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Space Research in Switzerland 2022–2024

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COVER PHOTO
Euclid's view of the Horsehead Nebula – Euclid shows us a spectacularly panoramic and detailed view of the Horsehead Nebula, also known as Barnard 33 and part of the constellation Orion.

At approximately 1375 light-years away, the Horsehead – visible as a dark cloud shaped like a horse's head – is the closest giant star-forming region to Earth. Many other telescopes have taken images of the Horsehead Nebula, but none of them are able to create such a sharp and wide view as Euclid can with just one observation. Euclid captured this image of the Horsehead in about one hour, which showcases the mission's ability to very quickly image an unprecedented area of the sky in high detail. Image and text credits: ESA.

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1 Foreword

The Committee on Space Research (COSPAR) was established in 1958 to promote open collaboration at the international level in the domain of space research. Switzerland is a member of COSPAR through the Swiss Committee on Space Research (CSR) of the Swiss Academy of Sciences (SCNAT). The 45th Scientific Assembly in Busan, South Korea, this summer is the occasion for the delegations to advertise their activities in the domain. The present report is a compilation of projects that have been conducted in Swiss research institutes over the period 2022 – 2024.

Space research in Switzerland benefits from the very strong support of the Swiss Space Office (SSO), the national agency for national and international space matters. Thanks to this support, Swiss research institutions have been able to participate in a large number of very high-profile scientific missions. Most projects where Switzerland is involved are led by the European Space Agency (ESA). The long-term commitment with ESA originates from its very foundation, and remains a tenet of the Swiss space policy. This does not preclude, however, collaboration with other agencies, and the Swiss space research community is always eager to seize such opportunities.

Space research in Switzerland is mostly conducted in the Swiss Federal Institutes of Technology of Zürich (ETH) and Lausanne (EPFL), the Universities of Bern, Geneva and Zürich, the Technical Universities of Windisch and Luzern, as well as the Physical and Meteorological Observatory of Davos (affiliated to ETH). Most space research domains are covered by the different research institutions, from the Sun and the heliosphere, to Solar system exploration, to astrophysics, as well as the more applied space science domains of Earth observations, space situational awareness, navigation satellite systems and life science in space. Swiss industries play a fundamental, and enabling, role for all space activities, such that the CSR maintains close contacts with the Swiss Space Industries Group, a body representing most of the Swiss industries active in the space domain.

Over the last two years, several important events took place in the Swiss community. The XRISM mission led by the Japan Aerospace Exploration Agency (JAXA) was launched in September 2023. XRISM embarks, in particular, a revolutionary X-ray detector based on micro-calorimeter with several components developed in Switzerland. JUICE is the first Large Mission of the Cosmic Vision Programme of ESA with the goal of exploring three of the large moons of Jupiter. JUICE was launched in April 2023. It contains three instruments with large Swiss contributions. Finally, the second Medium Mission of the ESA Cosmic Vision Programme, Euclid, was launched in July 2023. Euclid will map the dark components of the Universe and help us to understand its evolution. The Swiss participation is very large, with significant contributions to one of the two instruments and to the very complex and data intensive data processing.

Two new centres dedicated to space technology development have also been created over this period. The European Space Deep-Tech Innovation Centre (ESDI) was created at the Paul Scherrer Institute as a joint initiative between ESA and Switzerland, with the goal to foster the transfer of space technologies from the research institutes to the private sector. ESDI has passed several milestones of the build-up phase, and is gaining a lot of momentum. At the same time, ETH has created a new entity, ETH | Space, to bring together all space-related activities at the ETH. Most importantly, ETH | Space introduces a new curriculum in space engineering at the master level, which, together with a similar programme at eSpace, EPFL, will considerably help to develop the ecosystem of space technologies in Switzerland.

Despite these successes, space research faces difficulties, in Switzerland and everywhere. Post-COVID inflation puts a strain on the funding institutions, and limits the ability of researchers to propose and implement ambitious contributions. More sadly, space is at the forefront of political tensions, and the ability to collaborate freely with different international partners has significantly dwindled over the past years.

The above list does not intend to provide an exhaustive list of the Swiss achievements over the last two years. We invite the reader to peruse the following compilation of Swiss projects related to space research to get a more comprehensive picture of the dynamism of this research sector in Switzerland.

Stéphane Paltani

2 Institutes and Observatories

2.1 ISSI – International Space Science Institute

INTERNATIONAL SPACE SCIENCE INSTITUTE

Mission

The International Space Science Institute (ISSI) is a scientifically independent and neutral Space and Earth Science institute that advances science by facilitating open multi-disciplinary discourse in a stimulating environment, reaching out towards new scientific horizons.

Fields of Research

ISSI's programme covers a widespread range of disciplines from the physics of the solar system and planetary sciences to astrophysics and cosmology, and from Earth sciences to astrobiology.

Introduction

ISSI is an Institute of Advanced Studies where scientists from all over the world are invited to work together to analyse, compare and interpret their data. Observers, theorists, modellers, data scientists and laboratory researchers meet at ISSI to formulate interdisciplinary interpretations of experimental data and observations, with a focus on data from space-borne facilities but drawing on data from ground-based observatories as well where this adds scientific value. The scientists working on common projects are thus encouraged to pool their data and results. The conclusions of these activities – published in peer-reviewed journals or books – advance our understanding of key scientific questions. All ISSI programme elements are selected in consultation with the members of the ISSI Science Committee.

The European Space Agency (ESA), the Swiss Space Office (a division of the State Secretariat for Education, Research and Innovation; SERI), and the Swiss Academy of Sciences (SCNAT) provide most of the financial resources for ISSI's operations. The University of Bern contributes in-kind through a grant to the Director and the provision of infrastructure. The Institute of Space and Astronautical Science (ISAS, JAXA, Japan) also supports ISSI with an annual financial contribution.

Application for Space Sciences Research Projects Funded by ISSI

ISSI supports the scientific community within the following programmes: multi- and interdisciplinary International Teams, Workshops, Working Groups, Forums and a Visiting Scientists' programme. More information on all of these and how to apply for them can be found here: issibern.ch/program/tools.

Scientific Activities at ISSI in 2022 and 2023

ISSI welcomed around 2200 individual scientists to its facilities in 2022/23, for a total of 100 (2022) and 104 (2023) activities. About 80% of ISSI's onsite visitors attended meetings organised by ISSI International Teams. The meetings drawing the largest number of participants in 2022/23 were the following ISSI Workshops and Forums:

Community networking programmes offered by ISSI.

Directors
A. Nota (Executive Director, as of Jan. 2023)
T. Spohn (Executive Director, until Dec. 2022)
T. Dudok de Wit
M. Falanga
M. Rast

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11 Scientific
8 Administrative

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– New vision of the Saturnian system in the context of a highly dissipative Saturn.
– Solar and stellar dynamos: A new era.
– Magnetic reconnection: Explosive energy conversion in space plasmas.
– Strong gravitational lensing as a cosmological tool.
– Global water energy cycle and its changes in response to greenhouse gas emissions.
– Tipping points and understanding EO data needs for a Tipping Element Model Intercomparison Project (TipMip).
– Lunar gravitational wave observatories.
– Physical links between weather in space and weather in the lower atmosphere.
– Evolution of the Solar System: Constraints from meteorites.
– Magnetic switchbacks in the young solar wind.
– International cooperation in space to advance science I.
– Remote sensing in climatology - Essential climate variables and their uncertainties.
– Megavolt sky astronomy.

Online Seminar Series

ISSI has continued its series of webinar talks, inaugurated in August 2020, that have become known as the Game Changers Online Seminars with speakers from all over the world. The seminars are currently held with a monthly cadence: issibern.ch/publications/game-changers-seminars and also disseminated to a broader audience via the ISSI YouTube channel.

Publications

Scientific activities at ISSI each year result in 300–400 peer-reviewed papers in international journals. All results, published papers, and books can be found in ISSI's Annual Reports 27 (2022) and 28 (2023), which are available on issibern.ch.

In collaboration with Springer, ISSI releases the Space Sciences Series of ISSI (SSSI) to gather the collections of review papers arising from ISSI workshops, and the ISSI Scientific Reports (SR) to capture the output of other selected activities. As of the end of 2023, 86 volumes of SSSI, and 17 volumes of SR have been published. Information about the complete collection can be found on issibern.ch, in the section 'Publications'. In 2022 and 2023, the following volumes appeared:

SSSI Volume 76: **Oscillatory Processes in Solar and Stellar Coronae**, V.M. Nakariakov, D. Banerjee, B. Li, T. Wang, I. Zimovets, M. Falanga (Eds.), ISBN 978-94-024-2195-8

SSSI Volume 85: **Probing Earth's Deep Interior Using Space Observations Synergistically**, V. Dehant, M. Mandea, A. Cazenave, L. Moreira (Eds.), ISBN 978-3-031-39281-8

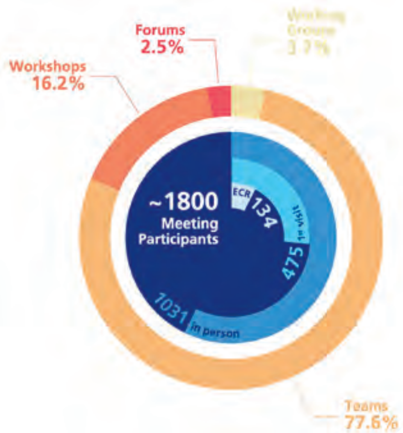
SSSI Volume 86: **Global Change in Africa**, A. Cazenave, D. Baratoux, T. Lopez, J.K. Kouamé, J. Benveniste, L. Moreira (Eds.)

SSSI Volume 88: **The Heliosphere in the Local Interstellar Medium: Into the Unknown**, J. Richardson, A. Bykov, F. Effenberger, K. Scherer, V.J. Sterken, R. von Steiger, G.P. Zank (Eds.), ISBN 978-94-024-2228-3

Outlook

Through its yearly Call for International Team proposals, ISSI selects approximately 30 new Teams. Each year a small number of between 3-5 Working Groups are also accepted into the programme. The following ISSI Workshops and Forums are currently scheduled to take place in 2024/25, with more to be approved at the upcoming meetings of the ISSI Science Committee.

– Cosmic footprint, large-scale space ethics.
– Physical links between weather and climate in space and the lower atmosphere.
– The chronology of the very early Universe according to JWST: the first billion years.
– Geoscience of (exo)planets: Going beyond habitability.
– Electron kinetic physics: The next frontier in space and astrophysical plasmas.
– Coastal blue carbon from space
– International cooperation in space to advance science II.
– Scientific measurement disparities in imaging spectroscopy of terrestrial ecosystems.
– 50 years of accretion disks.
– Using Earth observation systems to improve climate adaptation policy and action.
– Exocomets: bridging our understanding of minor bodies in solar and exoplanetary systems.
– Machine learning applications in space science: How to implement and use responsibly.



Distribution of ISSI meeting participants across the different ISSI networking activities (2022).

2.2 ISDC – INTEGRAL Science Data Centre

Institute
Dept. Astronomy, Univ. Geneva (UNIGE)
Versoix, Switzerland

In cooperation with
European Space Agency (ESA)
German Aerospace Centre (DLR)
Swiss Space Office (SSO)

Principal/Swiss Investigator(s)
C. Ferrigno (UNIGE)

Contribution
Main data center of the INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL)

Websites
isdc.unige.ch
astro.unige.ch/mmoda

Purpose of Research

The INTEGRAL Science Data Centre (ISDC) was established in 1996 as a consortium of 11 European institutes and NASA. It has a central role in the ground-segment activities of ESA's INTernational Gamma-Ray Astrophysics Laboratory (INTEGRAL). INTEGRAL operates a hard-X-ray imager with a wide field-of-view, a gamma-ray polarimeter, a radiation monitor, and X-ray and optical monitors, which have significantly advanced our knowledge of high-energy astrophysical phenomena. INTEGRAL's ground segment activities are divided into a Mission Operation Centre, Science Operation Centre (both operated by ESA), and ISDC which is a PI partner of the mission and provides essential services for the astronomical community to exploit mission data.

ISDC processes spacecraft telemetry to generate a set of widely usable products, as well as performing a quick-look analysis to assess the data quality and discover transient astronomical events. Data are distributed to guest observers and archived at ISDC which is the only complete source of INTEGRAL data. ISDC also has the task of integrating and distributing software for the offline analysis of INTEGRAL data together with handbooks, and of giving support to users. Only as a result of the ISDC contribution, is INTEGRAL data available to the astronomy community. The presence of the ISDC has guaranteed Swiss scientists a central role in the exploitation of INTEGRAL data. To date, ISDC members have participated in about 20% of publications based on INTEGRAL data.

Past Achievements and Status

INTEGRAL was launched in October 2002 and its data are not only used for papers and PhD theses, but also as a near-real time monitor: several astronomical telegrams per month are published and, every second day, an automatic alert for a gamma-ray burst (GRB) is sent to robotic telescopes within seconds of detection so that GRBs can be localised.

INTEGRAL carries the most sensitive all-sky monitor for GRBs without a localisation capability, and is an essential tool to discover a gamma-ray counterpart of a gravitational wave event (Savchenko et al., 2016). The INTEGRAL team has produced stringent upper limits on 85% of double black-hole mergers detected by LIGO and on neutrino events detected by IceCUBE. Together with the gamma-ray monitor on the Fermi observatory, it found a flash of gamma-rays two seconds after the arrival on Earth of gravitational waves, originating as a result of a binary neutron star merger (Savchenko et al., 2017). This historical achievement has opened the era of multi-messenger astronomy with the subsequent observation of a kilonova in the optical, X-ray, and radio bands.

ESA conducted reviews from 2010 to 2020. They concluded that solar panel and battery ageing, and orbital evolution will allow the mission to be prolonged for many more years. In 2020, an anomaly in the propulsion system revealed that the onboard fuel was exhausted. The ESA mission operation center found an ingenious way to operate the spacecraft without loss of scientific performance by implementing a pointing strategy that prevents excessive accumulation of angular momentum, induced by solar wind pressure. Scientific operations are planned to terminate in December 2024, even if the spacecraft is in good condition.

ISDC is an essential pillar of the mission and is currently funded by the Swiss Space Office, Univ. Geneva

(UNIGE), and ESA, with contributions from the German Aerospace Center through the Inst. Astronomy and Astrophysics, Tübingen, Germany. ISDC counts on the contribution of about five software engineers and scientists who work in synergy with other space missions within UNIGE and EPFL.

To ensure data quality and to exploit the potential of the INTEGRAL observatory, ISDC staff perform scientific validation of sampled data to report relevant 'hot' discoveries in collaboration with guest observers. Several astronomer's telegrams and circulars, led or promoted by ISDC staff, are highly cited, and illustrate the importance of these discoveries. In April 2020, the INTEGRAL team was the first to report a burst with Associated Radio Emission from the highly magnetised neutron star, SGR 1935+2154, establishing the first link between the mysterious fast radio burst and an astrophysical object (Mereghetti et al., 2020). Months later, the INTEGRAL contribution was key to triangulate the location of a giant magnetar flare in a nearby Galaxy (Svinkin et al., 2021).

To facilitate the access to INTEGRAL data analysis, ISDC has developed the the Multi-Messenger online analysis (MMODA) that allows an inexperienced user to obtain high-level data products for the IBIS/ISGRI, JEM-X, and SPI-ACS instruments for any data selection and a wide range of parameter choices (SPI data analysis is provided by the SPI PI institute). The user can explore the platform capability anonymously, while, upon login and acceptance of terms of service, one can easily obtain images, spectra and light curves from the web interface for a larger dataset. This platform runs on the computing infrastructure at UNIGE and provides the capability to perform customised analysis with state-of-the-art methods without installing software and downloading raw data: the barrier to exploit INTEGRAL data is greatly lowered for newcomers, the access facilitated for experienced users, and legacy preserved. We have also provided a gallery of pre-computed products for legacy.

The studies performed at ISDC are mainly in the field of high-energy astrophysics. Although a significant fraction of the research topics are linked to areas in which INTEGRAL makes a significant contribution, a variety of other observation facilities and future missions are supported.

Publications

Mereghetti S, Savchenko V, Ferrigno C et al. (2020) **INTEGRAL discovery of a burst with associated radio emission from the Magnetar SGR 1935+2154**, Astrophys. J. Lett. 898(2): id.L29.

Savchenko V, Ferrigno C et al. (2016) **INTEGRAL upper limits on gamma-ray emission associated with the gravitational wave event GW150914**, Astrophys. J. Lett. 820(2): L36, 5 pp.

Savchenko V, Ferrigno C et al. (2017) **INTEGRAL detection of the first prompt gamma-ray signal coincident with the gravitational-wave event GW170817**, Astrophys. J. Lett. 848(2): L15, 8 pp.

Svinkin D, … Ferrigno C et al. (2021) **A bright γ-ray flare interpreted as a giant magnetar flare in NGC 253**, Nature 589: L36, 211–213.

Abbreviations

INTEGRAL	International Gamma-Ray Astrophysics Laboratory
ISDC	INTEGRAL Science Data Centre
LIGO	Laser Interferometer Grav. Wave Observatory

Time-Line	From	To
Measurement phase	Oct. 2002	Dec. 2024
Data evaluation	Oct. 2002	–

2.3 eSpace – EPFL Space Center

Institute
eSpace – EPFL Space Center

Academic Director
J.-P. Kneib

Executive Director
E. David

Staff
2 Engineers,
1 PhD,
3 Administrative & Support Staff
4 Affiliated Researchers

Contact Information
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CH-1015 Lausanne
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Website
eSpace.epfl.ch

Description

eSpace is an interdisciplinary hub, working with students, academic institutions, international space agencies, and industry partners, with an overall mission to promote space related research and education at EPFL. The center coordinates the popular EPFL Minor in Space Technologies, which allows around 90 master's students each year to acquire extensive formal education in the field of space science and technologies.

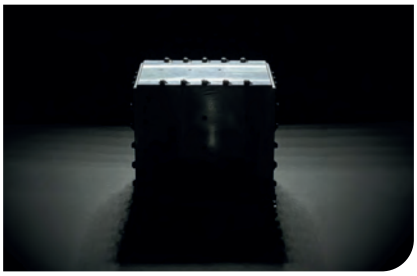
eSpace also provides guidance and support to various student-led associations on campus such as the EPFL Rocket Team, the Spacecraft Team, the Xplore Team, the Space Situational Awareness association, and the Asclepios association, encompassing over 300 students. Some highlights of these projects were: i) in 2023, an on-board computer built by the EPFL Spacecraft Team was launched into space; ii) the EPFL Rocket Team has won awards in numerous editions of the European Rocketry Competition, including winning first place in 2021; iii) in 2023, Radio Télévision Suisse (RTS) produced a documentary on the Asclepios Association.

eSpace boasts a team of experts with a wide range of industry and academic experience, and benefits from close collaborations with 40 research laboratories and institutes at EPFL. In many cases, the research and development activities performed are carried out directly within these entities, with support or coordination from eSpace. In this way, eSpace profits from the extensive knowledge base and state-of-the-art research in a number of areas, ranging from robotics, artificial intelligence, and precision engineering to computer vision, and helps launch these technologies to Space.

Space Sustainability

eSpace is a pioneer in space sustainability. With the Clean Space Initiative, initially proposed to de-orbit Swisscube which eventually became a spin-off from EPFL as the ClearSpace-1 mission to recover the Vega Secondary Payload Adapter (VESPA), the Center can draw on a decade of experience in space sustainability. In 2021, eSpace became the host of the Space Sustainability Rating (SSR), which incentivises safe and sustainable behaviour by space operators through a voluntary rating system. The SSR spun off into its own association in 2022, and as of early 2024 performed six ratings.

In 2024, eSpace completed its Research Initiative on Sustainable Space Logistics (RISSL). This initiative was the starting point of several consortium projects that attracted many stakeholders, resulting in several publications and the development of a space logistics modelling software for mission profile evaluation and optimisation. The next phase of this project has begun under the new project, called REACT (gREen spACe logistics Tool). This new activity will still be led by EPFL with a larger consortium including the University of Stuttgart and ISAE SUPAERO in Toulouse, in addition to the GSL partners, Paul Scherrer Institute (PSI) and Ateleris GmbH.



In 2023, the Bunny on-board computer built by the EPFL Spacecraft Team was launched into space with D-Orbit by SpaceX. Image credit: EPFL Spacecraft Team.

Over the span of two years, the goal is to iterate on the development of the Assessment and Comparison Tool (ACT), improve its proof of concept to answer potential users' needs, and to enable its adoption in the design process of European space industries. This tool will enable the modelling and comparisons of space transportation systems, including in-space transportation vehicles, and will be usable in the early design phase for actors to make decisions on (eco)design choices while still remaining technically and financially possible. Indeed, the early design is lacking the precision in data, which is necessary for robust life-cycle assessment. The tool shall then enable the use of heritage data and simplify the LCA process with accurate results that enable the identification of environmental hotspots and the comparison of similar systems. Relative values from the analysis will support decision-making and allow the European space sector to reduce its environmental impact, in Space and on Earth.

In order to unite EPFL's forces in the domain of sustainability in Space, eSpace launched the Sustainable Space Hub (SSH) in 2023. The goal of the Hub is to coherently manage and foster the growth of these topics. A growing community of students and researchers within EPFL are currently involved in research and development projects in the field of space sustainability. The hub is connecting these individual projects in a workflow that rests on three intertwined pillars: 'measure', 'understand', and 'act for space sustainability'.

Publications

Billot N, Hellmich S, Benz W (2023) **Passive orbital debris detection from low Earth orbit: The CHEOPS viewpoint after 3 years of operations**, 2nd Int. Orbital Debris Conf., Abstract #6089.

Hellmich S, Udriot M, David E (2023) **Sustainable Space Hub at EPFL: a review of ongoing research projects**, Aerospace Europe Conf., 10th EUCASS, 9th CEAS.

Markard J, Wells P, Yap X-S, van Lente H (2023) **Unsustainabilities: A study on SUVs and Space Tourism and a research agenda for transition studies**, Energy Res. & Social Science 106: Dec. 2023.

Rachith E, Hellmich S, Irureta-Goyena BY (2023) **A novel machine learning based algorithm for efficient streak detection**, 2nd Int. Orbital Debris Conference, Abstract #6132.

Rathnasabapathy M, David E (2023) **Space sustainability rating in support of the development and adoption of regulatory guidelines related to long-rerm sustainability**, Air and Space Law 48: Special Issue, pp. 155–178.

Udriot M, Treyer K, David E, Buehler O, Etesi L, Girardin V (2023) **Rapid life cycle assessment software for future Space transportation vehicles' design**, Aerospace Europe Conf., 10th EUCASS, 9th CEAS.

Members of the Asclepios Team: a group of EPFL students who are simulating a mission to the moon using the former military fortress of Sasso San Gottardo, Switzerland, as a 'lunar base'. Image credit: Asclepios.

2.4 ETH Zurich | SPACE

Director
T. Zurbuchen

Staff
8 Scientific
1 Administrative

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Mission

ETH Zurich | Space boosts space activities internally and externally with stakeholders, to establish ETH Zurich as the leading university in space research and space education within Europe, and as an excellent partner within Switzerland and beyond.

Vision

ETH Zurich | Space aims to become a leading hub for space research and education, contributing significantly to the global space ecosystem. By bridging the gap between scientific inquiry and technological innovation, the institute seeks to address some of the most pressing challenges in astrophysics, earth observation, navigation systems, robotics, and beyond.

Description

ETH Zurich | Space was established to synergise the various activities in the space sector under a unified banner, enhancing collaboration within ETH Zurich and with external partners. As a cornerstone of space research and technology, the institute serves as a central liaison, offering support in project planning, funding acquisition, and consortium formation. Its role extends beyond the academic realm, inviting external stakeholders and institutions to engage in cooperative efforts aimed at advancing space exploration and technology. The institute's involvement spans an array of space-related projects, from conceptual studies like the LIFE mission aimed at exploring exoplanets, to technological contributions to the James Webb Space Telescope.

Furthermore, ETH Zurich | Space is committed to the dissemination and application of its research findings, working closely with international space agencies, industry partners, and academic institutions world-wide. This collaborative approach ensures that discoveries and innovations not only contribute to the scientific community but also have practical implications for space missions and technologies of the future.

Educational Initiatives

Recognising the critical role of education in fostering the next generation of space scientists and engineers, ETH Zurich | Space is dedicated to offering state-of-the-art educational programs that reflect the dynamic and interdisciplinary nature of space research. The institute will launch a new Master's programme in Space Systems, set to commence in Autumn 2024. This programme represents a significant leap forward in space education, designed to meet the growing industry demand for highly skilled professionals equipped with a thorough understanding of complex space systems.

The curriculum covers a broad spectrum of topics, from the engineering of spacecraft and satellites to the scientific exploration of the cosmos. Students will delve into the fundamentals of astrophysics, earth and planetary sciences, and will have the opportunity to specialise in areas such as space engineering, space communication, robotics, and earth observation. The program places a strong emphasis on practical, hands-on experience, incorporating team projects and case studies that encourage students to apply their knowledge to real-world challenges in space exploration.

Through these initiatives, ETH Zurich | Space aims to not only advance scientific knowledge and technological innovation but also to inspire and educate future leaders in the space sector. By providing a comprehensive and interdisciplinary education, the institute prepares students to make significant contributions to space research and industry, ultimately driving progress and exploration beyond our planet.

Examples of space projects at ETH Zurich

LIFE (Large Interferometer for Exoplanets): Spearheaded by ETH, LIFE is an ambitious mission concept aimed at exploring exoplanets and searching for signs of life. This project represents a significant step forward in understanding the conditions of planets beyond our solar system.

ESA LISA & Pathfinder: ETH Zurich contributes to this ground-breaking project with expertise in control electronics, drive mechanisms, data acquisition, noise mitigation, and signal identification, paving the way for future gravitational wave observatories.

James Webb Space Telescope (JWST): As part of a consortium, the Institute for Particle Physics and Astrophysics at ETH Zurich played a key role in the development of the MIRI instrument, enhancing our ability to observe the early universe.

Robotic Technologies for Space Exploration: Projects such as Spacebok, GLIMPSE, SpaceHopper, and ARISE showcase ETH Zurich's leadership in developing robotic systems that could redefine mobility in space exploration contexts.

Satellite-Based Crop Monitoring: This initiative leverages satellite imagery to perform large-scale classification of crops, contributing to food security, biodiversity, and forestry management.

For a comprehensive list of all space activities at ETH Zurich please refer to this brochure at: ethz.ch/content/dam/ethz/main/industry/Space/Brochure_Overview space activities at ETH Zurich.pdf.

2.5 Satellite Laser Ranging (SLR) at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald (SwissOGS)

Laser beam transmitted from the 1-meter ZIMLAT telescope to measure mm-accuracy distances of artificial satellites.

Institute
Astronomical Institute, Univ. Bern (AIUB), Bern

In cooperation with
Bundesamt für Landestopographie (swisstopo), Wabern, Switzerland

Principal Investigator(s)
T. Schildknecht (AIUB)

Co-Investigator(s)
L. Kleint (AIUB)
P. Lauber (AIUB),
A. Villiger (swisstopo)

Website
aiub.unibe.ch

Purpose of Research

The Zimmerwald Geodynamics Observatory, part of the SwissOGS (Swiss Optical Ground Station), is a station of the global tracking network of the International Laser Ranging Service (ILRS). Satellite Laser Ranging (SLR) observations to satellites equipped with laser retro-reflectors are acquired with the monostatic 1-m multi-purpose Zimmerwald Laser and Astrometric Telescope (ZIMLAT). The system is operated 24 hours a day and 7 days per week.

The collected data are delivered in near real-time to the global ILRS data centers, and official products are generated by the ILRS analysis centers using SLR measurements to the geodetic satellites, in particular LAGEOS 1 and 2 (Laser Geodynamics Satellite), and LARES (Laser Relativity Satellite). Products derived from these SLR observations include precise satellite ephemerides, station positions and velocities of sites in the ILRS network, as well as Earth Orientation Parameters (EOPs, i.e., polar motion and rates, length-of-day).

The contribution of SLR measurements to the definition of the origin of the International Terrestrial Reference Frame (ITRF) (the so-called geocenter coordinates), the global scale, precise orbit parameters, and low-degree spherical harmonics of the Earth's gravity field (especially the dynamic oblateness term) is essential due to the unique orbit precision of geodetic satellites and the precision of laser observations at a level of a few millimetres per normal point. The latter are derived from raw measurement data by averaging over a short time interval.

Past Achievements and Status

The Zimmerwald SLR station continues to provide high quality range data to the scientific community on a 24/7 basis and keeps being the most productive SLR station in the northern hemisphere.

The design of the 100 Hz Nd:YAG laser system used at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald enables a high flexibility in the selection of the actual firing rate and epochs, which also allows for synchronous operation in one-way laser ranging experiments to spaceborne optical transponders such as the Lunar Reconnaissance Orbiter (LRO), or the European Laser Time Transfer experiment (ELT) to be flown on the International Space Station. The highly autonomous management of the SLR operations by the in-house developed control software allowed the Zimmerwald Observatory to evolve in the last decades to one of the most productive SLR stations worldwide. This achievement is remarkable when considering the facts that weather conditions in Switzerland only allow operations about two thirds of the time, and that observation time is shared during the night between SLR operations and the search and characterisation of space debris with CCD cameras attached to the multi-purpose telescope.

All these efforts have to be seen in the larger context of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). In order to achieve the GGOS science goals, the accuracy and amount of SLR measurements need to be significantly improved. The Zimmerwald SLR station will be upgraded with cutting-edge innovative laser systems. A new kHz laser with a pulse length of 8 ps in combination with new receiver electronics and picosecond event timers will improve the single observation range accuracy from 1.2 cm to 2 mm and at the same time increase the number of measurements by a factor of 10. In addition, a 200 Hz high power laser was installed in order to measure ranges to targets, which are not equipped with laser retro-reflectors. This system will in particular be used to provide high precision orbit and attitude information for the target object of the ESA-CH Active Debris Removal and In Orbit Servicing project (ADRIOS).

Publications

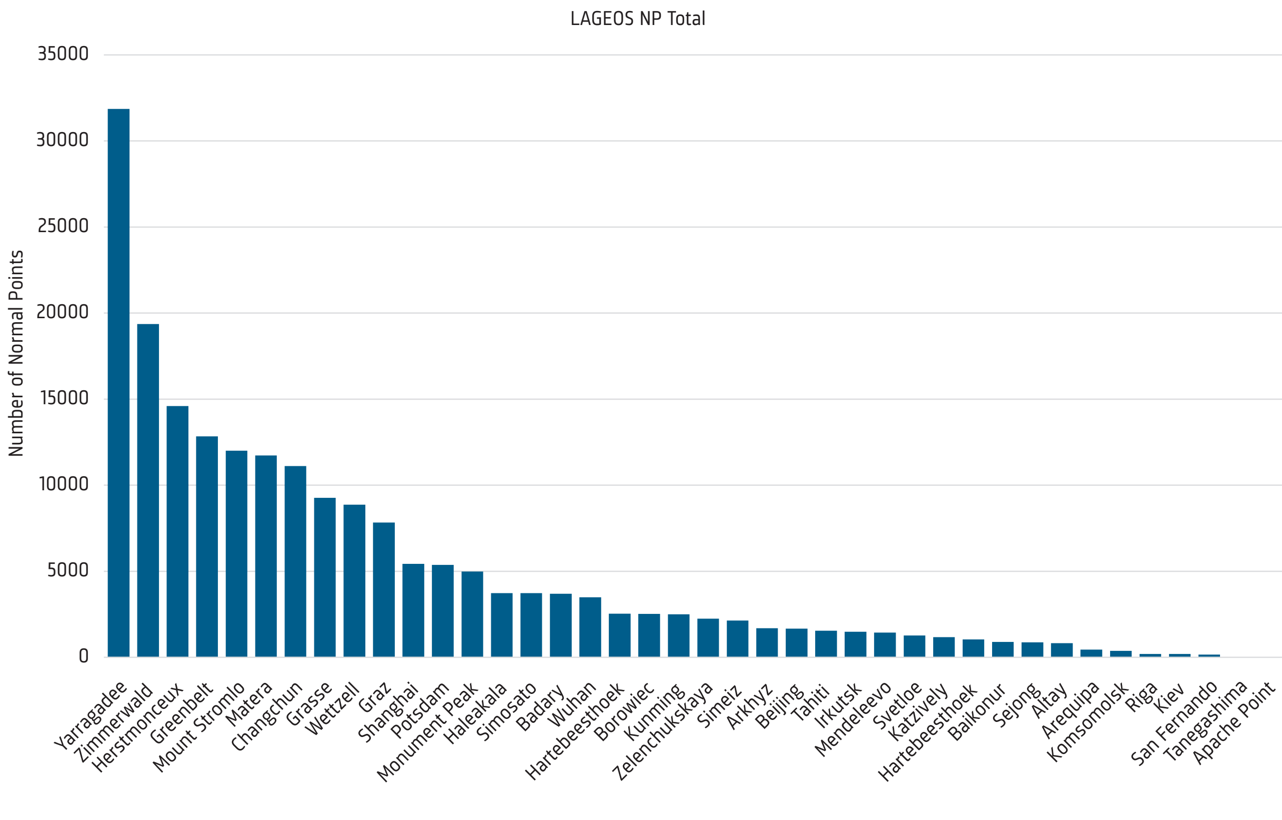
Rodriguez J, Lauber P, Schildknecht T (2022) **Novel data analysis strategy at the SwissOGS Zimmerwald**, Proc. 22nd Int. Workshop on Laser Ranging, Yebes, Spain.

Rodriguez J, Schildknecht T (2023) **Laser ranging to space debris: Overcoming challenges**, Proc. 74th Int. Astron. Congress (IAC), Baku, Azerbaijan.

Schildknecht T, Kleint L, Lauber P, Prohaska M, Jäggi A (2023), **Satellite laser ranging at Zimmerwald**, Swiss National Report on the Geodetic Activities in the years 2019–2023.

Abbreviations

ADRIOS	Active Debris Removal and In Orbit Servicing project
GGOS	Global Geodetic Observing System
ILRS	International Laser Ranging Service
ITRF	International Terrestrial Reference Frame
LAGEOS	Laser Geodynamics Satellite
LARES	Laser Relativity Satellite
SLR	Satellite Laser Ranging
ZIMLAT	Zimmerwald Laser and Astrometry Telescope



Number of 'normal points' (NP) for the LAGEOS geodetic satellite acquired in the ILRS network in 2021.
The Zimmerwald Observatory is the most productive SLR station in the northern hemisphere (second worldwide).

2.6 CODE – Centre for Orbit Determination in Europe

Institute
Astronomical Inst., Univ. Bern (AIUB), Bern, Switzerland

In cooperation with
Bundesamt für Landestopographie (swisstopo), Wabern, Switzerland
Bundesamt f. Kart. u. Geodäsie (BKG), Frankfurt a. M., Germany
Inst. Astronom. u. Physikal. Geodäsie (IAPG), Technische Universität München, Germany

Principal/Swiss Investigator(s)
R. Dach (AIUB)

Co-Investigator(s)
A. Jäggi (AIUB)
A. Villiger (swisstopo)
D. Thaller (BKG)
U. Hugentobler (IAPG)

Contribution
Research based on existing instruments: GNSS data analysis and software development.

Website
aiub.unibe.ch/code

Purpose of Research

Using measurements from Global Navigation Satellite Systems (GNSS) is (among many other applications) well established for the realisation of the global reference frame, the investigation of the system Earth, or the precise geolocation of Low Earth Orbiting (LEO) satellites in space. To support the scientific use and the development of GNSS data analysis, the International GNSS Service (IGS) was founded by the International Association of Geodesy (IAG) in 1994.

CODE is one of the leading global analysis centers of the IGS. It is a joint venture of the Astronomical Institute of the University of Bern (AIUB), Bern, Switzerland, the Bundesamt für Landestopographie (swisstopo), Wabern, Switzerland, the Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt a. M., Germany, and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München, Munich, Germany. Since the early pilot phase of the IGS (21 June 1992), CODE is continuously contributing to the IGS. The operational processing is located at AIUB using the Bernese GNSS Software package that is developed and maintained at AIUB for many years.

Nowadays, data from more than 250 globally distributed IGS tracking stations are processed every day in a rigorous combined multi-GNSS (currently the American Global Positioning System (GPS), the Russian counterpart, GLONASS, and the European Galileo system) processing for all IGS product lines (with different latencies). CODE started with the inclusion of GLONASS in its regular processing scheme already back in May 2003. For five years it was the only one following this approach. Meanwhile, other IGS analysis centers have started to follow this strategy as well. In addition, the inclusion of Galileo in the operational product chains of the IGS was initiated by CODE in September 2019 as the first of the analysis centers.

In a separate processing line, a fully integrated five-system solution has been developed, including not only the established GNSS, GPS, GLONASS and Galileo, but also the Chinese BeiDou (since March 2021 also those of the third generation), and the Japanese QZSS as additional systems. The resulting solution is generated in the frame of the IGS multi-GNSS extension (IGS MGEX).

Past Achievements and Status

The main products are precise GNSS satellite orbits, satellite and receiver clock corrections, station coordinates, Earth orientation parameters, troposphere zenith path delays, and maps of the total ionospheric electron content. The coordinates of the global IGS tracking network are computed on a daily basis to study vertical and horizontal site displacements and plate motions, and to provide information for the realisation of the International Terrestrial Reference Frame (ITRF). The daily positions of the Earth's rotation axis with respect to the Earth's crust, as well as the exact length-of-day, is determined for each day and provided to the International Earth Rotation and Reference Systems Service (IERS).

Apart from regularly generated products, CODE significantly contributes to the development and improvement of modelling standards. Members of the CODE group contribute or chair different IGS product committees, e.g., on Bias and Calibration or on GNSS antennas. Since 2023, Rolf Dach – another member of the CODE team – became the elected chair of the Governing board.

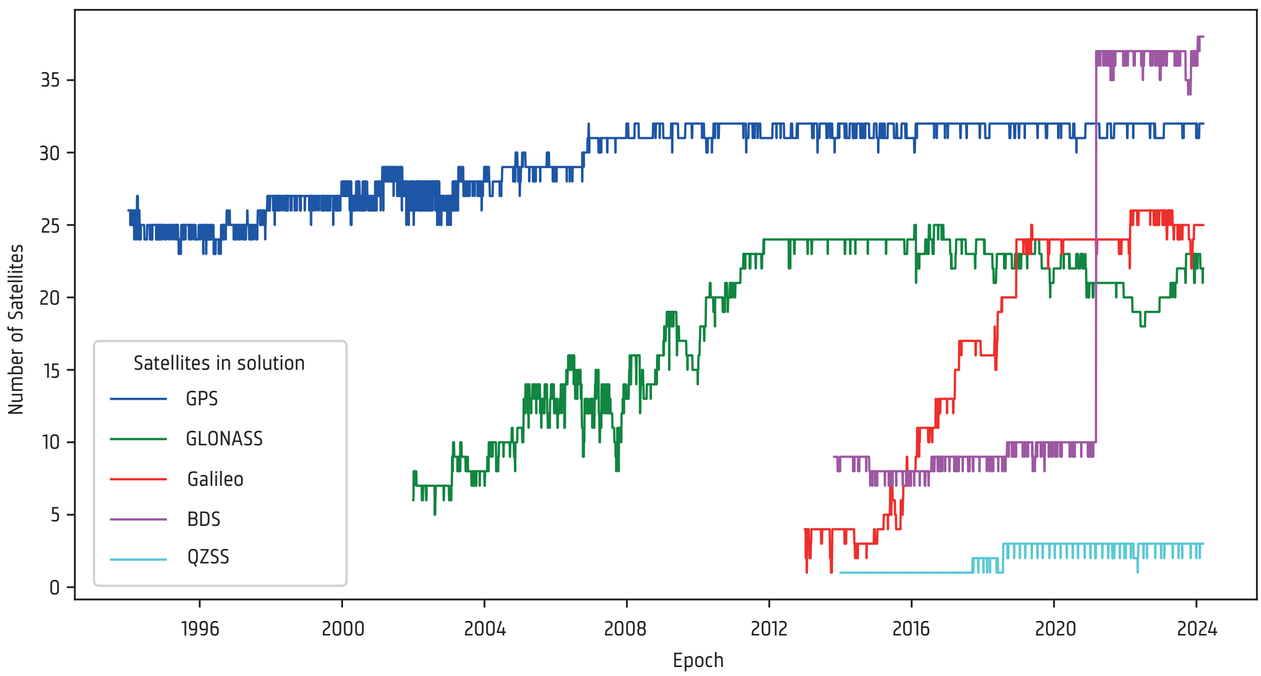
CODE is contributing in a series of satellite antenna calibration computations in order to also include the Asian satellite systems (Beidou and QZSS) consistently into the legacy product series. Other activities are focusing on the preparation of ESA's Genesis mission where several geometric space-geodetic techniques will be combined via a space-tie.

Abbreviations

CODE	Centre for Orbit Determination in Europe
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IERS	International Earth Rotation & Reference Systems Service
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
LEO	Low Earth Orbit
QZSS	Quasi-Zenith Satellite System

Publications

A list of recent publications is available at:
bernese.unibe.ch/publist



Number of satellites in the orbit product files provided by CODE.

3 Swiss Space Missions

3.1 CHEOPS – CHaracterising ExOPlanet Satellite

Artist's impression of CHEOPS in orbit. Image credit: ESA.

Institute
Center for Space & Habitability, Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Institut für Weltraumforschung Graz, Austria
Center Spatial de Liege, Belgium
Obs. de Genève, Genève, Switzerland
Lab. d'Astrophys., Marseille, France
DLR Inst. Planetary Res., Germany
DLR Inst. Opt. Sensor Sys., Germany
Konkoly Observatory, Hungary
INAF Osserv. Astrofisico di Catania, Italy
INAF Osserv. Astro. di Padova, Italy
Centro de Astro. da Univ. do Porto, Portugal
Deimos Engenharia, Portugal
Onsala Space Observatory, Sweden
Stockholm Univ., Sweden
Univ. Warwick, Univ. Cambridge, UK

Principal/Swiss Investigator(s)
W. Benz (UNIBE)

Co-Investigator(s)
The CHEOPS team includes more than 100 scientists and engineers from 40 institutions in 11 ESA Member States (see cheops.unibe.ch/about-us/core-science-team).

Purpose of Research

CHEOPS is the first mission dedicated to search for transits of exoplanets by means of ultra-high precision photometry on bright stars already known to host planets.

It will provide the unique capability of determining accurate radii for a subset of those planets for which the mass has already been estimated from ground-based spectroscopic surveys, providing on-the-fly characterisation of exoplanets located almost everywhere in the sky.

It will also provide precise radii for new planets discovered by the next generation of ground or space-based transit surveys (Neptune-size and smaller).

By unveiling transiting exoplanets with high potential for in-depth characterisation, CHEOPS will also provide prime targets for future instruments suited to the spectroscopic characterisation of exoplanetary atmospheres.

In particular, CHEOPS will:

- Determine the mass-radius relation in a planetary mass range for which only a handful of data exist and to a precision not previously achieved.
- Identify planets with significant atmospheres in a range of masses, distances from the host star, and stellar parameters.
- Place constraints on possible planet migration paths followed during the formation and evolution of planets. By unveiling transiting exoplanets with high potential for in-depth characterisation, CHEOPS will also provide prime targets for future instruments suited to the spectroscopic characterisation of exoplanetary atmospheres.
- Bring new constraints on the atmospheric properties of known hot Jupiters via phase curves.
- Provide unique targets for detailed atmospheric characterisation by future ground (e.g. the European Extremely Large Telescope, E-ELT) and space-based (e.g. the James Webb Space Telescope, JWST) facilities with spectroscopic capabilities.

Since the beginning of the mission extension in September 2023, 30% of CHEOPS observing time has been made available to the community through a selection process carried out by ESA.

Past Achievements and Status

- Mission selection: Oct. 2012.
- Mission adoption: Feb. 2014.
- Instrument Critical Design Review: Dec. 2015.
- Telescope shipped to ADS Madrid for integration: Apr. 2018.
- Satellite ready for launch, and placed in storage at ADS: May 2019.
- CHEOPS is successfully launched from Kourou as a secondary passenger on a Soyuz- Fregat rocket: 18 Dec. 2019.
- Successful completion of the in-orbit commissioning review: 25 Mar. 2020.
- Hand-over of the responsibility for CHEOPS operations from ESA to the Consortium: Apr. 2020.
- Apr. 2020 – Sep. 2023: Nominal mission successfully completed.
- Nov. 2021 – Mar. 2022: Mission extension operations review.
- May 2022: Mission extension science case presented to SSAC.
- Jun. 2023: In-orbit performance review and lessons learned.
- September 2023 – Begining of the first mission extension.

Publications

Benz W, Broeg C, Fortier A, et al. (2021) **The CHEOPS Mission**, Exp. Astron. 51: 109–151.

Scientific results: CHEOPS publications derived fron the Guaranteed Time Observing (GTO) programme can be obtained here: ui.adsabs.harvard.edu/user/libraries/cxJTRv4OTV2SHn_p_xpl2Q

CHEOPS publications derived from the Guest Observer programme can be obtained here: ui.adsabs.harvard.edu/public-libraries/Do7dSW94QiefOrgZt5YwbA

Abbreviations

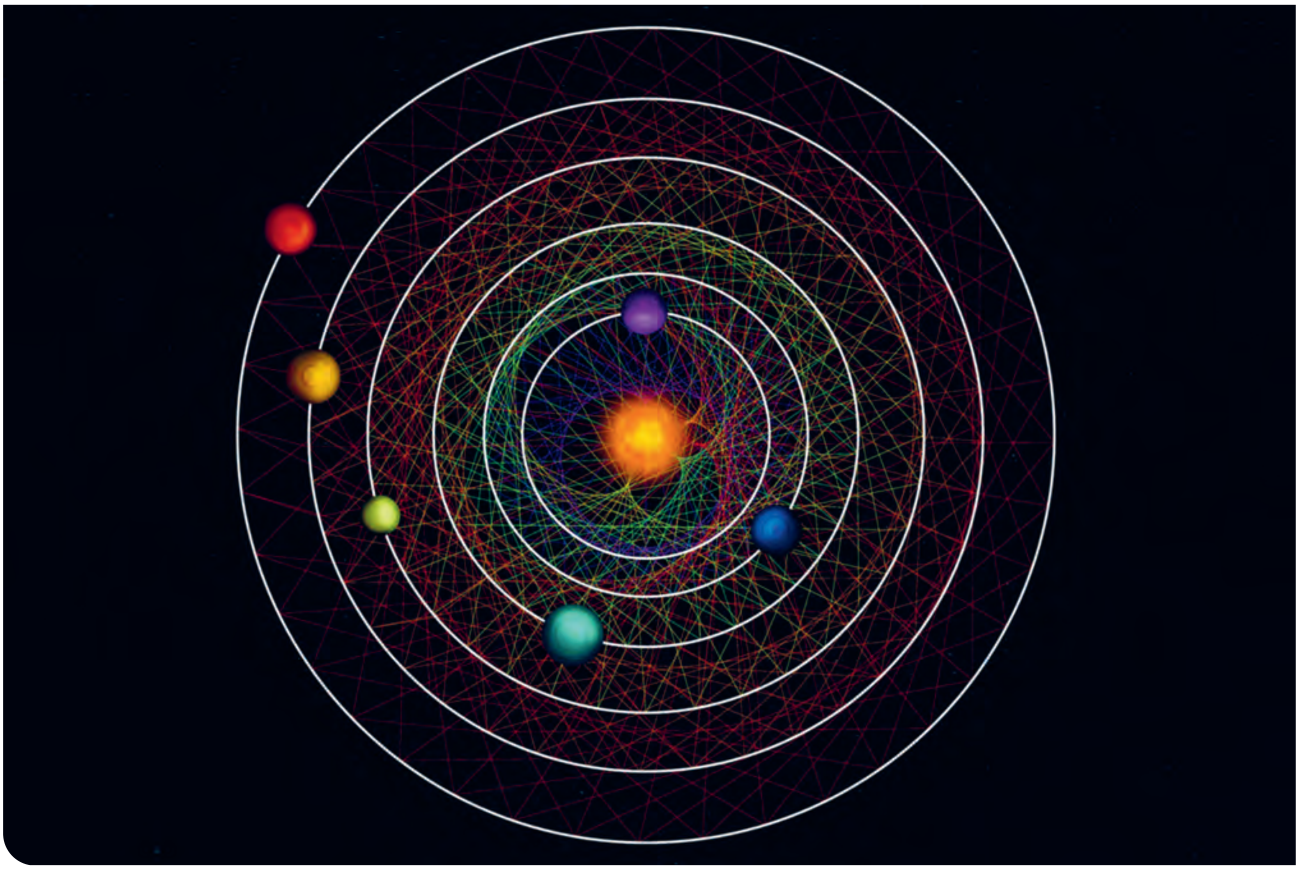
CHEOPS CHaracterising ExOPlanet Satellite

Time-Line	From	To
Planning	Mar. 2013	Feb. 2014
Construction	Mar. 2014	Jul. 2019
Measurement phase	Apr. 2020	open
Data evaluation	Apr. 2020	open

Contribution
Development & construction of instrument(s): Switzerland is responsible for the development, assembly, and verification of a 33 cm diameter telescope as well as the development and operation of the mission's ground segment.

