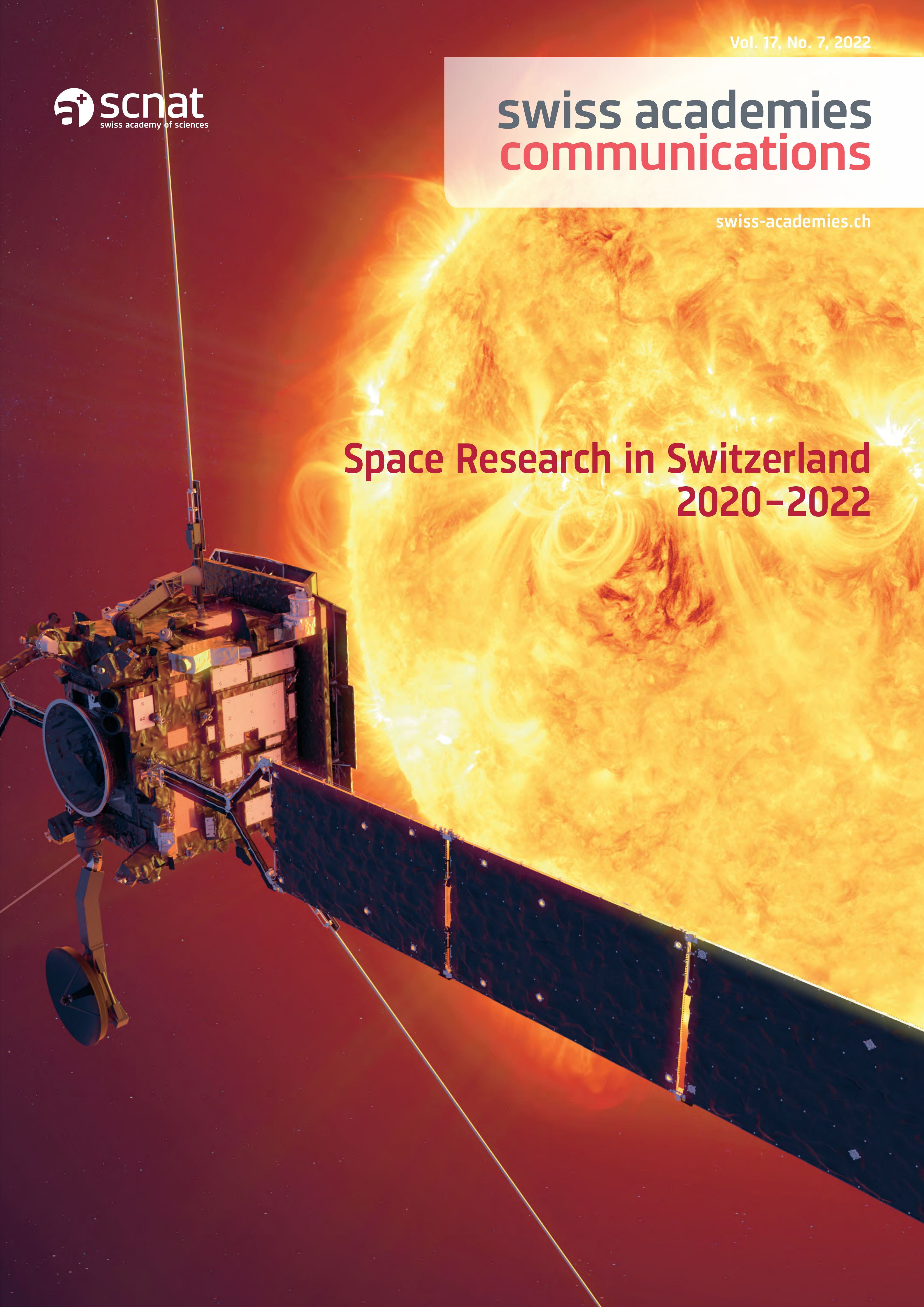
Vol. 17, No. 7, 2022

scnat
swiss academy of sciences

swiss academies communications

swiss-academies.ch

Space Research in Switzerland 2020–2022



ABOUT THIS PUBLICATION

PUBLISHER
Swiss Academy of Sciences (SCNAT) • Swiss Committee on Space Research (CSR)

CONTACT
Prof. Dr. Stéphane Paltani • Department of Astronomy • University of Geneva • Ch. d'Écogia 16 •
1290 Versoix • Switzerland • +41 22 379 21 49 • stephane.paltani@unige.ch • csr.scnat.ch

RECOMMENDED FORM OF CITATION
S Paltani, S Nyeki (2022)
Space Research in Switzerland 2020–2022
Swiss Academies Communications 17 (7)

EDITORS
Stéphane Paltani • Stephan Nyeki

EDITORIAL REVIEW/COOPERATION
Stephan Nyeki, PMOD/WRC • Monica Freeman, Freelance

LAYOUT
Stephan Nyeki, PMOD/WRC • Olivia Zwygart, SCNAT

COVER PHOTO
Solar Orbiter is a space mission of international collaboration between ESA and NASA to study the Sun, its outer atmosphere and what drives the constant outflow of solar wind that affects Earth. Image and text credits: ESA and NASA.

Edition 2022, 800 ex.
This communication can be dowloaded from csr.scnat.ch/publications.

ISSN (print) 2297–8275
ISSN (online) 2297–184X

DOI: doi.org/10.5281/zenodo.6543449

Cradle to Cradle™-certified and climate-neutral communication printed by Vögeli AG in Langnau.

Space Research in Switzerland
2020–2022

Contents

→

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 44th Scientific Assembly in Athens this summer is the occasion for the delegations to advertise their activities in this domain sciences. The present report is a compilation of the projects that have been conducted in Swiss research institutes over the period 2020 – 2021.

The many missions with Swiss participation benefit from the very strong support of the Swiss Space Office (SSO), the federal agency for national and international space matters. The vast majority of Swiss activities in space research are related to projects led by the European Space Agency (ESA). This is of course in large part due to the long involvement of Switzerland in the development of ESA since its foundation. However, the Swiss space research community is very open to international collaborations, in the spirit of the COSPAR, and participates actively in missions led by NASA, Japan, Russia or China, with the encouragement of the SSO.

Space research in Switzerland is mostly conducted in the Swiss Federal Institutes of Technology (ETH) of Zürich and Lausanne, the Universities of Bern, Geneva and Zürich, the Technical Universities of Windisch and Luzern, as well as the Observatory of Davos (linked to ETH Zürich). They are mostly active in research involving the Sun and heliosphere, as well as the Solar system and astrophysics, but Earth observations, space situational awareness, navigation satellite systems and life science in space are also represented. Most activities in the research institutes are performed in collaboration with local industries, which are organised into the Swiss Space Industries Group.

The last two year have obviously been marred by the COVID pandemic. In addition to the huge human suffering that resulted, space research activities have been strongly impacted. The space research community has been extraordinarily resilient, so that the impact has been relatively moderate in comparison with the huge disruption incurred by our societies.

Launched in February 2020, ESA's Medium-class Solar Orbiter mission is certainly one of the highlights of Swiss space research over the last two years, with the Swiss-led STIX instrument and Swiss participation in three other instruments. Solar Orbiter, which studies the inner heliosphere and the nascent solar wind, has been commissioned successfully and is currently taking data of numerous solar flares and producing many scientific papers.

ESA's Cornerstone mission, BepiColombo, will reach a stable orbit around Mercury in 2025. A first flyby occurred in October 2021, already providing us with spectacular images. BepiColombo contains the laser altimeter BELA, a major instrument co-led by Switzerland. Switzerland was also involved in the development of mass spectrometers for BepiColombo. ESA's Large-class JUICE mission, which will explore Jupiter and its icy moons, is now in the final stages of integration with several Swiss contributions: the GALA laser altimeter, the Neutral and Ion Mass spectrometer of the PEP instrument, as well as a contribution to the SWI heterodyne receiver.

The first Swiss-led scientific satellite CHEOPS, whose goal is to characterize exoplanets around nearby stars, has been performing flawlessly for two years already. Several major discoveries have already been made, while CHEOPS will hopefully enter an extended operational phase.

ESA's Cornerstone Gaia astrometry mission produced the Early Data Release 3 in 2020. Gaia is currently the most productive mission in space astrophysics, with more than three times the number of publications of any other ESA-led mission in 2021, even largely exceeding the Hubble Space Telescope for the same year. Switzerland plays a significant role in Gaia by leading all aspects linked to stellar variability. ESA's Medium-class cosmology mission Euclid achieved a very significant milestone with the delivery of the complete payload. Switzerland contributed to some hardware for the VIS instrument and to the extremely complex data processing system. The perfect launch and deployment of NASA's James Webb Space Telescope in 2021 was a wonderful Christmas present for astrophysicists that is sure to bring many extraordinary discoveries. Switzerland participated in the development of MIRI, one of the two European instruments.

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.

Stéphane Paltani

2 Institutes and Observatories

2.1 ISSI – International Space Science Institute

INTERNATIONAL SPACE SCIENCE INSTITUTE

Directors
T. Spohn (Executive Director)
M. Falanga
M. Rast
R.-M. Bonnet (Honorary Director)

Staff
9 Scientific
6 Administrative

Contact Information
International Space Science Institute (ISSI),
Hallerstrasse 6,
CH-3012 Bern, Switzerland
Tel. +41 31 684 48 96
www.issibern.ch
E-mail: firstname.name@issibern.ch

Fields of Research

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

Introduction

The International Space Science Institute (ISSI) is an Institute of Advanced Studies at which scientists from all over the world are invited to work together to analyse, compare and interpret their data. Scientists, theorists, modellers, ground-based observers and laboratory researchers meet at ISSI to formulate interdisciplinary interpretations of experimental data and observations. Therefore, the scientists are encouraged to pool their data and results. The conclusions of these activities – published in several peer-reviewed journals or books – are expected to help identify the scientific requirements of future space science projects. ISSI's study projects on specific scientific themes are selected in consultation with the Science Committee members.

ISSI's operation mode is fivefold: multi- and interdisciplinary International Teams, Workshops, Working Groups, Visiting Scientists and Forums cover the activities of ISSI.

The European Space Agency (ESA), the Swiss Confederation, and the Swiss Academy of Sciences (SC NAT) provide the financial resources for ISSI's operation. The University of Bern contributes through a grant to the Director and in-kind facilities. The Institute of Space and Astronautical Science (ISAS, JAXA, Japan) supports ISSI with in-kind contributions.

ISSI established, jointly with the National Space Science Centre of the Chinese Academy of Sciences (NSSC/CAS), the International Space Science Institute Beijing (ISSI-Beijing) in 2013. ISSI-BJ is a close partner of ISSI and shares the same Science Committee. Together with ISSI-BJ, ISSI releases an annual joint Call for Proposals for International Teams in Space and Earth Sciences. Further details about ISSI Beijing and its activities can be found on www.issibj.ac.cn

Realisations in 2020 and 2021

The Workshop on "Surface Bounded Exospheres and Interactions in the Solar System" took place in January 2020. The peer-reviewed papers resulting from this Workshop are continuously published in Topical Collection in Space Science Reviews.

In mid-March, 2020, Switzerland was ordered into a lockdown due to the global Covid-19 pandemic. Therefore, ISSI's planned activities (International Teams, Working Groups etc.) primarily took place in virtual meetings or semi-virtual meetings.

Four further Workshops took place (with a limited number of participants at ISSI and remote participants):

- Probing the Earth's Deep Interior Using in Synergy Observations of the Earth's Gravity and Magnetic Fields, and of the Earth's Rotation (1–4 September 2020).
- Global Change in Africa (11–15 January 2021).
- Venus: Evolution Through Time (13–17 September 2021).
- The Heliosphere in the Local Interstellar Medium (8–12 November 2021).

Two Forums were organised: "Tipping Points in the Earth's Climate" (26-29 January 2021) and "Ground and Space Astronomy: Challenges and Synergies" (18 and 19 November 2021).

Online Seminar Series

Since August 2020, ISSI has been organising a weekly webinar series called "Game Changers", where renowned scientists talk about missions in the solar system, the universe and planet Earth. Starting with "Missions that Changed the Game in Solar System, Astrophysics and Earth Sciences", the focus shifted in 2021 to "Ideas and Findings about the Solar System, the Universe and our Terrestrial Environment". All 49 webinars, recorded in 2020 and 2021, can be watched on the website: https://www.issibern.ch/publications/game-changers-seminars/.

Publications

All scientific activities result in some form of publication, e.g. in the Space Sciences Series of ISSI (SSSI), ISSI Scientific Report Series (SR), both published by Springer, or individual papers in peer-reviewed international scientific journals. As of the end of 2021, 82 SSSI volumes, and 17 SR volumes have been published. Information about the complete collection can be found on www.issibern.ch, in the section "Publications".

In 2020 and 2021, the following volumes appeared:

SSSI Volume 73: **Cometary Science: Insights from 67P/Churyumov-Gerasimenko**, N. Thomas, B. Davidsson, L. Jorda, E. Kührt, R. Marschall, C. Snodgrass, R. Rodrigo (Eds.), ISBN 978–94–024-2089–0, 2021.

SSSI Volume 74: **Role of Sample Return in Addressing Major Questions in Planetary Sciences**, Anand M, Russell S, Lin Y, Wadhwa M, Marhas KK, Tachibana S (Eds.), ISBN 978–94–024–2074–6, 2020.

SSSI Volume 75: **Relationships Between Coastal Sea Level and Large Scale Ocean Circulation**, Ponte R, Meyssignac B, Domingues C, Stammer D, Cazenave A, Lopez T (Eds.), ISBN 978–3–030–45633–7, 2020.

SSSI Volume 77: **Ocean Worlds – Habitability in the Outer Solar System and Beyond**, Coustenis A, Rodrigo R, Spohn T, Hand KP, Hayes A, Olsson-Francis K, ostberg F, Sotin C, Tobie G, Raulin F, Walter N, L'Haridon J (Eds.), ISBN 978–94–024–2069–2, 2020.

SSSI Volume 78: **Auroral Physics**, Knudsen DJ, Borovsky JE, Karlsson T, Kataoka R, Partamies N (Eds.), ISBN 978–94–024–2121–7, 2021.

SSSI Volume 79: **The Tidal Disruption of Stars by Massive Black Holes**, Jonker P, Arcavi I, Phinney ES, Rossi EM, Stone NC, van Velzen S (Eds.), ISBN 978–94–024–2145–3, 2021.

SSSI Volume 80: **Reading Terrestrial Planet Evolution in Isotopes and Element Measurements**, Lammer H, Marty B, Zerkle A, Blanc M, O'Neill H, Kleine T (Eds.), ISBN 978–94–024–2093–7, 2021.

SSSI Volume 81: **Understanding the Diversity of Planetary Atmospheres**, Forget F, Korablev O, Venturinib J, Imamura T, Lammer H, Blanc M (Eds.), ISBN 978–94–024–2125–5, 2021.

SSSI Volume 82: **Geohazards and Risks Studied from Earth Observations**, Lopez T, Cazenvae A, Mandea M, Benveniste J (Eds.), ISBN 978–3–030–87988–4, 2021.

SSSI Volume 83: **Star Formation**, Bykov AM, Charbonnel C, Hennebelle P, Marcowith A, Meynet G, Falanga M, von Steiger R (Eds.), ISBN 978–94–024–2061–6, 2020.

On average, the International Teams publish over 200 peer-reviewed papers per year. All results, published papers, and books can be found in ISSI's Annual Reports 25 (2019–2020) and 26 (2021), which are available at www.issibern.ch.

Outlook

Twenty five new International Teams, approved in 2021 by the Science Committee, started their activities in the present business year (2022), and three Teams are associated with ISSI-Beijing. Furthermore, nine Workshops are scheduled for 2022 and 2023:

- 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
- Solar and Stellar Dynamos: A New Era
- Evolution of the Solar System: Constraints from Meteorites
- Megavolt Sky Astronomy
- Tipping Points and Understanding EO data needs for a Tipping Element Model Intercomparison Project (TipMip)
- Regular "State of" Carbon Sink Reporting and Data Provision

2.2 ISDC – INTEGRAL Science Data Centre

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

In cooperation with
European Space Agency
German Aerospace Centre

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

Method
Measurement

Research based on existing instruments
INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL)

Websites
www.isdc.unige.ch/integral
www.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, due to 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. An operational review in 2022 will ascertain the reliability of INTEGRAL until the end of 2025, and a possible extension will be discussed by the ESA SPC in early 2023.

ISDC is an essential pillar of the mission and is currently funded by the

Swiss Space Office, UNIGE, and ESA, with contributions from the German Aerospace Center through the Institute of 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 the 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, 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).

To facilitate the access to INTEGRAL data analysis, ISDC has developed a 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 obtain images, spectra and light curves from the web interface for a larger dataset. This platform runs on the computing infrastructure at UNIGE and it 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 is facilitated for experienced users; and legacy is preserved.

The studies at ISDC are mainly in the field of high-energy astrophysics. Although a large fraction of the research topics are linked to areas in which INTEGRAL makes a significant contribution, a variety of other observation facilities, such as XMM-Newton, RXTE, Chandra, Planck, and Fermi, have so far been exploited.

Publications

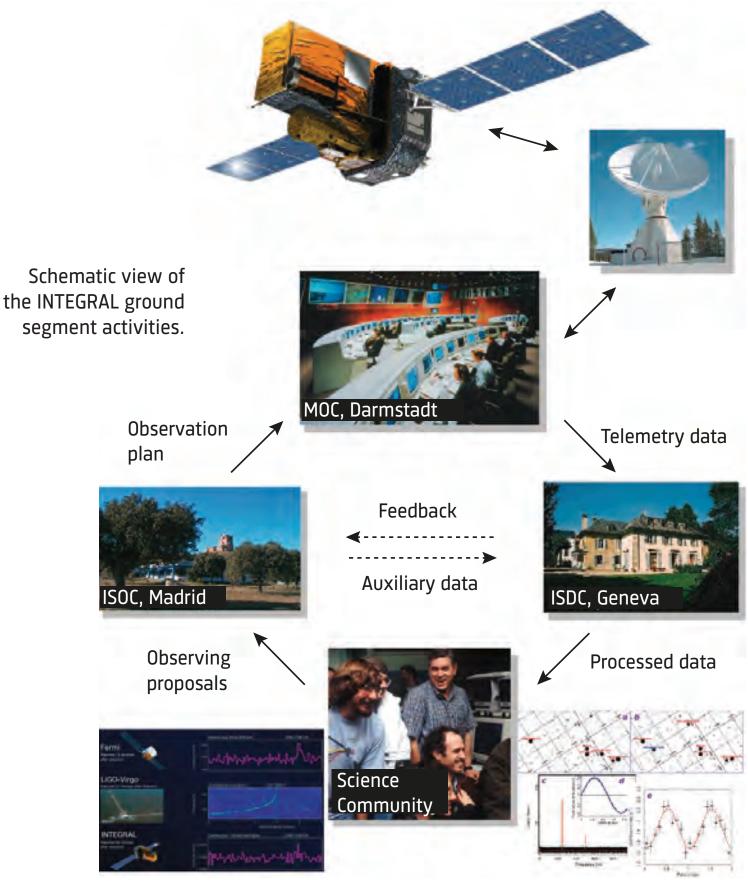
Mereghetti S, Savchenko V, Ferrigno C et al. (2020) **INTEGRAL discovery of a burst with associated radio emission from the Magnetar SGR 1935+2154**, Astrophys. J. Lett. 898(2): id.L29, 10.3847/2041-8213/aba2cf

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.

Abbreviations

INTEGRAL	International Gamma-Ray Astrophysics Laboratory
ISDC	INTEGRAL Science Data Centre
HESS	High Energy Stereoscopic System
LIGO	Laser Interferometer Grav. Wave Observatory



Schematic view of the INTEGRAL ground segment activities.

2.3 eSpace – EPFL Space Center

eSpace EPFL Space Center

Institute
eSpace – EPFL Space Center

Academic Director
J.-P. Kneib

Executive Director
E. David

Staff
2 Directors, 4 Engineers, 1 Project Manager, 1 Postdoc, 2 PhDs, 4 Administrative & Support Staff

Contact Information
eSpace – EPFL Space Center
EPFL AVP CP ESC, PPH 335, Station 13,
CH-1015 Lausanne
Tel. +41 21 693 6967
espace@epfl.ch

Website
eSpace.epfl.ch

Mission

The EPFL Space Center (eSpace) has three complementary missions: i) to inspire the new generation of students in space-related projects and activities, ii) to develop novel space science and technology research topics in partnership with EPFL labs and beyond, and iii) to foster innovative space initiatives.

Vision

To establish EPFL as a world-renowned center of excellence in space science and technology research, education and innovation.

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. eSpace achieves its mission through three key areas: education, fundamental research and innovative development projects.

The center coordinates the popular EPFL Minor in Space Technologies which allows master-level students to acquire extensive formal education in the field of space science and technologies. These theoretical classes are complemented by hands-on multidisciplinary projects which often lead to the construction of hardware (e.g. the SwissCube satellite, launched into space in 2008, as well as the recently selected mission, ClearSpace-1).

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.

The center boasts a team of experts with a wide range of industry and academic experience, and benefits from close collaborations with 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, the center can lean on an 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 help launch these technologies to space.

Research Initiative on Sustainable Space Logistics

eSpace continues to focus on the Sustainable Space Logistics research initiative, which involves missions such as the active removal of space debris, and technologies such as Relative Navigation and Orbital Robotics. One of the timely developments is the partnership with eSpace's commercial spin-off, Clearspace SA, which will launch the first satellite removal mission in 2025.

Space Sustainability Rating

More than one million objects larger than 1 cm are orbiting the Earth, posing significant challenges to current and future operations in space and presenting a risk of impacting people on Earth in case of loss or disruption of space-based infrastructures due to a collision. Given the growing number of actors, the plans to establish large constellations, and the absence of binding guidelines at an international level, there is a critical need to implement tools that will incentivise space actors and foster responsible behaviour in order to ensure the long-term sustainability of the space environment. In 2021, eSpace was selected to host and operate the Space Sustainability Rating (SSR), a voluntary rating system that assesses the level of sustainability of space missions and advises on good practices and ways to improve, allowing participating space operators to proactively contribute towards a more sustainable use of outer space.

