessibility of space data. Every five years, CNES convenes its Science Survey Seminar (SPS), a flagship event that brings together the French space science community to take stock of recent achievements and define strategic directions for the next five years. The 2024 edition, held in Saint-Malo, mobilized all major thematic committees to review progress and set priorities for future missions, innovations and collaborations. Preparations for this seminar were undertaken by the scientists themselves, working within committees and thematic working groups: TOSCA (Land, Ocean, Surfaces Continental, Atmosphere) for Earth observation and CERES (Space Science Research and Exploration Committee) for the study and exploration of the universe, as well as two thematic working groups devoted to life and material sciences. Other working groups have also been set up to tackle cross-functional issues and more general questions, such as links with our international partners or environmental issues. Through interdisciplinary discussion, international coordination and long-term vision, SPS ensures that CNES's scientific programmes remain ambitious, timely and aligned with both national and global research needs — from climate and Earth monitoring to fundamental physics and deep-space exploration. In 2025, CNES organized the third 'Science Day' in Paris, as one of its annual events—excepting the year of the agency's SPS—offering opportunities to discuss the remarkable results obtained in space science. We also note that CNES supports Sophie Adenot's mission aboard the International Space Station through biomedical experiments and physiological monitoring designed to advance our understanding of human adaptation to space and to prepare future long-duration missions.

Since mid-2024, CNES issues a quarterly Scientific Newsletter, a succinct but rich publication showcasing the latest discoveries from French space missions and research activities supported by the agency. Each edition highlights major scientific advances, from Earth observation and climate monitoring to planetary science, astrophysics, space plasmas, life sciences and fundamental physics. The Newsletter serves not only as a report card on the results of recent missions, but also as a bridge between CNES, the national and international scientific community and broader audiences, including researchers, decision-makers and the lay public. With its regular publication and broad scope, it underlines CNES's commitment to transparency, data-sharing and scientific excellence.

We extend our gratitude to all committee members, laboratory teams and contributors whose dedication ensures that France remains at the forefront of space science, both nationally and in collaboration with European and international partners. We would like to take the opportunity to thank the project and programme managers and the experts from CNES involved in producing this report. We also thank Michèle Dupire, Kenza Regy and Boyd Vincent for assistance with editing.

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1. Space studies of Earth’s surface, meteorology and climate

Selma Cherchali

Head of Earth Observation Department

“ Addressing climate change and environmental challenges facing humankind remains the core objective of CNES’s Earth Observation Programme. Grounded in science data, key operational services have been developed in hydrology, ocean and coastal areas. Over the past two years, along with its partners, CNES has delivered flagship scientific, innovative and breakthrough missions with significant progress: the Surface Water and Ocean Topography (SWOT) mission celebrated its third year in orbit and groundbreaking results have been published on fine ocean scales, as well as global river discharge, opening also promising perspectives in coastal and cryosphere domains. The recently launched MicroCarb satellite is now on track for monitoring global carbon dioxide fluxes. In addition, IASI-NG is continuing the 15-year legacy of infrared sounders and is setting new standards of accuracy for atmospheric composition and short-term weather prediction.
Our future missions like Trishna, in partnership with ISRO, will further develop cutting-edge technologies, providing high-quality data for science and supporting the sustainable preservation of our planet. ”

Interview

Looking back over your career, what has most marked you in your field of research?

One of the projects in the field of Earth science I’m very proud to have contributed to is the SWOT mission. SWOT has been a breakthrough mission in many fields of science, technology and applications. This mission was a top priority of the scientific community in 2009 and we have worked very closely with our NASA colleagues to make it a reality. The results are amazing and proving very valuable in numerous fields of research and applications such as oceanography, hydrology and coastal cryosphere studies. Another very emotional moment was the selection of the Biomass mission in 2013 after having supported the French science community with an airborne campaign that validated the physics of P-band radar measurement! Both SWOT and Biomass are delivering exceptional data to the entire community.

In your opinion, what are the best and worst aspects of your scientific field of research?

The best aspect is clearly when you manage to fulfil the needs of the research community with projects that are successful in terms of cooperation, technologies and scientific data quality, but that can also open new research areas not initially anticipated. The worst aspect is when you hear that some facts are denied despite the scientific results/evidence achieved by the community through rigorous and hard work, in the field of climate change studies for instance.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

Last year, CNES organized its Science Survey Seminar (SPS) in Saint-Malo, and my hope is that CNES will be able, together with its partners, to further as many scientific priorities as possible in the coming years, since they clearly address fundamental integrated questions about planet Earth as a system and its evolution.

TRISHNA

Trishna is a French-Indian mission to acquire imagery of Earth's surface in the visible and thermal infrared with a resolution and revisit frequency never seen before. The satellite is scheduled to launch in 2026.

KEY MILESTONES

2027
Start of operational phase

2026
Scheduled launch of Trishna

2026
Delivery of instrument to India

March 2025
TIR instrument Detailed Design Review

Autumn 2024
System Interface Performance and Validation Review Part #2

November 2023
System Interface Performance and Validation Review Part #1

February 2023
Preliminary definition key point meeting for French mission ground segment

May 2022
System Preliminary Definition Review

June 2021
TIR instrument Preliminary Definition Review

4 June 2020
Start of TIR instrument development by Airbus

October 2019
Mission Requirements Preliminary Definition Review in India

FIGURE 1
Artist's view of Trishna
© CNES/ill./REGY Michel, 2021

KEY INFORMATION

MISSION
Measure surface temperature of land surfaces and coastal strips at high resolution and frequent revisit intervals

DOMAIN
Earth observation

LAUNCH DATE
2026

LIFETIME
5 years

PARTNERS
ISRO

WHERE
761-km Sun-synchronous orbit, local crossing time (descending node) 12:30 p.m.

STATUS
In development

KEY FIGURES

34°	3	57	2
satellite field of view (+/-)	days between observations of same point at the equator	to - 90 m camera resolution; 60-m product resolution	instruments

PROJECT IN BRIEF

Developed by CNES and ISRO, the Trishna mission will observe Earth's surface in thermal infrared, providing high-resolution temperature data to monitor water stress, evapotranspiration, and other water cycle phenomena. Current satellite measurements offer only monthly field-level resolution or 1-km resolution at more frequent intervals. Trishna aims to achieve better than 60-metre resolution with revisits several times a week, enabling detailed analysis of biological, physical, and climate processes.

This enhanced resolution will support sustainable farming, water resource management and land planning by delivering precise global surface temperature measurements. Trishna's thermal infrared instrument, developed by CNES, will be paired with an ISRO-provided optical sensor, allowing simultaneous visible and thermal observations. This dual capability will improve data analysis across multiple fields, making Trishna a vital tool for informed policy decisions and sustainable water use.

CNES's ROLE

Trishna is being developed jointly by CNES and ISRO.

TRISHNA

Philippe Maisongrande
Land Programme Manager

TRISHNA (Thermal InfraRed Imaging Satellite for High-Resolution Natural Resource Assessment) is a French-Indian Earth-observation mission jointly developed by CNES and ISRO.

Planned for launch in 2027, it will operate in a polar orbit for five years, with possible two-year extensions. TRISHNA is designed to deliver thermal-infrared images with high spatial resolution (60 metres) and frequent revisit time (every three days), overcoming the trade-offs of current missions such as Landsat, ASTER, MODIS and Sentinel-3. The mission will enable the first high-resolution global maps of land and sea surface temperature (LST, SST) and land surface emissivity (LSE) across diverse surfaces, including ecosystems, urban and coastal areas, water bodies, soils, snow and ice. Advanced pre-processing, including calibration and atmospheric corrections, will ensure an LST accuracy of about 1 K. TRISHNA's primary objectives are focused on monitoring water stress and energy exchanges, supporting applications in water resources, urban climate, cryosphere studies and biogeochemical cycles. In addition, numerous coastal and inland applications are also foreseen (water quality, water discharges, etc.).

Here is a subset of ongoing research efforts, which include numerous additional studies and developments currently underway:

- The development of DirecTES by CNES, a deterministic approach for retrieving surface temperature and emissivity from thermal infrared observations, based on a spectral emissivity library.
- Investigation into the directional anisotropy of thermal infrared signals, aimed at supporting the design of in-flight directional calibration strategies.
- The establishment of a collaborative processing infrastructure to generate high-resolution sea surface temperature (SST) products from Landsat-9 and ECOSTRESS observations.

An international workshop held in Toulouse in November 2025 focused on product definition and calibration/validation activities, as well as the full range of science themes and associated applications. This workshop marked a key milestone toward convergence on the mission science plans, including calibration and validation strategies, data-processing algorithms and product specifications, while strengthening coordination among all partners.

In particular, the findings of this workshop about ecosystem stress activities highlighted the need for harmonized algorithms, for shared CAL/VAL resources, and coordinated user engagement to ensure consistent evapotranspiration, water stress and ecosystem productivity products across upcoming thermal missions (TRISHNA, LSTM, SBG). They emphasize advancing science beyond evapotranspiration toward water stress characterization, evapotranspiration partitioning and integrated thermal-fluorescence approaches, supported by multi-mission data assimilation. Demonstration studies at farm to sub-basin scales and stronger involvement of international and national stakeholders are essential to enable operational applications and quantify irrigation and economic benefits.

FIGURE 2
© CNES/Emmanuel Grimault, 2025

CFOSAT

In 2018, CFOSat (China-France Oceanography SATellite) was placed into Earth orbit to study ocean surface winds and waves. These data are enabling more reliable sea-state forecasts and yielding new insights into ocean-atmosphere interactions.

KEY MILESTONES

29 October 2018
CFOSat launched by Long March 2C

30 March to 12 April 2016
Testing of flight models and ground segment

9 December 2010
Start of C/D development phase

22 July 2008
Start of B development phase

19 to 23 March 2007
Project inception in Beijing, China

KEY INFORMATION

MISSION Study of physical characteristics of wind and waves	**PARTNERS** CNSA, CNRS, IFREMER, SHOM, Meteo-France	**LAUNCH DATE** 29 October 2018
		LIFETIME 3 years
DOMAIN Earth observation	**WHERE** Sun-synchronous orbit at an altitude of 520 km	**STATUS** In operation

KEY FIGURES

2 instruments	**13.2** to -13.6-GHz radar frequency range	**650** kg satellite mass	**10** to 20% measurement precision for wavelengths between 70 and 500 m

PROJECT IN BRIEF

The CFOSat satellite's mission is to study the characteristics of ocean surface winds and waves.
Developed jointly by CNES and the China National Space Administration (CNSA), CFOSat is carrying two radar instruments: SWIM (Surface Waves Investigation and Monitoring), developed by CNES; and SCAT (wind SCATterometer), supplied by CNSA. SWIM's six rotating beams enable it to measure wave properties (direction, wavelength, etc.), while SCAT measures wind intensity and direction. The data are downlinked to French and Chinese receiving stations.
These data are telling climatologists more about ocean-atmosphere exchanges, which play a key role in climate. CFOSat is also aiding more accurate marine forecasting and earlier warning of severe weather events like storms and cyclones.
Conceived by the LATMOS atmospheres, environments and space observations laboratory in Paris and Guyancourt, the SWIM instrument was developed by Thales Alenia Space with oversight and funding from CNES.
Other mission partners include the French institute of marine research and exploration IFREMER, the French national weather service Meteo-France, and SHOM, the French naval hydrographic and oceanographic office.

CNES's ROLE

CFOSat was developed jointly by CNES and CNSA.

FIGURE 1
Artist's view of the CFOSat satellite

CFOSAT

Yannice Faugère
Ocean Programme Manager

CFOSat (China France Oceanography Satellite) is an innovative mission of the Chinese and French space agencies (CNSA, CNES),

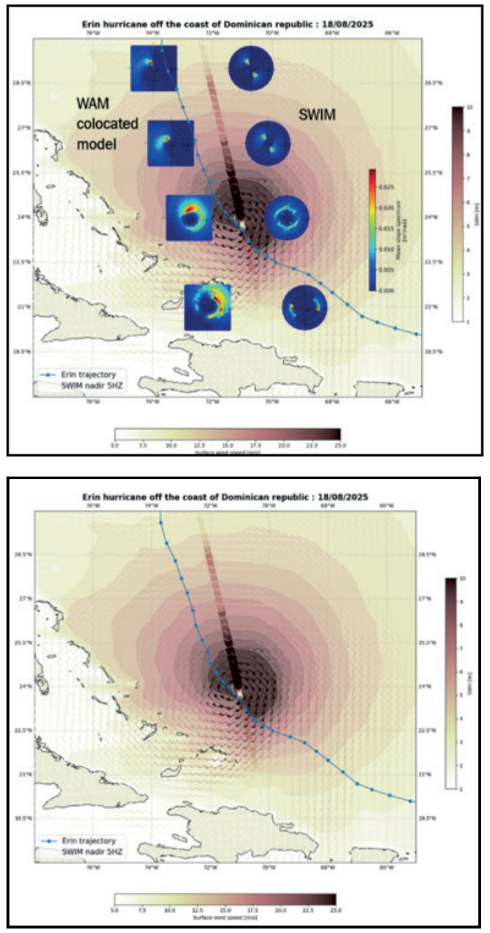
launched on 29 October 2018, carrying two K_u-band active instruments, SWIM measuring ocean surface wave direction, and SCAT measuring wind vectors. In 2025 CFOSat completed its seventh year in operation. During this period, it has contributed to global surface wind field observations alongside existing scatterometer missions (e.g. ASCAT on Metop, SCAT on HY-2A, HY-2B and HY2C), and significant wave height (SWH) measurements alongside other altimeter missions (like the Jason-3, Altika, Sentinel 3A, 3B, 6-MF, HY-2 series,). But with respect to existing satellite missions, the uniqueness of CFOSat is that it provides continuous, co-located surface wind vector fields and directional spectra of ocean waves for wavelengths in the range of about 30-500 metres. The SWIM instrument provides wave properties not only for long swells, but also for wind waves and mixed sea conditions, making CFOSat very complementary to SAR missions (like Sentinel-1).

The CFOSat Science Team, renewed in 2023, worked hard to exploit these unique capabilities, producing numerous scientific results and publications. Particular advances have been made on various topics related to the understanding of the wave field, wind-wave analysis, wave/ocean coupling, Stokes drift, sea-ice, etc. The latest CFOSat science meeting was held in Biarritz from 18 to 20 March 2025.

High-quality upgraded Level 2 SWIM products have been generated (processing IPF-V7.2), enabling an extension of wave spectra retrieval to wave lengths exceeding 500 metres. New user-oriented parameters have been implemented in the products, like "dangerous seas parameters" or wave uncertainties. Many scientific papers have been published, such as the Impact of SWIM wave spectra on the marine atmospheric boundary layer (Giordani et al. 2025 under review).

Besides the high-level scientific results obtained in recent years, a great achievement of the mission is the positive impact of the assimilation of its wave measurements, SWH and wave spectra, in numerical wave models. While CFOSat SWH measurements are assimilated operationally since 2021, directional wave spectra are used in the NRT wave models of Météo-France and Copernicus Marine Service global and regional (Iberian-Biscay-Ireland) since February 2021, with big benefits for wave forecasts. The use of these additional directional observations induces a better scaling of wave energy and dominant wave periods, particularly on storm tracks in the North-East Atlantic, notably improving initial wind-wave conditions during the growth phase of storm events. Assimilation of CFOSat also impacts wave forecasts near cyclones. Fig 1 shows SWIM observations of Hurricane Erin in August 2025. This kind of improvement is of the utmost importance for applications such as marine safety and wave submersion prediction along coasts. Seven years after its launch, CFOSat measurements have thus brought direct benefits for citizens, in a context of increasingly extreme weather events. SWIM wave products have also used seven years of SWIM L2 wave spectra and SWH in the Copernicus Marine service global wave reanalysis (WAVERYS version 2).

FIGURE 2
Illustration of a severe storm captured by CFOSat. Hurricane Erin was a long-lived and powerful Cape Verde hurricane that crossed the North Atlantic Ocean in August 2025. It was the fifth named storm, first hurricane and first major hurricane of the 2025 Atlantic hurricane season. In the left panel, SWIM nadir SWH 5HZ reveals the hurricane eye and suggests a storm centre slightly north of the estimated track (offset between track and SWH minimum). In the right panel, 2D ocean wave spectra highlight different sea states along the hurricane track with complex seas after the cyclone's passage to the South and strong swell generated by the hurricane and propagating following its trajectory to the North (Credit CLS)



SWOT

The SWOT satellite (Surface Water and Ocean Topography) was sent into orbit on 16 December 2022 by a Falcon 9 launcher operated by SpaceX from U.S. Vandenberg Space Force Base in California.

KEY MILESTONES

October 2024
Public release of version 2 of SWOT products and start of second complete reprocessing campaign of SWOT products since launch.

June 2024
Official validation of SWOT products by the SWOT Science Team.

July 2023
Satellite transferred to its "science" orbit at an altitude of 890 km, with a 21-day orbital cycle. Start of operational science phase on 26 July 2023. First products available to public.

16 December 2022
Launch of SWOT by Falcon 9

2021/2022
Satellite assembly and integration, operational qualification of system

Autumn 2019
Delivery of French RFU, Poseidon-3 and DORIS instruments to JPL. Delivery of SWOT Control Centre to CNES.

Mid-2016
Start of phase C/D of development, start of satellite construction

November 2013
Start of phase B of development

September 2009
Start of phase A of development

19 September 2008
SWOT programme kicks off

DID YOU KNOW?

SWOT is set to measure the height of two million lakes around the globe.

KEY INFORMATION

MISSION
Measure heights of Earth's rivers, lakes, flood zones, deep oceans and coastal waters

DOMAIN
Earth observation

LAUNCH DATE
16 December 2022

LIFETIME
3 years

PARTNERS
NASA, CSA, UKSA

WHERE
Circular orbit inclined 78° at an altitude of 891 kilometres

STATUS
In operation

KEY FIGURES

250	15	2,000	6
x 250 m2 : surface area of each body of water mapped	km spatial resolution	kg satellite mass	instruments

PROJECT IN BRIEF

At 891 km altitude, SWOT is revolutionizing hydrology with its KaRIn altimeter, a wide-swath K_a-band radar interferometer. This French-U.S. mission breaks from current technologies. Two radar antennas on a 10-metre boom provide continuous 120-km swath coverage, compared to a few kilometres for traditional altimeters. KaRIn measures surface water height in rivers wider than 100 metres, lakes and flood zones exceeding 250×250 metres, with accuracy better than 10 metres. Slopes are quantified with precision better than 1.7 cm/km. Combined with GOCE geoid models and digital terrain models, SWOT data improve hydrodynamic models for river discharge estimates and track temporal variations in lakes, reservoirs and wetlands. Over 30 million lakes larger than one hectare exist worldwide. Oceanographers also benefit: KaRIn detects mesoscale and sub-mesoscale circulation patterns like eddies and filaments, studying coastal circulation and refining ocean and climate prediction models with centimetre accuracy. The mission's innovations build on over 20 years of NASA-CNES collaboration in satellite altimetry. SWOT extends the satellite revolution from oceanography to hydrology, offering unprecedented observation capabilities for global water resources monitoring. This breakthrough enables comprehensive water management, flood forecasting, and climate modelling at unprecedented spatial resolution.

CNES's ROLE

SWOT is a joint mission of CNES and NASA. The two agencies are working together in numerous technical and operational areas.

SWOT

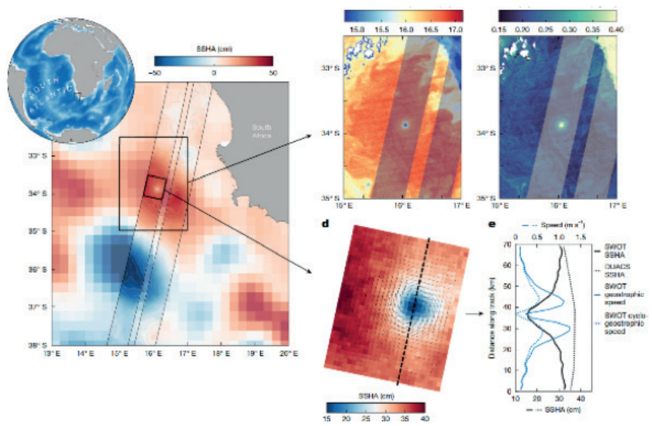
Yannice Faugère & Delphine Leroux
Ocean & Hydrology Programme Managers

SWOT is a pathfinder mission, carrying the novel K_a-Band Radar Interferometer instrument (KaRIN), deploying for the first time a wide-swath altimeter. The mission was designed to provide a global two-dimensional map of the world's inland, coastal and ocean waters. The SWOT satellite, now in orbit for almost three years, began delivering valuable data as soon as the KaRIN instrument was activated. After spending three months on a calibration/validation (Cal/Val) orbit (data available from 30 March to 11 July 2023), it transitioned to its nominal "science" orbit on 26 July 2023. Today, the satellite is performing superbly.

SWOT measurements were validated at a meeting in June 2024 in Chapel Hill, North Carolina, USA, demonstrating that it has met, and indeed sometimes exceeded, the pre-launch science requirements at the calibration and validation sites. The complete reprocessing of the mission data in 2025 has resulted in improved quality across all ocean, continental, coastal and cryosphere surfaces. SWOT's innovations have led to significant scientific advances, with more than 200 publications since launch. The user community is growing rapidly, with more than 400 people attending the last science team meeting organized by CNES in Arcachon in October 2025.

In oceanography, many discoveries have been made, like the detection of sub-mesoscale eddies, long swells after storms, internal waves and tsunamis, the concomitant information on ocean currents and waves for studying air-sea interaction, all-weather characterization of sea ice at resolutions of 2 kilometres and better. CNES's SWOT L3 ocean products have established themselves as the leading product for oceanography users, with more than 300 user teams worldwide. They have been improved in terms of quality and availability, with a turnaround time of less than two days, enabling operational centres (such as Mercator Ocean International) to use them for ocean forecasts in 2026. Among the science papers published in the field of oceanography, a Nature paper (Archer et al. 2025) revealed that SWOT can detect sub-mesoscale eddies (vortices spanning a few tens of kilometres) and internal waves in sea surface height maps. Its precise measurement of surface currents can be used in some cases to estimate the vertical velocities associated with these small circulation structures, potentially opening new ways to estimate exchanges of properties and matter between the ocean surface and interior.

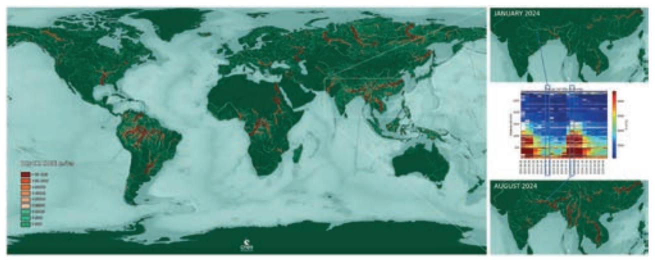
FIGURES
1 - Artist's view of SWOT © CNES/ill./DUCROS David, 2022
2 - Example of a sub-mesoscale eddy detected by SWOT and not visible in nadir altimetry maps. From Archer et al. 2025.



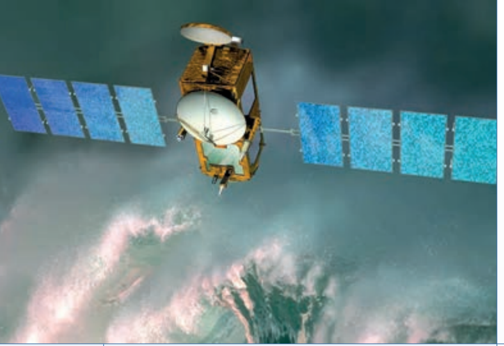
In hydrology, the main breakthrough has been the public release of the discharge product. This has been a great effort by the French and US teams to deliver six different discharge algorithms and one consensus product (Level 4).

The contribution of the French scientific community, led and supported by CNES, has been decisive in the development of these hydrological products. French scientists were responsible for designing two of the six modelling algorithms used to calculate river flows. These algorithms are essential for combining the three measured variables (height, slope and width) and obtaining the most accurate estimate possible of river flows on a global scale.

3 - © CNES/Mira – Average yearly global discharge, with two zooms on the southern region of Asia in January and August 2024, as well as a timeline of these flow rates along the Ganges River from August 2023 to April 2025, showing the effect of the monsoon on the discharge (strong increase shown in red).



SWOT observations reveal a comprehensive picture of river discharge like never before, capturing seasonal evolutions and powerful hydrological phenomena resulting from weather events like the monsoon. The data shown in Figure 1 here reveal a striking contrast between hydrological discharge before and after the monsoon in the major rivers of South and Southeast Asia, which increases in volume as rainfall intensifies over the region. In July 2024, satellite data showed a peak flow rate of 10,000 m^3/s in the Ganges River near Varanasi, India, equivalent to four Olympic swimming pools per second. These figures have been validated with measurements from ground stations, demonstrating the mission's ability to track river dynamics.



DATA CENTRES

Data and services hubs have been set up to foster uptake of data for users.

KEY MILESTONES

2026
BDSC draft release opened to French labs

2024
Inception of GEODES

2022
CDS celebrates 50th anniversary

January 2019
Interdisciplinary structure named Data Terra and made part of national research infrastructures roadmap

2018
Inception of PNBD

2017
Inception of DINAMIS

2016
Inception of an interdisciplinary structure comprising AERIS, Theia, ODATIS and FormaTerre

2016
Inception of ODATIS

September 2015
PEPS platform enters service

End 2014
Inception of FormaTerre

2014
Inception of AERIS

2012
Inception of Theia

1998
Inception of CDPP

1995
Inception of MEDOC

1972
Inception of CDS

KEY INFORMATION

MISSION
Offer easy access to data and group them according to theme

DOMAIN
Earth observation, Science

LAUNCH DATE
1972

LIFETIME
Indefinite

PARTNERS
CNRS

WHERE
Data and services hubs

STATUS
In operation

KEY FIGURES

30
data and services hubs

~100
Pb of data

PROJECT IN BRIEF

Science data from space missions funded by CNES are made available to the scientific community via specialist data and services hubs covering a range of research fields:

• Universe Sciences
- CDPP (Plasma Physics Data Centre)
- CDS (Centre de Données de Strasbourg)
- MEDOC (Multi Experiment Data & Operations Centre)
- SBDSC (Small Body Data and Services Center)

• Earth Observation and Research
- Data Terra
- AERIS (part of Data Terra)
- FormaTerre (part of Data Terra)
- PNDB (part of Data Terra)
- ODATIS (part of Data Terra)
- THEIA (part of Data Terra)
- DINAMIS
- GEODES

CNES's ROLE

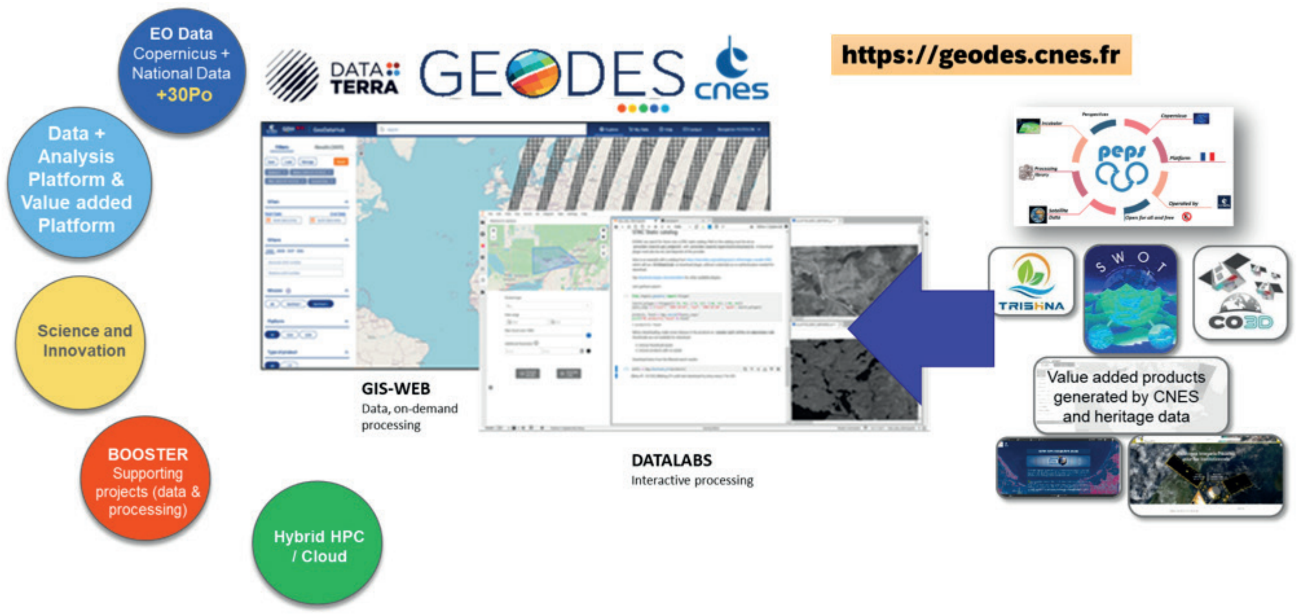
CNES manages some of these data and services hubs and is a stakeholder in others.