Industrial hardware contract(s)
Major contracts with: Airbus Defense & Space (ADS); Almatech; Connova AG; Pfeiffer Vacuum AG; P&P, RUAG Space

Website
cheops.unibe.ch



Orbital geometry of HD 110067. The system of planets originally discovered by the NASA satellite, TESS, has been followed-up by CHEOPS, which has allowed the geometry of the entire system of six planets in orbital resonances to be unlocked. Tracing a link between two neighbouring planets at regular time intervals along their orbits, creates a pattern unique to each couple. The six planets of the HD110067 system together create a mesmerising geometric pattern due to their resonance-chain. There are only three 6-planet systems known today and this is the second one found by CHEOPS. Image credit: ESA.

4 Solar Physics

4.1 SPICE and EUI on Solar Orbiter

Artist's impression of Solar Orbiter.
Image credit: ESA.

Institute
Phys. Met. Observatorium Davos/
World Radiation Centre (PMOD/WRC),
Davos, Switzerland

In cooperation with
Centre Spatiale de Liège (CSL), Belgium
Royal Observatory Belgium (ROB), Belgium
Mullard Space Science Lab. (MSSL), UK
Rutherford Appleton Lab. (RAL), UK
Institut d'Astrophysique Spatiale (IAS), France
Max Planck Institut f. Sonnensystem-forschung (MPS), Germany
University of Oslo (UiO), Norway
South West Research Institute (SWRI), USA

Principal Investigator(s)
D. Berghmans (ROB), Belgium (EUI)
F. Auchère (IAS), France (SPICE)

Swiss Principal Investigator(s)
L. Harra (PMOD/WRC)

Co-Investigator(s)
There are 62 EUI and 59 SPICE co-Investigators with international representation

Industrial hardware contract(s) to
APCO Technologies
Almatech

Website
pmodwrc.ch

Purpose of Research

The EUV Imager (EUI; Rochus et al., 2020) and Spectral Imaging of the Coronal Environment (SPICE; SPICE team et al., 2020) are two instruments onboard the ESA/NASA Solar Orbiter mission. The mission was successfully launched on 9 February 2020 from Cape Canaveral, USA. The mission's over-arching goals are to understand how the Sun creates and controls the heliosphere. The spacecraft used gravity assists from Venus and the Earth to slowly place the spacecraft into a 180-day orbit around the Sun. One set of instruments was designed to measure, in-situ, the solar plasma and magnetic fields – these are operated continuously. The other set of instruments, remotely sense the Sun, measuring the dynamics and plasma parameters of solar wind sources.

The remote sensing instruments mostly operate intensively during the closest points of the orbit to the Sun (perihelia). The EUI instrument provides both full Sun images in the EUV through the Full Sun Imager (FSI) and two high resolution imagers (HRIs) that provide high resolution data of a smaller field-of-view – one telescope measuring in the corona and the second in the chromosphere.

The FSI instrument enables an understanding of large-scale global eruptions and context of the mutiple sources of the solar wind. The HRIs can observe small-scale jets and brightenings at a high time cadence. Although not in science mode yet, the EUI instrument has already produced science quality data. It has also observed the smallest and weakest brightenings ever observed. These have length scales of 400–4000 km, and durations between 10 s and 200 s, observed at a position 0.55 A.U. from the Sun.

In 2022, the spacecraft was closer to the Sun (0.28 A.U.), and higher spatial resolutions were achieved. These observations reveal structures that were not observed before and are creating upflowing plasma (Schwanitz et al., 2023). These small-scale structures are a key component in understanding the dynamics of the solar wind.

The SPICE instrument provides spectroscopy at EUV wavelengths, allowing measurements of plasma between temperatures of 20,000 K to >1 million K. This provides a range of temperature, density and abundance measurements to explore different sources of the solar wind, and link them to the in-situ measurements.

In 2022, the science operations began with coordinated measurements between the instruments with Solar Orbiter, but also other facilities including spectrometers onboard Hinode and IRIS. In October 2022 a complex observing campaign took place between the 4 m ground-based telescope, DKIST, in Maui and Solar Orbiter. These campaigns will continue and opportunities of alignments with Parker Solar Probe will be continued. By the end of 2023, Solar Orbiter successfully completed four successful science perihelia and the data is released publicly once calibrated.

Past Achievements and Status

The SPICE Low Voltage Power Supply (LVPS) was built at PMOD/WRC. Together with APCO Technologies, PMOD/WRC was responsible for the EUI Optical Bench Structure (OBS). In addition, the SPICE Slit Change Mechanism (SCM) was provided by Almatech, and the SPICE contamination door (SCD) by APCO Technologies, both managed by PMOD/WRC.

Abbreviations

EUI	Extreme Ultraviolet Imager
FSI	Full Sun Imager
HRI	High Resolution Imager
LVPS	Low Voltage Power Supply
OBS	Optical Bench Structure
SCD	SPICE Contamination Door
SCM	Slit Change Mechanism
SPICE	Spectral Imaging of the Coronal Environment

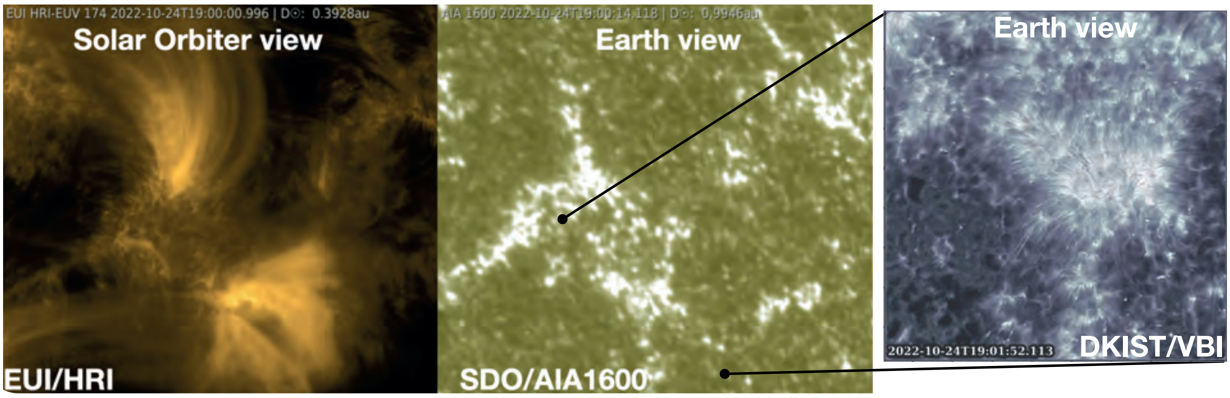
Publications

Rochus P., Auchère F., Berghmans D., Harra L. et al. (2020) **The Solar Orbiter EUI instrument: The Extreme Ultraviolet Imager**, A&A 642: A8, doi.org/10.1051/0004-6361/201936663

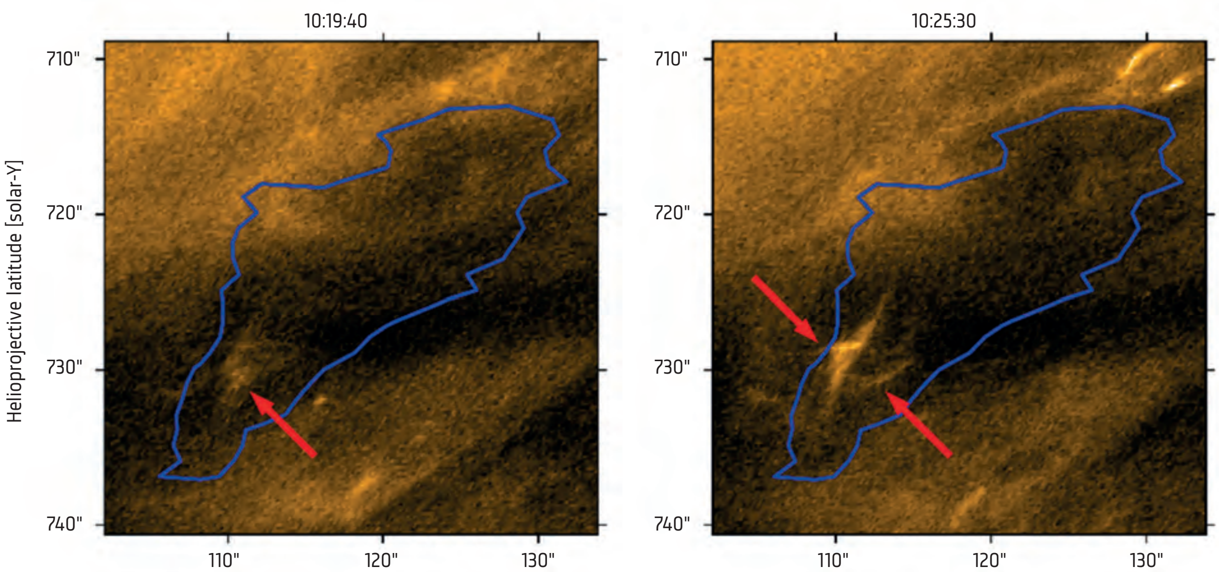
Schwanitz, C., Harra, L., Mandrini, C. et al. (2023) **Small-scale EUV features as the drivers of coronal upflows in the quiet Sun**, A&A 674: 219, ui.adsabs.harvard.edu/link_gateway/2023A&A...674A.219S/doi:10.1051/0004-6361/202346036

SPICE Team, Anderson M., Appourchaux T., Auchère F. et al. (2020) **The Solar Orbiter SPICE instrument**, A&A, 642, A14, doi.org/10.1051/0004-6361/201935574

Time-Line	From	To
Planning	2008	2010
Construction	2010	2017
Measurement phase	2021	2029
Data evaluation	2021	2030

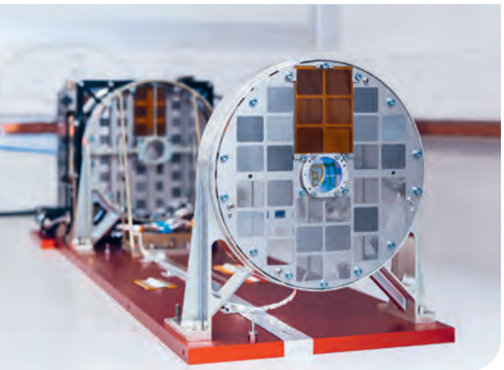


An example of data from the Solar Orbiter and DKIST observing campaign in 2022 when the Earth and spacecraft were at quadrature, providing a unique dataset of an active region.



An example of small-scale jets seen with HRI that are creating upflowing plasma (Schwanitz et al., 2023).

4.2 STIX – Spectrometer/Telescope for Imaging X-rays on Solar Orbiter



The STIX Flight Model.

Institute
Inst. for Data Science, Fachhochschule Nordwestschweiz (FHNW), Windisch, Switzerland

In cooperation with
SRC, Poland; CEA Sacaly, France; Leibniz-Institut für Astrophysik Potsdam (AIP), Germany; Czech Space Office, CZ; Univ. Graz, Austria; Trinity College, Dublin; LESIA, France; Univ. Genova, Italy

Principal/Swiss Investigator(s)
S. Krucker (FHNW)

Co-Investigator(s)
J. Sylwester (SRC); O. Limousin (CEA); G. Mann (AIP); F. Farnik (CSO); A. Veronig (Uni Graz); P. Gallagher (TCD) N. Vilmer (LESIA); M. Piana (Univ. Genova)

Contribution
STIX is a Swiss-led instrument onboard Solar Orbiter to study magnetic energy release and particle acceleration in solar flares.

Industrial contract(s) to
Almatech, Lausanne; Ateleris, Brugg; SYDERAL, Gals; Art of Technology, Zurich,

Website
stix.i4ds.net

Purpose of Research

Solar Orbiter is a joint ESA-NASA collaboration that addresses the central question of heliophysics: How does the Sun create and control the heliosphere? To achieve this goal, Solar Orbiter carries a set of 10 instruments to perform joint observations. Through hard X-ray imaging and spectroscopy, the Spectrometer/Telescope for Imaging X-rays (STIX) instrument provides information of heated (>10 MK) plasma and accelerated electrons that are produced as magnetic energy is released during solar flares. By using this set of diagnostics, STIX plays a crucial role in enabling Solar Orbiter to achieve two of its major science goals of:

- understanding the acceleration of electrons at the Sun and their transport into interplanetary space.
- determining the magnetic connection of Solar Orbiter back to the Sun.

In this way, STIX provides a crucial link between the remote and in-situ instruments of the Solar Orbiter mission.

Past Achievements and Status

Solar Orbiter was launched on 9 February 2020, and the commissioning of STIX was successfully completed in June 2020. In the nominal science phase, STIX has been continuously observing the Sun, and more than 50,000 solar flares have been recorded so far.

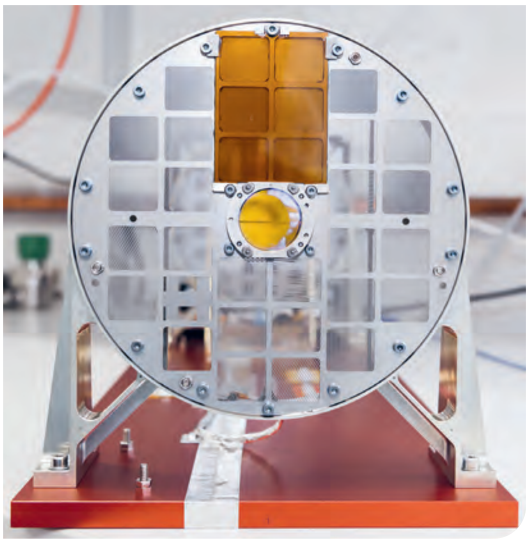
Publications

Krucker S et al. (2020) Astron. Astrophys. 642: id. A15, 21 pp.

Abbreviations

STIX Spectr./Telescope for Imaging X-rays

Time-Line	From	To
Planning	2010	2014
Construction	2014	2017
Measurement phase	2020	2027
Data evaluation	2020	open



Close-up view of the STIX Flight Model.

4.3 SWA – Solar Wind Plasma Analyser on Solar Orbiter

Purpose of Research

Solar Orbiter was launched in February 2020 to examine how the Sun creates and controls the heliosphere, the vast bubble of charged particles blown by the solar wind into the interstellar medium.

The spacecraft will combine in-situ and remote sensing observations to gain new information about the solar wind, the heliospheric magnetic field, solar energetic particles, transient interplanetary disturbances and the Sun's magnetic field.

The Solar Wind Plasma Analyser, SWA, which is part of the science payload, consists of a suite of plasma sensors (Electron Analyser System (EAS), a Proton and Alpha Particle Sensor (PAS) and a Heavy Ion Sensor (HIS). These will measure the ion and electron bulk properties (including density, velocity, and temperature) of the solar wind, thereby characterising the solar wind between 0.28 and 1.4 AU from the Sun.

In addition to determining the bulk properties of the wind, SWA will also provide measurements of the solar wind ion composition for key elements.

Past Achievements and Status

We calibrated the HIS instrument of the SWA experiment with highly charged ions as they are found in the solar wind, e.g. the C, N, O group and Fe, Si or Mg.

Solar Orbiter was successfully launched on 10 February 2020 from Cape Canaveral, USA, and started its science operations in November 2021 with a nominal mission duration of seven years.

Publications

Gruchoła S, Galli A, Vorburger A, Wurz P (2021)**Future Venus missions and flybys: A collection of possible measurements with mass spectrometers and plasma instruments**, Adv. Sp. Res., 68(8): 3205–3217, doi.org/10.1016/j.asr.2021.07.024

Livi S et al. (2023) **First results from the Solar Orbiter Heavy Ion Sensor**, Astron. Astrophys. 676: A36, 14 pp, doi.org/10.1051/0004-6361/202346304

Owen CJ, Bruno R, Livi S et al. (2020) **The Solar Orbiter Solar Wind Analyser (SWA) Suite**, Astron. Astrophys. 642(A16): 36 pp, doi.org/10.1051/0004-6361/201937259

Abbreviations

EAS	Electron Analyser System
HIS	Heavy Ion Sensor
MEFISTO	MEsskammer für Flugzeit-InStrumente u. Time-Of-Flight
PAS	Proton and Alpha Particle Sensor
SWA	Solar Wind Plasma Analyser

Time-Line	From	To
Planning	2007	2010
Construction	2010	2020
Measurement phase	2021	2029
Data evaluation	2021	2030

Heavy Ion Sensor (HIS) during calibration in the MEFISTO facility for highly charged ion beams at the Univ. of Bern.

Institute
Space Res. & Planet., Phys. Inst., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Mullard Space Science Lab. (MSSL), Univ. College, London, UK
Southwest Research Institute, USA

Principal Investigator(s)
C. J. Owen (MSSL)

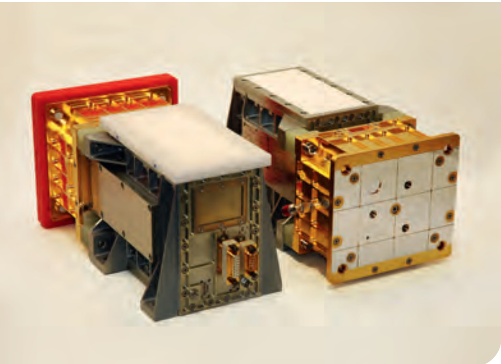
Swiss Principal Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Galli (UNIBE)

Contribution
Development & construction of The Heavy Ion Sensor (HIS) of the Solar Wind Plasma Analyser (SWA)

Website
esa.int/Science_Exploration/Space_Science/Solar_Orbiter

4.4 DARA – Digital Absolute Radiometer on PROBA-3



The DARA Flight Spare is seen from the back (left, with protective covers) and the DARA Flight Model from the front (right).

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC),

In cooperation with
European Space Agency (ESA)

Principal/Swiss Investigator(s)
W. Schmutz, W. Finsterle (PMOD/WRC)

Co-Investigator(s)
J.-P. Montillet, M. Haberreiter, D. Pfiffner (PMOD/WRC)
G. Kopp, Lab. Atmos. & Space Phys. (LASP), USA
A. Zhukov, Royal Obs. Belgium (ROB), Belgium

Contribution
Development & construction of instruments: DARA is an abolute radiometer to measure the solar energy input to Earth.

Industrial contract(s)
Almatech, Lausanne; dlab GmbH, Winterthur; Astorcast SA (else), Ecublens

Websites
esa.int/Enabling_Support/Space_Engineering_Technology/Proba_Missions/Proba-3_Mission3
pmodwrc.ch

Purpose of Research

DARA is a 3-channel active cavity electrical substitution radiometer (ESR), comprising the latest radiometer developments at PMOD/WRC to achieve long-term stability and high accuracy in the measurement of Total Solar Irradiance (TSI). The calibration of DARA against the NIST traceable TSI Radiometer Facility (TRF) and the World Radiometric Reference (WRR) will guarantee full SI-traceability of the TSI measurements.

The instrument will fly on the ESA PROBA-3 (Project for On-Board Autonomy-3) mission. PROBA-3 is the fourth satellite technology development and demonstration precursor mission within ESA's GSTP (General Support Technology Program) series. The PROBA-3 mission concept comprises two independent mini-satellites in a highly-elliptical Earth Orbit in Precise Formation Flying, close to one another with the ability to accurately control the attitude and separation of both satellites. The mission launch is scheduled in September 2024.

Past Achievements and Status

In the report period, DARA underwent structural, thermal, and Electromagnetic Compatibility (EMC) qualification tests. The optical alignment of the three radiometric channels was determined with respect to the reference surface before DARA was integrated on the PROBA-3 occulter spacecraft in January 2023.

Due to the travel restrictions imposed during the COVID19 pandemic, the calibration campaign at the Laboratory for Atmospheric and Space Physics (LASP, Boulder, USA) was delayed and was finally carried out remotely by the PMOD/WRC and LASP engineers. A comparison with the WRR at PMOD/WRC in Davos was also performed. We have calibrated several parameters (e.g., aperture area, reflectance, lead heating), which are used to transform the raw measurements (voltage, current) into calibrated irradiance observations. Overall, the results are satisfactory and agree with the component level characterisation for each cavity. The full characterisation of the instrument has been summarised in a paper which is currently in internal review by the co-authors.

Publications

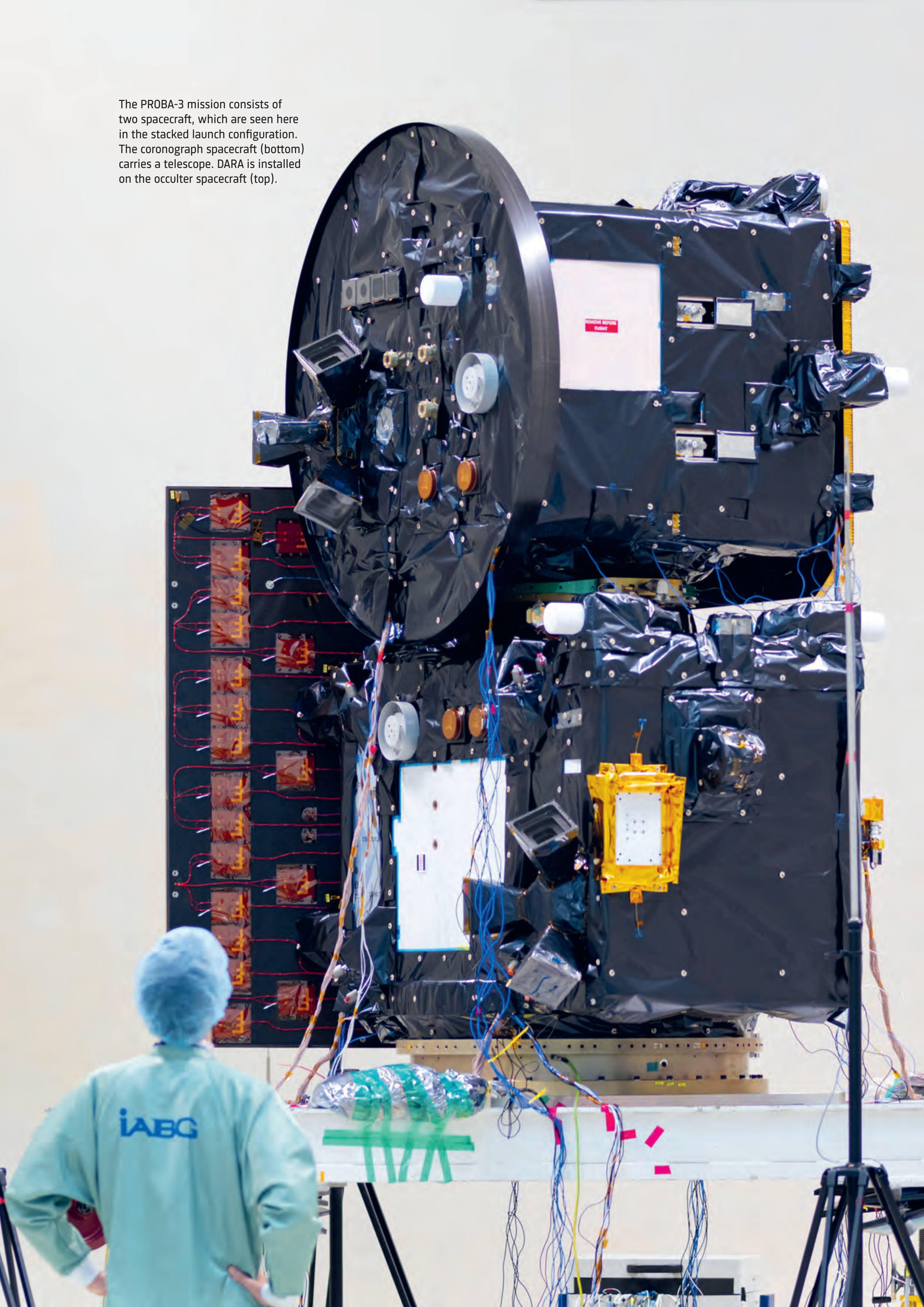
Montillet J, Schmutz W, Finsterle W et al. (2023) **The DARA/PROBA-3 radiometer: results from the preflight calibration campaign**, EGU, Vienna, Austria, 24–28 Apr 2023, EGU23–9007, doi.org/10.5194/egusphere-egu23-9007

Schmutz W (2021) **Changes in the Total Solar Irradiance and climatic effects**, J. Space Weather Space Clim. 11: 40.

Abbreviations

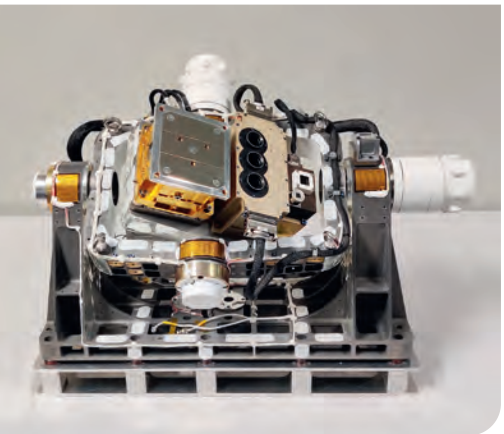
DARA	Digital Absolute Radiometer
EMC	Electromagnetic Compatibility
PROBA-3	Project for On-Board Compatibility
TRF	TSI Radiometer Facility
WRR	World Radiometric Reference

Time-Line	From	To
Planning	2013	2016
Construction	end 2016	end 2020
Measurement phase	2024/25	2026
Data evaluation	2024/25	2027



The PROBA-3 mission consists of two spacecraft, which are seen here in the stacked launch configuration. The coronograph spacecraft (bottom) carries a telescope. DARA is installed on the occulter spacecraft (top).

4.5 JTSIM-DARA on FY-3E



DARA (left) is integrated on the 2-axis JTSIM solar tracker alongside the Chinese SIAR (right). The JTSIM solar tracker was then integrated on the FY-3E satellite.

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC), Davos, Switzerland

In cooperation with
Changchun Inst. Optics, Fine Mechanics & Physics (CIOMP)/Chinese Acad. Sci. (CAS), China
Chinese Met. Administration (CMA), China

Principal Investigator(s)
W. Fang (CIOMP)

Swiss Principal Investigator(s)
W. Finsterle (PMOD/WRC)

Co-Investigator(s)
J.-P. Montillet (PMOD/WRC), D. Pfiffner (PMOD/WRC)

Contribution
Development and operations of the JTSIM-DARA experiment on the FY-3E spacecraft

Industrial hardware/software contract(s) to
dlab GmbH, Switzerland

Website
pmodwrc.ch

Purpose of Research

Continuous and precise Total Solar Irradiance (TSI) measurements are indispensable to evaluate the influence of short and long-term solar radiative emission variations on the Earth's climate. The Joint Total Solar Irradiance Monitor – Digital Absolute Radiometer (JTSIM-DARA) instrument on the Chinese FY-3E satellite is one of PMOD/WRC's current contributions to the almost seamless series of spaceborne TSI measurements since 1978.

Past Achievements and Status

After the commissioning phase which lasted until mid-August 2021, PMOD/WRC has routinely analysed the observations from the DARA radiometer and implemented the data pipeline by converting the raw observations recorded by the instrument (Level 0) to irradiance measurements (Level 2). Level 2 observations are corrected for all a-priori known factors (e.g., aperture area, reflectance, diffraction) and calibrated against the World Radiometric Reference (normalised to 1 AU). Radiative losses to deep space are regularly measured in orbit and TSI measurements are corrected accordingly. TSI is measured with all three cavities of the DARA-JTSIM instrument at different intervals to estimate the degradation of the cavity absorptance. The first TSI data product (JTSIM-DARAv1) is publicly available from the PMOD/WRC website (pmodwrc.ch/en/research-development/space/fy-3e) and in the Astromat public repository (repo.astromat.org/view.php?id=3105&system=astro).

Publications

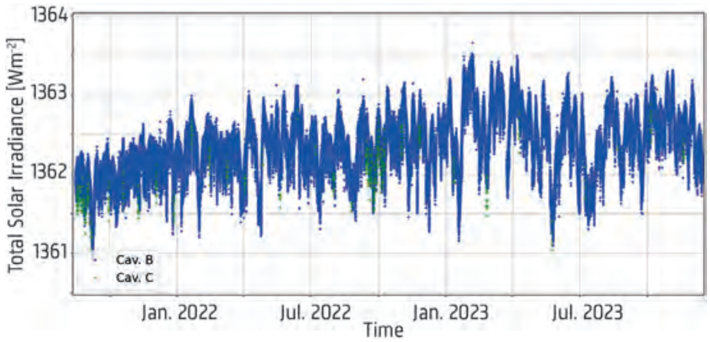
Montillet J-P, Finsterle W, Zhu P et al. (2023) **Assessment of solar variability through the analysis of TSI observations recorded by the FY3E/JTSIM/DARA radiometer**, ESS Open Archive: doi.org/10.22541/essoar.170365223.34450405/v1

Song B, Ye X, Finsterle W et al. (2021) **The Fengyun-3E/Joint Total Solar Irradiance Absolute Radiometer: Instrument design, characterization, and calibration**, Solar Physics, 296: doi.org/10.1007/s11207-021-01794-5

Abbreviations

DARA Digital Absolute Radiometer
FY-3E Fengyun 3E satellite
JTSIM Joint TSI Monitor
TSI Total Solar Irradiance

Time-Line	From	To
Planning	2014	2015
Construction	2015	2018
Measurement phase	2021	ongoing
Data evaluation	2021	ongoing



Total Solar Irradiance (TSI) measurements from JTSIM-DARA cavities B and C.

4.6 SoSpIM – Solar Spectral Irradiance Monitor on Solar-C

Purpose of Research

Solar-C_EUVST is the next JAXA solar physics mission. The mission carries an EUV imaging spectrometer with a slit-jaw imaging system called EUVST (EUV High-Throughput Spectroscopic Telescope) as the main mission payload, to take a fundamental step towards understanding how the Sun influences the Earth and other planets in our solar system.

A second, smaller instrument provides spectral irradiance capability through a Solar Spectral Irradiance Monitor (SoSpIM). This provides both scientific and calibration capabilities. SoSpIM and EUVST will work together. EUVST will provide spectral observations from the chromosphere to the corona, tracking the energy flow on small spatial scales. SoSpIM will provide 'Sun-as-a-star' measurements in two wavelength bands also covered by EUVST. This provides measurements of all solar flares visible from Earth, not only those within the EUVST field-of-view. The SoSpIM instrument provides the connectivity between the flare processes captured in detail on the Sun by EUVST and the impact of that irradiance changes in different layers of Earth's atmosphere.

The SoSpIM instrument aims to specifically address two aspects:
– Understand how the solar atmosphere becomes unstable, releasing the energy that drives solar flares - achieved through probing fast time cadence solar flare variations.
– Measuring solar irradiance that impacts the Earth's thermosphere and the mesosphere, linking to spatially resolved measurements of the solar atmosphere with EUVST.

In order to achieve these goals, the SoSpIM instrument will monitor the spectrally resolved solar irradiance with a sub-second time cadence. There will be two channels with redundancy in the following bands:
– Channel 1: covering 170 – 215 Å (Al/Zr/Al filter combination).
– Channel 2: covering 1115 – 1275 Å (MgF_2 filter).

A key advantage of having a 'Sun-as-a-star' instrument onboard the mission is that all solar flares visible from Earth can be observed. SoSpIM will allow the direct connection to the impact on the Earth. The two channels on SoSpIM will probe the effects on the ionosphere/thermosphere (mainly with Channel 1) and the mesosphere and stratosphere (with Channel 2).

Past Achievements and Status

The phase C/D proposal was endorsed by the Swiss Space Office (SSO). The Preliminary Design Review (PDR) successfully took place in autumn 2023.

Publications

A spectral solar irradiance monitor (SoSpIM) on the JAXA Solar-C mission, scostep.org/wp-content/uploads/2021/04/SCOSTEP_PRESTO_Newsletter_Vol27_high_reso.pdf.

Abbreviations

EUVST	Extreme UV High-Throughput Spectroscopic Telescope
SoSpIM	Solar Spectral Irradiance Monitor

Time-Line	From	To
Planning	2019	2020
Construction	2020	2026
Measurement phase	2029	2031
Data evaluation	2029	2031

The SoSpIM Engineering Model.

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC), Davos, Switzerland

In cooperation with
ROB, Belgium
FHNW, Switzerland
JAXA, Japan
ESA

Principal Investigator
T. Shimizu (ISAS, JAXA)

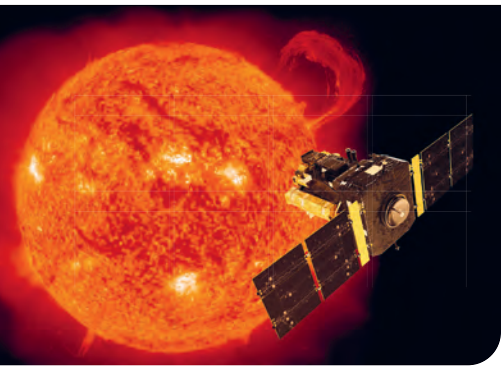
Swiss Principal Investigator
L. Harra (PMOD/WRC & ETHZ)

Co-Investigator(s)
Marie Dominique (ROB)
Säm Krucker (FHNW)

Industrial hardware contract to
dlab GmbH; MICOS GmbH; AOT

Website
pmodwrc.ch

4.7 VIRGO on SOHO



VIRGO on the SOHO spacecraft. Image credit: ESA.

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC), Davos, Switzerland

In cooperation with
ESA
NASA
Inst. Royal Met. Belgique (IRMB), Brussels, Belgium
European Space Res. & Tech. Centre (ESTEC), Nordwijk, The Netherlands
Instituto de Astrofísica de Canarias (IAC), Spain

Principal/Swiss Investigator(s)
W. Finsterle (PMOD/WRC)

Co-Investigator(s)
J.-P. Montillet (PMOD/WRC)
S. Dewitte (IRMB)
T. Appourchoux (CNRS, France)

Contribution
Development and operations of the VIRGO experiment on the SOHO spacecraft

Website
pmodwrc.ch

Purpose of Research

The Variability of Irradiance and Global Oscillations (VIRGO) instrument onboard the Solar and Heliospheric Observatory (SOHO) provides continuous high-precision measurements of the Total and Spectral Solar Irradiance (TSI, SSI). TSI measurements are used to estimate a potential solar influence on terrestrial climate change and to determine the Earth's energy imbalance. The spectral solar irradiance (SSI) measurements contribute to the SSI database, which is used to model the chemistry and dynamics in the upper atmosphere of the Earth.

Past Achievements and Status

VIRGO has provided the longest continuous time-series of TSI and SSI. Sensor degradation is regularly assessed and corrected, based on a machine learning algorithm. SSI measurements are strongly affected by filter degradation. New TSI data are published every four months. The data pipeline for the VIRGO data on the SOHO archive is currently being updated at: soho.nascom.nasa.gov/data/archive.

All information about the mission and new products are available on the PMOD/WRC website at: pmodwrc.ch/en/research-development/space/soho.

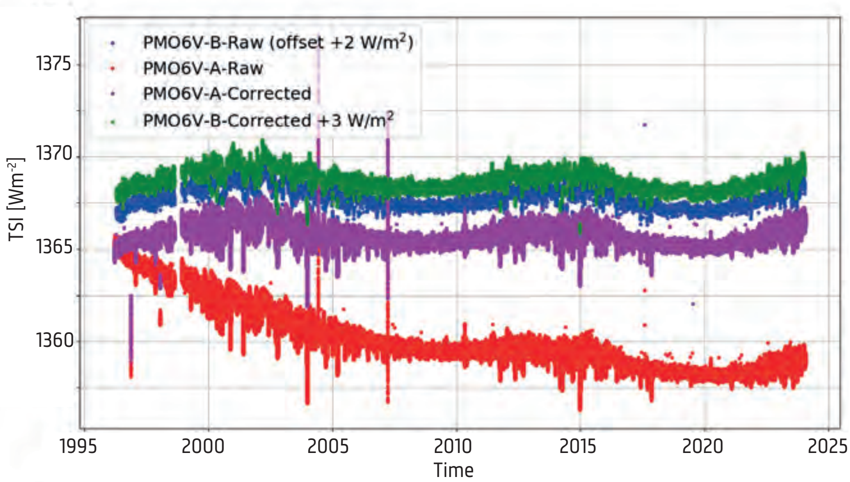
Publications

Montillet JP, Finsterle W, Kermarrec G, Šikonja R, Haberreiter M, Schmutz W, Dudok de Wit T (2022) **Data fusion of Total Solar Irradiance composite time series using 41 years of satellite measurements**, J. Geophys. Res. Atmos. 127: 13, e2021JD036146, doi.org/10.1029/2021JD036146

Abbreviations

SOHO	Solar and Heliospheric Observatory
SSI	Spectral Solar Irradiance
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradiance and Gravity Oscillations

Time-Line	From	To
Planning	~1985	~1990
Construction	~1990	1995
Measurement phase	1996	ongoing
Data evaluation	1996	ongoing



Total Solar Irradiance measurements with the VIRGO PMO6-A and -B channels: Before and after degradation corrections.

4.8 CLARA – Compact Lightweight Absolute Radiometer on NorSat-1

Purpose of Research

The Compact Lightweight Absolute Radiometer (CLARA) instrument, onboard the Norwegian micro-satellite NorSat-1, is one of PMOD/WRC's operational absolute radiometers to measure the Total Solar Irradiance (TSI) and to ensure a continuous record of the essential climate variable (ECV) TSI. Along with PMOD/WRC's earlier instruments, VIRGO, PREMOS, and DARA-JTSIM, CLARA continues the long-term involvement of PMOD/WRC in solar research.

Since 2020, CLARA also measures the Outgoing Longwave Radiation (OLR) at the top of the Earth's atmosphere when the satellite is on the night-side of Earth. These measurements serve as a technical demonstration, and pave the way for future absolute radiometers to ultimately determine the Earth Radiation Budget and the Earth Energy Imbalance.

Past Achievements and Status

CLARA onboard NorSat-1 was launched on 14 July 2017, and after a successful commissioning phase, started taking measurements on 25 August 2017. The CLARA instrument (Finsterle et al., 2014; Walter et al., 2017) onboard the NorSat-1 satellite has been measuring OLR since 2020. The data pipeline and analysis tools were improved during the reporting period, and current TSI data from CLARA is available at ftp.pmodwrc.ch/pub/data/irradiance/CLARA/TSI. The CLARA OLR data analysis requires the determination of CLARA's footprint, which has a radius of 40 km on the Earth's surface for the case of nadir pointing. The figure shows the latest CLARA outgoing radiances obtained from almost two years of data. Within the ISSI International Team #500 'Towards Determining the Earth Energy Imbalance from Space', we collect and compare, where possible, OLR and OSR data from RAVAN, GERB, CERES, CTIM, and INSPIRE-Sat (Haberreiter et al. 2024).

Publications

Finsterle W, Koller S, Beck I et al. (2014) **Earth Observing Missions and Sensors: Development, Implementation, and Characterization** III, SPIE Conf. Series 9264: 92641S

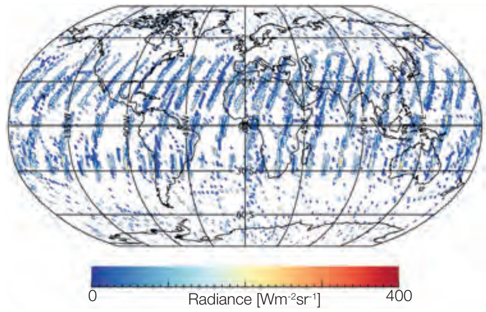
Haberreiter M et al. (2024) **Towards determining the Earth energy imbalance from Space – Outcome of a recent ISSI International Team**, EGU, Vienna, Austria, EGU24-12284, doi.org/10.5194/egusphere-egu24-12284

Walter B, Andersen B, Beattie A et al. (2020) **First TSI results and status report of the CLARA/NorSat-1 solar absolute radiometer**, Astronomy in Focus, Proc. IAU, pp. 358–360, doi.org/10.1017/S1743921319004617

Abbreviations

CERES	Clouds and Earth's Radiant Energy System
CLARA	Compact Lightweight Absolute Radiometer
CTIM	Compact Total Irradiance Monitor
OLR	Outgoing Longwave Radiation
OSR	Outgoing Shortwave Radiation
PREMOS	Precision Monitor Sensor
RAVAN	Radiometer Assessment using Vertically Aligned Nanotubes
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradiance and Gravity Oscillations

Time-Line	From	To
Planning	2013	2013
Construction	2014	2016
Measurement phase	Jun. 2017	open
Data evaluation	Aug. 2017	ongoing



In 2020, CLARA started measuring the outgoing longwave radiation (OLR) on the night-side of Earth. Shown here is a map of CLARA OLR measurements from January 2020 to September 2022.

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC), Davos, Switzerland

In cooperation with
Norwegian Space Center (NSC), Oslo, Norway
UiO, Norway
UTIAS-SFL, Toronto, Canada
Lab. Atmos. Space Phys. (LASP), Boulder, USA

Principal/Swiss Investigator(s)
W. Finsterle (PMOD/WRC)

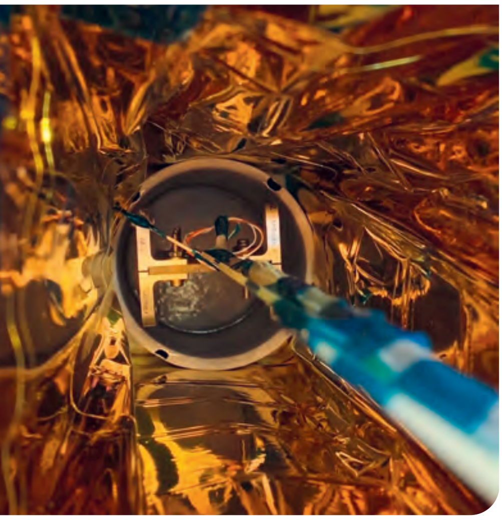
Co-Investigator(s)
M. Haberreiter, J.-P. Montillet, W. Schmutz (PMOD/WRC)
B. Andersen (UiO)
G. Kopp (LASP)

Contribution
CLARA was developed and constructed by PMOD/WRC from 2013 to 2015

Websites
pmodwrc.ch
eoportal.org/satellite-missions/norsat-1-2#norsat-1-and-norsat-2-microsatellites

5 Heliospheric Physics

5.1 SXI – Soft X-Ray Imager on SMILE



Picture taken during the thermal cycling test of the SXI support assembly breadboard to verify the durability of the selected materials (fibre-reinforced plastic and aluminum) at ZHAW. Image credit: ZHAW.

Institute
Univ. Applied Sciences & Arts Northwestern Switzerland (FHNW), Switzerland

In cooperation with
Univ. Leicester (UoL), UK

Principal Investigator(s)
S. Sembay (UoL)

Swiss Principal Investigator(s)
S. Krucker (FHNW)

Co-Investigator(s)
H.-P. Gröbelbauer (FHNW)
G. Peikert (ZHAW, Switzerland)
W. Hajdas (Paul Scherrer Inst., Switzerland)

Contribution
Thermal design and radiator assembly

Industrial hardware contract(s) to
KOEGL Space, Dielsdorf, Switzerland
Space Acoustics, Rafz, Switzerland

Website
astro-helio.ch/project/sxi

Purpose of Research

The Solar wind Magnetosphere Ionosphere Link Explorer, or SMILE, is a joint mission between the European Space Agency (ESA) and the Chinese Academy of Sciences. SMILE aims to build a more complete understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere.

While previous magnetospheric studies were mainly driven by single or multi-point in-situ observations from within or around the Earth's magnetosphere, SMILE's novel approach will take images and movies from outside the magnetosphere, thus revealing the global picture of the solar wind's interaction with the magnetosphere. With these global and time-dependent images, SMILE will revolutionise magnetospheric physics.

In collaboration with Swiss industry, FHNW is in charge of the thermal design including the design and manufacturing of the radiator assembly of the Soft X-ray imager (SXI) onboard SMILE. FHNW is also part of the SXI software and data analysis team.

Past Achievements and Status

The Flight Model of the SXI radiator was delivered in 2023. The SMILE mission is expected to launch in May 2025.

Publications

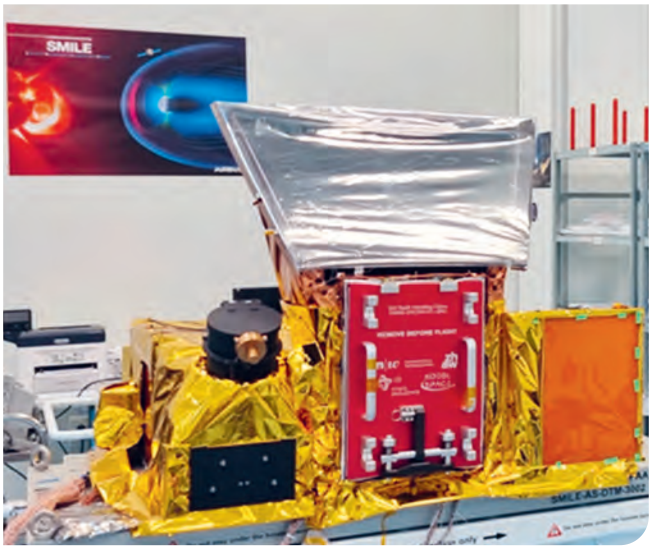
Raab W et al. (2016) **SMILE: a joint ESA/CAS mission to investigate the interaction between the solar wind and Earth's magnetosphere**, SPIE: 9905E, 02R.

Sembay S et al. (2024) **The Soft X-ray Imager (SXI) on the SMILE Mission**, Earth & Planet. Phys. 8: 1, 5–14, doi.org/ 10.26464/epp202306

Abbreviations

SMILE	Solar wind Magnetosphere Ionosphere Link Explorer
SXI	Soft X-Ray Imager

Time-Line	From	To
Planning	2017	2020
Construction	2021	2024
Measurement phase	2025	2028
Data evaluation	2025	2028



Structural Thermal Model of the SMILE payload module before delivery to China in March 2022. The SXI instrument is seen in the center with the silver top. The Swiss contribution is the radiator (a red cover plate has been put over the radiator for transport).

5.2 LIA – Light Ion Analyser on SMILE

Purpose of Research

The Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission is a joint mission between ESA and the Chinese Academy of Sciences (CAS), which is expected to launch in May 2025. SMILE aims to build a more complete understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere. We are participating in the Light Ion Analyser (LIA) instrument to investigate the interaction of the solar wind and the magnetosheath under various conditions.

Past Achievements and Status

LIA (Light Ion Analyser) is a top-hat plasma ion analyser for detection of protons and alpha particles operating in the energy range 50 eV – 20 keV.

The flight models of the LIA instrument (LIA1 and LIA2) are finished, have passed environmental testing, and are currently undergoing calibration. Integration on the spacecraft will start in September 2024 at the ESA European Space Research and Technology Centre (ESTEC) in Nordwijk, Netherlands.

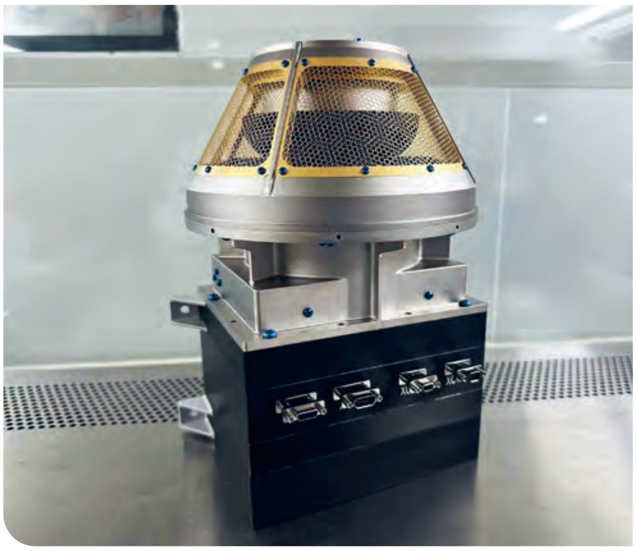
Publications

Wurz P, Balogh A, Coffey V et al. (2007) **Calibration Techniques**, in Calibration of Particle Instruments in Space Physics, (eds. Wüest M, Evans DS, von Steiger R), ESA Comm., ISSI Sci. Rep., SR-007, 117–276.

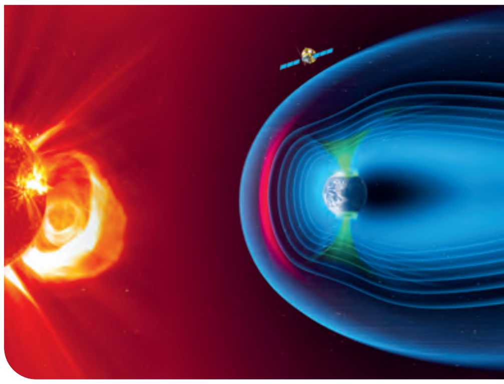
Abbreviations

CAS	Chinese Academy of Sciences
LIA	Light Ion Analyser
SMILE	Solar Wind Magnetosphere Ionosphere Link Explorer

Time-Line	From	To
Planning	2015	2017
Construction	2017	2024
Measurement phase	2025	2027
Data evaluation	2025	2030



The Light Ion Analyser (LIA), shown on the right, will help to investigate the properties and behaviour of the solar wind and Earth's magnetosphere where it meets the solar wind. Image credit: L. Dai and L.-G. Kong, National Space Science Center, Chinese Academy of Sciences.