Lunar Research and Technology Development Initiative

In 2020, eSpace introduced its Lunar Research and Technology Development initiative, aimed at bridging a series of identified knowledge and technology gaps within current global plans for the effective exploration of the Moon and the sustainable use of its resources. By leveraging eSpace expertise and EPFL's network of labs, professors, researchers, and students, eSpace is placed in an ideal position to act as initiator, mediator, and facilitator of opportunities and collaborations between EPFL laboratories, Swiss enterprises, and international partners and institutions. eSpace advocates for a holistic space programme that effectively and sustainably explores and develops the Moon. Currently planned lunar projects span from prospecting of permanently shadowed regions to human-robot integrated operations.

Publications

Juillard M, Kneib J-P (2021) **Simulation Tool: Resources Management in High Performance Avionic for ADR Missions**, 2021 IEEE Aerospace Conference.

Juillard M, Kneib J-P (2021) **Optimal Control Approach for Dedicated On-Board Computer in Active Debris Removal Mission**, 35th Proc. AIAA/USU Conf. on Small Satellites.

Juillard M, Kneib J-P (2022) **Onboard Computer and Dedicated Payload Interaction: Study case for Active Debris Removal Mission**, 2022 IEEE Aerospace Conference.

One of the technologies being developed as part of the lunar initiative is compact, lightweight lunar drones for surface prospection and mapping.

Promote sustainable behaviour of space operators by issuing a recognised, fair, and impartial rating – the Space Sustainability Rating.

2.4 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)
E. Brockmann (swisstopo)
D. Thaller (BKG)
U. Hugentobler (IAPG)

Method
Measurement

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

Website
www.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 established 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 has been continuously contributing to the IGS. The operational processing is located at AIUB using the Bernese GNSS Software package that has been developed and maintained at AIUB for many years.

Nowadays, data from about 250 globally distributed IGS tracking stations are processed every day in a rigorously combined multi-GNSS (currently the American Global Positioning System (GPS), the Russian counterpart, GLONASS, and the European Galileo system) processing procedure 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 also started to follow this strategy. 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 rotational 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 working groups, e.g., the working group on Bias and Calibration and the antenna working group. With the ongoing modernisation programmes of the established GNSS and the upcoming GNSS, e.g., the European Galileo, such work is highly relevant because of the increasing manifold of signals that need to be consistently processed in a fully combined multi-GNSS analysis scheme. Other contributions from CODE are the derivation of calibration values for the GNSS satellite antenna phase center model, GLONASS ambiguity resolution, and the refinement of the CODE orbit model.

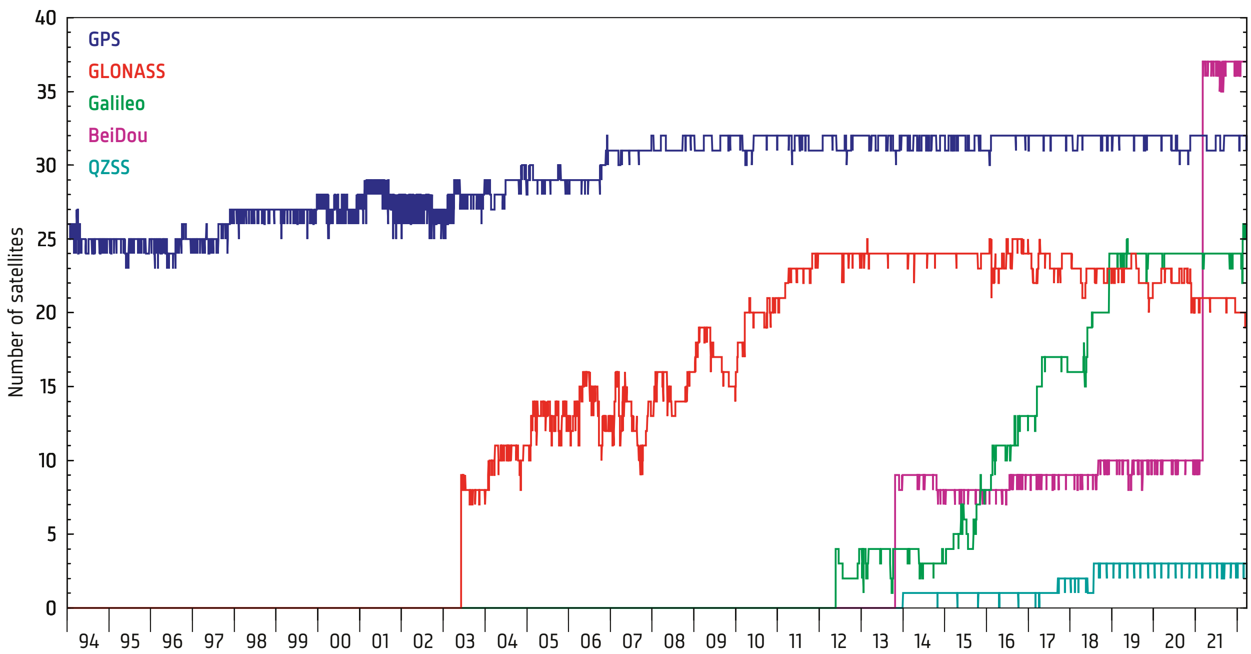
Abbreviations

CODE	Centre for Orbit Determination in Europe
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema
GNSS	Global Navigation Satellite Sys.
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:

www.bernese.unibe.ch/publist



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

2.5 Satellite Laser Ranging (SLR) at the Zimmerwald Geodynamics Observatory

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

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)
P. Lauber (AIUB), E. Brockmann (swisstopo)

Method
Measurement

Website
www.aiub.unibe.ch

Purpose of Research

The Zimmerwald Geodynamics Observatory, part of the Swiss Optical Ground Station (SwissOGS), is a station of the global tracking network of the International Laser Ranging Service (ILRS). 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 measurement to the geodetic satellites, in particular LAGEOS (Laser Geodynamics Satellite) 1 and 2, and LARES (Laser Relativity Satellite) products derived from these SLR observations which include precise satellite ephemerides, station positions and velocities of sites in the ILRS network, and Earth Orientation Parameters (EOPs, i.e., polar motion and rates, length-of-day).

The contribution of SLR 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 (normal points 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 is still the most productive SLR station in the northern hemisphere.

The design of the 100 Hz Nd:YAG laser system used at the SwissOGS 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 has allowed the Zimmerwald Observatory to evolve in the past 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 lasers systems. A new kHz laser with a pulse length of 8ps 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 will be installed in order to measure ranges to targets which are not equipped with laser retro-reflectors. This system, in particular, will 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 (ADRIOS) project.

Publications

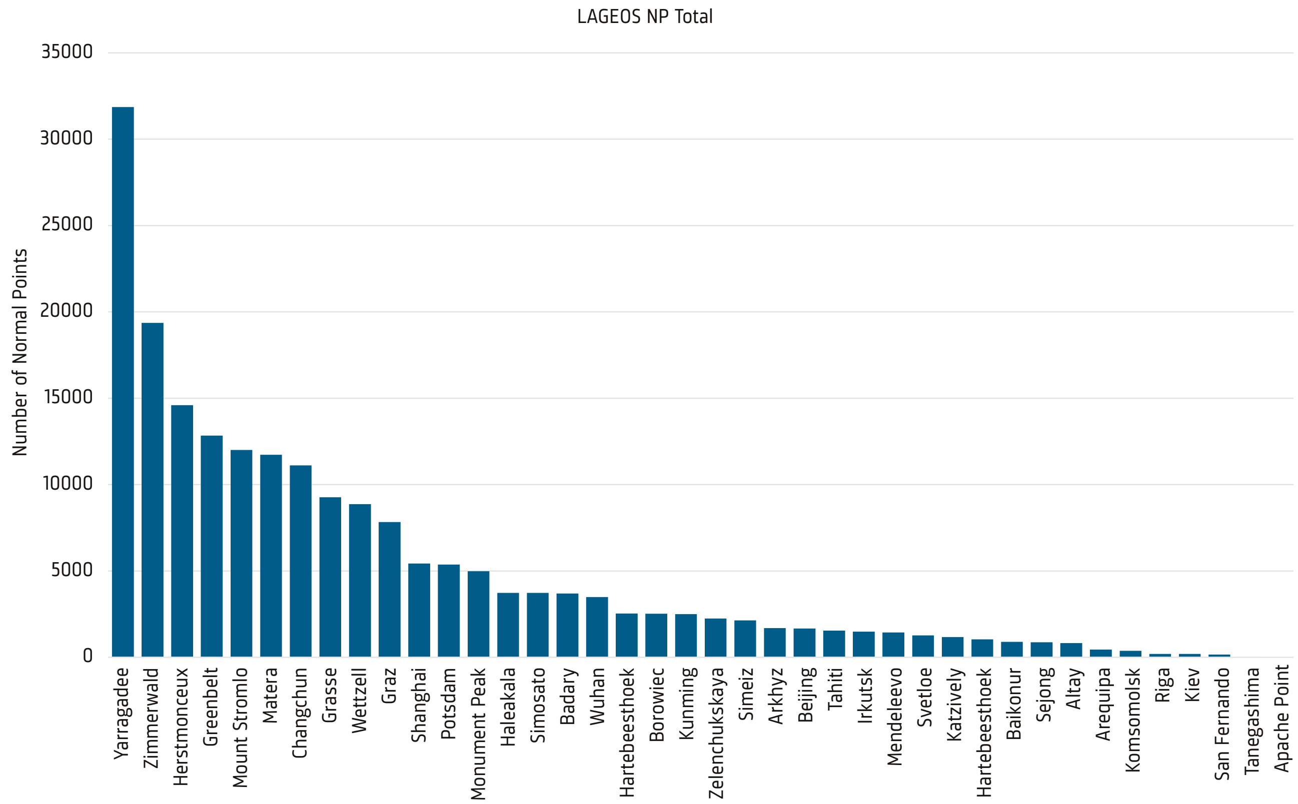
Andritsch F, Grahsl A, Dach R et al. (2020) **Simulation of tracking scenarios to LAGEOS and Etalon satellites**, J. Geod. 94: 40, doi.org/10.1007

Cordelli E, Lauber P, Schildknecht T, Prohaska M, Brockmann E, Jäggi A (2019) **Satellite Laser Ranging at Zimmerwald, Swiss National Report on the Geodetic Activities in the years 2015–2019**.

Rodriguez J, Cordelli E, Schildknecht T (2021) **The stare and chase observation strategy at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald: From concept to implementation** Acta Astronautica, 189.

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).

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 https://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 characterization, 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.

In addition, 20% of the CHEOPS observing time will be made available to the community through a selection process carried out by ESA.

Past Achievements and Status

- Mission selection: October 2012.
- Mission adoption: February 2014.
- Instrument Critical Design Review: December 2015.
- Telescope shipped to ADS Madrid for integration: April 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 December 2019.
- Successful completion of the in-orbit commissioning review: 25 March 2020.
- Hand-over of the responsibility for CHEOPS operations from ESA to the Consortium: April 2020.
- Since April 2020: Ongoing successful scientific operations.

Publications

Benz W, Broeg C, Fortier A, and 107 more authors (2021) **The CHEOPS Mission**, Experimental Astronomy 51: 109–151.

Leleu A, Alibert Y, Hara N, and 152 more authors (2021) **Six transiting planets and a change of Laplace resonances in TOI-178**, Astron. Astrophys. 649: A26.

Morris B, Delrez L, Brandeker A, and 79 more authors (2021) **CHEOPS precision phase curve of the super-Earth 55 Cancrie**, Astron. Astrophys. 653: A173.

Abbreviations

CHEOPS	CHaracterising ExOPlanet Satellite
E-ELT	European Extremely Large Telescope
JWST	James Webb Space Telescope

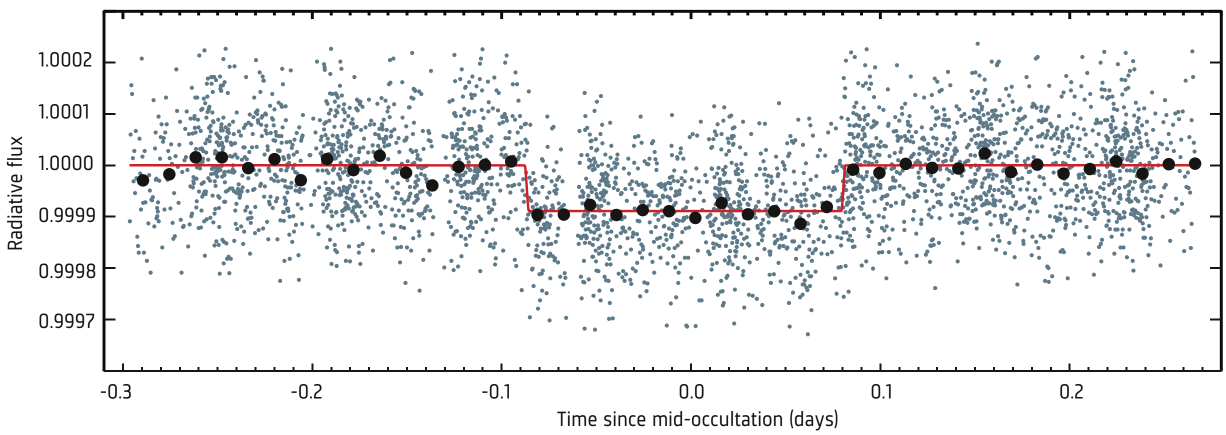
Time-Line	From	To
Planning	Mar. 2013	Feb. 2014
Construction	Mar. 2014	Jul. 2019
Measurement phase	Apr. 2020	open
Data evaluation	Apr. 2020	open

Method
Measurement

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

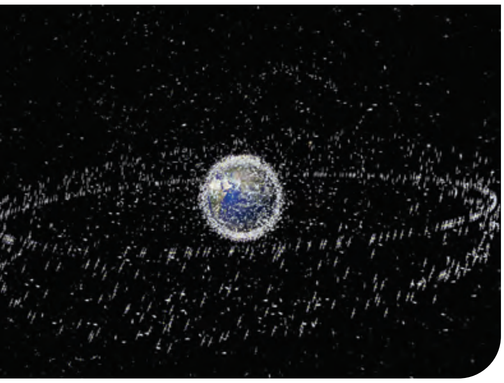
Website
www.cheops.unibe.ch



Light curve of occultation of WASP-189b behind its host star HD 133112, observed with CHEOPS. The light grey points are the CHEOPS observations at the full time resolution of 33.4 seconds, whilst the larger black points are the same data, binned into 10 minute time intervals. The red line represents the best occultation fit to the CHEOPS data. These data show how the light coming from the planet is missing while it passes behind its star. The decrease in light has been measured to be 87.9 ± 4.3 ppm which indicates the extraordinary photometric precision achieved by CHEOPS. Graph credit: Lendl M et al. (2020), Astron. Astrophys., 643: A94.

4 Space Safety

4.1 SSA – International Space Situational Awareness



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)

Method
Measurement, Compilation

Observatories
Zimmerwald, Switzerland
Sutherland, South Africa
Toowomba, Australia
ESA, Tenerife
ISON telescopes

Website
www.aiub.unibe.ch

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 organizations 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, by characterising objects to assess their nature and to identify the sources of space debris. This 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 DLR. Optical surveys performed by AIUB using its ZIMLAT and ZimSMART telescopes at the Zimmerwald Observatory and the ESA telescope in Tenerife 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.

Important sources 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 made essential contributions to the identification and cataloguing of the resulting debris clouds. The figure on the right shows debris clouds of three of these events.

AIUB also hosts and operates the ESA/AUB Expert Centre for Space Debris Monitoring, a service and co-ordination facility in support of space safety.

Publications

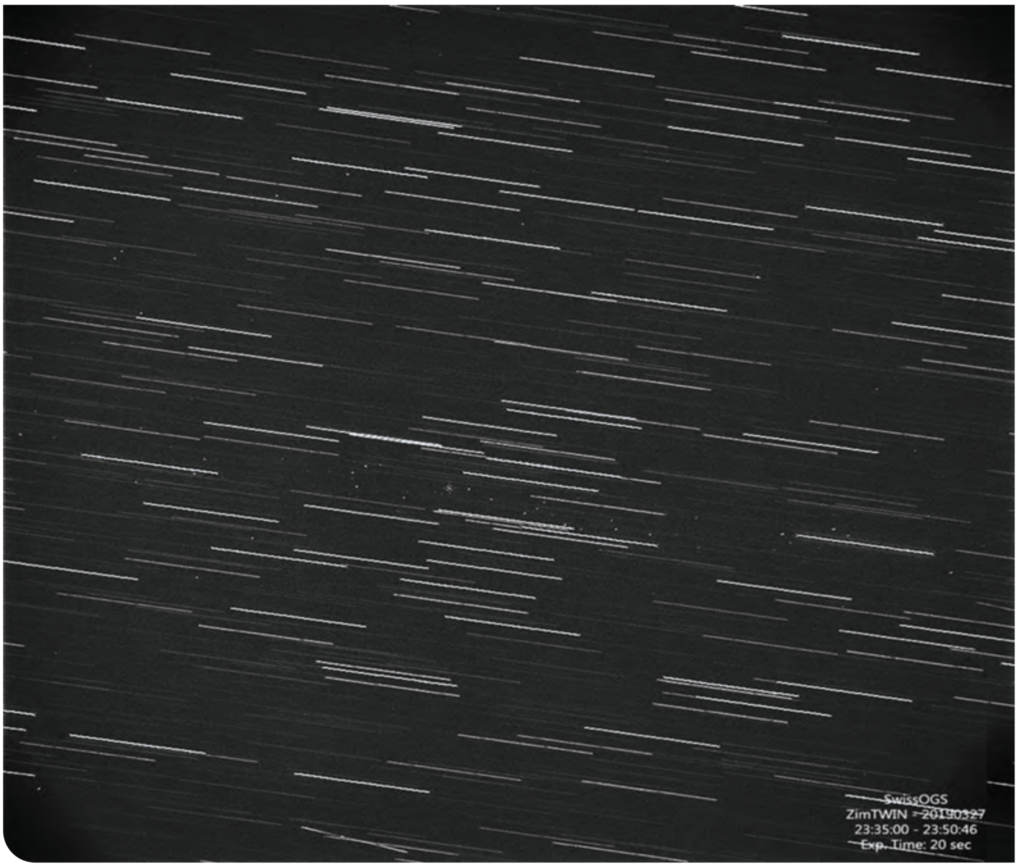
Cordelli E, Vananti A, Schildknecht T (2020) **Analysis of laser ranges and angular measurements data fusion for space debris orbit determination**, Advances in Space Research 65.

Reihs B, Vananti A, Schildknecht T, Siminski J, Flohrer T (2021) **Application of attributables to the correlation of surveillance radar measurements**, Acta Astronautica 182.

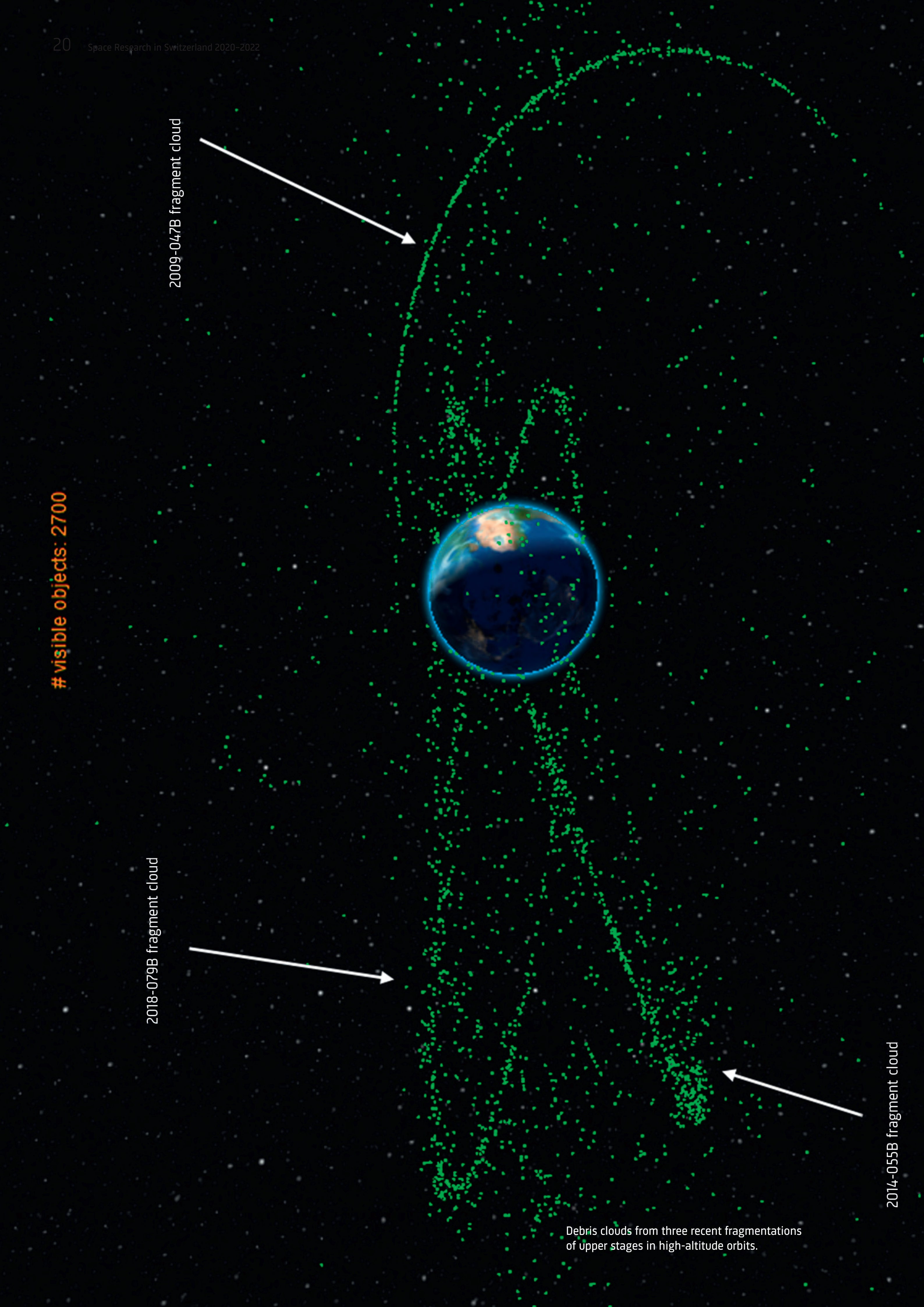
Schildknecht T, Vananti A, Cordelli E, Flohrer T (2019) **Optical surveys to characterize recent fragmentation events in GEO and HEO**, Proc. 1st Int. Orbital Debris Conf., Sugar Land, Texas.