DATA CENTRES

Alice Andral
Deputy, Earth Observation Sub-directorate

Initiated by CNES and co-funded by ANR and Toulouse Métropole through the Gaia data project, the GEODES (https://geodes.cnes.fr) information portal and single access point to Earth-observation data came on line in 2024. Replacing the PEPS platform (Sentinel Product Exploitation Platform), it translates CNES's closer involvement in the data and services hubs of the IR Data Terra research infrastructure.
GEODES has two components: an information portal on CNES activities and contributions to Earth observation, and a data and services platform aimed at facilitating access, dissemination and uptake of Earth-observation data for a wide range of users.
It distributes Sentinel-1 and Sentinel-2 data from the Copernicus programme to the public and private sectors (Copernicus Collaborative Segment), as well as legacy data from the SPOT and Pleiades programmes. This collaborative platform will extend its distribution services to Earth-observation data from CNES missions (CO3D, TRISHNA, etc.). The infrastructure used to store, process and archive data has recently been upgraded (Datalake, HPC and networks). Integrated into a national and European ecosystem, as part of the Data Terra research infrastructure, and serving CNES projects and programmes, GEODES offers services for the dissemination, exploration, incubation and management of Earth-observation satellite data in order to promote and foster innovation and Earth system science. The interoperability of GEODES with European platforms (ESA, EUMETSAT, etc.) is of prime importance.
The main advantage of GEODES lies in the centralized and simplified access to data from CNES Earth-observation missions and the Copernicus programme, which is crucial for many fields including natural resource management, land planning and monitoring of natural disasters. By coordinating longstanding national efforts with the Data Terra research infrastructure and promoting collaboration with international partners, CNES helps make these data accessible to many users, whether from scientific and institutional communities or the private sector.
GEODES promotes science and innovation, particularly through the implementation of a set of data dissemination, exploration and user support services. Public and private stakeholders are able to access a wider range of services, such as data downloads and on-demand processing, through a user account. They can also receive more specific support for feasibility studies or project maturation with expert assistance after their request is reviewed and approved.

FIGURES
1 - Artist's view of the CoRoT space telescope © CNES/ David Ducros
2 - The GEODES platform. @CNES



IASI-NG

The IASI instrument (Infrared Atmospheric Sounding Interferometer) has been flying on Europe's MetOp weather satellites since 2006. As well as acquiring temperature and humidity data, IASI also measures more than 25 other atmospheric components with a high degree of precision. IASI data are vitally important for weather forecasting, pollution monitoring and climate research. To ensure continuity, CNES is working on its successor, the IASI-NG next-generation instrument.

KEY MILESTONES

2039
Launch of MetOp-SG A3

2032
Launch of MetOp-SG A2

2026
Delivery of third IASI-NG flight model

2025
Delivery of second IASI-NG flight model

August 2025
Launch of MetOp-SG A1

2024
Delivery of IASI-NG data processing chain

2022
Delivery of first IASI-NG flight model

March-April 2020
Detailed Design Review of IASI-NG system

End 2019
Detailed Design Review of IASI-NG instrument

Mid-2015
Preliminary Definition Review of IASI-NG system

2015
Preliminary Definition Review of IASI-NG instrument

2013
CNES selects IASI-NG as instrument prime contractor

2013
CNES gives go-ahead for IASI-NG programme

KEY INFORMATION

MISSION Analyse Earth's atmosphere (temperature, humidity, composition, climate variables)	**LAUNCH DATE** 12 August 2025 **LIFETIME** 20 years	**WHERE** MetOp-SG-A1, MetOp-SG-A2, MetOp-SG-A3 satellites
DOMAIN Earth observation	**PARTNERS** Eumetsat	**STATUS** In development

KEY FIGURES

1.3	**0.25**	**0.25**	**20**	**12**	**25**
million atmospheric spectra measured daily	cm^{-1} spectral resolution	K radiometric performance	years of observations	km spatial resolution	atmospheric components measured

PROJECT IN BRIEF

Like its predecessor, the IASI New Generation instrument (IASI-NG) is an infrared atmospheric sounding sensor designed to determine temperature and water vapour profiles in the atmosphere, record ocean surface and land temperatures and monitor a vast range of chemical compounds and other key variables for climate research, including greenhouse gases, desert dust and cloud cover. With its innovative optical configuration, IASI-NG's spectral resolution and signal-to-noise ratio will be improved by a factor of two. Measurement precision will also be improved (1 K for temperature and 10% for humidity).

More than just a continuation of IASI, IASI-NG is a real asset for atmosphere sciences, particularly numerical weather prediction models, atmospheric composition studies and climate research, thanks to its far-reaching engineering and technological innovations. It is a key element of Europe's three future MetOp-SG-A series weather satellites, scheduled to launch in 2025, 2032 and 2039.

CNES's ROLE

IASI-NG is scheduled to fly with other instruments on the MetOp-SG satellite developed by the European Space Agency (ESA) and operated by Eumetsat. Within this partnership, CNES has overall technical responsibility for the three flight models of the IASI-NG instruments up to in-orbit commissioning. It is also tasked with developing the chain for processing raw data from the instrument into Level 1 products. Further, CNES is in charge of developing and operating a technical expertise centre to monitor the instrument's performance in orbit.

IASI-NG

Adrien Deschamps
Atmosphere-Meteorology Programme Manager

First data from IASI-NG instrument on Metop-SGA1

The IASI-NG instrument (Infrared Atmospheric Sounding Interferometer – New Generation) aboard the Metop-SGA1 satellite marks a major step forward in observing Earth's atmosphere. Launched on 12 August 2025 from the Guiana Space Centre by Ariane 6, the instrument sent back its first atmospheric sounding data on 22 October 2025, after acquiring a first spectrum on 30 September 2025 over Toulouse. IASI-NG follows in the footsteps of the first-generation IASI instruments in service since 2006 on the Metop satellites, extending the long-term record of climate data.

Developed by Airbus Defence & Space with technical oversight from CNES and support from the national scientific research centre CNRS and national weather service Meteo-France, IASI-NG is designed to deliver far superior performance to its predecessors. It sounds the atmosphere with approximately two times more radiometric sensitivity and spectral resolution.

IASI-NG is an infrared spectrometer that senses radiation from Earth's surface and atmosphere. By splitting this radiation into its constituent wavelength components, the instrument identifies molecules in the atmosphere from their characteristic spectral "fingerprints". It simultaneously measures the atmosphere's temperature, humidity and chemical composition, including key gases like ozone, methane and carbon dioxide, as well as aerosols. Analysing the depth of absorption lines enables us to estimate the quantity of these components according to altitude, thus providing fine detail about the vertical structure of the atmosphere.

One of IASI-NG's major innovations is its use of a Mertz interferometer concept that significantly improves vertical temperature and humidity profiles, particularly in the lower layers of the atmosphere. This improvement is crucial, as conditions near Earth's surface have a big influence on weather phenomena like precipitation, wind and extreme episodes. IASI-NG data are thus strengthening the quality of regional and global numerical weather prediction models.

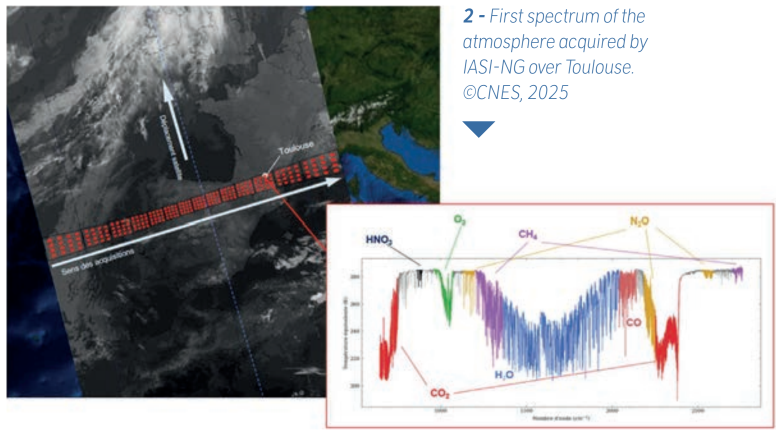
Thanks to its increased resolution and sensitivity, IASI-NG is delivering finer and more reliable observations than the previous-generation instrument. These data are fed directly into operational weather forecasting systems, helping to better anticipate variations in atmospheric conditions and enabling more reliable forecasts.

In addition to weather forecasting, IASI-NG is playing a key role in monitoring climate and air quality. Planned to operate up to at least 2047, it will allow us to compile a continuous record of more than 40 years of climate data, combining observations from first-generation IASI instruments with those of IASI-NG. Such continuity is vital to detect and analyse long-term climate trends.

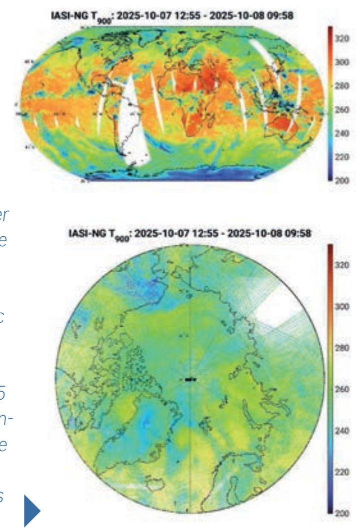
CNES, national scientific research centre CNRS and national weather service Meteo-France are closely involved in processing spectra acquired by IASI-NG to extract geophysical and climate parameters required to precisely characterize Earth's atmosphere. This work is supporting scientific research, climate expertise and public environmental policies.

In conclusion, IASI-NG marks a significant leap forward in observing Earth's atmosphere from space. With its enhanced performance, innovative measurement concepts and longer timescales, it is making an essential contribution to improving weather forecasts, gaining new insights into climate change and monitoring air quality, with direct spin-offs for the safety of populations and numerous sectors of the economy.

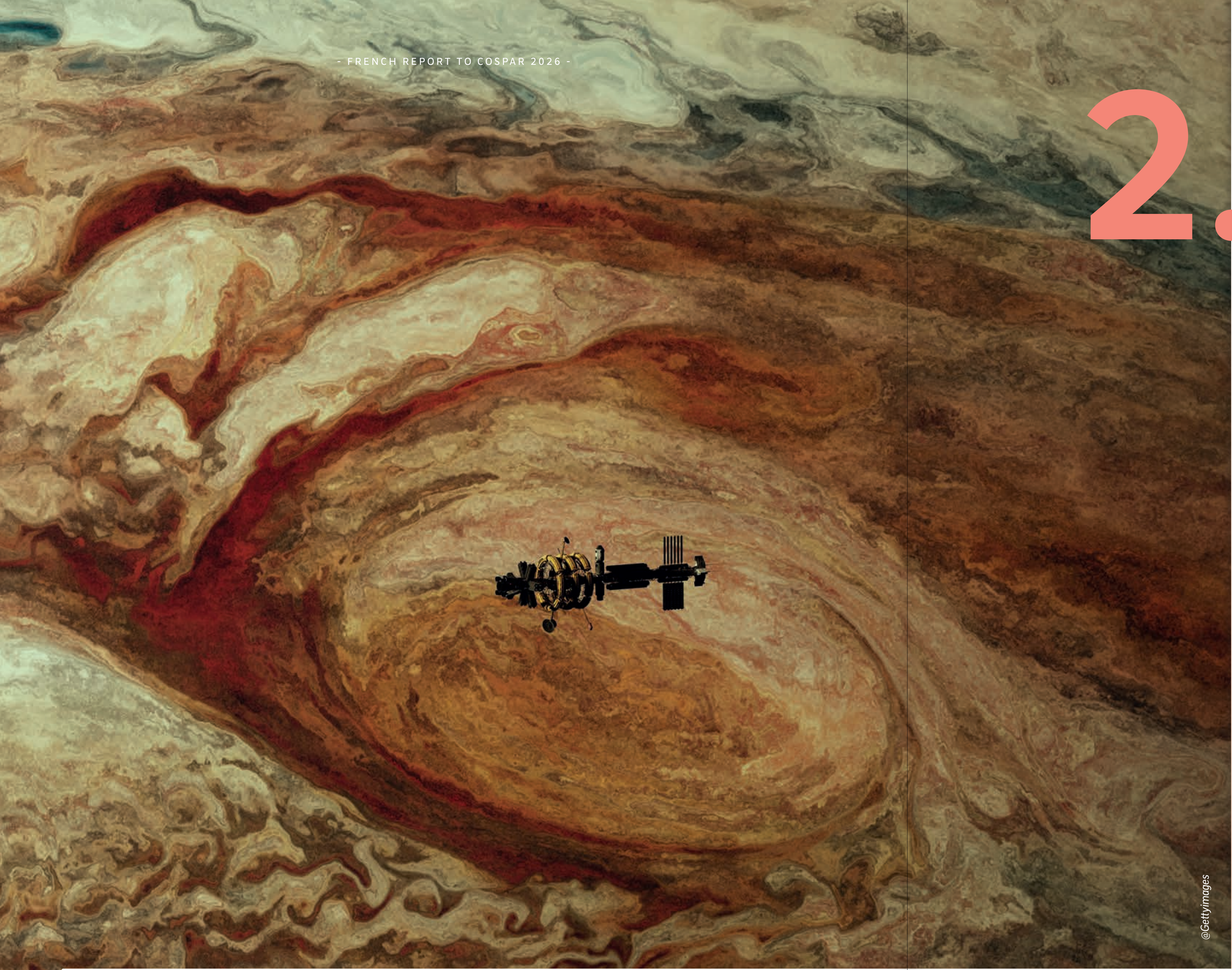
FIGURES
1 - Artist's view of the IASI-NG instrument on the MetOp-SG satellite © CNES/ill./REGY Michel, 2021



2 - First spectrum of the atmosphere acquired by IASI-NG over Toulouse. ©CNES, 2025



3 - By compiling data from a single spectral channel over several orbits, we are able to generate a broad picture of this specific atmospheric parameter. Below is a composite image from 7 October 2025 using the 11-µm channel that highlights the thermal properties of clouds and Earth's surface.



@Gettyimages

2. Space studies of system planets and bodies of the solar system

Francis Rocard & Christian Mustin
Solar System Programme Managers

" The French space agency CNES is currently engaged in a number of international partnership missions to explore planets closest to the Earth and their moons. Mars exploration remains a cornerstone for planetology and exobiology, as evidenced by the French contribution to developments and operations of rover instruments SuperCam on Perseverance and ChemCam and SAM on Curiosity. CNES is also supporting the next two robotic missions to Mars:

(i) JAXA's MMX mission, with joint responsibility for the IR mapping spectrometer (MIRS) and the Idefix rover
(ii) ESA's ExoMars 2028, through hardware contributions to Wisdom, MicrOmega, Moma, RLS and Clupi

For Venus and Mercury exploration, French contributions are mainly focused on UV and radio-science investigations with the Phebus, VenSpec and VEM spectrometers respectively on board BepiColombo, EnVision and Veritas. France is also a major participant in the ESA JUICE and NASA DragonFly missions with the development of the Vis-IR imager, the MAJIS spectrometer and the DraMS chromatograph to study the mineral or organic composition of the surface of Jupiter's icy moons, Ganymede, Europa and Callisto; and the largest moon of Saturn, Titan. "

Interview

Looking back over your career, what has most marked you in your field of research?

The most memorable moments are undoubtedly when a spacecraft lands on a celestial body. We experienced that with Philae in 2014 and Huygens in 2005. The first landscape we see tells us a great deal about the body's nature. Such strong feelings of joy or disappointment (sometimes!) show how much time and effort have gone into the mission.

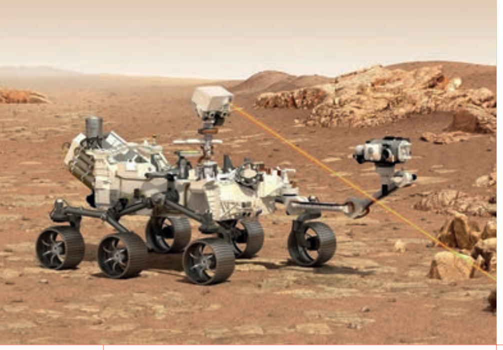
In your opinion, what are the best and worst aspects of your scientific field of research?

The best thing about being a researcher is seeing your project or ideas develop over time. The best moments are the culmination of a project, when you get the first data and make major or unexpected discoveries. Surprises are often part of the journey.

The worst moments are when something doesn't work, whether at launch or at completion. All of the effort that you put in over more than ten years can be lost in a matter of seconds. It's painful for all the teams who have worked so hard. And even when everything goes well, a lack of caution in initial scientific interpretations and the exaggerated self-assurance displayed by some scientists can erode public confidence in science.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

For many years, the scientific community has been advocating for a mission to bring samples from Mars back to Earth. Indeed, only laboratory analysis of such samples will provide a potentially definitive answer to the question of whether life emerged on Mars. This would undoubtedly be the greatest scientific discovery of this century. Moreover, the discovery of another form of life different from what we know on Earth would lead us to think not only about Life more broadly, but also about the diversity of life forms existing in the universe.



SUPERCAM

Mars 2020 is a space mission to explore Mars developed by NASA. The centrepiece of the mission is its rover, named Perseverance, which landed on the surface of the red planet on 18 February 2021.

KEY MILESTONES

25 January 2024
End of Ingenuity's mission after 72 flights

19 April 2021
First flight of Ingenuity

3 April 2021: Ingenuity
helicopter deployed on surface of Mars

18 February 2021
Perseverance rover lands on Mars

30 July 2020
Mars 2020 mission launched by Atlas V 541

November 2018
Jezero Crater selected as landing site

July 2014
Instruments selected by NASA

4 December 2012
NASA announces start of development of Mars 2020 Perseverance mission

KEY INFORMATION

MISSION
Study the geologic diversity of Mars to seek signs of ancient life. Cache, seal and store samples for return to Earth by later missions.

DOMAIN
Science

LAUNCH DATE
30 July 2020

PARTNERS
CNRS, NASA, JPL, LANL, University of Valladolid (Spain)

STATUS
In operation

WHERE
Mars, Jezero Crater (ancient lakebed and delta)

LIFETIME
1½ Mars years (about 1,000 Earth days)

KEY FIGURES

7	9	3	1,050
instruments on rover	cameras on rover	x 2.7 x 2.2 m: rover dimensions	kg: rover mass

CNES's ROLE

CNES was in charge of designing and building the French component of SuperCam. SuperCam represents an advanced version of the ChemCam instrument, which has been operational on the surface of Mars since August 2012 on NASA's Curiosity rover.

PROJECT IN BRIEF

Launched on 30 July 2020, NASA's Perseverance rover landed in Jezero Crater on 18 February 2021 to explore an ancient lake and river delta that may preserve traces of past life. One of its seven instruments, SuperCam, is a sophisticated suite combining three spectrometers, a colour camera and a microphone. Derived from ChemCam on Curiosity, SuperCam analyses rocks remotely using laser-induced breakdown spectroscopy (LIBS), Raman and infrared spectrometry to determine chemical and mineral composition and detect possible organic molecules. The camera provides geological context, while the microphone studies rock properties and the Martian atmosphere. SuperCam was developed through collaboration between Los Alamos National Laboratory in the United States and several French laboratories coordinated by IRAP and CNES, with support from Spain's University of Valladolid. Perseverance also collects Martian rock samples for future return to Earth under strict planetary protection procedures.

FIGURE
Artist's view of the Perseverance rover on Mars
© CNES-Davis Ducros, 2020

SUPERCAM & CHEMCAM

Christian Mustin
Exobiology, Exoplanets and Planetary Protection Programme Manager

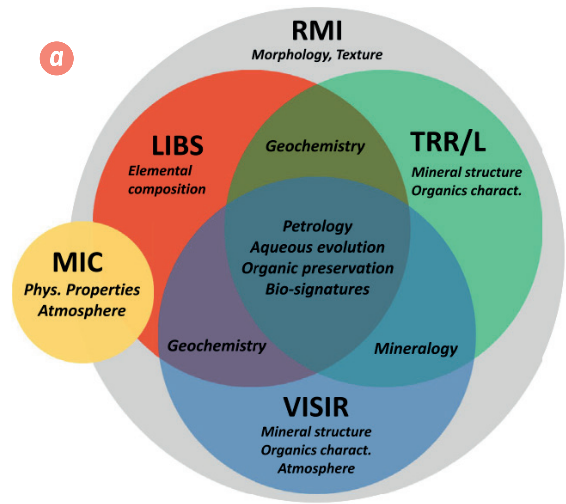
REFERENCES
- Cousin et al., Soil diversity at Jezero Crater and Comparison to Gale Crater, Icarus, 2024 - doi:10.1016/j.icarus.2024.116299.
- Wiens et al., Geochemistry of Mars with Laser-Induced Breakdown Spectroscopy (LIBS): ChemCam, SuperCam, and MarSCoDe, Mineral 2025 doi:10.3390/min15080882.

Robotic exploration of Mars is driven by key questions concerning the inner structure, early geological record and past habitability of the red planet. Scientific investigations have focused strongly on the geology, mineralogy and chemistry of the (sub-)surface rocks and soil. Among the tools to answer these questions are the two French-US instruments ChemCam and SuperCam, respectively aboard the Curiosity and Perseverance rovers.
Today, the rovers and instruments remain healthy and in operation on Mars. Curiosity is exploring lacustrine sediments and diagenetic features in Gale Crater, whereas Perseverance is collecting samples in the igneous bedrocks, deltaic features and the rim of Jezero Crater. Both use laser induced breakdown spectroscopy (LIBS) and a Remote Micro-Imager (RMI) to analyse morphologies of bedrocks and the chemical composition of rocks. In addition to LIBS and RMI, SuperCam employs time-solved Raman, luminescence and visible-infrared spectroscopies and a microphone (Figure 1a). For more than one decade, joint analysis with techniques available on board have provided valuable information on the past habitability of Mars and allowed the investigation of the geochemistry of bedrocks and regolith, a survey of the planet's atmosphere and the search for bio-signatures.

The uniquely versatile combination of LIBS and RMI is used extensively to explore the chemistry and facies of geological deposits of Gale Crater and Jezero Crater bedrocks. It has provided close-up and stand-off observation and analysis of rocks, regolith, pebbles, abraded zones and cuttings (Figure 1b). LIBS can quantify the abundance of major (Si, Al, Fe, Mg, Ca, Na, etc.) and minor (Ni, Zn, Cr) metals in rocks and soils, as well as the base elements of organic molecules essential for living systems (C, H, O, P, S). RMI can identify up to several kilometres from the rover geological features (strata, etc.) with a better resolution than orbiter cameras. Moreover, close-up observations and analysis at millimetre scale of rock texture (matrix and cement, veins, nodules, etc.) facilitate the identification of weathering processes of bedrocks and their physico-chemical change over time. A detailed catalogue of analysed outcrops, collected samples and calibration targets is now available to support extended scientific investigations.
SuperCam and ChemCam have already fired over 375,000 and 1,060,000 laser shots for LIBS analysis respectively and have helped to determine the chemical and mineral composition of roughly 30,000 Martian outcrops or samples of interest. With now thousands of LIBS sets of data available, a robust inter-comparison of the texture of various surface materials at Gale and Jezero sites could be done (Figure 3). As shown by ChemCam and SuperCam analysis, Martian soils, which are assumed relatively uniform across the planet, exhibit variations in silicate composition, sulphate content and hydration level.

FIGURE 1
[a] - Possible investigation at the crossroads of the different techniques available with ChemCam and SuperCam instruments.

[b]- Analytical transect of laser shots (red crosses) in an abraded outcrop. From Maurice et al., Space Sci. Rev. The Mars 2020 Mission, 629-736, 2021.

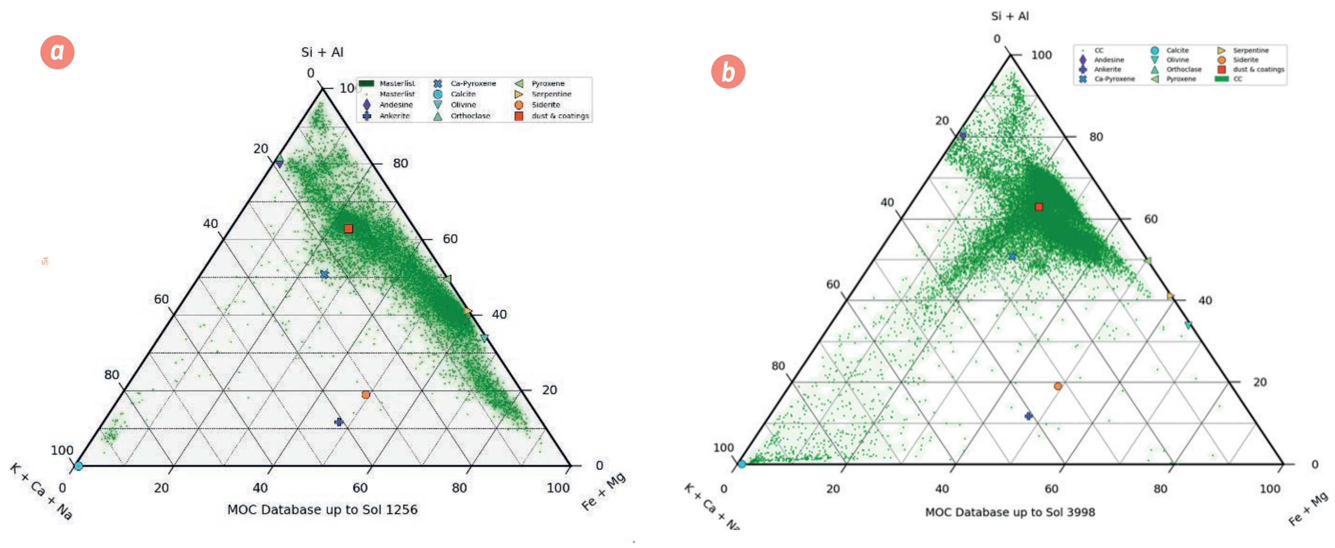


Joint LIBS/RMI analysis confirms the past existence of a lacustrine environment in some areas of Gale Crater and reveals physico-chemical traces of liquid water interaction with rocks on and near the surface during repeated 'wet' episodes. ChemCam analysis showed the multiple occurrences of magnesium- and calcium-rich sulphates and more exceptionally evidence of native sulphur crystals in rock cracks. The existence of seasonal drying-wetting cycles is hypothesized to explain the formation of evaporitic deposits in veins and desiccation cracks.

In contrast to ChemCam observations at Gale, SuperCam analysis proves that Jezero Crater is clearly a mafic site, with high magnesium content and relatively depleted silicon, aluminium, sodium, potassium and calcium content. This finding is consistent with the discovery of very coarse grains enriched in olivine, low-Ca pyroxene and iron carbonate in both the Jezero Crater floor and the delta front locations. In contrast, phyllosilicate-rich grains are only encountered in the delta front and are the markers of long-term aqueous weathering of pristine mafic mineral. In addition, for the first time, electric discharges have been identified in Martian dust storms and their acoustic signatures (shock waves) were captured by SuperCam's microphone. Such atmospheric discharges could produce highly oxidizing and gaseous compounds that could transform organic molecules and sensitive mineral components of soil and rocks. This discovery profoundly changes our understanding of interaction of atmospheric compounds with surface materials over time.

Following the success of French contributions to key instruments on Mars rovers, CNES is already participating in the development of micro-LIBS, a miniaturized version for future "light" robotic missions (small rovers, rotocraft, etc.) to asteroids, comets, the Moon, Mars or icy/ocean worlds such as Enceladus.