SMILE will investigate the interaction between the solar wind with the terrestrial magnetosphere from an orbit that even takes the spacecraft outside the magnetosphere into the solar wind. Image credit: ESA/ATG medialab.

Institute
Space Res. & Planet., Phys. Inst., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
National Space Science Center (NSSC), Chinese National Space Science Centre, Chinese Academy of Sciences (CAS), China

Principal Investigator(s)
L. Dai (NSSC)

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Galli (UNIBE)

Contribution
Participation in the design and calibration of the Light Ion Analyser (LIA)

Website
esa.int/Science_Exploration/Space_Science/Smile_factsheet

5.3 Interstellar Mapping and Acceleration Probe (IMAP)

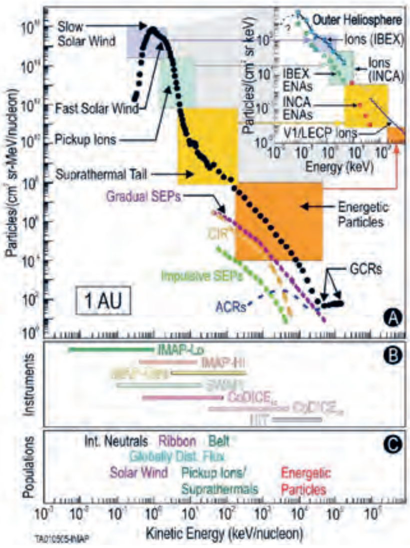


Figure text: see end of article.

Institute
Space Res. & Planetology, Physics Institute, Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Princeton Univ., Princeton, USA; SW Res. Inst., Austin, USA; Univ. New Hamp., Durham, USA; Los Alamos Nat. Lab., USA

Principal Investigator(s)
D. McComas (Princeton Univ.)

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Galli (UNIBE)

Contribution
Participation: ion-optical design, development, manufacture IMAP-Lo ENA camera. Calibration: IMAP-Lo calibration with ENAs.

Industrial hardware contract to
SMC Mould Innovation AG, Hallau; MECHA Eng. & Maschinenbau, Belp Switzerland

Website
science.nasa.gov/mission/imap

Purpose of Research

The Interstellar Mapping and Accelaration Probe (IMAP) mission of NASA is a heliophysics mission that will simultaneously investigate two important and coupled science topics in the heliosphere: the acceleration of solar energetic particles and interaction of plasma from the solar wind with the local interstellar medium.

These science topics are coupled because particles accelerated in the inner heliosphere play crucial roles in the outer heliospheric interaction.

IMAP was selected by NASA in 2018, and is scheduled to launch in February 2025. IMAP will be a Sun-tracking spin-stabilised satellite in orbit about the Sun-Earth L1 Lagrangian point with a science payload of ten instruments. IMAP will also continuously broadcast real-time in-situ data that can be used for space weather prediction.

The scientific instrumentation includes ENA (Energetic Neutral Atoms) cameras for the observation of the interface between the heliosphere and the interstellar medium. The University of Bern (Switzerland) is participating in the IMAP-Lo camera, which covers the energy range from 10 eV to 1 keV.

Past Achievements and Status

Since the calibration of the IMAP-Lo ENA camera is one of our contributions to the IMAP project, we have developed a novel Absolute Beam Monitor (ABM) for the precise determination of the flux of energetic neutral particles of the neutral atom beam used for the IMAP-Lo calibration.

Publications

Gasser J, Galli A, Wurz P (2022) **Absolute Beam Monitor: a novel laboratory device for neutral beam calibration**, Rev. Sci. Instr. 93: 093302, 11 pp, doi.org/10.1063/5.0092065

Gasser J, Galli A, Wurz P (2023) **Calibration beam fluxes of a low-energy neutral atom beam facility**, Rev. Sci. Instr. 94: 053302 (2023), 7 pp, doi.org/10.1063/5.0140759

McComas DJ et al. (2018) **Interstellar Mapping and Acceleration Probe (IMAP): A New NASA Mission**, Space Science Review 214: 116, 55 pp, doi.org/10.1007/s11214-018-0550-1

Abbreviations

ENA	Energetic Neutral Atoms
IMAP	Interstellar Mapping and Acceleration Probe

Time-Line	From	To
Planning	Jan. 2018	Dec. 2018
Construction	Jan. 2019	Aug. 2024
Measurement phase	May 2025	2029
Data evaluation	May 2025	2030

Figure text.

Top panel: Oxygen fluences measured at 1 AU by several instruments onboard ACE with representative particle spectra obtained for gradual and impulsive SEPs, co-rotating interaction regions (CIRs), anomalous cosmic rays (ACRs), and galactic cosmic rays (GCRs), and (top panel inset) ion fluxes in the Voyager 1 direction using in-situ observations from Voyager and remote ENA observations from Cassini and IBEX.

Middle and lower panels: IMAP ion instruments (SWAPI, CoDICE, HIT) and ENA Instruments (IMAP-Lo, -Hi, -Ultra) provide comprehensive ion composition, energy, and angular distributions for all major solar wind species (core and halo), interstellar and inner source PUIs, suprathermal, energetic, and accelerated ions from SEPs, CME-driven and CIR-associated interplanetary shocks, as well as ACRs.

5.4 Interstellar Boundary Explorer (IBEX)

Purpose of Research

The IBEX mission (NASA SMEX class) is designed to record energetic neutral atoms (ENA) arriving from the interface of our heliosphere with the neighbouring interstellar medium in an energy range from 10 eV to 6 keV.

This energy range is covered by two ENA cameras, IBEX-Lo measuring from 10 eV to 2 keV, and IBEX-Hi measuring from 500 eV to 6 keV. For each energy channel, a full-sky map is compiled every half year, which allows the study of the plasma physical processes at the interface between the heliosphere and the interstellar medium, located at a distance of about 100 AU.

Past Achievements and Status

IBEX was successfully launched in October 2008 and was first brought into a highly elliptical orbit around the Earth. In June 2011, the orbit was changed into an orbit that is in resonance with the Moon, which has significantly extended the orbital lifetime of the IBEX spacecraft and thus allows the mission to cover more than a solar cycle of 11 years with minimal fuel consumption. It is foreseen that IBEX will continue operations until 2025 to overlap with the IMAP mission.

IBEX continues to take nominal measurements of ENAs originating from the interface region between our heliosphere and the surrounding interstellar matter.

Time-Line	From	To
Planning	2005	2006
Construction	2006	2008
Measurement phase	2008	ongoing
Data evaluation	2008	ongoing

Publications

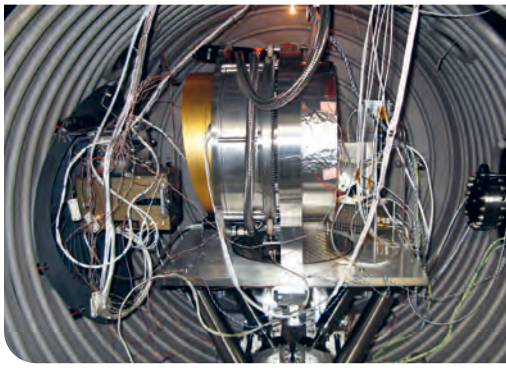
Galli A, Wurz P, Rahmanifard F, Möbius E, Schwadron NA, Kucharek H, Heirtzler D, Fairchild K, Bzowski M, Kubiak MA, Kowalska-Leszczynska I, Sokół JM, Fuselier SA, Swaczyna P, McComas DJ (2019) **Model-free maps of interstellar neutral hydrogen measured with IBEX between 2009 and 2018**, Astrophys. J, 871: 52, 18 pp., doi.org/10.3847/1538-4357/aaf737

Galli A, Wurz P, Schwadron NA et al. (2022) **One solar cycle of heliosphere observations with the Interstellar Boundary Explorer: Energetic neutral hydrogen atoms observed with IBEX-Lo from 10 eV to 2 keV**, Astrophys. J Suppl. 261: 18, 21 pp, doi.org/10.3847/1538-4365/ac69c9

Rodríguez Moreno DF, Wurz P, Saul L, Bzowski M, Kubiak MA, Sokół JM, Frisch P, Fuselier SA, McComas DJ, Möbius E, Schwadron N (2013) **Evidence of direct detection of interstellar deuterium in the local interstellar medium by IBEX**, Astron. Astrophys. 557: A125, 1–13, doi.org/10.1051/0004-6361/201321420

Abbreviations

ENA	Energetic Neutral Atom
IBEX	Interstellar Boundary Explorer
MEFISTO	MEsskammer für Flugzeit-InStrumente u. Time-Of-Flight



IBEX-Lo flight instrument in the MEFISTO calibration facility, Univ. Bern.

Institute
Space Research and Planetology, Physics Inst., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Southwest Res. Inst., Austin, USA
Lockheed Martin, Palo Alto, USA
Space Res. Centre PAS., Warsaw, Poland
Univ. New Hampshire, Durham, USA

Principal Investigator(s)
D. McComas, Princeton Univ., Princeton, USA

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

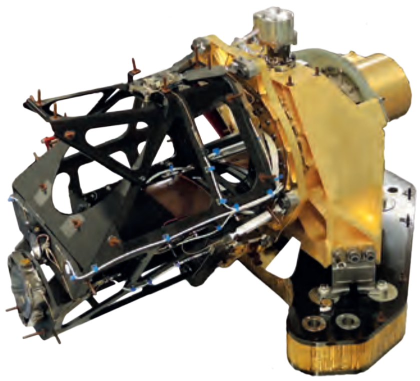
Co-Investigator(s)
A. Galli (UNIBE)

Contribution
We completed the ion-optical design, and participated in the development and manufacture of the IBEX-Lo and IBEX-Hi ENA cameras. The entire IBEX-Lo calib. using ENAs over the full energy range, and all species of interest, was conducted at UNIBE.

Industrial Hardware Contract to
Sulzer Innotec

6 Comets, Planets

6.1 The Colour and Stereo Surface Imaging System (CaSSIS)



The CaSSIS instrument onboard the ESA Trace Gas Or.biter (TGO) at Mars. Image credit: UNIBE.

Institute
Inst. Space Res. & Planetology Div., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Astronomical Observatory of Padova, Italy
Space Research Centre in Warsaw, Poland

Principal/Swiss Investigator(s)
N. Thomas (UNIBE)

Co-Investigator(s)
G. Cremonese (Co-PI), M. Banaskiewicz, J.C. Bridges, S. Byrne, V. Da Deppo, S. Diniega, M.R. El-Maarry, E. Hauber, A. Ivanov, L. Keszthelyi, R. Kirk, R. Kuzmin, N. Mangold, L. Marinangeli, M. Massironi, A.S. McEwen, C. Okubo, P. Orleanski, A. Pommerol, L.L. Tornabene, P. Wajer, J.J. Wray

Contribution
UNIBE developed and built CaSSIS with parts supplied by Italy, Poland and Hungary.

Industrial hardware contract(s) to
Thales-Alenia Space Switzerland, Zurich

Website
cassis.unibe.ch

Purpose of Research

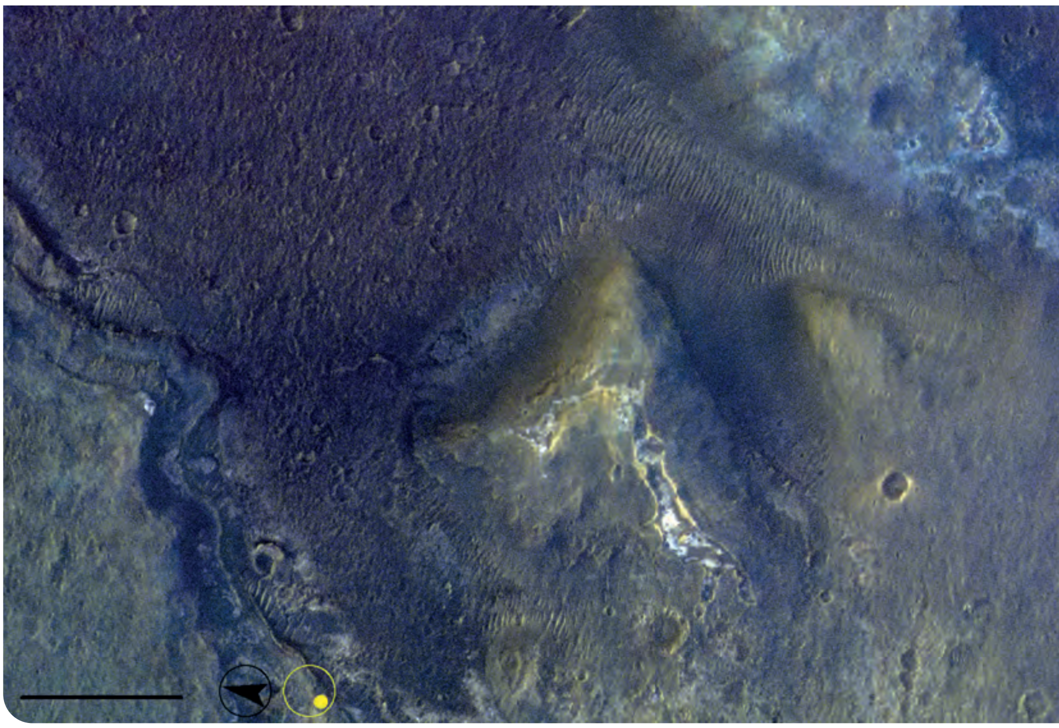
The Colour and Stereo Surface Imaging System (CaSSIS) is onboard ESA's ExoMars Trace Gas Orbiter (EMTGO) mission, which was launched in March 2016. The imaging system has the following main objectives.

1. Image and analyse surface features possibly related to trace gas sources and sinks in order to better understand the broad range of processes that might be related to trace gases. The science team will compile and prioritise a list of observation targets needed to test specific hypotheses concerning active surface processes on Mars. We will begin to address this objective early in the mission, prior to new trace-gas discoveries from EMTGO. CaSSIS can also investigate mineralogical diversity through colour variations in older terrains.

2. Map regions of trace gas origination as determined by other experiments to test hypotheses. EMTGO experiments are designed to discover trace gases and study atmospheric dynamics to trace the gases back to their source regions (perhaps to tens of km). Once these discoveries are made (if that goal is realised), CaSSIS will place top priority on imaging these regions to formulate and test specific hypotheses for the origin and/or release of trace gases.

3. Search for and help certify the safety of new candidate landing sites driven by EMTGO discoveries. The discovery of methane has helped stimulate exploration plans in Europe and the U.S. A portion of NE Syrtis Major has recently been approved for priority Mars Reconnaissance Orbiter (MRO) coverage as a candidate landing site; this site is at the margin of the Syrtis Major methane plume identified by Mumma et al. (2009).

It is likely that a pair of NASA/ESA landers will also consider methane



areas for landing sites in the 2020s and later. At the workshop 'Habitability and Landing Sites' held in the UK, the surfaces associated with methane plumes were identified as high priority exploration targets. CaSSIS will play a role in defining new landing sites.

Past Achievements and Status

The instrument entered its prime mission in April 2018 and has since returned over 42,000 images of the surface of Mars in colour and more than 2100 stereo pairs. The high signal-to-noise ratio has made it an excellent instrument for identifying subtle changes in surface mineralogy. The instrument has obtained numerous images of the ExoMars Rover landing site in Oxia Planum and is supporting the development of operational plans. It has also supported studies of the InSight and Perseverance landing sites. Images showing spectral diversity and active processes have been obtained as well as images of Phobos. Images are placed in ESA's Planetary Science Archive six months after acquisition. The instrument will run until at least the end of 2025 and possibly beyond.

Publications

Bilder vom Mars (2022) **Nicolas Thomas and the CaSSIS Team**, ISBN-13: 9783039221516, Pub. Werd & Weber, Thun.

Mumma MJ, Villanueva GL, Novak RE, Hewagama T, Bonev BP, DiSanti MA, Mandell AM, Smith MD (2009) **Strong release of methane on Mars in northern summer 2003**, Science 323: 1041–1045.

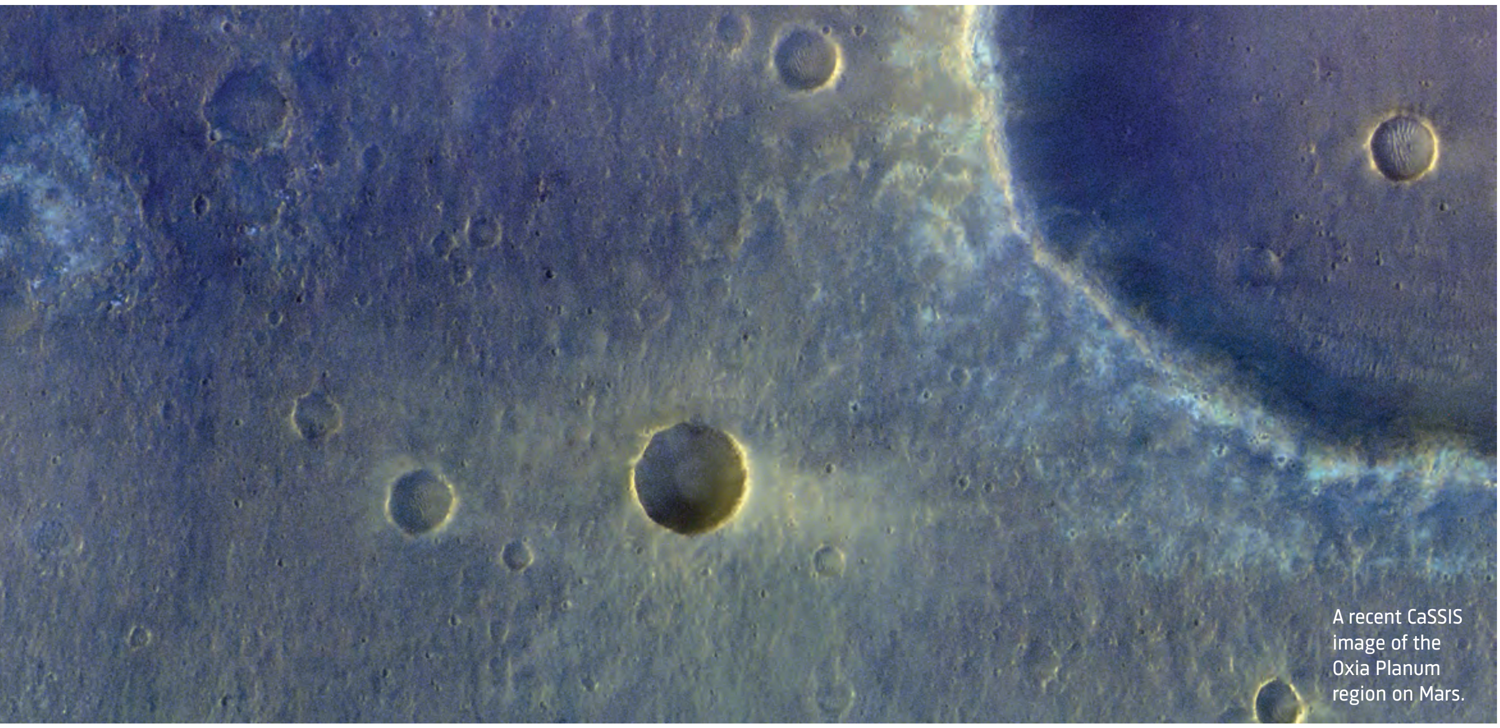
Roloff V, and 24 colleagues (2017) **On-ground performance and calibration of the ExoMars Trace Gas Orbiter CaSSIS Imager**, Space Science Reviews 212: 1871–1896.

Thomas N, and 60 colleagues (2017) **The Colour and Stereo Surface Imaging System (CaSSIS) for the ExoMars Trace Gas Orbiter**, Space Science Reviews 212: 1897–1944.

Abbreviations

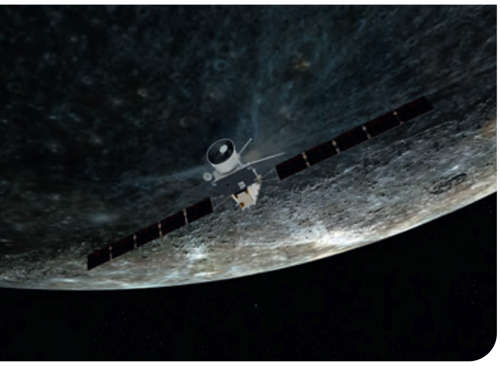
CaSSIS	Colour and Stereo Surface Imaging System
EMTGO	ExoMars Trace Gas Orbiter
MRO	Mars Reconnaissance Orbiter

Time-Line	From	To
Planning	Apr. 2010	Oct. 2013
Construction	Oct. 2013	Nov. 2015
Measurement phase	Apr. 2018	2025 at least
Data evaluation	2018	2026 and beyond



A recent CaSSIS image of the Oxia Planum region on Mars.

6.2 BELA – BepiColombo Laser Altimeter



Artist's impression of BepiColombo during a gravity assist flyby of Mercury in October 2021. Nine flybys in total of Earth, Venus and Mercury will occur before orbit insertion at Mercury in 2025. Image credit: ESA.

Institute
Space Res. & Planetology Div., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
DLR Institute for Planetary Res. (DLR), Berlin-Adlershof, Germany
Max-Planck-Inst. Sonnensystemforsch. (MPS), Katlenburg-Lindau, Germany

Principal Investigator(s)
N. Thomas (Co-PI, UNIBE),
H. Hussmann (Co-PI, DLR)

Swiss Principal Investigator(s)
N. Thomas (UNIBE)

Co-Investigator(s)
30 geophysicists from Europe

Contribution
UNIBE developed and built BELA with parts supplied by Germany and Spain.

Industrial hardware contract(s) to
Thales-Alenia Space Switzerland; SYDERAL SWISS SA; FISBA Optik; Cassidian Optronik, Germany

Websites
bela.space.unibe.ch
cosmos.esa.int/web/bepicolombo/bela

Purpose of Research

The BepiColombo laser altimeter (BELA) is a joint Swiss-German project with a smaller involvement from Spain. The scientific objectives of the experiment are to measure the:

- Figure parameters of Mercury to establish accurate reference surfaces.
- Topographic variations relative to the reference figures and a geodetic network based on accurately measured positions of prominent topographic features.
- Tidal deformations of the surface.
- Surface roughness, local slopes and albedo variations, also in permanently shaded craters near the poles.

BELA will form an integral part of a larger geodesy and geophysics package, incorporating radio science and stereo imaging. Although stand-alone instruments in their right, only the synergy between these will make full use of present-day technology and scientific capability. The synergy will cover the problems of planetary figure and gravity field determination, interior structure exploration, surface morphology and geology, and extend into the measurements of tidal deformations.

The reference surfaces and the geodetic network will provide the coordinate system for any detailed exploration of the surface, geological, physical, and chemical. The topography is needed to develop digital terrain models that allow quantitative explorations of the geology, the tectonics, and the age of the planet surface. The topography is further needed for a reduction of the gravity field data because topographical contributions to gravity must first be removed before using gravity anomalies for the investigation of sub-surface structures. The use of topography together with gravity data will constrain, by an admittance analysis, between the two and with the help of a flexure model for the lithosphere, lithosphere and crust properties. Examples here would include the lithosphere elastic thickness (essential for the reconstruction of the thermal history of Mercury) and the crustal density (essential for the construction of a Hermean internal model).

In addition to the moments of inertia, which will be provided by the radio science experiment, the tidal deformations measured by BELA and the radio science instrument will place further constraints of global models of the interior structure. BELA will contribute by providing the deformation of the surface while the radio science package will measure the mass relocations. Under favourable conditions, it will even be possible to constrain the rheology of the interior of the planet by measuring the time lag between the motion of the tidal bulge and the disturbing potential.

The instrument comprises a transmitter producing a 50 mJ laser pulse at 1064 nm. The laser passes through a beam expander to collimate the beam before exiting to the planet through a baffle. The return pulse is captured by a 20 cm beryllium telescope which is protected by a novel reflective baffle. The light then passes through a transfer optic containing a 1064 nm filter before collection on an avalanche photodiode detector. Conversion to a range is performed using time-of-flight electronics within an electronics box, which also houses the instrument computer and power supply.

Past Achievements and Status

The flight model was delivered to ESA and integrated on the spacecraft in 2016. Performance analyses indicate that excellent results should be obtained with the present instrument status. The spacecraft was launched in 2018 and is currently in-flight to Mercury. Testing of BELA has proceeded nominally and the instrument appears to be fully functional. Orbital insertion is foreseen at the end of 2025 and the prime mission will start in April 2026 for, nominally, a minimum of one Earth year.

Abbreviations

BELA BepiColombo Laser Altimeter

Publications

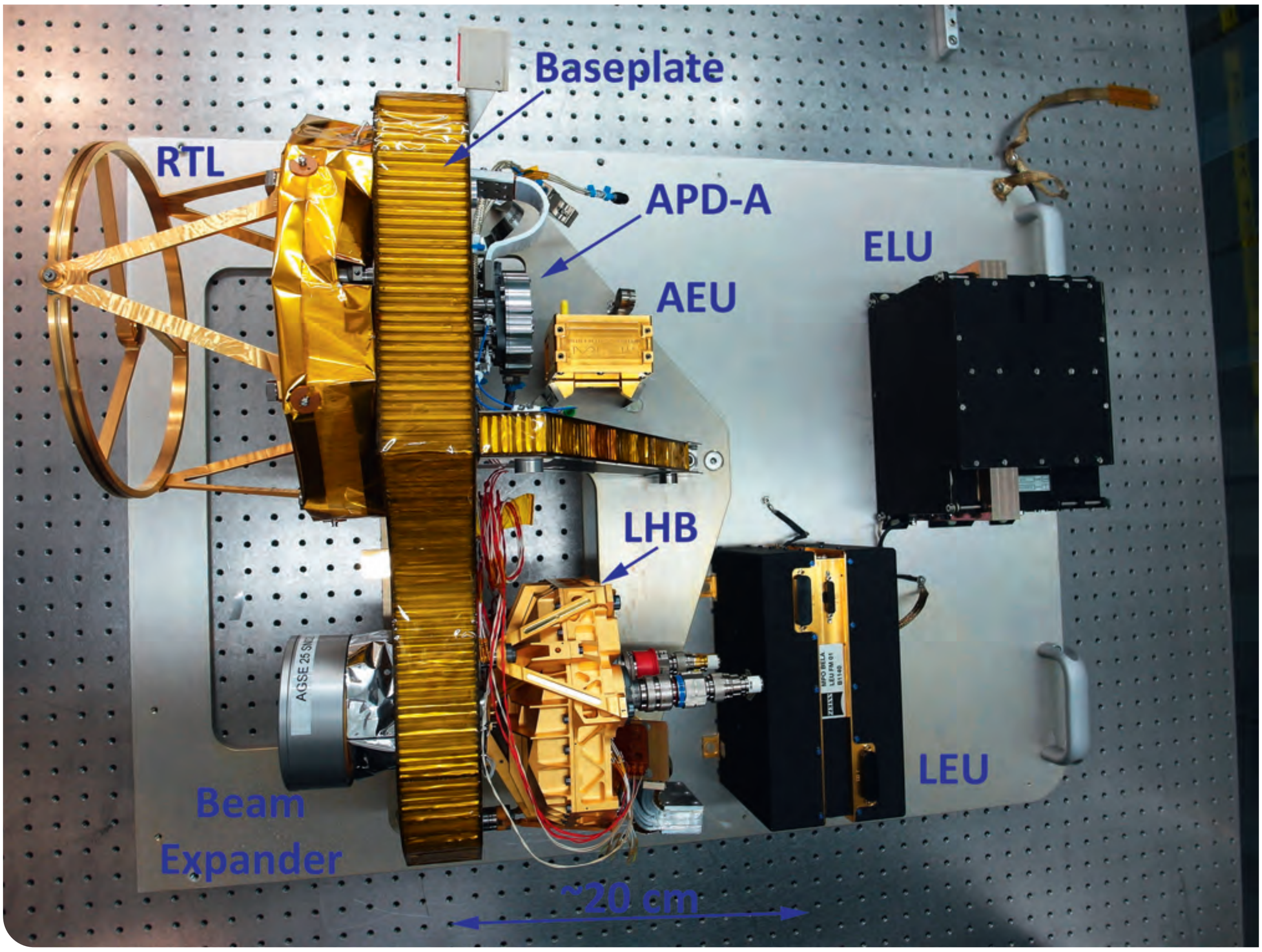
Gunderson K, Thomas N (2010) **BELA receiver performance modeling over the BepiColombo mission lifetime**, Planetary and Space Science 58: 309–318.

Seiferlin K et al. (2007) **Design and manufacture of a lightweight reflective baffle for the BepiColombo Laser Altimeter**, Optical Engineering 46(4): 043003-1.

Thomas N et al. (2007) **The BepiColombo Laser Altimeter (BELA): Concept and baseline design**, Planetary and Space Science 55: 1398–1413.

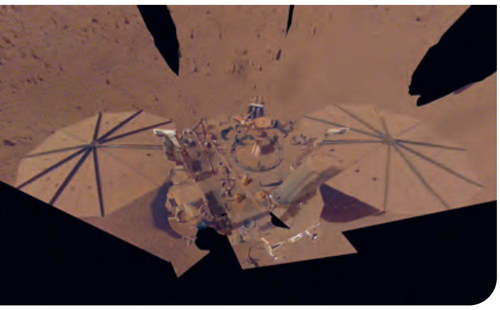
Thomas N, Hussmann H, Lara LM (2019) **The BepiColombo Laser Altimeter (BELA): A post-launch summary**, CEAS Space J. 11: 371.

Time-Line	From	To
Planning	2004	2008
Construction	2008	2016
Measurement phase	2026	2027
Data evaluation	2026	2029



The BELA system on the bench (without cabling). The transmitter comprises the LHB (laser head box), the beam expander and the LEU (laser electronics unit). The receiver comprises the RTL (receiver telescope), the avalanche photodiode (APD), and associated electronics. The electronics unit (ELU) houses boards for the rangefinder, the on-board computer and the power supply.

6.3 SEIS – InSight Seismic Experiment for Interior Structure



NASA InSight's final full selfie image taken on Mars. The selfie is a mosaic of images taken by InSight's Instrument Deployment Camera, located on its robtotic arm, on Sol1,211 of the mission or on 24 April 2022. The lander and solar panels are now covered in dust. Image credit: NASA.

Institute
Inst. Geophysics, ETH Zurich
Zurich, Switzerland

In cooperation with
Inst. Physique du Globe, Paris, France
Imperial College, London, England
Jet Propulsion Lab. (JPL), Pasadena, USA
Center National d'Études Spatiales (CNES), Toulouse, France

Principal Investigator(s)
P. Lognonné (Inst. Physique du Globe, Paris)

Swiss Principal Investigator(s)
D. Giardini (ETH Zurich)

Co-Investigator(s)
J. Clinton, S. Ceylan, L. Ferraioli, J. ten Pierick

Contribution
Electronics box, including instrument power conditioning and acquisition, and control electronics for the SEIS instrument.

Industrial hardware contract(s) to
SYDERAL SA, Switzerland

Website
insight.ethz.ch

Purpose of Research

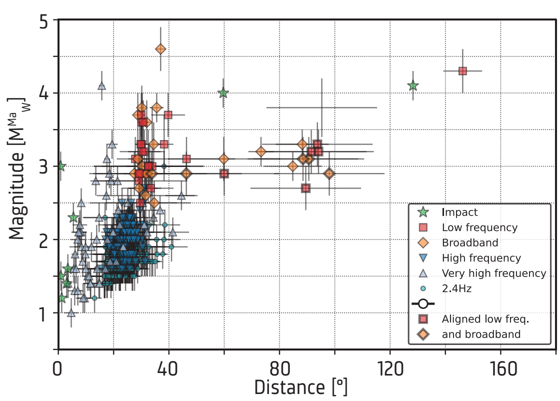
The InSight Lander arrived on the surface of Mars in November 2018. High quality science data was collected between February 2019 and December 2022, when the mission ended due to lack of power caused by the accumulation of dust on the solar panels. The key instrument onboard was SEIS (Seismic Experiment for Interior Structure) that measures seismic waves from impacts and tectonic events that travel through the interior structure. These signals are used to determine the composition of the planet Mars.

The mission was under the lead of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, USA, and the SEIS instrument was under the lead of CNES (Center National d'Etudes Spatiales) in Toulouse, France. The SEIS instrument included two 3-axial sensor assemblies: a very broad band (VBB) oblique seismometer, and an independent short period (SP) seismometer. The Institute of Geophysics, at ETH Zurich, was responsible for the Electronics Box which consisted of the data acquisition and control electronics for SEIS. The seismic sensors as well as the Electronics Box operated without issue for the nearly four years of operation, well beyond the nominal mission duration of one Martian year, equivalent to two Earth years.

In addition to the hardware contribution, the Swiss Seismological Service (SED) and the Seismology and Geodynamics Group (SEG) at the Institute of Geophysics were responsible for the Marsquake Service (MQS) that built a catalogue of seismic events from SEIS data. At the end of the mission, the MQS identified over 1,300 marsquakes, including both regional crustal events as well as significant teleseismic events. Eight events are confirmed to be from impacts, two of which produced craters in excess of 100 m. A large number of events are located at Cerberos Fassae, about 1500 km from InSight, that appears to be the most tectonically active region of the planet. From the global seismicity, scientists at ETH and across the science team have successfully been able to constrain the Martian structure, ranging from the first 100's of meters, though the entire crust and mantle, down to the molten core at 1,550 km below InSight.

Past Achievements and Status

The InSight mission was selected by NASA in 2012 in the frame of the NASA Discovery Programme. Under a challenging schedule, the Swiss contribution (the Electronics Box flight hardware) was delivered in Mar. 2017 to CNES for further instrument integration. Apart from the flight electronics,



Summary of events in the marsquake catalogue according to distance and magnitude. The maximum marsquake identified is M4.6. Events have been detected at distances ranging from some 10's of km from the lander to a nearly 150° distance. The minimal detected magnitude is about M1, and the ability to detect small events degrades with distance.

a qualification model (QM), an electrical model (ELM) and a hardware simulator (Simu-SEIS) were delivered to CNES and JPL/Lockheed Martin. The ELM is used in the Spacecraft Test Lab for flight software validation. The QM was integrated on the lander to support the ATLO (Assembly, Test and Launch Operations) process. Simu-SEIS is used to validate flight software with respect to certain instrument processes (sensor re-centering and levelling). The integration and test of the spacecraft instruments was successfully completed in Mar. 2018. The spacecraft was moved from Lockheed Martin to the launch pad in Vandenberg, California. A final check-up of the instrument was performed at the end of Apr. 2018. The launch took place on 5 May 2018, with a Mars landing six months later on 26 Nov. 2018. The InSight lander and the SEIS instruments operated until Dec. 2022. The MQS team are preparing for a final catalogue update to be released in summer 2024.

Publications

Ceylan S, Clinton JF, Giardini D et al. (2022) **The Marsquake catalogue from InSight, Sols 0–1011**, Phys. Earth Planet In., 333: doi.org/10.1016/j.pepi.2022.106943

Khan A, Ceylan S, van Driel M, Giardini D et al. (2021) **Upper mantle structure of Mars from InSight seismic data**, Science 373: 434–438.

Khan A et al. (2023) **Evidence for a liquid silicate layer atop the Martian core**, Nature 622: doi.org/10.1038/s41586-023-06586-4

Kim D, Banerdt B, Ceylan S, Giardini D et al. (2022) **Surface waves and crustal structure on Mars**, Science 378: doi/10.1126/science.abq7157

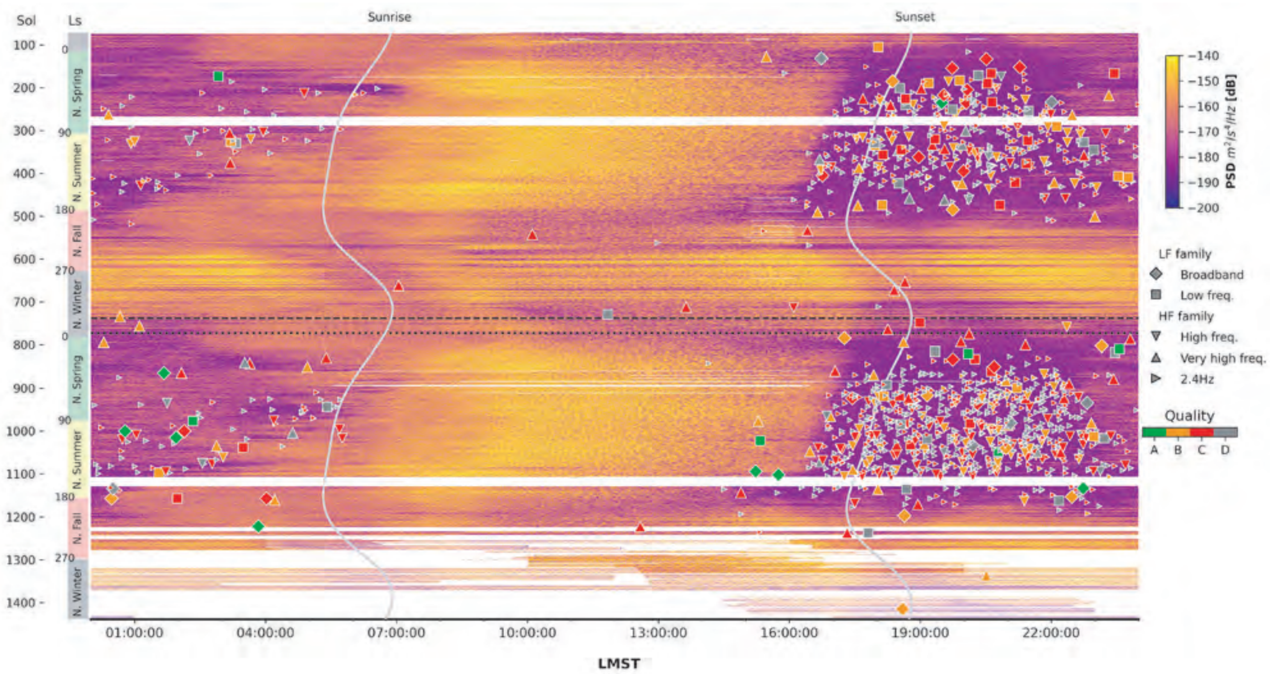
Stähler SC, Khan A, Banerdt W, Lognonné P, Giardini G et al. (2021) **Seismic detection of the martian core**, Science 373: 443–448.

Zweifel P, Mance D, ten Pierick J, Giardini D et al. (2021) **Seismic high-resolution acquisition electronics for the NASA InSight mission on Mars**, Bull. Seismol. Soc. Am. 111 (6): 2909–2923, doi.org/10.1785/0120210071

Abbreviations

InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
SEIS	Seismic Exp. for Interior Structure

Time-Line	From	To
Planning	2010	2012
Construction	2012	2018
Measurement phase	2018	2022
Data evaluation	2018	>2024



Evolution of seismic noise and marsquakes over the entire duration of the InSight mission. A spectrogram for each sol (day on Mars) is stacked from sols 72–1439. The x-axis shows time of day on Mars, and the y-axis, the sol number and the season. The colour indicates amplitude of seismic noise – yellow is noisy, purple is quietest. Marsquakes are shown by symbols. Different types and qualities are indicated. Note obvious seasonality of seismicnoise and the challenge to detect events during noisy periods, as well as the loss of data towards the end of the mission when power became constrained.

6.4 CLUPI – CLose-UP Imager for ExoMars Rover 2028

Institute
Space Exploration Institute (SEI), Neuchâtel, Switzerland

In cooperation with
F. Westall (Co-PI; CNRS, Orléans, France)
B.A. Hofmann (Co-PI; NHM, Bern)

Principal/Swiss Investigator(s)
J.-L. Josset (SEI)

Co-Investigator(s)
T. Bontognali, M. Josset, D. Koschny, L. Fayon, A. Bouquety (Co-I; SEI); N. Kuhn, (Univ. Basel) K. Foelmi †, E. Verreccia, S. Erkman (Univ. Lausanne); L. Diamond (Univ. Bern) and 15 other scientists from Canada, France, Italy, Germany, Austria, The Netherlands, Belgium, Belgium and United Kingdom

Contribution
High Res. Imaging instr. for colour close-up obs. of Martian rocks, surfaces, and samples.

Industrial hardware contract(s)
TAS-CH; CSEM; Fisba AG; Petitpierre SA; SYDERAL SWISS SA; e2v (funded by CNES)

Website
space-x.ch

Purpose of Research

The ExoMars mission aims to land a rover on Mars, dedicated to search for signs of life. The ExoMars rover is equipped with a drill to collect material from outcrops up to 2 m deep and a set of scientific payloads. CLUPI, the CLose-UP Imager, is a high-performance colour imaging system as part of this payload. It plays an important role in achieving mission objectives.

The two main scientific objectives are:

– Geological context for establishing habitability:
  · Identification of the lithologies.
  · Identification of eventual structures/textures (primary or secondary alteration features) that could provide information to interpret habitability.

– Identification of biosignatures:
  · Observation of structural features.
  · Observation of concentrations of carbon (EXM looking for carbonaceous biosignatures).

CLUPI is a miniaturised, low-power, efficient and highly adaptive imaging system of less than 1 kg, with specific micro-technical innovations regarding its sensor and focus mechanism.

The imager has the ability to focus from about 11 cm to infinity (about 16 µm/pixel at 20 cm from the target), with colour imaging achieved using a detector with three layers of pixels (red, green, and blue). CLUPI can also perform auto-exposure, auto-focus, binning, windowing, and z-stacking to send a flexible amount of data and increase the scientific return. A calibration target is used to colour calibrate images during science operations.

CLUPI will be accommodated on the drill box of the rover and use mirrors to observe in three different fields-of-view. Taking advantage of both the rover's mobility and the degrees of freedom of the drill, CLUPI will carry out specific science operations:

– Geological environment survey, for the area immediately in front of the rover.

– Close-up observation of outcrops, to obtain geological information on rock texture and structure, possible alterations, etc., to allow the geological history of targets to be established as well as appraising the potential preservation of biosignatures.

– Drilling area observation.

– Drilling operation observation, to monitor the process, observe the generated mound of fines with potential colour and textural variations, and obtain information on the mechanical properties of the soil.

– Drill hole observation (with deposited fines).

– Drilled core sample observation collected by the drill up to 2 m below the Martian surface.

Past Achievements and Status

This mission should have been launched in September 2022 but due to political reasons, the Russian col-

Time-Line	From	To
Planning	2003	2010
Construction	2011	2026
Measurement phase	2028	2031
Data evaluation	2030	2032

laboration, through its space agency Roscosmos, with the European Space Agency (ESA) was suspended. As a consequence, the launch of the mission was cancelled.

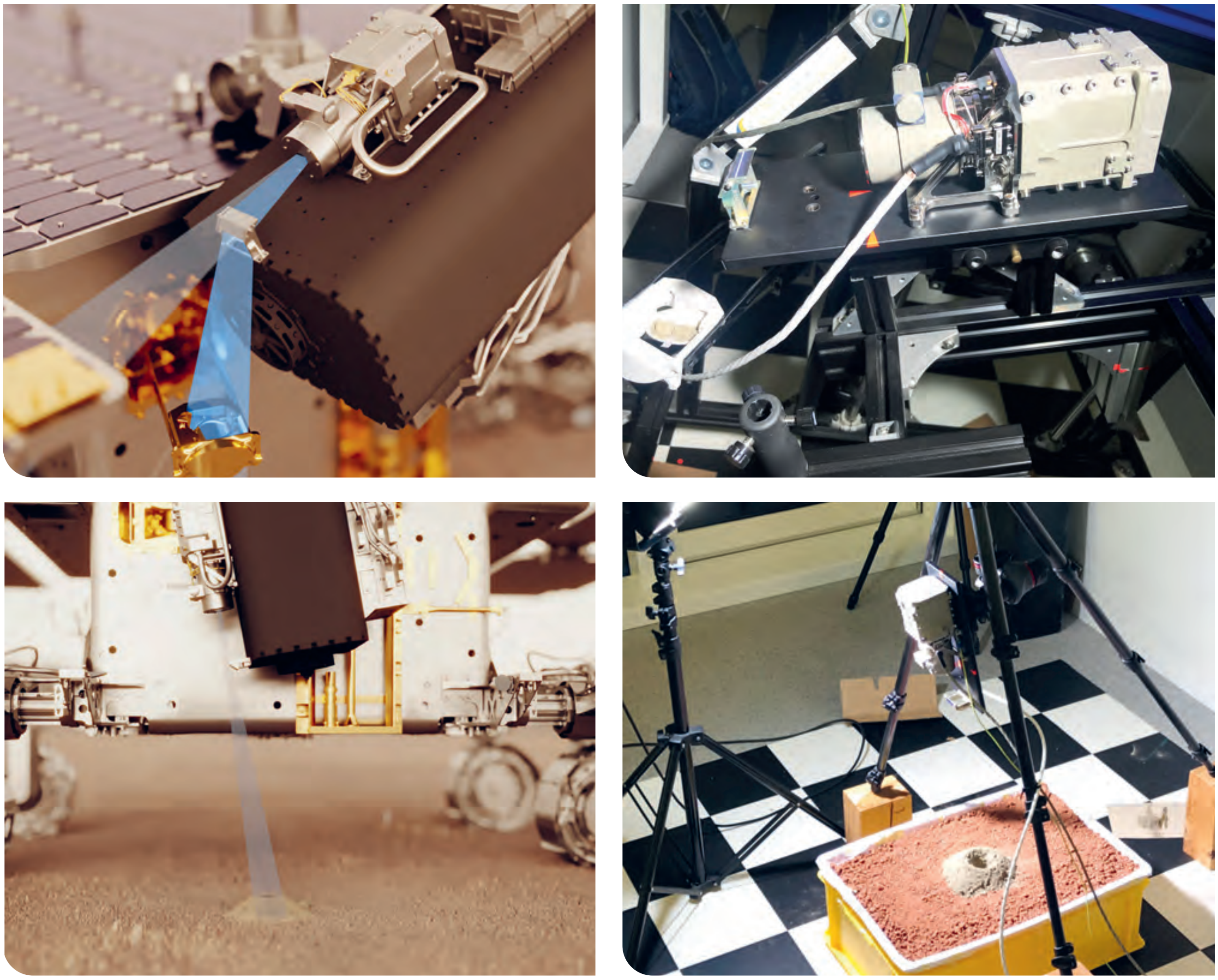
The ExoMars mission has now been approved in a new configuration with a launch planned in 2028 to allow for the replacement of the Russian components of the mission. A new collaboration agreement with NASA was signed in April 2024 in order to contribute key elements.

The instrument has been built but the 'new' mission requires maintenance and updates / refurbishment of the instrument to be compliant with the new mission configuration, in order to satisfy the operations optimisation and operations safety. The launch is now scheduled for 2028. A science validation phase with operation preparation is planned up to the arrival on the surface of Mars in 2030.

Publications

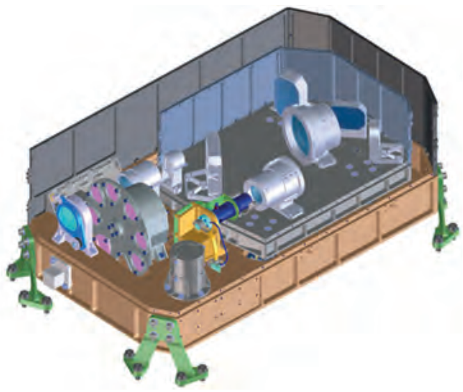
Josset J-L et al. (2017) **The Close-Up Imager (CLUPI) on board the ESA ExoMars Rover: Objectives, description, operations, and science validation activities**, Astrobiology 17:595–611.

Vago J et al. (2017) **Habitability on early Mars and the search for biosignatures with the ExoMars Rover**, Astrobiology 17: 471–510.



Top left: CAD view of CLUPI taking images of the sample in the drawer of the rover. Bottom left: CAD view of CLUPI taking images of the hole and drill fines. Top and bottom right: CLUPI Flight Model Representative on a Drill/Rover simulator taking pictures of samples and of a hole with drill fines during operations simulations in the CLUPI Science Operations Lab. of SEI in Microcity (Neuchâtel, Switzerland). Image credits: SEI.

6.5 The Swiss Contribution to the EnVision VenSpec-H Spectrometer



The VenSpec-H instrument box (optical bench).

Institute
Inst. Geophysics, Dept. Earth Sciences, ETH Zurich, Switzerland

In cooperation with
Fachhochschule Nordwestschweiz (FHNW)
Hochschule Luzern (HSLU)
KOEGL Space GmbH
Space Acoustics GmbH
Royal Belgian Inst. Space Aeronomy, Belgium
Instituto de Astrofisica de Andalucia, Spain
Instituto Universitario de Microgravedad 'Ignacio Da Riva' Spain
Netherlands Inst. Space Res., Netherlands
Inst. Astrophys. & Space Sciences, Portugal
J. Heyrovsky Inst., Czech Acad. Sci., Czechia
Deutsches Zentrum für Luft- u. Raumfahrt, Germany
ESA

Principal Investigator(s)
A. C. Vendaele (BIRA, Belgium)

Swiss Principal Investigator(s)
P. Tackley (ETH Zurich)

Purpose of Research

EnVision is an orbital mission to Venus being developed by the European Space Agency (ESA). Its overall science goals are:

– To decipher the sequence of tectono-magmatic events that generated the regional and global surface features of Venus, and understand the geodynamics framework that controls the release of internal heat over Venus history.