Abbreviations

IADC	Inter-Agency Space Debris Coordination Committee
SMARTnet	SMall Aperture Robotic Telescope network
SSA	Space Situational Awareness
UNCOPUOS	UN Committee on the Peaceful Uses of Outer Space
ZIMLAT	Zimmerwald Laser & Astrometry Telescope
ZimSMART	Zimmerwald SMall Aperture Robotic Telescope



Fragment cloud image from the breakup of a rocket upper stage just after the event at the Zimmerwald Observatory. The fragments can be seen as dozens of point-like objects in the centre of the image while stars appear as streaks (image exposure time of 20s). This event (2009-047b) is seen on the next page in the debris cloud visualisation tool. Image credit: SwissOGS.



Debris clouds from three recent fragmentations of upper stages in high-altitude orbits.

4.2 LUCI – Lagrange EUV Coronal Imager

Purpose of Research

The Lagrange EUV Coronal Imager, called LUCI, was one of the potential remote sensing instruments of ESA's space weather mission to the Lagrange point L5. The mission, formerly named "Lagrange", was renamed to "Vigil"' after a public competition published by ESA. LUCI is dedicated to image the full solar disk and the region of the outer corona up to 2.5 solar radii in a direction towards Earth. It builds on the heritage of two highly successful instruments, SWAP on PROBA-2 and EUI on Solar Orbiter.

LUCI is designed to obtain images in the extreme ultraviolet wavelength (EUV) range. It provides input to reliable space weather forecast and new insights into solar activity and its impact on Earth. In particular, the side view of the Sun-Earth line, allows for the first time, to observe the onset and the early acceleration phase of a Coronal Mass Ejection (CME) travelling in the direction of Earth. As a result, the arrival time of CMEs in the vicinity of Earth can be determined with higher accuracy than currently possible and vulnerable infrastructure can be protected in due time. In addition, the EUV images of the Sun obtained with LUCI allow our understanding and models of the variability of EUV radiation to be improved. The variability in the EUV range drives the temperature, density and total electron content of the Earth's upper atmosphere. As such, LUCI provides key observations to advance our knowledge of the Earth's response to solar activity.

Past Achievements and Status

The LUCI consortium successfully completed Phases A, B1 and the Pre-Development Phase I. A breadboard of the Front End Electronics (FEE) was built and commissioned. The thermo-mechanical design of the instrument was further developed towards the structural and thermal model (STM), whereas the hardware phase has not yet started. During the LUCI Pre-Development activities, the mission payload management was transferred from ESA to Airbus Defense and Space (ADS). In the frame of this transfer, an ITT for phases B2/C/D was published. For LUCI, an industry prime was introduced to link the consortium to the new mission organisation. Several instrument prime candidates submitted their proposals together with the pre-existing consortium to ADS. Thales Alenia Space Switzerland (TAS-CH) was finally selected as the LUCI instrument prime. Prior to the kick-off of the proposed activities, the LUCI instrument was de-selected from the Vigil payload.

A proper completion of the initiated activities is envisioned to reach TRL6 on the LUCI FEE. This would allow us to use the performed work for a future mission with an EUV imager onboard and to benefit from the exceptional advantages of LUCI at a later stage. The conditions for this closure and further applications are to be elaborated.

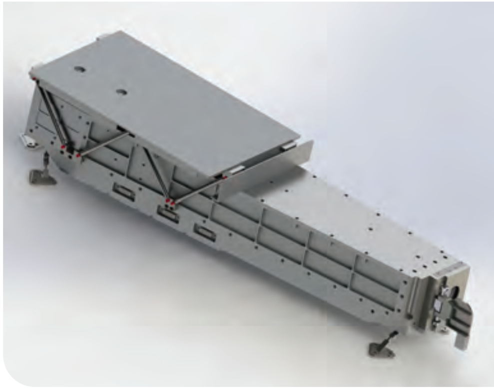
Publications

West M, Kintziger C, Haberreiter M, et al. (2020) **LUCI onboard Lagrange, the next generation of EUV space weather monitoring**, J. Space Weather Space Clim. 10: 49.

West M, Kintziger C, Haberreiter M, et al. (2020) **The LUCI instrument**, AGU Fall Meeting 2020, abstract #SH030-0007.

Abbreviations

LUCI	Lagrange EUV Coronal Imager



Rendered view of the LUCI instrument.

Institute
Physikalisch-Meteorologisches Observatorium Davos / World Radiation Centre (PMOD/WRC), Davos, Switzerland

In cooperation with
ESA
Centre Spatial de Liège (CSL), Belgium
Royal Observatory of Belgium (ROB), Belgium
Rutherford Appleton Lab. (RAL), UK
Thales Alenia Space (TAS-CH), Switzerland

Swiss Principal Contact
V. Büchel (PMOD/WRC)

Co-Investigator(s)
C. Kintziger, L. Jacques, B. Le Van (CSL)
D. Berghmans, M. West, S. Gissot (ROB)
J. Hurely (RAL)
L. Harra, S. Koller, V. Büchel, M. Haberreiter, D. Pfiffner, M. Gander, M. Gyo, P. Langer, M. Spescha, L. Zambila, L. Meier, D. Tye (PMOD/WRC)

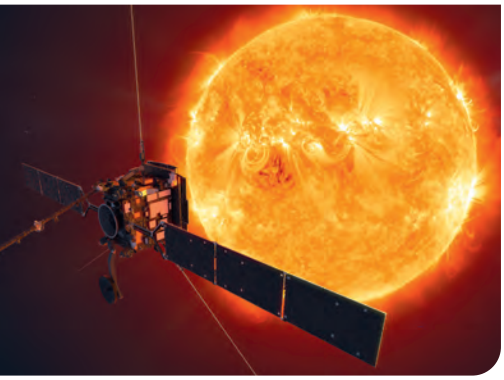
Method
Measurement

Development & construction of instrument(s)
Development of the LUCI EUV imager.

Website
www.pmodwrc.ch

5 Solar Physics

5.1 SPICE and EUI Instruments 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

Method
Measurement

Industrial hardware contract(s) to
APCO technologies
Almatech

Website
www.pmodwrc.ch

Purpose of Research

The EUV Imager (EUI) and Spectral Imaging of the Coronal Environment (SPICE) are two instruments onboard the ESA/NASA Solar Orbiter mission. The mission was successfully launched on 9 February 2020 from Cape Canaveral. The mission's over-arching goals are to understand how the Sun creates and controls the heliosphere. Following launch, the mission started its cruise phase which lasted just under two years. The spacecraft used gravity assists from Venus and the Earth to slowly place the spacecraft into a 180-day orbit around the Sun. During the cruise phase all ten instruments on the spacecraft were successfully commissioned and took their first data. 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 were switched on during the cruise phase during a series of planned "check-out" windows.

EUI 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. FSI 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, EUI has already produced science quality data. EUI observed the smallest and weakest brightenings ever observed. These have length scales of 400–4000 km and durations between 10 s and 200 s (Berghmans et al., 2021). These were observed at a position 0.55 A.U. from the Sun. In 2022, the spacecraft will reach closer to the Sun, and higher spatial resolutions will be possible.

The SPICE instrument provides spectroscopy in EUV wavelengths, allowing measurements of plasma between temperatures of 20,000 K to over 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. As with EUI, SPICE took observations during the series of check-out windows. In the first paper, measurements of spectra in different solar locations were made, with over 40 spectral lines being identified. SPICE has observed very bright features in the transition region that can last around 2.5 hours (Fludra et al., 2021). In 2022, the science operations begin with coordinated measurements between the instruments with Solar Orbiter, but also other facilities including spectrometers onboard Hinode and IRIS.

Past Achievements and Status

The SPICE Low Voltage Power Supply (LVPS) was built at PMOD/WRC. Together with APCO, 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, both managed by PMOD/WRC. Commissioning was completed successfully for both instruments in 2020, with first light successfully obtained. Data continued to be obtained during the check-out windows in the cruise phase of the mission.

Abbreviations

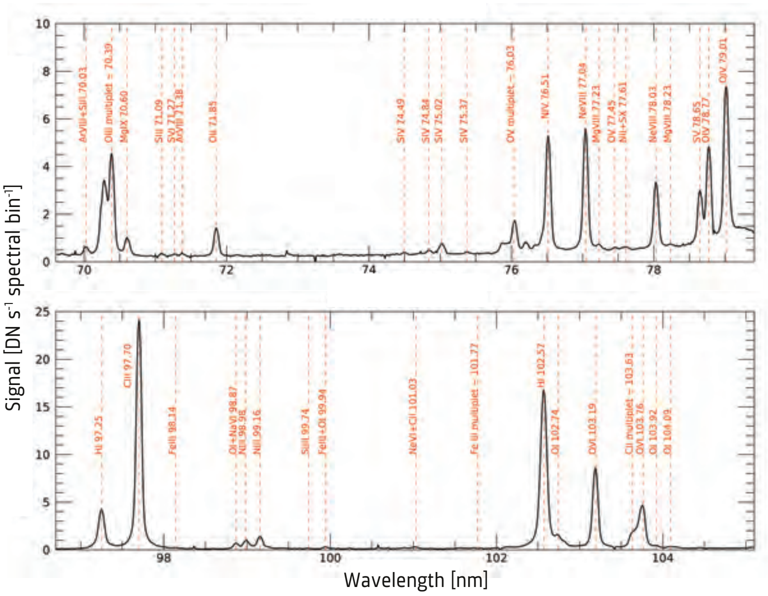
EUI	Extreme Ultraviolet Imager
FSI	Full Sun Imager
HRI	High Resolution Imager
LVPS	Low Voltage Power Supply
OBS	Optical Bench Structure
SCD	SPICE Contamination Door
SCM	Slit Change Mechanism
SPICE	Spectral Imaging of the Coronal Environment

Publications

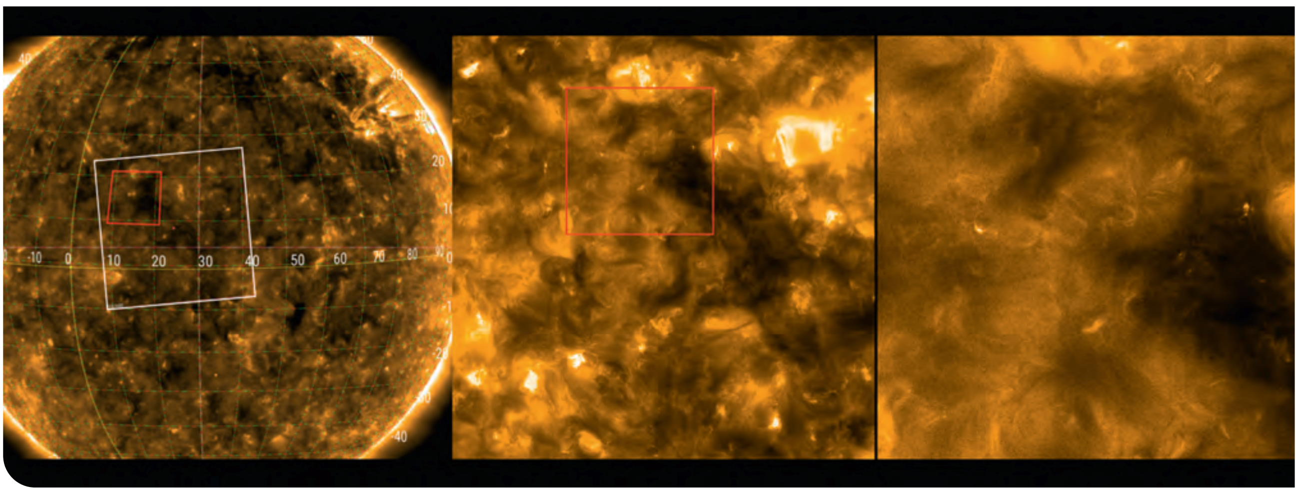
Berghmans D, et al. (2021) **Extreme-UV quiet Sun brightenings observed by the Solar Orbiter/EUI**, https://doi.org/10.1051/0004-6361/202140380

Fludra A, et al. (2021) **First Observations from the SPICE EUV spectrometer on Solar Orbiter**, https://doi.org/10.1051/0004–6361/202141221

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

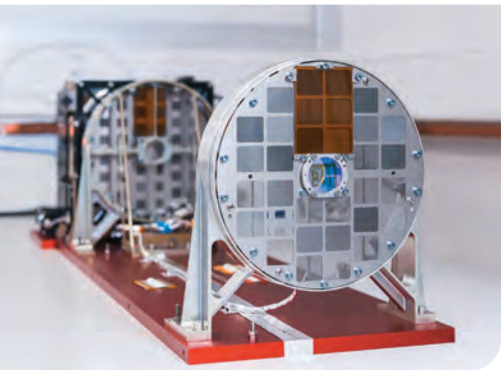


Spectra in the two spectral bands of SPICE taken near Sun centre on 21 April 2020, averaged over 400 pixels along the slit. Top panel: the short wavelength band, bottom panel: the long wavelength band. Fludra et al. (2021).



Images from EUI on 30 May 2020 taken during cruise phase. Left: The HRI field of view shown as a white square on the FSI image, middle: HRI image, right: sub field of HRI image corresponding to the red square in the middle and left panel. Berghmans et al. (2021).

5.2 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 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)

Method
Measurement

Development & construction of instruments
STIX is a Swiss-lead 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
www.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

Abbreviations

STIX Spectr./Telescope for Imaging X-rays

Past Achievements and Status

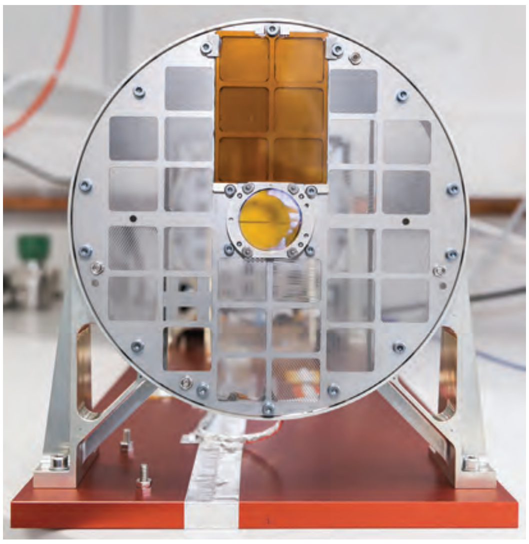
In October 2012, Solar Orbiter was selected as the first medium-class mission of ESA's Cosmic Vision 2015–2025. STIX was previously selected as one of the 10 instruments onboard Solar Orbiter. The STIX Flight Model was delivered to ESA in July 2017, and Solar Orbiter was launched on 9 February 2020. The commissioning of STIX was successfully completed in June 2020. As of January 2021, STIX has been continuously observing the Sun and more than 5000 solar flares have been recorded so far.

Publications

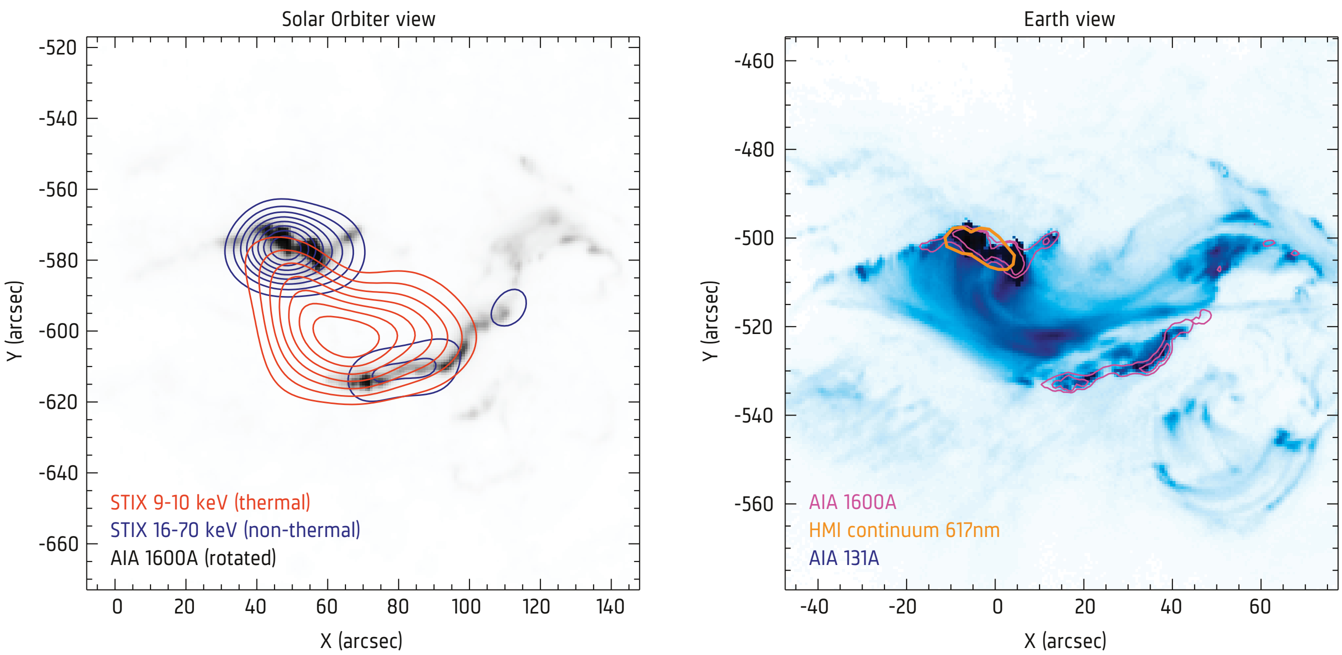
Battaglia et al. 2021, Astron. & Astrophys. 656: id. A4, 19 pp.

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

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.



STIX imaging results of the largest solar flare observed to date, and X-class flare on 28 October 2021. Images derived from STIX are shown revealing that the thermal emission is coming from a loop connecting the flare ribbons, while the non-thermal emissions are from the flare ribbons, produced by flare-accelerated electrons as they enter the dense ribbons.

SOLAR PHYSICS

5.3 SWA – Solar Wind Plasma Analyser on Solar Orbiter

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)

Method
Measurement

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

Website
www.sci.esa.int/web/solar-orbiter
www.ucl.ac.uk/mssl/research-projects/2020/feb/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, both for the regular slow and fast solar wind, as well as for transient events, such as coronal mass ejections propagating in interplanetary space. In addition to determining the bulk properties of the wind, SWA will also provide measurements of the solar wind ion composition for key elements.

SWA-HIS measures the heavy ion composition and kinetic properties from the solar wind regime up through suprathermal energies, covering solar wind ions, pickup ions, and suprathermal particles. To achieve these science goals, SWA-HIS addresses two fundamentally different sets of measurement objectives. First, SWA-HIS measures the ion and element composition and 3-D velocity distribution functions (VDFs) of heavy ions for He up to Fe in the bulk solar wind between 0.5 and 18 keV/e. Second, it measures the ion and element composition and 3-D VDFs of the major constituents: He, C, O, and Fe in the suprathermal energy range up to 60 keV/e.

Past Achievements and Status

We calibrated HIS 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 and is on a trajectory which will take it on a close proximity to the Sun.

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: 10.1016/j.asr.2021.07.024

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

Wurz P (2005) **Solar wind composition**, in "The Dynamic Sun: Challenges for Theory and Observations" ESA SP-600 (2005) 5.2, 1–9.

Abbreviations

EAS	Electron Analyser System
HIS	Heavy Ion Sensor
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

5.4 JTSIM-DARA on FY-3E

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 future contributions to the almost seamless series of space-borne TSI measurements since 1978.

The JTSIM-DARA/FY-3E experiment is a cooperation with the Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP) institute. Key aspects of the FY-3 satellite series include collecting atmospheric data for intermediate and long-term weather forecasting and global climate research.

The idea is to operate a standard group of (originally) three electrical substitution radiometers of a different make and model on one satellite, similar to the ground-based World Standard Group (WSG) located at PMOD/WRC (Davos, Switzerland), to provide improved long-term stability of TSI measurements. The first realisation of a space standard group will consist of a JTSIM-DARA radiometer, and a Solar Irradiance Absolute Radiometer (SIAR) instrument designed by CIOMP.

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

Past Achievements and Status

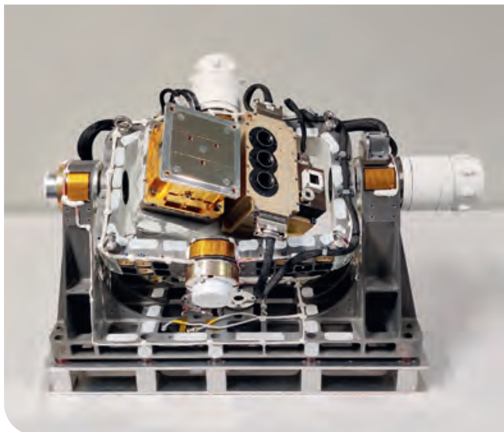
The JTSIM-DARA TSI radiometer proto flight model was integrated on the JTSIM solar tracking frame and FY-3E satellite, and successfully launched on 4 July 2021. After successful commissioning the measurements started one month after launch.

Publications

Song B, Ye X, Finsterle W, Gyo M, Gander M, Remesal Oliva A, Pfiffner D, Zhao Y, Fang W (2021) **The Fengyun-3E/Joint Total Solar Irradiance Absolute Radiometer: Instrument Design, Characterization, and Calibration**, Solar Physics, 296: https://doi.org/10.1007/s11207-021-01794-5

Abbreviations

DARA	Digital Absolute Radiometer
FY-3E	Fengyun 3E satellite
JTSIM	Joint TSI Monitor
SIAR	Solar Irradiance Absolute Radiometer
TSI	Total Solar Irradiance
WSG	World Standard Group



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)
W. Schmutz, J.-P. Montillet (PMOD/WRC)

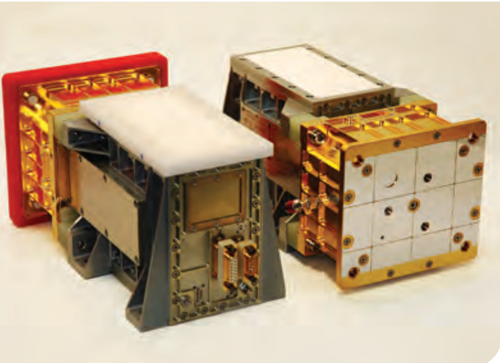
Method
Measurement

Research based on existing instruments
JTSIM-DARA experiment on the FY-3E spacecraft

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

Website
www.pmodwrc.ch

5.5 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), Davos, Switzerland

In cooperation with
European Space Agency (ESA)

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

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

Method
Measurement

Development & construction of instruments
DARA is an abolute radiometer to measure the solar energy input to Earth – a payload on the ESA satellite, PROBA-3.