FIGURE 2
Jezero and Gale ternary diagrams of Martian rock compositions, in molar units; Plots of overall available LIBS data showing trends in terms of major elements ***[a]*** *SuperCam's LIBS analysis to Sol 1256;* ***[b]*** *ChemCam's LIBS analysis to Sol 3998; Compositions of calibration targets (on board) are shown with symbols.*



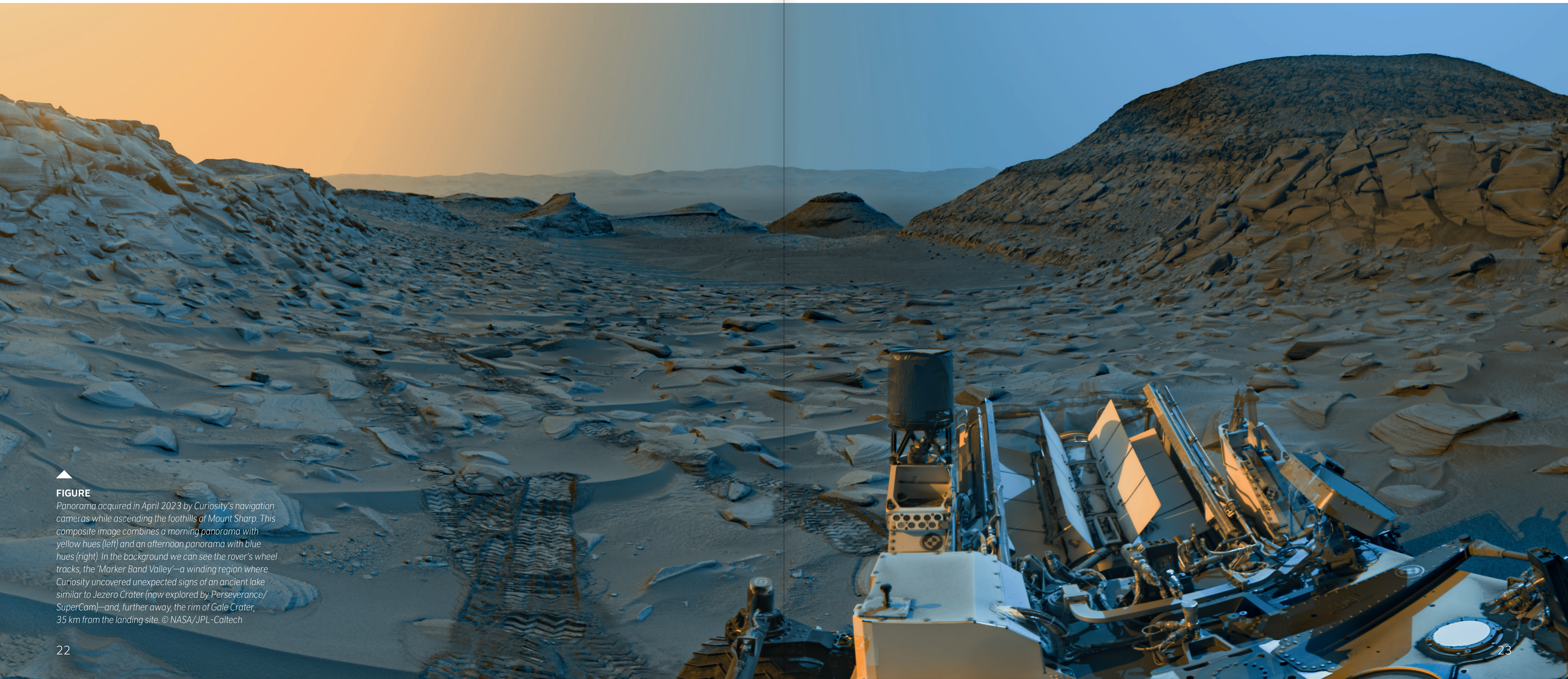
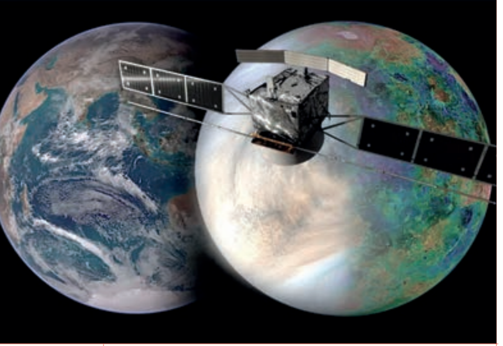


FIGURE
Panorama acquired in April 2023 by Curiosity's navigation cameras while ascending the foothills of Mount Sharp. This composite image combines a morning panorama with yellow hues (left) and an afternoon panorama with blue hues (right). In the background we can see the rover's wheel tracks, the 'Marker Band Valley'—a winding region where Curiosity uncovered unexpected signs of an ancient lake similar to Jezero Crater (now explored by Perseverance/SuperCam)—and, further away, the rim of Gale Crater, 35 km from the landing site. © NASA/JPL-Caltech



EnVision

EnVision is setting out to lift the veil on Venus in an attempt to understand how Earth's "twin sister" turned into the toxic hothouse it is today. Why, although the two planets are of similar size and composition, is the surface activity and climate on Venus and Earth so different? And what does that tell us about how Earth's climate is likely to evolve?

KEY MILESTONES

January 2039
Planned end of mission

December 2034
End of aerobraking phase and start of science mission

May 2033
Arrival in the vicinity of Venus

November 2031
Launch of EnVision mission by Ariane 62

January 2024
EnVision mission go-ahead

June 2021
EnVision selected by ESA

May 2018
EnVision selected as candidate ESA medium-class (M) mission

KEY INFORMATION

MISSION
Understand why Venus, our nearest neighbour, is today so different to Earth

DOMAIN
Science

WHERE
Quasi-polar low-altitude Venus orbit (210 to 520 km)

LAUNCH DATE
Scheduled November 2031

LIFETIME
6-month cruise phase, 18 months of aerobraking and 4-year science mission (end of mission January 2039)

STATUS
In development

PARTNERS
ESA (contracting authority), CNES (funding and instruments), NASA (one instrument), IRAP, LATMOS, LIRA (ex-LESIA) and LPG (instruments), and LMD, IPAG and LTE (ex-IMCCE) (science) research laboratories

KEY FIGURES

2	1.6	4	8
m x 2 m x 2 m: EnVision dimensions in stowed configuration	tonnes: satellite dry mass (excl. fuel)	instruments	contributing French laboratories

PROJECT IN BRIEF

The EnVision orbiter will study Venus' current conditions and evolution, launching late 2031 on an Ariane 62 from the Guiana Space Centre. Scientists hope this mission will deliver insights into why Venus and Earth evolved so differently and inform our understanding of similar-mass planets. Venus, Earth's nearest neighbour, remains mysterious despite their similar initial size and composition. Why did Venus become an inhospitable world with a runaway greenhouse effect? EnVision's primary goal is to explore Venus from core to upper atmosphere to obtain a synoptic picture of the planet and layer interactions. It will analyse volcanic and tectonic activity, climate, and atmosphere-surface-inner structure interactions. Broader objectives include understanding how Earth-like planets evolve and the conditions needed to support life. Key questions include: Is Venus still active? What is its volcanic and tectonic history? What are its core and rocks made of? Was there liquid water on its surface? What is its climate like today? How did its atmosphere evolve? Science operations will begin after 18 months of aerobraking in Venus' upper atmosphere, before reaching low-altitude polar orbit. The mission addresses three main questions: history (surface and interior evolution), activity (geological activity), and climate (atmospheric-climate interactions with geologic processes).

CNES's ROLE

As the national space agency, CNES is overseeing all French contributions to the mission.
In particular, it is in charge of supplying the VenSpec-U spectrometer that will study interactions between the lower and upper atmosphere and the sulphur cycle, by analysing the atmosphere above the clouds, and the RadioScience experiment that will probe Venus' inner structure.

EnVision

Jérôme Carron

Project Manager for the French contributions to EnVision

EnVision is an ESA-led mission that will be the first to provide a complete view of Venus from its inner core to its upper atmosphere and determine how and why Venus and Earth evolved so differently, despite being of similar size and composition. The mission was selected in 2021 and officially adopted by ESA and its member states in January 2024.

To achieve its science goals, EnVision will play with a set of six interlinked instruments to work on the interactions between the planetary properties of Venus. French research institutes (from CNRS) and CNES are playing a scientific role on all of them and are in charge of hardware developments for three of the six instruments and two ground segments:

• The VenSpec-U (Venus UV Spectrometer) instrument is dedicated to analysing the abundances of volcanic sulfide gases (SO, SO_2) at cloud tops, as well as UV contrasts, through spectral and spatial analysis of sunlight backscattered on the dayside of Venus (from 190 nm to 380 nm). The ground segment will also be developed alongside the instrument. The instrument principal investigator (PI) is Emmanuel Marcq from the LATMOS (CNRS/Sorbonne University/UVSQ) laboratory.

• The RadioScience experiment is under the scientific responsibility of Caroline Dumoulin from the LPG (CNRS/Nantes University/University of Angers) laboratory in Nantes. The instrument relies on the radio link between the spacecraft and ground antennas. The ground segment is divided into two distinct experiments:
- The Gravity Experiment, under French responsibility, will analyse the Doppler shift between the uplink and downlink radio frequencies of the satellite. The science data will determine the size of the main internal layers (crust/lithosphere, mantle and core) and the physical state of the planet's inner core (gravity field with a spatial resolution < 270 km).
- The Radio-occultation Experiment, in collaboration with the University of Cologne (Germany), will analyze the downlink radio frequency signal received on Earth after it has passed through the different layers of Venus's atmosphere to provide more information about the gas states, pressure and temperature that make up Venus' atmosphere between 35 and 90 km.

• The optical telescope of the VenSpec-M instrument is being built by LIRA (Obs. Paris/CNRS/Sorbonne University/ Paris Cité University). This telescope will select 14 narrow bands of interest in the near infrared (0.8-1.5 µm) coming from the surface of Venus. It will characterize rock types as well as surface clouds and their dispersion.

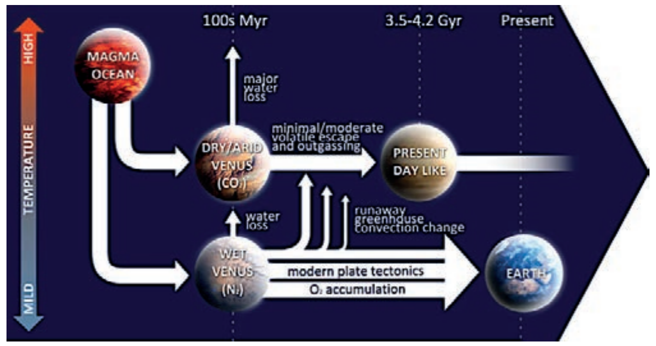


FIGURE - Left-hand page
The EnVision mission will set out to study Venus and find out why it took such a different evolutionary path to Earth © ESA Standard Licence

FIGURES - Above
1 - *Artist's view of the EnVision spacecraft orbiting Venus © ittiz / JAXA / VR2Planets*
2 - *Current understanding of the extreme tentative scenarios for the evolution of Venus' surface conditions, from its origins to present day, compared to Earth. On top, Venus lost its surface water early on (desiccated Venus, or stifled outgassing scenarios), while on the bottom, it evolved closer to Earth, retaining a larger portion of its water inventory, until its climate was destabilized. For now, both evolutionary pathways remain consistent with our overall knowledge of the planet. Only general evolution trends are represented, Earth-related processes (modern plate tectonics and accumulation) are not attributed a specific time and only included for comparison with Venus (from Gillmann et al.)*

REFERENCES
The Long-Term Evolution of the Atmosphere of Venus: Processes and Feedback Mechanisms Interior-Exterior Exchanges, C. Gillmann et al., Space Science Review, Volume 218, number 56, 2022.

JUICE

The JUICE mission (JUpiter ICy moons Explorer) launched on 14 April 2023 by Ariane 5 from the Guiana Space Centre is setting out to study Jupiter and three of its moons with a view to gaining new insights into how life emerged.

KEY MILESTONES

September 2035
Scheduled end of mission

December 2034
Insertion into Ganymede orbit

July 2031
Arrival at Jupiter, starts exploring the planet's moons

January 2029
Swings by Earth for gravity assist

September 2026
Swings by Earth for gravity assist

August 2025
Swings by Venus for gravity assist

August 2024
Swings by Earth-Moon system for gravity assist

14 April 2023
Launched by Ariane 5 from Guiana Space Centre

KEY INFORMATION

MISSION
Explore Jupiter and its icy moons

DOMAIN
Science

LAUNCH DATE
14 April 2023

LIFETIME
7.6-year cruise phase and then 3.5-year exploration phase

PARTNERS
ESA, CNRS, research laboratories (Europe and USA)

WHERE
Jovian orbit and then Ganymede orbit

STATUS
In operation (cruise phase)

KEY FIGURES

15 contributing French laboratories

12 instruments on spacecraft

9 months in Ganymede orbit

4 gravity assists

FIGURE
Artist's view of the JUICE spacecraft © /VR2Planets, 2023.

PROJECT IN BRIEF

What conditions enable planets to form and life to emerge? How was our solar system born? The JUICE mission, launching in 2031, seeks answers by exploring Jupiter and three of its moons over three and a half years. JUICE will focus particularly on Ganymede, believed to harbour a liquid ocean beneath its icy crust. By analysing this ocean, JUICE will gather crucial data about conditions required for life in such environments. The mission will also study Europa and Callisto, two other Jovian moons. Additionally, JUICE will probe Jupiter's atmosphere and magnetosphere—the layer where physical characteristics are governed by its magnetic field—and how it interacts with its moons. The JUICE mission is part of ESA's Cosmic Vision 2015-2025 programme. France is supporting multiple research laboratories that developed the satellite's instruments: GEOPS, IAS, IMCCE, IPAG, IPGP, IRAP, OASU, LAM, LATMOS, LUX, LIRA, LMD, LPC2E, LPG, LPP, and OCA. These include the French MAJIS instrument (Moons And Jupiter Imaging Spectrometer), designed to characterize Jupiter's icy moons' surfaces, supplied by the IAS space astrophysics institute in Orsay, France, under a CNES technical partnership. The agency funded industrial contracts for all French contributions, for MAJIS and five other instruments. JUICE will revolutionize our understanding of Jupiter's system and habitability conditions across our solar system.

CNES's ROLE

CNES is funding JUICE through ESA's mandatory scientific programme and France's national programme, contributing to satellite instruments. Representing France on ESA's Science Programme Committee, CNES is in charge of French deliverables: funding French laboratory contributions, overseeing development, providing technical support in quality assurance, mechanical engineering and thermal systems, managing ESA interfaces for technical and programmatic aspects, and funding French mission science activities.

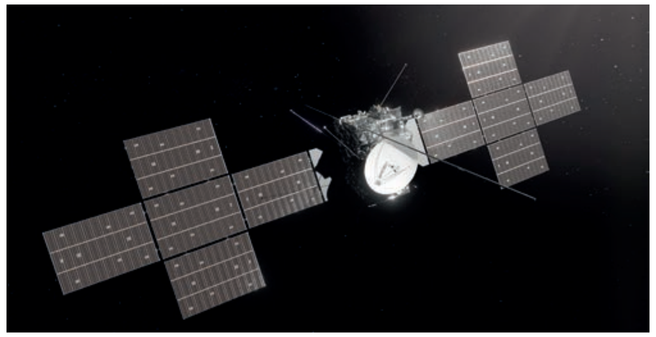
JUICE
en route to Jupiter

Francis Rocard
Solar System Programme Manager
Charlène Doucet
Head of JUICE Project

On 14 April 2023, the JUICE spacecraft was successfully launched from Kourou in French Guiana and is now en route to Jupiter. The spacecraft will arrive at its destination in 2031. CNES has been guiding and supporting French laboratories and companies involved in this first L-class (large) mission of ESA's Cosmic Vision Programme.

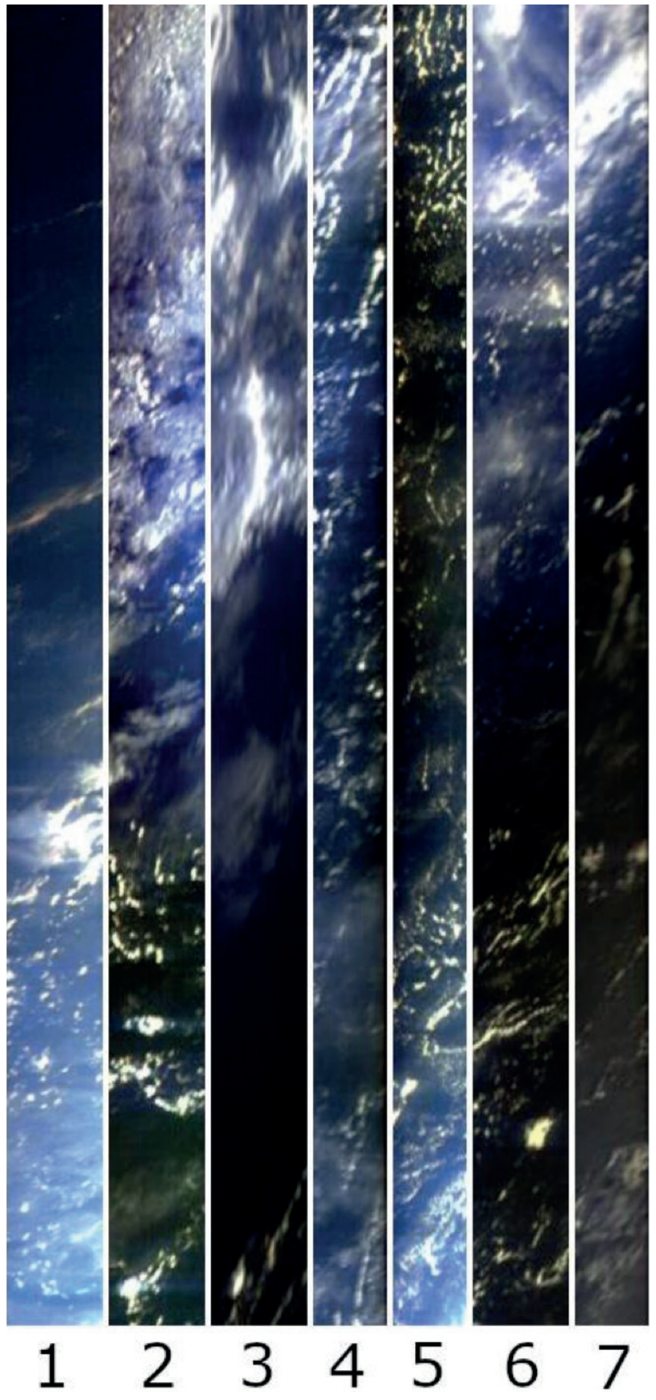
The JUICE mission has been designed to explore the icy moons of Jupiter (Europa, Callisto and Ganymede) and will especially focus on Ganymede during the last year of operations in the Jovian system. It will be the first spacecraft to orbit a moon of another planet.
The probe will also investigate the complex Jovian environment by studying the Jovian atmosphere, magnetosphere and their satellite and ring systems.

The JUICE payload consists of 10 instruments to achieve the mission's goals. They can be classified into three groups:
- A first group of remote-sensing instruments with the optical camera system JANUS (Italy) and spectral imaging going from ultraviolet to submillimetric wavelengths, the visible and infrared imaging spectrometer MAJIS (France), the UV imaging spectrograph (UVS) and the submillimetre wave instrument (SWI).



- A second group of geophysical instruments composed of a laser altimeter GALA (Germany), a radar sounder RIME (Italy) to explore the surface and sub-surface of the moons, and a radio science experiment 3GM (Italy) to probe the atmospheres of Jupiter and its moons, but also to measure gravity fields.
- A third group of in-situ instruments with the particle environment package PEP (Sweden), the magnetometer J-MAG (United Kingdom) and the radio and plasma wave instrument RPWI (Sweden), comprising electric field sensors and Langmuir probes.

An experiment (PRIDE) using Earth radiotelescopes in VLBI (Very Long Baseline Interferometry) configuration will also yield precise information on the spacecraft's position and speed, and a radiation monitor (RADEM) is also on board the satellite.



FIGURES
1 - © /VR2PLANETS, 2023
2 - Series of 7 observations from MAJIS acquired during the Earth flyby of the 20 August 2024. © MAJIS Team (IAS, INAF, LPG/Osuna, CNES, ASI, ESA and other international partners).

The MAJIS imaging spectrometer was developed under the responsibility of IAS (Principal Investigator: F. Poulet):
- Focal planes unit (FPU) of the VISNIR and IR channels
- Command-control electronics and instrument power delivery (PCDU)
- Proximity electronics (PE) of the VISNIR and IR channels
- Instrument calibration

Other institutes from Italy (ASI/Leonardo for the Optical Head) and French laboratories (LAB, LIRA, LPG and Nantes University) also contributed to the instrument.

French laboratories have made significant contributions to several scientific instruments:
For the SWI instrument, LIRA developed the microwave components of the LO chain, the submillimetric channel at 1200 GHz and the frequency doubler for the 600-GHz channel, and LAB developed the Observation Planning Tool for operations planning. For the RPWI instrument, LPC2E delivered the mutual impedance probe MIME board, LPP provided the Search Coil Magnetometer, and LIRA developed the JENRAGE experiment using RWI antennas and a high-frequency receiver. For the PEP instrument, IRAP was responsible for procuring micro-channel plates for the JENI sensor and developing the high-voltage boards for the JDC sensor. Additionally, LATMOS contributed to the UVS instrument by procuring a grating for the spectrometer, while IPAG provided modelling of instrument performance for RIME.

JUICE is now in cruise phase and has already successfully performed a Moon-Earth flyby on 19/20 August 2024 and a Venus flyby on 31 August 2025. It also had the opportunity to observe the 3I/ATLAS interstellar object in November 2025 and the data will be accessible to scientists in February 2026. The next mission milestones before the arrival at Jupiter in 2031 are the two Earth flybys planned in September 2026 and January 2029.

MAJIS results during Moon-Earth flyby

During the flyby, MAJIS successfully captured detailed spectra and images of Earth and the Moon, demonstrating its ability to identify atmospheric and surface compositions. The observations included the lunar highlands and seas, as well as Earth's atmosphere from night side to dayside, highlighting MAJIS's ability to detect thermal emissions and reflectance radiations. These tests were crucial for calibrating the instrument and preparing for its future mission to Jupiter and its moons.

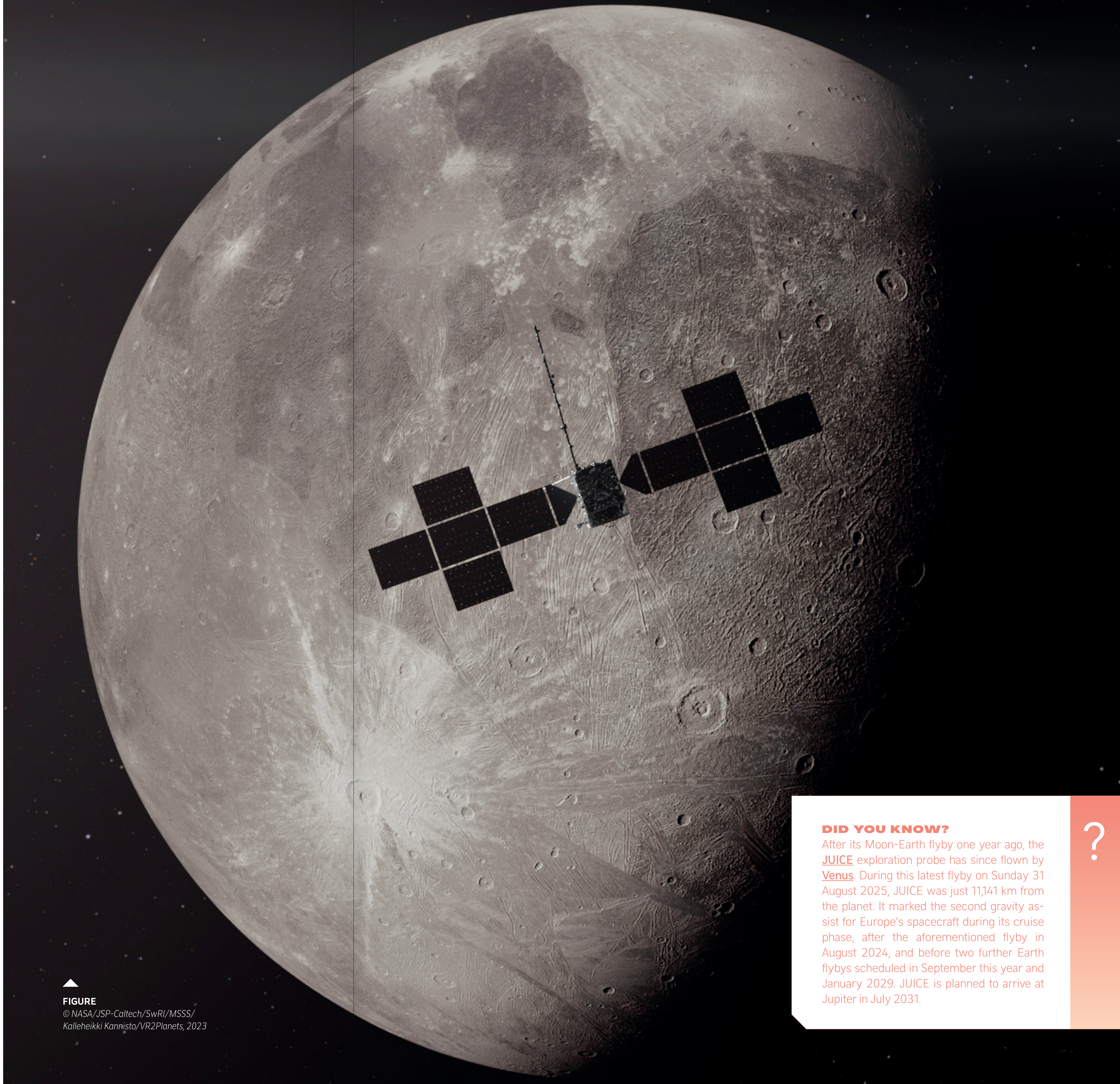


FIGURE
© NASA/JSP-Caltech/SwRI/MSSS/ Kalleheikki Kannisto/VR2Planets, 2023

DID YOU KNOW?

After its Moon-Earth flyby one year ago, the JUICE exploration probe has since flown by Venus. During this latest flyby on Sunday 31 August 2025, JUICE was just 11,141 km from the planet. It marked the second gravity assist for Europe's spacecraft during its cruise phase, after the aforementioned flyby in August 2024, and before two further Earth flybys scheduled in September this year and January 2029. JUICE is planned to arrive at Jupiter in July 2031.

HERA

The Hera mission is set to deliver new insights into the formation and evolution of asteroids by studying the geophysical characteristics of the Didymos-Dimorphos binary system. Hera will investigate the moonlet Dimorphos up close to observe the effects of the impact of the U.S. DART mission. The mission also aims to study possible planetary defence techniques. Hera is the first mission to rendezvous with a binary asteroid and with the smallest asteroid ever encountered, the first to probe an asteroid using radar tomography, and the first experiment to characterize an asteroid crater in situ. It is also carrying the first cubesats to orbit an asteroid up close.

KEY MILESTONES

September 2027
Scheduled end of mission

June 2027
Juventas to attempt landing on Dimorphos

January 2027
Separation of Juventas and Milani cubesats and start of proximity operations, exploring for 3 to 6 months, from a few tens of kilometres to a few kilometres

December 2026
Rendezvous and start of manoeuvres to insert Hera on a trajectory close to the asteroid (30 km)

March 2025
Flyby of Mars and Deimos

7 October 2024
Launch window opens for Hera

August 2024
Hera satellite and Juventas and Milani cubesats depart ESTEC for launch site in the U.S.A (Kennedy Space Center)

26 September 2022
NASA's DART impactor mission crashes into asteroid Dimorphos

24 November 2021
Launch of NASA's DART impactor mission

2017
ESA starts development of Hera mission

2013
AIDA project initiated by NASA and ESA

2007
ESA formulates asteroid deflection mission concept

KEY INFORMATION

MISSION Measure surface temperature of land surfaces and coastal strips at high resolution and frequent revisit intervals	**LAUNCH DATE** 2026	**LIFETIME** 5 years
DOMAIN Earth observation Science	**WHERE** 761-km Sun-synchronous orbit, local crossing time (descending node) 12:30 p.m.	**PARTNERS** ISRO **STATUS** In development

KEY FIGURES

1,150 kg: mass of Hera	**5** instruments on Hera spacecraft	**12** kg: mass of each cubesat	**5** instruments on cubesats

PROJECT IN BRIEF

The threat of a near-Earth asteroid (NEA) impact, though statistically low (<1 per 500,000 years for >1 km objects), could be catastrophic. The international AIDA programme is developing planetary defence techniques, favouring kinetic impactors. NASA's DART hit Dimorphos on 26 Sep 2022, shortening its orbit by 33 minutes, proving deflection is possible for future missions. ESA's Hera will rendezvous in 2026 to measure momentum transfer, study crater formation, and perform the first interior radar survey with the JuRa cubesat, demonstrating autonomous navigation and inter-satellite links in low-gravity environments.