– To search for ongoing geological processes and determine which parts of the planet are active in the present era.

– To characterise regional and local geological units, to better assess whether Venus once had condensed liquid water on its surface and was thus perhaps hospitable for life in its early history.

The result of these will be to provide a holistic view of the planet from its inner core to upper atmosphere to determine how and why Venus and Earth evolved so differently. The Swiss contribution to EnVision consists of co-developing VenSpec-H (Venus Spectrometer with High resolution).

VenSpec-H will monitor the composition of minor species in the lower atmosphere on the night-side and above the clouds on the day-side, to enable characterisation of volcanic plumes and other sources of gas exchange with the surface of Venus, complementing VenSAR and VenSpec-M surface and SRS subsurface observations.

VenSpec-H will focus on the volcanic and cloud forming gases, and search for composition anomalies potentially related to volcanic activity. The specific development tasks of the Swiss team are mechanical and thermal engineering of the Instrument Box, and development of the Filter Wheel mechanism.

EnVision will carry a further five instruments: the VenSAR synthetic aperture radar, the SRS Subsurface Radar Sounder, the RSE Radio Science Experiment, and three VenSpec spectrometers. The VenSpec instrument suite consists of three channels: VenSpec-M, VenSpec-H, VenSpec-U, and the Central Control Unit (CCU). All three channels have their independent optics due to the very different imaging concepts and wavelength ranges covered.

Past Achievements and Status

The EnVision mission was officially adopted by ESA in January 2024. Phase B1 will end June 2024 and is on schedule. As of March 2024, the Swiss team has built a Filter Wheel Mechanism Breadboard, which has successfully completed vibration and thermal environmental tests, and is currently undergoing the lifetime test.

Mechanical and thermal engineering for the design of the instrument breadboard has been completed. At present, preparations are ongoing for mechanical tests, which will be completed in April 2024. The manufacturing of the Filter Wheel Mechanism will be performed by Swiss industry during phases B2, C and D, starting in the second half of 2024.

Publications

Neefs E et al. (2024) **VenSpec-H spectrometer on the ESA EnVision mission: Design, modeling, analysis**, Acta Astronautica, submitted.

Székely GS, Eberli R, Grossmann M, Tenisch S, Gröbelbauer H-P, Wirz F, Seiler P, Kögl P, Kögl S, Tackley PJ, Gerya T, Vandaele A-C, Neefs E (2024) **VenSpec-H filter wheel mechanism breadboard development and test**, Proc. 47th Aerospace Mechanisms Symposium, May 2024.

Abbreviations

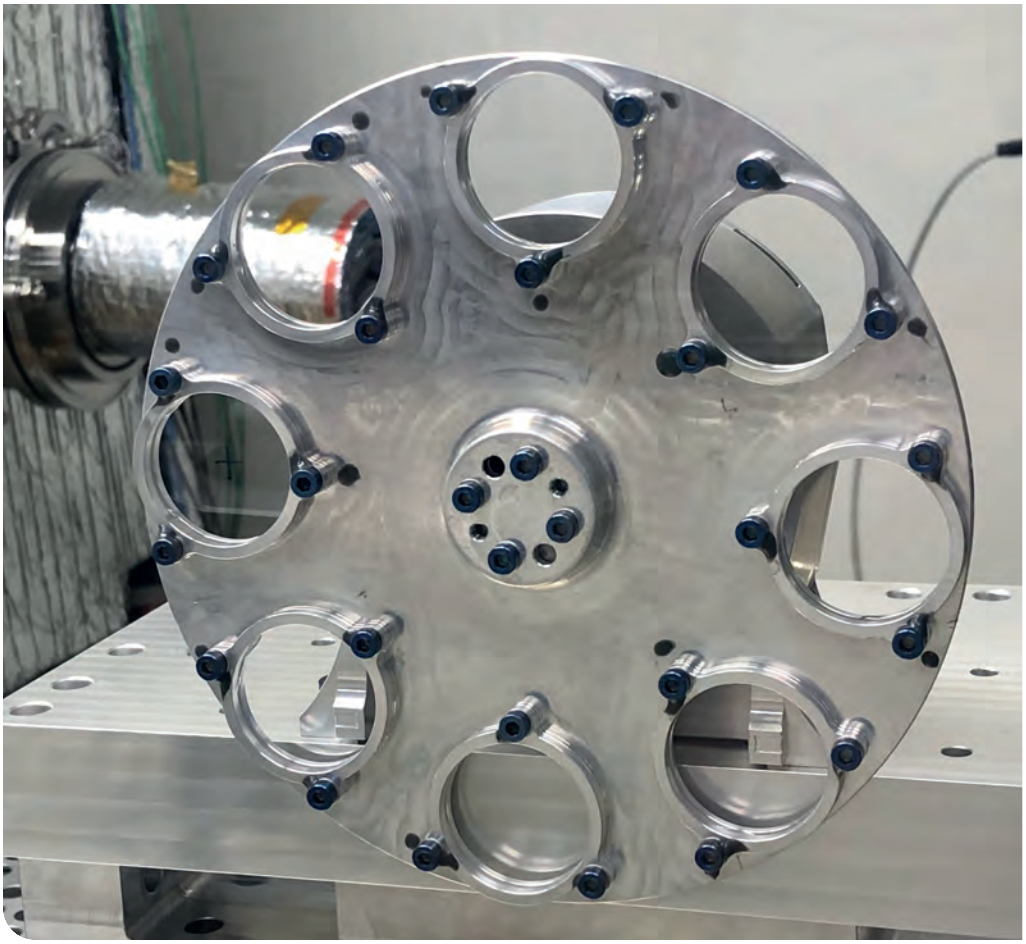
VenSpec-H Venus Spectrometer with High resolution
VenSpec-M Venus Spectrometer Multispectral imager
VenSpec-U Venus Spectrometer Ultraviolet

Time-Line	From	To
Planning	Jul. 2021	Oct. 2025
Construction	Nov. 2025	May 2029
Measurement phase	mid-2033	~2039
Data evaluation	2034	–

Co-Investigator(s)
(co-Instrument Lead Scientists)
L. Lara (IAA/IDR, Spain), M. Ferus (JHI-CAS, Czechia)

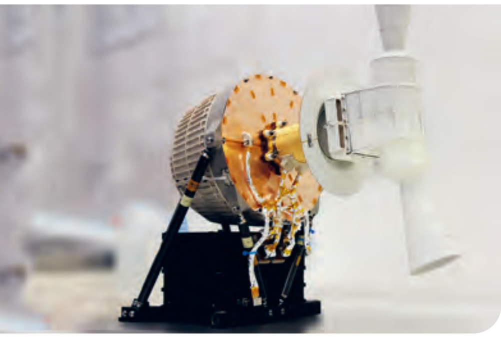
Contribution
Co-development of VenSpec-H spectrometer of the EnVision Venus orbiter.

Website
cosmos.esa.int/web/envision/venspec-h



The VenSpec-H filter wheel mechanism breadboard.

6.6 BepiColombo: Composition of crust, exosphere, surface evolution, formation and evolution of planet Mercury



The STROFIO instrument (part of SERENA experiment) on BepiColombo.

Institute
Space Res. & Planetology, Phys. Inst., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
Inst. Fisica dello Spazio Interplanetari (IFSI), Rome, Italy (S. Orsini, A. Milillo)
Swedish Space Research Inst. (SSRI), Kiruna, Sweden (S. Barabash, M. Wieser)
Southwest Research Inst. (SWRI), San Antonio, TX, USA (S. Livi)

Principal Investigator(s)
S. Orsini (IFSI), S. Barabash (SSRI)

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Vorburger, A. Galli, J. Hener (UNIBE)

Contribution
Participation in two instr.: 1) SERENA on MPO, for which Bern provided substantial hardware for the STROFIO mass spectrometer and MIPA ion sensor, and 2) MPPE on MMO, for which Bern provided substantial hardware for the ENA instr.

Industrial hardware contract(s) to
EMPA, Rekolas, Sulzer Innotec, SWSTech AG

Website
esa.int/Science_Exploration/Space_Science/BepiColombo

Purpose of Research

The European Space Agency (ESA) has defined the Cornerstone Mission, named BepiColombo, for the detailed exploration of planet Mercury. Because of observational difficulties, Mercury is a largely unknown planet and therefore a high scientific return is expected from such an exploratory mission.

The launch of BepiColombo successfully took place on 20 October 2018, and the spacecraft is on its way to Mercury, while the arrival is scheduted for 5 December 2025. After orbital insertion, the nominal dataphase will start in March 2026 and will last for one year with a possible extension of an additional year.

We are participating, within an international collaboration in the BepiColombo mission, by providing two mass spectrometers. One mass spectrometer is on the BepiColombo/MMO spacecraft, which will perform Energetic Neutral Atom (ENA) imaging of the space around Mercury. The second instrument is on the BepiColombo/MPO spacecraft of JAXA to measure the elemental, chemical, and isotopic composition of Mercury's exosphere with a sensitive neutral gas mass spectrometer. With these two instruments, we will substantially contribute to three out of the six main scientific goals, which have been set for BepiColombo.

Past Achievements and Status

During the spacecraft's journey to Mercury, BepiColombo has so far made two Venus flybys (on 15 October 2020 and 11 August 2021) and three Mercury flybys (2 October 2021, 23 June 2022, 20 June 2023). Three more Mercury flybys (5 September 2024, 2 December 2024; 9 January 2025) will be performed before orbital insertion. Data analysis of these encounters is ongoing.

Publications

Gamborino D, Vorburger A, Wurz P (2019) **Mercury's sodium exosphere: An ab initio calculation to interpret MESSENGER observations**, Ann. Geophys. 37: 455–470, doi.org/10.5194/angeo-2018-109

Wurz P, Gamborino D, Vorburger A, Raines JM (2019) **Heavy ion composition of Mercury's magnetosphere**, J. Geophys. Res. 124: 10 pp, doi.org/10.1029/2018JA026319

Wurz P et al. (2022) **Particles and photons as drivers for particle release from the surfaces of the Moon and Mercury**, Sp. Sci. Rev. 218(10): doi.org/10.1007/s11214-022-00875-6

Abbreviations

ENA	Energetic Neutral Atom
MIPA	Miniature Ion Precipitation Analyser
MMO	Mercury Magnetospheric Orbiter
MPO	Mercury Planetary Orbiter Experiment
MPPE	Mercury Plasma Particle Experiment
SERENA	Search Exopheric Refilling and Emitted Natural Abundances
STROFIO	Start from a Rotating FIeld mass spectrOmeter

Time-Line	From	To
Measurement phase	2026	2028
Data evaluation	2026	2030

6.7 Jupiter and Icy Moons Explorer (JUICE): Composition of Jupiter's Icy Moons

Purpose of Research

The European Space Agency selected the Jupiter and Icy Moons Explorer (JUICE) mission as an L-class mission to explore Jupiter and its icy moons (Europa, Ganymede, Callisto) in great detail, with particular emphasis on the moon Ganymede. The Particle Environment Package (PEP) investigates all particle populations of neutrals, ions, and electrons in Jupiter's magnetosphere and its moons in the energy range from thermal energies to beyond MeV.

The Neutral and Ion Mass spectrometer (NIM) of PEP will measure the chemical composition of the neutral atmospheres of the icy moons and their thermal ion population. With the NIM measurements, we will investigate the chemical composition of the icy moons, which is an important input to the understanding of their formation from Jupiter's subnebula at the time of the formation of the Jupiter system.

Past Achievements and Status

The JUICE mission is currently in the cruise phase to Jupiter. The JUICE mission adoption by ESA was in November 2014, and the industrial prime was selected in July 2015. The Particle Environment Package (PEP) is one of the 10 selected science experiments for the JUICE mission. The Swedish Institute for Space Physics is the PI institution, and the University of Bern is the Co-PI institution for the PEP experiment. The PEP PFM experiment and the NIM PFM instrument are on the spacecraft, and the flight spare instrument is used for post-launch calibrations and for support of flight operations.

JUICE was successfully launched on 14 April 2024, and completed the Near Earth Commissioning phase by July 2023. JUICE is scheduled to arrive at Jupiter in July 2031 after conducting fly-bys of the Moon-Earth (August 2024), Venus (August 2025) and the Earth (September 2026; January 2029).

Publications

Vorburger A, Pfleger M, Lindkvist J, Holmström M, Lammer H, Lichtenegger HIM, Galli A, Rubin M, Barabash S, Wurz P (2019) **3D-modeling of Callisto's surface sputtered exosphere environment**, J. Geophys. Res. 124: 13 pp, doi.org/10.1029/2019JA026610

Vorburger A, Wurz P (2021) **Modeling of possible plume mechanisms on Europa**, J. Geophys. Res. 126: 20 pp, doi.org/10.1029/2021JA029690

Vorburger A, Fatemi S, Carberry Mogan SR, Galli A, Liuzzo L, Poppe AR, Roth L, Wurz P (2024) **3D Monte-Carlo simulation of Ganymede's atmosphere**, Icarus 409: 115847, 19 pages, doi.org/10.1016/j.icarus.2023.115847

Abbreviations

JUICE	Jupiter and Icy Moons Explorer
NIM	Neutral and Ion Mass spectrometer
PEP	Particle Environment Package

Time-Line	From	To
Planning	2012	2014
Construction	2014	2022
Measurement phase	Jul. 2031	2036
Data evaluation	Jul. 2031	2038

NIM instrument of the PEP experiment on JUICE: NIM sensor head (left, golden structure) with electronic box attached (on the right).

Institute
Space Res. & Planet., Phys. Inst., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
Swedish Space Res. Inst., Kiruna, Sweden
App. Phys., Lab., John Hopkins Univ., Laurel, USA
Max-Planck-Inst. f. Sonnensystemforschung, Göttingen, Germany
Finnish Met. Inst., Helsinki, Finland
Univ. Wales Aberystwyth, Wales, UK

Principal Investigator(s)
S. Barabash (PI; IRF, Sweden)
P. Wurz (Co-PI, UNIBE)

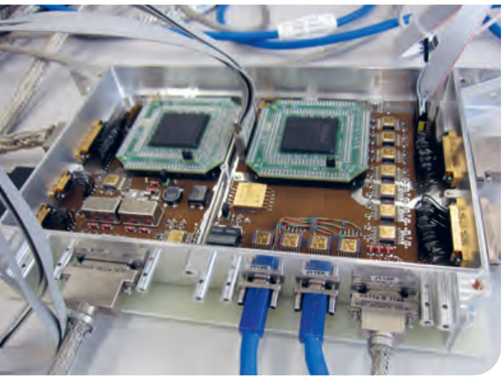
Swiss Principal Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Galli, N. Thomas, M. Tulej, A. Vorburger (UNIBE)

Contribution
Neutral and Ion Mass spectrometer (NIM) for the Particle Environment Package of JUICE.

Website
esa.int/Science_Exploration/Space_Science/Juice

6.8 GALA – Ganymede Laser Altimeter on JUICE



The Rangefinder Module (RFM) test-board.

Institute
Space Res. & Planetology Div., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
DLR Institute for Planetary Res. (DLR), Berlin-Adlershof, Germany
Chiba Institute of Technology, Japan
Instituto de Astrofisica de Andalucia (IAA), Granada, Spain

Principal Investigator(s)
H. Hussmann (DLR),

Swiss Principal Investigator(s)
N. Thomas (UNIBE)

Co-Investigator(s)
30 geophysicists from Europe

Contribution
UNIBE developed and built the GALA rangefinder module

Industrial hardware contract(s)
Thales-Alenia Space, Switzerland

Website
dlr.de/de/forschung-und-transfer/projekte-und-missionen/juice/der-hoehenmesser-gala

Purpose of Research

GALA will measure the topography of the Jovian moon, Ganymede, from onboard ESA's Jupiter and Icy Moons Explorer (JUICE) mission. The University of Bern contributed the rangefinder electronics to the laser altimeter system. This was a derivative of the BepiColombo Laser Altimeter (BELA) rangefinder, which was successfully implemented for the BepiColombo mission to Mercury. The rangefinder was mostly constructed by industry.

The rangefinder measures the time-of-flight of the laser pulse, and the laser pulse energy and pulse shape. These three quantities are the only immediate science result from a laser altimeter, and are used to compute:

– The altitude of the spacecraft above the surface.

– The topography of the surface (taking into account orbital data).

– The albedo of the surface at the laser wavelength.

– The slope of the surface (from shot-to-shot altitude data).

– The roughness of the surface inside the laser footprint, determined from the pulse shape.

The BELA rangefinder module is a novel type of digital signal processing module for laser altimetry and has been adapted for the higher pulse repetition frequency (30 Hz) to be used for GALA. The signal from the detector is digitised prior to the pulse detection and pulse/time-of-flight analysis.

The system is fully programmable and so can be adapted to expected pulse shapes even during flight. The improvement of the detection limit is significant because modified digital matched filtering can be applied.

Past Achievements and Status

The flight model of the rangefinder module (RFM) was delivered to DLR and integrated into the flight model of the GALA instrument. JUICE was launched by an Ariane 5 rocket on 14 April 2023, and near-Earth check out indicated that the GALA instrument is fully functional.

JUICE is scheduled to arrive at Jupiter in July 2031 after conducting fly-bys of the Moon-Earth (Aug. 2024), Venus (Aug. 2025) and the Earth (Sep. 2026; Jan. 2029).

Publications

Hussmann H et al. (2019) **The Ganymede laser altimeter (GALA): key objectives, instrument design, and performance**, CEAS Space Journal, 11, 381.

Abbreviations

BELA	BepiColombo Laser Altimeter
GALA	Ganymede Laser Altimeter
JUICE	Jupiter and Icy Moons Explorer
RFM	Rangefinder Module

Time-Line	From	To
Planning	2004	2008
Construction	2008	2016
Measurement phase	2026	2027
Data evaluation	2026	2029

6.9 SWI – Submillimeter Wave Instrument on JUICE

Purpose of Research

The Jupiter Icy Moons Explorer (JUICE) is an L-class mission of the ESA Cosmic Vision 2015–2025 programme to investigate Jupiter and its Galilean satellites as planetary bodies and potential habitats for life. The Submillimeter Wave Instrument (SWI) on JUICE will study the chemical composition, wind speeds and temperature variability of Jupiter's atmosphere, as well as the exosphere and surface properties of its icy moons.

SWI consists of two heterodyne receivers that are independently tunable between 530–625 GHz and 1080 –1280 GHz. It includes a steerable off-axis telescope with a 29-cm aperture and different high resolution and broadband spectrometers.

The Institute of Applied Physics (IAP), Bern, Switzerland, is responsible for the optical design of the instrument and the development of the optical components for the receiver unit. This includes the corrugated feed horn of the 600-GHz receiver, several focusing reflectors, a polarising beam-splitter and in particular, the onboard blackbody calibration target.

In addition, IAP conducts radiometric performance tests of the SWI receiver unit and supports the instrument prime contractor in the radio frequency characterisation of the complete instrument.

Time-Line	From	To
Planning	2010	2012
Construction	2013	2021
Measurement phase	2031	2035

Past Achievements and Status

IAP delivered all Flight Model and Flight Spare optical hardware as well as the onboard calibration target to the instrument prime contractor in 2020. In addition, IAP played an important role in the optical alignment of the instrument, provided an interferometric testbed for radiometric characterisation of the receivers, and supported the data analysis efforts related to the telescope near-field test campaign that took place at the ESA ESTEC centre in Nordwijk, Netherlands.

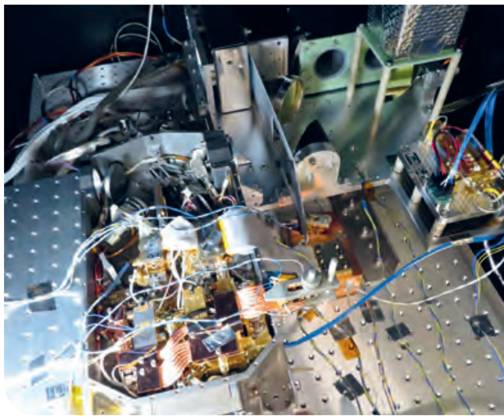
Juice was launched on 14 April 2023, and the Near Earth and Commissioning Phase of SWI was successfully concluded in July 2023. IAP continues to support the Max Planck Institute for Solar System Research (MPS) in the activities concerning the instrument ground reference model.

Publications

Kotiranta M et al. (2022) **Versatile radiometric testbed for the Submillimeter Wave Instrument**, 32nd Int. Symp. on Space THz Technol. ISSTT 2022, Baeza, Spain.

Abbreviations

JUICE Jupiter and Icy Moons Explorer
SWI Submillimeter Wave Instrument



Flight model of the SWI receiver unit during on-ground calibration with the UNIBE radiometric testbed. Image credit: MPS.

Institute
Inst. Applied Physics, Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
MPS, Germany
CBK, Poland
LERMA, France
NICT, Japan
Omnisys Instruments, Sweden
RPG, Germany

Principal Investigator(s)
P. Hartogh (MPS)

Swiss Principal Investigator(s)
A. Murk (Co-I, UNIBE)

Co-Investigator(s)
M. Kotiranta (UNIBE)
K. Jacob (UNIBE)

Contribution
Optics design, optical components, calibration unit, instrument testing

Industrial hardware contract(s) to
Micos Engineering, Switzerland

6.10 CoCa – Comet Camera on Comet Interceptor

Preliminary design of the CoCa camera system.

Institute
Space Research and Planetology Division, Phys. Inst., Univ. Bern, (UNIBE), Bern, Switzerland

In cooperation with
DLR Inst. Planetary Res., Berlin, Germany
Inst. de Astro. de Andalucia (IAA), Spain
Res. Centre Astron. & Earth Sci. Konkoly, Budapest, Hungary

Principal/Swiss Investigator(s)
N. Thomas (UNIBE)

Co-Investigator(s)
Numerous

Contribution
The University of Bern is developing and building the CoCa flight system in collaboration with our German, Spanish and Hungarian partners.

Industrial hardware contract(s) to
Thales-Alenia Space Switzerland

Websites
esa.int/Science_Exploration/Space_Science/Comet_Interceptor

Purpose of Research

The Comet Camera (CoCa) is the main imaging system onboard the European Space Agency's new F-class mission, Comet Interceptor. The spacecraft will be launched as a passenger together with the Ariel mission and will fly to a holding position at a Lagrangian point.

Ground-based observers will identify a prospective target. It is expected that this target will be a dynamically new comet entering the Solar System or possibly an interstellar object. The spacecraft will then be directed to the target and will complete a high velocity fly-by. The scientific aim of CoCa will be to obtain the first images of a nucleus of a dynamically new comet.

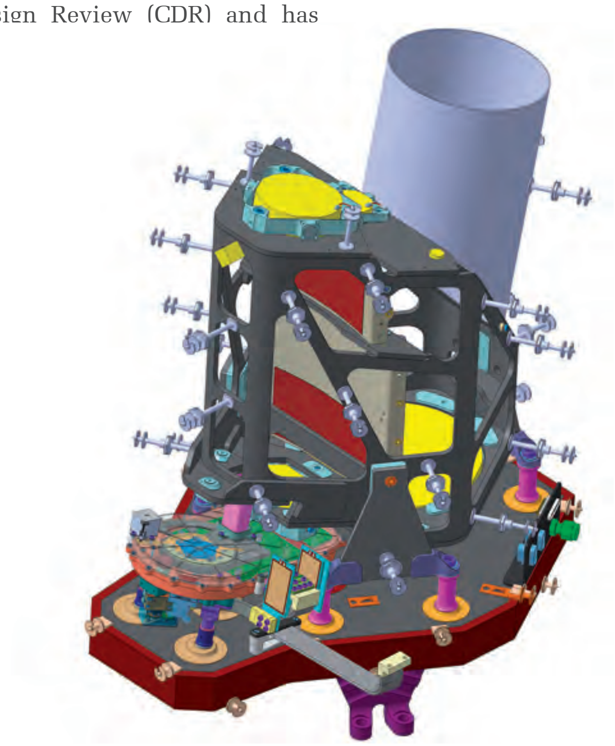
Past Achievements and Status

The instrument has passed the Critical Design Review (CDR) and has now entered the build phase. The Engineering Models (EMs) are currently being integrated with an expected completion date of the proto-flight model in the 4th quarter of 2025. Delivery to the spacecraft is foreseen in 2026.

Abbreviations

Ariel	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
CoCa	Comet Camera

Time-Line	From	To
Planning	2020	2022
Construction	2022	2026
Measurement phase	2029	2034
Data evaluation	2031	2035



Different view of the preliminary CoCa design.

6.11 MANiaC for Comet Interceptor

Purpose of Research

Comet Interceptor (CI) is an ESA mission designed to fly-by a Dynamically New Comet (DNC), Long Period Comet (LPC), or possibly even an Interstellar Object. The mission will launch in 2029 together with Ariel, be deployed at the second Sun-Earth Lagrangian point L2, and then embark to intercept the yet to be identified target comet. In the meantime, Earth-based telescope surveys, in particular the new Vera C. Rubin Observatory, will support the search for suitable targets which cross the ecliptic plane within 0.9 and 1.25 au from the Sun to be reachable by CI. DNCs, possibly also LPCs, may be less (thermally) processed objects compared to the known family of short-period comets. This makes them an ideal target to study the evolution of Oort Cloud and Kuiper-belt objects on their way to the inner solar system.

Part of the CI payload is the Mass Analyzer for Neutrals in a Coma (MANiaC) instrument. It consists of a time-of-flight mass spectrometer and a neutral gas density gauge. MANiaC is dedicated to measuring the abundances of the gases along the flyby trajectory. The volatile molecules in the coma originate from the sublimation of the ices inside the comet's nucleus. Therefore, one key investigation will be the search for highly volatile molecules, such as CO. Ices dominated by such species may sublimate already below 30 K and hence still be abundant in DNCs compared to known comets that have already visited the inner solar system several times. Other key molecules for analysis include carbon-bearing organic species, molecular oxygen, and water with its isotopes. There may even be the possibility to analyse small dust grains impacting MANiaC during the fast flyby (10 –70 km/s). All these measurements are contingent to the outgassing activity of the target comet, which poses a challenge to predict accurately at the time CI has to separate from L2.

Past Achievements and Status

In 2022, ESA adopted the CI mission, which is now in the implementation phase. Later in the same year, OHB Italy was selected to provide the main spacecraft A and probe B2 buses, and JAXA will deliver probe B1 with its payload. The MANiaC instrument will be integrated on spacecraft A. By now, the design has been finalised and the instrument successfully passed the Critical Design Review in 2023. Throughout this time, prototype testing within the consortium has been ongoing at unit and board level. Definition and development of the onboard software, including boot and application layers, is progressing as well. Also the next phase of assembly, integration, and testing of the Engineering Model as well as the Electrical and Functional Models is imminent and work on the Proto-Flight Model will start soon after for timely delivery in early 2026.

Publications

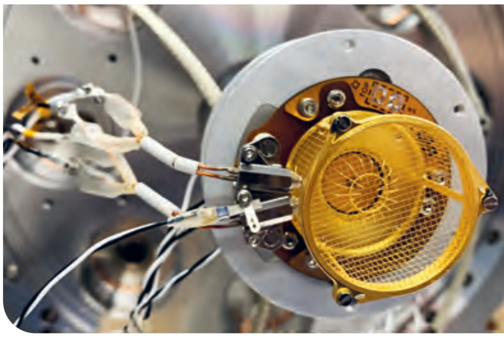
Jones GH et al. (2024) **The Comet Interceptor Mission**, Sp. Sci. Rev., 220: 9.

Snodgrass C, Jones GH (2019) **The European Space Agency's Comet Interceptor lies in wait**, Nature Communications 10: 5418.

Abbreviations

MANiaC Mass Analyser for Neutrals in a Coma

Time-Line	From	To
Planning	2020	2022
Construction	2023	2026
Measurement phase	2029	2033
Data evaluation	2029	2036



Prototype of the MANiaC Neutral Density Gauge ionization section composed of two grids, base, and two filaments (main and redundant).

Institute
Space Research and Planetary Sciences, Phys. Inst., Univ. Bern, (UNIBE), Bern

In cooperation with
European Space Agency (ESA),
Inst. Weltraumforschung (IWF), Graz, Austria
Inst. Astro. Andalucía (IAA), Granada, Spain
L'Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France
DLR Inst. Plan. Res. Berlin, Germany

Principal Investigator(s)
M. Rubin (UNIBE)

Swiss Principal Investigator(s)
M. Rubin (UNIBE)

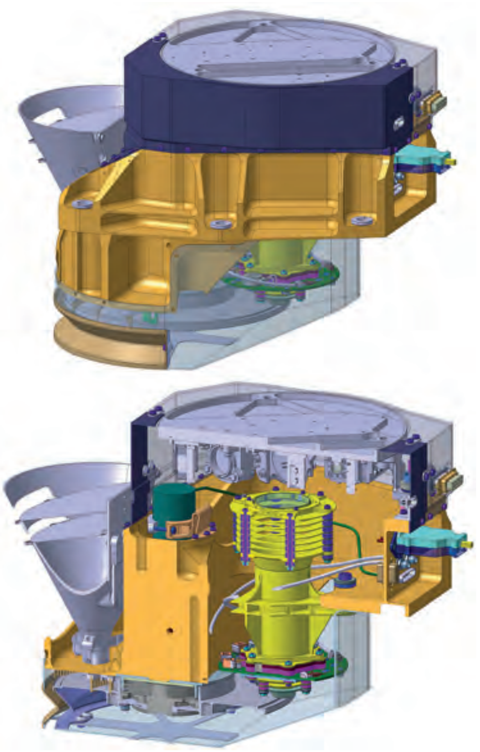
Co-Investigator(s)
P. Wurz (UNIBE), L. Lara (IAA), P. Garnier (IRAP), H. Lammer (IWF), J. Knollenberg (DLR), and others

Contribution
Development & Construction of the instrument Comet Interceptor/MANiaC

Industrial hardware contract to
Art of Technology, Zurich, Switzerland
Creotech Instrs. SA, Piaseczno, Poland
P&P Software, Tägerwilen, Switzerland
SENER Aerospace & Defence, Barcelona, Spain

Website
cosmos.esa.int/web/comet-interceptor
cometinterceptor.space

6.12 Chemical Composition of Lunar Regolith with the LIA instrument in the NASA Artemis Progamme



Top panel: Design of the LIMS instrument with funnel for regolith reception (left), laser system (top), mechanical structure (body), and the sample carousel (bottom); Bottom panel: section showing the funnel, the laser system, the mass spectrometer (right), the enclosure of the carousel motor (middle), and the sample carousel.

Institute
Space Res. & Planetology, Phys. Inst., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
NASA

Principal /Swiss Investigator(s)
P. Wurz (UNIBE)

Co-Investigator(s)
A. Riedo (UNIBE), M. Tulej (UNIBE)

Contribution
Development & construction of the Laser Ionisation Mass Spectrometer (LIMS)

Industrial hardware contract(s)
Spacetek Technology SA; Source Engineers; Thales Switzerland

Purpose of Research

We are building a laser-based mass spectrometer (LIMS) for the in-situ investigation of the chemical and mineralogical composition of lunar regolith grains. This development is for an application on a robotic mission within the Artemis Commercial Lunar Payload Services (CLPS) programme of NASA. The CLPS lander will be placed in the south polar region.

The LIMS system consists of a time-of-flight mass analyser (TOF-MS), a laser system (LSS) providing nano-second laser pulses focused to µm spots on the sample surface, electronics (ELU) to operate the LIMS system, and a sample handling system (SHS) for lunar regolith. The TOF-MS, LSS, and ELU are a further development of our established design of laboratory prototypes. The SHS is specially designed for the CLPS lander to collect and process regolith from the lunar surface in the vicinity of the lander for grain-by-grain analysis.

Past Achievements and Status

For more than two decades, we have developed highly miniature Laser Ablation Ionisation Mass Spectrometry (LIMS) instruments for in-situ planetary research, which were originally intended for a lander on Mercury as part of the BepiColombo mission of ESA. LIMS uses pulsed lasers of high intensity (MW/cm^2 to TW/cm^2) so that the material in the ablation plume is completely atomised and a large fraction of the atoms are ionised simultaneously.

We have continuously improved the LIMS instruments in preparation for future landed missions for versatile use on lunar, asteroid, Mars and other planetary surfaces. In 2022, our LIMS instrument was selected by NASA to be part of a CLPS mission in the Artemis lunar exploration programme.

Publications

Keresztes Schmidt P, Hayoz S, Piazza D, Bandy T, Mändli P, Blaukovitsch M, Althaus M, Plet BG, Riedo S, Studer S, Studer O, Bieri M, Tulej M, Riedo A, Wurz P (2024) **Sample handling concept for in-situ lunar regolith analysis by laser-based mass spectrometry**, IEEE Aerospace Conference Big Sky, MT, USA, in press.

Wurz P, Tulej M, Riedo A, Grimaudo V, Lukmanov R, Thomas N (2021) **Investigation of the surface composition by laser ablation/ionisation mass spectrometry**, IEEE Aerospace Conference Big Sky, MT, USA, 50100, 15 pp, doi.org/10.1109/AERO50100.2021.9438486

Wurz P, Hayoz S, Piazza D, Bandy T, Blaukovitsch M, Keresztes Schmidt P, Mändli P, Plet BG, Riedo S, Studer S, Tulej M, Riedo A (2023) **In situ lunar regolith analysis by laser-based mass spectrometry**, IEEE Aerospace Conference Big Sky, MT, USA, 10 pp, doi.org/10.1109AERO55745.2023.10115714

Abbreviations

CLPS	Commercial Lunar Payload Services
LIMS	Laser Ionisation Mass Spectrometer

Time-Line	From	To
Planning	2019	2021
Construction	2022	2027
Measurement phase	2027	2027
Data evaluation	2027	2028

6.13 Chemical Composition of Lunar Regolith with the DIMPLE instrument in the NASA Artemis Progamme

Purpose of Research

The Dating an Irregular Mare Patch with a Lunar Explorer (DIMPLE) experiment will determine the age and origin of the potentially young (33 ± 2 Ma) irregular Mare patch, Ina (location: 18.66 °N and 5.30 °E). DIMPLE is mounted on a robotic lander on a Commercial Lunar Payload Services (CLPS) platform.

DIMPLE will image the geologic context of Ina, analyse rock samples collected by a rover, and determine their age and composition. DIMPLE has been selected for flight as part of NASA's CLPS initiative of the Artemis programme.

Past Achievements and Status

DIMPLE, currently in Phase B, has four payload elements:

- The Chemistry, Organics, and Dating EXperiment (CODEX), which is comprised of a laser subsystem and a mass spectrometer (provided by the University of Bern).
- A sample handling system for gripping rocks from the lunar surface, creating smoothed rock faces, and presenting those smoothed faces first to a lander-mounted camera and then to CODEX.
- The Payload Control Unit that receives data from the CODEX instrument and operates the sample-handling system.
- A scooping rake to be mounted on a CLPS-provided rover, for collecting samples along traverses and carrying them to the lander.

Publications

Anderson FS et al. (2024) **Implementing Lunar in situ dating with the DIMPLE payload**, Lunar and Planetary Science Conference, 11–15 March 2024, LPSC Abstract Nr. 2547.

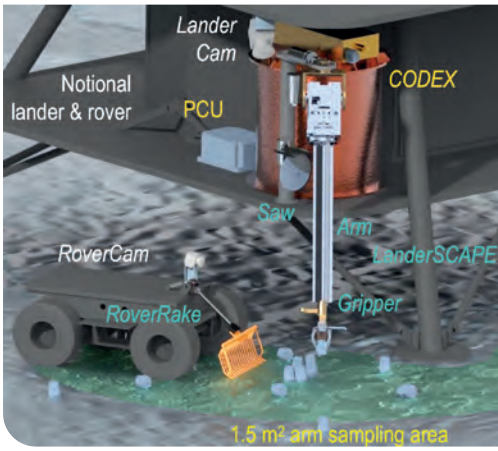
Anderson FS et al. (2024) **In situ dating of Lunar basalt samples at Ina**, Lunar and Planetary Science Conference, 11–15 March 2024, LPSC Abstract Nr. 2336.

Wurz P et al. (2021) **Investigation of the surface composition by laser ablation/ionisation mass spectrometry**, IEEE Aerospace Conference Big Sky, USA, 50100, 15 pp, doi.org/10.1109/AERO50100.2021.9438486

Abbreviations

CLPS	Commercial Lunar Payload Services
CODEX	Chemistry, Organics, and Dating EXperiment
DIMPLE	Dating an Irregular Mare Patch with a Lunar Explorer

Time-Line	From	To
Planning	2019	2021
Construction	2023	2027
Measurement phase	2027	2027
Data evaluation	2027	2028



Overview of a possible implementation of the Dating an Irregular Mare Patch with a Lunar Explorer (DIMPLE) experiment.

Institute
Space Res. & Planetology, Phys. Inst., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
NASA

Principal Investigator(s)
S. Anderson, Southwest Res. Inst. (SWRI), Boulder, USA

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

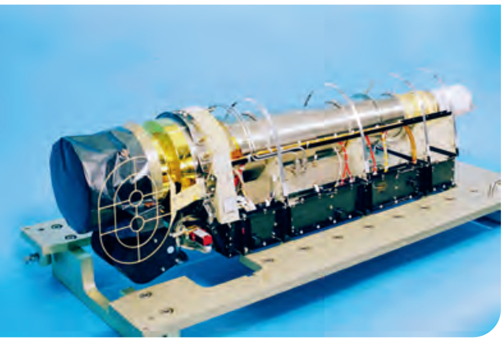
Co-Investigator(s)
R. Fausch (UNIBE)

Contribution
Development & construction of the Laser Resonant Ionisation Mass Spectrometer

Industrial hardware contract(s)
Spacetek Technology SA

Website
nasa.gov/commercial-lunar-payload-services

6.14 Rosetta/ROSINA Post Operation Phase



Rosetta/ROSINA Reflectron-type time-of-flight mass spectrometer (RTOF).

Institute
Space Res. & Planetary Sci., Inst. Phys., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
ESA, MPS, TUB, BIRA, CESR, CNRS, LATMOS, IPSL, LMM, UMich, SwRI

Principal/Swiss Investigator(s)
K. Altwegg (UNIBE)

Co-Investigator(s)
H. Balsiger (UNIBE), J.-J. Berthelier (LATMOS), C. Briois (CNRS), M. Combi (UMich), B. Fiethe (TUB), S. Fuselier (SwRI), T.I. Gombosi (UMich), K.C. Hansen (UMich), E. Kopp (UNIBE), A. Korth (MPS), U. Mall (MPS), H. Rème (CNRS), M. Rubin (UNIBE), H. Waite (SwRI), P. Wurz (UNIBE)

Contribution
Operations of the instrument Rosetta ROSINA

Industrial hardware contract(s) to
Contraves (RUAG) Space, APCO, Montena, etc.

Website
space.unibe.ch/research/research_groups/rosina

Purpose of Research

Comets are among the most pristine objects in our solar system. Investigating these bodies, therefore, reveals key information on the bulk material as well as the physical and chemical conditions under which the solar system formed. ESA's Rosetta mission carried out an in-depth study of Jupiter-family comet 67P/Churyumov-Gerasimenko (67P). Rosetta launched on 2 Mar. 2004 with the ROSINA instrument suite, composed of the mass spectrometers, DFMS and RTOF, as well as the neutral gas pressure gauge, COPS. ROSINA continuously measured the abundances of major and minor volatile species in-situ in the coma surrounding the comet's nucleus. Evaluation of ROSINA data is ongoing. Three recently obtained key results are summarised below.

Hänni et al. (2023) identified and characterised a plethora of chain-based, cyclic, and aromatic hydrocarbons with an average composition that resembles material in other solar system reservoirs, such as the soluble organic matter in meteorites. Notable, however, was the absence of polymeric molecules, which were proposed based on low resolution data obtained by the Giotto fly-by at comet 1P/Halley in 1986.

ROSINA measured a number of isotope ratios, including the deuterium-to-hydrogen (D/H) ratio in water. Its elevated ratio shows that comets like 67P are not a major contributor to the water on Earth. Recently, Müller et al. (2022) investigated the D/H in the water throughout the whole comet escort phase and showed that the ratio does not change. This strengthens the notion that the isotope ratio is homogeneous inside the nucleus and independent of the outgassing activity. The same authors also reported elevated D/H ratios in methane, ethane, and propane, the three simplest alkanes, which is in line with other organic molecules found in comets and hints at an inheritance from stages prior to solar system formation.

In a third paper, Rubin et al. (2023) showed that the abundance of highly volatile molecules in the coma of 67P, such as carbon monoxide, methane, and molecular oxygen, can be reproduced by a linear combination of the two dominant gaseous species, water and carbon dioxide. This indicates that high-volatile molecules are predominantly trapped in and co-released with the two main ices. In turn, this also suggests that ice phases dominated by highly volatiles were either never present or lost through thermal processing of the comet's interior as it travelled to the inner solar system.

Past Achievements and Status

ESA's Rosetta mission followed comet 67P for over two years from early August 2014 to the end of September 2016. Among the payload instruments was the ROSINA mass spectrometer suite, dedicated to the measurement of elemental, molecular and isotopic composition of the neutral gas coma, the detection of low energy ions, and the characterisation of the occasional icy dust grain sublimating near or inside one of the ROSINA sensors. All the raw data and higher level data products of ROSINA acquired throughout the active mission are publicly available through ESA's Planetary Science Archive and NASA's Planetary Data System.

Publications

Hänni N et al. (2022) Nat. Comm., 13, 3639

Müller et al. (2022) A&A, 662, A69

Rubin M et al. (2023) Month. Not. R. Astron. Soc., 526, 3, 4209–4233

6.15 MINPA – Mars Ions and Neutral Particles Analyser

Purpose of Research

The Mars Global Remote Sensing Orbiter and Small Rover mission, also known as Tianwen-1 (formerly Huoxing-1), is a mission by China to send a spacecraft to Mars, which consists of an orbiter, a lander and a rover.

Tianwen-1 launched on 23 July 2020, went into Mars orbit on 21 February 2021, and deployed the lander on 14 May 2021. The scientific instruments on the orbiter are:

- Medium Resolution Camera (MRC) with a resolution of 100 m from a 400 km orbit.
- High Resolution Camera (HRC) with a resolution of 2 m from a 400 km orbit.
- Mars Magnetometer (MM).
- Mars Mineral Spectrometer (MMS), to determine mineral composition.
- Orbiter Sub-surface Radar (OSR).
- Mars Ions and Neutral Particles Analyser (MINPA).

The University of Bern (UNIBE) is participating in the MINPA instrument to study the interaction of the solar wind with the Mars atmosphere by measuring the ion and energetic neutral atom (ENA) environment at Mars.

Past Achievements and Status

MINPA combines, for the first time, the capability to record plasma ions as well as ENAs. For the plasma ions, MINPA performs full-sky observations resolved in energy, angle (elevation and azimuth) and species.

For the registration of energetic neutral atoms, charge conversion technology developed by UNIBE is employed, with the ionised particles being analysed with the ion optical system of the ion measurement. MINPA was successfully built and calibrated. First results of solar wind observations have been published, and analysis of the Martian magnetosphere is ongoing.

Publications

Wang L, Li L, Li W et al. (2024) **Characterizing and removing ultra-violet contamination in ion observations on board Tianwen-1**, MDPI Atmosphere 15(1): 19, 17 pp, doi.org/10.3390/atmos15010019

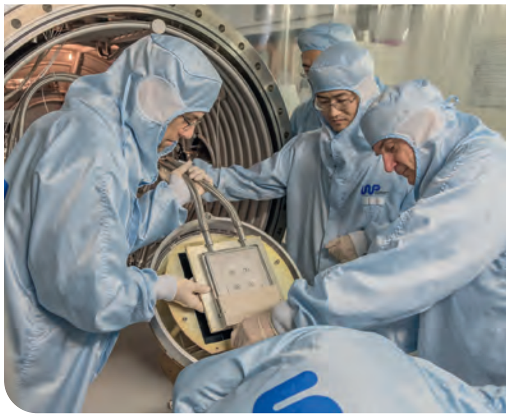
Wurz P (2000) **Detection of Energetic Neutral Particles**, in "The Outer Heliosphere: Beyond the Planets", (eds. K Scherer, H Fichtner, and E Marsch), Copernicus Gesellschaft e.V., Katlenburg-Lindau, Germany, 251–288.

Zhang A-B, Kong L-G, Li W-Y et al. (2022) **Tianwen-1 MINPA observations in the solar wind**, Earth and Planetary Physics 6(1): 1–9, doi.org/10.26464/epp2022014

Abbreviations

ENA	Energetic Neutral Atom
MEFISTO	MEsskammer für Flugzeit-InStrumente u. Time-Of-Flight
MINPA	Mars Ions and Neutral Particles Analyser

Time-Line	From	To
Planning	2017	2018
Construction	2019	2019
Measurement phase	2021	ongoing
Data evaluation	2021	ongoing



Integration of the MINPA flight instrument, for the Chinese Mars Global Remote Sensing Orbiter and Small Rover mission, into the MEFISTO calibration facility for calibration with ions and ENAs.

Institute
Phys. Inst., Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
National Space Science Center, NSSC
Chinese National Space Science Centre, CAS
China

Principal Investigator(s)
A. Zhang (NSSC)

Swiss Principal Investigator(s)
P. Wurz (UNIBE)

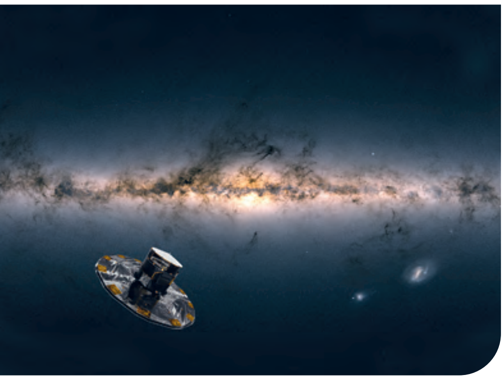
Co-Investigator(s)
A. Galli (UNIBE)

Contribution
Operations of the instrument Mars Ions and Neutral Particles Analyser (MINPA)

Website
en.wikipedia.org/wiki/Tianwen-1

7 Astrophysics

7.1 Gaia – Variability Processing and Analysis



Artist impression of ESA's Gaia satellite observing the Milky Way. The background image of the sky is compiled from data from more than 1.8 billion stars. It shows the total brightness and colour of stars observed by Gaia released as part of Gaia's Early Data Release 3 (Gaia EDR3) in Dec. 2020. Image credits: Spacecraft: ESA/ATG medialab; Milky Way: ESA/Gaia/DPAC.

Institute
Dept. Astronomy, Univ. Geneva (UNIGE), Versoix, Switzerland

In cooperation with
17 Institutes in Europe, USA and Israel (80 people)

Principal Investigator(s)
ESA

Swiss Principal Investigator(s)
L. Eyer (UNIGE)

Co-Investigator(s)
M. Audard, C. Chaudet, N. Chornay, B. Holl, G. Jevardat, D. Krefl, N. Mowlavi, K. Nienartowicz, L. Rimoldini (UNIGE, SixSq, Sednai Sàrl)

Industrial contract to
Sednai Sàrl

Website
esa.int/Science_Exploration/Space_Science/Gaia

Purpose of Research

The Gaia project, a cornerstone mission of the European Space Agency (ESA), conducts a comprehensive and unprecedented multi-epoch astrometric, photometric, and spectroscopic survey of more than 2 billion celestial sources: stars of the Milky way and beyond, asteroids, quasars and galaxies, up to a brightness of 20.7 mag. This mission has no equivalent in any other of the major space agencies.

Gaia's achievements are remarkable. Its data utilisation by the scientific community is setting new benchmarks. Not only does it hold the distinction of being the ESA mission with the highest data utilisation, but it also leads in citations across all domains of astrophysics!

Part of the mandate of the Gaia consortium involves detecting and analysing variable celestial objects. This task, overseen by approximately 80 experts from 17 institutes, is orchestrated by the University of Geneva and its affiliated Data Processing Center in Geneva. Our primary aim is to statistically characterise the time-series data of the two billion sources, discerning and categorizing them based on various types of variability.

Furthermore, we conduct detailed analyses on sources displaying specific variability types to unravel their astrophysical properties. Gaia data is made accessible to the public through successive Gaia data releases. Currently, our focus is on the fourth Gaia data release, scheduled for 2026, for which we are channelling all our efforts. Additionally, preparations are underway for the subsequent fifth data release.

Past Achievements and Status

In 2023, the articles of the third Gaia data release were published. Out of 41 articles published from the entire Gaia consortium, the University of Geneva had significant contributions in 21 articles of which we led/coordinated 15 articles.