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

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

www.pmodwrc.ch

Purpose of Research

The Sun is the primary energy source for the Earth's climate system. The existence of a potentially long-term trend in the Sun's activity and whether or not such a trend could affect Earth's climate, is still a matter of debate.

Continuous and precise Total Solar Irradiance (TSI) measurements are indispensable to monitor variations in short and long-term solar radiative activity. The Digital Absolute Radiometer (DARA) onboard the ESA PROBA-3 (Project for On-Board Autonomy) mission is one of PMOD/WRC's future contributions to the almost seamless series of spaceborne TSI measurements since 1978.

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. The calibration of DARA against a NIST calibrated cryogenic radiometer guarantees full SI-traceability of the irradiance measurements.

PROBA-3 has a nominal mission duration of two years, and will be the world's first precision formation flying mission. A pair of satellites will fly together and create, for part of the orbit, a configuration resembling a "large structure" in space, representing a coronagraph configuration.

The DARA instrument is situated on the sun-facing occulter spacecraft which always faces the Sun, and from this location it is expected that the measurements of solar irradiance can be maintained over almost the full duration of the eccentric orbit which will have a duration of 19 hours 38 minutes.

Past Achievements and Status

The DARA Flight Model and the Flight Spare were fully assembled in 2019. In the report period, tasks for the instrument qualification were, among others, the comparison of the vibration test results with the structural analysis and similarly, the comparison of the thermal test findings with the thermal analysis.

A very important check was to verify if any of the optical elements had moved during the vibration test. This would result in a deviation of the optical axis in relation to the built-in alignment mirror, which is used as an optical reference during instrument mounting on the spacecraft. For this purpose existing infrastructure at PMOD/WRC was used. In the optics laboratory, the angular-dependent response of the radiometer was used to determine the line-of-sight of the receiver cavities and then compared to the alignment mirror. The results were entirely satisfactory, hence proving the mechanical design, the manufacturing precision and instrument assembly process.

PMOD/WRC staff were due to attend the final end-to-end radiometric calibration campaign at the Laboratory for Atmospheric and Space Physics in Boulder, USA, but plans had to be modified due to the pandemic situation. The instrument and ground support equipment was shipped to the TRF facility at LASP and from the PMOD/WRC side, the campaign was attended remotely. We received great support from our American collaborators and thanks to their experience, DARA was handled professionally, resulting in a successful calibration. This concluded the major activities on the Flight Model in Summer 2021.

At the end of November 2021, the DARA FM was taken to QinetiQ Space NV in Antwerp, Belgium, for integration of the different PROBA-3 occulter spacecraft units. The PROBA-3 spacecraft is not yet fully assembled and final instrument integration is planned in late 2022. The PROBA-3 launch is currently foreseen at the end of 2023.

Time-Line	From	To
Planning	2013	2016
Construction	end 2016 (EM)	end 2020 (EQM/FS)
Measurement phase	2024	2026
Data evaluation	2024	2027

Publications

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

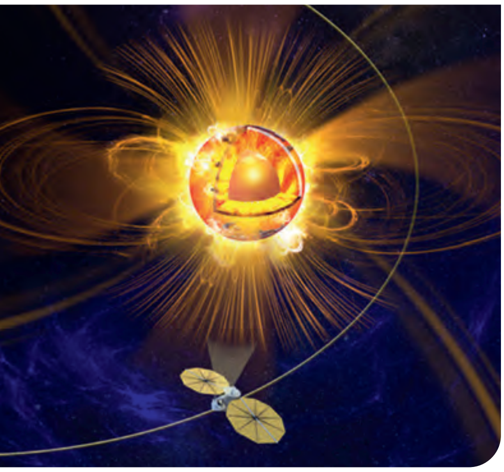
Walter B, et al. (2017) **The CLARA/NORSAT-1 solar absolute radiometer: instrument design, characterization and calibration**, Metrologia 54: 674–682.

Abbreviations

EQM	Engineering Qualification Model
ESR	Elec. Substitution Radiometer
FM/FS	Flight Model/Flight Spare
NIST	National Inst. Stand. & Technol.
TSI	Total Solar Irradiance

A PMOD/WRC staff member is preparing the DARA FM for thermal-vacuum tests at the University of Bern.

5.6 S-EUVI – Solaris EUV Imager on Solaris



Artists impression of the Solaris spacecraft.
Image credit: SwRI.

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

Fachhochschule Nordwestschweiz (FHNW),
Switzerland

In cooperation with
SwRI, USA; Ball Aerospace, USA
IAS, France
ROB, Belgium
NASA/GSFC, USA
NCAR, HAO
Northrop Grumman, USA

Principal Investigator(s)
Don Hassler, SwRI, USA (mission)
David Berghmans, ROB, Belgium (S-EUVI)

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

Co-Investigator(s)
S. Krucker (FHNW)
F. Auchère (PMOD/WRC)

Method
Measurement

Website
www.pmodwrc.ch

Purpose of Research

Solaris is a solar polar mission of discovery to address fundamental questions about the Sun and Heliosphere that can only be answered from a high latitude (polar) vantage point. Solaris will be the first mission to obtain sustained coverage of the solar interior and atmosphere from high latitudes, uniquely and comprehensively investigating the global Sun and Heliosphere.

Solaris transforms our understanding of the solar activity cycle and the global heliosphere through direct imaging of the solar poles and the ecliptic-plane corona viewed at all longitudes simultaneously. It will use a Jupiter fly-by, and achieve an inclination of >70° above the ecliptic, and have a 3-month pass over each pole (see figure).

Solaris has three primary science goals:

– To understand how polar magnetic fields and flows distinguish between the mechanisms of the solar dynamo that shape the solar activity cycle.
– To determine how high-latitude coronal magnetic fields connect the Sun and Heliosphere.
– To reveal longitudinal structure and variability, and determine the role of transient dynamics in structuring the solar wind.

The Swiss contribution is involvement in the S-EUVI instrument which will image the million-degree solar corona (Fe IX/X, 17.4 nm). It builds on Swiss, Belgian and French involvement in the Solar Orbiter and Lagrange imagers. The imager is key to answering all three science questions, which are building significantly on Solar Orbiter science. Solaris will have two polar passes during its nominal operation phase from June - Sept 2030 and then from December 2030 - April 2031.

Past Achievements and Status

Solaris is a mission selected for a phase A study for the NASA MIDEX class C programme. There is one European instrument, S-EUVI. A proposal covering Phase A for the Swiss contributions to the development and selection of the S-EUVI experiment via the PRODEX Programme was approved by SSO and ESA in early 2021.

The Swiss contributions are the electronics and structure for S-EUVI. The NASA review took place for the mission in Autumn 2021. NASA made the announcement in February 2022 that Solaris was not selected in this round.

Publications

Hassler D M, Newmark J, Gibson S, Wuelser J-P, Gosain S, Harvey J, et al. (2019) **The Solaris Solar Polar Mission Concept & the Compact Doppler Magnetograph (CDM)**, L5 Consortium Meeting, Stanford, Calif., 2019.

Hassler DM, Newmark J, Gibson S (2020) **The Solaris Solar Polar MIDEX Mission Concept: Revealing the Mysteries of the Sun's Poles,** AGU.

Abbreviations

S-EUVI Solar EUV Imager

Time-Line	From	To
Planning	2020	2022
Construction	2022	2025
Measurement phase	2027	2030
Data evaluation	2027	2032

5.7 SoSpIM – Solar Spectral Irradiance Monitor on the JAXA Solar-C Mission

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' measures 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 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

A proposal covering the Phases A2 and B, for contributions to the development and realisation of SoSpIM onboard Solar-C by institutions based in Switzerland via the PRODEX Programme, was approved by ESA in October 2020. System requirements and architecture have been established. The main sub-systems have been specified. Industrial contracts are being formed. The preliminary design is proceeding with a SoSpIM PDR planned for Q1 in 2023.

Publications

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

Time-Line	From	To
Planning	2019	2020
Construction	2020	2026
Measurement phase	2027	2029
Data evaluation	2026	2030

The Solar-C spacecraft.
Image credit: NAOJ/JAXA.

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

In cooperation with
ROB, Belgium
JAXA/ISAS, Japan
NAOJ, Japan

Principal Investigator
T. Shimizu (JAXA/ISAS)

Swiss Principal Investigator
L. Harra (PMOD/WRC)

Co-Investigator(s)
David Berghmans, ROB, Belgium
Säm Krucker, FHNW, Switzerland

Method
Measurement

Website
www.pmodwrc.ch

5.8 CLARA – Compact Lightweight Absolute Radiometer on NorSat-1

Illustration of NorSat-1 with CLARA onboard.

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, W. Schmutz (PMOD/WRC)
B. Andersen (UiO)
G. Kopp (LASP)

Method
Measurement

Research based on existing instruments
CLARA was developed and constructed by PMOD/WRC from 2013 to 2015

Websites
www.pmodwrc.ch

https://directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/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 and PREMOS, CLARA continues the long-term involvement of PMOD/WRC in solar research.

CLARA also measures the Outgoing Longwave Radiation (OLR) at the top of the Earth atmosphere. These measurements will serve as a technical demonstration and pave the way for future absolute radiometers to ultimately determine the terrestrial Earth radiation budget, and in case of sufficient precision, 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 first light value of CLARA of 1360.18 Wm^{-2} (Walter et al., 2020) confirmed the TSI values of TIM/SORCE, PREMOS/PICARD and VIRGO/SOHO.

At the end of 2019, CLARA started taking measurements of OLR on the night-side of Earth.

After the failure of a reaction wheel in May 2018, a second reaction wheel stopped working in August 2021. While the first occurrence was a permanent failure, this time the interruption was caused by the wheel software. Fortunately, UTIAS in collaboration with the reaction wheel supplier, were able to solve the problem. The updated firmware was uploaded to the spacecraft in February 2022 and the reaction wheel became functional again. While the CLARA instrument status is nominal, further platform tests are still necessary before the payload becomes fully operational again.

Publications

Haberreiter M, Finsterle W, Montillet J-P, Walter B, Andersen B, Schmutz W (2021) **TSI and TOR measurements with CLARA onboard NorSat-1**, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-6437, https://doi.org/10.5194/egusphere-egu21-6437

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: 10.1017/S1743921319004617

Abbreviations

CLARA	Compact Lightweight Absolute Radiometer
NorSat-1	Norwegian satellite
PREMOS	Precision Monitor Sensor
SORCE	Solar Radiation and Climate Experiment
TIM	Total Irradiance Monitor
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradiance and Gravity Oscillations

Time-Line	From	To
Planning	2013	2013
Construction	2014	2015
Measurement phase	Jun. 2017	open
Data evaluation	Aug. 2017	ongoing

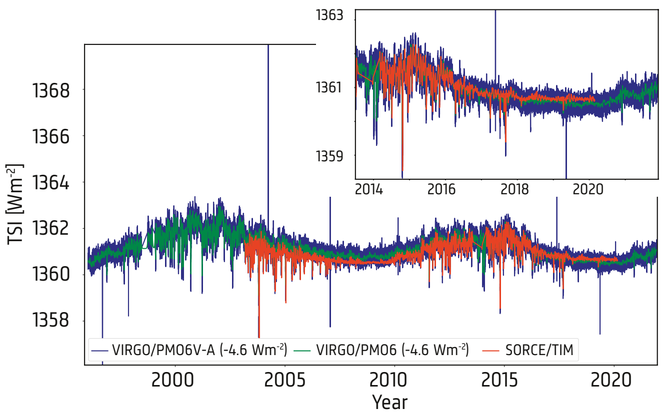
5.9 VIRGO on SoHO

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. A new method for correcting sensor degradation based on machine learning and data fusion has been implemented (Finsterle et al., 2021). The figure below illustrates the corrected time-series. Of particular interest is the long-term trend of TSI. The current version shows no significant difference in the TSI level between the solar minima in 1996, 2008 and 2019.



The degradation corrected VIRGO/PMO6-active channel (blue) and the PMO6-V composite (VIRGO/PMO6 active + backup channels, green). For comparison we also show the SORCE/TIM timeseries (red). The inset zooms in on the period of the last solar minimum in 2019 (Finsterle et al., 2021).

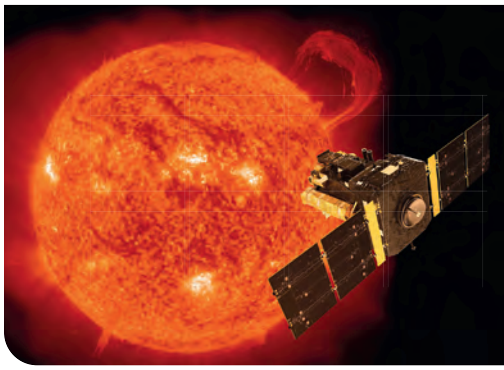
Publications

Finsterle W, Montillet JP, Schmutz W, Šikonja R, Kolar L, Treven L (2021) **The total solar irradiance during the recent solar minimum period measured by SOHO/VIRGO**, Sci. Rep. 11: 7835, https://doi.org/10.1038/s41598-021-87108-y

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
Measurement phase	1996	ongoing
Data evaluation	1996	ongoing



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
Inst. Atmos. Climate Sci. (IAC), ETH Zurich, Zurich, Switzerland

Principal Investigator(s)
W. Finsterle (PMOD/WRC)
B. N. Andersen (UIO, Norway)

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

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

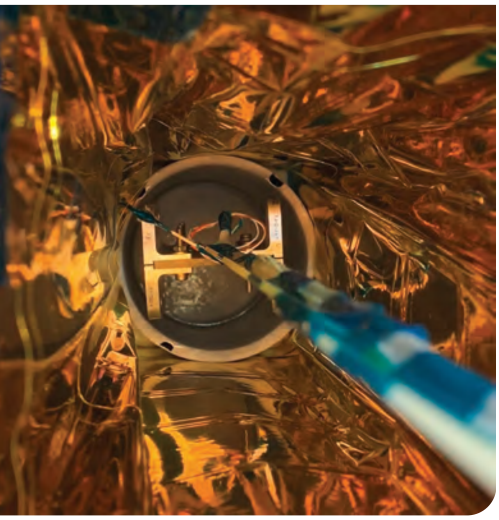
Method
Measurement

Research based on existing instruments
VIRGO experiment on the SoHO spacecraft

Website
www.pmodwrc.ch

6 Heliospheric Physics

6.1 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)

Method
Measurement

Development & construction of instruments
Thermal design and radiator assembly

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

Website
https://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 Thermal Test Model of the SXI radiator was manufactured and verified in 2021. Phase D will start after successful completion of the instrument Critical Design Review, planned for mid-2022.

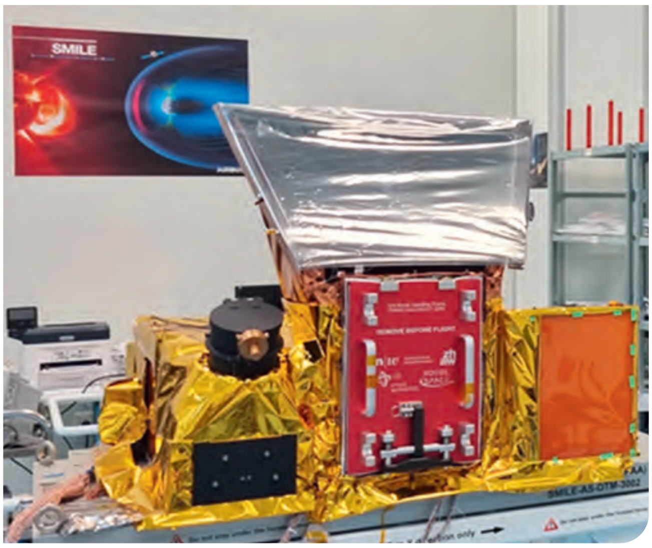
Publications

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.

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).

6.2 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). SMILE will launch in late 2024 or early 2025 with a 3-year nominal mission lifetime. 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. SMILE will tackle three key questions that currently remain unresolved:

i) What are the fundamental modes of interaction between the dayside magnetosphere and the solar wind? The manner in which energy and plasma enters the magnetosphere is crucial to understanding and predicting how the magnetosphere will respond. SMILE will explore the phenomenon of magnetopause reconnection, and seek to determine when and where transient and steady reconnection states dominate.

ii) What defines the magnetospheric sub-storm cycle? The sub-storm, a disturbance in Earth's magnetosphere that causes energetic particles to enter the ionosphere from higher latitudes, is thought to control how energy and plasma circulate within Earth's magnetosphere. SMILE aims to define this cycle, including timing and amplitudes.

iii) How do CME-driven storms arise, and what is their relationship to substorms? Geomagnetic storms driven by coronal mass ejections (CME) represent a severe space weather threat. SMILE will study how and why CME-driven storms develop, and determine whether or not they are always separate phenomena, or can be considered as sequences of substorms.

We are participating in the Light Ion Analyser (LIA) instrument to investigate the interaction of the solar wind and magneto-sheath under various conditions. LIA will determine the properties and behaviour of the solar wind and magnetosheath ions under various conditions by measuring the 3-D velocity distribution of protons and alpha particles. It is made of two top-hat-type electrostatic analysers, each mounted on opposite sides of the platform. LIA can sample the full 4π 3-D distribution of the solar wind, and can measure ions in the 0.2-20 keV energy range with a resolution of up to 0.5ς.

Past Achievements and Status

The LIA instrument is currently under development.

Abbreviations

LIA	Light Ion Analyser
SMILE	Solar Wind Magnetosphere Ionosphere Link Explorer

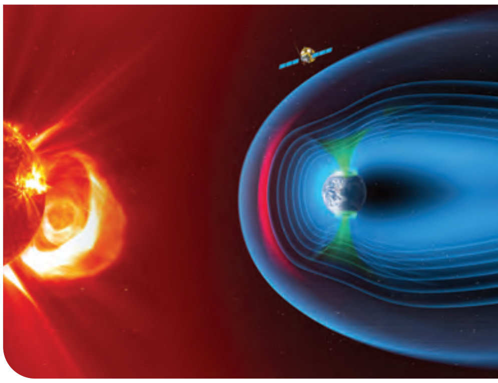
Publications

Fuselier SA, Funsten HO, Heirtzler D et al. (2010) Geophys. Res. Lett. 37: 13101, doi:10.1029/2010GL044140

Petrinec SM, Dayeh MA, Funsten HO et al. (2011) J. Geophys. Res. 116: A7, CiteID A07203, doi: 10.1029/2010JA016357

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

Time-Line	From	To
Planning	2015	2017
Construction	2017	2022
Measurement phase	2025	
Data evaluation	2025	



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)

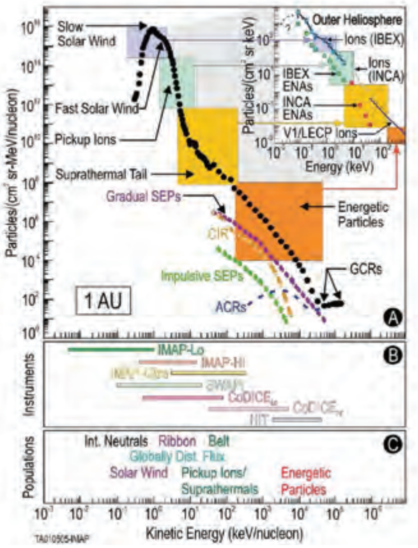
Co-Investigator(s)
A. Galli (UNIBE)

Method
Measurement

Development & construction of instruments
Participation in the design and calibration of the Light Ion Analyser (LIA)

Website
www.sci.esa.int/web/smile

6.3 Interstellar Mapping and Acceleration Probe (IMAP)



Caption text: see end of article.

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

In cooperation with
Princeton Univ., Princeton; SW Res. Inst., Austin; Univ. New Hamp., Durham; 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), J. Gasser (UNIBE)

Method
Measurement

Development & construction of instruments
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
www.imap.princeton.edu

Purpose of Research

The Interstellar Mapping and Acceleration 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.

Part of the scientific instrumentation are 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 calibration.

Publications

Fuselier SA et al. (2009) **The IBEX-Lo Sensor**, Space Science Review 146: 117–147.

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

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

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

Caption 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.

6.4 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 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 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.

IBEX continues to take nominal measurements of ENAs originating from the interface region between our heliosphere and the surrounding interstellar matter. Continuation of the IBEX mission is foreseen until 2025 to allow sufficient overlap with the successor mission, the Interstellar Mapping and Acceleration Probe (IMAP).

Publications

Galli A, Wurz P, Fichtner H, Futaana Y, Barabash S (2019) **An empirical model of Energetic Neutral Atom imaging of the heliosphere and its implications for future heliospheric missions at great heliocentric distances**, Astrophys. J, 886: 70, 16 pp, doi: 10.3847/1538–4357/ab4e94

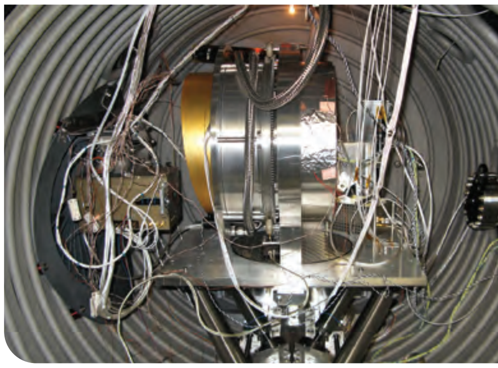
Galli A, Wurz P, Rahmanifard F, Möbius E, Schwadron NA, Kucharek H, Heirtzler D, Fairchild K, Bzowski M, Kubiak MA, Kowalska-Leszczynska I, Sokół JM, Fuselier SA, Swaczyna P, McComas DJ (2019) **Model-free maps of interstellar neutral hydrogen measured with IBEX between 2009 and 2018**, Astrophys. J,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

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: 10.1051/0004-6361/201321420

Abbreviations

ENA	Energetic Neutral Atom
IBEX	Interstellar Boundary Explorer
IMAP	Interstellar Mapping and Acceleration Probe
MEFISTO	MEsskammer für Flugzeit-InStrumente u. Time-Of-Flight

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



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)

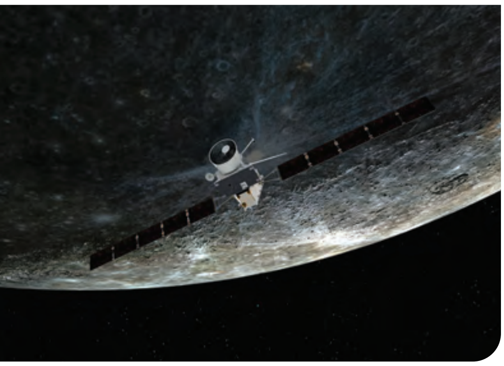
Method
Measurement

Development & construction of instruments
We completed the ion-optical design, and participated in development and manufacture of the IBEX-Lo ENA camera. The entire IBEX-Lo calib. with ENAs over the full energy range, and all species of interest, was conducted.