CNES's ROLE

France is supplying the JuRa low-frequency radar receiver board (PI Alain Herique, IPAG Grenoble), and CNES is overseeing proximity operations—including trajectory control and instrument tasking from separation to asteroid landings—for the Juventas and Milani cubesats, collaborating with industry partners SpaceBel, GomSpace, Tyvak and research teams from IPAG, ROB, Helsinki University, INAF, and UNIBO.

HERA

Aurelie Moussi
Project Manager and Head of Moons and Small Bodies department

Launched on 7 October 2024, Hera is a planetary defence mission of the European Space Agency's (ESA) Space Safety programme. Its objectives are to investigate the Didymos binary asteroid and to measure in great detail the outcome of NASA's DART mission kinetic impactor test on its small moon, Dimorphos. Hera is the first mission to rendezvous with a binary asteroid and to probe the internal properties of an asteroid using radar tomography. It is also the first mission to visit a small body from which we already have an image of its original state, but whose properties have been modified by an impact in a way that remains to be discovered.

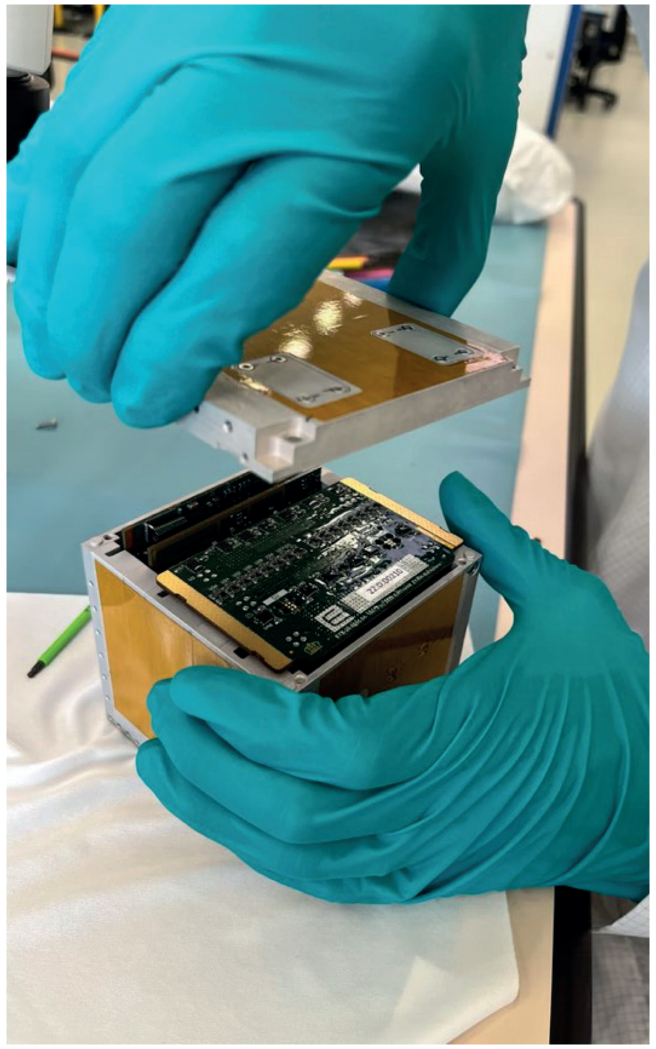
Any structural changes and morphological deformations will thus be due to the DART impact, and some alterations may still be ongoing. Measuring them precisely will deliver new insights into the collision process that plays a key role on all solar system bodies and in all phases of the solar system's history. This is also extremely valuable to calibrate deflection techniques aimed at impacting Earth-threatening asteroids.

Hera is also the first mission that includes a mother spacecraft and two cubesats for deep space exploration of an asteroid. In particular, the Juventas cubesat will conduct the first ever radar survey of an asteroid's interior with the JuRa low-frequency radar, for which the IPAG planetology and astrophysics institute of the Grenoble-Alpes University is the French principal investigator (PI). Data from this survey will be matched against the theoretical interpretations and models on which our current knowledge relies. Juventas will then land on Dimorphos and measure the gravity field of the asteroid with a gravimeter. The second cubesat, Milani, is carrying a near-infrared imager and a dust detector and analyser.

CNES is in charge of proximity operations for both Juventas and Milani, which will involve trajectory control and instrument operations, from their separation from the Hera mothercraft at the beginning of 2027 to asteroid landings. These operations will be conducted with industry partners (SpaceBel, GomSpace and Tyvak) and instrument teams (IPAG, Royal Observatory of Belgium, Helsinki University, Instituto nazionale di astrofisica and University of Bologna.

Hera is set to accomplish several technological feats:
- Navigating autonomously around a low-gravity asteroid, which is actually a binary system
- Using an inter-satellite link to support communications between the spacecraft and its two cubesats, a first in interplanetary space that will also be used with radio science to enhance our knowledge of the asteroid's gravity field.
- A cubesat has never landed on such a small body before. Proximity flight dynamics operations (as close as two kilometres) on a body approximately 150 metres in diameter involve determining trajectories in a very-low-gravity environment (thought to be a million times lower than on Earth) surrounded by uncertainties. In this respect, Hera is also a technology demonstration mission.

FIGURES
1 - Artist's view of the Hera satellite and its two cubesats © ESA
2 - JuRa low-frequency radar packaging © Credit: ESA/IPAG



While Hera is designed as a planetary defence mission, it will also contribute substantially to asteroid science as Patrick Michel (CNRS/Côte d'Azur Observatory), Hera's French PI, emphasizes. Hera will:

• Make the first rendezvous for a first comprehensive characterization of a binary near-Earth asteroid (NEA), noting that 15% of small asteroids are binaries, allowing a precise comparison with theoretical models and assessment of the binary NEA formation mechanism.
• Probe for the first time the subsurface and interior properties of an asteroid.
• Constrain the surface structure and regolith mobility on both Didymos and Dimorphos, thereby allowing a first insight into how material properties may affect asteroid satellite formation.
• Provide a remarkable opportunity to study the surface geophysics of two objects of different size and surface gravity, which probably formed from the same material.
• Obtain the first in-situ characterizations of the properties of an asteroid, Dimorphos, whose size (≈160 m) is at the frontier between gravity- and strength-dominated structures.
• Investigate an asteroid, Didymos, whose spin period of 2.26 hrs places it at the limit of stability.
• Allow, for the first time, the measurement of the outcome of an asteroid impact at an impact speed (≈6 km/s) similar to inter-asteroid collisions, including its surface and sub-surface properties.
• Characterize an impact outcome performed with known energy and initial conditions on a body 150 metres in diameter for the first time, allowing us to verify whether strength or gravity is the most influential parameter in crater production on such a small asteroid.
• Investigate the crater or asteroid reshaping produced by the DART impact for the potential identification of fresh unweathered material on a silicate asteroid to understand possible space weathering processes.
• Determine whether the crater resulting from the Small Carry-on Impactor (SCI) experiment performed by the Japanese space mission Hayabusa2 on asteroid Ryugu, which is larger than expected, is due to control by gravity as currently understood or a consequence of major flaws in current cratering theory in low-gravity regimes.

FIGURE
Artist's view of Dimorphos, Didymos, Hera spacecraft, Juventas and Milani cubesats © Photo Credit: ESA

@Gettyimages

3. Space plasmas in the solar system, including planetary magnetospheres

Kader Amsif

Heliophysics Programme Manager

“ The French Sun Heliosphere Magnetospheres (SHM) community is actively involved in several projects spanning the vast domain of the heliosphere. These projects cover solar physics, Earth's magnetosphere and environment, and the interactions between the Sun, solar wind, magnetosphere, ionosphere and thermosphere. Space weather is also a key component of this programme. ”

Interview

Looking back over your career, what has most marked you in your field of research?

In my work, I'm privileged to see projects flourish from conception to operational success. For me, each launch is a powerful moment when we relinquish control and our creation truly takes flight.

In your opinion, what are the best and worst aspects of your scientific field of research?

The most rewarding moments are those when we finally get to use the data, after overcoming all the obstacles. The hardest part is that, out of hundreds of projects, only a few actually succeed.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

In the short term, I believe that multipoint observation is the solution for analysing the temporal and spatial aspects of many events. This requires very-high-performance instruments, ideally smaller ones. I hope we'll have access to these resources soon.

SOLAR ORBITER

The mission of the European Space Agency's Solar Orbiter satellite is to study the Sun's heliosphere and observe it in unprecedented detail in an attempt to unmask the secrets of the solar wind.

KEY MILESTONES

2 September 2030
8th Venus gravity assist

10 June 2029
7th Venus gravity assist

17 March 2028
6th Venus gravity assist

24 December 2026
5th Venus gravity

18 February 2025
4th Venus gravity assist

October 2022
Perihelion less than 0.3 AU

3 September 2022
3rd Venus gravity assist

26 November 2021
Earth gravity assist

8 August 2021
2nd Venus gravity assist

February 2021
Perihelion less than 0.5 AU

27 December 2020
Venus gravity assist

15 June 2020
1st perihelion 77 million km

31 May and 6 June 2020
Solar Orbiter flies through tail of comet C/2019 Y4 (ATLAS)

10 February 2020
Solar Orbiter launched by Atlas V from Kennedy Space Center

September 2018
Spacecraft delivered for environmental testing in Germany

April 2012
ESA selects Astrium UK to build spacecraft

October 2011
ESA selects Solar Orbiter for its Cosmic Vision programme

KEY INFORMATION

MISSION
Observe the Sun

DOMAIN
Science

LAUNCH DATE
10 February 2020

WHERE
Elliptical orbit around the Sun with a perihelion of 42 million km and increasing inclination up to more than 30° with respect to the solar equator

LIFETIME
7½ years, with possible extension for a further 2.4 years

PARTNERS
ESA, NASA, CNRS

STATUS
In operation

KEY FIGURES

42	70	10	1,800
million km at closest perihelion	km/pixel spatial resolution	instruments	kg: spacecraft mass

PROJECT IN BRIEF

In 2020, the Solar Orbiter satellite departed Earth atop an Atlas V launcher on a mission to approach the Sun to within 62 solar radii or 42 million kilometres, closer than any spacecraft has ever been before. From this vantage point, it will be ideally positioned to observe our star at unprecedented resolution (70 km/pixel) and analyse its heliosphere in fine detail.
Solar Orbiter will also acquire imagery and data from the Sun's polar regions and on the side not visible from Earth. The main aim of these measurements will be to identify the underlying processes driving the solar wind, the stream of particles continuously escaping the Sun.
To accomplish this goal, Solar Orbiter will combine in-situ measurements in the satellite's immediate environment with remote-sensing observations.

CNES's ROLE

Solar Orbiter is a mission of ESA's Cosmic Vision 2015-2025 programme. ESA oversaw development of the satellite, which was launched by NASA. CNES was involved in building six of Solar Orbiter's ten instruments. The agency supplied the RPW instrument in partnership with the LESIA space and astrophysics instrumentation research laboratory at the Observatoire de Paris.

FIGURE 1
Artist's view of Solar Orbiter © ESA/ATG Medialab, 2019

SOLAR ORBITER

Kader AMSIF
Heliophysics Programme Manager

The Influence of Whistler Waves Revealed by Solar Orbiter and Parker Solar Probe

The electronic structure of the solar wind comprises three primary electron populations, each crucial to interplanetary space dynamics. The dominant core population consists of low-energy thermal electrons, making up nearly 95 percent of all solar wind electrons. Surrounding this core is the halo population, with suprathermal electrons capable of broad pitch angles. The Strahl population is the most directional, composed of highly energetic electrons travelling along magnetic field lines from the Sun. While these groups have been understood for decades, their evolution in interplanetary space remains partially explained.

Whistler-mode waves are a proposed mechanism for reshaping these populations. These electromagnetic waves, often observed in the inner heliosphere, have not been comprehensively assessed for their interaction with suprathermal electrons until recently. Their role in scattering Strahl electrons, broadening angular distributions, and isotropizing the halo was uncertain.

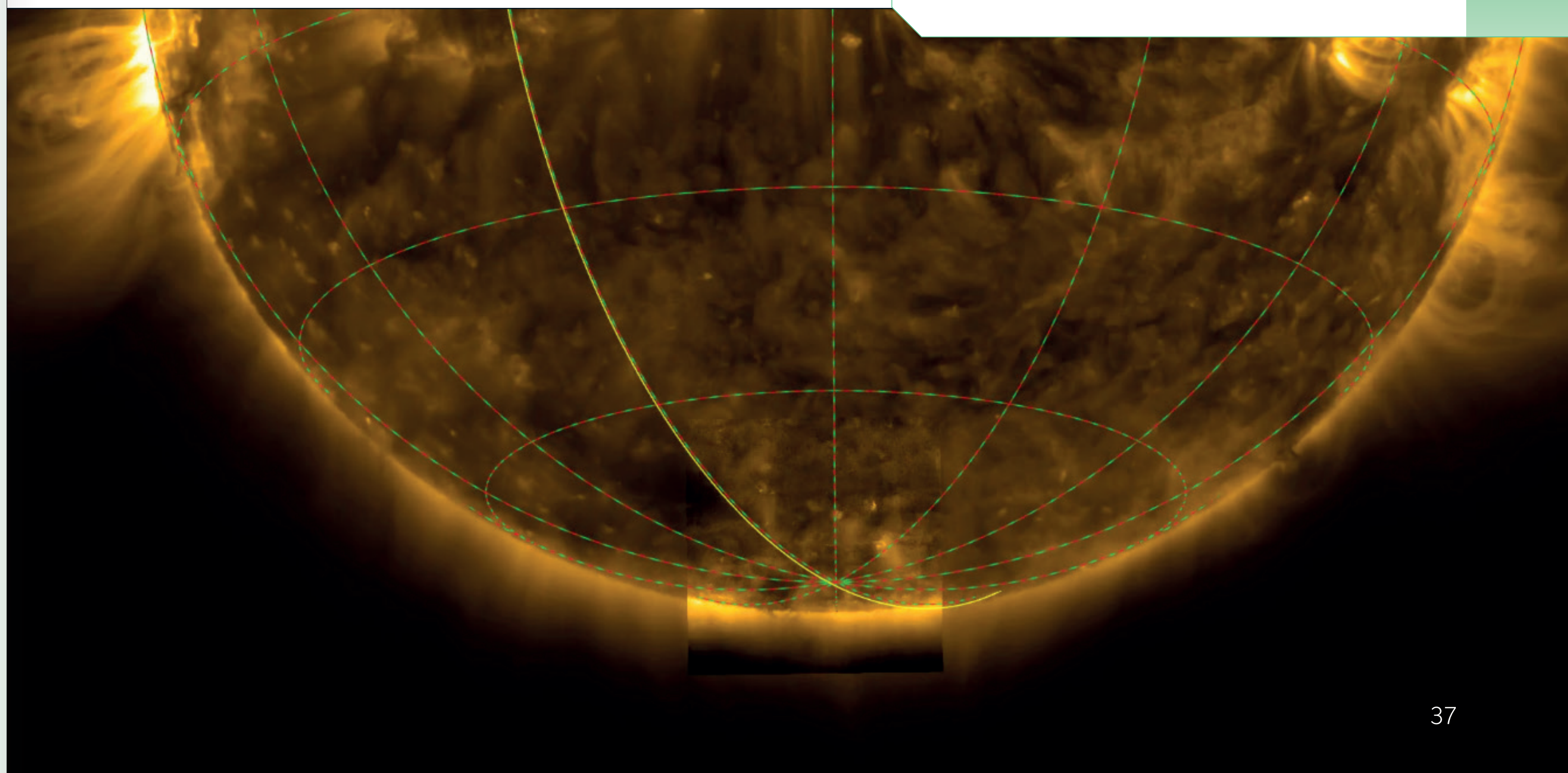
This knowledge gap has been narrowed by the Solar Orbiter and Parker Solar Probe missions. Equipped with the RPW instrument and FIELDS suite, respectively, these missions allowed researchers to analyse over 110,000 individual whistler-wave packets. The study, led by LPC2E, shows that whistler-mode interactions scatter Strahl electrons, reducing their field-aligned anisotropy, and redistribute halo electrons, contributing to their gradual isotropization as the solar wind moves away from the Sun.

For the first time, researchers characterised the key parameters of whistler waves: amplitudes, frequencies, and propagation angles relative to the magnetic field. These measurements quantified the efficiency of scattering mechanisms on suprathermal electrons, crucial for understanding how plasma processes scale to shape the solar wind's macroscopic structure, influencing energy distribution and electron evolution over vast heliocentric distances.

The French space agency (CNES) played a pivotal role in this discovery. CNES managed the RPW instrument's integration, testing, and delivery for Solar Orbiter and contributed to five additional instruments—SWA, EUI, STIX, SOPHI, and SPICE. CNES also provides financial and institutional support to French research teams analysing data from Solar Orbiter and Parker Solar Probe, ensuring the missions' scientific potential is fully harnessed through programs like the Research Proposal Call.

DID YOU KNOW?
The "Where is Solar Orbiter?" tool on ESA's website shows you where the satellite is now.
Go to website

FIGURE 2
Solar Orbiter's view of the Sun's south pole. ©ESA



PARKER SOLAR PROBE

The U.S. Parker Solar Probe launched on 12 August 2018 is the first spacecraft to venture into our star's outer atmosphere.

KEY MILESTONES

2023 to 2025
Closest flybys of the Sun

2018 to 2023
7 gravity assists from Venus

12 August 2018
Parker Solar Probe launched by Delta IV Heavy

May 2017
Mission renamed Parker Solar Probe

2014
Phase C/D of development

2008
Project refined, funded and renamed Solar Probe Plus

2004
Solar Probe project kicks off

KEY INFORMATION

MISSION
Study the Sun's corona

DOMAIN
Science

LAUNCH DATE
12 August 2018

LIFETIME
6.9 years

PARTNERS
NASA, CNRS, LPC2E, OBSPM/LIRA, IRAP, LPP, LAM, PROMES

WHERE
Elliptical orbit around the Sun with perihelion of 0.045 AU and aphelion of 0.73 AU

STATUS
In operation

KEY FIGURES

685
kg: spacecraft mass

4
instruments

7
gravity assists from Venus

6
contributing French laboratories

PROJECT IN BRIEF

Lofted into space by a Delta IV Heavy launcher, Parker Solar Probe received seven gravity assists from Venus to reach the Sun's corona. These successive gravitational boosts make it the fastest spacecraft of all time. It is also the first to study the solar wind in situ with its four suites of instruments (the solar wind is the stream of ions and electrons that our star ejects at high speed into interplanetary space). Parker Solar Probe plans to pass several times within less than seven million kilometres of the Sun's surface, exposing it to temperatures of 1,400°C.
One of Parker Solar Probe's main objectives is to characterize the different types of waves in the solar wind, between the spacecraft's perihelion (9.86 solar radii) and aphelion (55 solar radii). The nature of these waves and the dynamics of the solar wind are the keys to understanding how it is heated and accelerated. Other science goals include determining the nature of the sources—intermittent or otherwise—of the solar wind and the impact of wave activity on particle transport.
Fluctuations in the Sun's magnetic field are being measured by the spacecraft's SCM instrument (Search-Coil Magnetometer) designed and operated by the LPC2E environmental and space physics and chemistry laboratory. SCM is the only French—and indeed international—instrument on Parker Solar Probe.

CNES's ROLE

French research laboratories—the LPC2E environmental and space physics and chemistry laboratory, the LIRA space and astrophysics instrumentation research laboratory, the IRAP astrophysics and planetology research institute, the LPP plasma physics laboratory and the LAM astrophysics laboratory in Marseille—contributed to Parker Solar Probe's instruments, with support from CNES. The PROMES processes, materials and solar energy laboratory, which operates the solar furnace in Odeillo in the French Pyrenees, also worked on the mission, studying the behaviour at high temperatures of the parts of the science instruments not protected by the probe's solar shield.

PARKER SOLAR PROBE

Kader AMSIF
Heliophysics Programme Manager

Parker Solar Probe Observes the Source of Solar-Wind "Switchbacks"

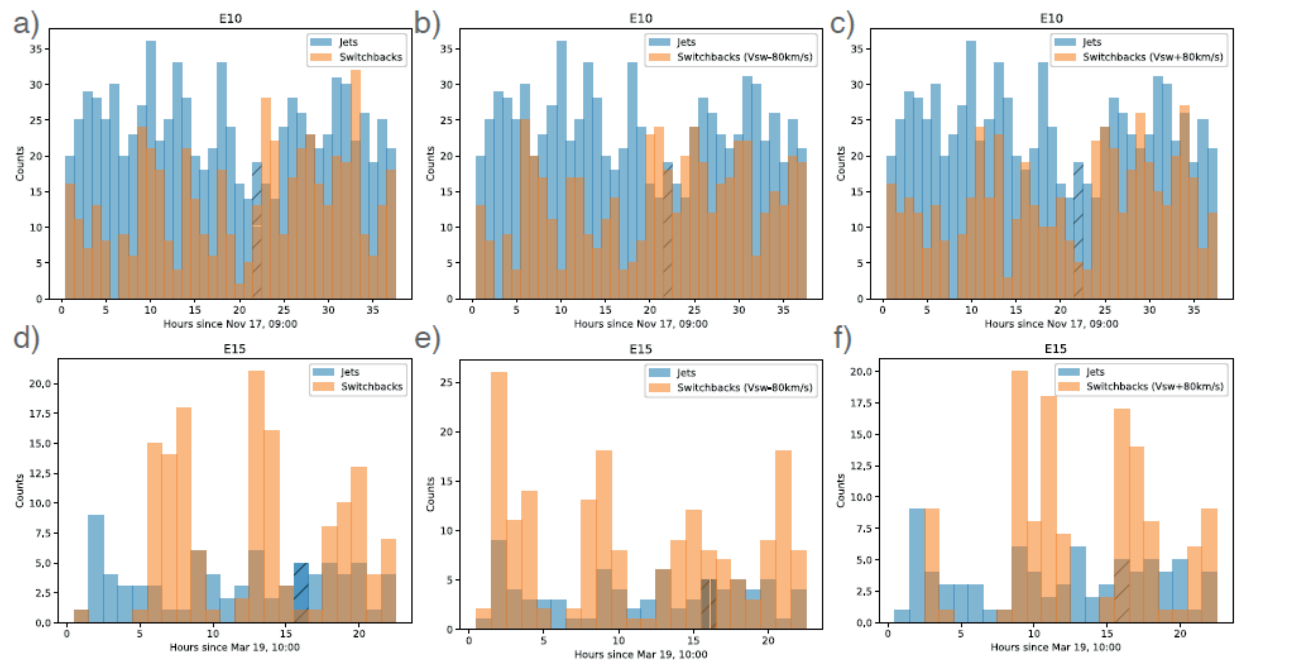
The origin of magnetic switchbacks, sudden and sometimes dramatic reversals of the solar wind's magnetic field direction, remains a significant mystery in heliophysics research. The Parker Solar Probe has revealed that these structures are prevalent throughout the inner heliosphere, appearing as large-amplitude deviations in in-situ magnetic-field measurements. Their widespread occurrence has led scientists to suspect that switchbacks may play a crucial role in the acceleration and heating of the solar wind. However, the mechanisms responsible for generating these features are still under active investigation.

One leading hypothesis suggests that switchbacks are linked to activity in the lower solar corona, a region bustling with small-scale, impulsive energy-release events. These events are often driven by magnetic reconnection, where magnetic field lines break and reconnect, releasing energy and forming coronal jets. In a recent study led by a French researcher, the possibility that such jets might act as either direct or indirect progenitors of magnetic switchbacks was examined in detail.

By correlating the Parker Solar Probe's magnetic-field observations with remote-sensing imagery of solar source regions, the team evaluated whether the occurrence of coronal jets aligned with the frequency of observed switchbacks. They discovered that periods of high jet activity often coincided with periods of frequent switchbacks, indicating a broad statistical relationship. However, a direct one-to-one temporal correspondence between individual jets and specific switchback events could not be firmly established. Several factors—such as the sensitivity limits of jet detection, the selection criteria for identifying switchbacks, and the complex geometry of the solar wind's source regions—complicate efforts to define a simple causal chain.

CNES has actively supported the French laboratories involved in the Parker Solar Probe mission, including LPC2E, LIRA, IRAP, LPP, and LAM, all of which contributed to the development of its scientific instruments. Furthermore, CNES provides long-term financial support to research teams analysing data from Sun-environment missions through its Space Research Support Program (PARS) as well as its Doctoral and Post-Doctoral Program (PDOC+).

FIGURES
1 - Artist's view of Parker Solar Probe © NASA/Johns Hopkins University Applied Physics Laboratory
2 - Histogram of jet and switchbacks counts. The hourly counts of jets are shown in blue and the corresponding counts of swichbacks in orange. The reference time corresponds to the start of the jet-counting interval. (a): E10 counts with constant velocity. (b): E10 counts with acceleration correction. (c): E10 counts with acceleration and Alfvén velocity. Each switchback bin, which is equivalent to the 1 hr. interval of solar eruptions, corresponds to counts over 50 min. (d), (e) and (f): Same as panels (a), (b), and (c) but for E15. The hashed bins correspond to the counts in figs. 1c and 2c, respectively. Each switchback bin, which is equivalent to the 1 hr. interval of CBP eruptions, corresponds to counts over 1 hr. 10 min. Bizien, N., et al.: A&A, 694, A181 (2025)



4. Research astrophysics from space

Philippe Laudet
Astronomy & Astrophysics Programme Manager

" CNES is pursuing an ambitious astrophysics programme. The main questions being addressed derive from the agency's Science Survey Seminar held in Saint-Malo in 2024. Understanding the origin and evolution of the universe, as well as the formation of stars, physics of galaxies, of the interstellar and intergalactic medium, high-energy physics... are major drivers for this programme. Working with research institutes and universities, the agency and its technical field centre are developing space instruments for cutting-edge international astrophysics missions and contributing to science data processing. "

Interview

Looking back over your career, what has most marked you in your field of research?

Explaining the universe to people and raising their awareness of it is an exciting and essential experience that I never tire of.

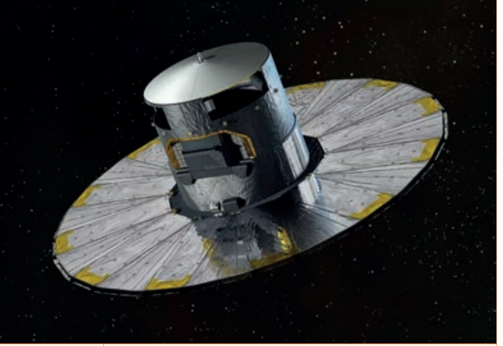
In your opinion, what are the best and worst aspects of your scientific field of research?

The best aspects are:
- confronting hypotheses or models against experimental measurements or observations
- by popularizing the sciences of the universe, astrophysics raises awareness and an infinite number of existential questions, while familiarizing us with the scientific methodology that Galileo taught us, and developing stimulating technologies.

The worst aspect is fundraising, which is very time-consuming.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

Understanding the laws of physics in the universe, quantum mechanics and general relativity, dark matter and dark energy.



GAIA

The ambitious goal of the Gaia spacecraft launched by the European Space Agency (ESA) in December 2013 is to chart a three-dimensional map of more than 1 billion objects in our galaxy with unprecedented accuracy. In so doing, it is seeking to tell us more about the mechanisms driving galaxy formation.