We were also instrumental in driving the release of the Focused Product, which included the publication of radial velocities of Long Period Variables. This release can be seen as a preview for the fourth data release. Notably, this dataset represents the largest collection of such stars to date, setting a new record.

We are currently deeply engaged in the preparation of the fourth data release. This involves the software developments to incorporate new data types, such as astrometric time-series, the implementation of additional processing functionalities, and the inclusion of new types of variability. While the third data release shattered several records in the Time Domain Astrophysics, the upcoming fourth release is poised to be another significant milestone in the field of astronomy.

The Gaia Geneva team (Sednai Sàrl and the University of Geneva) applied for and is leading the application pilots' effort of the EU Horizon 2022 European Processor Initiative (Aero project) in the scope of HPC and Big

Time-Line	From	To
Planning	2002	2030
Construction	cyclic dev.	up to 2031
Measurement phase	2014	2025
Data evaluation	cyclic	up to 2032

Data analysis. The Geneva team is part of the consortium of 11 European entities that enable European industry and academia to create a full stack hardware and software ecosystem based on European-designed chips and to enable seamless hardware acceleration for scientific algorithms and big data analysis in parallel databases. This work will already be used for Data Release 4.

The pioneering citizen science project centered on Gaia data is dedicated to the classification of light curves. This ESA-funded initiative, conducted in close collaboration with the Geneva team (comprising Sednai Sàrl and the University of Geneva), serves two primary objectives: first, to enhance the results for DR4, and second, to raise awareness of the Gaia mission among a broader audience. In both respects, this project has been a resounding success with over 200,000 classifications performed by citizen scientists from all around the world.

The University of Geneva created and is leading the Gaia black hole task force. This task force brings together diverse and unique expertise from members of the Gaia consortium, in order to maximise Gaia's impact on this crucial topic.

Abbreviations

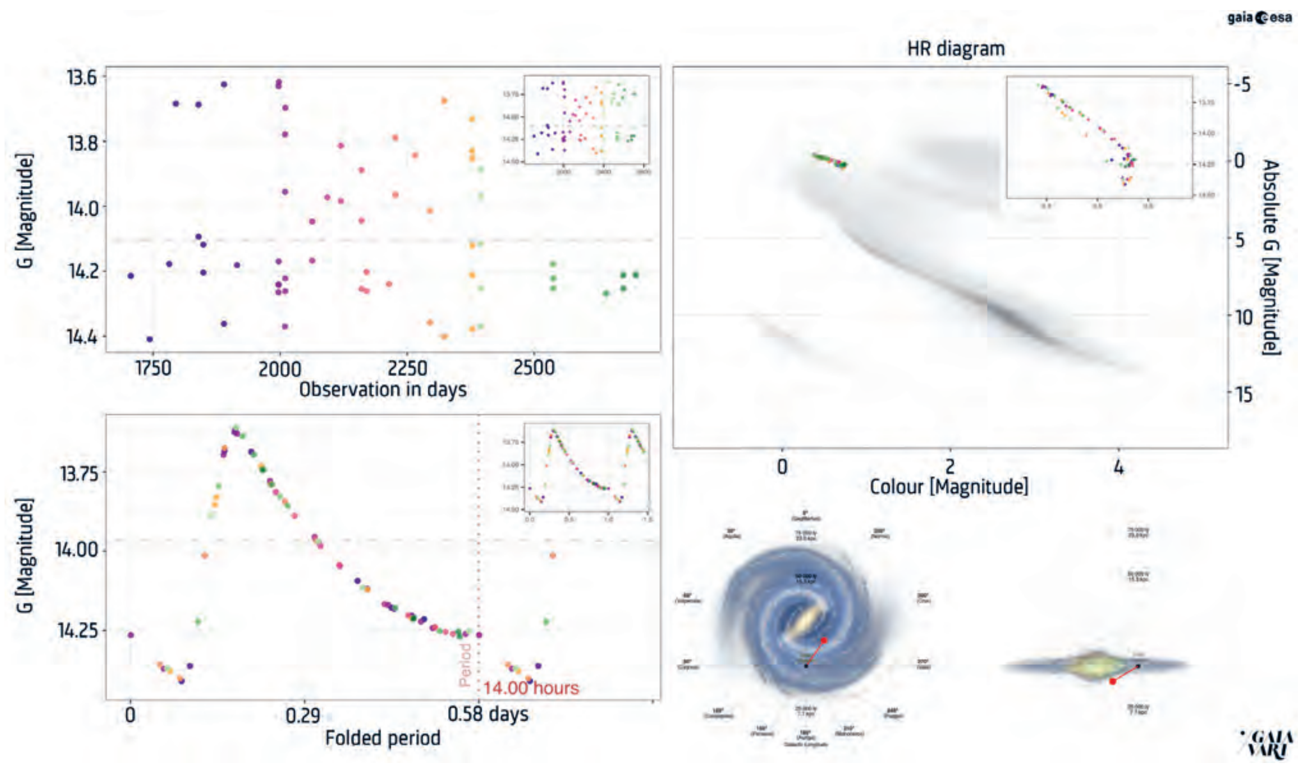
DR4 Gaia Data Release 4 (2026)

Publications

Eyer L, Audard M, Holl B et al. (2023) **Gaia Data Release 3. Summary of the variability processing and analysis**, A&A 674: 13.

Gaia Collaboration, Trabucchi M, Mowlavi N, Lebzelter T et al. (2024) A&A 682: 88.

Rimoldini L, Holl B, Gavras P et al. (2023) **Gaia Data Release 3. All-sky classification of 12.4 million variable sources into 25 classes**, A&A 674: 14.



Citizen scientists classify the variable stars based on several factors, including the light curve, folded curve with an estimated period, position and shape in the Hertzsprung-Russell diagram, as well as the location within the Milky Way.

7.2 The Swiss Contribution to Euclid

Euclid moments before it was encapsulated in a SpaceX Falcon 9 fairing. Image credits: SpaceX/ESA.

Institute
École Poly. Fédérale de Lausanne (EPFL)
Fachhochschule Nordwestschweiz (FHNW)
Univ. Geneva, (UNIGE); Univ. Zurich, (UNIZH)
Switzerland

In cooperation with
ESA and ~100 European institutes, NASA
>1000 astronomers and engineers worldwide

Principal Investigator(s)
Y. Mellier, Inst. d'Astrophys. de Paris, Paris, France

Co-Investigator(s)
F. Courbin (EPFL), M. Melchior (FHNW)
S. Paltani (UNIGE), R. Teyssier (UNIZH)

Contribution
Development and construction of the Readout Shutter Unit of the VIS instr. Development of algorithms for photometric redshifts, and strong lensing. Development of infrastructure and processing software.

Industrial Hardware Contract to
APCO Technologies SA

Website
esa.int/Science_Exploration/Space_Science/Euclid

Purpose of Research

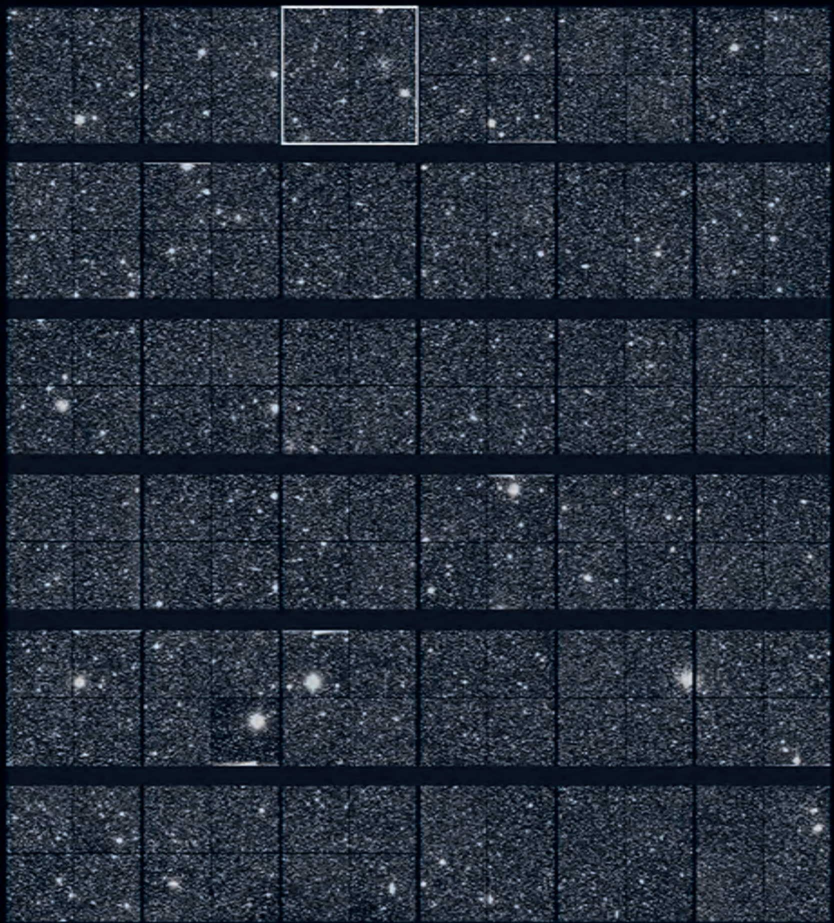
Euclid is the second Medium-Class mission of the ESA Cosmic Vision 2015 – 2025 programme and is designed to understand the origin and evolution of the Universe by investigating the nature of its most mysterious components: dark energy and dark matter, and by testing the nature of gravity. Euclid will achieve its scientific goal by combining two main cosmological probes, and several secondary ones. The weak gravitational lensing is the study of the very tiny deformations in the images of distant galaxies due to the distribution of dark matter along the line of sight that acts as optical lenses. Baryonic acoustic oscillations is the study of the imprint of the gravitational collapse of the first structures in the spatial distribution of galaxies. Both probes are sensitive to the detailed energy content of the Universe, which consists of about 70% dark energy and about 25% dark matter, two components whose nature is largely unknown.

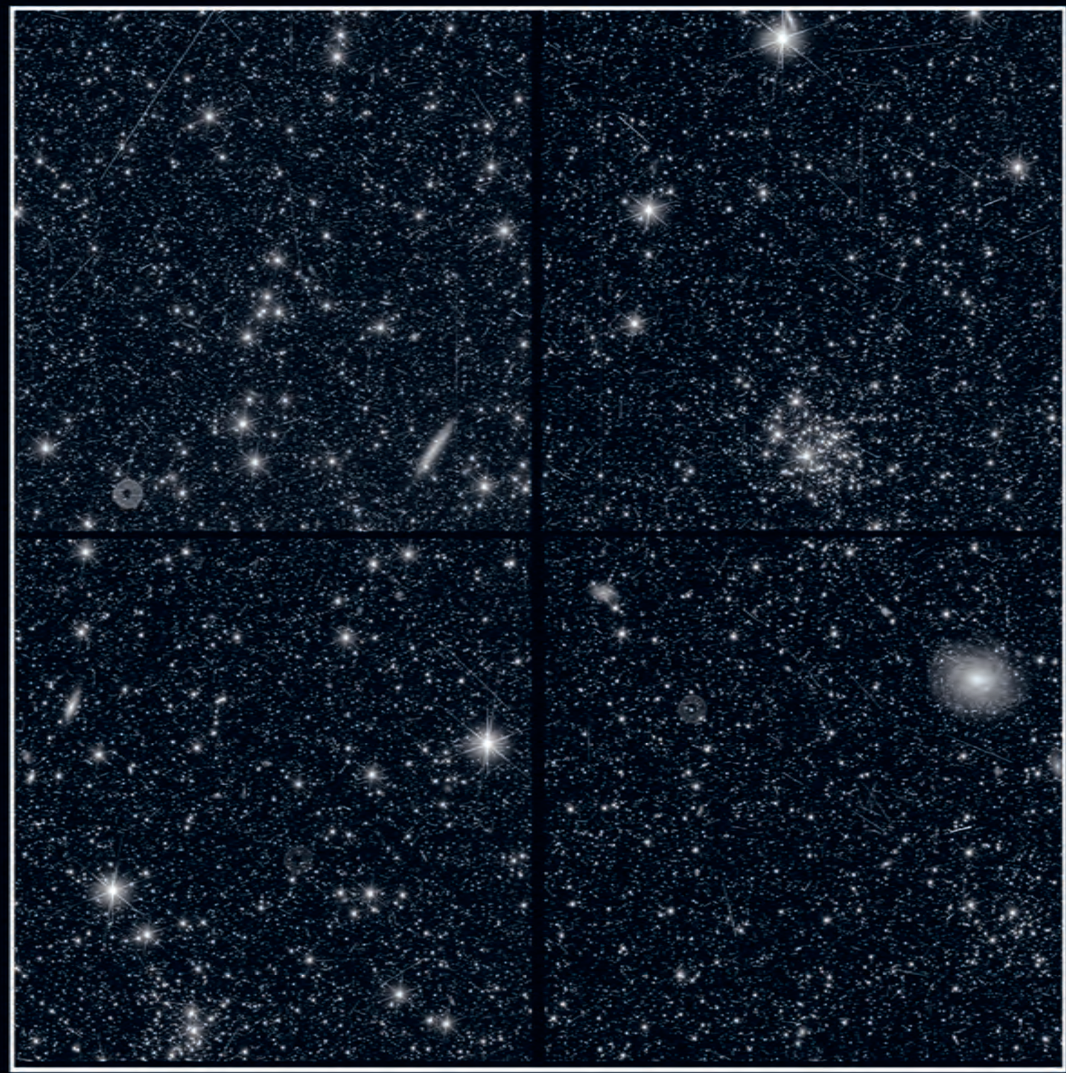
The Euclid payload consists of a 1.2 m Korsch telescope designed to provide a large field-of-view. The Euclid survey will cover 14,000 deg^2, i.e. a third of the sky, with its two instruments. The VISual imager (VIS) is a matrix of 6 × 6 CCDs providing a diffraction-limited spatial resolution (about 0.15") over a large field of 0.25 deg^2, equivalent to about 100 times the field-of-view of the Hubble or the James Webb space telescopes. The Near-Infrared Spectrometer Photometer instrument (NISP) is a matrix of 4 x 4 near-infrared detectors. NISP can be used as a photometer in three bands between 1 and 2 µm. Gratings can be placed in the optical beam in order to transform it into a slitless spectrometer.

Switzerland, under the lead of the University of Geneva (UNIGE), plays an important role in Euclid, with participation at all levels, from the science definition, to the building of space hardware, the development of analysis algorithms, the participation in the data processing and the science exploitation. Several Swiss institutes are strongly involved in Euclid: EPFL, FHNW, UNIGE and UZH. On the science level, EPFL (strong lensing), UNIGE (theory) and UZH (cosmological simulations) are co-coordinating the respective Science Working Groups. On the software and algorithm level, EPFL coordinates the development of algorithms for the detection of strong gravitational lenses. FHNW contributes an important component of the data processing infrastructure called the Infrastructure Abstraction Layer (IAL), which integrates the different Euclid data centers into a uniform processing environment under a central orchestrator. UNIGE is in charge of the development of algorithms and software for the determination of photometric redshifts for the Euclid Pipeline, which is a central component of the weak-lensing science probe. UNIGE also hosts the Swiss Euclid Science Data Center and is in charge of the implementation of the algorithms for the determination of the photometric redshifts and for the detection of strong lenses. The Swiss Euclid Science Data Center also participates in the processing of the Euclid data as one of the ten distributed Euclid data centers. The global data processing effort is huge, with an expected need of about 20,000 cores and several tens of petabytes of storage. The Euclid data center in Geneva already hosts about 1200 cores and 1 petabyte.

UNIGE was responsible for the development of the Readout Shutter Unit (RSU), a very high-reliability mechanism for the VIS instrument, whose goal is to block the optical beam during the readout of the CCDs. It is a very complex mechanism that needs to be operated at cold temperatures (about 140

EARLY COMMISSIONING TEST IMAGE, VIS INSTRUMENT





First released image from Euclid's VISible instrument (VIS). The image is essentially unprocessed, and shows artefacts such as cosmic rays and ghosts that are removed during image processing. Image credits: ESA/Euclid/Euclid Consortium/NASA

K); it must not export any momentum, and has very stringent micro-vibration requirements. In addition, it should be able to open and close approximately 350,000 times. The RSU was initially designed by UNIGE. In Phase C/D, the responsibility was transferred to APCO Technologies, that finalised the design, manufactured the unit, and performed the qualification and testing.

Past Achievements and Status

Euclid was launched on 1 July 2023, from Cape Canaveral on a Falcon 9 rocket from SpaceX, and was successfully injected into a halo orbit around L2. Commissioning started soon after, and both the VIS and NISP instruments were found to be working nominally. In particular, the VIS RSU, which plays a crucial role in obtaining high-quality images from the VIS instrument, was operated successfully at the very beginning of the commissioning, and has been in continuous operations since then. The first engineering images from VIS were publicly released on 31 July 2023, demonstrating unprecedented image quality over such a large field-of-view of a quarter of a square degree, which is larger than the moon.

The spacecraft has suffered from several anomalies. Very weak stray-light contamination was found, depending on the solar aspect angle of the spacecraft. Despite this weakness, and because of the very high sensitivity of Euclid, stray-light has affected image quality to an unacceptable degree. This is mitigated in operations by setting a constraint on the solar aspect angle to those angles where stray-light is negligible, with the only impact being a moderate increase in the mission duration. The VIS CCD detectors are sensitive to X-rays, and, in the case of solar flares, images show the X-rayed structure of the solar panels, and have to be discarded in the presence of strong solar flares. Finally, the very stringent requirements on pointing stability could not be met. In particular, the Fine Guidance System responsible for the tracking of stars in order to maintain a very precise attitude, seemed to be disoriented by occasional cosmic rays in the star tracker images. This has been resolved by a software patch, and adequate pointing stability is now achieved for 99% of the pointings.

The first science images, the Euclid Early Release Observations, were released on 6 November 2023. They consist of six targets, highlighting the imaging capabilities of both the VIS and NISP instruments. These are currently being used by the Euclid Consortium for scientific exploitation, and the data will be fully released to the public in May 2024.

Euclid started its nominal science operations on 14 February 2024, and has already acquired 1% of its planned survey of 14,000 deg^2. On 15 February, the first tiles of the nominal surveys were sent to the Swiss Euclid Science Data Centers and processed successfully.

Over the last two years, most efforts in Switzerland have revolved around the development and tuning of the IAL, the infrastructure software making the interface between the HPC in the ten different data centers and the central orchestrator, and around the finalisation of the Swiss components of the Euclid Pipeline. The main contribution is the photometric-redshift pipeline for the main science developed at UNIGE. It consists of a set of pipelines to perform source classification, determine galaxy photometric redshifts, and reconstruct star and galaxy spectral energy distributions. On the formal side, all components went through the last review before the start of the nominal scientific operations, the Mission Commissioning Results Review, which took place in November 2023, and was successfully completed in February 2024. After the start of the Performance Verification phase, data started being processed and software anomalies were quickly discovered and addressed. Improvements are being planned in view of the reprocessing that is going to start after May 2024. A first 'quick' public data release of 50 deg^2 is planned for March 2025, while the first data release of 1500 deg^2 will take place in June 2026.

Publications

Euclid Collaboration: Desprez G, Paltani S et al. (2020) **Euclid preparation. X. The Euclid photometric-redshift challenge**, Astron. Astrophys. 644: A31.

Larchevêque C et al. (2017) **The EUCLID VIS read-out shutter unit: a low disturbance mechanism at cryogenic temperature**, 17th European Space Mech. & Tribology Symp., arXiv: 1801.07496.

Laureijs R et al. (2011) **Euclid Definition Study Report**, Euclid Red Book, ESA/SRE(2011)12, eprint arXiv: 1110.3193.

Abbreviations

IAL	Infrastructure Abstraction Layer
NISP	Near-Infrared Spectrometer Photometer instrument
RSU	Read-out Shutter Unit
VIS	Visible Imager

Time-Line	From	To
Planning		2012
Construction	2012	2021 (HW)/ 2023 (SW)
Measurement phase	2023	2029
Data evaluation	2023	2032

7.3 PLATO Mission – The Mechanical Structure of the Telescope Optical Unit

Purpose of Research

The PLAnetary Transits and Oscillations of stars (PLATO) is the third medium-class mission in ESA's Cosmic Vision programme. Its objective is to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. PLATO has also been designed to investigate seismic activity in stars, enabling the precise characterisation of the planet host star, including its age. PLATO will assemble the first catalogue of confirmed and characterised planets with known mean densities, compositions, and evolutionary ages/stages, including planets in the habitable zone of their host stars.

Past Achievements and Status

PLATO has been given the green light to continue with its development after the Critical Milestone Review concluded successfully on 11 January 2022. The review verified the maturity of the complete space segment (spacecraft platform and payload module), confirming the solidity of the spacecraft-to-payload interfaces, the payload schedule with particular focus on the series production of the 26 cameras, and the robustness of the spacecraft schedule. After launch, currently planned for the end of 2026, PLATO will travel to the Lagrange point 2. From this point, the PLATO Payload will analyse the photometric signal stability of stars to detect Earth-like planets in an unprecedented field-of-view of 2200 deg^2. The requirement of photometric stability is a key technical challenge. UniBern is responsible for the thermal and structural design of the Telescope Optical Unit (TOU), as well as for the manufacturing of its mechanical structure, which are key elements for the stability of the observation with outstanding structural and thermo-optical performances.

UniBern has made a substantial contribution to the engineering of the Telescope Optical Unit (TOU) and has designed a stable opto-mechanical structure, capable of withstanding the ground, launch and orbital life environments with a budget of micronic stability on the six lenses that compose the telescope. The mechanical design was fully qualified on the TOU STM at Univ. of Bern (UNIBE) in Feb. 2020. The detailed definition and procurement specification of the telescope structural parts were realised at UNIBE, while the manufacturing was subcontracted to a cluster of partners from Swiss and German industry. The production of the TOU mechanical structure parts for the Flight Models started in mid-2020 and was finished, with all hardware delivered to Italy, by the end of 2023. This hardware project ended with this delivery. Milestones included:

- June 2017. Adoption at the Science Program committee (ESA).
- 2020 Delivery of 26 MTD (Mass and Thermal Dummy) to OHB Munich.
- 2020 Payload PDR cycle, TOU STM Test Campaigns.
- 2021 Payload CDR cycle, Camera EM testing.
- 2022 PLATO Critical Milestone Review (CMR).
- 2020-2023: Delivery of 33 complete TOU mechanical structures and spares to INAF/Leonardo, Italy.

Publications

Rauer H (2014) **The Plato 2.0 mission,** Experimental Astronomy 38: 249.

Time-Line	From	To
Planning	2017	open
Construction	2020	end 2025
Measurement phase	2027	open
Data evaluation	2027	open

The Plato STM with its 26 telescopes (24 + 2) on the QUAD shaker at ESA/ESTEC. The Spacecraft is undergoing vibration tests to simulate launch conditions.

Institute
Div. Space & Planetology, Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
Plato Consortium

Principal Investigator(s)
H. Rauer, DLR Berlin, Berlin, Germany

Swiss Principal Investigator(s)
W. Benz (UNIBE)

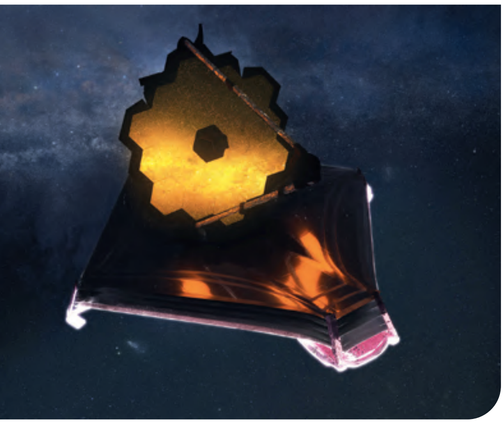
Contribution
Development & construction of the PLATO Telescope Optical Unit (TOU) Structure

Industrial Hardware Contract to
MECHA AG, EMPA, Collini AG, DISTEC AG, Switzerland
Rigo GmbH & Co. KG, Germany

Website
esa.int/Science_Exploration/Space_Science/Plato

ASTROPHYSICS

7.4 MIRI – Mid-Infrared Instrument for the James Webb Space Telescope



Artist's impression of the James Webb Space Telescope. Image credit: NASA.

Institute
ETH Zurich, Zurich, Switzerland

In cooperation with
MIRI European Consortium
ESA, NASA

Principal Investigator(s)
G. Wright (UK ATC)

Swiss Principal Investigator(s)
M. Güdel (Univ. Vienna/ETH Zurich)

Co-Investigator(s)
A. Glauser (ETH Zurich)
S. Lilly (ETH Zurich)

Contribution
Cryogenic Mechanisms and Cryoharness. Calibration, pipeline development and commissioning of the Medium Resolution Spectrometer (MRS) of MIRI

Industrial Hardware Contract to
RUAG Space, Switzerland
Syderal Swiss SA, Switzerland

Websites
esa.int/Science_Exploration/Space_Science/Webb

Purpose of Research

The James Webb Space Telescope (JWST, or Webb) is the current flagship of modern Astronomy. Undoubtedly, JWST has already revolutionised many fields in Astronomy and much more can be expected in the near future. JWST has a 6.5 m deployable primary mirror that is passively cooled to 45 K behind a very large sun shield in order to provide unprecedented sensitivity for the 0.6 - 28 µm wavelength range. The four science instruments include cameras and spectrographs, providing a large set of observational capabilities. The Mid-Infrared Instrument (MIRI) is the only instrument on JWST that operates in the mid-infrared range between 5 and 28 µm. MIRI provides imaging, coronagraphy, long-slit low-resolution spectroscopy and mid-resolution integral field spectroscopy. The JWST is exceptionally powerful for the study of the very first galaxies seen at $z > 10$ and their evolution until the present, it studies complex processes in star and planet formation and provides indicators in the search for the origins of life.

Past Achievements and Status

The Swiss hardware contribution was developed at the Paul Scherrer Institute in collaboration with the industrial partners, RUAG Space (now Beyond Gravity) and Syderal Swiss SA. The hardware contribution consists of a cryogenic mechanism operating at 7 K and the non-isothermal cabling of the instrument that was optimised for minimum thermal conductivity. The flight hardware was successfully tested and delivered in 2008. After delivery, the Swiss project was moved to ETH Zurich to guarantee continuation of the required post-delivery support.

MIRI was integrated and cryogenically tested in 2011. The instrument was then formally delivered to NASA in 2012, integrated and tested over an extensive period between 2013 and 2017. The Swiss Team continued its involvement during all these phases by providing on-site support in the test control rooms, leading aspects of the calibration of MIRI, and preparation for the in-orbit commissioning.

JWST was launched on 25 Dec. 2021 by an Ariane V launcher from French Guiana, then successfully deployed and transferred to its orbit around L2. After cool-down, its science instruments were commissioned before the routine science operation started in June 2022. The Swiss team was part of the Mission Operation Center at the Space Telescope Science Institute in Baltimore and supported the instrument commissioning on-site over several months. This included the MIRI calibration.

Publications

Gardner J et al. (2023) **The James Webb Space Telescope Mission**, PASP 135.

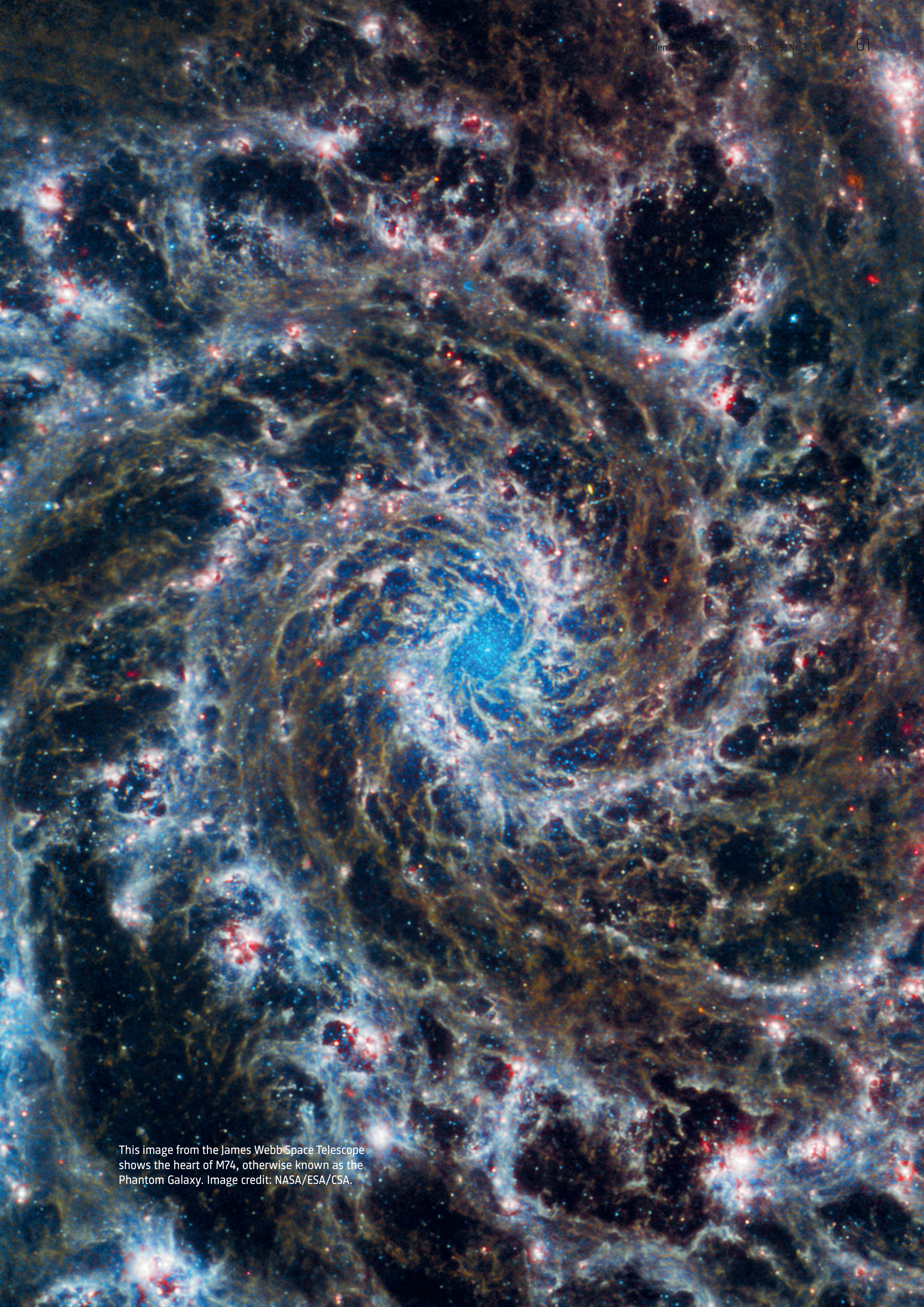
Patapis P et al. (2024) **Geometric distortion and astrometric calibration of the JWST MIRI Medium Resolution Spectrometer**, A&A 682.

Wright GS et al (2023) **The Mid-Infrared Instrument for the James Webb Space Telescope and its in-flight performance**, PASP, 135.

Abbreviations

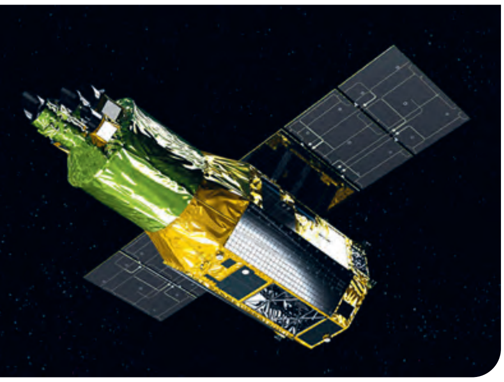
JWST James Webb Space Telescope
MIRI Mid-Infrared Instrument

Time-Line	From	To
Planning	2001	2021
Construction	2006	2021
Measurement phase	2022	2032
Data evaluation	2022	2032



This image from the James Webb Space Telescope shows the heart of M74, otherwise known as the Phantom Galaxy. Image credit: NASA/ESA/CSA.

7.5 The Swiss Contribution to XRISM



Artist's impression of the XRISM spacecraft. Image credit: JAXA.

Institute
Dept. Astronomy, Univ. Geneva (UNIGE)
Versoix, Switzerland

In cooperation with
Netherlands Institute for Space Research (SRON)
European Space Agency (ESA)

Principal Investigator(s)
Japan Aerospace Exploration Agency (JAXA)

Swiss Principal Investigator(s)
S. Paltani (UNIGE)

Contribution
Manufacture of the filter wheel mechanism and filter wheel electronics.

Industrial Contracts to
Ruag Space AG
Syderal Swiss SA

Website
astro.unige.ch/xrism

Purpose of Research

The X-Ray Imaging Spectroscopy Mission (XRISM) is a mission of the Japan Aerospace Exploration Agency (JAXA) planned to recover the most ambitious scientific objectives of the Hitomi mission, which was successfully launched on 17 February 2016, but experienced a failure after six weeks in operation. In spite of its extremely short life, Hitomi has been incredibly successful, thanks to its new-generation Soft X-ray Spectrometer (SXS) instrument. Among a handful of scientific observations, the observation of the Perseus galaxy cluster resulted in two major discoveries published in the journal Nature.

XRISM is an essential mission for high-energy astrophysics, between the current generation of facilities with XMM-Newton, INTEGRAL, Chandra and Suzaku, and Athena, the future Large Mission of ESA's Cosmic Vision programme dedicated to the study of the hot and energetic Universe. The main science goals of XRISM is the study of the dynamics of the hot gas in galaxy clusters and of the matter around super-massive black holes.

The University of Geneva (UNIGE) is participating in the XRISM mission together with the Dutch space research institute, SRON, by developing a filter wheel for the SXS; a rebuild of the Swiss contribution to Hitomi has been prepared for the Resolve spectrometer on XRISM. Like the SXS, Resolve uses a cryogenic silicon detector working at 50 mK, aiming to provide outstanding energy resolution (about 4 eV) in the 0.3 - 10 keV energy range, while preserving some imaging capabilities and high throughput. The purpose of the filter wheel is to select different optical elements, either to reduce the X-ray count rate or the optical load on the detector, as well as to protect the detector from micro-meteorites. It also supports and commands active X-ray calibration sources, which are provided by SRON, and assembled on top of the filter wheel. The Resolve instrument is complemented with the Xtend instrument, a wide-field imager based on CCDs.

The Filter Wheel consists of two separate units: the Filter Wheel Electronics (FWE) and the Filter Wheel Mechanism (FWM). For Hitomi, the control and power electronics module, the FWE, has been designed by industry and assembled and qualified by UNIGE. The filter wheel mechanism (FWM) has been built and qualified by Ruag Space. The Filter Wheel sub-system also includes modulated calibration X-ray sources (MXS) developed by SRON. The MXS and its associated high-voltage power supplies have been integrated on the FWM by SRON.

Past Achievements and Status

The rebuild of the FWE and FWM sub-systems for the Resolve instrument onboard XRISM was successfully completed by the Swiss companies Syderal Swiss and Ruag Space, respectively, and the sub-systems were delivered to SRON for integration with the calibration sub-system in 2019. The UNIGE team supported the integration and calibration activities in Japan.

XRISM was successfully launched on 7 September 2023 from Tanegashima Space Center in Japan with the H-IIA 202 rocket. The Performance Verification (PV) phase started on 8 February. All instruments are currently nominal. However, the gate valve, a door protecting the entrance of the dewar of Resolve, has not opened. This anomaly unfortunately restricts the science activities of XRISM, as low-energy X-ray photons are fully blocked by the door. However, the science activities relying on high-energy photons (mostly associated with atomic transitions of neutral and ionised iron) are essentially unaffected. Further attempts to open the door will be performed.

The most promising sources will be observed during the PV phase and analysed by the XRISM Science Team. The team at UNIGE is in charge of or involved in the scientific analysis of several of them, including stars, galaxy clusters, Seyfert galaxies and blazars.

Publications

Tashiro M et al. (2020), **Status of x-ray imaging and spectroscopy mission (XRISM)**, Proc. SPIE 1444: id. 1144422.

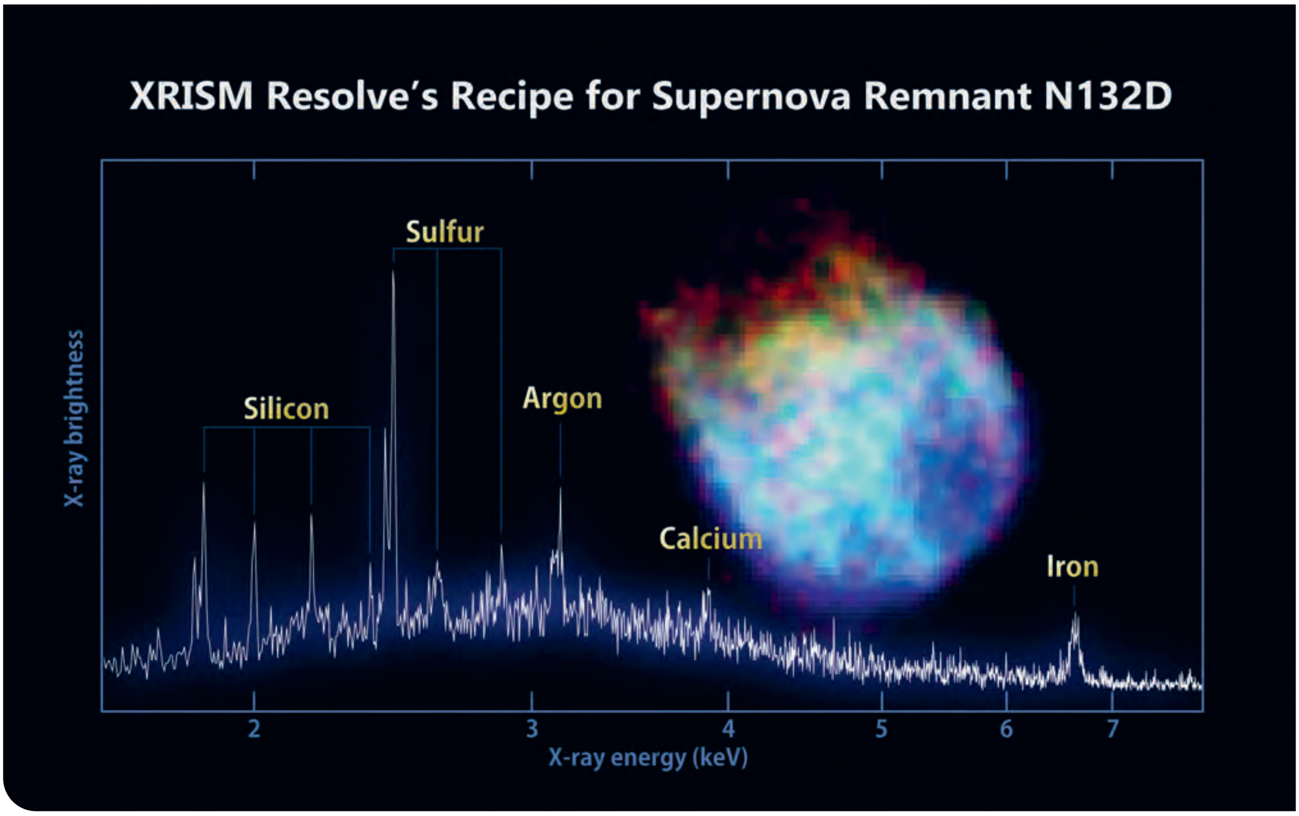
The Hitomi Collaboration (2016) **The quiescent intracluster medium in the core of the Perseus cluster**, Nature 535: 117.

The Hitomi Collaboration (2017) **Solar abundance ratios of the iron-peak elements in the Perseus cluster**, Nature 551: 478.

Time-Line	From	To
Planning	2017	2017
Construction	2018	2019
Measurement phase	2023	2028
Data evaluation	2023	2033

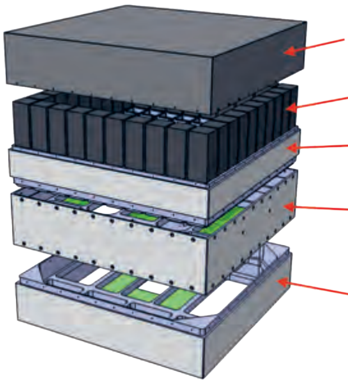
Abbreviations

FWE	Filter Wheel Electronics
FWM	Filter Wheel Mechanism
JAXA	Japanese Aerospace Exploration Agency
MXS	Modulated X-ray Sources
PV	Performance Verification
SRON	Netherlands Institute for Space Research
SXS	Soft X-ray Spectrometer
XRISM	X-Ray Imaging Spectroscopy Mission



XRISM's first-light observations of the supernova remnant N132D in the Large Magellanic Cloud. The Resolve spectrum reveals the presence of silicon, sulphur, argon, calcium, and iron. The inset is an image of N132D captured by XRISM's Xtend instrument (Image credits: JAXA/NASA/ESA).

7.6 POLAR-2



Exploded view of the POLAR-2 instrument.

Institute
Dept. Nucl. Part. Phys. (DPNC), Univ. Geneva, Geneva, Switzerland

Dept. Astronomy (DA), Univ. Geneva, Geneva, Switzerland

In cooperation with
Max Planck Inst. Extraterr. Physics (MPE), Germany
Nuclear Research Institute of Poland (NCBJ), Warsaw, Poland
Inst. High Energy Physics (IHEP), Beijing, China

Principal/Swiss Investigator(s)
Xin Wu (DPNC)

Co-Investigator(s)
M. Kole (DPNC)
N. Produit (DA)

Industrial hardware contract(s) to
Hybrid SA
Composite Design SARL

Website
unige.ch/dpnc/fr/groups/xin-wu/experiences/polar-2

Purpose of Research

The POLAR-2 project is a follow-up of the successful POLAR project, which collected data for six months on the Tiangong-2 Spacelab. The aim of POLAR was to perform the most detailed polarisation measurements of Gamma-Ray Bursts (GRB) in order to answer fundamental questions regarding their origin.

Results from POLAR, published in the Nature Astronomy journal, indicated an overall low polarisation as well as an unexpected complexity in the time evolution of the polarisation during a GRB. These results indicate that time-domain measurements with a significantly improved precision are required in the future. In addition, with the recent discovery of gravitational waves and their connection to GRBs, a new era in multi-messenger astrophysics has started. This major advance in the field together with the discoveries made by POLAR, warrant a high precision GRB polarimeter capable of providing both high precision polarisation measurements as well as detecting very weak GRBs.

An international collaboration, led by the DPNC group and consisting of leading members of the POLAR collaboration and new members from the Max Planck Institute for Extraterrestrial Physics (MPE), proposed the POLAR-2 instrument with the required capabilities based on recent advances in the field.

POLAR-2 is foreseen to answer several fundamental questions regarding the origin of GRBs by performing polarisation measurements for two years. Furthermore, as the most sensitive instrument in its energy range, POLAR-2 will be capable of detecting weak GRBs. It will therefore play an important role in multi-messenger astrophysics and will be capable of issuing alerts with position information for transient events to other instruments, thereby increasing the scientific potential of both POLAR-2 and other instruments.

Past Achievements and Status

The POLAR-2 instrument was selected in 2019 in the framework of the Call for Experiments onboard the China Space Station (CSS), issued by the UN Office for Outer Space Affairs (UNOOSA) and China's Manned Space Agency (CMSA), and is expected to be launched in 2027.

The Swiss contribution to the POLAR-2 payload development is supported by the Swiss Space Office through the ESA PRODEX programme. The prototyping stage has been completed and the project is now entering the next phase, the production stage.

A complete prototype of the Detector Module (DM) was produced and tested for its scientific performance at the European Synchroton Research Facility (ESRF) in 2023, which has matched the design requirements. A module prototype has also successfully undergone shock and vibration tests, as well as thermal vacuum tests using facilities at the MPE. Several radiation campaigns were performed at the proton radiotherapy facility at the Institute of Nuclear Physics Polish Academy of Sciences in Krakow, Poland. The results showed that it will be possible to maintain the scientific performance of POLAR-2 for up to 10 years in space.

Publications

De Angelis N et al. (2023) Nucl. Instr. and Meth A1048: 167934.

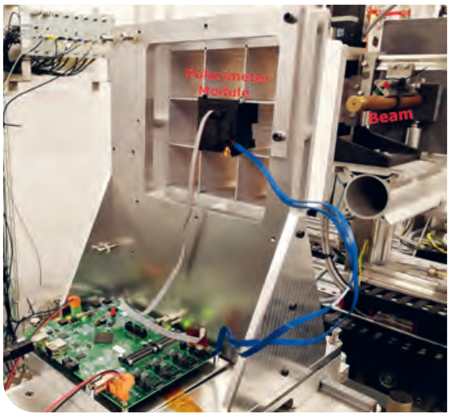
Produit N et al. (2023) PoS, ICRC2023: 55.

Zhang SN, Kole M et al. (2019) Nature Astronomy 3 (3): 258–264.

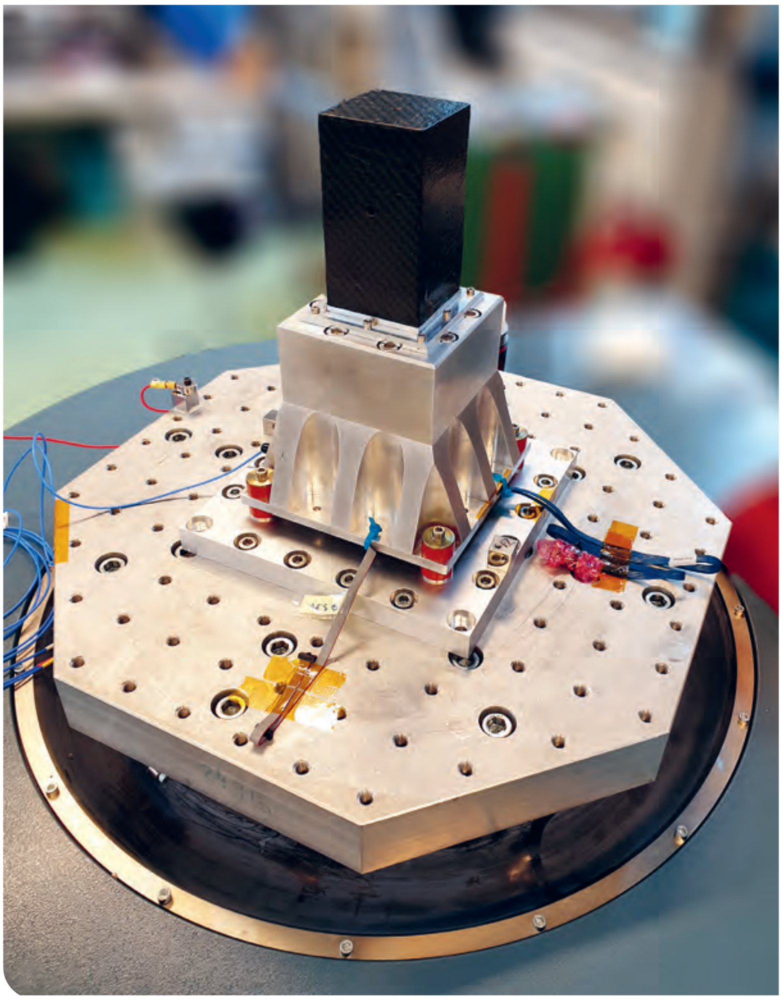
Abbreviations

GRB Gamma-Ray Bursts

Time-Line	From	To
Planning	2018	2019
Construction	2020	2026
Measurement phase	2027	>2029
Data evaluation	2027	>2029



The test setup of a single POLAR-2 module in the ESRF photon beamline.



A POLAR-2 module undergoing vibration tests.

7.7 The Gravitational Reference Sensor Front-End Electronics on LISA

LISA Mission logo. Image credit: ESA.

Institute
Inst. Geophysics, ETH Zurich
Zurich, Switzerland
Physics Inst., Univ. Zurich (UNIZH),
Zurich, Switzerland

In cooperation with
ESA
Univ. Trento, Italy
Albert Einstein Inst., Max Planck Inst. for Gravitational Physics, Germany

Principal Investigator(s)
Karsten Danzmann (Albert Einstein Institute)

Swiss Principal Investigator(s)
D. Giardini (ETH Zurich)

Co-Investigator(s)
P. Jetzer (UNIZH), L. Ferraioli (ETH Zurich)

Contribution
Development & construction of the Gravitational Reference Sensor Front-End Electronics (GRS FEE) for the LISA mission.

Industrial hardware contract to
Thales Alenia Space Switzerland

Website
lisamission.org

Purpose of Research

The Laser Interferometer Space Antenna (LISA) will be the first ever space based gravitational waves observatory. LISA is aiming to detect gravitational waves emitted by sources located in the whole Universe, enhancing our knowledge about the beginning, evolution and structure of our Universe. The observatory will provide highly accurate tests of the theory of general relativity and will potentially uncover hints about the nature of quantum gravity.

LISA is the largest and most complex mission ever undertaken by ESA, with support from NASA. It also marks the largest participation by Switzerland in a scientific space mission to date. The LISA constellation consists of three identical spacecraft forming an equilateral triangle in a heliocentric orbit following the Earth and maintaining a mutual spacecraft-to-spacecraft distance of 2.5 million km. The Gravitational Reference Sensor (GRS) is the core of the LISA instrument. It hosts the test masses that are the free-falling reference for the measurement of the gravitational waves.