Industrial Hardware Contract to
Sulzer Innotec

7 Comets, Planets

7.1 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

Method
Measurement

Development & construction of instrument(s)
UNIBE developed and built BELA with parts supplied by Germany and Spain.

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

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

Purpose of Research

BepiColombo Laser Altimeter (BELA) forms part of a suite of experiments designed to perform geodesy experiments at Mercury from onboard ESA's BepiColombo spacecraft. BELA is a joint Swiss-German project with a smaller involvement from Spain. The scientific objectives of the experiment are to measure:

- 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 own 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 on 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 a 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 excellent results should be obtained with the present instrument status. The spacecraft was launched in October 2018 from Kourou and is currently underway to Mercury. Testing of BELA has proceeded nominally and the instrument appears to be fully functional. Orbit insertion is foreseen at the end of 2025 and the prime mission will start in April 2026 for, nominally, a minimum of 1 Earth year.

Abbreviations

BELA BepiColombo Laser Altimeter

Publications

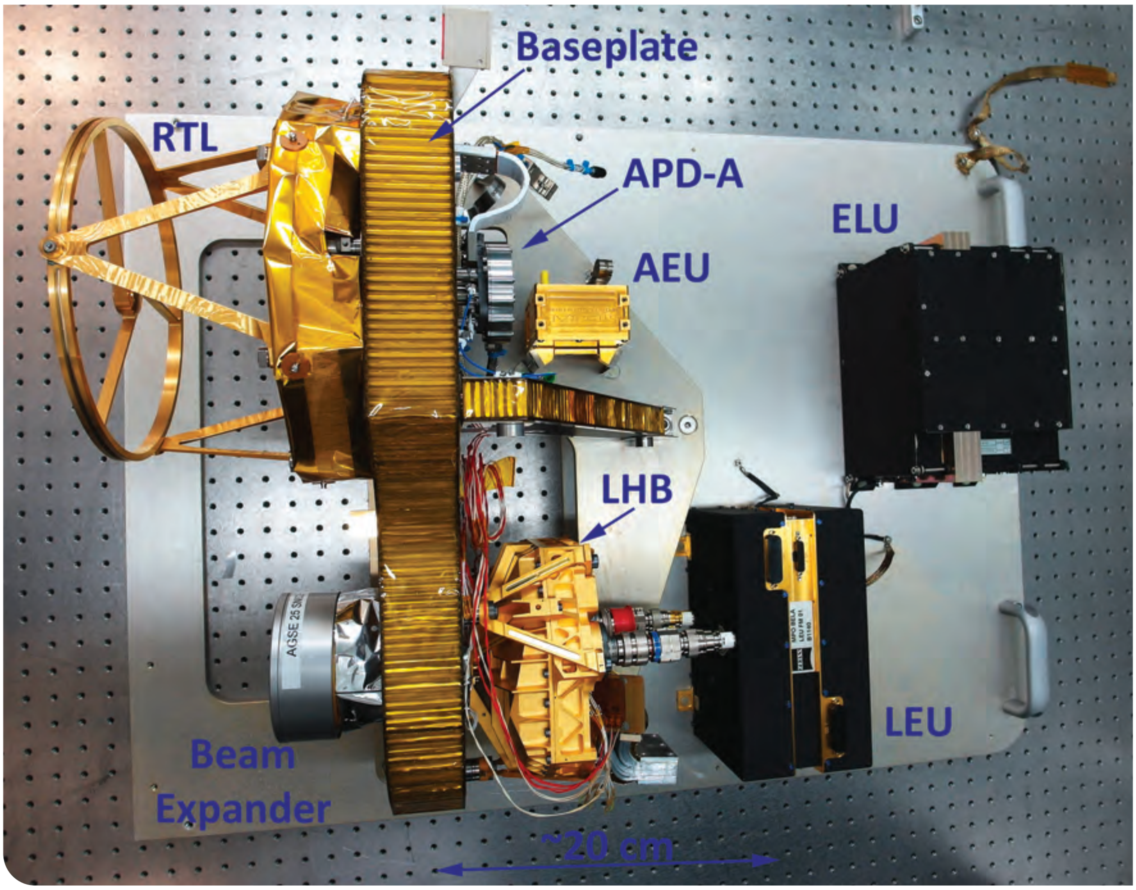
Gunderson K, Thomas N (2010) **BELA receiver performance modeling over the BepiColombo mission lifetime**, Planetary and Space Science 58: 309–318.

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.

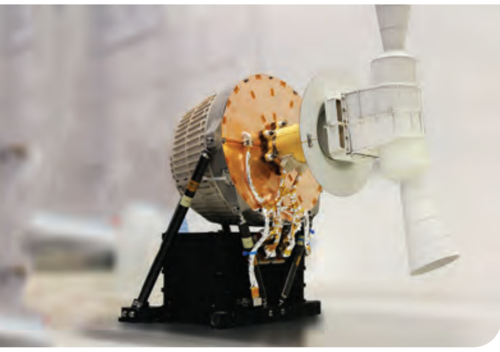
Thomas N, Hussmann H, Lara LM (2019) **The BepiColombo Laser Altimeter (BELA): A post-launch summary**, CEAS Space Journal 11: 371.

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.

7.2 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, N. Jäggi (UNIBE)

Method
Measurement

Development & construction of instrument(s)
Participation in two instruments: 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 instrument.

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

Website
www.sci.esa.int/web/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.

Launch of BepiColombo was successfully executed on 20 October 2018, and the spacecraft is on the way to Mercury, while the arrival is on 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 developing 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 the first (1 October 2021) of several Mercury flybys. 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: 10.5194/angeo-2018-109

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: 10.1016/j.asr.2021.07.024

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

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

7.3 Jupiter and Icy Moons Explorer (JUICE)

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.

JUICE is scheduled for launch in April 2023 and will arrive in the Jupiter system in 2031.

Past Achievements and Status

The JUICE mission is currently in the implementation phase, and was adopted by ESA in November 2014. The industrial prime contractor was selected in July 2015. 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 this experiment. The PEP experiment and the NIM instrument were successfully integrated on the spacecraft in Autumn 2020, and the flight spare units will be completed in 2022.

The spacecraft is now ready for launch in April 2023.

Publications

Vorburger A, Wurz P, Lammer H, Barabash S, Mousis O (2015) **Monte-Carlo Simulation of Callisto's Exosphere**, Icarus 262: 14–29.

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: 10.1029/2019JA026610

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

Abbreviations

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

Time-Line	From	To
Planning	Oct. 2012	Feb. 2014
Construction	Mar. 2014	Dec. 2022
Measurement phase	Dec. 2032	2036
Data evaluation	Dec. 2032	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, Katlenburg-Lindau, 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)

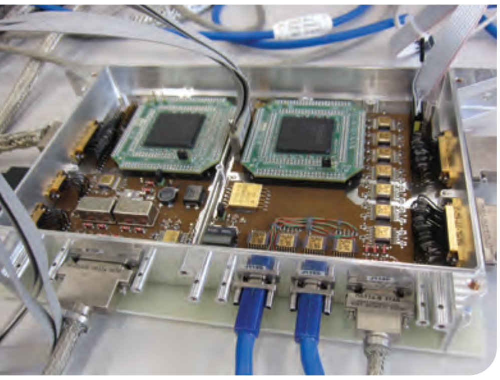
Co-Investigator(s)
A. Galli, N. Thomas, M. Tulej, A. Vorburger (UNIBE)

Method
Measurement

Development & construction of instrument(s)
Neutral and Ion Mass spectrometer (NIM) for the Particle Environment Package of JUICE.

Website
www.sci.esa.int/web/juice

7.4 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

Method
Measurement

Development & construction of instruments
UNIBE developed and built the GALA rangefinder module

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

Website
www.dlr.de/pf/desktopdefault.aspx/tabid-10617/18438_read-43017

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 will contribute the rangefinder electronics to the laser altimeter system. This will be a derivative of the BepiColombo Laser Altimeter (BELA) rangefinder which has been successfully implemented for the BepiColombo mission to Mercury. The rangefinder will mostly be 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) has been delivered to DLR and integrated into the flight model of the GALA instrument.

The instrument itself is now on the JUICE spacecraft and under test at ESA. Launch of the spacecraft is expected in 2023.

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

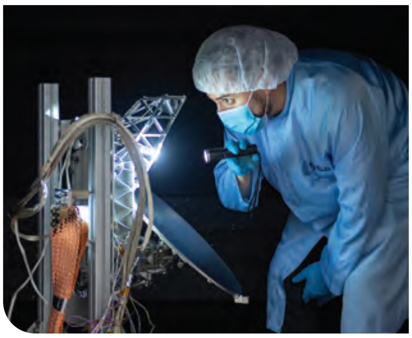
Time-Line	From	To
Planning	2004	2008
Construction	2008	2016
Measurement phase	2026	2027
Data evaluation	2026	2029

7.5 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) 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 on-board blackbody calibration target. In addition, IAP is conducting radiometric performance tests of the SWI receiver unit.



SWI telescope under inspection during antenna near-field test at ESTEC. Image credit: ESA.

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 the fourth quarter of 2020. Optical alignment of SWI was carried out in collaboration between MPS and IAP, and radiometric characterisation of the receivers was performed with the help of the interferometric testbed developed at IAP. An antenna near-field test campaign then took place at ESA/ESTEC, and IAP contributed strongly to the analysis of the measurement data.

The instrument was delivered to the spacecraft prime in the third quarter of 2021 and has now been integrated into the spacecraft. The launch is planned in 2023.

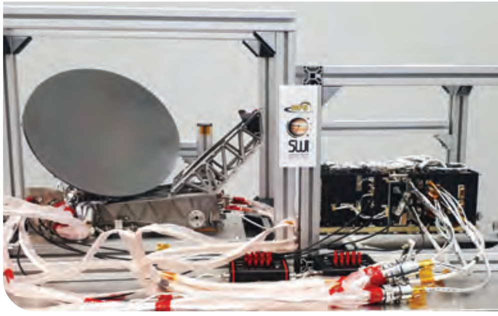
Publications

Kotiranta M et al. (2020), **Optics for the Submillimeter Wave Instrument on Jupiter Mission JUICE**, 14th Eur. Conf. Antennas Propag. EuCAP 2020, Copenhagen, Denmark.

Abbreviations

JUICE Jupiter and Icy Moons Explorer
SWI Submillimeter Wave Instrument

Time-Line	From	To
Planning	2010	2012
Construction	2013	2021
Measurement phase	2030	2033
Data evaluation	2030	2036



SWI instrument prepared for integration into the JUICE spacecraft. Image credit: MPS.

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

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

Principal Investigator(s)
P. Hartogh (MPS)

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

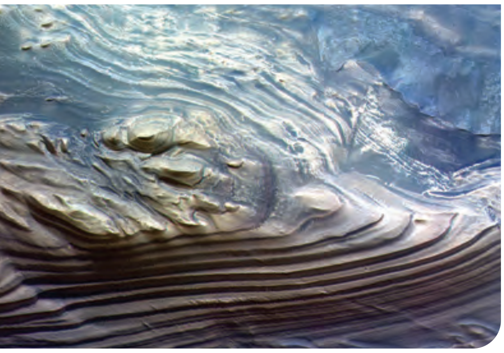
Co-Investigator(s)
M. Kotiranta (UNIBE)
K. Jacob (UNIBE)

Method
Measurement

Development & construction of instrument(s)
Optics design, optical components, calibration unit, instrument testing

Industrial hardware contract(s) to
Micos Engineering, Switzerland

7.6 The Colour and Stereo Surface Imaging System (CaSSIS)



Layered sediments on Mars in a 7 × 10 km area imaged by CaSSIS. This layered mound lies in Juventae Chasma, just north of Valles Marineris. Image credit: ESA/Roscosmos/CaSSIS.

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. Debei, M.R. El-Maarry, E. Hauber, C.J. Hansen, A. Ivanov, L. Keszthelyi, R. Kirk, R. Kuzmin, N. Mangold, L. Marinangeli, W.J. Markiewicz, M. Massironi, A.S. McEwen, C. Okubo, P. Wajer, P. Orleanski, A. Pommerol, L.L. Tornabene, P. Wajer, J.J. Wray

Method
Measurement

Development & construction of instrument(s)
UNIBE developed and built CaSSIS with parts supplied by Italy, Poland and Hungary.

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

Website
www.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 in 2020 will also consider methane areas for landing sites. 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 25,000 images of the surface of Mars in colour and more than 1500 stereo pairs. The high signal-to-noise 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 within ESA's Planetary Science Archive 6 months after acquisition.

The instrument will run until at least the end of 2022 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.

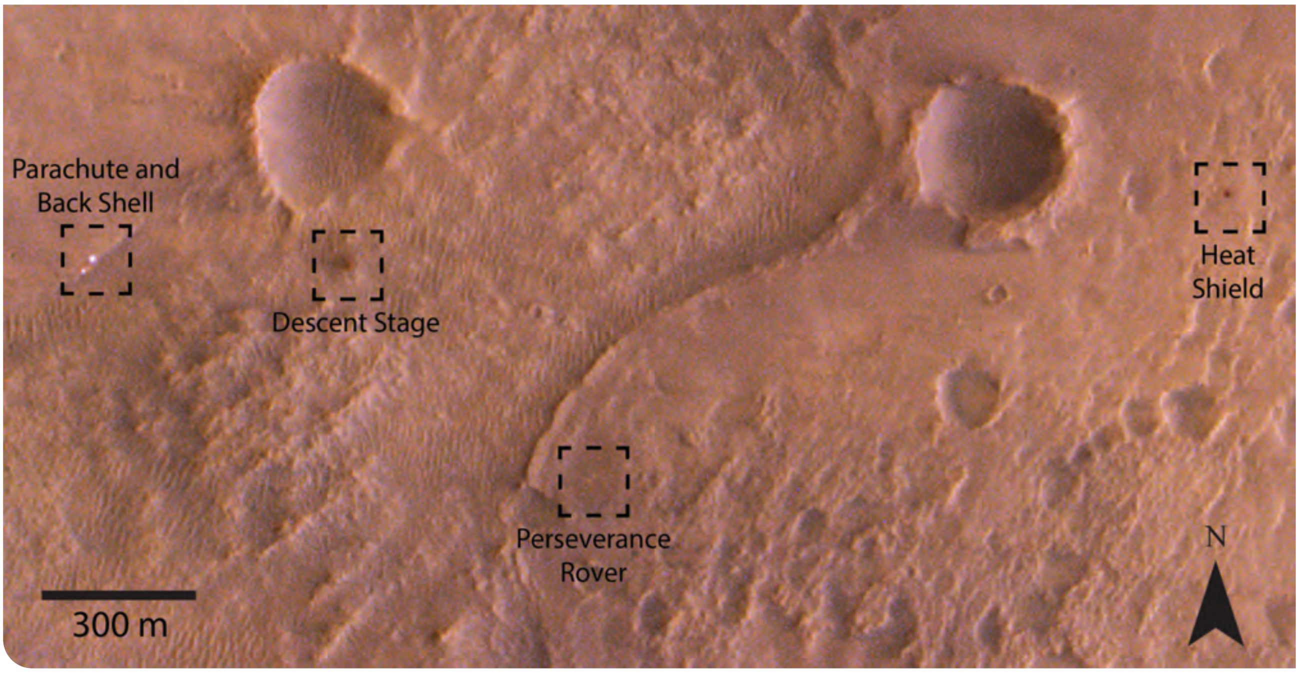
Roloff V, and 24 colleagues (2017) **On-ground performance and calibration of the ExoMars Trace Gas Orbiter CaSSIS Imager**, Space Science Reviews 212: 1871–1896.

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	2022 at least
Data evaluation	2018	2023 and beyond



CaSSIS image of the landing site of NASA's Perseverance rover, along with its parachute, heat shield and descent stage, in the Jezero Crater region of Mars, on 23 February 2021.

7.7 CLUPI – CLose-UP Imager for ExoMars Rover 2022

Illustration of the ExoMars Rover 2022: Image credit: ESA.

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, 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, Germany, Austria, The Netherlands, Belgium, United Kingdom, Italy, and Russia

Method
Measurement

Development & construction of instrument(s)
High Res. Imaging instr. for colour close-up obs. of Martian rocks, surfaces, and samples.

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

Website
www.space-x.ch

Purpose of Research

The CLose-UP Imager (CLUPI), part of the Pasteur Payload onboard the ESA ExoMars Rover 2022, is a powerful high-resolution colour camera specifically designed for close-up observations, so as to obtain visual information similar to what geologists would get using a hand-lens.

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

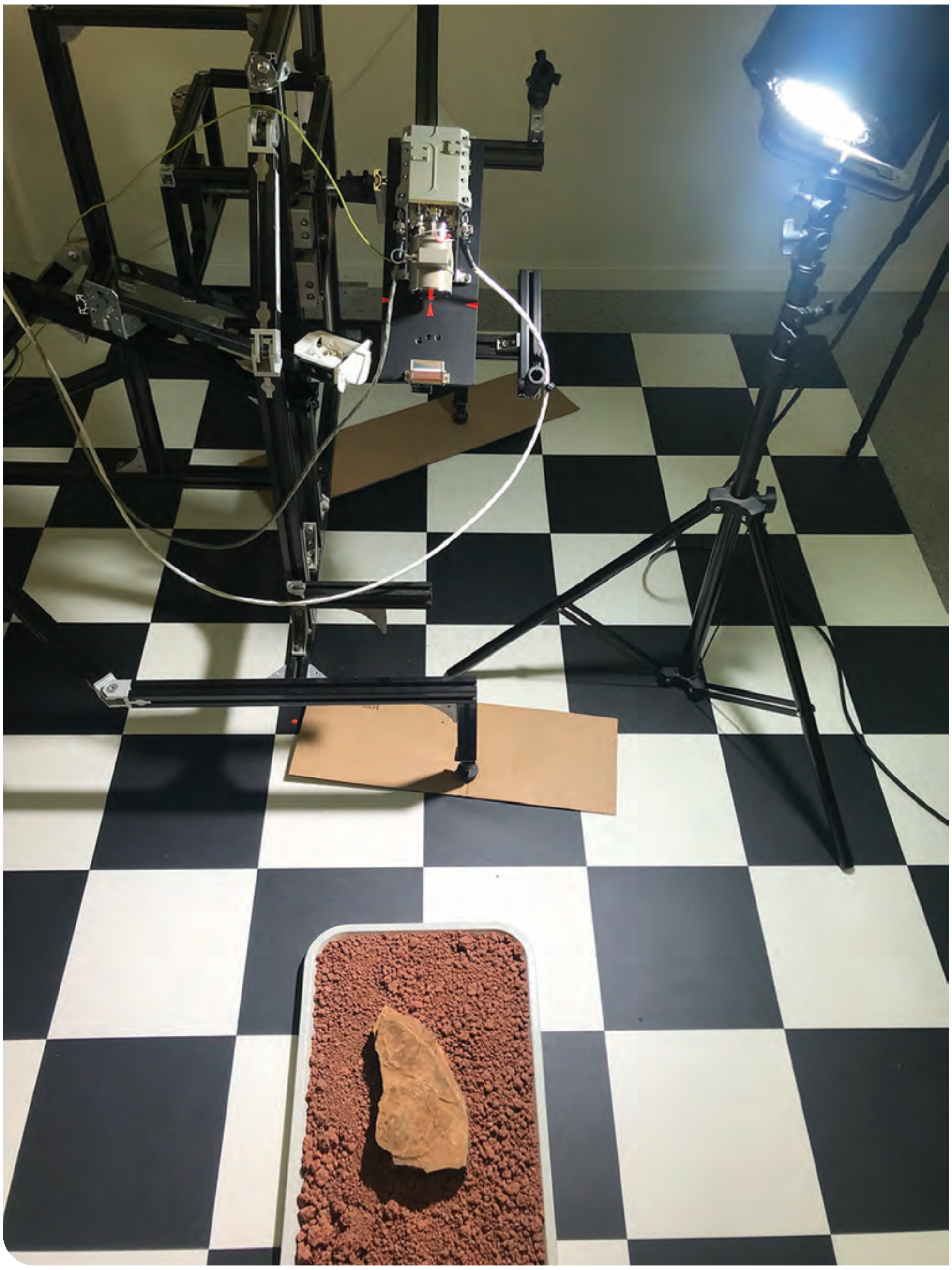
The development of the CLUPI Flight Model was completed, and delivery occurred in Sept. 2020, including complementary tests and software updating. The launch is foreseen in September 2022. A science validation phase with operation preparation is planned before the arrival on the surface of Mars in June 2023.

Time-Line	From	To
Planning	2003	2010
Construction	2011	2020
Measurement phase	2023	2024
Data evaluation	2023	2026

Publications

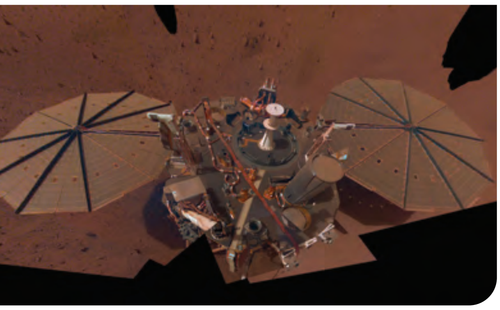
Josset J-L et al. (2017) **The Close-Up Imager (CLUPI) on board the ESA ExoMars Rover: Objectives, description, operations, and science validation activities**, Astrobiology 17: 595–611.

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



CLUPI Flight Model Representative on a Drill/Rover simulator taking pictures of samples during operations simulations in the CLUPI Science Operations Lab. of SEI in Microcity (Neuchâtel). Image Credit: SEI.

7.8 SEIS – InSight Seismic Experiment for Interior Structure



NASA InSight's second full selfie image taken on Mars. This selfie is a mosaic of 14 images in early 2019 by InSight's Instrument Deployment Camera, located on its robotic arm. A thin coating of dust covers the spacecraft. 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

Method
Measurement

Research based on existing instruments
Electronics box, including instrument power conditioning and acquisition, and control electronics for the SEIS instrument.