KEY MILESTONES

2030
Fifth and final Gaia catalogue released

2026
Fourth Gaia catalogue released

2025
End of satellite mission

10 October 2023
Focused Product Release

March 2023
ESA extends mission to second quarter 2025

13 June 2022
Third Gaia catalogue released

End 2020
ESA extends mission to end 2022

25 April 2018
Second Gaia catalogue released

End 2017
ESA extends mission to 31 December 2020

14 September 2016
First Gaia catalogue released

July 2014
Start of science mission

8 January 2014
Satellite inserted into orbit around Earth-Sun L2 Lagrange point

19 December 2013
Gaia launched by Soyuz-Fregat

25 May 2007
Management of Gaia data processing entrusted to Data Processing and Analysis Consortium (DPAC)

9 February 2006
Airbus Defence & Space (ex-EADS Astrium) appointed prime contractor

12 October 2000
Gaia project adopted by ESA

KEY INFORMATION

MISSION
Chart a three-dimensional map of part of the Milky Way and gauge the proper velocity of surveyed celestial bodies

DOMAIN
Science

LAUNCH DATE
19 December 2013

LIFETIME
Mission extended to 2025

PARTNERS
ESA, Airbus Defence & Space

WHERE
In orbit around the L2 Lagrange point (1.5 million km beyond Earth's orbit)

STATUS
In operation

KEY FIGURES

7	106	2,030	1.8	10,000
microarcsecond spatial resolution	CCD sensors	kg: satellite mass	billion stars surveyed	+ scientific papers published

PROJECT IN BRIEF

Launched on 19 December 2013, Gaia aims to survey 1 billion celestial objects to map part of our galaxy by estimating distances and velocities. It determines positions with unprecedented accuracy—within 7 microarcseconds. Gaia's observations will reveal the formation, structure and history of the Milky Way. The spacecraft is carrying two optical telescopes for precise positioning and light spectrum analysis. Three instruments work are onboard: BP/RP (Blue and Red Photometers) for star properties like temperature, mass and age; RVS (Radial Velocity Spectrometer) for celestial velocity; and an astrometer for position measurement. Initially scheduled for five years and extended multiple times, Gaia is ESA's sixth flagship mission. Airbus Defence & Space built the satellite. Data processing involves 430 scientists and engineers across 24 nations in the Gaia Data Processing and Analysis Consortium, with a significant technical and human resources contribution from CNES..

CNES's ROLE

Twenty-five CNES scientists in Toulouse develop essential algorithms for processing Gaia data. They extract meaningful information from raw observations, drawing on 15 years of astrometry expertise from the Hipparcos mission. In 2010, CNES adopted web technologies to handle massive datasets efficiently. The third Gaia catalogue, released June 2022, reflects CNES, French laboratories and Toulouse providers' dedication. Their teamwork ensures accurate data for studying our galaxy's formation and evolution worldwide.

GAIA

Philippe Laudet

Astronomy & Astrophysics Programme Manager

By combining data from the U.S. TESS satellite and the European Gaia space telescope, astronomers from the University of North Carolina at Chapel Hill have revealed that this cluster, known since antiquity as the "Seven Sisters" belongs to a structure 20 times larger, called the "Greater Pleiades Complex".

Most stars, including the Sun, are born in pairs within vast clouds of gas. But these original bonds weaken over time: stars drift slowly, scattered by galactic dynamics. Finding their "brothers and sisters" then becomes a major challenge for understanding how stellar systems are born and evolve.

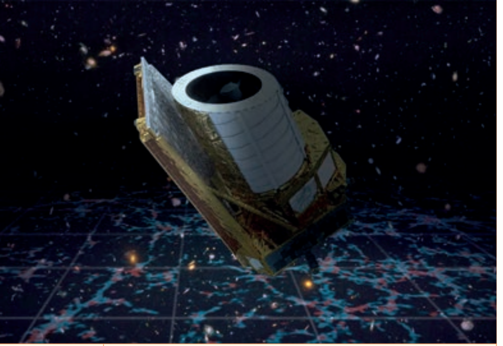
To achieve this, the team led by Andrew Boyle, a doctoral student at Chapel Hill, relied on a key physical property: rotation speed. "Young stars rotate quickly, older ones much more slowly," he explains in a press release. By measuring this rotation speed, the researchers were able to identify stars scattered across the sky that share the same age and origin as the Pleiades.

Data from TESS allowed scientists to determine the rotation periods of thousands of stars, while data from Gaia provided their precise positions and movements. By combining this information, the team was able to map a gigantic stellar structure extending far beyond the constellation Taurus. "What we saw as a small cluster was actually just the luminous core of a vast family of stars," summarizes Andrew Boyle.

"We realize that many stars near the Sun belong to large and complex families," explains Andrew Mann, professor of astronomy and co-author of the study. These groupings, difficult to identify using classical methods, become visible thanks to the combination of stellar rotation and the ultra-precise motion measurements provided by Gaia.

The stakes go beyond simply redefining a cluster; indeed, the goal is to better understand the conditions under which stellar and planetary systems are formed. If the Sun, too, originated from such an association, as several studies suspect, its "lost family" could one day be reunited. "By measuring how stars rotate, we can detect groups too scattered to be recognized otherwise," concludes Andrew Boyle.

FIGURES
1 - *Artist's view of the Gaia space telescope © ESA/DUCROS David, 2013*
2 - *The Pleaides or Seven Sisters cluster has been known since antiquity. Anglo-Australian Observatory/Dav / Bridgeman Images via AFP*



EUCLID

On 1 July 2023, the European Euclid satellite departed Earth on an extraordinary mission to map the large-scale structure of the universe in an effort to understand why it has been expanding at an accelerating rate for the last ten billion years. In so doing, it will be seeking to unveil the secrets of mysterious dark energy and dark matter. Thirteen French research laboratories are involved.

KEY MILESTONES

- **June 2030**
  Planned end of mission
- **June 2026**
  Publication of Data Release 1, covering one year of survey (2,500 deg^2)
- **March 2025**
  First data release, covering 50 deg^2
- **December 2023**
  Official start of mission
- **28 July 2023**
  Arrival at L2 Lagrange point
- **1 July 2023**
  Launch by Falcon 9
- **March 2022**
  Final assembly of satellite
- **20 June 2012**
  Project adopted by ESA

KEY INFORMATION

MISSION
Measure and study the effects of dark energy and gravity on the history of the universe's expansion and of the structuring of matter

DOMAIN
Science

LAUNCH DATE
1 July 2023

LIFETIME
6 years

PARTNERS
ESA, NASA

WHERE
L2 Lagrange point

STATUS
In operation

KEY FIGURES

40	2	170	1.2
contributing French laboratories	instruments	million Gb of planned data	m: diameter primary mirror

FIGURES
1 - Artist's view of Euclid © ESA/Euclid/Euclid Consortium/NASA
2 - Visualization of cosmic web reconstruction based on Euclid Q1 data release. Credits: C.Laigle

PROJECT IN BRIEF

Launched 1 July 2023, Euclid is ESA's second medium-class mission (M2) under the Cosmic Vision programme, selected October 2011 and adopted June 2012. Developed by Thales Alenia Space Italy, this astronomy and astrophysics mission focuses on cosmology. Euclid aims to unravel two cosmic mysteries: dark energy driving the universe's accelerating expansion, and dark matter providing gravitational glue for galaxy formation. Over its six-year nominal mission, Euclid will survey approximately one-third of the sky (under 15,000 square degrees), mapping billions of galaxies and cosmic structures back ten billion years. The mission is carrying two instruments—the Near Infrared Spectro Photometer (NISP) and VISible Instrument (VIS)—developed by an international consortium led by France's IAP/CNRS. Over 2,200 researchers across 250 laboratories in 16 countries are contributing (425 French researchers, 40 French laboratories). Using spectrometry and photometry in visible and near-infrared wavelengths (550 to 2,000 nm), Euclid will determine redshifts of observed sources. Beyond cosmology, Euclid's data will serve the global astronomy community for decades, providing new astronomical objects for study by telescopes including JWST, E-ELT, TMT, ALMA, SKA and Vera C. Rubin Observatory.

CNES's ROLE

CNES is part of the Euclid consortium and funding the 13 French research laboratories and institutes working on the VIS and NISP instruments. The agency also has a key role in the mission's ground segment.

EUCLID

Martin Boutelier
Fundamental Physics Programme Manager

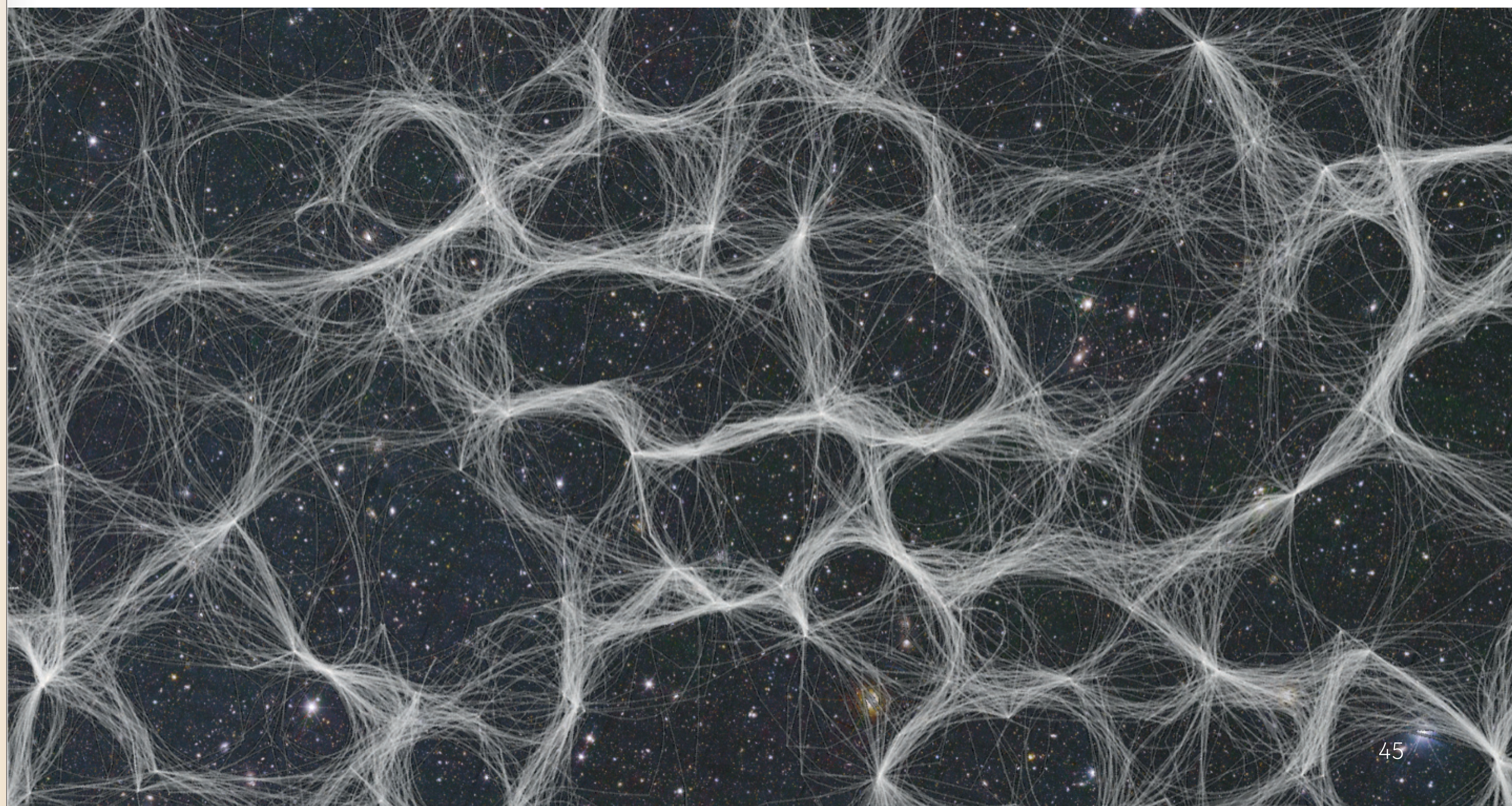
The Euclid mission, led by the European Space Agency (ESA), represents a monumental leap in our quest to understand the fundamental components of the universe. Launched on 1 July 2023, Euclid is designed to map the universe with unprecedented precision, focusing on two of the most enigmatic components: dark energy and dark matter. These components, which make up approximately 95% of the universe, remain largely unknown, and their study is crucial for advancing our understanding of cosmology.

On 19 March 2025, the Euclid Consortium published the first data release, known as the Quick Release (Q1). This milestone marks the public availability of the first scientific observations, providing a wealth of data for the scientific community. The Q1 data cover a sky area of approximately 63 square degrees, which represents about 0.45% of the total survey that will be published at the end of the mission. While this area is still too small to obtain the first cosmological results, it has already fuelled numerous astrophysical studies, leading to 34 scientific publications that appear in a special issue of Astronomy & Astrophysics. These publications demonstrate the incredible potential of the Euclid mission across a wide range of research fields.

The Q1 data have enabled the detection, identification and mapping of over 30 million objects, including a majority of galaxies, as well as quasars, brown dwarfs and even solar system objects. The data also include observations of part of the Orion Nebula, conducted to optimize the fine guidance system of the platform. This initial dataset not only showcases the quality and depth of Euclid's observations, but also serves as a foundation for future research and data processing.

One of the most significant results from the Q1 data concerns the link between galaxy morphology and the cosmic web. In the standard cosmological model (ΛCDM), galaxies are born, grow and evolve at the centre of dark matter halos that are not randomly distributed in the universe. Their properties, such as masses and morphology, are primarily determined by the mass of the dark matter halo and the history of its successive mergers. These mergers are closely linked to the distribution of matter in the universe, which forms a complex multi-scale network known as the cosmic web, composed of filaments that converge in galaxy clusters.

Galaxies develop by accreting matter from the cosmic web and are subject to interactions with other galaxies, which influence their shapes and orientations. A new study using Euclid's Q1 data reveals a correlation between galaxy morphology and their large-scale environment. Specifically, a signal indicating a preferential alignment



of the major axis of massive early-type galaxies along the cosmic filaments reconstructed from Euclid data has been detected. This finding demonstrates Euclid's ability to conduct detailed studies of galactic environments, with prospects for extension to higher redshifts and lower stellar masses in future deep surveys.

Among the numerous discoveries made possible by the Q1 data, gravitational lensing stands out as a particularly exciting area of research. Euclid has detected 83 strong gravitational lens candidates. Among them, a strong majority have been detected for the first time from space by Euclid, highlighting the telescope's excellent potential. In the long term, scientists hope to obtain a catalogue of approximately 4,500 gravitational lenses, which will provide invaluable insights into the distribution of matter in the universe.

One particularly exceptional example of a strong gravitational lens was spotted very early in the observations in the galaxy NGC 6505. This discovery is all the more remarkable because NGC 6505 is a very well-known galaxy that has been observed multiple times since the 1880s without ever revealing this structure. This phenomenon is predicted by general relativity and occurs when two massive objects, such as galaxies, are perfectly aligned with respect to our line of sight. The light emitted by the background galaxy is bent by the mass of the first galaxy, creating a ring structure known as an Einstein ring.

Studying the structure of this ring provides very important information about the visible and invisible matter (i.e., dark matter) present in the lensing galaxy. In this specific case, a dark matter fraction of approximately 11% was measured. This measurement not only confirms the presence of dark matter but also offers a unique opportunity to study its distribution and properties.

The Q1 data release is just the beginning of Euclid's mission. The upcoming DR1 data release, scheduled for October 2026, will cover a significantly larger portion of the sky, enabling scientists to obtain the first cosmological results. These results will be crucial for understanding the nature of dark energy and dark matter, as well as the evolution of the universe.

In addition to its primary goals, Euclid's data will continue to fuel a wide range of astrophysical studies, from the study of galaxy formation and evolution to the search for exoplanets and the exploration of the solar system. The mission's ability to conduct detailed studies of galactic environments and its potential for future deep surveys make it an invaluable tool for astronomers and cosmologists alike.

FIGURE 3
False-colour image combining data from the VIS and NISP instruments. The light from the central galaxy has been removed to better highlight the ring structure. Credits: Euclid ConsortiumCredits: C.Laigle

DID YOU KNOW?

Quick Data Release 1 (Q1), published on 19 March 2025, marks the first release of science data from ESA's Euclid mission. Three mosaics cover a vast area of the sky, including numerous galaxy clusters and active galactic nuclei, transient phenomena and the first classification survey of more than 380,000 galaxies and 500 gravitational lenses.
Euclid has scouted out these three areas in the sky where it will eventually provide the deepest observations of its mission. In just one week of observations, with one scan of each region so far, Euclid has already spotted 26 million galaxies. The farthest of these are up to 10.5 billion light-years away. The fields also contain a small population of bright quasars—the brightest objects in the universe—that can be seen much farther away.

SVOM

SVOM is a French-Chinese astrophysics mission to detect gamma-ray bursts, the most distant star explosions in the universe.

KEY MILESTONES

22 June 2024
SVOM launched by Long March 2C

March to September 2023
Environmental testing and validation of flight model

21 April 2023
French ECLAIRs and MXT instruments delivered to CNSA

11 September 2020
Critical Design Review signed off and start of phase D of development

8 December 2016
Start of phases CDE1 of development

March 2007
Start of phase A of development

25 October 2006
CNES and CNSA initiate SVOM project

KEY INFORMATION

MISSION
Detect and observe gamma-ray bursts

WHERE
In orbit at an altitude of 625 km

DOMAIN
Science

LAUNCH DATE
22 June 2024

PARTNERS
CNSA, CAS, CNRS, CEA

LIFETIME
At least 3 years + 2-year extension

STATUS
In development

KEY FIGURES

80 expected observations of gamma-ray bursts a year	**4** instruments	**950** kg: satellite mass	**10** contributing French laboratories

FIGURES
1 - Artist's view of the SVOM satellite © CNES
2 - Generated with Astropy using the Planck model (2018). Background adapted from © ESA, ©Planck Collaboration.

PROJECT IN BRIEF

SVOM (Space Variable Objects Monitor) is a joint mission of the China National Space Administration (CNSA) and CNES to observe gamma-ray bursts (GRBs) from a 625-kilometre Earth orbit. GRBs are some of the highest-energy phenomena known in the universe, generated from the explosion of massive stars more than 20 times the mass of our Sun, and from the merger of binary star systems composed of compact objects like neutron stars or black holes. The SVOM satellite is carrying four instruments, two of which were designed and built in France: ECLAIRs, a wide-field X-ray and gamma-ray camera; and MXT, a Microchannel X-ray Telescope. When ECLAIRs detects a GRB, the satellite is repointed within minutes to precisely target the event so that instruments with a narrower field of view (MXT and VT) can observe it. Alerts are also relayed to ground in less than one minute whenever a burst is detected, indicating the location of the GRB to cue large ground telescopes. This synergy between ground and space systems, allied to the multi-wavelength observations, is what makes the SVOM mission so special for scientists. China is in charge of the mission, launch, satellite and operations, and shared responsibility with France for design and construction of the instruments and ground segment. The French contribution was developed in partnership with research laboratories at the IRFU research institute at CEA, the French atomic energy and alternative energies commission, and at INSU, the national institute of universe science, and IN2P3, the national institute of nuclear and particle physics, both attached to the national scientific research centre CNRS.

CNES's ROLE

CNES was involved in system, satellite and payload definition studies and oversaw development of the French payload (ECLAIRs and MXT), as well as the alerting system (ground VHF network) and French components of the ground segment (payload monitoring centre and scientific expertise centres).

SVOM

Philippe Laudet
Astronomy & Astrophysics Programme Manager

On 14 March 2025, the French-Chinese SVOM satellite (Space-based multi-band astronomical Variable Objects Monitor) detected an exceptional gamma-ray burst, named GRB 250314A, originating from the far reaches of the universe. As soon as the alert was triggered by the ECLAIRs and GRM instruments, the satellite rotated and positioned its small-field X-ray (MXT) and visible (VT) instruments to observe this source, which, thanks to joint observations from several observatories and satellites, including the James Webb Space Telescope (JWST), would prove to be one of the most distant gamma-ray bursts ever recorded. GRB 250314A is a long gamma-ray burst, originating from the explosion of a star when the universe was only 730 million years old, and which travelled for nearly 13 billion years before being detected by our instruments. 110 days after its discovery by SVOM, JWST searched for the galaxy hosting this burst. Initial photometric analyses suggest it could be associated with a supernova resulting from the violent gravitational collapse of a massive star in its death throes, closely resembling local supernovae of the same type. This result could indicate a surprising continuity in the explosion processes of massive stars (> 20 solar masses), from the early universe to the present day.

SVOM is a French-Chinese satellite (see Figure 1) designed to detect the intense bursts of gamma radiation that briefly illuminate the sky: gamma-ray bursts (GRBs). Most of these phenomena, when they last several seconds, are linked to the collapse of very massive stars. Their afterglow, although it fades rapidly, can reach exceptional brightness in the optical and near-infrared wavelengths. This extreme brightness allows them to be observed at immense cosmological distances, making GRBs invaluable tools for exploring the early universe, the first galaxies and the very first stars. On 14 March 2025, at 12:56 UTC, SVOM detected a signal from deep within the universe using its ECLAIRs instrument. It immediately rotated to observe the source with its MXT and VT cameras, while the alert was transmitted in real time to other observatories via the VHF network. Swift, the Einstein Probe and several ground-based telescopes mobilized to locate X-ray, optical and infrared counterparts. An X-ray counterpart was quickly identified by Swift, and the Nordic Optical Telescope detected the near-infrared counterpart.

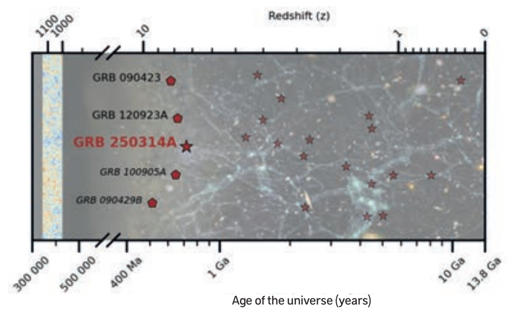
Observations multiplied: the Einstein Probe confirmed the transient nature of the source, a strong indication of a gamma-ray burst. While SVOM's instruments failed to detect the counterpart—possibly because the event was extremely distant—other observatories refined the location. The anticipation reached its peak when the Very Large Telescope obtained a spectrum of the object. Approximately 17 hours after the alert, a redshift of about z ~ 7.3 was detected, quickly confirmed by the Canary Islands Telescope.

Such a redshift means that the observed light was emitted when the universe was only 730 million years old. This gamma-ray burst could correspond to the death of one of the very first stars into a black hole. It is the fifth most distant gamma-ray burst ever detected (see Figure 2), and the third whose distance has been precisely measured using a spectrum, unlike other very distant GRBs assessed solely by photometry. This exceptional result sheds light on the origins of the universe.

To be absolutely certain, 110 days after the discovery by SVOM, JWST was deployed to observe the region of the sky where the burst had been detected. Using its NIRCam instrument, JWST revealed an emission in its reddest filters (see Figure 3). This luminous signature is interpreted as a combination of the host galaxy of the gamma-ray burst and the supernova resulting from the gravitational collapse of the massive star that gave rise to GRB 250314A. The shape and intensity of this emission strongly resemble those of local supernovae associated with gamma-ray bursts, notably SN 1998bw, linked to GRB 980425.

These initial observations suggest that the mechanism of massive star collapse, which gives rise to long gamma-ray bursts, is the same in the early universe as in the local universe, despite being separated by more than 13 billion years of cosmic evolution. Such a similarity would reinforce the idea that massive stars, even in the very early universe, died in the same way as those observed today near the Milky Way.

If this interpretation is correct, the supernova's brightness should naturally fade over time. To confirm this hypothesis, a new observation with JWST is already scheduled for nine months from now, which will allow scientists to verify the supernova's gradual disappearance and determine the exact origin of the observed signal.



XMM-Newton

Launched in 1999 and tipping the scales at 3,800 kg, XMM-Newton is the largest scientific satellite ever built in Europe, designed to observe X-rays across the universe.

KEY MILESTONES

31 December 2025
End of mission

10 December 1999
XMM-Newton launched by Ariane 5 G

March 1997 to September 1999
Construction and testing of telescope

1993
XMM-Newton project kicks off

KEY INFORMATION

MISSION	LIFETIME	LAUNCH DATE
X-ray astronomy	Initially 2 years, extended several times, most recently to 31 December 2025	10 December 1999
WHERE	**PARTNERS**	**DOMAIN**
40°-inclined elliptical Earth orbit (perigee: 7,000 km, apogee 114,000 km)	ESA, NASA, CEA, IAS, IRAP, Observatoire de Strasbourg	Science
		STATUS
		In operation

KEY FIGURES

- **3,764** kg: mass of space telescope
- **10** m x 16 m x 4 m: dimensions of space telescope
- **3** instruments
- **4** contributing French laboratories

PROJECT IN BRIEF

X-rays are emitted by the hottest known sources such as stars, hot interstellar gases, black holes, galaxies and galaxy clusters. The cameras on the XMM-Newton satellite (for X-ray Multi-Mirror) are the most sensitive yet built to detect them and its mirrors are among the most powerful ever developed for X-rays.
XMM-Newton was launched on 10 December 1999 from Kourou by an Ariane 5 vehicle. It's still operating today, circling Earth in a 48-hour, 40°-inclined elliptical orbit at a distance of 114,000 kilometres at its furthest point and 7,000 kilometres at its closest.
XMM-Newton is the 2nd cornerstone mission of the European Space Agency's Horizon 2000 programme. Some 2,000 astronomers all over the world use the telescope's data.

CNES's ROLE

CNES helped to fund the XMM-Newton mission through its contribution to ESA's mandatory scientific programme and directly through the national programme for France's contribution to the EPIC and ERMS instruments, and to the XMM-Newton Survey Science Centre (SSC).

FIGURE 1
Artist's view of the XMM-Newton space telescope © ESA - D. Ducros

FIGURE 2
Artist's depiction of a supermassive black hole surrounded by an accretion disk and emitting powerful jets of polar particles © Emanuela Tortosa

XMM-Newton

Philippe Laudet
Astronomy & Astrophysics Programme Manager

How could supermassive black holes, with masses ranging from several million to several billion solar masses, have formed so rapidly (in less than a billion years) in the early universe?

ESA's XMM-Newton and NASA's Chandra X-ray telescopes have observed 21 quasars with a redshift greater than 6 (whose distance is so great that they are seen as they were when the universe was less than a billion years old).

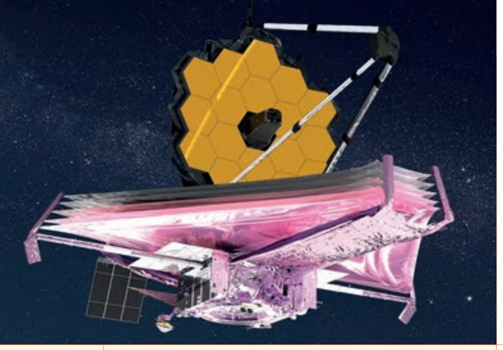
Quasars are active galactic nuclei, supermassive black holes that devour immense quantities of matter and whose surroundings emit large amounts of radiation and particles.

Contrary to some hypotheses involving the successive merger of small stellar black holes (a phenomenon that would take far too long to reach the observed masses), the data suggest that the supermassive black holes at the centre of these quasars could have attained their gigantic masses through a very rapid and very large accumulation of matter.
This study highlights a relationship between X-ray emission and the speed of particle winds ejected by these quasars.

The results indicate an extremely rapid growth phase, even exceeding a physical limit to matter accretion called the Eddington limit. This is why this phase is called "super-Eddington."

"Our work suggests that the supermassive black holes at the centre of the first quasars formed during the first billion years of the universe's life may actually have increased their mass very rapidly, defying the limits of known physics," explains Alessia Tortosa, lead author of the study and a researcher at INAF in Rome.

For further reading: A. Tortosa et al., HYPERION. Shedding light on the first luminous quasars: A correlation between UV disc winds and X-ray continuum, Astronomy & Astrophysics (2024).



JAMES WEBB SPACE TELESCOPE

MIRI is an infrared instrument on the James Webb Space Telescope (JWST), acquiring images in a range of wavelengths from 5 to 28 microns.