The LISA GRS Front-end Electronics (FEE) is the Swiss Contribution to LISA. It provides the sensing and control electronics for the GRS, which is critical for the achievement of the GRS and LISA performances. The GRS FEE is based on amplitude modulated capacitive sensing and audio-frequency actuation. It has both High Resolution and Wide Range modes, offering, respectively, science mode operation with small displacements (up to 100 µm) and small actuation forces (several nN) and a test mass acquisition/accelerometer mode with 'wall-to-wall' sensing (4 mm) and larger (µN) forces. The sensing and actuation for the LISA GRS requires ultra-stable performances in the low-frequency band from 1 Hz down to 100 µHz.

Past Achievements and Status

The LISA GRS FEE is the Swiss Contribution to the LISA mission and it is currently in Phase B1 of the instrument development (2022–2024). ETH Zurich and Thales Alenia Space Switzerland are consolidating the instrument requirement specifications, developing the design concept and completing an elegant breadboard unit to verify the critical performances and to consolidate the critical design items.

The LISA mission phase A was successfully completed in 2021. During phase A, the LISA mission passed two important reviews; the Mission Consolidation Review in 2019 and the Mission Formulation Review (MFR) at the end of 2021. The mission Phase B kicked-off in Spring 2022. In June 2023, the LISA instrument successfully passed the Instrument System Requirements Review (ISRR) performed by ESA. The ISRR paved the way to a successful Mission Adoption Review in Fall 2023. The LISA mission was finally adopted by ESA in January 2024.

Publications

Armano M et al. (2020) **Analysis of the accuracy of actuation electronics in the laser interferometer space antenna pathfinder, accepted for publication**, Rev. Sci. Instr. 91: 045003.

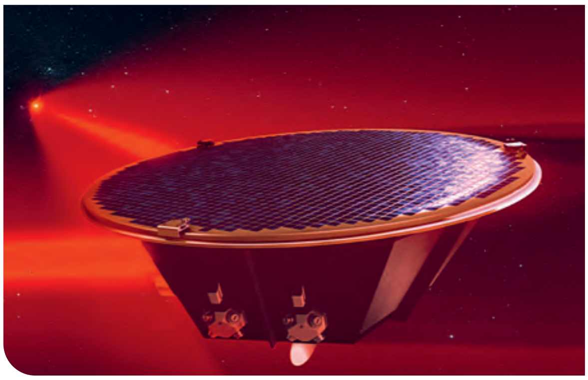
Armano M et al. (2023) **NanoNewton electrostatic force actuators for femtoNewton-sensitive measurements: system performance test in the LISA Pathfinder mission**, arXiv: 2401.00884.

Meshksar N et al. (2020) **Analysis of the accuracy of actuation electronics for the Laser Interferometer Space Antenna**, Rev. Sci. Instr. 91: 095003.

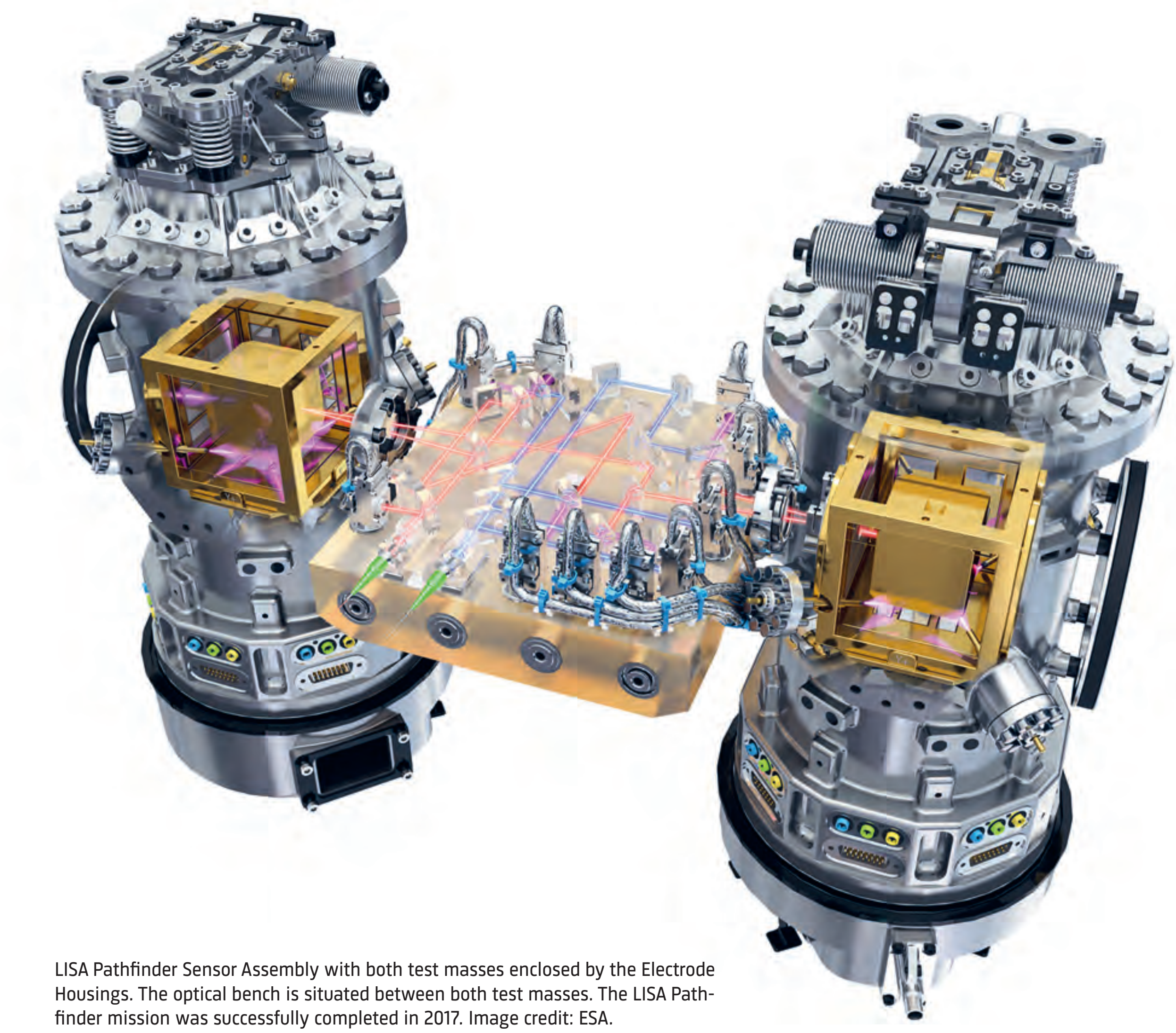
Abbreviations

FEE	Front-End Electronics
GRS	Gravitational Reference Sensor
LISA	Laser Interferometer Space Antenna

Time-Line	From	To
Planning	2019	2024
Construction	2025	2035
Measurement phase	2035	2045
Data evaluation	2035	2045



Artist's impression of a Laser Interferometer Space Antenna (LISA) mission concept spacecraft. Image credit: AEI/Milde Marketing/Exozet



LISA Pathfinder Sensor Assembly with both test masses enclosed by the Electrode Housings. The optical bench is situated between both test masses. The LISA Pathfinder mission was successfully completed in 2017. Image credit: ESA.

7.8 ATHENA – Advanced Telescope for High Energy Astrophysics

Artist's impression of the ATHENA spacecraft. Image credit: IRAP, CNES, ACO, ESA.

Institute
Dept. Astronomy, Univ. Geneva (UNIGE)
Versoix, Switzerland

In cooperation with
European Space Agency (ESA)
Inst. Rech. en Astrophys. et Planét. (IRAP), Toulouse, France
Max-Planck-Inst. Extraterr. Physik (MPE), Garching-bei-München, Germany

Principal Investigator(s)
K. Nandra (MPE), D. Barret (IRAP)

Swiss Principal Investigator(s)
S. Paltani (UNIGE)

Co-Investigator(s)
E. Bozzo, M. Audard, L. Genolet (UNIGE)

Contribution
Development of: i) X-IFU filter wheel mechanism, control electronics and filters, ii) cryo-cables for X-IFU, iii) thick filter for soft X-ray suppression of the WFI filter wheel. Development of data center activities for the WFI and X-IFU instrument science centers.

Industrial hardware contract to
APCO Technologies, Beyond Gravity, Syderal Swiss, ThalesAlenia Swiss, Hightec MC

Website
isdc.unige.ch/athena

Purpose of Research

ATHENA (Advanced Telescope for High Energy Astrophysics) is a large X-ray observatory mission selected by ESA for the so-called L2 slot of the Cosmic Vision Programme. Thanks to its two instruments, a large field-of-view fast imager, the Wide Field Imager (WFI), and a cryogenic imaging calorimeter, the X-ray Integral Field Unit (X-IFU), Athena will provide tremendous improvements over the current generation of X-ray telescopes for high spatial and spectral resolution spectro-imaging and for survey grasp (effective area x field-of-view).

The WFI will be equipped with a 2 × 2 mosaic of large-area DEPFET (depleted p-channel field-effect transistor) active pixel sensor matrices covering a field-of-view of 40’ x 40’, together with a single smaller gateable DEPFET sensor matrix optimised for the high count-rate applications and achieving a time resolution of 80 µs. The X-IFU uses Transition Edge Sensors, operated at cryogenic (50 mK) temperatures, to perform imaging of the X-ray sky with ~ 3 eV resolution. This provides an improvement by a factor >50 over current imaging instruments.

UNIGE is leading the development of the X-IFU filter wheel mechanism, together with the corresponding control electronics and all planned filters. The filters are needed to either reduce the load of soft X-ray photons from very bright X-ray sources, or limit the optical load due to UV photons from the bright counterparts of the observed X-ray sources. The filter wheel will also host the radioactive source needed for the calibration of the instrument. Beside controlling the filter wheel mechanism, the filter wheel electronics will also drive active X-ray sources, which can generate mono-energetic photons for the gain calibration of the detector simultaneously with the scientific observation. This allows the X-IFU instrument to achieve an optimal calibration stability. The X-IFU filter wheel development at UNIGE heavily relies on the heritage from the Swiss contribution to the JAXA ASTRO-H/Hitomi and XRISM missions. UNIGE is also responsible for the initial development of the cryo-cables to be used right at the core of the X-IFU instrument, within the cryostat.

UNIGE is also responsible for one of the filters that will be mounted on the WFI filter wheel. This filter has the function of reducing the load on the detector from the soft X-ray photons of very bright X-ray sources, avoiding saturation and degradation of the instrument performances. The filter is being designed on the model of one of the X-IFU filters that has exactly the same function.

Concerning the mission ground segment and operations, UNIGE has a prominent central role in both the X-IFU and WFI Instrument Science Centers (ISCs). These centers will cover a number of key functions during the entire period of the mission development, operations, and post operations. These roles include the software development, the instrument health monitoring and calibrations, as well as the development of all data reduction/analysis software. UNIGE is responsible for the bulk of the science software production for the X-IFU ISC and the development of the data reduction pipelines of the WFI ISC. For the WFI ISC, UNIGE will also take care of the daily data processing, mainly for quick-look analysis purposes, and will provide support for part of the science software development.

Past Achievements and Status

The Athena mission successfully completed a phase A study in 2019 and continued its development through Phase B1 between 2019 and 2022. In 2022, concerns about the cost of the mission forced ESA, in collaboration with the instrument consortia, to engage in an in-depth re-design of the mission to fit the available financial envelope.

The re-design activities were carried out between 2022 and 2023. At the end of 2023, the reshaped mission was declared feasible in terms of technical and programmatic constraints and entered a new phase, A/B1, to be completed by the end of 2026. The adoption of the mission is now expected in 2027, when Athena will enter the implementation phase, with a planned delivery of the flight models to ESA in 2033 and an expected launch in 2037.

During 2022 - 2023, the team at UNIGE supported the mission re-design activities and spent the largest effort in the test and characterisation of the largest, and thus technologically-wise most critical, X-IFU filters procured at LUXEL (USA). The large aluminum filter frames were fabricated at the mechanical laboratory of the Department of Astronomy and shipped to LUXEL for gluing the filter membranes. Contamination and vibration tests of these filters have been successfully performed and final reports have been delivered to the X-IFU partners for consideration and inclusion in the mission documentation.

The four contracts granted to Swiss industries to carry out a critical analysis of the X-IFU filter wheel mechanism and control electronics were concluded between 2022 and 2023. Due to the re-design of the mission, these activities are planned to be extended in order to revise, as needed, the industrial inputs required by the UNIGE team to plan the next mission phases after adoption (B2/C/D).

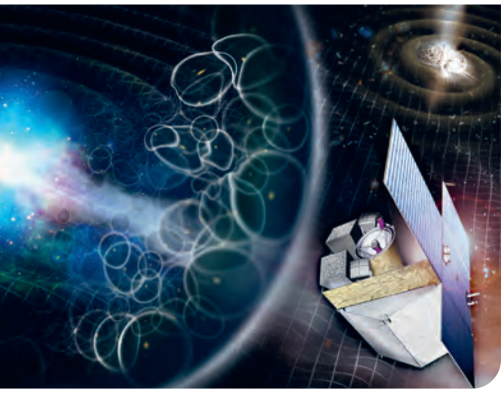
Abbreviations

ATHENA	Advanced Telescope for High-Energy Astrophysics
ISC	Instrument Science Centre
WFI	Wide-Field Imager
X-IFU	X-ray Integral FIeld Unit

Time-Line	From	To
Planning	2014	2026
Construction	2027	2036
Measurement phase	2037	2041
Data evaluation	2037	2041

One of the four full-scale X-IFU optical blocking filters procured by the UNIGE team from LUXEL (USA). The filter membrane is mounted on an aluminum frame, designed and manufactured by UNIGE. The filter has a clear aperture of 160 mm, and the photo shows the complex honeycomb structure of the metallic mesh, glued on the filter to support the membrane.

7.9 THESEUS – The Transient High Energy Sky and Early Universe Surveyor



Artist's impression of the THESEUS spacecraft. Image credit: THESEUS consortium.

Institute
Dept. Astronomy, Univ. Geneva (UNIGE)
Versoix, Switzerland

In cooperation with
INAF-OAS, Bologna, Italy

Principal Investigator(s)
L. Amati

Swiss Principal Investigator(s)
S. Paltani (UNIGE)

Co-Investigator(s)
E. Bozzo, L. Genolet (UNIGE)

Contribution
Contribution to the IRT instrument, to the mission science ground segment and to the mission project office.

Website
isdc.unige.ch/theseus

Purpose of Research

The Transient High Energy Sky and Early Universe Surveyor (THESEUS) is a space mission concept developed by a large international collaboration in response to the seventh call for M-class missions by the European Space Agency (ESA). THESEUS is designed to vastly increase the discovery space of high-energy transient phenomena over the entire cosmic history. Its driving science goals aim to find answers to multiple fundamental questions of modern cosmology and astrophysics, by exploiting the unique mission capability to: a) unveil the physical conditions of the Early Universe (the cosmic dawn and re-ionisation era) by detecting the Gamma-Ray Burst (GRB) population in the first billion years; b) perform an unprecedented deep monitoring of the soft X-ray transient Universe, thus providing a fundamental synergy with the next generation of gravitational wave and neutrino detectors (multi-messenger astrophysics), as well as the large electromagnetic (EM) facilities of the upcoming decades.

The most critical THESEUS targets, i.e. GRBs, are unique and powerful tools for cosmology, especially thanks to their huge luminosities, mostly emitted as X-rays and gamma-rays, their redshift (z) distribution (extending at least to z ~ 10, when the Universe was less than 500 million years old), and their association with the explosive death of massive stars. In particular, GRBs represent a unique tool to study the early Universe up to the re-ionisation era.

Besides high-redshift GRBs, THESEUS will serendipitously detect and localise, during regular observations, a large number of X-ray transients and variable sources, collecting prompt follow-up data in the IR. These observations will provide a wealth of unique science opportunities, by revealing the violent Universe as it occurs in real-time, exploiting the all-sky X-ray monitoring of extraordinary grasp and sensitivity carried out at high cadence. THESEUS will be able to locate and identify the electromagnetic counterparts to sources of gravitational radiation and neutrinos, which will be routinely detected by next generation facilities, such as aLIGO/aVirgo, LISA, the Einstein Telescope, Cosmic Explorer, and Km3NET. In addition, the provision of a high-cadence soft X-ray monitoring capability in the 2030s together with a 0.7 m infrared telescope in orbit will enable a strong synergy with transient phenomena observed with the large facilities that will be operating in the EM domain (e.g., ELT, SKA, CTA, ATHENA).

The foreseen payload of THESEUS includes the following instrumentation:

- The Soft X-ray Imager (SXI, 0.3–5 keV): a set of two lobster-eye telescope units, covering a total field-of-view (FOV) of ~1 sr with source location accuracy <1–2 arcmin.
- The InfraRed Telescope (IRT, 0.7–1.8 µm): a 0.7 m class IR telescope with 15 × 15 arcmin FOV, for fast response, with both imaging and spectroscopic capabilities.
- The X-Gamma Ray Imaging Spectrometer (XGIS, 2 keV–20 MeV): a set of 2 coded-mask cameras using monolithic X-gamma ray detectors based on bars of silicon diodes coupled with a CsI crystal scintillator, granting up to 4 sr FOV, a source location accuracy of ~10 arcmin in 2–150 keV and an unprecedented broad energy band.

The Swiss THESEUS team, based at the Department of Astronomy of the University of Geneva, is part of the coordination team over-viewing all engineering and scientific activities around THESEUS. The University of Geneva contributes to the mission project office and hosts the mission website. The other responsibilities of the Swiss team cover the development of the cryogenic filter-wheel mechanism for the IRT and a leading role in the design of the mission science ground-segment.

Past Achievements and Status

THESEUS was originally selected as one of the three mission candidates for the 5th ESA call for medium-sized missions of the Cosmic Vision Programme. THESEUS underwent a successful phase A study between 2018 and 2021, but was finally not selected by the Agency in June 2021 as the M5 mission to be implemented. Activities in Switzerland included some prototyping and proof-of-concept development of the IRT filter wheel and were successfully completed in February 2022.

THESEUS was re-selected by ESA in 2022 as a candidate for the 7th call for medium-size missions, and it is undergoing a new phase A study, planned to be concluded by the end of 2026. If selected at the end of the new phase A study, THESEUS could be implemented and launched into a low equatorial orbit in 2037. Nominal scientific operations are planned for at least four years after launch and commissioning.

Time-Line	From	To
Planning	Jan. 2024	Dec. 2026
Construction	2027	2037
Measurement phase	2037	2041
Data evaluation	2037	2041

Publications

Amati L et al. (2021) **The THESEUS space mission: science goals, requirements and mission concept**, ExA 52: 183.

Stratta G et al. (2022) **Breakthrough Multi-Messenger Astrophysics with the THESEUS Space Mission**, Galaxies 10: 60.

Abbreviations

GRB	Gamma Ray Burst
IRT	InfraRed Telescope
SXI	Soft X-ray Imager
THESEUS	Transient High Energy Sky and Early Universe Surveyor
XGIS	X and Gamma Ray Imaging Spectrometer.

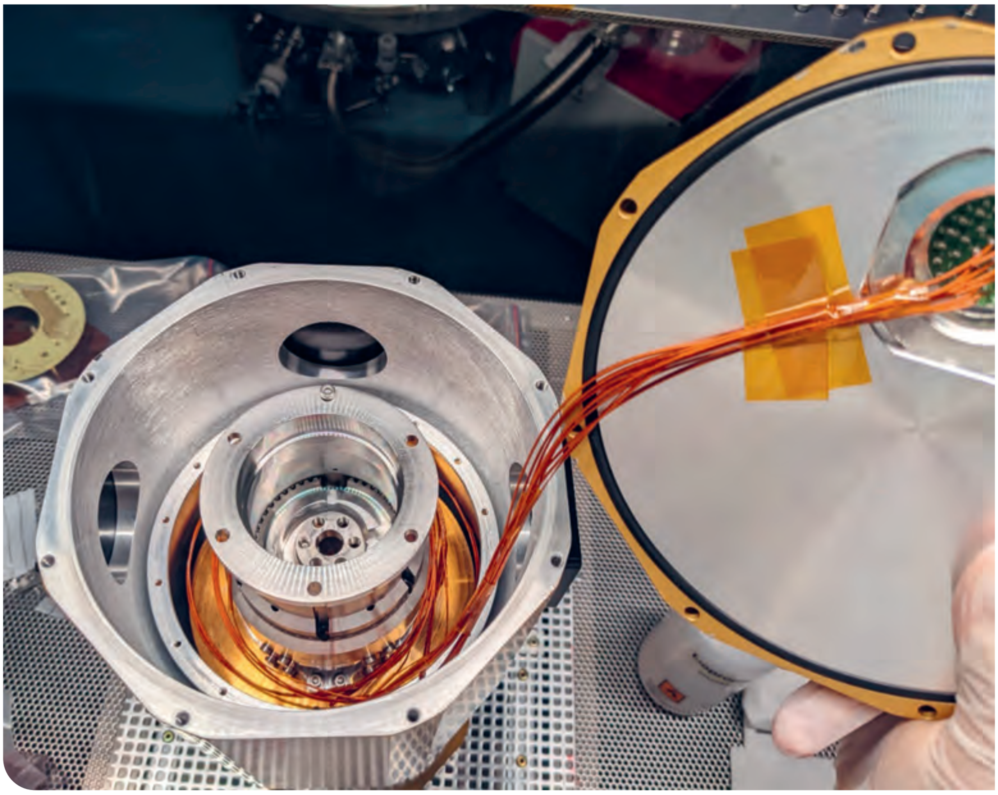
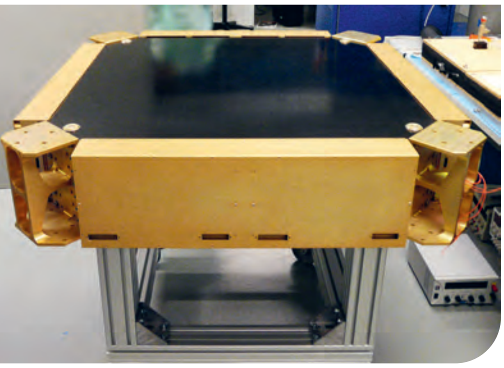


Photo of the IRT filter wheel prototype realised as a proof of concept by the team at the University of Geneva (Switzerland).

7.10 DAMPE – DArk Matter Particle Explorer



The Silicon-Tungsten Tracker of DAMPE constructed at the University of Geneva

Institute
Dept. Nucl. & Part. Phys. (DPNC), Univ. Geneva, Geneva, Switzerland

In cooperation with
Istituto Nazionale di Fisica Nucleare (INFN), INFN Perugia; INFN Bari; INFN Lecce, Italy
Inst. High Energy Phys. (IHEP), Beijing, China
GSI, L'Aquila, Italy
PMO, Nanjing, China
Univ. Sci. Technol. China (USTC), Hefei, China
Inst. Modern Physics (IMP), Lanzhou, China

Principal Investigator(s)
J. Chang (PMO, China)

Swiss Principal Investigator(s)
X. Wu (DPNC)

Co-Investigator(s)
A. Tykhonov (DPNC)

Contribution
Operations of the DAMPE experiment

Website
dpnc.unige.ch/dampe

Purpose of Research

DAMPE (Dark Matter Particle Explorer) is a satellite mission of the Chinese Academy of Sciences (CAS) dedicated to high energy cosmic ray detection. Since its successful launch on 17 December 2015, a large amount of cosmic ray data has been collected and significant results published.

With a relatively large acceptance, DAMPE is designed to detect electrons (and positrons) up to 10 TeV with unprecedented energy resolution to search for new features in the cosmic ray electron plus positron (CRE) spectrum. It will also study cosmic ray nuclei up to 100 TeV with good precision, which will bring new input to the study of their still unknown origin and their propagation through the Galaxy.

DAMPE consists of a plastic scintillator strip detector (two layers) that serves as an anti-coincidence detector, followed by a Silicon-Tungsten Tracker (STK) converter, then an imaging calorimeter of about 31 radiation lengths in thickness, constructed of 14 layers of bismuth germanium oxide bars in a hodoscopic arrangement. Finally, a layer of neutron detectors is situated at the bottom of the calorimeter. The STK, which greatly improves the tracking and photon detection capability of DAMPE, was proposed by the Geneva DPNC group. An international collaboration led by DPNC, including INFN Perugia, INFN Bari, INFN Lecce and IHEP, Beijing, is responsible for the development, construction, qualification, on-ground calibration, and in-orbit calibration and monitoring of the STK.

The DPNC group played a leading role both in the hardware construction of the DAMPE payload, and is currently a major contributor to the science data processing and analysis.

Past Achievements and Status

The development and construction of the STK was finished after three years of intensive effort. The final assembly was completed at the DPNC and delivered to China in April 2015. Integration into the satellite occurred in May 2015. The DAMPE satellite was successfully launched on 17 December 2015. All sub-systems of DAMPE are functioning well.

The STK is performing above expectations. In-orbit mechanical, thermal and electronic conditions have been very stable. The figure on the right shows the evolution of the noise situation of the 73728 STK readout channels during the past eight years. The fraction of good channels (green points in the figure), conservatively defined as noise < 5 ADC (analogue-to-digital counts) started out at 99.55% at the beginning of data taking, and improved as a function of time due to the stabilisation in space, to a stable value around 99.73% by the end of 2019. The DPNC group has major responsibilities for the ground science data operation, including periodic monitoring, calibration and alignment of the STK, as well as the development and the operation of the STK track reconstruction software.

In 2017, DAMPE published the most precisely measured CRE spectrum up to 4.6 TeV, and the detection of a break of the CRE spectral index at ~1 TeV, providing a new input to understand the orgin(s) of these particles. The DPNC group played a leading role in the electron analysis, and is currently extending the analysis to above 10 TeV with more than eight years of data, using machine learning techniques.

The DAMPE experiment is providing the most precise measurements of cosmic rays above 1 TeV to 1 PeV with direct detection. The proton flux up to 100 TeV and the helium flux up to 80 TeV (20 TeV/nucleon) have been published. Both exhibited an intriguing spectral softening at about 10 TeV/nucleon. Currently, the Geneva group is extending these measurements to higher energy with more data and with deep learning algorithms that are more efficient and more precise compared to traditional algorithms.

Abbreviations

CRE	Cosmic ray electron plus positron
DAMPE	DArk Matter Particle Explorer
STK	Silicon-Tungsten Tracker

Publications

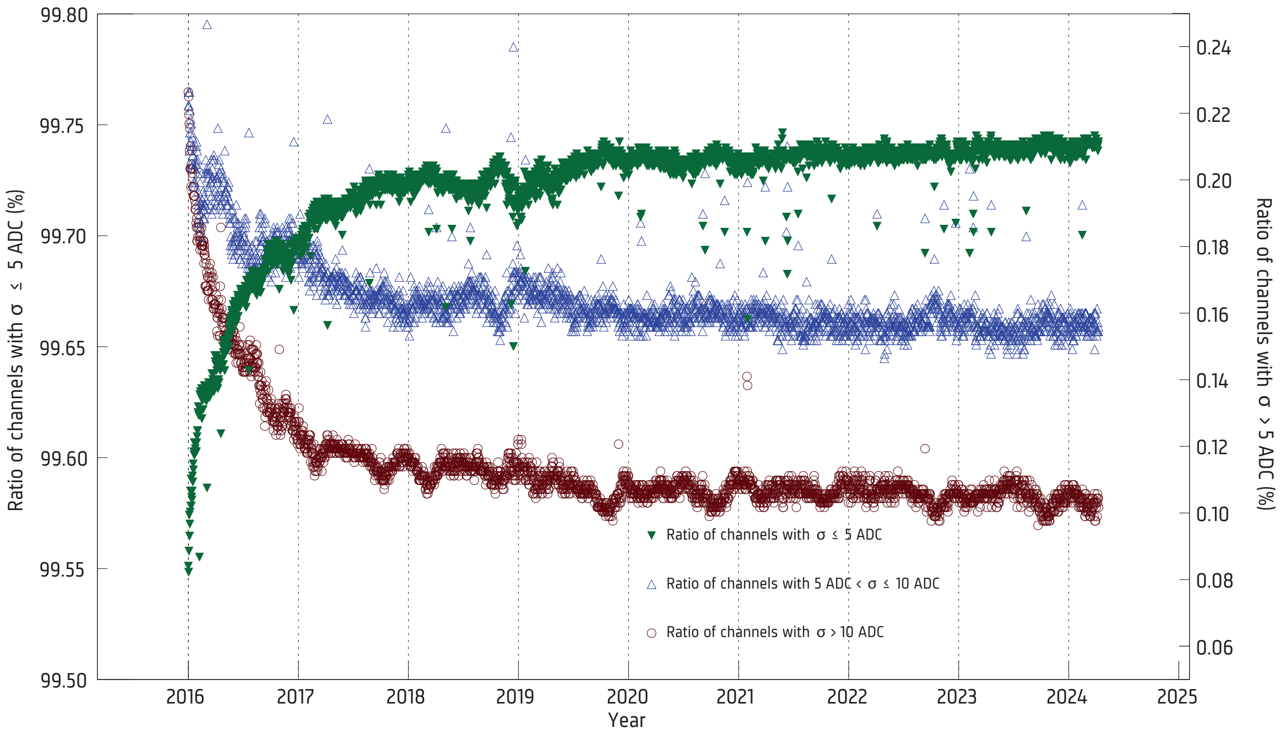
Alemanno F et al. (2022) **Detection of spectral hardenings in cosmic-ray boron-to-carbon and boron-to-oxygen flux ratios with DAMPE,** Science Bulletin 67: 21, 2162–2166.

Droz D et al. (2021) **A neural network classifier for electron identification on the DAMPE experiment**, J. Instr. 16: P07036.

Stolpovskiy M et al. (2022) **Machine learning-based method of calorimeter saturation correction for helium flux analysis with DAMPE experiment**, JINST 17: P06031.

Tykhonov A et al. (2023) **A deep learning method for the trajectory reconstruction of cosmic rays with the DAMPE mission**, Astropart. Phys. 146: 102795.

Time-Line	From	To
Planning	2012	2013
Construction	2013	2015
Measurement phase	2016	>2025
Data evaluation	2016	>2025



Fraction of good STK channels with noise below 5 ADC (analogue-to-digital counts; green), compared to those with noise between 5 and 10 (blue), and above 10 ADC (red). Data from Jan. 2016 to Dec. 2023.

7.11 The Swiss Contribution to eXTP

Artist's impression of eXTP. Image credit: IHEP.

Institute
Dépt. Phys. Nucl. Corp. (DPNC), Univ. Geneva (UNIGE), Geneva, Switzerland
Dept. Astronomy (DA), Univ. Geneva (UNIGE), Versoix, Switzerland

In cooperation with
Inst. High Energy Phys. (IHEP), Beijing, China

Principal Investigator(s)
S-N. Zhang (IHEP)

Swiss Principal Investigator(s)
X. Wu (DPNC, UNIGE)

Co-Investigator(s)
S. Paltani (DA, UNIGE), E. Bozzo (DA, UNIGE)

Contribution
Development of the LAD front-end electronics, LAD detectors, ASICs, front-end electronics assembly, contribution to the mission science ground segment.

Website
isdc.unige.ch/extp

Purpose of Research

The enhanced X-ray timing and Polarimetry mission (eXTP) is a science mission designed to study the state of matter under extreme conditions of density, gravity and magnetism. Primary targets include isolated and binary neutron stars, strong magnetic field systems such as magnetars, and stellar-mass and supermassive black holes. The mission carries a unique and unprecedented suite of state-of-the-art scientific instruments enabling, for the first time ever, the simultaneous spectral-timing polarimetry studies of cosmic sources in the 0.5 – 30 keV energy range (and beyond). Key elements of the payload are:

- The Spectroscopic Focussing Array (SFA): a set of 11 X-ray optics for a total effective area of about 0.9 m^2 and 0.6 m^2 at 2 keV and 6 keV, respectively, equipped with Silicon Drift Detectors (SDDs) offering <180 eV spectral resolution.

- The Large Area Detector (LAD): a deployable set of 640 SDDs, with a total effective area of ~3.4 m^2, at 6-10 keV, and spectral resolution <250 eV.

- The Polarimetry Focussing Array (PFA): a set of two X-ray telescopes, with a total effective area of 250 cm^2 at 2 keV, equipped with imaging gas pixel photoelectric polarimeters.

- The Wide-Field Monitor (WFM): a set of three coded mask wide-field units, equipped with position-sensitive SDDs, each covering a 90° × 90° field-of-view.

The eXTP international consortium mostly includes major institutions of the Chinese Academy of Sciences and Universities in China, as well as major institutions in several European countries. The eXTP mission has been under development since 2017 and is currently waiting to have a secured launch opportunity in China.

The Swiss eXTP team comprises scientists at the Department of Particle Physics (DPNC) and the Department of Astronomy (DA), both at the University of Geneva. The DPNC is leading the design of the front-end electronics (FEE) for the LAD instrument, together with the definition of the chain of assembly of the front-end electronics with the SDD detectors and the Application-Specific Integrated Circuits (ASICs). The DA is involved in the design of the science ground segment of the mission and the coordination of part of the scientific activities.

Past Achievements and Status

The eXTP mission underwent a phase B1 study in China and Europe between 2020 and 2023. The programmatic aspects of the mission are currently being consolidated by looking for a launch opportunity in the early 2030s.

In the period 2022–2023, the DA team mainly focused on the re-definition of the science case, in view of the most recent developments, especially in the field of X-ray polarimetry. A first FEE prototype with readout ASICs was developed at DPNC in 2023 and its functionalities were successfully tested. The FEE-SDD has also been integrated at DPNC, which is an important milestone. This first LAD Detector Assembly will then be used to build a LAD demonstrator model in Italy.

Publications

Feroci M et al. (2022) **The large area detector onboard the eXTP mission**, Proc. SPIE, 12181: id. 121811X

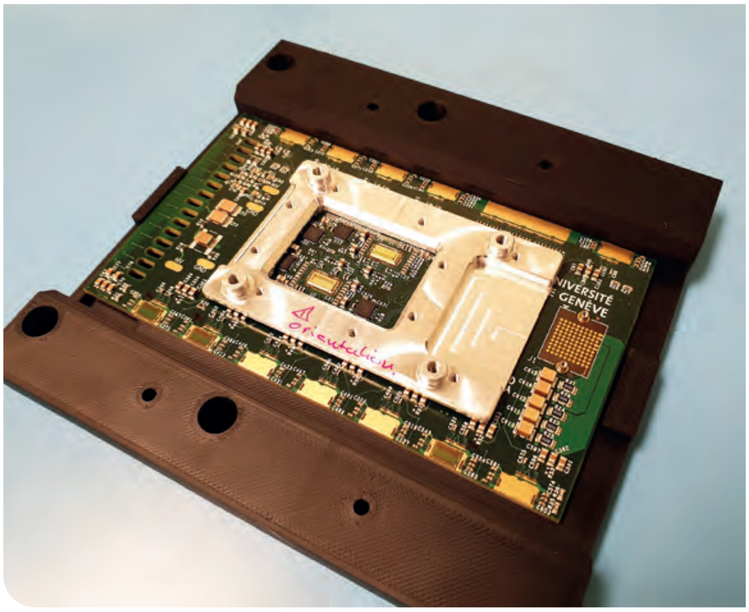
Hernanz M et al. (2022) **The wide field monitor onboard the Chinese-European X-ray mission eXTP**, Proc. SPIE, 12181: id. 121811Y

Shuang-Nan Z et al. (2022) **Enhanced X-ray Timing and Polarimetry mission: eXTP: an update on its scientific cases, mission profile and development status**, Proc. SPIE, 12181: id. 121811W

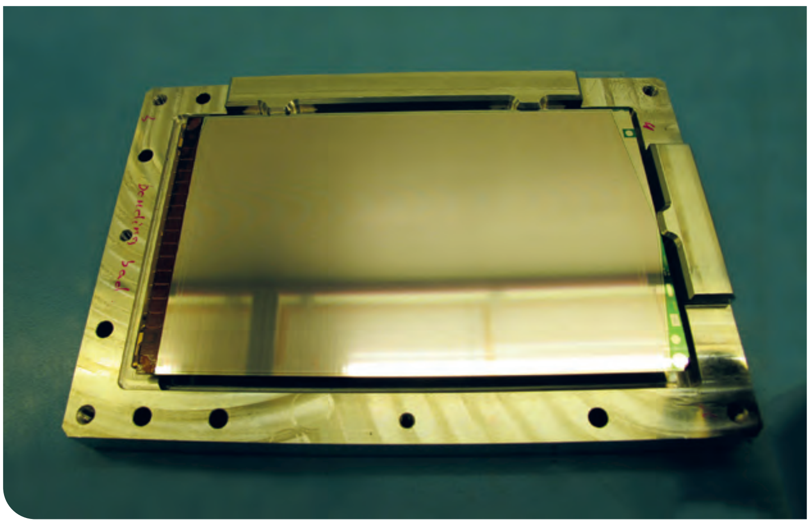
Abbreviations

ASIC	Application-specific integrated circuit
eXTP	The enhanced X-ray Timing and Polarimetry Mission
FEE	Front-End Electronics
SDD	Silicon Drift Detector

Time-Line	From	To
Planning	2017	2024
Construction	2025	2030
Measurement phase	2031	2036
Data evaluation	2031	2036

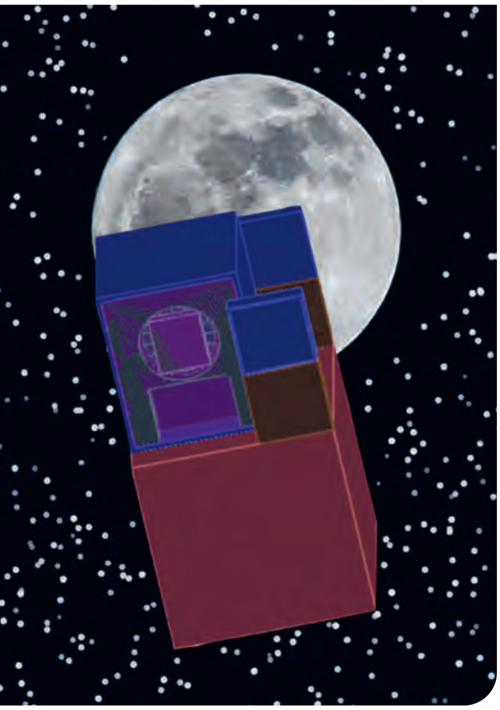


A photo of the FEE prototype developed during 2023 by the DPNC team.



The first LAD detector assembly produced at DPNC.

7.12 PAN – Penetrating Particle Analyser



Sketch of the LunPAN lunar orbital mission.

Institute
Dépt. Phys. Nucl. Corp. (DPNC), Univ. Geneva, Geneva, Switzerland

In cooperation with
Istituto Nazionale di Fisica Nucleare (INFN), Perugia, Italy
Czech Technical Univ. of Prague, Prague, Czech Republic
CERN, Switzerland

Principal/Swiss Investigator(s)
Xin Wu (DPNC)

Website
pan-space.eu

Purpose of Research

PAN is an innovative energetic particle detection technology to precisely measure and monitor the flux and composition of highly penetrating particles (> ~100 MeV/nucleon) in deep space, which will have broad applications. PAN will fill an observation gap of galactic cosmic rays (GCRs) in the 100 MeV/n - GeV/n region, helping to improve our understanding of the origin of GCRs and their propagation through the Galaxy and Solar system. It will provide precise information of the spectrum, composition and timing of energetic particles originating from the Sun, which is essential to study the physical process of solar activities, in particular those that produce an intensive flux of energetic particles.

The precise measurement of penetrating particles is also a unique contribution to space weather studies, in particular to the development of predictive space weather models in a multi-wavelength and multi-messenger approach, using observations which are both space and ground-based.

As indicated by the name of this project, penetrating particles cannot be shielded effectively. PAN can monitor the flux and composition of these particles precisely and continuously, thus providing a real-time radiation hazard warning against long-term radiation health risks for human space travellers.

Once developed, PAN can become a standard device for deep space human bases and for deep space exploration and commercial spacecraft, or as part of a space weather advance warning system, permanently deployed in space.

Past Achievements and Status

PAN was funded by an EU H2020 FETOPEN grant to develop a demonstrator (Mini.PAN) in 2020 - 2023. The consortium consists of DPNC, INFN Perugia and the Czech Technical University in Prague and CERN. The demonstrator has been developed and its main functionalities validated with particle beams at accelerator labs. The H2020 project has successfully passed the final review in February 2024.

A variant of PAN, called Pix.PAN, has been proposed as the Ultra Relativistic Particle Detector (URPD) of a mission concept to Jupiter's radiations belts, called COMPASS, that has been selected by NASA for pre-Phase A conceptual studies. The COMPASS pre-Phase A studies were completed in 2023, and the results published in a white paper. A separate white paper on the implemention of Pix.PAN was also published.

PAN has also been adopted as the main payload of REMEC (Radiation Environment Monitor for Energetic Cosmic rays), a mission concept that has been selected for the ESA program 'Ambitious Projects (Mission Proposals) for the Czech Republic: Phase 0/A/B1 studies'. The studies were finished in 2021–2023. Although REMEC was not selected for implementation, the results obtained from this work have laid down a solid groundwork for future mission opportunities.

Pix.PAN was submitted in July 2022 to ESA's Call for Reserve Pool of Science Activities for the Moon. Pix.PAN was among one of the five proposals selected in June 2023 and was placed in the pool for the next launching opportunities. An Activity Requirements Document (ARD) has been prepared.

In November 2023, a proposal for a lunar orbital mission, called LunPAN, with Pix.PAN as the main payload, was submitted to ESA's call for 'Small Missions for Exploration – Destination the Moon'. The goal of LunPAN is to comprehensively map the lunar radiation field. The decision on the first selection is expected in April 2024.

Publications

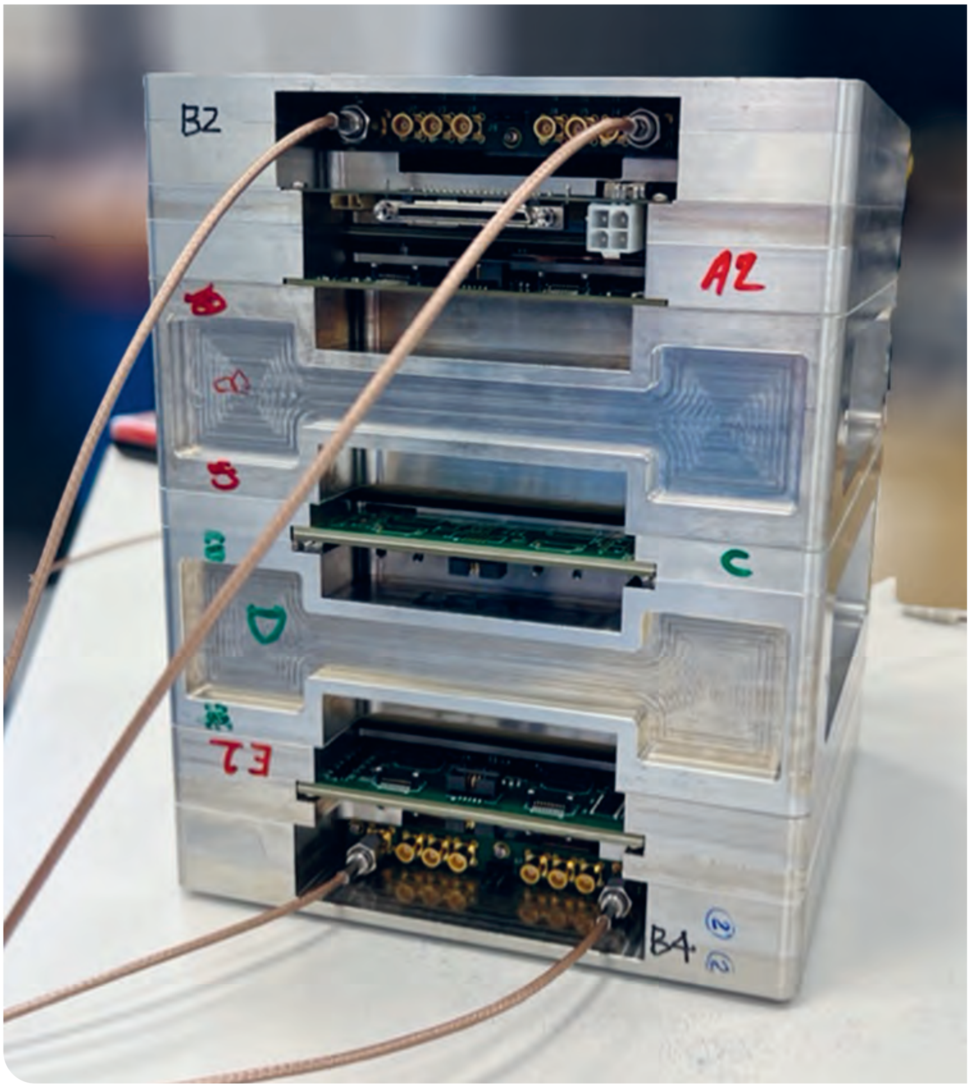
Hulsman et al. (2023) **Relativistic particle measurement in Jupiter's magnetosphere with Pix.PAN**, Exp Astron. 56: 371–402.

Sukhinos S et al. (2023) **Penetrating particle ANalyzer (PAN)**, PoS ICRC2023 (2023) 045.

Wu X et al. (2019) **Penetrating particle Analyzer (PAN)**, Adv. Space Res. 63: 2672–2682.

Abbreviations

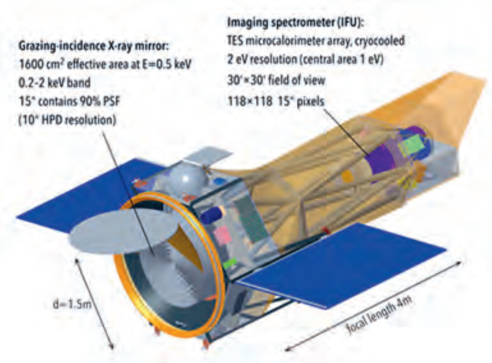
Mini.PAN	PAN demonstrator
PAN	Penetrating Particle Analyser
Pix.PAN	Variant of PAN



The Mini.PAN demonstrator instrument.

ASTROPHYSICS

7.13 LEM – Line Emission Mapper



Artist's impression of the LEM spacecraft (Image credit: CfA). The figure shows a sketch of the spacecraft and the allocations for both the X-ray optics and the focal plane. The expected spacecraft size and the main payload scientific specifications are also indicated.

Institute
Dept. Astronomy, Univ. Geneva (UNIGE), Geneva, Switzerland

In cooperation with
Center for Astrophys. (CfA), Harvard College, Obs. & Smithsonian Astrophys. Obs, USA

Principal Investigator(s)
R. Kraft (CfA)

Swiss Principal Investigator(s)
D. Eckert (UNIGE)

Co- Investigator(s)
E. Bozzo, L. Genolet (UNIGE)

Contribution
Development of the LEM filter wheel and the corresponding filters. Contribution to the mission science ground segment.

Purpose of Research

LEM (Line Emission Mapper) is an X-ray probe that will answer the outstanding questions of the Universe's structure formation in the 2030s. It will also provide transformative new observing capabilities for every area of astrophysics, as well as heliophysics and planetary physics. LEM's main goal is to take a comprehensive look at the physics of galaxy formation, including stellar and black-hole feedback, and flows of baryonic matter into and out of galaxies. Given the high temperatures involved, these processes are best studied in X-rays; as emphasised by the 2020 Decadal Survey, emission-line mapping is the pressing need in this area.

LEM will use a large microcalorimeter array/IFU (that builds on Athena XIFU technology developments), covering a 30 × 30 arcmin field with a spectral resolution of 1000, to map the soft X-ray line emission from the gas that fills the halos of galaxies. This includes supernova remnants, star-forming regions, superbubbles, galactic outflows, the circum-galactic medium in the Milky Way and other galaxies, and the warm-hot intergalactic medium at the outskirts and beyond the confines of galaxies and clusters. LEM's 1–2 eV spectral resolution in the 0.2–2 keV band will make it possible to disentangle the faintest emission lines in those objects from the bright Milky Way foreground, providing ground-breaking measurements of the physics of these plasmas, from temperatures, densities, chemical composition to gas dynamics.

The UNIGE team is deeply involved in the science of LEM and is responsible for the development and construction of the filter wheel mechanism needed by LEM to optimise the scientific observations. The team is also responsible for the design and procurement of the filters to be mounted on the filter wheel and is planning to contribute to the mission science ground segment (under definition).

Past Achievements and Status

The team at UNIGE has so far contributed to the preparation of the LEM proposal that was submitted to NASA in November 2023 for the probe mission call. As part of the proposal preparation, the UNIGE team has developed a mechanical design for the LEM filter wheel mechanism that can optimally fit the preliminary expected mass and volume budgets. This activity has benefited from the strong heritage of UNIGE in the field of space mechanisms being developed in partnership with Swiss industries. The Swiss contribution is also expected to cover the procurement and characterisation/test of the filter wheel filters. These are similar in terms of size and requirements to the so-called Optical Blocking Filters (OBFs) that the University of Geneva team has already procured and characterised for the Athena/X-IFU filter wheel during the concluded Athena mission phase A/B1 (2014–2023).