Industrial hardware contract(s) to
SYDERAL SWISS SA, Switzerland

Website
www.insight.ethz.ch

Purpose of Research

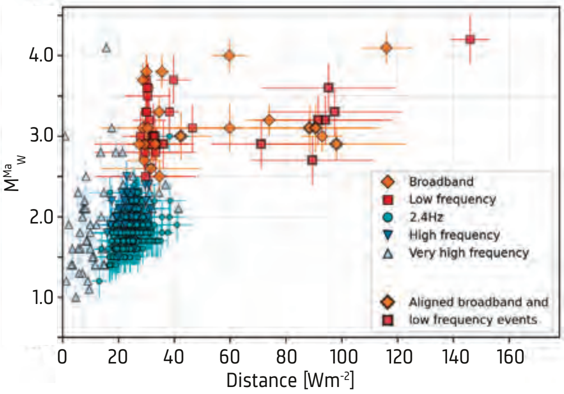
The InSight Lander arrived on the surface of Mars in November 2018 and since February 2019 has been collecting high quality science data. The key instrument onboard is SEIS (Seismic Experiment for Interior Structure) that can measure seismic waves travelling through the interior structure and hence is used to determine the composition of the planet Mars.

The mission is under the lead of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, USA, and the SEIS instrument is under the lead of CNES (Center National d'Etudes Spatiales) in Toulouse, France. The SEIS instrument includes 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 is in charge of the Electronics Box which consists of the data acquisition and control electronics for SEIS. The seismic sensors as well as the Electronics Box continue to operate without issue nearly 3 years after landing, well beyond the nominal mission duration of 1 Martian year (i.e. 2 Earth years). Unfortunately, steadily increasing dust on the solar panels mean the mission is unlikely to survive beyond the next months.

In addition to the hardware contribution, the Swiss Seismological Service (SED) and the Seismology and Geodynamics Group (SEG) at the Institute of Geophysics are responsible for the Marsquake Service that continues to build a catalogue of seismic events from SEIS data. As of April 2022, the Marsquake service (MQS) identified over 1300 marsquakes, including both regional crustal events as well as significant teleseismic events. A large number of events are located at Cerberos Fassae, about 1500 km from InSight, apparently the most tectonically active region of the planet. From the global seismicity, scientists at ETH Zurich and across the science team have succesfully been able to constrain the martian structure ranging from the first few meters, through the entire crust and mantle, down to the molten core at 1550 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 March 2017 to CNES for further instrument integration. Apart from the flight electronics, a qualification model (QM), an electrical model (ELM) and a hard-



Summary of events in the marsquake catalogue according to distance and magnitude. The maximum marsquake identified so far is M4.2. 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.

ware 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 instruments on the spacecraft was successfully completed in March 2018. The spacecraft was moved from Lockheed Martin to the launch pad in Vandenberg, California, USA. A final check-up of the instrument was performed at the end of April 2018. The launch took place on 5 May 2018, with a Mars landing six months later on 26 November 2018. The InSight lander and the SEIS instruments are currently operating and recording marsquakes.

Publications

Clinton JF, Ceylan S, van Driel M, Giardini D, et al. (2021) **The Marsquake catalogue from InSight, Sols 0–478**, Phys. Earth Planet In. 310: doi: 10.1016/j.pepi.2020.106595

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.

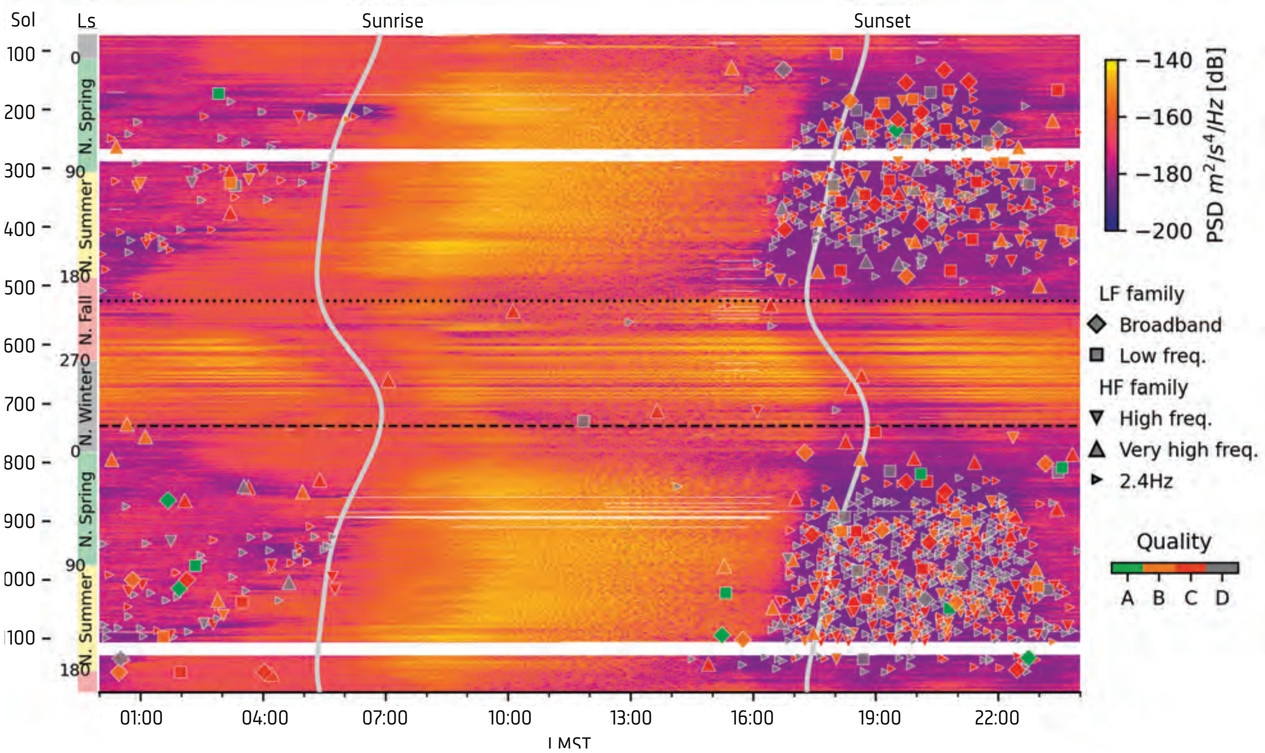
Stähler SC, Khan A, Banerdt W, Lognonné P, Giardini G, et al. (2021) **Seismic detection of the martian core**, Science 373: 443–448.

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, https://doiorg/10.1785/0120210071

Abbreviations

InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
MQS	Marsquake Service
SEIS	Seismic Experiment for Interior Structure

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



Evolution of seismic noise and marsquakes over the duration of the InSight mission so far. A spectrogram for each sol (day on Mars) is stacked from sols 72–1192, the x-axis shows time of day on Mars, the y-axis, the sol number and the season. 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 seismic noise, and the challenge to detect events during noisy periods.

7.9 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

Method
Measurement

Development & construction of instrument(s)
The University of Bern is developing and building the CoCa flight system in collaboration with our German, Spanish and Hungarian partners.

Websites
www.cosmos.esa.int/web/comet-interceptor/home

www.cometinterceptor.space

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 is currently in Phase A and will form part of the mission that is proposed for adoption by ESA in June 2022.

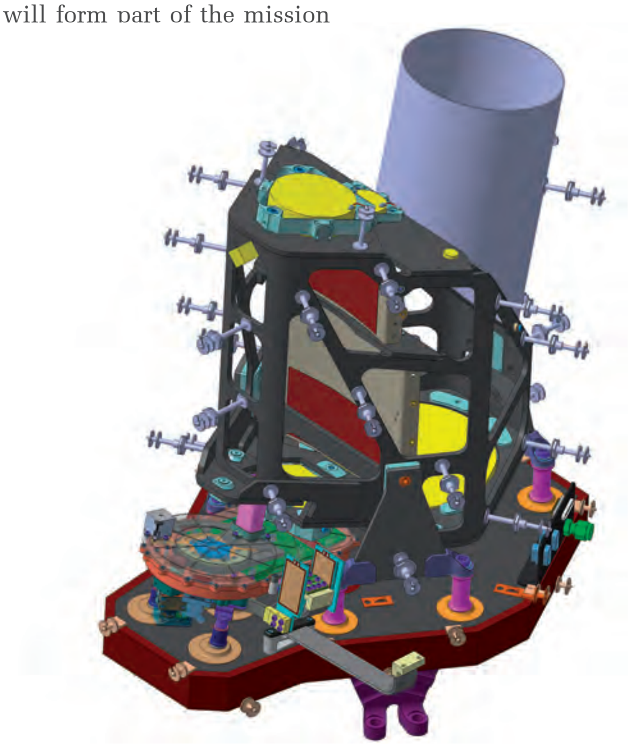
Publications

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

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.

7.10 MANiaC for Comet Interceptor

Purpose of Research

The Comet Interceptor (CI) F-class mission of the European Space Agency will be launched in 2029 and sent to the L2 Lagrangian point. In the meantime, an Earth-based campaign is dedicated to the search for a suitable target comet (Dynamically New Comet, DNC; Long Period Comet, LPC; Interstellar Object, IO) for a fly-by.

CI will then be sent on an intercept course and deploy two probes from ESA and JAXA prior to the encounter (Snodgrass and Jones, 2019). The "Mass Analyser for Neutrals in a Coma" (MANiaC) instrument suite is composed of a time-of-flight mass spectrometer and neutral density gauge. Both sensors are mounted on the main spacecraft and will measure the neutral gases in the coma of the comet. MANiaC is under development by a consortium led by the University of Bern.

The design of the CI mission allows an in-situ study of a family of comets that have not yet been visited by spacecraft. One prime goal of the mission is therefore a comparative study of different types of comets, including those encountered by previous space missions.

MANiaC will measure the chemical composition and the density of the neutral gas along the flyby trajectory and hence provide key information on the ices in the comet's interior. This is of particular interest since DNCs, LPCs, and IOs are thought to be less processed compared to short-period or Halley-type comets which have been exposed to solar insolation and processing during multiple prior passages through the inner solar system.

Past Achievements and Status

The CI mission is currently in its preparatory phase aimed at adoption in mid-2022. For MANiaC, detailed designs and requirements have been elaborated in accordance with the available platform and mission resources. Prototype (sub)units are undergoing in-depth testing and verification at the University of Bern, consortium institutions, and industrial partners.

MANiaC is nearing the conclusion of pre-development activities and the transition from definition to implementation phase is rapidly approaching.

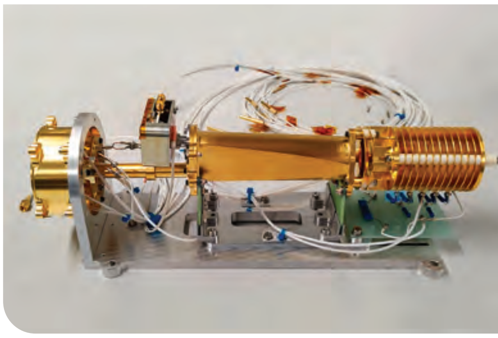
Publications

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

Abbreviations

CI	Comet Interceptor
DNC	Dynamically New Comet
IO	Interstellar Object
LPC	Long Period Comet
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 time-of-flight mass spectrometer.

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

In cooperation with
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

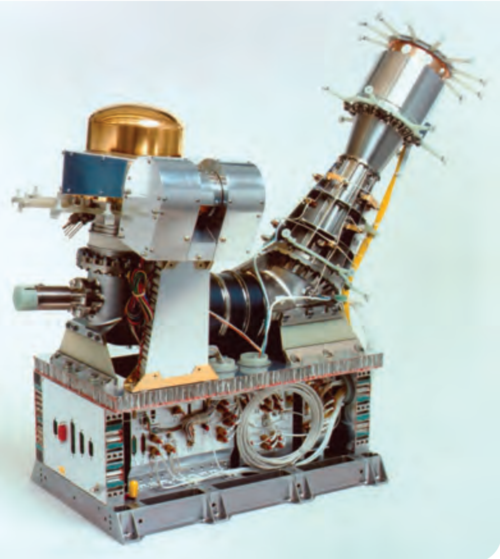
Method
Measurement

Development & Construction of Instruments
MANiaC

Industrial hardware contract to
Art of Technology, Zurich, Switzerland
Creotech Instrs. SA, Piaseczno, Poland

Website
www.cometinterceptor.space

7.11 Rosetta ROSINA Post Operation Phase



The ROSINA Double Focusing Mass Spectrometer (DFMS).

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)

Research based on existing instruments
Rosetta ROSINA

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

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

Purpose of Research

Rosetta ROSINA mass spectrometer data obtained in the coma of comet 67P is analysed to learn about the material from which the comet and our solar system formed and to investigate the interaction of the comet with the Sun. A first key result obtained recently shows that the isotope ratios in oxygen vary markedly from one molecule to the next (Altwegg et al. 2020). This has important implications on the origin of the surprising amounts of molecular oxygen (O_2) found in the gas phase around 67P at a few percent with respect to water (H_2O). It was speculated that O_2 was formed out of H_2O through processes such as radiolysis or dismutation. The disparate oxygen isotope ratios in both molecules, however, hints at a different origin, such as gas-grain chemistry, which occurred well before the solar system formed.

Throughout the Rosetta mission, numerous collaborative studies were carried out based on data from in-situ and remote sensing payload instruments. Another key result was the first detection of auroral phenomena in the UV wavelength regime at a comet (Galand et al. 2020). The observed process involves acceleration of solar wind electrons by the ambipolar electric field near the comet. Energetic electrons dissociate molecules, such as H_2O, to form excited hydrogen and oxygen atoms which then relax by producing UV emissions. The ROSINA team analysed and contributed neutral gas composition data.

A third key study focused on the search of possible parent species of the cyanide radical (CN) which is commonly observed in comets from the ground. The amount of CN observed cannot be explained by HCN alone. Hänni et al. (2021) investigated additional nitriles found in the coma of 67P and concluded that neither cyanoacetylene (HC_3N) or acetonitrile (CH_3CN) are sufficiently abundant to account for the observed amount of CN. The same applies to cyanogen (NCCN), which was observed for the first time in a comet.

Past Achievements and Status

The ESA Rosetta spacecraft closely followed comet 67P from Aug. 2014 to Sep. 2016, and carried out a detailed inspection of its nucleus and surrounding coma. During this time, the ROSINA instrument suite, composed of a pressure sensor (COPS) and two mass spectrometers (DFMS and RTOF) measured the neutral gas density and composition in the comet coma and provided a wealth of data that are still being analysed. All data is publicly available, e.g., through ESA's Planetary Science Archive (https://archives.esac.esa.int/psa).

Publications

Altwegg K, et al. (2020), Mon. Not. R. Astron. Soc. 498: 5855–5862, doi 10.1093/mnras/staa2701

Galand M, et al. (2020) Nat. Astron. 4: 1084–1091, doi 10.1038/s41550-020-1171-7

Hänni N, et al. (2021), Astron. Astrophys. 647: A22, doi 10.1051/0004-6361/202039580

Abbreviations

67P	67P/Churyumov-Gerasimenko
DFMS	Double Focusing Mass Spectr.
RTOF	Reflectron-type Time of Flight
ROSINA	Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

Time-Line	From	To
Measurement phase	2014	2016
Data evaluation	2014	ongoing

7.12 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 is participating in the MINPA instrument to study the interaction of the solar wind/Mars atmosphere by measuring the ion and energetic neutral atom (ENA) environment at Mars.

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

Past Achievements and Status

MINPA combines, for the first time, the capability to record plasma ions as well 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

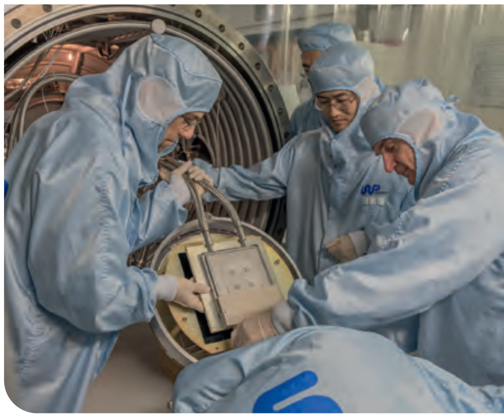
A-B Zhang, L-G Kong, W-Y Li et al. (2022) **Tianwen-1 MINPA observations in the solar wind**, Earth and Planetary Physics 6(1): 1–9, doi: 10.26464/epp2022014

Galli A, Wurz P, Kallio E, Ekenbäck A, Holmström M, Barabash S, Grigoriev A, Futaana Y, Fok M-C, Gunell H (2008) **The tailward flow of energetic neutral atoms observed at Mars**, J. Geophys. Res. 113: E12012, doi:10.1029/2008JE003139

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.

Abbreviations

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



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)

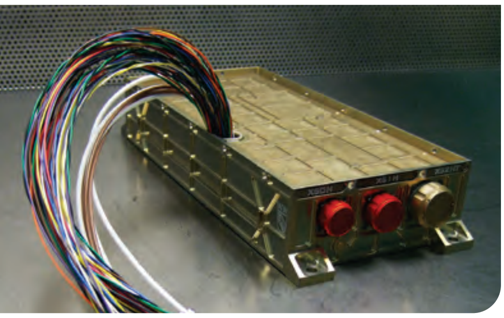
Co-Investigator(s)
A. Galli (UNIBE)

Method
Measurement

Research based on existing instrument(s)
Mars Ions and Neutral Particles Analyser (MINPA)

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

7.13 Investigation of the Chemical Composition of Lunar Soils (Luna-Glob and Luna-Resurs Missions)



The LASMA electronics box fabricated at Univ. Bern, Bern, Switzerland

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

In cooperation with
Inst. Space Research, IKI, Moscow, Russia (A. Chumikov)

Principal Investigator(s)
A. Chumikov (IKI)
P. Wurz (Co-PI, UNIBE)

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

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

Method
Measurement

Development & construction of instrument(s)
LASMA for direct measurements of the elemental composition of solid materials

Industrial hardware contract(s) to
WaveLab Eng. AG; Montena Technology SA
nanoTRONIC GmbH

Website
https://en.wikipedia.org/wiki/Luna-Glob
https://en.wikipedia.org/wiki/Luna_27

Purpose of Research

The Russian Space Agency will launch two landers as part of a Moon exploration programme to land near the lunar South Pole, Luna-Glob (Luna-25) and Luna-Resurs (Luna-27).

LASMA, a Laser Ablation Mass Spectrometer, is part of the scientific payload of both landers, and will perform direct elemental analysis of soil samples collected from the lunar surface in the vicinity of the spacecraft landing site and from the sub-surface (Luna-Resurs only).

The main scientific goals of LASMA-LR are:

- Direct investigation of element and isotope composition of collected soil samples.
- Derive the chemical composition to infer the mineralogical composition.
- Identify and quantify volatile bearing minerals (e.g. apatites) in the soil samples.
- Identify and quantify cold-trapped volatiles (e.g. H_2O, CO_2, hydrocarbons, …) in the soil samples.

To achieve these scientific goals, the LASMA-LR will be supplied with up to 12 soil samples from the vicinity of the spacecraft landing place with the help of a robotic arm. These soil samples will be accommodated on the LASMA sample carousel with 12 separate sample containers. Upon intense laser irradiation, material is released from the sample and directly analysed by a time-of-flight mass spectrometer.

Laser irradiation will be optimised either for elemental and isotopic analysis (ablation mode analysis) or to chemical analysis (desorption mode analysis).

Past Achievements and Status

The Luna-Glob spacecraft has been completed and the Luna-Resurs spacecraft is currently under development. The LASMA instruments were delivered for integration on the spacecraft in Autumn 2017, and are a copy of the LASMA instrument onboard the previous Phobos-Grunt mission.

The launch of Luna-Glob is planned on 23 July 2022, and Luna-Resurs in 2025.

Publications

Chumikov AE, Cheptsov VS, Wurz P, Lasi D, Jost J, Managadze NG, Managadze GG (2021) **Design, Characteristics and Scientific Tasks of the LASMA-LR Laser Ionization Mass Spectrometer onboard Luna-25 and Luna-27 space missions**, Int. Jou. Mass Spectr., 469, 116676 (2021), 12 pages, DOI: 10.1016/j.ijms.2021.116676

Wurz P, Abplanalp D, Tulej M, Iakovleva M, Fernandes VA, Chumikov A, Managadze G (2012) **Mass spectrometric analysis in planetary science: Investigation of the surface and the atmosphere**, Solar System Research 46: 408–422.

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: 10.1109/AERO50100.2021.9438486

Abbreviations

LASMA Laser Ablation Mass Spectrometer

Time-Line	From	To
Measurement phase	2022	2026
Data evaluation	2022	2028

7.14 Investigation of the Volatiles Contained in Lunar Soils (Luna-Resurs Mission)

Purpose of Research

The Russian Space Agency will launch a lunar lander, Luna-Resurs, to land near the lunar South Pole. The gas-chromatography mass spectrometer complex, GC-MS, which is part of the scientific payload of the Luna-Resurs lander, will perform detailed investigations of the volatile content of soil samples collected in the vicinity of the spacecraft landing site and from the sub-surface by means of a drill.

The GC-MS experiment consists of a thermal differential analyser, a gas chromatograph, and the neutral gas mass spectrometer (NGMS) which is provided by the University of Bern.

The main scientific goals that will be achieved by application of the GC-MS complex are:
- Investigation of chemical composition and inventory of volatiles (water, CO_2, N_2, H_2, organics, noble gases, etc.) of the lunar soil at the landing place.
- Investigation of organic species in the lunar soil.
- Measurement of isotopic composition of major elements ($^{13}C/^{12}C$, D/H, $^{17}O/^{16}O$, $^{18}O/^{16}O$, $^{15}N/^{14}N$) and noble gases.
- Investigation of volatile-containing phases in the lunar soil.
- To constrain the minerealogical composition of the lunar soil (with emphasis on the volatile-bearing minerals) on the basis of thermal and gas evolving experiments with the use of data from LASMA-LR, and other experiments.

Time-Line	From	To
Measurement phase	2025	2025
Data evaluation	2025	2027

Past Achievements and Status

The Luna-Resurs spacecraft and scientific instruments are currently under development. The launch of Luna-Resurs is foreseen for 2025.