KEY MILESTONES

25 December 2021
JWST launched by Ariane 5 ECA

End 2016
Assembly of JWST

2009
Construction of JWST elements gets underway

End 2008
Transition to phase C of development

September 2002
Telescope named James Webb Space Telescope

2002
Transition to phase B of development

1995
Transition to phase A of development

1995
NASA extends mission of Hubble Space Telescope to 2005

1989 to 1994
Studies begin to develop successor to Hubble Space Telescope

KEY INFORMATION

MISSION
Observe the distant universe, galaxies, exoplanets and the solar system in the infrared

DOMAIN
Science

LAUNCH DATE
25 December 2021

LIFETIME
5 years

STATUS
In operation

PARTNERS
NASA, ESA, CSA, CEA, CNRS

WHERE
L2 Sun-Earth Lagrange point

KEY FIGURES

6,200 kg: mass of space telescope

4 instruments

6.5 metres: diameter of primary mirror

5 to 28 micrometres: range of observed wavelengths

PROJECT IN BRIEF

MIRI (Mid-Infrared Instrument) aboard the James Webb Space Telescope (JWST) succeeds the 1990-launched Hubble. Unlike Hubble's visible/ultraviolet observations, Webb analyses infrared radiation, enabling observation of distant, ancient objects including the first galaxies. Webb is carrying four instruments: MIRI, NIRISS, NIRCam and NIRSpec. MIRI was developed under ESA leadership with NASA's Jet Propulsion Laboratory. The international consortium includes the United Kingdom (Principal Investigator), France, Germany, Belgium, Denmark, Spain, Ireland, Netherlands, Sweden and Switzerland. MIRI comprises two main components: spectrometers by the Netherlands and UK, and the MIRIM imager developed in France under CNES by CEA, LIRA, LAM and IAS. MIRI features four observing modes: imaging, coronagraph, low-resolution spectroscopy and medium-resolution integral field spectroscopy. The Webb mission is led by NASA with the Canadian Space Agency and European Space Agency, which provided the Ariane 5 launch vehicle. ESA developed Ariane 5 adaptations, supplied NIRSpec and 50% of MIRI. With enhanced performance, Webb surveys the sky approximately 13.5 billion years in the past, observing star formation and exoplanets. Unlike Hubble, Webb orbits the L2 Lagrange point of the Earth-Sun system.

CNES's ROLE

CNES oversaw development of the MIRI instrument's MIRIM imager in partnership with the prime contractor CEA, with contributions from the LIRA space and astrophysics instrumentation research laboratory, the LAM astronomy laboratory in Marseille and the IAS space astrophysics institute.

FIGURE 1
Artist's view of the James Webb Space Telescope © NASA GSFC/CIL/Adriana Manrique Gutierrez, 2021

JWST

Christian Mustin
Exobiology, Exoplanets and Planetary Protection Programme Manager
Philippe Laudet
Astronomy & Astrophysics Programme Manager

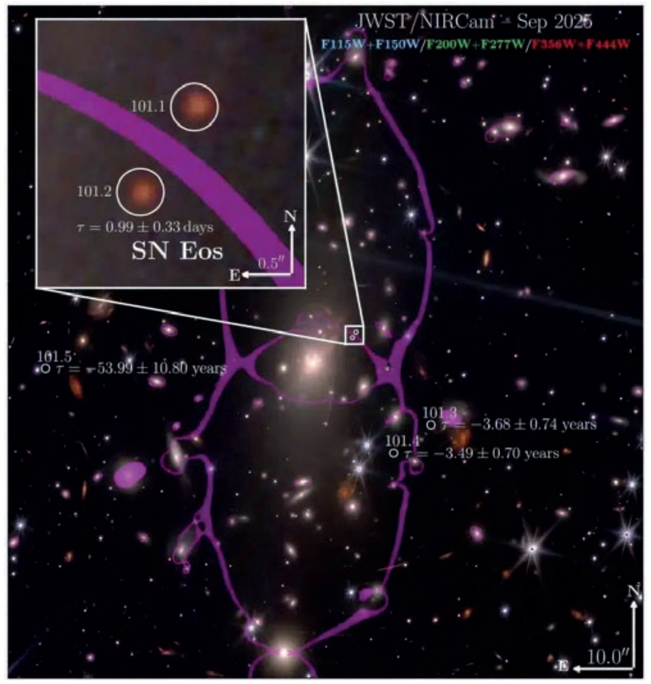
It's a ghostly message that took over 12 billion years to reach us. In the vast blackness of the cosmos, the James Webb Space Telescope (JWST) has just captured the dying glow of a massive star that exploded as a supernova when the universe was still in its infancy. Named "Eos" by astronomers, in homage to the Greek goddess of the dawn, this supernova offers a rare glimpse into the primordial chemical composition of our world, long before the formation of Earth.

Observing an individual star at such a distance is theoretically impossible, even for the powerful JWST. The object is too far away, too small and too faint. To achieve this feat, scientists had to rely on cosmic help: gravitational lensing.

This phenomenon, predicted by Einstein, occurs when an extremely massive object (such as a galaxy cluster) lies between the observer and the target. The cluster's gravity is so strong that it distorts the fabric of spacetime, acting like a giant magnifying glass. The light from the distant star is thus bent and amplified, making it visible to our instruments.

This discovery confirms our theoretical models: the first stars were primarily composed of hydrogen and helium. It is precisely these titanic explosions, like that of Eos, that gradually "polluted" the cosmos by dispersing the heavy elements (calcium, iron, gold) that today constitute the planets and... our own bodies.

FIGURE 2
Credit: Coulter et al. / JWST. Supernova SN Eos was observed within the galaxy cluster MACS 1931.8-2635, visible here. The magenta area delineates the region amplified by the cluster's gravity. The supernova appears twice (numbered 101.1 and 101.2) due to gravitational lensing.



It is thanks to this perfect alignment that JWST was able to capture images of the supernova on 1 September and 8 October 2025. The event occurred only a billion years after the Big Bang, a pivotal moment when the universe was just beginning to ignite and take shape.

Analysis of the light from Eos, detailed in a study published on the preprint server arXiv, reveals crucial information about the chemical "cooking" of the early universe. Astronomers have determined that it was a type II supernova, that is, the violent collapse of the core of a massive star (at least 8 times the mass of our Sun).

What fascinates researchers is the purity of this star. Unlike our Sun, which is a recently formed star rich in recycled "waste" from older stars (iron, carbon, oxygen), Eos formed in an almost pristine environment. Spectral analysis shows that it contained less than 10% of the heavy elements found in our Sun.

Detailed study of the light curve allowed Eos to be classified as a Type II-P supernova. The "P" stands for "Plateau." Unlike other explosions that dim rapidly (Type II-L), Eos's luminosity remained intense and stable for a long period after the explosion's peak, before slowly declining.

This technical characteristic is invaluable: it allows astronomers to deduce the mass and structure of the star's hydrogen envelope before its death. It is a crucial piece of the puzzle for understanding how these giant stars lived and died in an era when the rules of the galactic game were slightly different than they are today.

As the study's authors point out, Eos is just the beginning. The discovery proves that JWST is capable of tracking the deaths of the very first stars. By multiplying these observations, we will soon be able to reconstruct the full story of the chemical enrichment of the universe, from the simplicity of the Big Bang to the complexity of life on Earth.

5. Life Sciences related to space

Guillemette Gauquelin-Koch

Head of Life Sciences

" Since the first human spaceflight in 1961, 650 people have ventured into space. This number is rapidly growing and, as human space travel ramps up, the need to understand physiological adaptations to this new environment remains greater than ever. Regular missions to low Earth orbit are currently ongoing, and future missions set to go further afield and for longer periods are being planned.
Extensive scientific research is needed to both understand the underlying mechanisms behind these changes and develop effective countermeasures to prevent them. However, space agencies and the scientific teams working with them are faced with several issues. First, the number of astronauts, while increasing yearly, is still insufficient to gather extensive medical and scientific data. Second, for technical and scheduling reasons, extensive medical research in space is scarce. As a result of this, space agencies have promoted Earth-based models reproducing the effects of microgravity on the human body. Two models are long-term head-down bedrest (HDBR) and dry immersion (DI). This model helps scientists understand underlying mechanisms behind observed physiological changes and develop means to prevent them. "

Interview

Looking back over your career, what has most marked you in your field of research?

Having worked with many nationalities, it's very interesting to adapt to their very different ways of working.

In your opinion, what are the best and worst aspects of your scientific field of research?

The best aspects are the constant questioning, the sometimes surprising results, and the most negative is the constant search for funding.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

With technological progress, it's obvious that many diseases will be treatable in a few years, but unfortunately others will emerge.

DRY IMMERSION MODEL:
from Spaceflight Physiology to Clinical Translation

—

Guillemette Gauquelin-Koch
Head of Life Sciences

—

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Microgravity induces multisystem deconditioning in astronauts, including orthostatic intolerance, muscle and bone loss, metabolic changes and sensorimotor alterations. Because opportunities to study these syndromes in orbit are limited, the medical and scientific communities rely on ground-based analogs. Head-down bedrest (HDBR) and dry immersion (DI) are the two models of microgravity most used. DI consists of immersing a subject up to the neck in thermoneutral water while separated from the water by an elastic waterproof sheet. The subject is freely suspended and experiences a drastic decrease in apparent weight with almost complete support unloading ("supportlessness"), pronounced thoracic fluid shift and extreme hypoactivity. This short review focuses on the contribution of DI campaigns at the MEDES space clinic (Toulouse, France) for CNES and ESA, and on how this space research model could be translated into innovative therapeutic strategies for patients on Earth.

1) Dry immersion as a microgravity analog

Historically developed in Russia in the 1970s, DI rapidly reproduces most spaceflight-induced changes across neuromuscular, cardiovascular, metabolic and sensorimotor systems. Compared with the HDBR model, DI is characterized by support unloading which accentuates postural muscle deconditioning [1,2].

2) Ten years of using this model in MEDES France with CNES and ESA

As part of French–Russian cooperation, this model was installed at MEDES/CNES and several campaigns have been carried out over the past ten years: a three-day DI without countermeasure (2015), a five-day DI to study the effects of thigh cuffs as a countermeasure (2018-2019), and the Vivaldi programme with ESA to produce an extensive mapping of the deconditioning induced by five days of immersion in women (Vivaldi I – 2021) and in men (Vivaldi II – 2022). With the Vivaldi III study (2025), the aim is to compare the dry immersion and head-down bedrest models over a 10-day period.

• Three days of strict DI in 12 men at MEDES caused a sharp reduction in orthostatic tolerance to combined tilt + lower body negative pressure (LBNP) test (from about 27 to 9 minutes), markedly impaired glucose tolerance with a ~70% increase in net insulin response, reduced leg muscle tone, altered day-night variations in potassium excretion and increased cortisol levels.

• In the five-day DI with and without thigh cuffs (n = 18 men) we showed a 15–20% loss of plasma volume and a 3–6% reduction in total body water (mainly from the extracellular compartment), together with pronounced orthostatic intolerance. Venoconstrictive thigh cuffs slowed down and limited body water loss, tended to limit plasma loss, but did not counteract orthostatic intolerance. Spine MRI revealed increased thoracic and lumbar intervertebral disc height and reproduced the spinal changes seen in astronauts. Finally, marked muscle deconditioning was observed with reduced knee extensor strength and a ~22% decrease in muscle fibre cross-sectional area [3,4,5].

• From the Vivaldi I and II studies we observed comparable multisystem changes in both sexes. However, women showed lower tolerance to simulated gravity stress after immersion, greater elevation of the atherogenic index, more signs of reduced insulin sensitivity, and, to some extent, stronger bone-resorption markers. These findings support the development of sex-specific strategies to protect astronaut health during space missions [6].

Dry immersion may have different mechanisms of effects on cerebral and ocular hydrostatic pressures compared with strict HDBR, but is generally considered to induce faster and deeper deconditioning, making it a very useful model for shorter studies and countermeasure testing.

3) From space clinic to patients: potential clinical and therapeutic applications

DI shows strong potential in healthcare. Short DI sessions induce marked diuresis, reduce muscle spasticity and relieve pain linked to muscle hypertonia, with no reported side effects. Taken together, these effects suggest that DI could become an effective, low-cost, non-pharmacological option for refractory oedema, and a useful co-treatment in cerebral palsy and post-stroke rehabilitation. DI has also been proposed to alleviate muscle rigidity in Parkinson's disease. Its effect on the centralization of fluids and blood flow could have therapeutic applications by promoting the perfusion of abdomino-pelvic organs. Overall, its effects on body fluid compartments and blood flow distribution make it a particularly suitable model for studying drug pharmacokinetics.

Dry immersion reproduces the main features of spaceflight-induced deconditioning in both men and women. Over the past 10 years, several experimental campaigns at MEDES in France have greatly expanded and refined the use of this model. The next step is to strengthen the evidence base and regulatory framework needed to validate dry immersion as a clinical therapeutic tool and to integrate it safely into patient care.

b

RERENCES

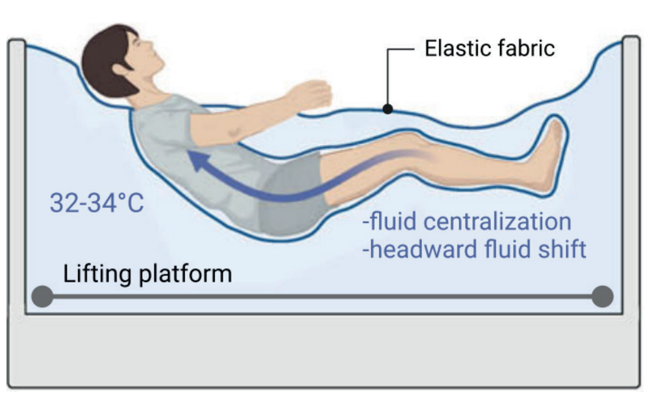
1- *Navasiolava NM, et al. Long-term dry immersion: review and prospects. Eur J Appl Physiol. 2011;111(7):1235–1260.*
2- *Robin A, et al. DI-5-CUFFS: venoconstrictive thigh cuffs limit body fluid changes but not orthostatic intolerance induced by a 5-day dry immersion. Front Physiol. 2020;11:383.*
3- *Tomilovskaya E, et al. Dry immersion as a ground-based model of microgravity physiological effects. Front Physiol. 2019*
4- *Fovet T, et al. Early Deconditioning of Human Skeletal Muscles and the Effects of a Thigh Cuff Countermeasure. Int J Mol Sci. 2021 Nov 8;22(21):12064.*
5- *Robin A, et al. Spinal changes after 5-day dry immersion as shown by magnetic resonance imaging (DI-5-CUFFS). Am J Physiol Regul Integr Comp Physiol. 2022;323:R310–R318.*
6- *Robin A, et al. Comprehensive assessment of physiological responses in women during the ESA dry immersion VIVALDI microgravity simulation. Nat Commun. 2023;14:6311.*

FIGURES
(a) *Vivaldi III mission patch*

Implementation of the DI model.
(b) *DI bath in the MEDES space clinic (Toulouse, France).*
(c) *Schematic representation of a participant in the DI bath.*
Credits - [6] . http://creativecommons.org/licenses/by/4.0/

a

c



Airbus Zero-G A300 – vol parabolique (vue d'artiste) © ESA

6. Material and Fluid Sciences in Space Conditions

Guillaume Legros

Materials Science Programme Manager, researcher on combustion

" CNES's physical sciences programme gives French research laboratories the opportunity to do science in microgravity conditions. This programme especially covers airborne weightlessness campaigns providing about 100 periods of 22 seconds of microgravity each. In addition, casual campaigns at intermediate gravitational levels, e.g. lunar or Martian ones, are also organized. When longer periods of microgravity are required, after validation of the prototype we look for international opportunities to share our knowledge and access experiments in sounding rockets or on the ISS, most of the time through ESA. CNES has also been developing some instruments with bilateral partners, such as to measure convection, sedimentation or buoyancy. The broad goal of physical sciences in microgravity is to understand the self-organization of matter together with heat and mass transfer fundamental processes. Depending on the fields investigated, the issues raised may have exploration-related ambitions. Those covered by CNES include physics of fluids, complex materials, biophysics, phase changes, heat transfer and combustion. "

Interview

Looking back over your career, what has most marked you in your field of research?

More than specific moments, I now realize how meaningful CNES's continuous support has been through the years. From our initial trips to JAXA with Bernard Zappoli, head of the physical sciences in microgravity at CNES 10 years ago, up to the ERC Synergy grant awarded to our investigations on fire mitigation in crewed spacecraft, I believe our agency can help to identify, create and develop fields of scientific expertise at international level.

In your opinion, what are the best and worst aspects of your scientific field of research?

I have to admit that bringing together scientific experts to work on a hot topic may turn out to be a big gamble given the way funding for fundamental sciences is going. That said, the French research framework is sustained by the status of government employees, which allows CNES or other national agencies to build long-term expertise.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

Outstanding experiments were identified as top priorities at the latest Science Survey Seminar (SPS) in 2024, some of them within the sphere of matter sciences in microgravity at CNES. Hopefully the end of operations on the ISS will not jeopardize these ambitions. To illustrate, the dynamics of condensation in clouds or wave turbulence are fields that expect major breakthroughs through experimental projects supported by CNES.

PARABOLIC FLIGHTS

With the Airbus A310 Zero G operated by its subsidiary Novespace, CNES possesses an ideal and inexpensive way to perform science in microgravity. Experiments in microgravity conditions also serve to test out systems and equipment before sending them into space.

KEY MILESTONES

2019
30 years of parabolic flights and new livery for A310 Zero G aircraft

5 May 2015
A310 Zero G makes first parabolic flight for scientific research

June 2014
Novespace buys Airbus A310 and outfits it as A310 Zero G

1995
Novespace buys Airbus A300 and outfits it as A300 Zero G

1986-1995
Science campaigns organized on Caravelle Zero G at Brétigny flight test centre

8 July 1986
CNES creates Novespace subsidiary

FIGURE
Scientists conduct experiments in weightlessness on a zero-g flight
©CNES/PEDOUSSAUT Manuel, 2008

KEY INFORMATION

MISSION Observe physical, chemical and physiological phenomena in weightless conditions, test science and technology experiments on parabolic flights	**DOMAIN** Science **START DATE** 1988 **PARTNERS** Novespace	**WHERE** Airbus A310 Zero G **LIFETIME** Indefinite **STATUS** In operation

KEY FIGURES

22 seconds of weightlessness	**3** hrs: duration of flight in Zero G aircraft	**31** parabolas flown per day	**100** m²: cabin area available for experiments

PROJECT IN BRIEF

The Airbus A310 Zero G operated by CNES subsidiary Novespace is not an ordinary aircraft. It recreates weightless conditions for 22 seconds at a time, so passengers can observe physical and physiological phenomena otherwise masked by gravity on the ground, only at much lower cost than in space. For example, scientists can study how the human heart works, how neurosensory perception adapts to weightlessness, analyse fluid properties or observe how a material behaves at high temperature. Such experiments also serve to test out systems and equipment before sending them into space. To create these weightless conditions, the A310 Zero G flies a series of 30 bell-shaped parabolic trajectories on each sortie. Specially fitted out for this type of flight, the aircraft is used by CNES for its parabolic flight programme, initiated in 1988. Every year, CNES conducts two parabolic flight campaigns, each comprising three flights. Each flight carries a dozen science and technology experiments. The A310 Zero G also flies parabolas simulating lunar and Martian low-gravity conditions to prepare for future exploration missions to the Moon and Mars.

CNES's ROLE

Novespace (CNES subsidiary, 1988) owns the A310 Zero G, maintained by Sabena Technics. It organizes campaigns with ESA and CNES (2/year), DLR (3/2 years), plus NASA and JAXA. AirZeroG offers discovery flights since 2013. French campaigns serve CNRS, Inserm and university research labs.

PARABOLIC FLIGHTS

Thierry Bret-Dibat
Head of Science and Exploration Department
Guillaume Legros
Material Science Programme Manager

Since 1988, the French space agency CNES has offered the French scientific community parabolic flight campaigns, primarily for life sciences and material sciences, as well as fundamental physics and technology validation. These campaigns provide the opportunity to develop a full-fledged scientific programme or prepare for longer-duration experiments in sounding rockets or the International Space Station (ISS).

These campaigns are organized and operated by Novespace, a CNES subsidiary, currently using its Airbus A310 Zero-G. Novespace also organizes campaigns on behalf of ESA and DLR. To achieve weightlessness, the A310 Zero-G performs "parabolas," flying bell-shaped trajectories. During a single flight, the aircraft performs about 30 parabolas providing 22 seconds of microgravity. Every year, CNES conducts two parabolic flight campaigns, each consisting of three flights. Each flight carries a dozen of scientific and technical experiments. Notably, the A310 Zero-G can also fly parabolas at non-zero reduced gravity, such as lunar or Martian gravity, to prepare for future exploration missions to the Moon and Mars.

Among the dozen experiments conducted in recent years in matter sciences in microgravity:

• Cell Culture in Acoustic Levitation and Microgravity
This study focuses on the activity of 2D or 3D neuron networks in microgravity and manipulating objects with dimensions close to the acoustic wavelength using acoustic force. For 2D or 3D neuron networks, the goal is to study the influence of gravity changes and acoustics on their activity.

Publication Reference: P. E. Lecoq, C. Dupuis, G. Viraye, X. Benoit-Gonin, J.-M. Peyrin, J.-L. Aider, Microgravity stimulates network activity of 3D neuronal spheroids in an acoustic trap, Nature Microgravity, 2024, doi: 10.1101/2024.07.03.601873

• AEROSOL
This project develops an insert for conducting experiments on aerosols. Aerosols are naturally influenced by gravity, which determines particle sedimentation rates. When particle mass becomes sufficiently large, gravity dominates, making it impossible to precisely study their mutual interactions over long periods. Conducting experiments in microgravity is essential for understanding aerosol evolution mechanisms. Temperature, pressure conditions and hydrodynamics are fundamental, raising questions about heat and mass transfer mechanisms. An instrument for a space experiment is under study.

Publication Reference: Charles Graziani, Mathieu Nespoulous, Renaud Denoyel, Stefan Fauve, Christian Chauveau, Luc Deike, Mickaël Antoni, A new experimental set-up for aerosol stability investigations in microgravity conditions, Comptes Rendus de l'Académie des Sciences, 2023. doi: 10.5802/crmeca.159

• Propagation Modes of Slow Flames under Pressure
This experiment characterizes ignition and propagation conditions of weakly reactive mixtures in microgravity, quantifies heat release rate and studies radiative effects. Experimental campaigns combine parabolic flights (DLR/CNES) and drop towers in Bremen (ZARM), allowing complementary exploration of thickened and slow flames. Results will provide reference data for space environment safety standards and improve combustion understanding in reduced gravity.

Publication Reference: S. Zitouni, R. Glaznev, H. Pitsch, J. Beeckmann, P. Brequigny, C. Mounaim-Rousselle, F. Halter, Accounting for buoyancy and ignition influence in the experimental measurement of laminar flame speeds and Markstein lengths from spherical ammonia/air flames, Proceedings of the Combustion Institute, 2025

• Rheology of Blood
Blood is a complex suspension of deformable red blood cells in plasma. Circulatory consequences of reversible red blood cell aggregation remain poorly understood, particularly in low or transient shear regimes and pathological contexts. Under microgravity, blood stagnation or retrograde flow have been observed

Publication Reference: M. Puthumana Melepattu, G. Maîtrejean, C. Wagner, T. Podgorski, Influence of erythrocyte density on aggregability as a marker of cell age: Dissociation dynamics in extensional flow, Journal of Biomechanics, 2025, doi: 10.1016/j.jbiomech.2025.112603

COMBUSTION AND FIRE SAFETY

Thierry Bret-Dibat & Guillaume Legros
Head of Science and Exploration Department
Material Science Programme Manager

COMBUSTION AND SPACECRAFT FIRE SAFETY

The objectives of scientific research into combustion in microgravity are primarily to increase knowledge of the fundamental phenomena that control combustion, and then to use the findings to advance technologies for controlling combustion.

Combustion processes at Earth gravity are generally strongly influenced by natural convection. Microgravity research allows new experiments to be conducted in which gravity-induced flows and sedimentation are practically eliminated.

Fire represents one of the major risks for crews in space exploration missions. Understanding the effects of gravity on the processes of triggering and propagating fire is therefore essential, particularly within a context where human exploration is taking on an new dimension through the U.S. Artemis exploration programme.

Among others, studies have been conducted on the propagation, detection and control of an established flame in microgravity on small, cylindrical configuration samples. These studies, conducted in parabolic flights and combined with modelling of the phenomena governing fire spread, have made it possible to develop optical techniques for detecting soot particles, to better understand the impact of the surrounding conditions (chemical composition, pressure, ventilation speed) that can lead to flame extinction and to assess the effectiveness of retardants.

An international team has been collaborating on this subject for more than 10 years. More specifically, some of the partners, mainly Japanese and French scientists, have measured the effects of microgravity on the propagation speed of flames along electrical wires and on the limiting oxygen concentration of the atmosphere over which a fire can spread. During a flight campaign allowing different gravitational levels to be set, the scientists showed that electrical wires made of a metallic core of lower thermal conductivity, such as nickel chrome alloy, become more flammable as the level of gravity is decreased. These results, illustrated in Fig.1, were rewarded in June 2024 with a Distinguished Award Paper at the 39th International Symposium on Combustion. To refine the assessment of the energy balance that drives the potential of this flame to spread, a major step has been bridged with the aid of a numerical tool able to predict soot production. As shown in Fig.2, the field of soot volume and temperature within the flame can then be decently computed, enabling the distribution of the radiative heat feedback to be evaluated, mainly attributed to soot radiative intensity, along the burning sample.

Parabolic flight experiments, involving participation in a dozen campaigns over several years, have been of great value in preparing JAXA's SCEM experiment scheduled on the ISS in 2026. The cooperation between the Japanese and French scientific teams has made it possible to optimize the experimental protocols and diagnostic settings in parabolic flights. The context of SCEM is essentially fire safety for exploration, notably in view of the ambition for a high oxygen content (~35%) in the atmosphere of future spacecraft.

ROLE OF CNES

CNES funds the team of French scientists through its yearly Research Call for Proposals, in particular to develop hardware, and offers the opportunity for the experiment to fly aboard the Airbus A310 operated by Novespace. This support was crucial to evidence the scientific scope of the work, leading to the success of FireSpace, a European project awarded an ERC Synergy grant in 2025. Two of the four FireSpace PIs were initially funded by CNES.