At present, NASA has planned the selection of one probe mission in the X-ray domain by October 2024. If LEM is selected as the X-ray probe concept to be further investigated, a phase A study will kick-off in 2025 and will last nine months. At the end of phase A, one probe mission will be chosen to be implemented either in the X-ray or in the InfraRed domain (several probe concepts are currently being reviewed by NASA in both domains and only one per domain will be chosen to enter the phase A study).

Publications

Kraft R et al. (2022) **Line Emission Mapper (LEM): Probing the physics of cosmic ecosystems**; White paper for a mission concept submitted for the 2023 NASA Astrophysics Probes opportunity, arXiv:2211.09827.

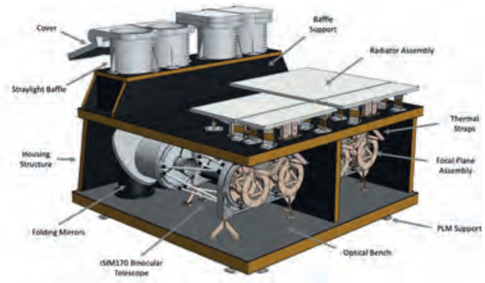
Abbreviations

LEM	Line Emission Mapper
OBF	Optical Blocking Filter

Time-Line	From	To
Planning	2023	2025
Construction	2026	2032
Measurement phase	2033	2038
Data evaluation	2033	2038

Sketch of the present University of Geneva preliminary design for the LEM filter wheel. The wheel hosts four positions for different filters, plus an open position, a closed position, and a position to place the required radioactive ^{55}Fe calibration sources.

7.14 ARRAKIHS – Analysis of Resolved Remnants of Accreted Galaxies as a Key Instrument for Halo Surveys Line Emission Mapper



A schematic of the ARRAKIHS payload.

Purpose of Research

In November 2022, ARRAKIHS (Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys Line Emission Mapper) was selected as ESA's second F-class mission, with a launch date target of 2030. Using a dual binocular telescope on a mini satellite in low Earth orbit, it will catalogue ultra-low surface brightness images of Milky Way-like galaxies. ARRAKIHS will annually capture 50 square degrees of the sky in four bands, aiming at 31 mag./arcsec^2 in visible and 30 mag./arcsec^2 in the near-infrared. It will specifically:

– Characterise the abundance and locations of satellite galaxies, down to MV < -6 for a complete sample of Milky Way-like galaxies beyond the Local Group.

– Characterise the shape and extent of the ultra-faint intra-halo light. These data will be used to test different theories for the nature of dark matter that dominates the mass component of galaxies.

– Provide robust statistics of the numbers and shapes of wide and thin stellar streams.

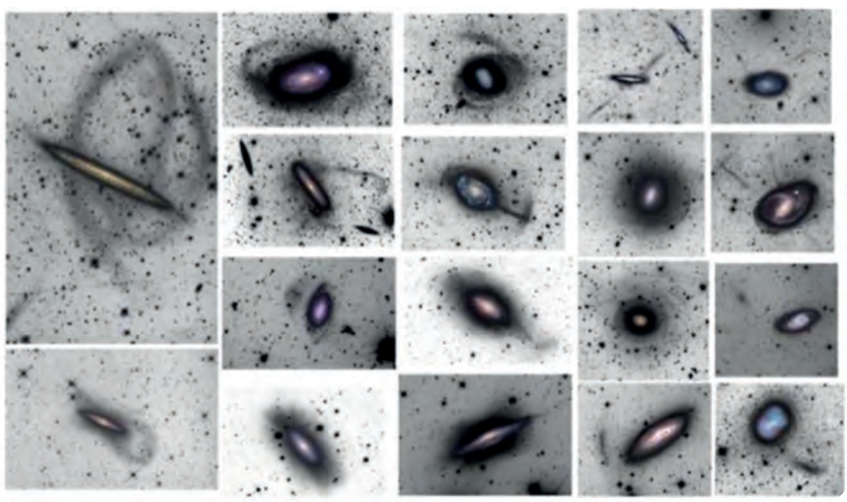
Past Achievements and Status

– Mission selection Nov. 2022.
– MDR review passed Sep. 2023.
– Phase A passed Mar. 2024.
– Phase B started Apr. 2024.
– PDR Q2 2026.

Abbreviations

ARRAKIHS Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys Line Emission Mapper

Time-Line	From	To
Planning	Jan. 2023	Jul. 2026
Construction	Aug. 2026	Jan. 2030
Measurement phase	2030	2033
Data evaluation	2030	open



Luminance filter images of nearby galaxies from the Stellar Tidal Stream Survey showing large, diffuse light structures in their outskirts (Image credit: David Martinez-Delgado, IAA).

Institute
Dept. Astrophysics, University of Zurich, Zurich, Switzerland

In cooperation with
Spain, Belgium, Sweden, UK, Austria, ESA, Switzerland: HSLU, FHNW, EPFL, ZHAW, KOEGL Space

Principal Investigator(s)
R. Guzman (IFCAL)

Swiss Principal Investigator(s)
B. Moore (UZH)

Co-Investigator(s)
The ARRAKIHS team includes over 100 scientists and engineers from 7 ESA member states

Contribution
Switzerland is in charge of the design and production of the thermal and structural subsystem (Florian Kehl, UZH), the overall project payload management (Stefan Kögl, KOEGL Space), as well as scientific support using supercomputer simulations of galaxy formation (EPFL, UZH).

7.15 LIFE – Large Interferometer For Exoplanets

Purpose of Research

LIFE (Large Interferometer For Exoplanets) is an ambitious space mission featuring a mid-infrared nulling interferometer to directly detect hundreds of extrasolar planets in the Solar neighbourhood and characterise their atmospheres. A significant fraction of these objects will have masses, sizes and orbital periods similar to the terrestrial planets in the Solar System. LIFE is uniquely suited to investigate the atmospheric diversity among temperate rocky worlds, quantify the fraction of potentially habitable exoplanets, and, most importantly, search for indications of life beyond the Solar System via atmospheric biosignature gases (e.g., methane and ozone).

Past Achievements and Status

LIFE has gained significant momentum over the last two years and continued to attract a strong and diverse community. Visits to NASA/JPL, NASA/Goddard, JAXA and discussions with colleagues from many European countries, Australia and Canada have resulted in a broad international support base. Worth highlighting is the international workshop 'Exploring Exoplanets with Interferometry', which was held at the Keck Inst. for Space Studies (Pasadena; Dec. 2022) and brought together experts from all relevant areas to derive a set of recommendations and an action plan to move (space-based) interferometry for exoplanet science forward. The peer-reviewed LIFE publication series, show-casing the unique scientific capabilities of the LIFE mission and discussing technological trade-off, continues to grow. LIFE has been recognised as one of the future flagship missions in the exoplanet community and is being mentioned in an increasing number of publications and conferences. On the mission side, the first set of science objectives has been re-assessed, and a rigorous flowdown to mission and technology requirements is ongoing. A preliminary baseline mission concept will be fixed in 2024. A mission concept study to demonstrate the general feasibility of the mission is foreseen and first discussions with potential industrial partners have taken place.

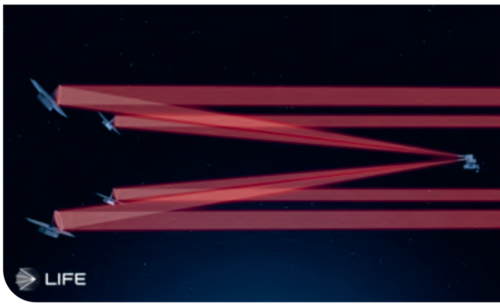
Significant progress was made with the Nulling Interferometry Cryogenic Experiment (NICE) at ETH Zurich. The goal of the experiment is to demonstrate the LIFE measuring principle under realistic conditions. First null-depth measurements at a wavelength of 4 μm with the warm precursor experiment were successful and the integration of the metrology system to further stabilise the measurements is ongoing. Funding to fully develop NICE in the coming four years has been provided by Prodex. In parallel, funding to develop mid-infrared waveguides operating over the full LIFE wavelength range has been secured via ETH Zurich internal grants. Discussions to develop dedicated detectors and optical elements have started with colleagues in the Netherlands, and corresponding grants were submitted or are in preparation. For formation flying technologies, collaborations with colleagues in Japan and Australia were intensified, and ideas for a dedicated (small-sat) nulling interferometry technology demonstration mission are being assessed.

Publications

Dannert FA, Ottiger M, Quanz SP et al. (2022) A&A 664: A22, doi.org/10.1051/0004-6361/202141958

Kammerer J, Quanz SP, Dannert F et al. (2022), A&A 668: A52, doi.org/doi:10.1051/0004-6361/202243846

Quanz SP, Ottiger M, Fontanet E et al. (2022) A&A 664: A21, doi.org/10.1051/0004-6361/202140366



Artist's impression of the LIFE nulling interferometry mission consisting of four collector spacecraft in a rectangular array configuration sending light to a beam combiner spacecraft in the centre.

Institute
Inst. Particle Physics & Astrophysics,
ETH Zurich,
Zurich, Switzerland

In cooperation with
NCCR PlanetS, LIFE Consortium

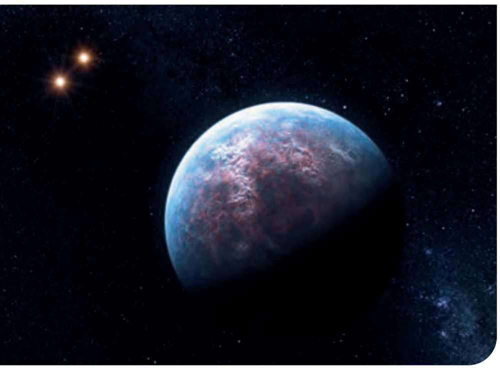
Principal/Swiss Investigator(s)
S. P. Quanz (ETH Zurich)

Co-Investigator(s)
A. Glauser (ETH Zurich)

Contribution
Development & construction of instruments:
LIFE is in its mission defintion phase.

Website
life-space-mission.com

7.16 NuANCESTOR



An artist impression of the planetary system Gliese 667, discovered by the Swiss team at UNIGE thanks to the precise radial velocity measurements obtained with the Swiss instrument, HARPS (High Accuracy Radial velocity Planet Searcher), which is mounted on the ESO 3.6-metre telescope (Image credit: ESO).

Institute
Univ. Geneva (UNIGE), Geneva, Switzerland

In cooperation with
Centre Suisse d'Electronique et de Microtechnique (CSEM), Neuchatel, Switzerland
ETH Zurich (ETHZ), Zurich, Switzerland
Univ. Bern (UNIBE), Bern, Switzerland
Haute Ecole Spécialisée de Suisse Occidentale (HES-SO), Delémont, Switzerland

Principal/Swiss Investigator(s)
F. Pepe (UNIGE)

Co-Investigator(s)
C. Mordasini (UNIBE), S. Lecomte (CSEM), J. Moershell (HSO-SO), B. Soja (ETHZ)

Contribution
Feasibility study for the entire mission, including the spacecraft and the payload.

Website
astro.unige.ch/nuancestor

Purpose of Research

The study of exoplanets, the search for Earth analogues and investigation of the nature of the Universe are the main subjects of high-fidelity astronomical spectroscopy. Since the discovery of the first exoplanet orbiting a solar-type star by Michel Mayor and Didier Queloz using the radial velocity technique, the field has been thriving, with new, often unexpected discoveries emerging one after the other. High-fidelity spectroscopy has become the main technique to detect planetary atmospheres and bio-signatures, to characterise host stars, to measure the expansion of the Universe, or even to test fundamental physics by measuring the possible variability of fundamental constants. At present, there are several tens of high-resolution astronomical spectrographs scattered all around the world. Their scope ranges over various domains of astrophysics, from the search and characterisation of habitable exoplanets, through fundamental physics, e.g., the study of the variability of physical constants, to the direct measurement of the expansion rate of the Universe. These fundamental questions of astrophysics can all be addressed by high-fidelity spectroscopy provided that extreme accuracy is achieved.

The accuracy of the mentioned instruments, representing the state-of-the-art science and technology development, depends on the access to extremely precise and stable wavelength calibration sources. There are several available calibration sources (e.g., emission lamps, laser frequency combs, reference cavities) that can be used to calibrate an astronomical spectrograph. However, the calibration as it is currently performed is always local, limiting the achievable accuracy and the simultaneous usability of data from different spectrographs.

The usual scheme for spectrograph calibration requires that somewhere along the optical path from the telescope to the spectrograph, light from the calibrator is injected to calibrate the latter, ie only part of the optical path is used. Any error introduced in the path before the injection of the calibrator (atmosphere and telescope front-end) is not monitored, which may lead to additional unwanted effects in the scientific data that cannot be identified nor corrected. NuANCESTOR will address the above-mentioned issues with the wavelength calibration of astronomical spectrographs by using an optical frequency comb onboard a satellite equipped with an active-pointing telescope and precision orbitography. This will provide an optical frequency anchor in the form of an absolute laser source operating in several wavelength bands and a means for calibrating the full telescope–spectrograph optical paths.

Past Achievements and Status

The project has been granted financial support from the Swiss Space Office for a phase 0 and phase A study, covering the period 2024–2027. In these three years, a consortium of Swiss Institutes (UNIGE, UniBe, ETHz, HSO-SO, and CSEM) will first develop the basic requirements for the spacecraft, its operations, as well as all payload elements, and will then rely on the support from Swiss industries to carry out the most critical prototyping activities to prove the feasibility of such a mission. The future construction of the mission is subject to the participation of additional international partners in order to cover the cost of the platform, payload, launch, and operations. The cooperation scheme will be investigated as part of the phase A objectives.

8 Space Safety

8.1 SSA – International Space Situational Awareness

Purpose of Research

The proliferation of space debris – man-made non-functional objects of all sizes in near-Earth space and the increased probability of collisions and interference between man-made objects in space, raise concerns about the long-term sustainability of space activities, particularly in the low-Earth orbit (LEO) and geostationary orbit (GEO) environments. International organisations at different levels are examining measures to enhance the long-term sustainability of such activities, among them the UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and the Inter-Agency Space Debris Coordination Committee (IADC).

Our modern societies increasingly depend on vital services provided by infrastructure in space. Among them are navigation services, critical data for weather forecast and climate models, Earth observation data used for agriculture, disaster management, monitoring of environmental pollution, etc., to name just a few. Protecting infrastructure in space is thus pivotal to protecting and furthering the success of important infrastructure on Earth.

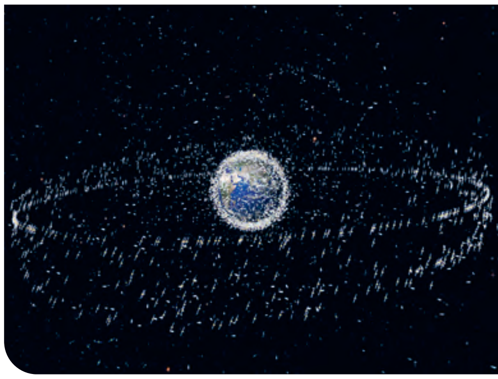
The central aim of Space Situational Awareness/Space Safety is to acquire information about natural and artificial objects in Earth orbits. The growing number of space debris results in an increasing threat to operational satellites and manned spaceflight. Research in this domain aims at a better understanding of the near Earth environment through extending the catalogues of known space objects toward smaller sizes, by acquiring statistical orbit information on small-size objects in support of statistical environment models, and by characterising objects to assess their nature and to identify the sources of space debris. The research is providing the scientific rationale to devise efficient space debris mitigation and remediation measures enabling sustainable outer space activities.

Past Achievements and Status

This is an ongoing international collaboration between the Astronomical Institute of the University of Bern (AIUB), the Keldish Institute of Applied Mathematics (KIAM; Moscow), ESA, and the German Aerospace Center (DLR). Optical surveys performed by AIUB using its ZIMLAT and ZimSMART telescopes at the Zimmerwald Observatory and the ESA telescope in Tenerife (Spain) on behalf of ESA, as well as the surveys performed by KIAM using the ISON telescopes, and the data from the AIUB/DLR SMARTnet sensor network, provide the data to maintain orbit catalogues of high-altitude space debris.

These catalogues enable follow-up observations to further investigate the physical properties of the debris and to eventually discriminate sources of small-size debris. Results from this research are used as key input data for the European ESA meteoroid and space debris reference model, MASTER. The AIUB telescopes constitute primary optical sensors in the ESA Space Safety programme.

An important source of space debris are fragments from on-orbit breakup events. During the past years, several severe fragmentations of upper stages have taken place in high-altitude orbits producing several thousand debris pieces of substantial size. The SSA / Space Safety collaboration has



Graphical representation of the space debris population of objects >10 cm as seen from 15 Earth radii (ESA).

Institute
Astronomical Inst., Univ. Bern (AIUB), Bern, Switzerland

In cooperation with
European Space Agency (ESA)
Keldish Inst. Applied Mathematics (KIAM), Moscow, Russia
International Scientific Optical Observation Network (ISON)
DLR/German Space Operation Centre (GSOC), Oberpfaffenhofen, Germany

Principal Investigator(s)
T. Schildknecht (AIUB)

Co-Investigator(s)
I. Molotov (KIAM), H. Fiedler (DLR)

Contribution
Measurement, Compilation

Observatories
Zimmerwald, Switzerland
Sutherland, South Africa
Mount Kent, Australia
El Sauce, Chile
ESA, Tenerife
ISON telescopes

Website
aiub.unibe.ch

made essential contributions to the identification and cataloguing of the debris clouds. As an example, the figure on the right shows the debris clouds of three of these events.

AIUB also hosts and operates the ESA/AIUB Space Safety Expert Centre, a service and coordination facility in support of space safety.

Publications

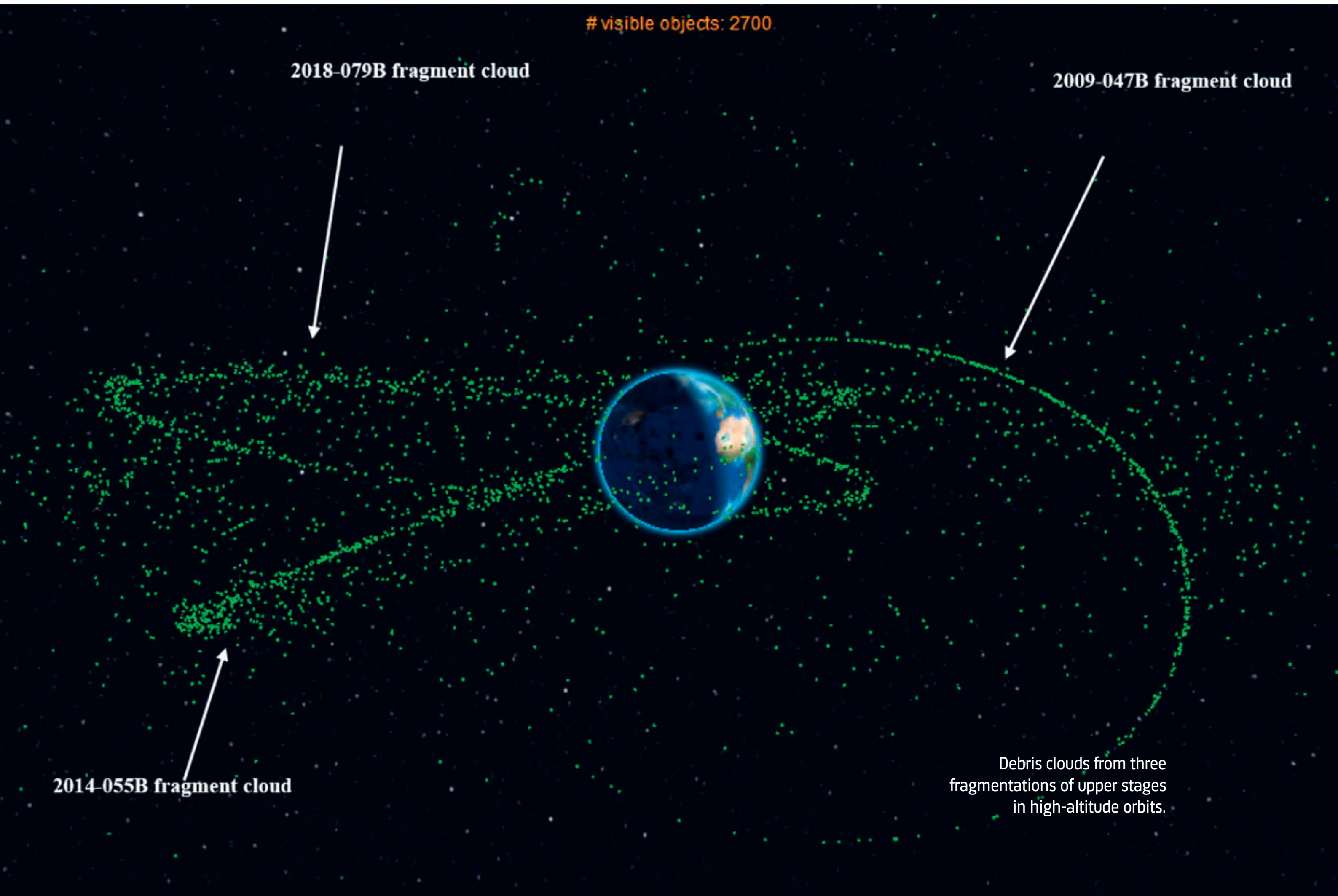
Schildknecht T et al. (2023) **Statistical analysis of space debris surveys in high-altitude orbital regions**, Proc. 24th AMOS conf., Maui, Hawaii.

Schildknecht T et al. (2023) **European Expert Centre for Space Safety providing services and support for space surveillance and traffic management**, Proc. 2nd ESA NEO and debris detection conference, Darmstadt, Germany.

Vananti A, Lu Y, Schildknecht T (2023) **Attitude estimation of H2A rocket body from light curve measurements**, Int. J. Astrophys. Space Sci. 11.

Abbreviations

AIUB	Astronomical Institute, Univ. Bern
IADC	Inter-Agency Space Debris Coordination Committee
ISON	International Scientific Optical Network
SMARTnet	SMall Aperture Robotic Telescope network
SSA	Space Situational Awareness
ZIMLAT	Zimmerwald Laser & Astrometry Telescope
ZimSMART	Zimmerwald SMall Aperture Robotic Telescope



Debris clouds from three fragmentations of upper stages in high-altitude orbits.

8.2 ESA Mission VIGIL/EUV Imager

Purpose of Research

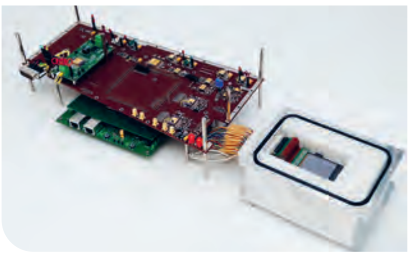
The Vigil Mission's primary objective is to station a satellite at the 5th Lagrange point (L5) to continuously monitor the Sun and the region between Earth and the Sun. It aims to enhance space weather predictions by providing real-time data, issuing event-based warnings for solar events, and improving forecasts for space weather impacts. Observing from L5 complements existing monitoring along the Sun-Earth line, enabling more accurate predictions and early warnings for potentially hazardous solar conditions.

The EUV imager will allow us to study extreme space weather events, and answer fundamental questions about the ground state of Space Weather as well – this includes solar wind formation, coronal mass ejection acceleration and propagation. The Extreme UV (EUV) imager will coordinate with the magnetic field measurements and coronagraphic images to provide a full view of solar activity that has an impact on the Earth's atmosphere.

Past Achievements and Status

The EUV imager planned for VIGIL was announced by NASA in June 2023 as an Instrument of Opportunity. PMOD/WRC was involved in different US consortia proposals. In all instrument proposals, PMOD/WRC is listed as the supplier of the Front-End-Electronics. NASA announced the selection of the Joint EUV coronal Diagnostic Investigation (JEDI) imager on 21 May led by Don Hassler at SWRI – work will commence soon. Due to the tight schedule after selection, PMOD/WRC applied for a pre-development contract at ESA. The goal of this activity was basically a Technology Readiness Level (TRL) rise for the complete FEE, as well as to reduce known risks by developing a fully functional breadboard FEE. Spare detectors from the Solar Orbiter EUV imager were integrated, as these are also to be used in the planned VIGIL EUV imager.

A camera FEE breadboard has been constructed to verify performance requirements, such as signal resolution, signal-to-noise ratio, pixel sensor control and overall telemetry/telecommand (TM/TC) functionality. This included image acquisition, signal conversion and data transfer via a SpaceWire interface. Analogue and digital hardware have been developed at PMOD/WRC. The instrument controller incorporates a Field Programmable Gate Array (FPGA) with a soft-core processor. FPGA programming and the Electrical Ground Support Equipment (EGSE) software to operate the electronics were provided by a Swiss industry partner.



Front-End Electronics during characterisation.

Time-Line	From	To
Planning	Jul. 2023	Sep. 2023
Construction	Aug. 2023	Nov. 2023
Measurement phase	Dec. 2023	Jan. 2024
Data evaluation	Jan. 2024	Mar. 2024

The VIGIL mission. Image credit: ESA.

Abbreviations

EUV	Extreme UV
FEE	Front-End Electronics

Institute
Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre (PMOD/WRC), Davos, Switzerland

In cooperation with
ESA

Swiss Principal Contact
L. Harra (PMOD/WRC)

Co-Contacts(s)
S. Koller, A. Morandi (PMOD/WRC)

Contribution
Research based on existing instrument(s)

Industrial hardware/software contract(s) to
dlab GmbH, Switzerland

Website
esa.int/Space_Safety/Vigil

9 Earth Observation, Remote Sensing, GNSS

9.1 COST-G – Combination Service for Time-Variable Gravity Fields

COST-G
Combination Service for Time-variable Gravity Fields

Purpose of Research

Ultra-precise inter-satellite ranging, as performed from 2002 to 2017 by the Gravity Recovery And Climate Experiment (GRACE) mission, has been established as the state-of-the-art technique to globally observe mass variations in the Earth system from space. Such measurements have continued since March 2018 with the follow-on mission, GRACE-FO. An increasing number of institutions are processing the GRACE/GRACE-FO Level-1B instrument data to derive mass variations on a monthly basis.

Although each new release of monthly gravity fields represents a significant improvement with respect to earlier releases, the solutions of different institutions usually differ considerably in terms of their signal-to-noise ratio. In the frame of the European Gravity Service for Improved Emergency Management (EGSIEM) initiative (2015–2017), which received funding from the European Commission, a prototype of a scientific combination service was set up to demonstrate that improved solutions may be derived by combining individual solutions which are based on different approaches but also on commonly agreed processing standards.

Since July 2019, the Combination Service of Time-Variable Gravity Fields (COST-G) continues the activities of the scientific combination prototype service of the EGSIEM initiative to realise a long-awaited standardisation of gravity-derived mass transport products under the umbrella of the International Association of Geodesy (IAG). In the frame of the Global Gravity-based Groundwater Product (G3P) initiative, which again was funded by the European Commission, the COST-G combination was extended to the monthly gravity fields derived from GRACE-FO data, and the weighting scheme has been adapted to better accommodate the continuously advancing analysis techniques of the individual COST-G Analysis Centers (ACs).

Past Achievements and Status

COST-G was formally established at the 2019 General Assembly of the International Union of Geodesy and Geophysics (IUGG) as a new Product Center of IAG's International Gravity Field Service (IGFS) for time-variable gravity fields. COST-G is providing consolidated monthly global gravity models with improved quality, robustness, and reliability of either reprocessed time-series of the GRACE mission, where the COST-G analysis centers agreed upon consistent processing standards, or operationally produced solutions based on GRACE-FO low-low satellite-to-satellite tracking (ll-SST), where the analysis centers are free to apply their most recent analysis techniques and tools. In addition, COST-G makes use of existing and publicly available solutions or normal equations of Partner Analysis Centers, who are directly linked to the GRACE and GRACE-FO project.

The combined products are provided in terms of spherical harmonic coefficients and derived global grids or time-series of surface mass variations in specific areas. COST-G is providing a first release of combined GRACE monthly gravity fields covering the entire GRACE time period between April 2002 and June 2017, and since November 2020 also operational combinations of GRACE-FO, which are made available with a latency of 3 months. Currently, COST-G is being extended to collaborate with the very active Chinese ACs of GRACE/GRACE-FO data and a second release of the GRACE combination is being

Institute
Astronomical Inst., Univ. Bern (AIUB), Bern, Switzerland

In cooperation with
COST-G Consortium

Principal/Swiss Investigator(s)
A. Jäggi (AIUB)

Co-Investigator(s)
U. Meyer (AIUB)

Website
cost-g.org

prepared, based on the most recent gravity field releases of the established ACs, but also taking into account the GRACE time-series of the new COST-G partners. COST-G also provides combined monthly gravity fields from non-dedicated data such as GPS high-low satellite-to-satellite tracking (hl-SST) data of the Swarm mission as an operational product in the frame of an ESA initiative. In addition, a fitted signal model (FSM) for application in operational precise orbit determination (POD) of Low Earth Orbiters (LEO) is generated and updated quarterly, to always allow for up-to-date predictions of gravity field variations. The COST-G FSM has recently been adapted by the Copernicus POD Service (CPOD) for the operational orbit determination of ESA's fleet of Sentinel satellites.

Publications

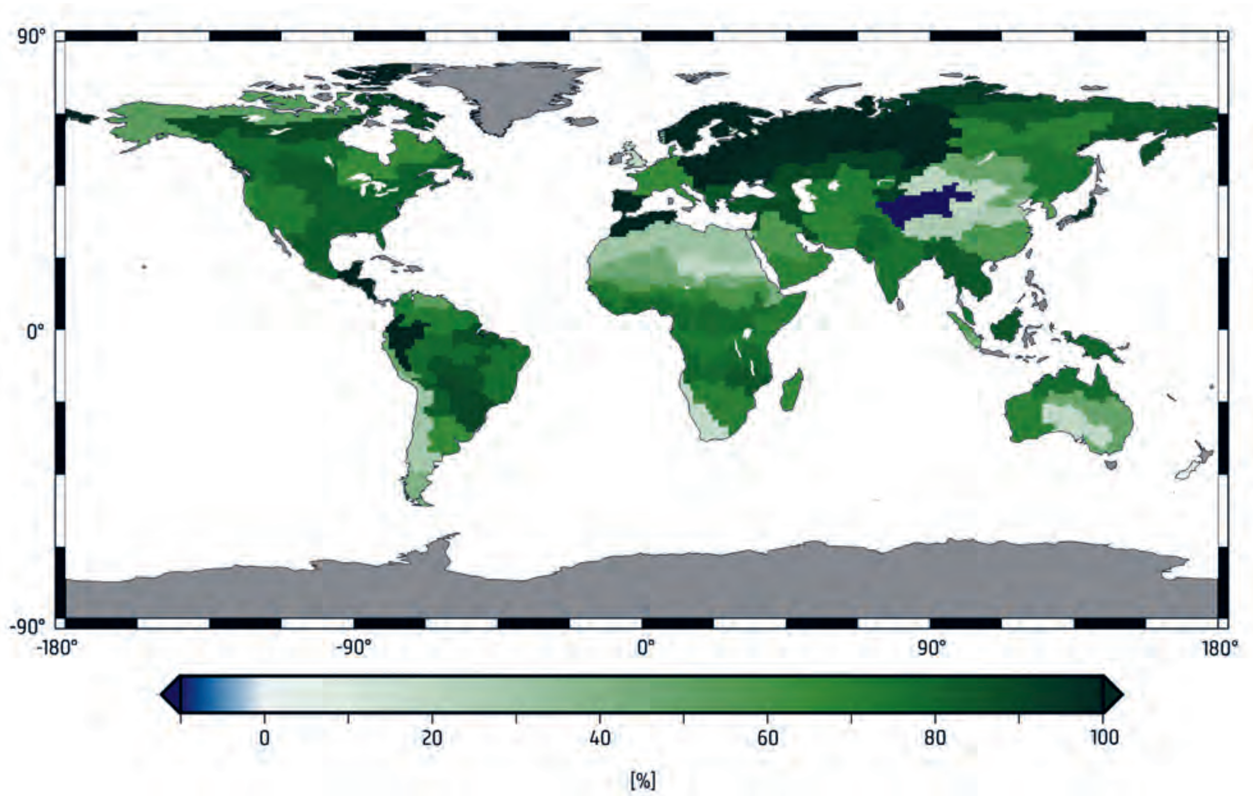
Jäggi A et al. (2020) **International Combination Service for Time-variable Gravity Fields (COST-G) – Start of Operational Phase and Future Perspectives**, Int. Assoc. Geodesy Symposia Series, 152: 57–65, doi.org/10.1007/1345_2020_109

Meyer U et al. (2024) **Combined monthly GRACE-FO gravity fields for a Global Gravity-based Groundwater Product**, Geophys. J. Int., 236(1): 456–469, doi.org/10.1093/gji/ggad437

Peter H, Meyer U, Lasser M, Jäggi A (2022) **COST-G gravity field models for precise orbit determination of Low Earth Orbiting Satellites**, Adv. Space Res., 69(12): 4155-4168, doi.org/10.1007/s00190-022-01678-x

Abbreviations

AC	Analysis Center
COST-G	Combination Service for Time-Variable Gravity Fields
EGSIEM	European Gravity Service for Improved Emergency Management
GRACE	Gravity Recovery And Climate Experiment
GRACE-FO	GRACE Follow-On
G3P	Global Gravity-Based Groundwater Product



Percentage-wise improvement in signal-to-noise ratio within major river basins, comparing the G3P combination for the GRACE-FO period with the time-series from the German Research Centre for Geosciences (GFZ), Potsdam, Germany (plot courtesy of GFZ).

9.2 Copernicus Precise Orbit Determination Service

Purpose of Research

Copernicus is the European Programme for the establishment of a European capacity for Earth Observation. Based on satellite and in-situ observations, the Copernicus services deliver near-real-time data on a global level to improve the understanding of our planet and to sustainably manage our environment.

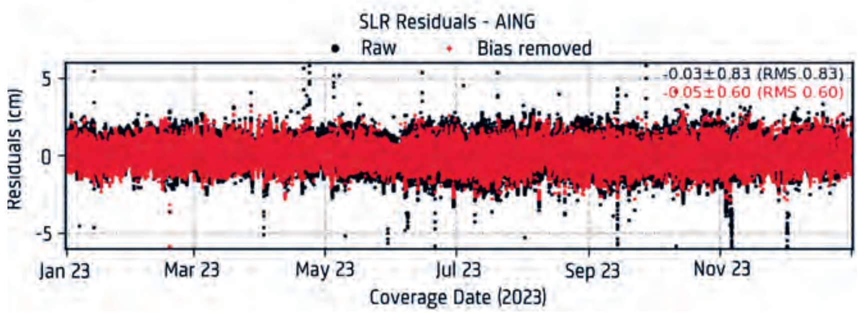
The core of the Copernicus programme consists of Earth observation satellites. The so-called Sentinel satellites are developed for the specific needs of the Copernicus programme. Sentinel-1 provides all-weather, day and night radar imagery for land and ocean services. The twin satellites, Sentinel-1A and Sentinel-1B, were launched on 3 April 2014 and 25 April 2016, respectively. The official, non-time-critical Sentinel-1 orbit solutions are expected to fulfill an accuracy requirement of 5 cm 3D root-mean-square (RMS).

Sentinel-2 provides high-resolution optical imagery for land services. The twin satellites, Sentinel-2A and Sentinel-2B, were launched on 22 June 2015 and 7 March 2017, respectively. No stringent accuracy requirement has to be fulfilled for the Sentinel-2 orbit solutions.

Sentinel-3 provides high-accuracy optical, radar and altimetry data for marine and land services. The twin satellites, Sentinel-3A and Sentinel-3B, were launched on 16 February 2016 and 25 April 2018, respectively. The official, non-time-critical Sentinel-3 orbit solutions need to fulfill an accuracy requirement of 2 cm in the radial component.

Sentinel-6 Michael Freilich is the world's next radar altimetry reference mission, set to extend the legacy of sea-surface height measurements until at least 2030. The satellite was launched on 21 November 2020. It is the first Sentinel satellite equipped with a multi-GNSS receiver, which can make use of both GPS and Galileo signals, to perform the mission-critical precise orbit determination.

As part of ESA's Copernicus Precise Orbit Determination (CPOD) Service, the CPOD Quality Working Group (QWG) regularly delivers independent orbit solutions for Sentinel 1A/B, 2A/B, 3A/B, and 6A generated with different state-of-the-art software packages and based on different reduced-dynamic orbit determination techniques. These alternative orbit solutions are used to check the quality and to improve the official, non-time-critical orbit solutions of the CPOD Service.



SLR residuals of the dynamic orbit solutions (AING) computed at AIUB for the satellite Sentinel-6A for the year 2023 (black: original residuals, red: after bias removal).

Institute
Astronomical Inst., Univ. Bern (AIUB), Bern, Switzerland

In cooperation with
ESA's CPOD Quality Working Group

Principal Investigator(s)
J. Fernandez (www.GMV.com)

Swiss Principal Investigator(s)
A. Jäggi (AIUB)

Co-Investigator(s)
D. Arnold (AIUB)

Website
copernicus.eu

Past Achievements and Status

Orbit solutions delivered by the members of the CPOD QWG are used for the validation of the non-time-critical orbit solutions on a regular basis. Every four months a so-called Regular Service Review (RSR) is performed. Orbit solutions from a selected time interval within the RSR period are compared with each other, to a combined solution and, in the case of Sentinel-3 and Sentinel-6, to Satellite Laser Ranging (SLR). The Astronomical Institute of the University of Bern (AIUB) contributes two solutions, a reduced-dynamic solution without explicit modelling of non-gravitational forces and a fully dynamic solution relying on a more detailed force model. The RSR analyses confirm that the quality of the delivered AIUB solutions is among the best of all solutions contributing to the CPOD QWG. Recently, the AIUB processing has also started to include improved manoeuvre handling strategies.

In order to further improve the quality of the official CPOD solutions, replacements of the EIGEN-GRGS-RL04 mean gravity field model were investigated to better reflect the time-varying part of the Earth's gravity field. Based on reprocessing campaigns of Sentinel-3A/B, it was shown that the COST-G Fitted Signal Models, which are operationally computed at the AIUB in the frame of the Combination Service of Time-Variable Gravity Fields (COST-G), significantly improve the orbital accuracy and yield smaller empirical accelerations estimated in the orbit determination process. Starting on 18 July 2023, ESA's CPOD Service deployed a new version of the system (3.3.0) which uses the COST-G Fitted Signal Models for gravity field modelling in all the operational chains.

Artist's impression of the Sentinel-6A satellite. Image credit: ESA.

Publications

Fernández M et al. (2022) **Copernicus Sentinel-1 Reprocessing Campaign**, Adv. Space Res., 70(2): 249–267, doi.org/10.1016/j.asr.2022.04.036

Fernandez J et al. (2024) **The Copernicus POD Service**, Adv. Space Res., in press, doi.org/10.1016/j.asr.2024.02.056

Mao X, Arnold D, Kalarus M, Padovan S, Jäggi A (2023) **GNSS-based precise orbit determination for maneuvering LEO satellites**, GPS Solutions, 27: 147, doi.org/10.1007/s10291-023-01494-6

Peter H, Meyer U, Lasser M, Jäggi A (2022) **COST-G gravity field models for precise orbit determination of Low Earth Orbiting Satellites**, Adv. Space Res., 69(12): 4155-4168, doi.org/10.1007/s00190-022-01678-x

Abbreviations

AIUB	Astronomical Institute, Univ. Bern
CODE	Center for Orbit Determination in Europe
COST-G	Combination Service for Time-variable Gravity Fields
CPOD	Copernicus Precise Orbit Determination
CPOD QWG	CPOD Quality Working Group
GNSS	Global Navigation Satellite System
RSR	Regular Service Review

9.3 ARES – Airborne Research Facility of the Earth System

AIRBORNE RESEARCH OF THE EARTH SYSTEM

Institute
Remote Sensing Labs. (RSL)
Dept. Geography, Univ. Zurich,
Zurich, Switzerland

In cooperation with
ETH Zurich
Institute for Mathematics, Univ. Zurich (UZH)
Inst. Atmos. Climate Science
(IAC, ETH Zurich)
Inst. Agricultural Sciences (IAS, ETH Zurich)
Inst. Geodesy & Photogramm.
(IGP, ETH Zurich)
EMPA; EAWAG; EPFL ENAC; Univ. Fribourg (UniFr); Inst. des Dynam. de la Surface Terrestre, Univ. Lausanne (UniL)

Principal/Swiss Investigator(s)
M. E. Schaepman (RSL)

Co-Investigator(s)
A. Hueni (RSL), R. Furrer (UZH)
S. Seneviratne (IAC. ETHZ), N. Buchmann (IAS, ETHZ)
K. Schindler (IGP, ETHZ), D. Brunner (EMPA)
D. Odermatt (EAWAG), M. Hoelzle (UniFr)
R. Veron (EPFL ENAC), G. Mariethoz (UniL)

Contribution
ARES is an airborne research facility to predominantly address research questions within the Earth System Sciences

Industrial hardware contract(s)
NASA/JPL for the development of the IS sensor head in collaboration with the Zurich Univ. for Applied Sciences (ZHAW) for the development of the flight hardware and software in collaboration with UZH

Website
ares-observatory.ch

Purpose of Research

The Airborne Research Facility of the Earth System (ARES) is an airborne research facility to mainly address research questions within the Earth System Sciences.

The main components of ARES are:
- An aircraft, leased or contracted during flight periods.
- An instrument package consisting of an imaging spectrometer (IS), a multispectral LiDAR, and a high-performance photogrammetric camera (hpPC).
- A flight management, instrument control and navigational system giving attitude and positional information allowing an automated georectification of data products.

The goal of this project is to establish the ARES infrastructure, including purchase/development of hardware and software, integration of the components, airworthiness certifications, acceptance tests and establishment of payload specific processing and archiving facilities. In parallel, flight missions are carried out within the ARES framework using existing sensors such as the Airborne Prism Exp. (APEX) or AVIRIS-NG (next generation) until the native ARES sensors are operational.

Past Achievements and Status

The CWIS-II sensor head, now referred to as AVIRIS-4, has been integrated with flight hardware and software by ZHAW. AVIRIS-4 obtained flight certification in Feb. 2024 and a first successful test flight was carried out in Mar. 2024. From Spring of 2024 onwards, AVIRIS-4 imaging missions can take place for interested parties across Europe. The next phase includes the certification to allow tandem operations with a full waveform LIDAR onboard the same aircraft. Updates and further information can be found on the ARES web page: ares-observatory.ch

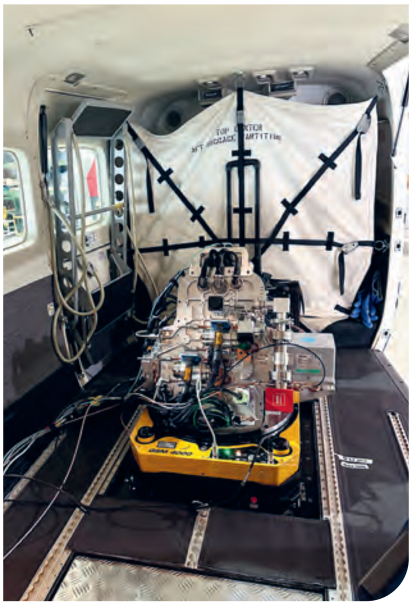
Time-Line	From	To
Planning	2017	2018
Construction	2018	2024
Measurement phase	2024	ongoing
Data evaluation	2024	ongoing

Publications

Green RO et al. (2022) **Airborne Visible/ Infrared Imaging Spectrometer 3 (AVIRIS-3)**, IEEE Aerospace Conference (AERO).

Abbreviations

ARES	Airborne Research Facility of the Earth System
AVIRIS	Airborne Visible / Infrared Imaging Spectrometer



AVIRIS-4 instrument built into a Cessna Caravan operated by Swiss Flight Services.

9.4 Arctic Weather Satellite

Purpose of Research

The Arctic Weather Satellite (AWS) is a prototype mission for the first meteorological constellation (EPS-Sterna) that will be used for operational weather forecasting. This constellation will consist of six SmallSats built by OHB Sweden on three orbital planes. Each satellite carries a single instrument: The microwave crosstrack radiometer, which is built by AAC Omnisys. The radiometer operates in the 54, 89, 183 and 325 GHz bands which are used to retrieve temperature and water vapour profiles as well as liquid water content and precipitation. The Institute of Applied Physics (IAP) at the University of Bern is designing and manufacturing the onboard calibration target (OBCT) and three different on-ground calibration targets (OGCT). The first OGCT is at a cryogenic temperature, representing the cold sky view in orbit. The second OGCT can have a variable temperature, representing the brightness temperature of the atmosphere. The third OGCT is at room temperature as an independent target from the OBCT for on-ground calibration. IAP developed a custom absorber for the variable target, built and delivered all targets, and consulted during the radiometric test measurements. Furthermore, the IAP optimised the quasi-optics of the radiometer, and simulated the antenna patterns for all bands and several scan angles using physical optics and a method of moment simulations, which included the complete structure of the radiometer.

Past Achievements and Status

The OBCT was manufactured, and thermally, mechanically and RF tested at the University of Bern. It was then delivered and integrated in the instrument. Furthermore, all OGCTs were designed, RF tested and delivered to AAC Omnisys, and radiometric testing of the instrument was performed. The instrument has successfully completed the test campaign and is due to launch in June 2024.

Publications

Albers R, Emrich A, Murk A (2023) IEEE Open J. Antennas and Propagation 4: 686–694, doi.org/10.1109/OJAP.2023.3295390

Albers R et al. (2024) 18th Eur. Conf. Antennas and Propagation (EUCAP2024).

Plüss T et al. (2023) Space Microwave Week, ESTEC.

Abbreviations

AWS	Arctic Weather Satellite
OBCT	Onboard Calibration Target
OGCT	On-ground Calibration Target

Time-Line	From	To
Planning	2020	2022
Construction	2022	2023
Measurement phase	2023	2023
Data evaluation	2024	2024

The Arctic Weather Satellite (AWS) during vibration testing at OHB, Sweden. Image credit: OHB.

On-board calibration target developed and manufactured by UNIBE. Image credit: UNIBE.

Institute
Inst. Applied Phys. (IAP), Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
AAC Omnisys, Sweden

Swiss Principal Investigator(s)
A. Murk (UNIBE)

Co-Investigator(s)
R. Albers (UNIBE)

Contribution
Development of on-board and on-ground calibration equipment and simulation of instrument performance.

Industrial hardware contract(s)
AAC Omnisys, Sweden

Website
esa.int/Applications/Observing_the_Earth/Meteorological_missions/Arctic_Weather_Satellite

9.5 SPECCHIO – Spectral Information System

Institute
Remote Sensing Labs. (RSL)
Dept. Geography, Univ. Zurich
Zurich., Switzerland

In cooperation with
Geoscience Australia (GA)
SENSECO COST Action
EcoSIS

Principal/Swiss Investigator(s)
A. Hueni (RSL)

Co-Investigator(s)
L. Chisholm (UoW, Australia)
M. E. Schaepman (RSL)
M. Thankappan (GA)
N. Fox, National Physical Lab., (NPL)

Contribution
Development of software: Spectral Information System for the storage of spectral field and laboratory data and associated metadata.

Website
specchio.ch

Purpose of Research

Scientific efforts to observe the state of natural systems over time, allowing the prediction of future states, have led to a burgeoning interest for organised storage of spectral field data and associated metadata, seen as being key to the successful and efficient modelling of such systems.

A centralised system for such data, established for the remote sensing community, aims to standardise storage parameters and metadata, thus fostering best practice protocols and collaborative research. The use of a spectral information system not only ensures the long-term storage of data but supports scientists in data analysis activities, essentially leading to improved repeatability of results, superior reprocessing capabilities, and promotion of best practice.

Past Achievements and Status

The Spectral Information System (SPECCHIO) remains under active development. SPECCHIO is installed in about 40 research institutions world-wide, and is well-used in research and teaching activities at the Remote Sensing Laboratories, University of Zurich.

SPECCHIO has been updated to support the storage of uncertainty budgets in the structure of uncertainty tree diagrams. SPECCHIO is used operationally to carry out calibration/validation (CAL/VAL) for airborne imaging spectrometer campaigns with the Airborne Prism Experiment (APEX) and Airborne Visible/Infrared Imaging Spectrometer – Next Generation (AVIRIS-NG) instruments in support of satellite end-to-end simulations for ESA. The Australian instance of SPECCHIO is hosted by Geoscience Australia within the framework of Digital Earth Australia.

SPECCHIO is today the most advanced spectral information system within the domain of Earth observing remote sensing.

SPECCHIO is also open source and is available as a virtual machine image, which allows anyone to run the full system on their personal laptop, thus supporting its full functionality under field conditions.

For further information please visit: specchio.ch.