The proto-flight model (PFM) of the NGMS was finished at the end of 2017, while the flight spare model (FS) was finished in late 2018. The NGMS design is based on an earlier design used for stratospheric research.

Publications

Fausch RG, Wurz P, Tulej M, Jost J, Gubler P, Gruber M, Lasi D, Zimmermann C, Gerber T (2018) **Flight electronics of GC-mass spectrometer for investigation of volatiles in the lunar regolith**, IEEE Aerospace Conf., 1–13, doi: 10.1109/AERO.2018.8396788

Hofer L, Wurz P, Buch A, Cabane M, Coll P, Coscia D, Gerasimov M, Lasi D, Sapgir A, Szopa C, Tulej M (2015) **Prototype of the gas chromatograph – mass spectrometer to investigate volatile species in the lunar soil for the Luna-Resurs mission**, Plant. Sp. Science 111: 126–133.

Wurz P, Abplanalp D, Tulej M, Lammer H (2012) **A neutral gas mass spectrometer for the investigation of lunar volatiles**, Planet. Sp. Science 74: 264–269.

Abbreviations

NGMS Neutral Gas Mass Spectrometer

NGMS proto-flight instrument (left) and flight-spare (right) in cleanroom at UNIBE ready for delivery to Roskosmos.

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

In cooperation with
Inst. Space Research, IKI, Moscow, Russia (M. Gerasimov, A. Sapgir, D. Rodinov)
Univ. Pierre et Marie Curie, Paris, France (M. Cabane, D. Coscia)

Principal Investigator(s)
M. Gerasimov (IKI), P. Wurz (Co-PI, UNIBE)

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

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

Method
Measurement

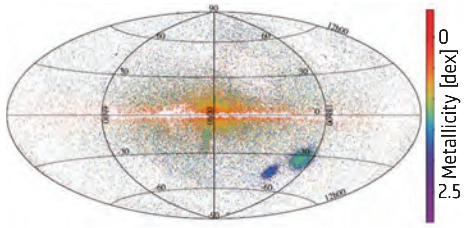
Development & construction of instrument(s)
NGMS to measure chemical composition of volatiles

Industrial hardware contract(s) to
EMPA Dübendorf

Website
www.en.wikipedia.org/wiki/Luna_27

8 Astrophysics

8.1 Gaia – Variability Processing and Analysis



A calibration of the metallicity of the stars can be determined from the light curve shape of RR Lyrae stars. The all-sky map (Aitoff projection) of 134,000 RR Lyrae stars shows the metallicity found in DR3 (low metallicity: blue, high metallicity: red). The Galactic bulge is metal-rich (red), while the Magellanic clouds are metal-poor (large green and blue overdensities in the lower right). The Sagittarius dwarf galaxy is also seen in the blue-green just below the plane of the Galaxy to the left of the bulge centre.
Gaia Image of the Week 25/02/2022.

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

In cooperation with
17 Institutes in Europe, USA and Israel (70 people)

Principal Investigator(s)
ESA

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

Co-Investigator(s)
M. Audard, B. Holl, G. Jevardat, I. Lecoeur, N. Mowlavi, K. Nienartowicz, L. Rimoldini (UNIGE, SixSq, Sednai Sàrl)

Method
Measurement

Development of software for
Producing parts of the Gaia catalogue

Industrial contract to
Sednai sàrl

Website
www.unige.ch/sciences/astro/variability
cosmos.esa.int/gaia

Purpose of Research

The Gaia project is a cornerstone mission from ESA, performing a multi-epoch survey of all stars in the Milky Way and beyond, brighter than magnitude 20.7, with astrometric, photometric, and spectroscopic measurements. More than 2 billion celestial objects are repeatedly measured, with more than 2 trillion CCD measurements (as of Feb. 2022).

One of the duties of the Gaia consortium is to detect and analyse the variable celestial objects. This effort of about 70 people, distributed over 17 institutes, is coordinated by the University of Geneva with its associated data processing centre. The task is to describe the time-series of all two billion sources statistically, then identify the variable sources and classify them into distinct variability types. Further specific analyses are done on sources in selected variability types to provide their astrophysical properties.

The Gaia data is made public through successive Gaia data releases, and over the past two years, the focus has been on producing the third Gaia data release, DR3.

Past Achievements and Status

The Gaia spacecraft has been in operations since 2014, and the Gaia Consortium has delivered two full data releases so far: DR1 in 2016 and DR2 in 2018. At each data release, more sources, more data types, and more analysis results are made available to the public. For example in DR1, as a showcase for the Coordination Unit on variability processing and analysis led by the University of Geneva, 3,194 variable stars were released in the direction of the Large Magellanic Cloud. In DR2, there were 550,737 variable stars, with some variability classes reaching among the largest sets ever published in the literature.

The third Gaia data release was published on 13 June 2022, with a total of 10.5 million variable sources, thanks to 34 months of multi-epoch observations allowing us to probe, characterise and systematically classify celestial variable phenomena. DR3 expands from the early data release (EDR3) in 2020, which contained the 5-parameter astrometric solution and the mean photometry for 1.8 billion sources. The time series in the G, BP, and RP bands were published for each of the 10.5 million variable objects, and radial velocity time-series for about 2,000 Cepheids and RR Lyrae stars. The variable sources sub-divide into 9.5 million variable stars, 1 million AGN. In addition, we identified 2.5 million galaxies. Among the different results, we detected exoplanets by the tiny variations caused by the eclipse of the planet on its parent star, and we discovered supernovae, stars that explode most visibly. We also were at the origin of the Gaia Andromeda Photometric Survey which released all photometric time-series for 1.3 million sources within a radius of 5.5° in the direction of the Andromeda Galaxy.

Within the Gaia consortium, we also created and currently manage a task force to detect black holes. The results of our variability analysis led to more than 15 articles published along with the content of the third data release. The Gaia DR3 data present the most extensive whole-sky variability analysis based on coherent photometric,

Time-Line	From	To
Planning	2002	up to 2029
Construction	cyclic dev.	up to 2030
Measurement phase	2014	up to 2025
Data evaluation	cyclic	up to 2030

astrometric, and spectroscopic data. These catalogues of variable sources will be a basis for many very diverse and impacting scientific studies.

Work is now dedicated to provide the output for the fourth data release, planned at the end of 2025, which will contain the full data sets for the Gaia nominal mission (which took data up to Jan. 2020). Sednai sàrl won an ESA contract to build and execute a citizen science project to attract the general public to help with variability studies in Gaia based on DR3 data. The goal of the project is to use Gaia time-series of variable stars classified by us in DR3 to fine-tune classification, validate certain variability characteristics and possibly uncover new types of stellar variability. The results of the citizen-science campaigns will be fed-back to CU7 in Geneva to further improve the quality of the results and machine learning algorithms for DR4.

A fifth data release is planned for 2030 as the legacy archive of Gaia, using all available data by the time of the end of operations (planned in 2025).

Publications

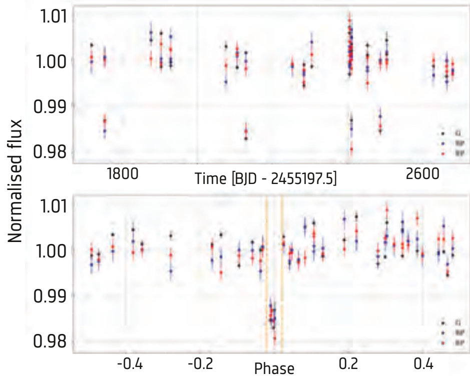
Gaia collaboration, Brown AGA et al. (2021) **Gaia Early Data Release 3.** Summary of the contents and survey properties, Astron. Astrophys. 649: p.1.

Eyer L et al. (2020) **Gaia's revolution in stellar variability**, Conf. Proc.: Stars and their variability observed from Space, Eds. Neiner C et al., p.11.

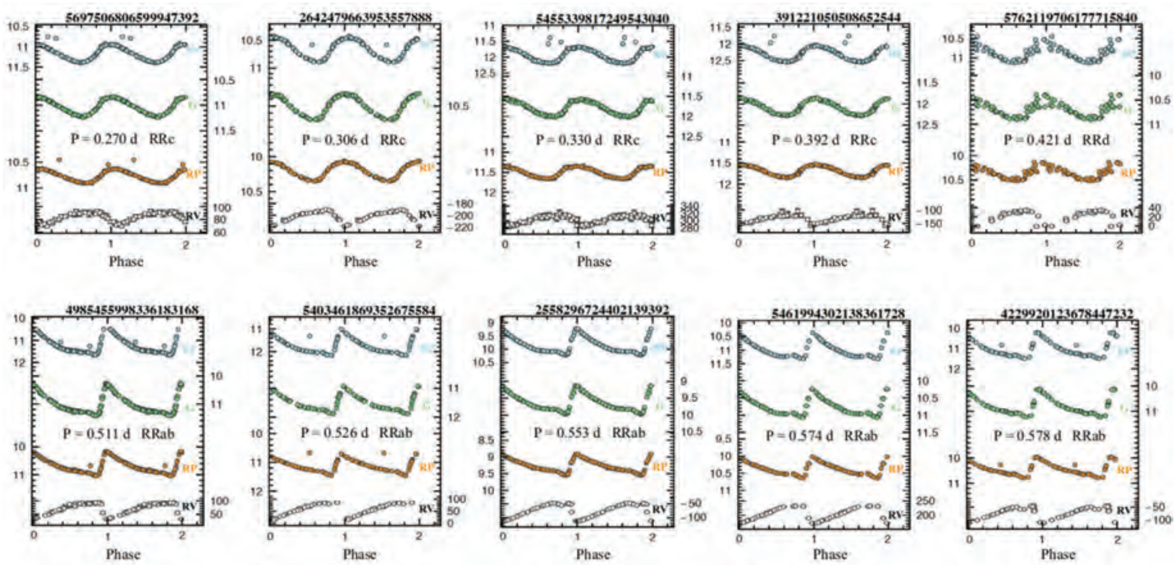
Mowlavi N et al. (2021) **Large amplitude variables in Gaia DR2**, Astron. Astrophys 648: p. 44.

Abbreviations

AGN	Active Galactic Nucleus
BP	Blue Photometer
DR1	Gaia Data Release 1 (14 Sep. 2016)
DR2	Gaia Data Release 2 (25 Apr. 2018)
DR3	Gaia Data Release 3 (13 Jun. 2022)
EDR3	Gaia Early Data Rel. 3 (3 Dec. 2020)
RP	Red Photometer

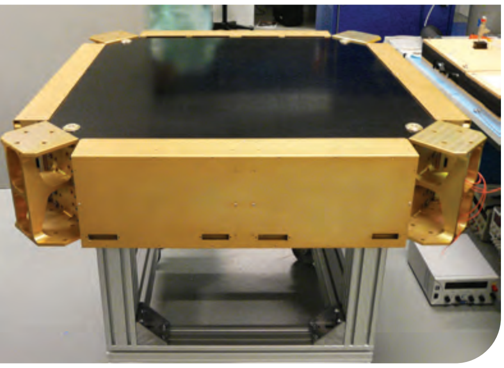


Gaia photometry of the star hosting the first exoplanet discovered by Gaia with the transit method. This system was confirmed by ground-based radial velocity measurements made by the Large Binocular Telescope in Arizona. The planet is named Gaia-1b. Top panel: Time-series of the G, BP, RP measurements. Bottom panel: Phase folded diagram using the period of 3.05 days: the signature of the exoplanetary transit is clearly detected at phase 0. Gaia Image of the Week 30/03/2021.



In Gaia DR3, there are 270,000 RR Lyrae stars with associated Fourier series light-curve decompositions. Furthermore, about 1,100 such stars have radial velocity measurements. The Gaia DR3 sample represents the largest, most homogeneous catalogue of all-sky RR Lyrae ever released. We present ten stars with folded diagrams. Gaia Image of the Week 25/02/2022.

8.2 DAMPE – DArk Matter Particle Explorer



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

Institute
Dépt. Phys. Nucl. Corp. (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)

Method
Measurement

Research based on existing instruments
Astroparticle physics research using data collected by the DAMPE mission

Website
http://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.

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 currently is 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. More than 99.7% of the STK 73728 readout channels are functioning well after more than six-years in orbit. 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. The group is also coordinating the Monte Carlo simulation of the DAMPE detector.

DAMPE published (Ambrosi et al., 2017) 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 six years of data, using machine learning techniques (D. Droz et al., 2021).

The cosmic ray proton spectrum up to 100 TeV energy was published (An et al., 2019) several years ago. This measurement revealed for the first time, direct evidence of spectral softening at 10 TeV, which was previously only indirectly hinted at by other experiments. The DPNC group is a key contributor to this analysis. In 2021, DAMPE published (Alemanno et al., 2021) the helium nuclei energy spectrum from 70 GeV to 80 TeV (20 TeV/nucleon), significantly extending previous measurements with large statistics and well-controlled systematic uncertainties (see figure below). A hardening of the spectrum is observed at an energy of about 1.3 TeV, similar to previous observations. In addition, a spectral softening at about 10 TeV/n, intriguingly similar to the one observed by DAMPE for protons, is revealed for the first time with an overall significance of 4.3s.

Abbreviations

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

Publications

Alemanno F et al. (2021) **Measurement of the cosmic ray helium energy spectrum from 70 GeV to 80 TeV with the DAMPE space mission**, Phys. Rev. Lett. 126: 041104.

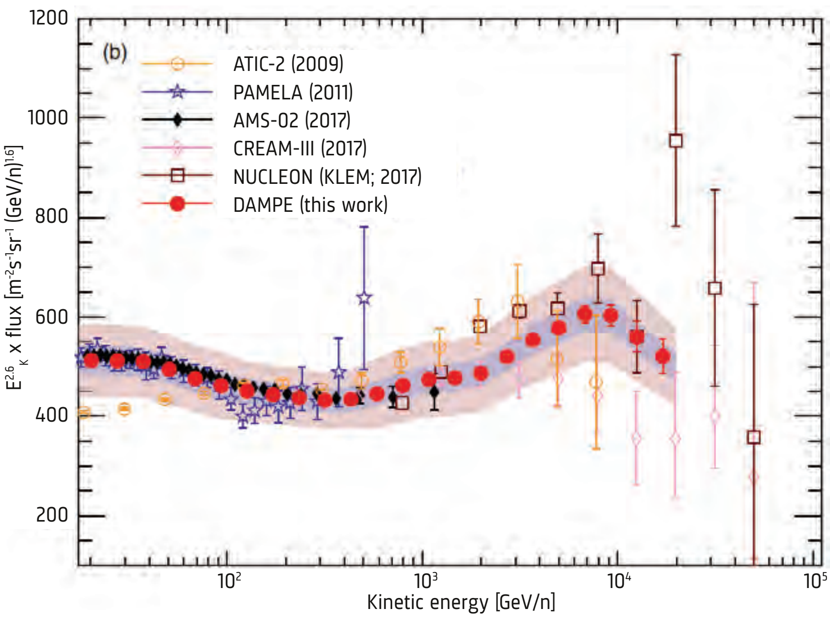
Ambrosi G et al. (2017) **Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons**, Nature 552: 63.

An Q et al. (2019) **Measurement of the cosmic-ray proton spectrum from 40 GeV to 100 TeV with the DAMPE satellite**, Sci. Adv. 5: eaax3793.

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

Wu X et al. (2015) **The Silicon-Tungsten Tracker of the DAMPE Mission**, PoS, ICRC2015, 1192.

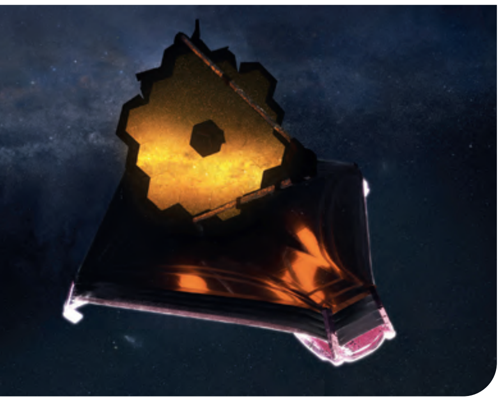
Time-Line	From	To
Planning	2012	2013
Construction	2013	2015
Measurement phase	2016	>2021
Data evaluation	2016	>2021



Cosmic ray helium spectrum measured with DAMPE data compared with the results of other experiments. Outer and inner bands correspond to the total systematic uncertainty with and without the hadronic model uncertainty included, respectively.

ASTROPHYSICS

8.3 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)

Method
Measurement

Development & construction of instruments
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
https://www.jwst.nasa.gov/
ipa.phys.ethz.ch/research/ResearchProjects/jwst.tml

Purpose of Research

The James Webb Space Telescope (JWST) is the next big space telescope and the successor of the famous Hubble Space Telescope. 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 in 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 of the James Webb Space Telescope operating in the 5–28 μm mid-infrared range. MIRI provides imaging, coronagraphy, long-slit low-resolution spectroscopy and mid-resolution integral field spectroscopy.

JWST will be exceptionally powerful in studying the end of the "Dark Ages" of the universe by detecting first light objects. It will further detect and observe the very first galaxies seen at z>10 and their evolution until the present. In addition, it will study complex processes in star and planet formation and provide 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 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 the delivery, the Swiss project was moved to ETH Zurich to guarantee the continuation of the required post-delivery support. MIRI was integrated and cryogenically tested in 2012. The instrument was then formally delivered to NASA in 2012. Thereafter, three cryogenic test campaigns were conducted between 2013 and 2015 as part of the development of the Integrated Science Instruments Module (ISIM) at NASA Goddard. ISIM was then combined with the optical telescope, and cryogenically tested at the NASA Johnson Space Center in Summer 2017 using the world's largest cryogenic facility.

JWST was finally lauched on 25 December 2021 by an Ariane V launcher from French Guyana. Webb was successfully deployed and transferred to an orbit around the second Lagrange point, L2. After the cooling down phase, JWST and its science instruments will be commissioned in the first half of 2022 before it can begin routine science operations.

Publications

Glauser AM et al. (2008) **A contamination control cover for the Mid Infrared Instrument of the James Webb Space Telescope**, SPIE 7018: 70184L.

Wright GS et al. (2015) **The Mid-Infrared Instrument for the James Webb Space Telescope**, I-X, PASP, 129, 953 (Spec. Issue).

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

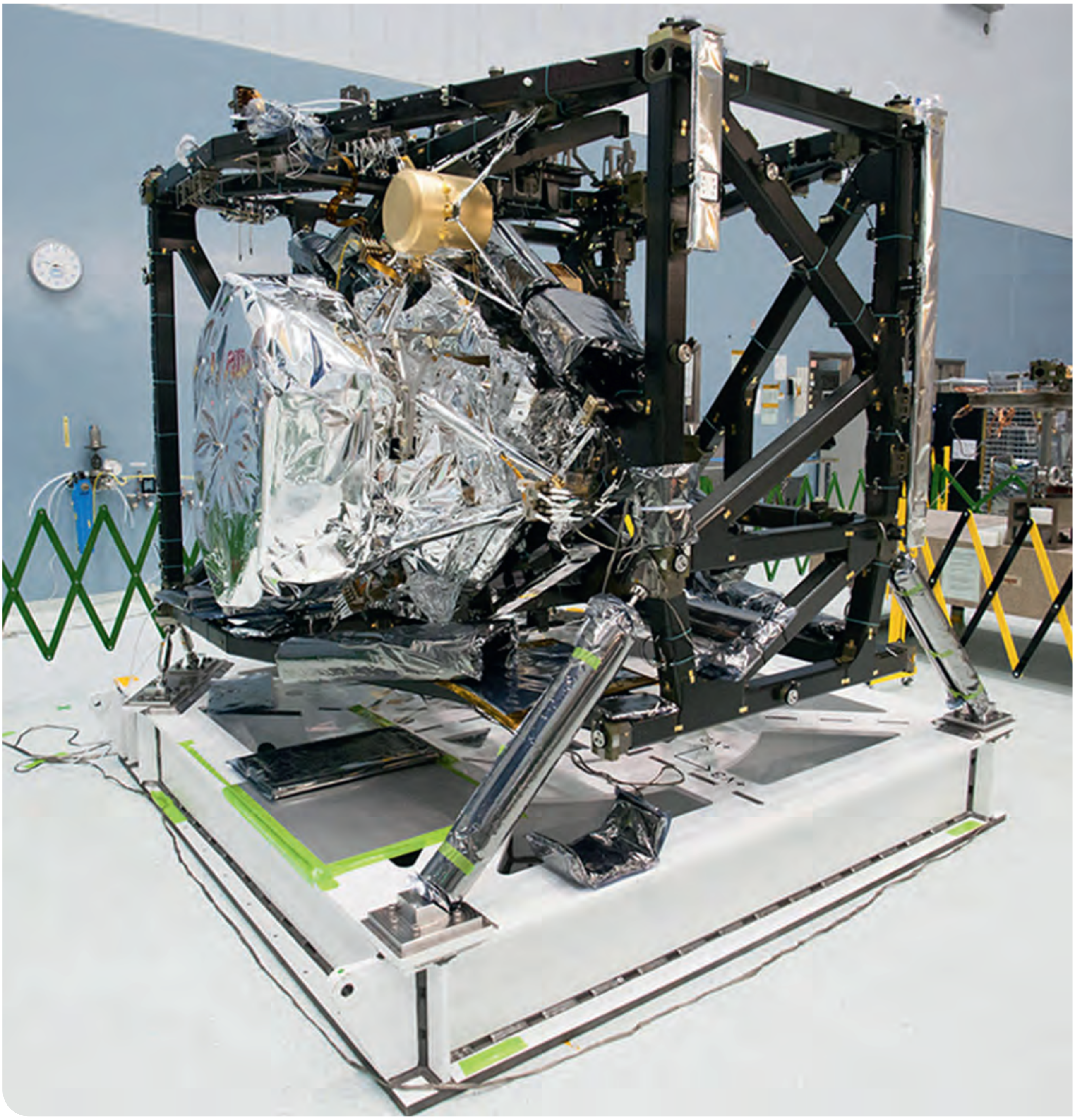
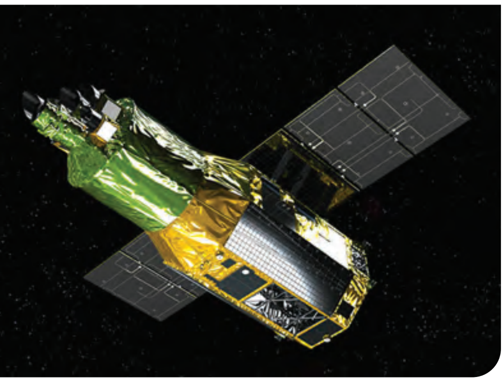


Image of MIRI (wrapped in an aluminium thermal shield) to the left of the JWST Integrated Science Instrument Module (ISIM; black structure).
Image credit: NASA/Goddard Space Flight Center/Chris Gunn, July 2013.