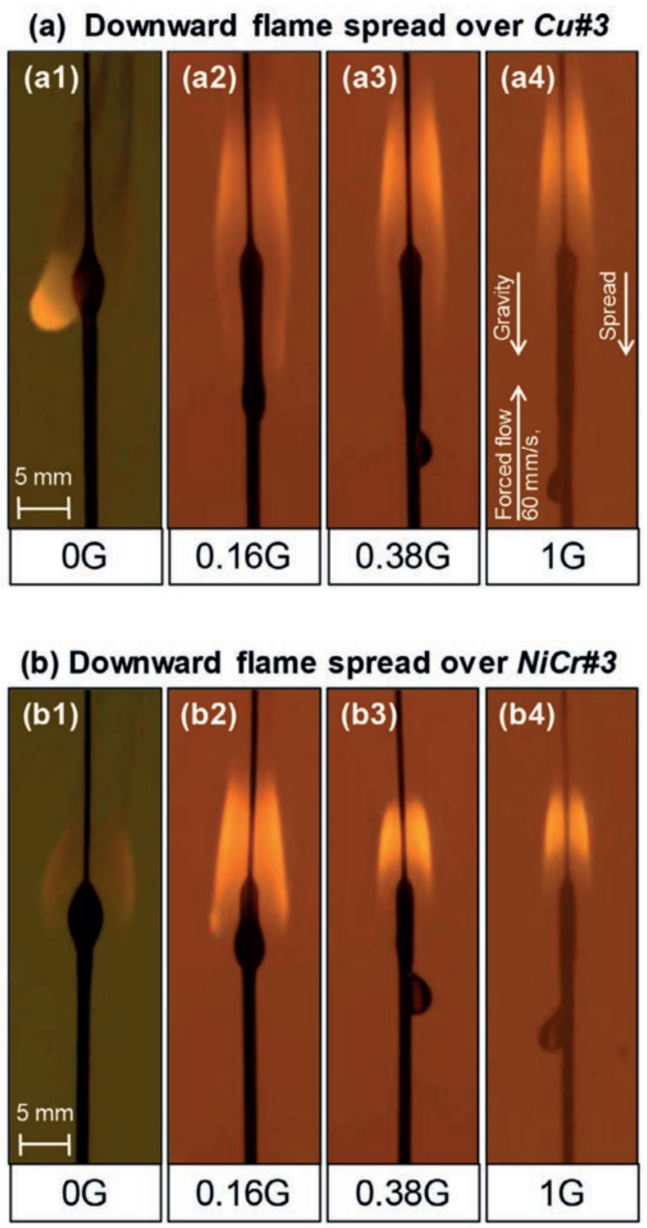


FIGURE 1
*Flames spreading at different levels of gravity in an opposed flow over the polyethylene coating of an electrical wire with the metallic core made of **(a)** copper; **(b)** nickel chrome [1]. The features of the surrounding forced flow are kept constant, i.e. velocity of 60 mm.s-1, oxygen content of 21% and ambient pressure of 101.3 kPa. Especially due to the lower heat diffusivity of nickel chrome, the pyrolysis area is more constrained, making the flame stronger.*

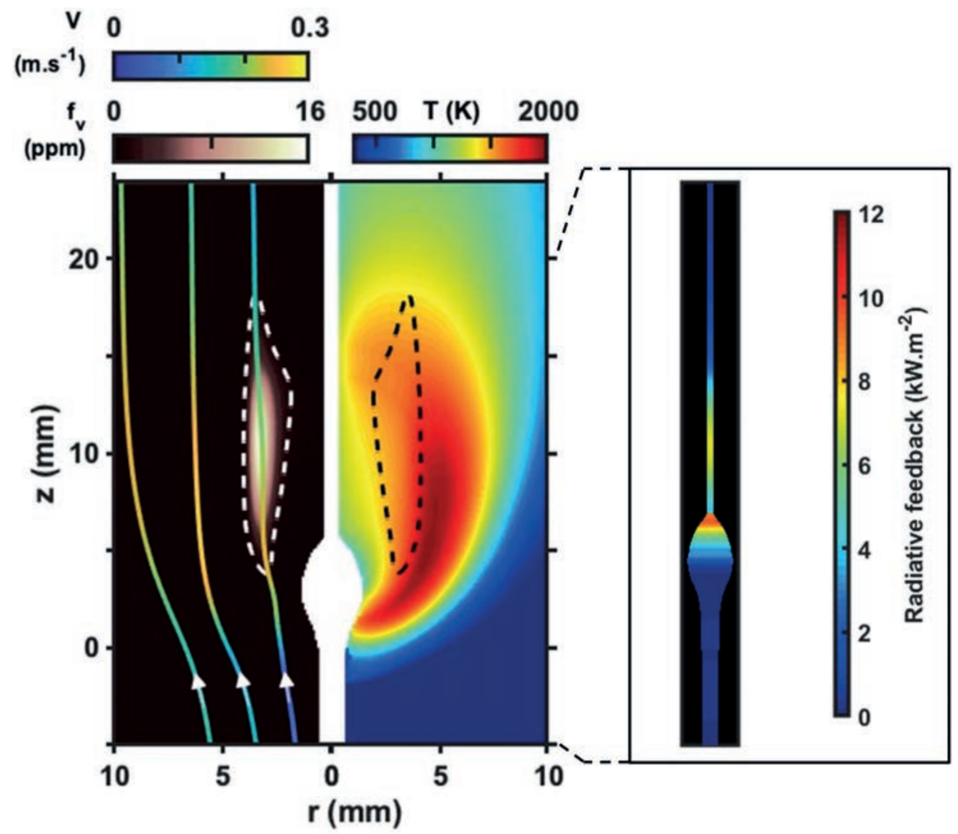
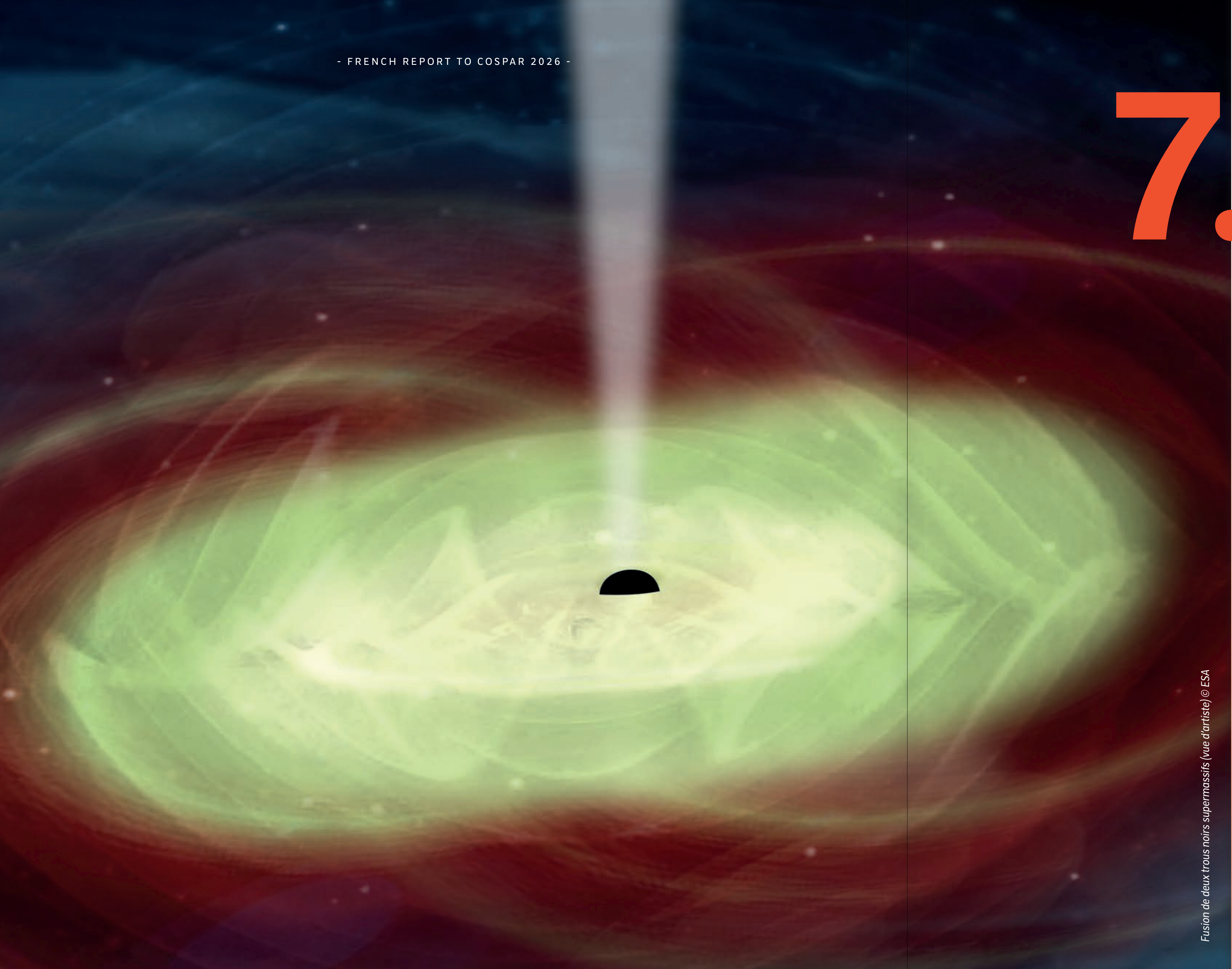


FIGURE 2
Fields obtained by numerical simulation of soot volume fraction fv (left) and temperature T (right) around the axis of symmetry r=0 within the kind of non-buoyant flame [2] shown in Fig.1. Both fields are required to compute the distribution of radiative feedback from the flame to the sample's surface shown in the insert. The streamlines displayed over the soot volume fraction field are coloured as a function of the velocity magnitude V, evidencing relatively a long characteristic residence time in the non-buoyant flame.

REFERENCES
1 - *Y. Konno et al., Experimental study on downward/opposed flame spread and extinction over electric wires in partial gravity environments, Proc. Combust. Inst. 39 (2023) 3785-3794, doi: 10.1016/j.proci.2022.07.002.*
2 - *A. Guibaud et al., Accessing the soot-related radiative heat feedback in a flame spreading in microgravity: optical designs and associated limitations, Proc. Combust. Inst. 38 (2021) 4805-4814, doi: 10.1016/j.proci.2020.06.036.*



Fusion de deux trous noirs supermassifs (vue d'artiste) © ESA

7. Fundamental physics in space

Martin Boutelier

Fundamental Physics Progamme Manager

" Space and microgravity offer an unparalleled environment for testing the fundamental laws of the universe. Far from Earth's perturbing influences, space-based experiments can measure the structure of space and time with exceptional precision, yielding new insights that complement ground-based research. The absence of gravitational noise allows scientists to conduct experiments that would be impossible on Earth, pushing the boundaries of our understanding of physics.
As France's space agency, CNES is deeply engaged in advancing fundamental physics in space and raising awareness within the French scientific community about the contributions of space missions to this field. CNES's programme primarily focuses on bridging the gap between gravity and quantum theories, two pillars of modern physics that have yet to be fully reconciled. These efforts not only satisfy scientific curiosity but are also driving technological innovation for various sectors, including telecommunications, secure data transmission and space exploration.
By leveraging the unique advantages of space, CNES's missions pave the way for groundbreaking discoveries that could redefine our understanding of the universe and its fundamental laws. "

Interview

Looking back over your career, what has most marked you in your field of research?

The detection of gravitational waves in 2015 left a lasting impression on me, as it was a monumental achievement in physics that unleashed unprecedented opportunities for studying cosmic events. This breakthrough has opened a new observational window into extreme phenomena, potentially leading to a paradigm shift in our understanding of fundamental physics.

In your opinion, what are the best and worst aspects of your scientific field of research?

The most difficult thing in fundamental physics is that we observe very tiny effects and we're not even sure if they'll occur at the scale we're looking for. In most of our past and future experiments, we're tracking a zero signal and it's not easy to convince people to fund research to find nothing. But the reward is also exceptional: the day we detect a non-zero signal, it'll mark a revolution in physics.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

The advent of quantum sensors marks the beginning of a new era in fundamental physics by enabling unprecedented levels of precision in measurements. This capability allows scientists to probe the fundamental laws of nature more deeply, test theories with higher accuracy and explore phenomena that were previously beyond our reach. Quantum sensors have the potential to revolutionize our understanding of gravity, dark matter and the quantum nature of space-time, paving the way for groundbreaking discoveries that could reshape our comprehension of the universe.

ACES PHARAO

In April 2025, PHARAO became the first caesium cold-atom clock ever to orbit Earth, operating outside the International Space Station as part of a time-comparison network. Does this mean the station's crew will be able to keep time more accurately than on Earth?

KEY MILESTONES

May 2025
first PHARAO data

21 April 2025
Launch of PHARAO

July 2014
Delivery of PHARAO flight model to ESA

March 2014
Start of PHARAO performance tests

January 2011
Testing of ground segment prototype

December 2008
CNES approves construction of PHARAO flight model

FIGURE
Schematic view of PHARAO
© CNES/ill./VOUILLON Jean, 2005

KEY INFORMATION

MISSION
Measure time with an accuracy of 10^{-16} and test Albert Einstein's theory of gravitation more precisely than ever before

DOMAIN
Science

LAUNCH DATE
Launch to ISS on 21 April 2025

PARTNERS
ESA and industry, working with French research laboratories (ENS-LKB and OBSPM-SYRTE)

WHERE
International Space Station (ISS), Columbus module

LIFETIME
3 years

STATUS
In operation

KEY FIGURES

40	91	5	10^{-16}
microseconds/day: time difference between positioning satellites and ground	kg: mass of PHARAO	subsystems	precision

PROJECT IN BRIEF

Albert Einstein's theory of general relativity predicts that time slows near a source of gravitation. As a result, it passes more quickly at the top than at the foot of the Eiffel Tower. This 'Einstein effect'—also called gravitational redshift—is even more clearly perceptible in space, which is why satellite positioning systems like GPS or Europe's Galileo have to factor it in to obtain a precise positional fix. In their 20,000-km orbit, these systems' atomic clocks gain 40 microseconds every day with respect to Earth-bound clocks. The PHARAO mission is designed to measure this effect with new levels of accuracy. PHARAO has become the first caesium cold-atom clock ever to orbit Earth and operate as part of a time-comparison network, attached to a porch on the European Columbus module outside the International Space Station (ISS). PHARAO is called a 'cold-atom' clock because its caesium atoms are laser-cooled to a temperature approaching absolute zero (–273°C) to render them virtually motionless so that the 'tick-tock' oscillations of the wave they emit can be counted more accurately. According to the SI international system of units, a second is defined as the duration of 9,192,631,770 oscillation cycles of a caesium atom. Cold-atom clocks are currently the best clocks operating on Earth. In the microgravity environment of space (the ISS orbits Earth at an altitude of 400 kilometres), they will be even more accurate. For example, PHARAO is expected to lose no more than one second every 300 million years. Such extreme accuracy will enable the effects predicted by the theory of general relativity to be verified more precisely than ever before.

CNES's ROLE

The PHARAO mission's clock draws extensively on research conducted at French laboratories. Its constituent elements were built by French manufacturers and then assembled and tested by CNES. PHARAO is the core component of the European ACES mission (Atomic Clock Ensemble in Space).

ACES PHARAO

Martin Boutelier
Fundamental Physics Programme Manager

The ACES mission was launched on 21 April 2025 aboard a Falcon 9 and delivered to the International Space Station (ISS) two days later. Using the Canadian robotic arm (Canadarm2), the payload—including the PHARAO atomic clock—was installed on the exterior of the Columbus module on 25 April. Commissioning began on 28 April, initiating a sequence of checks and adjustments required to validate the system's performance in orbit.

PHARAO (PHoto-Realisation d'Atomes Oscillateurs) is the mission's core instrument. It is an ultra-stable atomic clock that, by design, should lose no more than one second over 300 million years. Within days of commissioning, PHARAO was switched on and its subsystems were verified. By 14 May the clock produced its first Ramsey fringes—an essential milestone that confirms the proper operation of the atom-interrogation cycle.

Ramsey fringes plot the probability that an atom makes a transition between two energy states as a function of the applied microwave frequency ω. The probability peaks when ω matches the atom's natural transition frequency ω_0. The fringe sharpness grows as the atom's velocity decreases, because slower atoms spend more time in the field-free (non-interaction) zone. The clear, narrow fringes obtained on-orbit indicate that PHARAO is in excellent condition and ready for scientific measurements.

The next phase will involve fine-tuning more than 5,000 clock parameters. In the microgravity environment of the ISS, atom velocities can be reduced far below terrestrial limits, extending the interaction time and dramatically increasing the clock's stability and accuracy.

Science goals

- **Fundamental physics:** By comparing PHARAO's time-keeping with ground-based atomic clocks, ACES will test Einstein's general-relativity prediction of the gravitational redshift with unprecedented precision.
- **Search for new physics:** Ultra-precise timing may reveal subtle anomalies that point to dark-matter or dark-energy effects.
- **Technological impact:** Results will improve satellite navigation, telecommunications and future time-distribution systems.

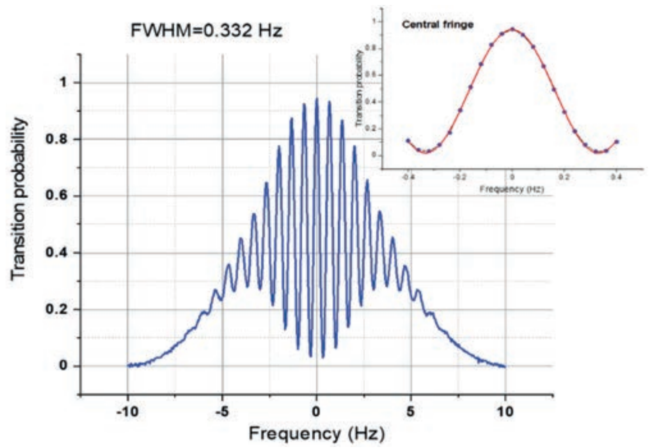
Systematic-effects analysis

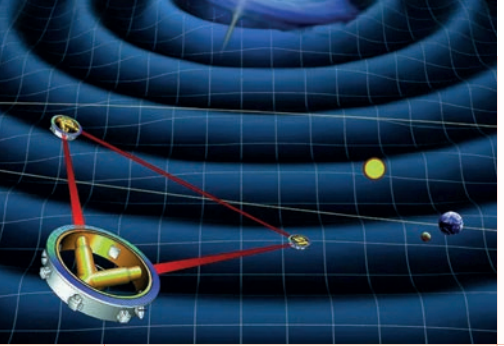
Even the most accurate clock is susceptible to its environment. Throughout the planned 2.5-year mission, the team will analyse and mitigate influences such as temperature drift, magnetic-field variations, mechanical vibrations and residual gravitational gradients. This exhaustive characterization will not only maximize PHARAO's performance but also generate mitigation strategies for the next generation of space- and ground-based clocks.

The data will be cross-checked against theoretical models of atomic structure and relativistic physics, offering a stringent validation (or possible revision) of these frameworks.

FIGURE 1
ACES (red box) on board Columbus module. The ACES space segment was docked to the Columbus module the 25th of April 2025. It started its in orbit commissioning phase a few days later. Credits: ESA/NASA

FIGURE 2
Ramsey fringes obtained after 1 hour of measurement using an atom velocity of 147 mm/s. These are the thinnest Ramsey fringes measured using a microwave atomic clock. Credit: LTE/CNES





LISA

LISA (Laser Interferometer Space Antenna) is an international mission led by ESA to detect gravitational waves from the most violent events in the universe.

KEY MILESTONES

2037
Final positioning in space and start of science operations

2035
Launch of LISA

25 January 2024
ESA gives go-ahead to LISA mission

20 June 2017
LISA selected by ESA

3 December 2015
Launch of LISA Pathfinder

14 September 2015
Gravitational waves observed from Earth

1997
Project initiated by ESA and NASA

KEY INFORMATION

MISSION
Detect gravitational waves in a new frequency range from space

DOMAIN
Science

LAUNCH DATE
Scheduled in 2035

LIFETIME
At least 6½ years (2-year positioning and in-orbit commissioning phase, followed by 4½ years of science operations), with possible extension of 2½ years

PARTNERS
ESA and NASA

WHERE
Heliocentric orbit, trailing 50 million km behind Earth

STATUS
In development

KEY FIGURES

2.5
million km: length of each interferometer arm

3
satellites making up the interferometer

10^{-11}
m: precision with which the 2.5 million km separating each satellite will be measured

0.1
mHz-to-1 Hz frequency range

PROJECT IN BRIEF

LISA aims to detect gravitational waves using three satellites trailing Earth by 50 million km in its solar orbit. Predicted by Einstein's theory of general relativity and first observed in 2015, these cosmic echoes are nearly impossible to detect from Earth due to ambient noise. ESA selected LISA as its third large-class mission (L3) for launch in 2035. The satellites will form an equilateral triangle with 2.5-million-km arms, linked by lasers measuring free-fall test masses. LISA's 10-picometre sensitivity will measure low-frequency waves inaccessible to ground-based detectors like LIGO. CNES is leading the LISA-France consortium, responsible for instrument integration and ground segment development. ESA's 2015-2017 LISA Pathfinder mission successfully validated key technologies for LISA.

CNES's ROLE

CNES is coordinating French research laboratories on LISA. It is leading ground operations by developing the Distributed Data Processing Centre in France for daily mission data analysis. CNES is also leading two spacecraft contributions: testing interferometric performance on Toulouse prototypes and supplying Optical Test System facilities to measure and minimize stray light effects along the optical path.

?

DID YOU KNOW?

Gravitational waves propagate throughout the universe without significant distortion, which allows us to see phases of the universe preceding the cosmic background radiation (CBR), which is as far back as we can see in visible light.

FIGURES

1 - Artist's impression of the LISA project. Top, a distant galaxy with two merging supermassive black holes generating gravitational waves; bottom right, the Earth and Moon orbiting the Sun; bottom left, the three LISA satellites in formation © NASA
2 - Overview of IDS performance test set-up developed under France's and CNES's leadership. Credit: CNES
3 - Amplitude signal of LISA common data set (Mojito data) simulated to train detection algorithm. Contribution from different signal sources are represented in different colours.

LISA

Martin Boutelier

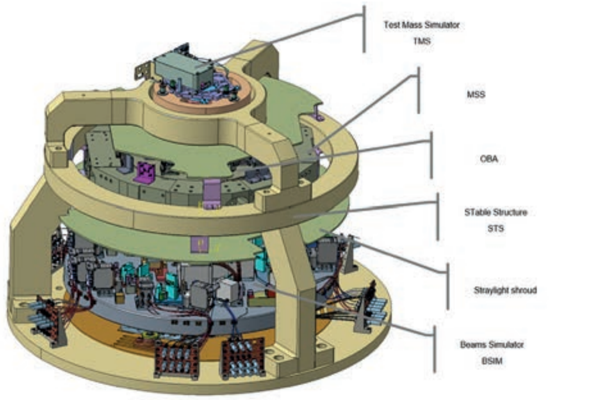
Fundamental Physics Programme Manager

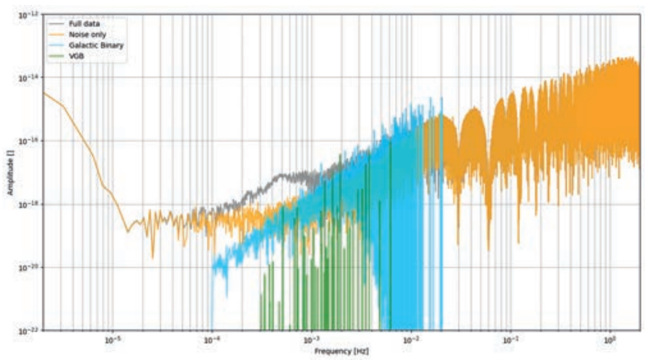
Since the adoption of the LISA mission by CNES's Space Programmes Committee (SPC) in January 2024 and the validation of France's participation at the the agency's board meeting in March 2024, the project is progressing nominally. On the spacecraft side, the activities of the industrial team, led by OHB (Germany), are progressing nominally. The industrial consortium is being built in line with the Industrial Procurement Plan. Six invitations to tender (ITT) have been released (on-board computer, Solar Array, RF Subsystem, Star Tracker, Sun Sensor, Optical Ground Support Equipment), with nine more to be released by the end of 2025. The System Requirements Review (SRR) was successfully completed on 12 September with all objectives fully achieved.

On the payload side, the Preliminary Definition Review (PDR) of the Gravitational Reference System (GRS) was completed on 23 July. The Interferometric Detection System (IDS) PDR is ongoing. French teams have made remarkable progress on activities within their scope. France is primarily engaged in three main contributions: defining and conducting performance tests on engineering and qualification models of the interferometric core of the instrument (Interferometric Detection System); managing and implementing the European scientific ground segment (DDPC); and supporting performance and operational activities carried out by ESA teams.

To define and conduct performance tests, France must build and set up all necessary infrastructure. This infrastructure consists of ISO8 and ISO5 cleanrooms, thermal vacuum chambers to simulate the space environment, and a set of electrical, mechanical and optical test ground support equipment to stimulate the instrument or simulate other components of the measurement chain. This ground support equipment is mainly: a test mass simulator (TMS, see Figure 1), which aims to simulate the free-falling test mass within the instrument; a beam simulator (BSIM, see Figure 1) that simulates the distant incident laser and telescope; and a stable structure (STS see Figure 1) that will pull all subsystems together in a very stable set-up. This set-up is completed by a straylight shroud to protect measurements from any parasitic light. The beam simulator is a very complex optical device that will be used to measure any effects of the laser system and the telescope on the LISA instrument's final performance. This work is the result of a close collaboration between CNES and laboratories for the definition and prototyping phases, and industrial partners for implementation. In 2025, the prototyping and definition phase was nearly completed, and most industrial contracts were established. The first elements, such as vacuum chambers, cleanrooms and some metrology equipment, have already been delivered. Test preparation activities will continue in the coming months with the receipt of the first components constituting the interferometric core.

The implementation of the scientific ground segment also progressed significantly in 2025 with the establishment of an organization in coordination units (CU) and a detailed definition of responsibilities. In this organization, each level of data processing (L0, L1, L2 and L3) is handled by a dedicated CU that is in charge of defining the best algorithms to process the data. In addition, specific CUs are also in place to manage the system (infrastructure, coordination between CUs), the link with the scientific community, simulation of data to train all teams and definition of waveforms. On 18 December 2025, the DDPC achieved a major milestone with the release of its first common dataset to test the first versions of data processing algorithms. These simulated data, named Mojito Light, represent a simplified version of real data. Based on a very detailed instrument model, they have been generated without including any discontinuities like gaps and glitches. They contain a limited number of gravitational wave sources, such as a few verification galactic binary systems (VGB) and a few mergers of supermassive black holes. Despite this relative simplicity, they are well suited to test a first prototype of processing algorithms. This major step is also the first opportunity for the DDPC to work as a complete and functional entity.





@Lapin-O'Rabit

8. Ethics and Space Studies

Jacques Arnould
Ethics Senior Adviser
Philippe Clerc
Corporate Compliance, Ethics and Scientific Integrity Officer

" Founded on the values of charity, respect, responsibility, liberty and equity, ethics initially concerned humans, how they live, their rights and the duties that go with them. During the course of the last century, it extended its remit to other living things and to Earth's environment. And from the moment space activities came on the scene, it "broke through" the barrier of the atmosphere and space ethics was born at the dawn of the 21st century. With the development of New Space and an increasing diversity of stakeholders and interests, it has even become a necessity in the eyes of the public. In other words: What projects do our societies have for space? What do we deem acceptable or undesirable in this realm to ensure that space activities remain sustainable and that data and resources from space are fairly shared?

CNES has been active in the field of ethics since 2001, with a special focus on scientific research issues. This effort was stepped up in 2018 with the creation of a corporate compliance and ethics office within the agency's inspectorate general, aimed at controlling integrity risks for all scientific and technical research, whether conducted internally or under agreement with a third-party scientific or industrial entity.

Ethics questions concerning projected or already ongoing space activities can be submitted for consultation to a dedicated committee set up in 2024. This committee open to participants from outside the agency finalized in 2025 a first study into "ethics of the production and dissemination of space-based data". It is currently working on issues specific to satellite mega-constellations. "

Interview

Looking back over your career, what has most marked you in your field of research?

One of the things that has most marked us at CNES is our pioneering commitment to making ethics integral to space missions. The creation of a dedicated ethics committee has been a significant step forward, as has the strengthening of our processes for controlling scientific, technical and economic probity risks. These initiatives put CNES among the first space agencies to address ethics in a truly structured fashion.

In your opinion, what are the best and worst aspects of your scientific field of research?

The best part of our field is its multidisciplinary nature, combining experts in hard and human sciences, and international cooperation on major projects with partners in government, agencies, scientific organizations, industry and users. These collaborations are pursuing the greater good of humankind and future generations.
Among the worst aspects is falsified, counterfeit, plagiarized or disreputable research, and research that is unethical or of little interest. The uncontrolled development of artificial intelligence is increasing these risks.

What progress/results do you hope to see in your field of research in the coming years, or even in a more distant future?

In the years ahead, we hope to see significant advances in ethics, notably through the development of an integrated European and international framework associating the private sector. The goal is to further thinking about ethics issues to fuel progress in research, science, business and our societies. Looking further ahead, these efforts should enable us to consolidate a broad collaborative approach, guaranteeing responsible and innovative research for the benefit of all.

CNES' Ethics
and Professional Conduct Charter and Space Mission Ethics Committee

—

Philippe Clerc
corporate compliance, ethics and scientifc integrity officer

—

In 2021, CNES adopted an Ethics and Professional Conduct Charter to mark the 60th anniversary of its founding law.[1]

This charter aims to bring together and promote the values and good practices that guide the actions of its representatives in relation to its ecosystem, in the service of research and development in space activities, for the benefit of society and future generations, in cooperation with and respect for the fundamental rights and principles of the United Nations.

This charter brings together the two ethical components of CNES, now united within the General Inspectorate and Quality Department[2]. The first, known as *compliance and corporate ethics*[3], ensures that risks to integrity in business, contracts, and scientific or technical research are properly managed. The second, led by an *ethics expert*[4], focuses on issues specific to any space mission involving the organization.

To ensure the proper application of the principles set out in this charter, CNES has created a Space Mission Ethics Committee (CEM). This committee was established at the 54th International Paris Air Show in 2023.

Its main mission is to advise the governing body, the CEO or, at the latter's initiative, the board of directors and government authorities on any issues relating to the ethics of CNES missions, from proposal to completion. It also advises the CEO of CNES on ethical aspects relating to the responsibilities entrusted to him under the 2008 French Space Operations Act (FSOA).

In a global context of openness to new private players and strong economic and strategic rivalries, this committee seeks to promote the right balance between cooperation, competition, sovereignty, and responsibility by following the principles of United Nations international space law, while taking into account respect for terrestrial and planetary environments and the interests of future generations.