Publications

Hueni A, Chisholm L, Ong C, Malthus T, Wyatt M, Trim SA, Schaepman M E, Thankappan M (2020) **The SPECCHIO Spectral Information System**, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 13: 5789–5799.

Hueni A, Mason K, Trim S (2023) **Uncertainty support in the spectral information system SPECCHIO**, IEEE J. Selected Topics in Applied Earth Observations and Remote Sensing 16: 2668–2680.

Abbreviations

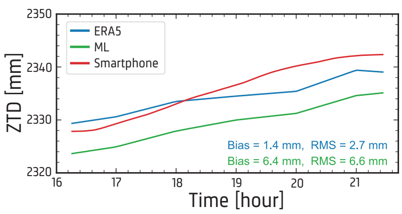
APEX	Airborne Prism Experiment
AVIRIS-NG	Airborne Visible / Infrared Imaging Spectrometer – Next Generation
CAL/VAL	Calibration/Validation
FLEX	Fluorescence Explorer Mission
SPECCHIO	Spectral Information System

9.6 CAMALIOT – AppliCation of Machine Learning Technology for GNSS IoT Data Fusion

Purpose of Research

GNSS infrastructure has been growing significantly in recent years. In the space segment, four global constellations are operational, including the European Galileo system. On the Earth's surface, tens of thousands of permanent GNSS stations are continuously recording data. In addition, millions of Internet-of-Things (IoT) devices, including smartphones, use GNSS for positioning. Due to the large number of devices, IoT data offer great potential for GNSS science exploitations, with unprecedented spatio-temporal resolution. However, access to IoT data for scientific purposes is currently limited and the data processing is challenging.

The project CAMALIOT aims to address these issues in order to increase the usability of IoT GNSS data for scientific purposes. It encompasses the whole pipeline from collecting raw IoT GNSS data, developing methods for efficiently and automatically processing them, to finally demonstrate their suitability for scientific applications, including the determination and prediction of atmospheric parameters. This way, the project will extend the capabilities of the GNSS Science Support Centre (GSSC) by ESA, which offers GNSS data and processing services for various domains.



Zenith Total Delay (ZTD) estimates from an example of crowdsourced smartphone GNSS data. The ZTDs derived from ERA5, an ML-based ZTD product and the smartphone GNSS data are represented by blue, green and red lines, respectively (Pan et al., 2024).

Past Achievements and Status

The CAMALIOT Android app was developed to collect GNSS observations through crowd-sourcing, with successful campaigns reaching more than 1200 active participants and gathering a significant data volume with global coverage (see image on right). Cloud-native software was designed to handle GNSS data acquisition, ingestion, preprocessing, and analysis. Careful processing of the smartphone data revealed that in optimal cases, tropospheric parameters can be determined with accuracies of less than 1 cm in terms of zenith total delay (see Figure below). The project also explored machine learning approaches for spatial modelling and forecasting of atmospheric parameters. Demonstrators of the ML approaches in the form of so-called datalabs have been created and run operationally on the GNSS Science Support Centre (GSSC) hosted by ESA. While the project officially ended in 2022, data collection through the Android app has been continued to extend the crowd-sourced GNSS dataset for scientific purposes. Additional capabilities were added to the Android app in 2023 to log additional sensor data to aid the retrieval of atmospheric parameters.

Publications

Pan Y et al. (2024) **Determination of high-precision tropospheric delays using crowdsourced smartphone GNSS data,** EGUsphere [preprint], doi.org/10.5194/egusphere-2024-66

See L et al. (2023) **Collecting volunteered geographic information from the Global Navigation Satellite System (GNSS): Experiences from the CAMALIOT Project**, Int. J. Dig. Earth, doi.org/10.1080/17538947.2023.2239761

Soja B et al. (2023) **Machine learning-based exploitation of crowdsourced GNSS data for atmospheric studies**, IEEE IGARSS, Pasadena CA, doi.org/10.1109/IGARSS52108.2023.10283441

Spatial distribution of crowd-sourced data collected between 17 March 2022 and 30 November 2022 (See et al., 2023).

Institute
Inst. Geodesy and Photogrammetry, Dept. Civil, Environ. & Geomatic Eng., ETH Zurich, Zurich, Switzerland

In cooperation with
Novel Data Ecosys. Sustainability, Int. Inst. Applied Sys. Analysis (IIASA), Laxenburg, Austria
European Space Astronomy Centre, ESA, Madrid, Spain

Principal/Swiss Investigator(s)
B. Soja (ETH Zurich)

Co-Investigator(s)
I. McCallum (IIASA), V. Navarro (ESA)

Contribution
Crowdsourcing of smartphone-based raw GNSS data.

Website
camaliot.org
space.igp.ethz.ch/research/camaliot.html

9.7 CSAR on TRUTHS

The TRUTHS mission will serve as an in-orbit calibration laboratory for other Earth observing missions by providing traceability to the on-board cryogenic radiometer CSAR.

Institute
Phys. Met. Observatorium Davos/ World Radiation Center (PMOD/WRC), Davos, Switzerland

In cooperation with
Thales Alenia Space CH

Principal Investigator(s)
Airbus Defence and Space UK (prime contractor)

Swiss Principal Investigator(s)
Thales Alenia Space CH (CSAR instrument prime)

Co-Investigator(s)
W. Finsterle (PMOD/WRC)

Contribution
Development & construction of the CSAR instrument for the TRUTHS spacecraft

Website
npl.co.uk/earth-observation/truths

Purpose of Research

The Traceable Radiometry Underpinning Terrestrial- and Helio-Studies, TRUTHS, mission will be a 'standards laboratory in space', setting the 'gold standard' reference for climate measurements. Carrying a Cryogenic Solar Absolute Radiometer (CSAR) and a hyperspectral imaging spectrometer as well as a novel onboard calibration system, TRUTHS will make continuous measurements of incoming solar radiation and reflected radiation to evaluate Earth's energy-in to energy-out ratio.

Past Achievements and Status

The ground-based CSAR, which has been operated at PMOD/WRC since 2010, has served as a testbed for studying and optimising the thermal performance of the CSAR instrument, which will be onboard TRUTHS. At present, the project is in phase B2, including pre-development studies and model simulations of the optical and thermal performance.

The photo shows a sensor cavity for TRUTHS. This prototype is used to optimise the process of applying a black carbon-nanotube coating to the inner surfaces of the cavity. Sophisticated and novel joining techniques are also being used for merging of the front and rear parts of the cavity to optimise heat conduction and to test the structural integrity at the temperature of liquid nitrogen (~77 K). CSAR on TRUTHS will eventually operate at even lower temperatures of 60–65 K.

Publications

Fehr T, Fox N, Marini A, Remedios J (2023), **Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) – A 'gold standard' imaging spectrometer in space to support climate emergency research**, EGU23, id. EGU-12399, DOI 10.5194/egusphere-egu23-12399

Abbreviations

CSAR	Cryogenic Solar Absolute Radiometer
TRUTHS	Traceable Radiometer Underpinning Terrestrial and Helio Studies

Time-Line	From	To
Planning	2022	2027
Construction	2027	2030
Measurement phase	2030	2035
Data evaluation	2030	2035

A prototype sensor cavity for the Cryogenic Solar Absolute Radiometer (CSAR).

9.8 Calibration Targets for MetOp-SG Instruments MWS and ICI

Purpose of Research

The Microwave Sounder (MWS) and Ice Cloud Imager (ICI) are two instruments for the second generation of Meteorological Operational Satellites (MetOp-SG). MWS includes microwave radiometers between 23 GHz and 230 GHz to measure atmospheric temperature and humidity profiles, while the ICI radiometers will cover frequencies between 175 GHz and 670 GHz to characterise ice clouds. A key component of MWS and ICI are their onboard blackbody targets, which are required for the accurate radiometric calibration of the instruments. The IAP at Univ. Bern is responsible for the electromagnetic design and the experimental verification of the on-board calibration targets of MWS and ICI.

The IAP is also contributing to the development of the on-ground calibration system for ICI, which will be used to verify the radiometric performance prior to launch by providing scenes with an either cryogenic or variable brightness temperature. It includes two temperature controlled wedged cavities for accurate calibration in a thermal-vacuum chamber, as well as a simpler liquid nitrogen target for system checks at ambient pressure. IAP optimised their geometry to match the ICI antenna pattern, verified the RF performance by measurements, and simulated the variation of the coupling efficiencies with the scan angle by using physical optics antenna simulations.

Past Achievements and Status

The RF performance of the three flight models and one spare model of the On-Board Calibration Targets (OBCT) for MWS and ICI were tested at UNIBE during 2020 to 2023 before they were shipped to Airbus for integration in the ICI and MWS instruments. The proto flight model of the ICI instrument successfully passed the test campaign with the on-ground calibration target designed by UNIBE. ICI and MWS are now installed on the first set of SAT-A and SAT-B satellites, which are scheduled for launch in 2025.

Publications

Döring D et al. (2021) **Thermal-Vacuum Qualification Testing of the MetOP-SG ICI OGCT, in: European Conference on Spacecraft Structures, Materials and Environmental Testing (ECSSMET 2021)**.

Murk A. (2022) **On-ground calibration of the MetOP-SG Ice Cloud Imager**, 32nd IEEE Int. Symp. Space THz Technology, (ISSTT 2022).

Schröder A et al. (2017), **Electromagnetic design of calibration targets for MetOp-SG microwave instruments**, IEEE Trans. THz Sci. Technol. 7: 677–685, doi.org/10.1109/TTHZ.2017.2757442

Abbreviations

ICI	Ice Cloud Imager
MWS	Microwave Sounder
OBCT	Onboard Calibration Target
OGCT	On-ground Calibration Target

Time-Line	From	To
Planning	2013	2015
Construction	2016	2018
Measurement phase	2018	2023

Installation of the ICI instrument on the MetOP-SG SAT-B satellite. Image credit: Airbus.

Institute
Inst. Applied Phys. (IAP), Univ. Bern (UNIBE), Bern, Switzerland

In cooperation with
TK Instruments, UK
Airbus Space and Defence, UK and Spain
IABG, Germany

Swiss Principal Investigator(s)
A. Murk (UNIBE)

Co-Investigator(s)
M. Kotiranta (UNIBE)

Contribution
Development of onboard and on-ground calibration equipment

Industrial hardware contract(s) to
TK Instruments, UK
IABG, Germany

10 Life Science

10.1 Low Back Pain of Astronauts: Holistic Approach to Determine Origin and Medical Implications

Measurement setup, Houston, USA, 2022.

Institute
Balgrist Univ. Hospital, Integrative Spinal Research ISR, Univ. Zürich (UNIZH), Zurich, Switzerland

In cooperation with
Inst. Medical Eng., Space Biology Group, Lucerne Univ. Applied Sciences and Arts (HSLU), Hergiswil, Switzerland

King's College London, Centre of Human & Applied Physiological Sciences (CHAPS), UK

Swiss Principal Investigator(s)
J. Swanenburg (UNIZH), M. Egli (HSLU)

Co-Investigator(s)
D. A. Green (ESA), F. Ille (HSLU), R. Sutter (Balgrist)

Contribution
Measurements of lumbar spinal motor control, ultrasonic examination of the lumbar intervertebral discs (IVD) and studies on isolated IVDs, cultivated under simulated microgravity

Websites
spacehub.uzh.ch/en/research-areas/space-life-science/spinal-health.html
balgrist.ch/forschung/forschergruppen/chiropraktische-medizin/jaap-swanenburg-phd

Purpose of Research

Astronauts exposed to microgravity often report lower back pain that can significantly affect their ability to work. Total unloading of the spine, which happens in microgravity, also leads to deconditioning of the paraspinal muscles and a change in spine movement kinematics. It has been shown that the lumbar curvature flattens by 11% after returning from an extended mission at the ISS. Only a few studies have investigated the thoracic portion of the spine. An assessment of the whole spine is needed for a complete and detailed picture of spinal curvature changes under various loading conditions. Unfortunately, ISS studies, parabolic flight studies, and bedrest studies have only been conducted among small subject groups. In summary, accurate and detailed measurement of the lumbar and thoracic spine with sufficient statistical power is required. This study aims to investigate lumbar and thoracic curvature and extensor muscle activity under changing gravity conditions.

Low back pain often relates to degenerated intervertebral discs (IVD). It is assumed that microgravity facilitates the degenerative processes of IVDs that then lead to a higher risk of astronauts developing an IVD herniation after their return from space. Furthermore, it is well known that microgravity induces swelling of the lumbar IVDs, which could also contribute to low back pain. To understand the microgravity-induced changes on a cellular level in IVDs, the science team will perform ground reference experiments on cultured bovine IVDs in a simulated microgravity environment. The data gathered by these experiments, in combination with the results from the astronaut studies, mentioned earlier, will provide a more holistic view of the low back pain problem astronauts are facing.

Past Achievements and Status

PI: Acceptance of Long Duration ISS Mission (Pre/Post) Study: Low back pain of astronauts: Holistic approach to determine the origin and medical implications (2020–2024).

PI: European Space Agency (ESA) access to 76th ESA partial gravity Parabolic Flight Campaign, December 2021: The effect of partial gravity on spinal stiffness.

PI: Access to 74th ESA partial gravity Parabolic Flight Campaign, December 2020: The effect of partial gravity on spinal stiffness.

PI: Access to 71st ESA Parabolic Flight Campaign, June 2019: The effect of changing gravity on spinal stiffness.

Publications

Swanenburg J et al. (2018) **Spinal stiffness in prone and upright postures during 0 – 1.8 g induced by parabolic flight**, Aerospace Medicine and Human Performance 89(6): 563–568.

Swanenburg J et al. (2020) **Microgravity and hypergravity induced by parabolic flight differently affect lumbar spinal stiffness**, Frontiers in Physiology 11: 562557.

Abbreviations

ISS	International Space Station
IVD	Intervertebral Discs
RPM	Random positioning machine

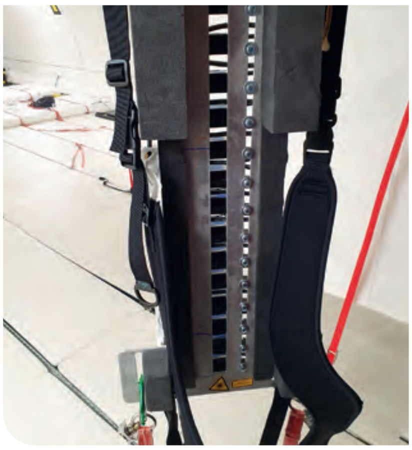
Time-Line	From	To
Planning	2019	2020
Construction	2021	2023
Measurement phase	2022	2026
Data evaluation	2023	2026

10.2 Spinal Curvature and Spinal Muscle Activity During Changing Gravity

Purpose of Research

Astronauts exposed to microgravity often report low back pain that can significantly affect their ability to work. Total unloading of the spine, which happens in microgravity, also leads to de-conditioning of the paraspinal muscles and a change in spine movement kinematics. It has been shown that the lumbar curvature flattens by 11% after returning from a long-duration mission at the Int. Space Station (ISS).

So far, only a few studies have investigated the thoracic portion of the spine and thus, crucial information is missing. A thorough assessment of the whole spine is needed for a complete and detailed picture of spinal curvature changes under various loading conditions. Unfortunately, ISS studies, parabolic flight studies, and bedrest studies have only been conducted among small subject groups, which lowers the scientific impact because of the potential lack of statistical power. In summary, accurate and detailed measurements of the lumbar and thoracic spine with sufficient statistical power are required. The objective of this study is to investigate lumbar and thoracic curvature and extensor muscle activity under changing gravity conditions.



Detailed view of the spinal curvature backpack.

Past Achievements and Status

We built a measurement set-up that fulfilled all parabolic flight requirements. Our set-up was a mobile and wearable device (see figures). The sensor array of 15 sensors fitted on an aluminium harness. These were connected to a micro controller attached to the leg holster. A Bluetooth transmitter is mounted on this leg holster that sends the measurement and control data to a laptop. In addition, a battery is attached to this leg holster, which provides the necessary power. For safety, an additional data logger is also mounted on the leg holster. The 'spinal curvature backpack' set-up has proven to be effective during the 80th and 83rd ESA Parabolic Flight Campaigns (PFC) to evaluate thoracic and lumbar spinal curvature.

So far, 18 subjects have been measured, and data analysis is ongoing.

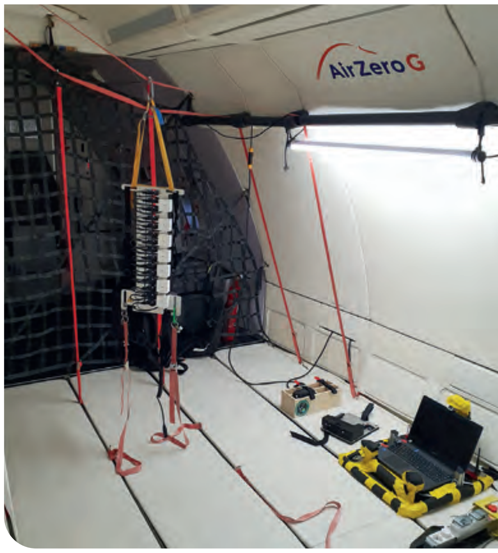
Publications

Häusler M, Hofstetter L, Schweinhardt P, Swanenburg J. (2020) **Influence of body position and axial load on spinal stiffness in healthy young adults**, Eur Spine J. 29(3): 455–461.

Swanenburg J et al. (2018) **Spinal stiffness in prone and upright postures during 0–1.8 g induced by parabolic flight**, Aerospace Medicine and Human Performance 89(6): 563–568.

Swanenburg J et al. (2020) **Microgravity and hypergravity induced by parabolic flight differently affect lumbar spinal stiffness**, Frontiers in Physiology 11: 562557.

Time-Line	From	To
Planning	Jun. 2021	Dec. 2021
Construction	Jan. 2022	Sep. 2022
Measurement phase	Oct. 2022	Dec. 2023
Data evaluation	Dec. 2023	Jun. 2024



Spinal curvature backpack.

Institute
Balgrist Univ. Hospital, Integrative Spinal Research ISR, Univ. Zürich (UNIZH), Zurich, Switzerland

UZH Space Hub, Air Force Center – Überlandstrasse 271, 8600 Dübendorf, Switzerland

In cooperation with
Inst. Medical Eng,. Space Biology Group, Lucerne Univ. Applied Sciences and Arts (HSLU), Hergiswil, Switzerland

Principal/Swiss Investigator(s)
J. Swanenburg (UNIZH)

Co-Investigator(s)
M. Egli (HSLU), A. Meinke (UNIZH)

Contribution
The spinal curvature is measured with the 'Spinal curvature backpack'.

Websites
spacehub.uzh.ch/en/research-areas/space-life-science/spinal-health.html
balgrist.ch/forschung/forschergruppen/chiropraktische-medizin/jaap-swanenburg-phd

10.3 Yeast Bioreactor Experiment

Institute
Inst. Medical Eng., School Eng. & Architecture, Lucerne Univ. Appl. Sci. & Arts (HSLU)
Hergiswil, Switzerland

In cooperation with
Vrije Univ. Brussel, Lab. Structural Biology, Dept. Bioeng. Sci., Brussels, Belgium

Ghent Univ., Lab. Protein Biochem. Biomol. Eng., Ghent, Belgium

KU Leuven & VIB, Dept. Molec. Microbiol., Lab. Molecular Cell Biology, Leuven, Belgium

Principal Investigator(s)
R. Willaert (Vrije Univ. Brussel)

Swiss Investigator(s)
M. Egli (HSLU)

Co-Investigator(s)
B. Devreese (Univ. Gent)
B. Rattenbacher (HSLU)
P. Van Dijck (KU Leuven & VIB)
B. Devreese (Univ. Gent)

Website
hslu.ch/de-ch/technik-architektur/ueber-uns/organisation/kompetenzzentren-und-forschungsgruppen/technik/bioscience-and-medical-engineering/weltraumbiologie

Purpose of Research

The project focuses on microgravity's effect on the physiology of the yeast strain Saccharomyces cerevisiae. Previous studies conducted in a simulated microgravity environment have shown a significant gene change. Furthermore, S. cerevisiae grows in clusters under microgravity, which is not the case when cultivated on the ground.

In the proposed experiment, S. cerevisiae will be used to investigate the effect of microgravity on yeast growth and induced stress responses by applying heat and osmotic shock.

An integrative-experimental approach will be used to assess the effect of microgravity. Therefore, various -omics technologies will be used to analyse the samples, i.e., fluxomics, transcriptomics, proteomics and genomics, and specific cell analysis methods. A network biology model for S. cerevisiae will be set up to process the -omics data.

This will lead to insight into how gravity influences global regulation of energy metabolism, (stress) signalling transduction pathways, transcriptional regulatory networks, gene regulatory networks, protein-protein interaction networks, and metabolic networks.

Yeast cultivation will be performed in a custom-made space bioreactor that allows continuous cultivation. This hardware will monitor and control growth parameters such as temperature and flow rate and monitor pH, oxygen, and carbon dioxide levels, which are necessary to achieve steady-state and stable growth. The samples will be automatically withdrawn, treated (shock), filtrated, and fixed.

Past Achievements and Status

The project's status is a delta B phase where scientific requirements for the hardware development are being established.

Further details can be found on our website:

hslu.ch/de-ch/technik-architektur/ueber-uns/organisation/kompetenzzentren-und-forschungsgruppen/technik/bioscience-and-medical-engineering/weltraumbiologie

Time-Line	From	To
Planning	2013	2014
Construction	2015	2023
Measurement phase	2024	2026
Data evaluation	2027	2028

10.4 OoDrop Experiment

Purpose of Research

Exposure to microgravity triggers numerous physiological adaptations in humans and animals. To date, the underlying molecular mechanisms are not well understood and several pathways have been proposed. Among other candidates, specific ion channels are hypothesised to be gravity- dependent, but until now it has not been possible to conclusively demonstrate gravity-dependency of specific protein entities.

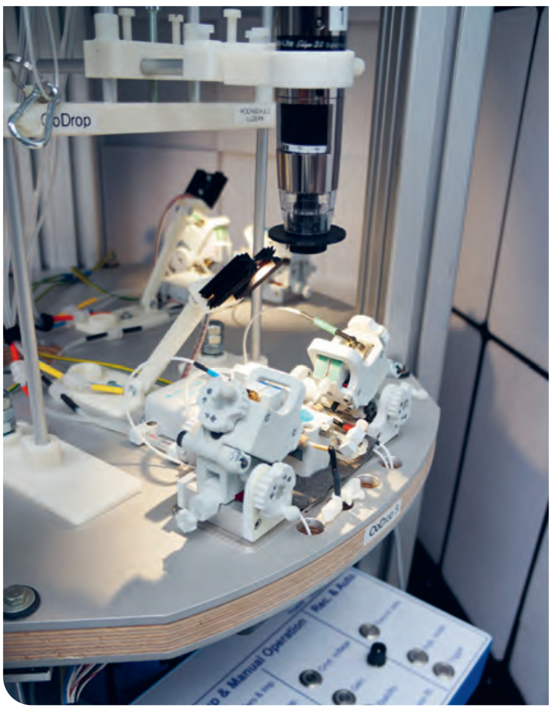
Past Achievements and Status

We developed a miniaturised two-electrode voltage clamp (TEVC), which allowed electrophysiological experiments on *Xenopus laevis* oocytes (frog eggs) using the GraviTower Bremen Prototype (GTB-Pro). The GTB-Pro, located at the Center of Applied Space Technology and Microgravity (ZARM; Bremen, Germany) is capable of flying experiments on a vertical parabolic trajectory, providing microgravity for a few seconds. As an interesting first candidate, we examined if the non-selective mechano-sensitive ion channel PIEZO1 is gravity-dependent. Oocytes were micro-injected with mRNA coding for PIEZO1, six days before the experiments. The results showed no difference between PIEZO1-overexpressing and control oocytes under acute microgravity conditions.

Abbreviations

GTB-Pro GraviTower Bremen Prototype
TEVC Two-Electrode Voltage Clamp
ZARM Center of Applied Space Technology and Microgravity

Time-Line	From	To
Planning	May 2020	Dec. 2020
Construction	Jan. 2021	May 2023
Measurement phase	Jun. 2023	Sep. 2023
Data evaluation	Nov. 2023	Mar. 2024



The OoDrop experiment hardware. A miniaturised two-electrode voltage clamp (TEVC) allows electrophysiological recordings on *Xenopus laevis* oocytes under microgravity conditions.

Institute
Lucerne Univ. Appl. Sci. & Arts (HSLU)
Horw, Switzerland

In cooperation with
Univ. Zurich, Faculty of Medicine, Inst. Anatomy & Zurich Kidney Center, Zürich, Switzerland

Principal/Swiss Investigator(s)
S. Wüest (HSLU)

Co-Investigator(s)
G. Cerretti, J. Polzer, S. Gerig, C. Zumbühl, C. Jost, L. Rüfenacht, R. Eberli, B. Bösch, J. Traversari, M. Horn, D. Invernot Pérez, C. Giger, K. F. Rattenbacher-Kiser, F. Ille, G. Székely, S. S. Lienkamp, M. Egli (HSLU)

Contribution
Miniaturisation of a two-electrode voltage clamp (TEVC) for *Xenopus laevis* oocytes.

Website
hslu.ch/imt

10.5 μFC – Microfluidic Concentrator for Potential Life Detection Mission

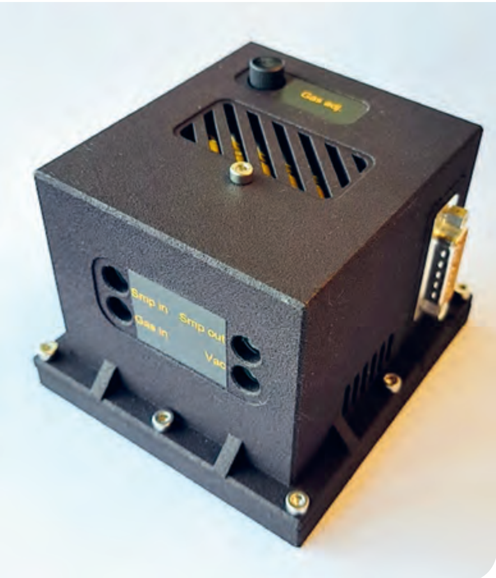


Image of the palm-sized uFC.

Institute
Univ. Zurich (UZH), Zurich, Switzerland

In cooperation with
NASA Jet Propulsion Lab. (JPL), USA

Principal Investigator(s)
P. A. Willis (JPL)

Swiss Principal Investigator(s)
F. Kehl (UZH)

Co-Investigator(s)
A. C. Noell, N. Oborny, M. Foote, M. Fernanda Mora (JPL)

Contribution
Development of a microfluidic sample concentrator for potential astrobiology spaceflight mission.

Website
astro.uzh.ch

Purpose of Research

A crucial aspect of our quest to explore the solar system involves the pursuit of discovering life beyond Earth. The potential signs of life, whether past or present, on other celestial bodies might be detectable through various means. A vital indicator could emerge at the molecular level, represented by organic biosignatures. These signatures might be observed as either the complexity within individual molecules or as specific distributions and characteristics of simpler organic compounds.

For the most effective investigation during astrobiology missions aimed at finding life, it is essential to employ techniques for organic compositional analysis alongside separation science. The exploration history of other planets, including endeavours by the Viking landers, the Huygens probe, and the Sample Analysis at Mars instrument suite currently in use on Mars, has heavily relied on gas chromatography coupled with mass spectrometry (GC-MS) for the segregation and identification of organic materials.

While GC-MS excels in analysing volatile or gaseous substances, it faces challenges with key polar molecules such as organic acids, especially when water, minerals, or salts are present in the samples. This issue becomes particularly significant as we plan for future astrobiology missions to ocean worlds such as Jupiter's moon, Europa, or Saturn's moon, Enceladus, where samples are expected to be aqueous and saline. For these types of samples, the most direct and effective analysis method involves liquid-based separation and analysis techniques.

Despite the high sensitivity of methods such as Capillary Electrophoresis coupled with Laser-Induced Fluorescence Detection (CE-LIF), it is anticipated that only very low concentrations of organics will be discovered during in-situ investigations on these icy moons. To address this challenge, Kehl and co-workers (University of Zurich) developed the μFC device, a compact, automated, gravity-independent microfluidic concentrator in collaboration with NASA's Jet Propulsion Laboratory (JPL, Pasadena, USA). This device is designed to concentrate dissolved components in a water sample by at least a factor of 10. The palm-sized prototype was delivered to JPL in early 2023 and is currently undergoing tests at the NASA laboratory.

Publications

Brinckerhoff WB, Willis PA, Ricco AJ, Kaplan DA, Danell RM, Grubisic A, … & Zacny K (2022) **Europan molecular indicators of life investigation (EMILI) for a future Europa lander mission**, Frontiers in Space Technologies 2: 12.

Mora MF, Kehl F, Tavares da Costa E, Bramall N, Willis PA (2020) **Fully automated microchip electrophoresis analyzer for potential life detection missions**, Analytical Chemistry 92: 19, 12959–12966.

Willis P, Mora MF, Noell A, Creamer J, Kehl F, Zamuruyev K, Templeton A (2021) **How to search for chemical biosignatures on ocean worlds**, Bull AAS: 53.

Abbreviations

CE-LIF	Capillary Electrophoresis coupled to Laser-induced Fluorescence Detection
GC-MS	Gas Chromatography–Mass Spectrometry
μFC	Microfluidic Concentrator

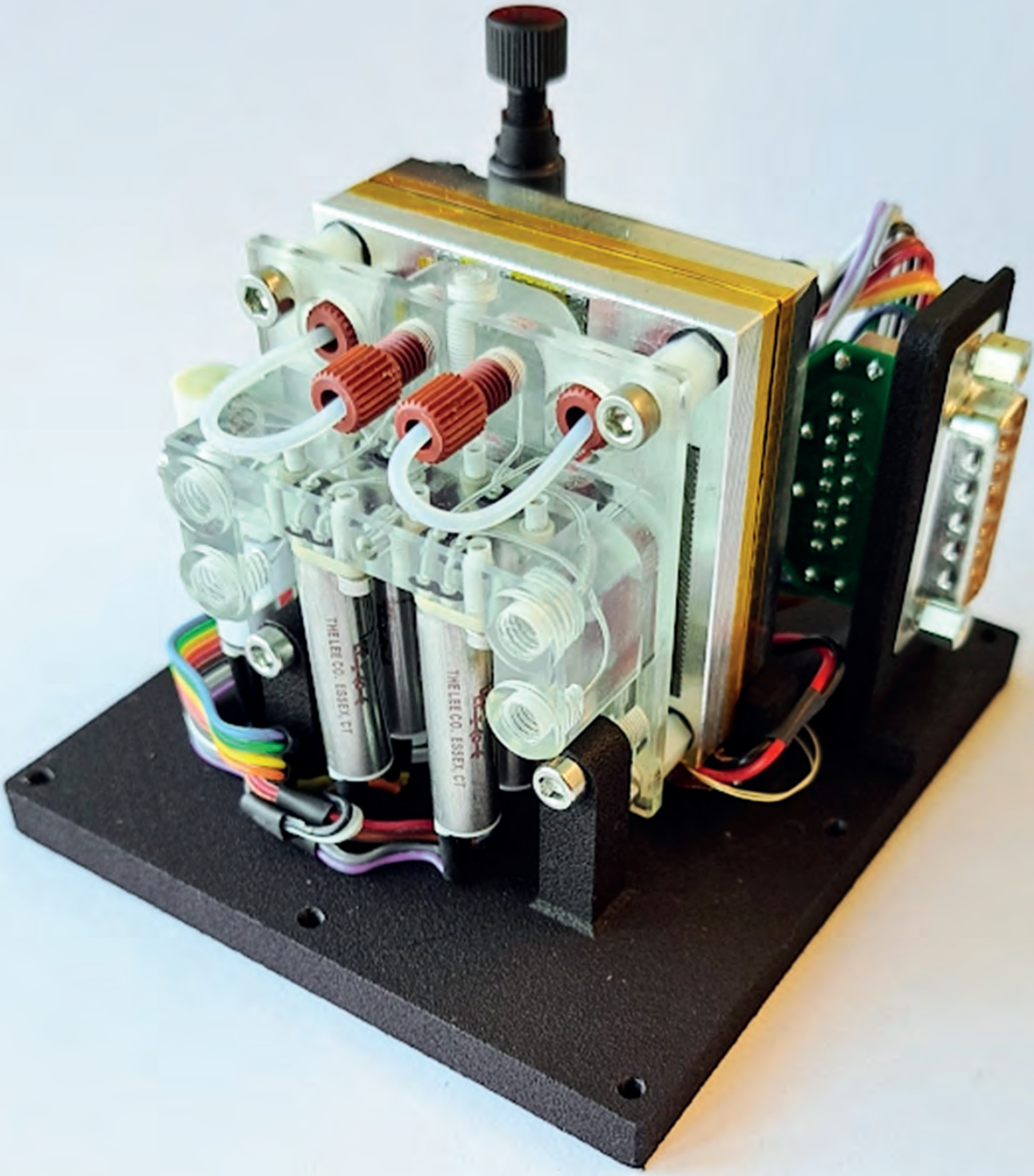


Image showing the internal components of the palm-sized uFC with the instrument cover removed.

11 Technologies

11.1 EURISA

Institute
Institute of Geophysics, ETH Zurich, Zurich, Switzerland

In cooperation with
EU Horizon2020
Exail, France
Airbus, France
German Aerospace Centre (DLR), Germany

Principal Investigator(s)
Elliot de Toldi (Exail)

Swiss Principal Investigator(s)
D. Giardini (ETH Zurich)

Co-Investigator(s)
L. Ferraioli (ETH Zurich)

Contribution
Development & construction of the Inertial Measurement Unit (IMU), accelerometer acquisition system

Website
eurisa-h2020.eu

Purpose of Research

EURISA is funded by the Horizon 2020 research and innovation programme of the European Union. EURISA aims to develop the first European cost-effective and efficient Inertial Measurement Unit (IMU) based on fibre-optic gyroscopes and quartz accelerometers for future space missions.

An IMU is a device that combines input from several different sensor types in order to accurately output a movement. It is composed of three accelerometers measuring velocity and acceleration and three gyroscopes measuring rotation and rotational rate. In space, IMUs are used on spacecraft, space probes, landers, rover and satellites.

Past Achievements and Status

ETH Zurich is in charge of the development of the data acquisition electronic system and of the sensor proximity electronics for the three accelerometers of the EURISA IMU. The accelerometers are based on Micro Electro-mechanical Systems (MEMS) technology developed by the company, Exail.

ETH Zurich developed two generations of the sensor proximity electronics in 2022 and 2023. Both units were delivered to Exail for integration with the sensors and testing.

A prototype of the acquisition electronics began in 2022 and was finished in 2023 by ETH Zurich. The prototype was delivered to Exail for system level flat-bed testing. The design of the engineering model of the acquisition electronics began in 2023, and the unit will be manufactured and tested in 2024.

Abbreviations

IMU	Inertial Measurement Unit
MEMS	Micro Electro-mechanical Systems

Time-Line	From	To
Planning	2020	2022
Construction	2022	2024
Measurement phase	2023	2025
Data evaluation	2024	2025

Rendering of the EURISA Inertial Measurement Unit assembly.

11.2 ARISE – Autonomous Robots for In-Situ Surface Exploration

Purpose of Research

The main goal of this activity is to identify, analyse and further advance critical technology for future lunar prospecting missions. Building on the knowledge of our teams acquired during the two consecutive ESA/ESTEC Space Resources Challenge field trials, it is key for us to critically assess the concepts and derive a number of development paths for further maturation.

This task is complemented by a review on likely lunar mission scenarios in terms of resource potential and international exploration focus. Based on the critical assessment of our technology and mission scenario, our objective is to define a plan to increase the technology readiness of selected technologies and to plan a path to verify the technology advancements.

Critical technologies include: i) global mission planning, ii) all-terrain mobility, iii) scalable autonomy, iv) self-aware navigation and planning, v) mapping and payload deployment, and vi) manipulation.

The outcome of these developments will be demonstrated in a lunar analogue mission at a Swiss test-site.

Past Achievements and Status

Winner of the ESA-ESRIC Space Resource Challenge 2020 - 2022. Winner of the DARPA Subterranean Challenge 2018 - 2021.

Publications

Arm P et al. (2022) **Results and lessons learned from the first field trial of the ESA-ESRIC space resources challenge of team GLIMPSE**, 16th Symp. Adv. Space Tech. Robotics & Automation (ASTRA 2022), ETH Zurich, Institute of Robotics and Intelligent Systems.

Arm P et al. (2023) **Scientific exploration of challenging planetary analog environments with a team of legged robots**, Science Robotics 8.80: eade9548

Kolvenbach H et al. (2022) **Traversing steep and granular Martian analog slopes with a dynamic quadrupedal robot**. Field Robotics 2: 910–939.

The legged robot ANYmal is investigating a scientifically interesting rock during a simulated lunar mission.

Three all-terrain robots prospecting the environment, similar as envisioned in future planetary exploration missions.

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Robotic Systems Lab, ETH Zurich, Zurich, Switzerland

In cooperation with
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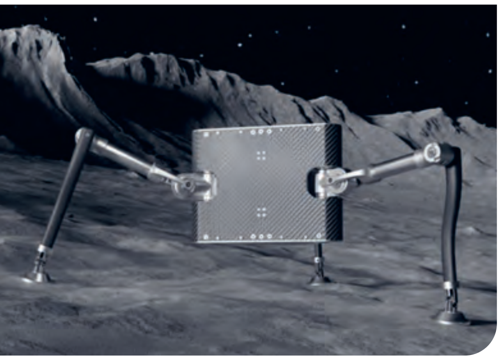
Contribution
Development of Missions and Robotics Technology for Resource Prospecting.

Website
rsl.ethz.ch/research/researchtopics/space-robotics.html

11.3 LunarLeaper



Artist's sketch of LunarLeaper.

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University of Bern (UNIBE), Bern, Switzerland
microcameras.space, Switzerland

and international partners:
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Poznan Univ. Technology (PUT), Poland
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KP Labs, Poland

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Contribution
Legged robot as robotic exploration platform

Industrial hardware contract(s)
microcameras.space, Switzerland

Website
lunarleaper.space

Purpose of Research

Lunar pits, also known as skylights, are collapse features on the lunar surface. As such, they might provide access to sub-surface lava tube systems that could harbour future human explorers for extended periods of time. They further provide a window into the Moon's ancient past, because they uniquely expose a record of the magnitude, timing, and composition of volcanic flows along their edges.

Here, we propose a mission to explore the Moon's sub-surface for the very first time: LunarLeaper. The mission is a 10 kg-class legged robot that is set to approach the Marius Hills pit, one of the skylights thought to tap into a cave system, located in one of the Moon's youngest and mysterious volcanic provinces. LunarLeaper's innovative design enables it to autonomously navigate challenging terrain around the pit, and characterise the traversed terrain using a combination of well-proven geophysical instrumentation and imaging.

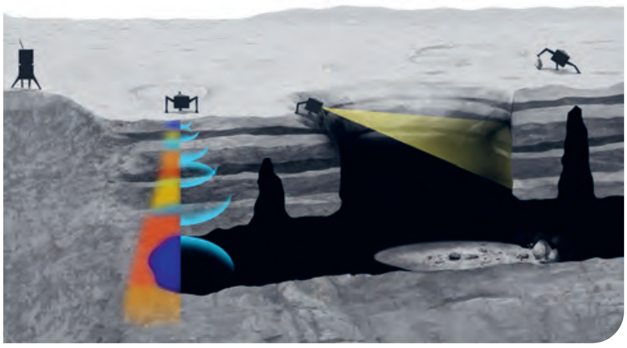
LunarLeaper will shed light on fundamental questions about the Moon's geological history: Are volcanic rilles the surface expression of large caves? What is the timing of lunar lava flow events? How did the composition of lunar volcanism change over time? LunarLeaper will confirm whether the pit indeed taps into the hypothesised cave system and further assess its suitability for human exploration and habitation.

LunarLeaper follows the strategies outlined in ESA's Terrae Novae programme: It represents a European mission that explores new territories with high scientific and exploration return. LunarLeaper exploits unique European expertise by relying on a novel robotic system that holds significant potential to reshape the future of planetary robotic exploration. As a landed mission, LunarLeaper will create new strategic capabilities, blazing a trail for other missions to follow – embodying the progress towards human exploration of the Moon and beyond, as outlined in ESA's roadmap. Ultimately, LunarLeaper will open a door to Europe's future in space.

Past Achievements and Status

A proposal has been submitted in response to ESA's call for small lunar missions to the Moon.

Time-Line	From	To
Planning	2024	2025
Construction	2025	2029
Measurement phase	2029	2029
Data evaluation	2029	2030



Conceptual sketch of the mission: LunarLeaper will land outside the lava tube. It will sound the sub-surface on its approach to the lunar pit to detect and map the lava tube and image the pit hole from the edge. The legged design allows the legs to be used as additional instruments.

11.4 Pioneers

Purpose of Research

PIONEERS is funded by the Horizon 2020 research and innovation program of the European Union. Within the PIONEERS project, a new generation of seismic instrumentation for future planetary missions is being developed by European partners. The applicable scientific requirements are being defined, including environment noise analysis, for the translation and rotation measurements of various physical processes in different planetary deployment conditions. The PIONEERS project is developing two 6-DoF instruments to measure ground deformations of planetary objects. They both respond to different kinds of mission scenarios for planetary science and have different performance requirements. The first is a planetary seismology development model, including a high-performance 6-DoF instrument. The second is a small bodies geophysics engineering-qualification model, consisting of a 6-DoF compact instrument fitting a CubeSat form-factor. The instrument includes compact fibre optic rotational sensors and MEMS accelerometers.

Past Achievements and Status

ETH Zurich is in charge of the development of several items of the compact instrument for small body geophysics. In particular:

- The acquisition electronic system for the three MEMS accelerometers, here, including the FPGA firmware for processing of the accelerometer data.
- The power interface electronics, which provides the interface with the platform and power conditioning and distribution to the instrument.
- The data processing and interface electronics, which provides the data interface with the platform, the processing and the conditioning of the instrument telemetry.

ETH Zurich completed the development of the accelerometer acquisition electronics in Summer 2023. The units were delivered to ISAE for integration in the instrument and system level testing. The power interface and data interface units were completed in January 2024 and delivered to ISAE for integration and system level testing to be completed in Spring 2024.

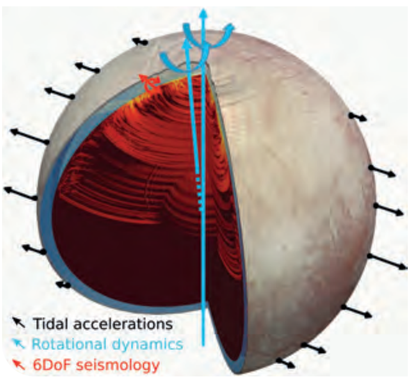
Publications

Bernauer F, Garcia RF, Murdoch N et al. (2020) **Exploring planets and asteroids with 6DoF sensors: Utopia and realism**, Earth Planets Space 72: 191, doi.org/10.1186/s40623-020-01333-9

Abbreviations

FPGA Field Programmable Gate Array
MEMS Micro Electro-mechanical Systems

Time-Line	From	To
Planning	2019	2020
Construction	2021	2023
Measurement phase	2023	2024
Data evaluation	2023	2024



Schematic illustration of the phenomena to be observed with the PIONEERS instruments at one point at the surface of a celestial body. Copyright: Bernauer et al. (2020), Earth Planets Space 72: 191

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Contribution
Accelerometer acquisition system; Data interface board; Power interface board

Website
h2020-pioneers.eu

12 Swiss Space Industries Group (SSIG)

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Scientific, Industrial and Economic Importance of the Institutional Space Sector

The world space industry is a strategically important growth sector of high value-creating potential and great economic importance. While the commercial sector is reshaping with an increasing interest for Low Earth Orbit constellation and space exploration, with private initiatives creating increasing impact, the truly scientific endeavours are still firmly in the hands of large institutions such as the European Space Agency (ESA). For Europe to compete globally and to secure a leading position in space science, the available resources must be efficiently deployed and activities pooled – tasks which are handled by ESA.

ESA coordinates and promotes the development of European space technology and ensures that the investment made goes to the lasting benefit of all Europeans. The EU aims to utilise the benefits of its space policy in its security, environment, transport, economic and social policy. ESA has an annual budget of more than five billion Euros. Switzerland contributes about 170 million Francs annually. As a result, funds flow into research, and enable Swiss scientists to participate in significant ESA missions, while the industry carries out the implementation of the hardware, from design to production and testing, for the research sector or directly through contracts awarded by ESA.

European and Swiss Collaboration

The European collaboration between ESA, EC and EUSPA (European Union Agency for the Space Programme) is going to be fundamental to the success of the EU Space Programme. EUSPA's core mission is to implement the EU Space Programme and to provide reliable, safe and secure space-related services, thereby maximising their socio-economic benefits for European society and business. The Swiss space industry will have ESA and EUSPA as essential partners and clients in future projects.

While the Swiss space market cannot match the biggest European countries for size, it can definitely keep up with them in terms of quality and innovation. For instance, the Ariane and Vega launchers, Galileo, the Sentinel satellites for Copernicus (Europe's Global Monitoring for Environment and Security system), the Earth Explorers or LISA and Comet Interceptor are just some examples of important space programmes in which Swiss manufacturers have played a major role. There is hardly a current European mission that does not incorporate Swiss technology. None of this would be possible without Switzerland's early commitment to ESA, right from day one.

ESA's ambitious programmes enable Swiss space companies to acquire the expertise that underpins its excellent reputation and promising position in the global growth market for space technology. Strengthening and further expanding this position has to be the goal in the coming years. This means not only overcoming technological and economic challenges but also dealing with difficult political issues. The leading players – science, politics and industry – have to work seamlessly together.

Engagements within the Space Industry

Swissmem unites the Swiss electrical and mechanical engineering industries and associated technology-oriented sectors. The space industry is an important division among them. International competitiveness is not guaranteed despite having ESA mem-

The VIS Read-Out Shutter Unit (RSU) mechanism for Euclid from APCO Technologies. Image credit: APCO.

Carbomill AG, www.carbomill.ch

Clearspace SA, clearspace.today

Clemessy (Switzerland) AG, clemessy.ch

CSEM, csem.ch

FAES-PWR ESTECH AG, estech.ch

Fisba AG, fisba.ch

Fly High Engineering AG fly-high-engineering.ch

Franke Industrie AG, industech.ch

General Atomics Synopta GmbH, ga-synopta.ch

Huber+Suhner AG, hubersuhner.com

icotec AG, icotec-medical.com

IHI Bernex AG, ihi-bernex.com

Klepsydra Technologies AG, www.klepsydra.com

nanoTRONIC GmbH, nanotronic.ch

RUAG AG, ruag.ch

Safran Timing Technologies SA, safran- navigation-timing.com/navigation-and-timing

SAPHYRION Sagl, saphyrion.ch

Sauter, Bachmann AG, sauterbachmann.ch

Schurter AG, schurter.ch

Solenix Engineering Schweiz GmbH, solenix.ch

SpacePNT Sarl, spacepnt.com

Thales Alenia Space Schweiz AG, thalesgroup.com

ViaSat Antenna Systems SA, viasat.com

bership. The ability to compete internationally is not a matter of course, it must be worked on. Having a location that is able to compete is the basis of success. Swissmem is committed to Swiss companies and the qualities of Switzerland as a centre of industry and research. Continuous groundwork has made Swissmem into a centre of strategic commercial and employer skills. This allows the association to represent the concerns of the sector to politicians, national and international organisations, representatives of employees and the public. Apart from this, Swissmem offers companies numerous practice-oriented services, which help them to maintain their ability to compete and to successfully meet new challenges.

The Specialists: SSIG, Swiss Space Industries Group

SSIG (Swiss Space Industries Group) is organised as a technology group within Swissmem. SSIG includes companies that are significantly involved in the wide-ranging, competitive Swiss space technology environment. These manufacturers and engineering companies play a prominent role in the broadly faceted, competitive Swiss space industry, and develop solutions for all areas of space business, including: structures for rockets, satellites, space transporters, components for propulsion engines, electronics and optics products and scientific instruments. Our companies participate in various ESA projects and earn themselves a merited high place in the fiercely competitive international market by delivering quality, expertise, flexibility and on-time reliability. Space research is a driving force of innovation. Space engineering brings together virtually all the strategic technologies. The sector therefore stands out as a future-oriented, innovative and attractive employer.

Jobs and Training

The Swiss Space companies of SSIG currently engage ~1000 employees in Switzerland in the Space sector, but thousands of other professionals are also indirectly connected. Many are university graduates who find attractive jobs in the diverse areas of the production of space components and systems and contribute specialist expertise to the companies concerned.

The employees of these companies, not only come from a broad spectrum of educational and training backgrounds, but also represent a wide range of disciplines and therefore help to create a highly diverse store of expertise. This includes specialist knowledge in the fields of electronics, optics, precision mechanics, aero and thermodynamics, tribology, information technology, material science and additive manufacturing. This broad spectrum of expert knowledge enables the companies to provide innovative solutions to the complex challenges arising in the space sector.

CaSSIS telescope on Exomars TGO during integration. Image credit: Thales Alenia Space Switzerland.

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