It welcomes high-level external experts and qualified individuals in Europe, including Mona Caroline Chammas, Eric Dautriat, Jean-Gabriel Ganascia, Pierre-Henri Gouyon, and Lesley-Jane Smith, under the chairmanship of Édouard Geffray[5].

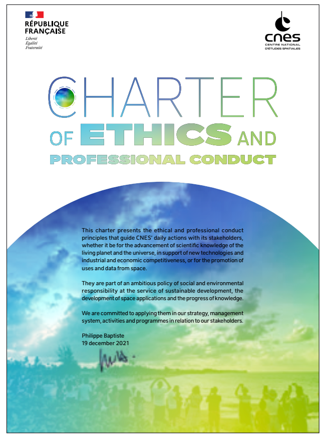
It began its work in 2024 on the ethics of the production and use of space-based data (SBD-DOS) and presented its conclusions to the board of directors on 3 July 2025[6].

It first recommends several measures of general interest to strengthen confidence: certification of origin, perpetuation of access and archiving tools, trust labels for deserving operators, etc. It calls for the recognition of this data as "humanity's heritage" in order to preserve its use for the benefit of future generations. It also invites downstream regulatory authorities to consult with each other to better control the risks of misuse or adjustments to be made to public data openness policies.

The committee is currently looking at the challenges posed by mega-constellations of satellites. A seminar is planned for 2027 to present the results and prospects of its work.

FIGURES

1 - *Charter of ethics and professional conduct. Credit: CNES*

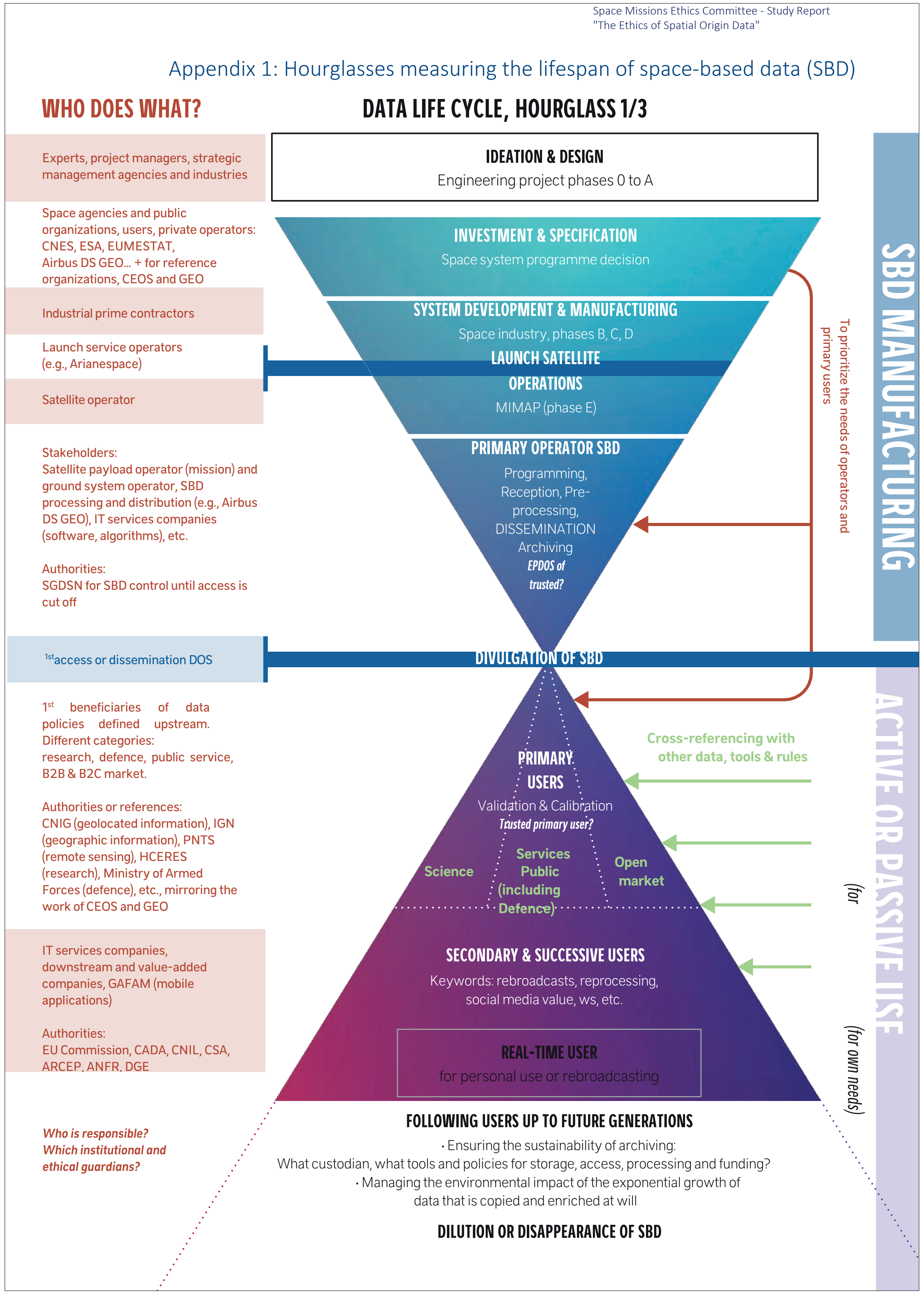


2 - *DOS report*

REFERENCES

1 - *Charter signed by its then president, Philippe Baptiste, now Minister of Research, Higher Education, and Space Policy.*
2 - *Under the direction of Philippe Guay.*
3 - *Under the responsibility of Philippe Clerc, Compliance and Corporate Ethics Officer, and the supervision of an Internal Ethics Committee (CID).*
4 - *Namely, Jacques Arnould.*
5 - *State Councillor, who was appointed Minister of National Education in France in October 2025.*
6 - *Under the chairmanship of François Jacq.*

FIGURE 3
Hourglass of recommendations - Page 1



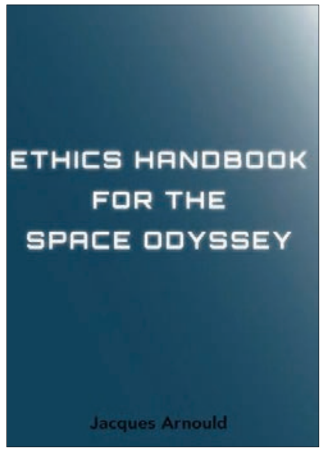
SPACE ETHICS:
a work in progress

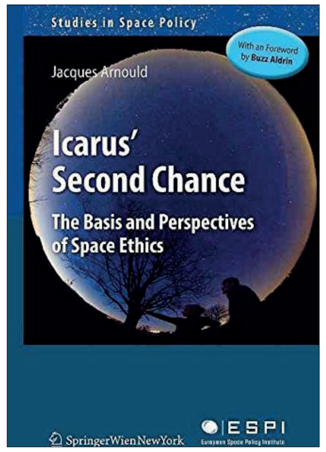
Jacques Arnould
Ethics Senior Adviser

At first sight, space science may seem far removed from ethics. Observing the universe, stars and planets may stir many philosophical considerations, but probably not moral ones. The issue of planetary protection, which first came on the scene in the 1960s, has however obliged the scientific community to establish "rules of the road" for space exploration, albeit for strictly scientific reasons. The workshop on "Ethical Considerations for Planetary Protection in Space Exploration" held in Princeton in June 2010 on the initiative of COSPAR clearly showed these limits: besides the planetary protection measures put forward and regularly updated by COSPAR for the scientific community, the value of space exploration, its ultimate aims and consequences for humankind, and its potential dangers proved difficult to grasp for the workshop's participants.

Before and since this event, CNES and COSPAR have engaged a number of new initiatives—publications, panel discussions at general assemblies, etc.—from which it has emerged that the main challenge facing us is to see ethical concerns as part and parcel of the research scientist's job and not something imposed "from outside". It is also worth underlining the initiative of the community of astrobiologists, which from the outset has embraced historians, sociologists and philosophers interested in the theme of terrestrial and extraterrestrial life.

FIGURES 1 & 2
Book covers





It is worthy of note that the use and exploration of space are today research topics for an increasing number of doctoral students and young research scientists. The advent over the last 15 years of New Space has certainly been a factor here: the spectacular achievements of its main players, the way they have transformed the space economy and their often exorbitant projects raise questions, stoke debate and stances, and in some cases opposition. In response, the space community must strive to provide reasoned and far-seeing answers, particularly with regard to the type of governance needed to manage near and far outer space.

Communication and outreach must therefore be given special attention. For 25 years now, CNES has published several books covering themes related to space ethics—debris management, Earth observation, human spaceflight, the militarization of space and exploration of the solar system—and is frequently called upon by the media and conference organizers to provide insight on this issue. Staying in touch with public opinion is of the utmost importance and is key to any ethics approach, and probably something to be furthered in the years ahead. It concerns all space activities, especially those undertaken or supported by governments and public institutions. In this respect, the scientific domain is in the vanguard. Through its outreach policy, CNES offers opportunities to gauge the expectations, questions and fears of our contemporaries; however, we are yet to undertake a broad survey and analysis of their views, and we must do this without delay.

Another challenge is to enable the astronautics community, both research and actual hard activities, to benefit from the recent academic work that has hitherto been lacking. This work can influence and inform decisions and programmatic choices. Bodies like COSPAR and COPUOS can play the role of go-between with space players, space agencies and entrepreneurs. A lot of work remains to be done.

Round table: 'What ethical framework for new space missions'. Le Bourget, 19 June 2025

FIGURE 3
From left: Eric Dautriat, Lesley-Jane Smith, Philippe Clerc, Mona Caroline Chammas, Édouard Geffray, Bernard Chemoul. © CNES/Christophe Peus, 2025

KEY POINTS

- Panel on Social Sciences and Humanities (PSSH) at general assemblies of 2022 and 2024.
- Social and Ethical Frontiers in Space Exploration, Kiruna, 23-25 September 2024. Joint meeting of the European Astrobiology Institute and the Society for Social and Conceptual Issues in Astrobiology
- Outer Space: A new fronter of the common good (Friday 13 February 2026).

Scientific Foresight Seminar in Saint-Malo

(8 to 10 October 2024)

Jean-Marie Hameury

—

Chair of the Scientific Programmes Committee

EXECUTIVE SUMMARY

—

Access to space is vital for all those working in the Earth and Universe sciences. It enables them to explore beyond the atmosphere, which is mostly opaque to the electromagnetic radiation emitted by celestial bodies, allowing it through in just a few places; it opens up in-situ exploration of bodies in the solar system; it provides a global and homogeneous planetary view over long periods, which is an essential complement to in-situ and airborne observations; and finally, it offers a stable environment over long periods.

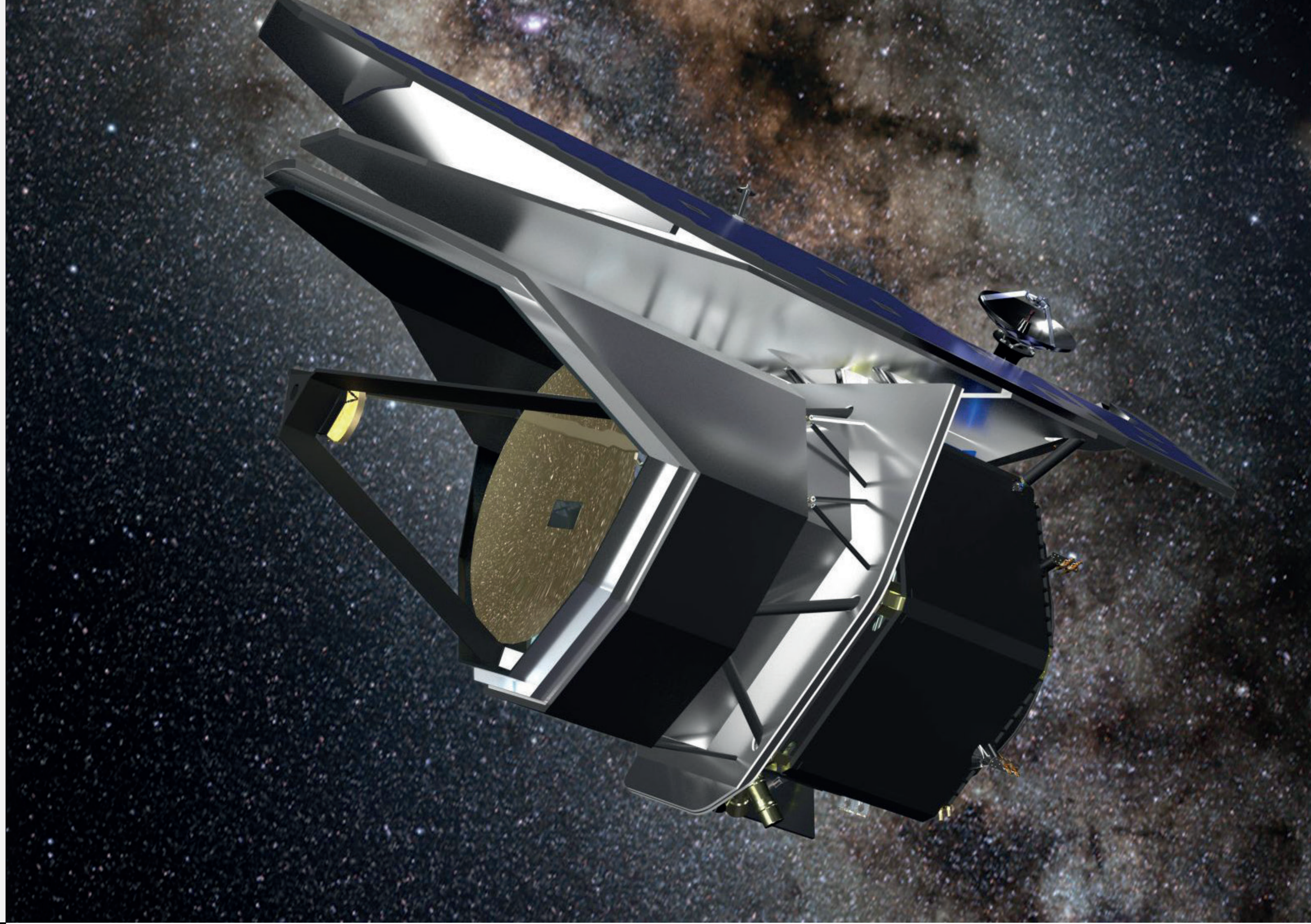
The CNES scientific foresight seminar (SPS - Séminaire de Prospective Scientifique) is therefore a major event for the disciplines concerned, crowning the preparatory work put in by some 200 people over 18 months. The seminar identified the most pressing scientific issues that could lead to major breakthroughs in the years ahead, along with the missions needed to address them. It also analysed the national and international context and the foreseeable developments that could affect space research, in order to propose building blocks for an appropriate strategy.

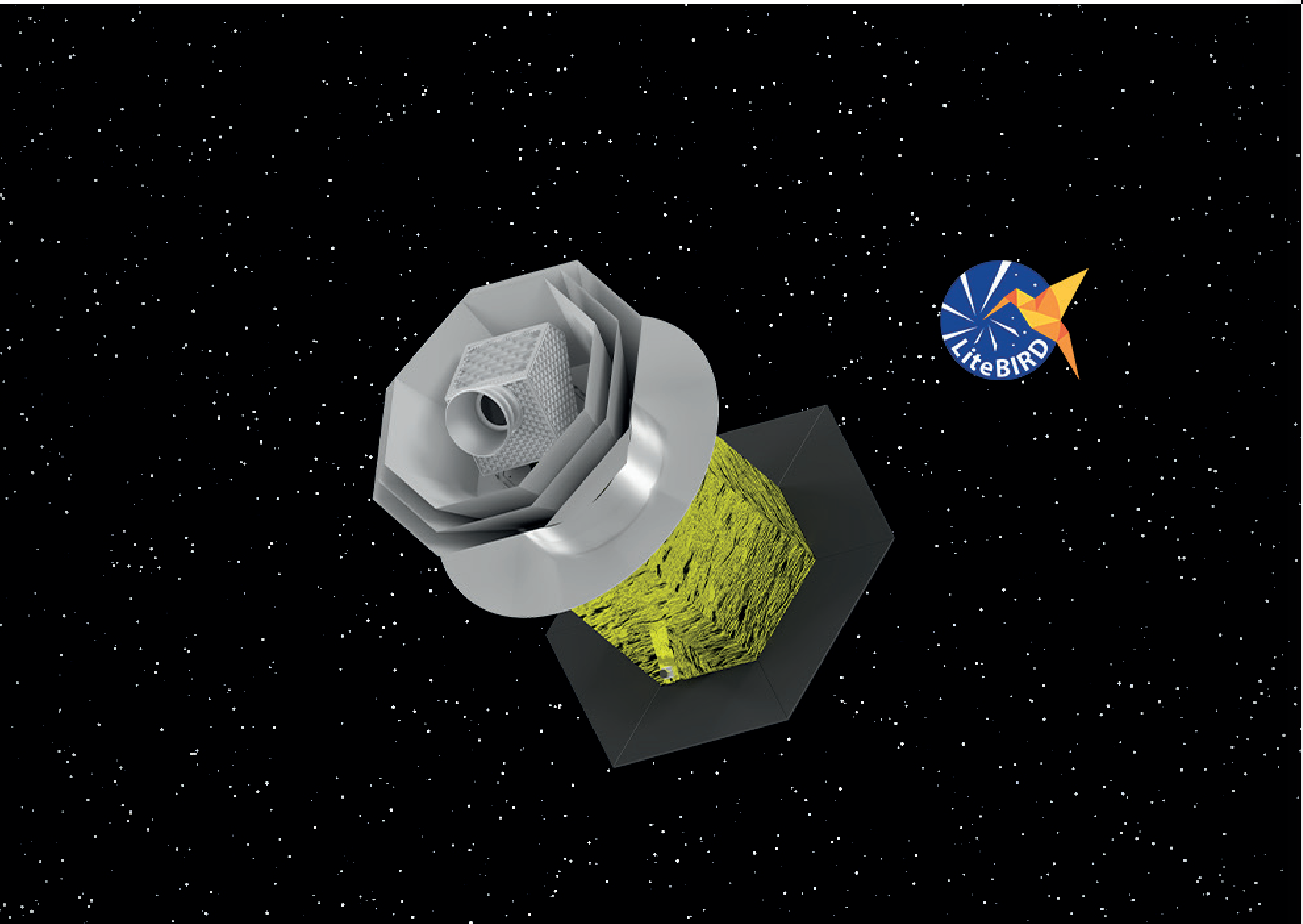
The SPS was also an opportunity to take stock of the scientific and programmatic advances made since the previous seminar. This largely positive review is the result of decisions taken ten or more years ago. The French scientific community has helped to bring about key achievements in both Universe and Earth sciences, and is an undisputed leader in Europe. In terms of programmatic content, most of the priority missions announced at the 2019 Le Havre seminar have been carried out or are ongoing; the 2022 ESA ministerial conference was a success concerning Earth sciences, thanks in particular to the joint development of its science component with the scientific community itself; lastly, a number of successful missions were launched in the intervening five years. Many payloads exceeded expectations, though the few failures unfortunately included Taranis.

The primary goal of the scientific community is to advance our knowledge of the world in which we live. It also serves other societal objectives, in particular those relating to the environmental crises facing humanity.

In Universe sciences and exploration, the priorities can be broken down into six main fields of investigation.

- Pushing back the frontiers of physics, with three focuses: the violation of the equivalence principle, predicted by the unification theories of general relativity and quantum mechanics; the physics of the primordial Universe, a mysterious phase during which the perturbations that were to give rise to the large structures of the Universe left their imprint on the polarization and spectrum of the cosmic microwave background; and finally, the physics of matter at mesoscopic scales, which is relevant for studying phase transitions between various states.
- Understanding the formation and evolution of Universe structures. On the largest scales, the aim is to study the cycle of hot baryons via their X-ray emission. On a smaller scale, the cold baryon cycle, observable in the mid- to far-infrared range, underpins the formation of stars, galaxies and protostellar disks in which molecular complexity emerges and exoplanetary systems are formed.
- Investigating the origin of the solar system and exoplanetary systems. It is essential to compare the solar system and exoplanetary systems to further our understanding of them. In the solar system, the focus is on the icy giant planets Uranus and Neptune, which differ from Jupiter and Saturn in their structure and atmospheric composition, while appearing to be representative of certain exoplanets.
- Investigating habitability and the origins of life. Continued exploration of Mars has long been a priority, complemented by exploration of the icy moons of giant planets that have a liquid ocean beneath an icy crust and where complex chemical interactions may have developed. The possible habitability of exoplanets and ultimately the detection of biosignatures remain major objectives.
- Investigating Sun-planet relations. Particle energization and energy transport processes play a key role in the formation and evolution of the radiative environments of the Earth and planets. Multi-point, multi-scale in-situ measurements are required to improve our understanding.
- Life sciences. Today, scientific priorities are largely determined by operational objectives, aimed at keeping astronauts alive and in good health.





FIGURES
1 - *Artist's impression of the PRIMA infrared space observatory project © Credit: NASA/JPL–Caltech/ESO/S. Brunier*
2 - *Artist's interprétation of LiteBIRD taking measurements in space. The Sun, Earth and Moon can be seen in the background, showing LiteBIRD is positioned at Lagrangian point L2. © Credit: ISAS/JAXA*

In terms of programming, ESA's mandatory scientific programme plays a major role, notably through its large (L-class) and medium (M-class) missions, with major priorities on NewAthena, the L3 X-ray observatory mission, the L4 mission to Enceladus, one of Saturn's moons and, in the longer term, a mission to characterize the atmospheres of terrestrial-type exoplanets, as well as two of the three competing projects for the M7 mission to study the magnetospheres of Mars and Earth. Another priority is that of the ESA and NASA missions for exploring Mars, ExoMars and Mars Sample Return, both with exobiology objectives. ESA's programmes do not cover all the research topics and must be complemented by bi- or multilateral cooperative projects, in particular with NASA — which remains the leading partner in Universe sciences — and JAXA. Our main priorities with NASA are, in the short term, the PRIMA L/M mission for a far-infrared observatory and Helioswarm to investigate energy processes in the solar wind. In the long term, France will be involved in the Uranus Orbiter and Probe and Habitable Worlds Observatory (HWO) missions. With JAXA, we are undertaking the LiteBIRD mission using B-mode polarization to study the cosmic microwave background. The Microscope2 project, which would make it possible to gain two orders of magnitude in testing the equivalence principle, has not yet been allocated to a particular programme framework. Lastly, access to low Earth orbit beyond the planned decommissioning of the International Space Station in 2030, remains vitally important for material and life sciences.

In Earth sciences, scientific priorities can be divided into four strategic fields of investigation:

- Understanding the major climate cycles, particularly the water cycle, the corresponding processes and the coupling mechanisms between Earth system components. The priorities are: (i) cloud formation mechanisms and deep convection processes in the atmosphere; (ii) ocean/atmosphere coupling with the simultaneous measurement of winds and surface currents; (iii) the penetration of freshwater flowing into the ocean and its impact on the stratification of surface layers and on coastal and polar circulation, and more generally, the quantification of land-sea fluxes (water, matter, chemistry).
- Investigating the impact of global change on vulnerable areas and objects. The aim is to characterize the exposure, vulnerability and dynamics of socio-ecosystems in response to global change, and to address the issues of adaptation and risk management along the coastline and in adjoining coastal zones.
- Forecasting and digital twins. The development of digital twins and their need for qualified data with high spatial and temporal resolution, as well as the rise of artificial intelligence techniques to improve the forecasting of extreme events, for example, require ever more numerous and accurate measurements.
- Studying interactions between the Earth's interior and its outer shells. This multidisciplinary theme requires a terrestrial reference frame that is as precise and stable as possible.

The programme context is more open than for Universe sciences, because the societal impact of research conducted in the Earth sciences means that it can be supported by organizations and programmes with a more operational focus. Thus, limiting ourselves to the major priorities, phase A of the CMIM concept (Constellation of Mini-sounders for Meteorology) could pave the way for its incorporation into the Eumetsat programme, while S3NG-TOPO, an altimetry mission to monitor and forecast the ocean and continental hydrology, will be carried out as part of the Copernicus programme. Furthermore, Genesis (a millimetre-precision reference frame) will be part of ESA's navigation programme, and the Carioqa project to develop a space-rated quantum accelerometer is being supported by the European Commission. In a national context, the SMASH (SMAll Satellites for Hydrology) mission with its frequent revisit capability, is being proposed as part of the France 2030 investment programme. Still limiting ourselves to the major priorities, the ODYSEA (Ocean DYnamics and Surface Exchange with the Atmosphere) mission and the MAGIC gravimetry mission have been proposed in partnership with NASA and ESA, respectively, within a more research-oriented framework, while the framework for SMOS-HR (Soil Moisture and Ocean Salinity, High Resolution) and Biodiversity (hyperspectral imaging at high spatial resolution for the study of biodiversity) has not yet been established. In addition to these satellite missions, there are priorities for a balloon programme (Stratofleet), which can be seen as the suborbital component of the AOS (Atmosphere Observing System) mission to study deep convection, clouds and aerosols, and support for the Tahiti geodetic observatory, which is essential for improving the coverage of the terrestrial reference frame.

Which is interested in space both for data and also as a fertile source for studies in its field; moreover, New Space, environmental crises and risk forecasting / management bring new societal issues. The creation of a dedicated humanities and social sciences group, along with its scope and interfaces with the existing thematic groups, will be addressed before the next SPS.

The balance between missions carried out within a European framework and those carried out within a national or bilateral framework, which varies from one investigative field to another, appears to be generally satisfactory. Without upsetting this balance, increased support for the mandatory science programme and a re-evaluation of the upper limits for Earth Explorer missions are necessary if Europe is to continue to carry out ambitious missions and remain at the forefront of international competition.

The scientific community must take advantage of the opportunities offered by New Space, and in particular the development of satellite constellations that could complement institutional Earth science missions. There is, however, the question of measurement accuracy, which shifts the difficulty to data processing; a detailed, case-by-case assessment of the usefulness of these projects for scientific purposes needs to be made.

For the first time, environmental footprint issues were explicitly addressed. Scientific space research must fully play its part in society's efforts to reduce its environmental footprint. There is a consensus on the need to take measures to reduce this footprint at a pre-determined cost, and these should be implemented rapidly. However, fundamental research brings benefits to society as a whole, which must be taken into account.

The division of tasks between CNES, laboratories and industry differs between Universe sciences, where instruments are practically always unique prototypes for which the laboratories focus on optimal performance, and the Earth sciences, for which their focus is on maintaining high-quality performance. In both cases, it is essential to maintain instrument skills in the laboratories in order to preserve their ability to implement the new technologies needed to carry out the most innovative missions. This is being jeopardized by the reduced technical potential of laboratories, which is affecting instrument researchers and engineers. One visible consequence right now is the decline in R&D activities in laboratories, whereas sustained activity to shape the future is vital for the medium and long term. System optimization has reached its limits, and we need to look for skills and resources in scientific communities outside the traditional space laboratories, by conducting actions for space instrumentation similar to those initiated following the recommendations of SPS2019 with respect to data. In addition, the reluctance of the major industrial prime contractors to commit themselves, if confirmed, should lead CNES to consider reorganizing its projects.

The implementation of the DataTerra data infrastructure must continue; the recommendation to define, jointly with the CNRS, the relevant systems (data hubs or services) to be set up for Universe sciences remains pertinent. In addition, initiatives to process massive quantities of complex data need to be continued and expanded, ensuring their long-term sustainability and opening them up to other organizations. In this area, as in instrumentation, CNES, other organizations and universities must openly support a clear, long-term strategy that emphasises the scientific/digital/instrument challenges, backed up by appropriate and sufficient financial and human resources.

The issue at stake in this SPS is therefore the preservation of scientific competitiveness of Europe and France in an international context in which the balance is shifting, with new tasks being entrusted by the government to the scientific community to respond to societal issues or to support the emergence of New Space. The quest for knowledge justifies a sustained effort on the part of the overseeing ministries, as well as a joint strategy on the part of CNES and other organizations supporting space research. This strategy could usefully be discussed in the partners' committee of the recently established 'Space Research' programme agency.

<u>The report is available here</u>

FIGURE
Artist's view of the CARIOQA demonstrator satellite © CNES

May 2026

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