8.4 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)

Method
Measurement

Development & construction of instruments
Manufacturer of the filter wheel mechanism and filter wheel electronics.

Industrial Contracts to
Ruag Space AG
Syderal Swiss SA

Website
www.astro.unige.ch/xrism

Purpose of Research

The X-Ray Imaging Spectroscopy Mission (XRISM, formerly XARM) 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. Hitomi was 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.

UNIGE has participated in the Hitomi mission, together with the Dutch space research institute SRON, by developing a filter wheel for the Soft X-ray Spectrometer (SXS). A rebuild of the Swiss contribution to Hitomi has been produced 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, was designed by industry and assembled and qualified by UNIGE. The FWM was 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 were integrated on the FWM by SRON. The sub-system was finally delivered to JAXA in Autumn 2013. All sub-systems operated nominally after launch.

Past Achievements and Status

Despite its extremely short life, Hitomi was incredibly successful, thanks to its new-generation 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. The first major result is related to the first direct measurement of the turbulence in the intra-cluster gas, which is too low to be the main mechanism of energy transport from the central active galactic nucleus to the inner regions of the cluster. The second result concerns the determination of the process of enrichment of the intra-cluster medium, which has been found to be consistent with that in the Solar neighbourhood, setting constraints on the nature of the supernova progenitors. Both results necessitated the operation of the Filter Wheel in order to reach a sufficient level of knowledge of the energy calibration of the SXS. In addition, more than ten other papers have been published in other refereed journals.

The rebuild of the FWE and FWM sub-systems for the Resolve instrument on board XRISM has been completed successfully 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 launch of XRISM is scheduled for the beginning of Spring 2023. Until then, the UNIGE team will focus on the study of the systematics of the energy calibration of the Resolve spectrometer.

Abbreviations

FWE	Filter Wheel Electronics
FWM	Filter Wheel Mechanism
MXS	Modulated X-ray Sources
SXS	Soft X-ray Spectrometer
XRISM	X-Ray Imaging Spectr. Mission

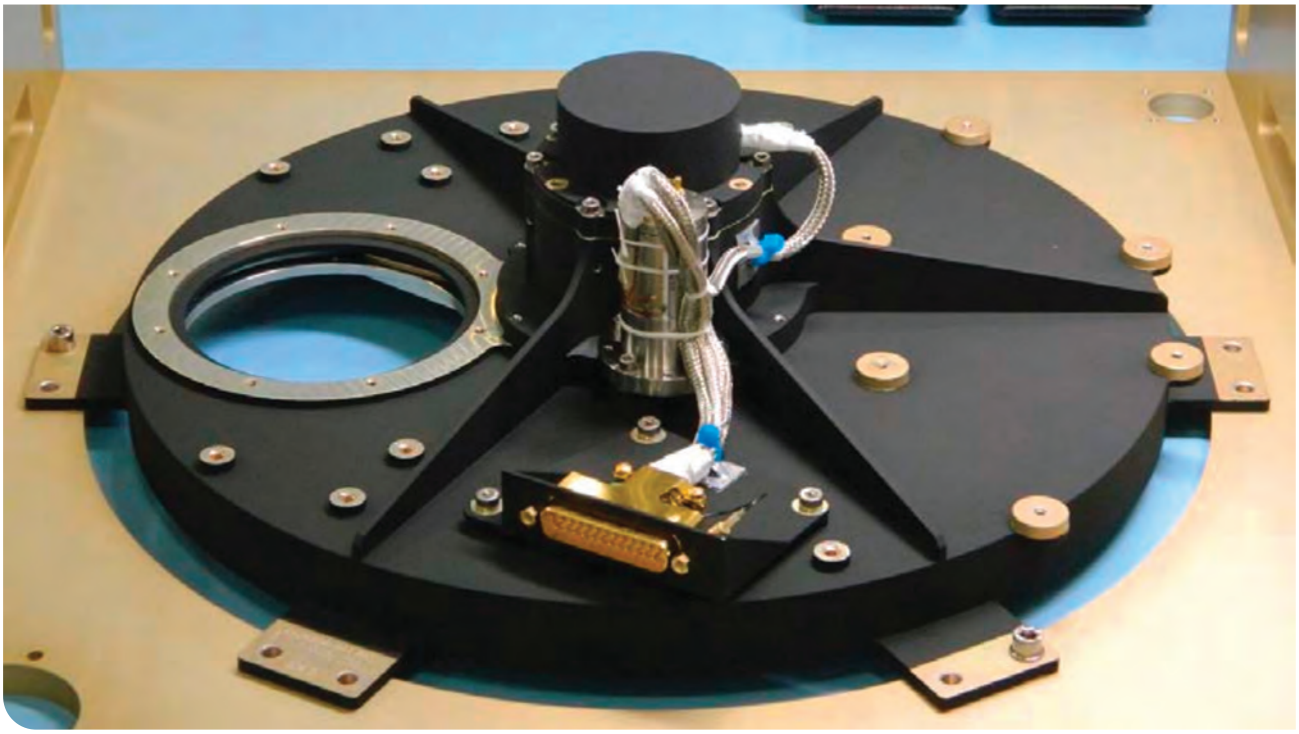
Publications

Makoto T 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.

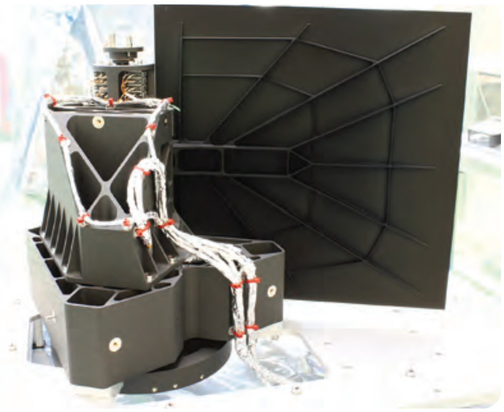
The Hitomi Collaboration (2017) **Solar abundance ratios of the iron-peak elements in the Perseus cluster**, Nature 551: 478.

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



The Flight Model of the XRISM Filter Wheel Mechanism. Image credit: Ruag Space.

8.5 The Swiss Contribution to Euclid



Flight Model of the Euclid VIS Readout Shutter Unit (RSU) being assembled at APCO Techologies.

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)

Method
Measurement

Developments
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
www.sci.esa.int/euclid

Purpose of Research

Euclid is an ESA mission designed to understand the origin and evolution of the Universe by investigating the nature of its most mysterious components: dark matter and dark energy, and by testing the nature of gravity. Euclid will achieve its scientific goal by combining a number of cosmological probes, among which the primary ones are weak gravitational lensing and baryonic acoustic oscillations.

The Euclid payload consists of a 1.2 m Korsch telescope designed to provide a large field-of-view. The Euclid survey will cover 15,000 deg^2 of the extragalactic sky with its two instruments: the VISual imager (VIS) and the Near-Infrared Spectrometer Photometer instrument (NISP) which includes a slitless spectrometer and a 3-band photometer. Euclid is the second Medium Class mission of the ESA Cosmic Vision 2015-2025 programme, with a foreseen launch date in 2023.

Switzerland is playing 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, participation in the data processing and science exploitation. Several Swiss institutes are strongly involved in Euclid: EPFL, FHNW, UNIGE and UNIZH. At the science level, the EPFL (strong lensing), UNIGE (theory) and UNIZH (cosmological simulations) are co-coordinating the respective Science Working Groups.

On the software and algorithms level, the EPFL is active in the development of algorithms for the detection of strong gravitational lenses, for which it plays the role of coordinator in the so-called Shear Organisation Unit. FHNW contributes an important component of the data processing infrastructure that integrates the data centres distributed in Europe into a uniform processing system.

UNIGE is in charge of the coordination of the development of algorithms for the determination of photometric redshifts, which is a central component of one of the main Euclid science goals, weak lensing. 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 the detection of strong lenses. The Euclid data processing is a large distributed effort, which will have to operate a multi-petabyte archive and a commensurate processing power. UNIGE has also developing the Readout Shutter Unit (RSU), a cryogenics shutter for the VIS instrument, which it has started to design and which has been manufactured by the Swiss company, APCO Technologies SA.

All participating institutes will partake in the science of Euclid, whether for the main science goals or for the very rich secondary science that will result from the huge Euclid survey.

Past Achievements and Status

The VIS RSU programme was completed in 2021, and the Flight Model (FM) and Flight Spare (FS) were successfully manufactured by APCO Technologies, under the lead of UNIGE. These were delivered to Airbus for assembly and system-level testing of the payload platform.

On the ground-segment side, Euclid has been undergoing a major test of the technical and scientific performance of the Euclid pipeline with the Scientific Challenge 8 (SC8). The main goal of this challenge was to test individual components and global integration from image simulations to photometric redshifts and shear determination. Code was run in the production infrastructure in the ten scientific data centers of the Euclid Consortium, including at UNIGE, and their outputs were used as inputs for testing the downstream codes.

The different science data centers were piloted by a central orchestrator, and integrated into a uniform processing system by the Infrastructure Abstraction Layer (IAL), an essential component of the Euclid data processing that is being developed at FHNW. The IAL is installed on all Euclid data centers. It receives and manages the different processing requests from the orchestrator on each computing infrastructure; it ensures the availability of the input data from the central archive and prepares the output products for use.

Development work on the algorithms for photometric-redshift determination has been ongoing. An important milestone was the publication of the Data Challenge 2 (Euclid Collaboration 2020), which compared the performance of 13 candidate algorithms in detail. The full photometric-redshift pipeline for the main science developed at UNIGE was deployed, which consists of a set of pipelines to perform source classification, determine galaxy photometric redshifts, and reconstruct star and galaxy homogenised photometry. Scientific quality assessment of the developed code has been performed, based on the results of SC8. In parallel, a significant product assurance effort has been performed to ensure the reliability and usability of the software.

The algorithms for strong-lens detection are still being investigated at EPFL, although convolutional neural networks seem to be the most promising approach. A preliminary pipeline has been put in place, which includes a cut-out service that is able to extract on-the-fly postage stamps around any object in any Euclid photometric tile. Such a service is necessary, because the data volume occupied by the cutouts would be too large.

Publications

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

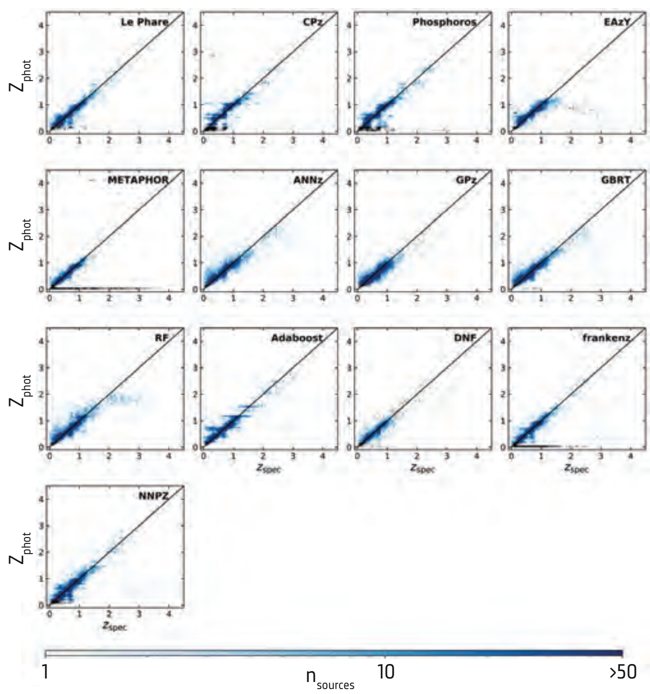
Larchevêque C et al. (2017) **The EUCLID VIS read-out shutter unit: a low disturbance mechanism at cryogenic temperature**, 17th European Space Mech. & Tribology Symp., arXiv: 1801.07496.

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



Comparison of the performance of 13 photometric-redshift algorithms in the Data Challenge 2 by comparing the predictions with the true photometric redshifts. Ideally, predictions should be concentrated on the black line. Image credit: Euclid Collaboration, et al. (2020).

The Structural and Thermal Model of ESA's Euclid mission's payload module seen in the clean room, with part of the VIS (covered in black Multi-Layer Insulation (MLI) and NISP (gold MLI) instruments installed. Image and text credit: Airbus and ESA.

8.6 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 evolution of the polarisation during a GRB. These results indicate that 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, 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 Chinese 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 2024-2025. The Swiss contribution to the POLAR-2 payload development is supported by the Swiss Space Office through the ESA PRODEX programme. The project is progressing rapidly. A prototype Detector Module (DM) has been produced and tested for its scientific performance which has so far matched the design requirements. The prototype successfully underwent shock and vibration tests at MPE, Germany. It will also undergo thermal vacuum tests at this institute in March 2022.

Publications

Burgess JM, Kole M et al. (2019) **Astron. Astrophys.** 627: A105.

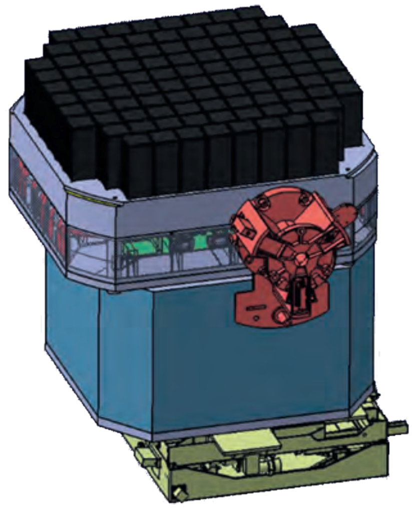
Kole M et al. (2019) **Conf. Proc, 36th Intl. Cosmic Ray Conf.** (IRC2019).

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	2024
Measurement phase	2025	>2027
Data evaluation	2025	>2027



Sketch of the POLAR-2 instrument.

Institute
Dépt. Phys. Nucl. Corp. (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)

Method
Measurement

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

8.7 The Swiss Contribution to ATHENA

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, 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, M. Sordet (UNIGE)

Method
Measurement

Development & Construction of Instruments
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
Hightec, APCO Technologies,Ruag Space, Syderal Swiss, ThalesAlenia Space Schweiz

Website
www.sci.esa.int/web/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' × 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 by exploiting a complex multi-stage mechanical cooling chain, to perform imaging of the soft X-ray sky with ~ 2 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 latter 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 X-ray sources to be observed. The filter wheel will also host the radiactive sources needed for the calibration of the instrument. Besides 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 calibrations of the detector simultaneously during the scientific observation. This allows the X-IFU to achieve an optimal calibration stability. The development of the X-IFU filter wheel at UNIGE heavily relies on our 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 softer 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 roles 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 this latter 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 its phase A study with the closure of the Mission Formulation Review (MFR) at the end of 2019. The project is curently in Phase B1, to be completed by the Summer 2022 after the System Requirement Review (SRR). Phase B2 will start in 2023, following the Mission Adoption review (MAR). The construction of the different instruments and sub-system models will start in the following years, leading to a launch date currently set for 2034.

During 2020-2021, the team at UNIGE advanced the hardware design and participated in the redaction of the first documents for the mission ground segment. The first prototypes of the X-IFU cryo-cables have been produced in collaboration with Hightec (Switzerland) and colleagues at the Netherlands Institute for Space Research (SRON).

At the beginning of 2022, competitive contracts were established with the Swiss companies, APCO and Ruag, for a number of pre-development activities focused on the X-IFU filter wheel mechanism. Similar contracts have also been established with Syderal and THALES Switzerland for the pre-development activities related to the X-IFU filter wheel electronics. All these contracts will be in place by mid-2022 and will lead to an optimal preparation of the instrument construction phases in Switzerland starting as of 2023.

In 2022, UNIGE has also manufactured the first representative frames for the X-IFU filter wheel mechanism. These have been shipped to the US manufacturer LUXEL for gluing of the filter membrane (polyimide and aluminum).

Publications

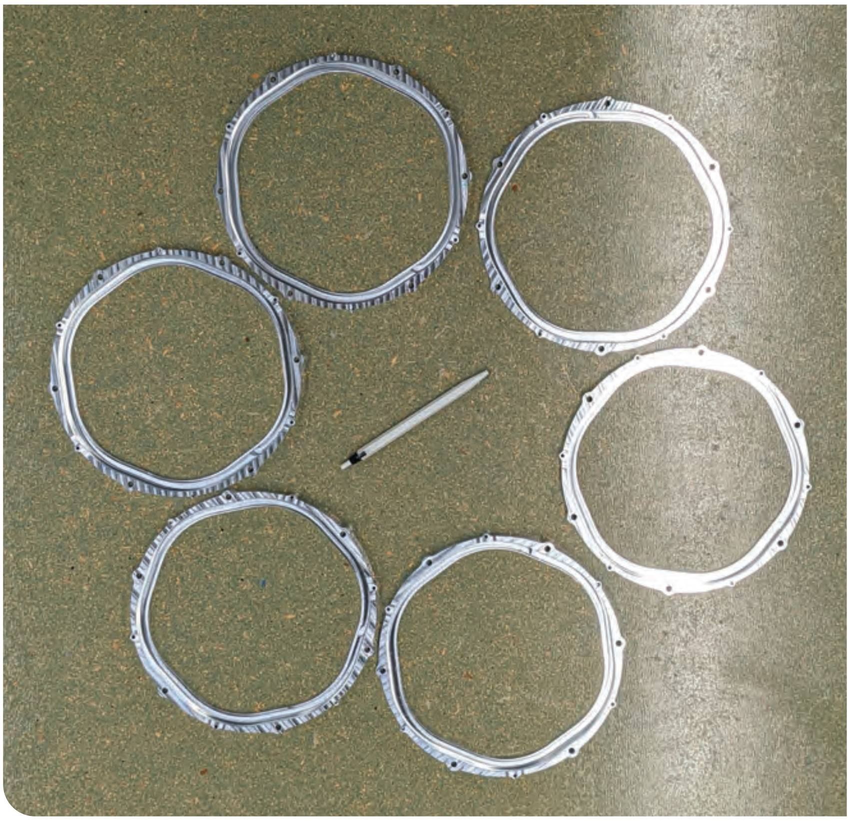
Barret D et al. (2018) Proc. SPIE 10699: id. 10699G.

Meidinger N (2019) Proc. SPIE 11118: id. 11180Y

Abbreviations

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

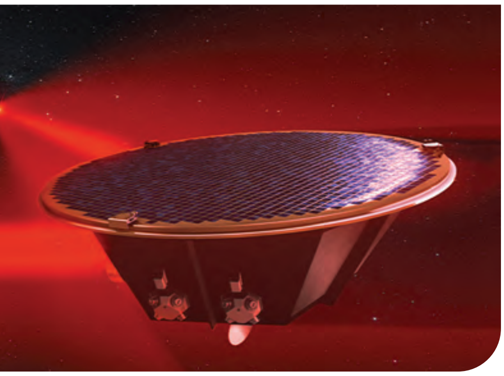
Time-Line	From	To
Planning	2014	2022
Construction	2023	2034
Measurement phase	2035	2039
Data evaluation	2035	2041



X-IFU filter wheel filter frame prototypes manufactured by UNIGE. The layout around a typical Swiss-made Caran d'Ache ballpoint pen shows the approximate size of the mechanism hosting in total seven positions. The filters have a clear aperture of 160 mm.

ASTROPHYSICS

8.8 The Gravitational Reference Sensor Front-End Electronics on LISA



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

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)
D. Bieri (ETH Zurich), Jan ten Pierick (UNIZH)

Method
Measurement

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

Industrial hardware contract to
Thales Alenia Space Switzerland

Website
www.lisamission.org

Purpose of Research

The Laser Interferometer Space Antenna (LISA) is the ESA L3 selected mission with a launch expected in the early 2030s. LISA aims to detect gravitational waves in space emitted by sources located in the whole Universe. LISA will enhance our knowledge about the beginning, evolution and structure of our Universe, and provide highly accurate tests of the theory of general relativity in an entirely new regime. The observatory also has the potential to uncover hints about the nature of quantum gravity, thus contributing to fundamental physics.

The LISA mission consists of three identical spacecrafts, forming an equilateral triangle in a heliocentric orbit following the Earth and maintaining a mutual spacecraft-to-spacecraft distance of 2.5 million kilometers. 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 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 are 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 LISA GRS requires ultra stable performance in the low-frequency band from 1 Hz down to 20 µHz.

Past Achievements and Status

LISA GRS FEE is the Swiss Contribution to the LISA mission, and is currently starting Phase B (2022–2024). ETH Zurich and Thales Alenia Space Switzerland are establishing the instrument requirement specifications, developing the design concept and initiating a breadboarding campaign to consolidate the design of critical elements before the LISA Mission Adoption.

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. MFR provided the green light to move the mission into Phase B and the mission Phase B kick-off is expected in Spring 2022. The next milestone is Mission Adoption, which is expected in 2024.

Publications

Armano M, et al. (2017) **Capacitive sensing of test mass motion with nanometer precision over millimeter-wide sensing gaps for space-borne gravitational reference sensors**, Phys. Rev. D 96: 062004.

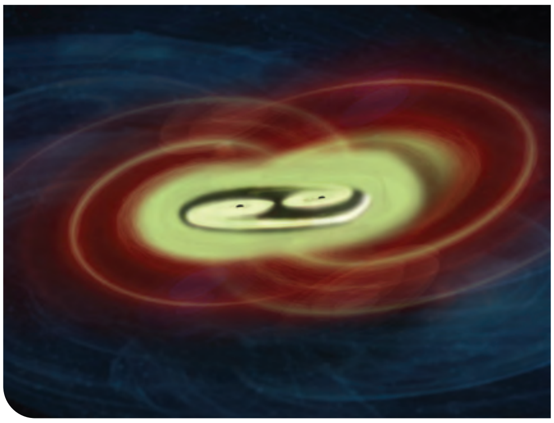
Armano M, et al. (2020) **Analysis of the accuracy of actuation electronics in the laser interferometer space antenna pathfinder, accepted for publication**, Rev. Sci. Instr.: 91, 045003.

Meshksar N, Ferraioli L, Mance D, ten Pierick J, Giardini D (2020) **Analysis of the accuracy of actuation electronics for the Laser Interferometer Space Antenna**, Rev. Sci. Instr.: 91, 095003.

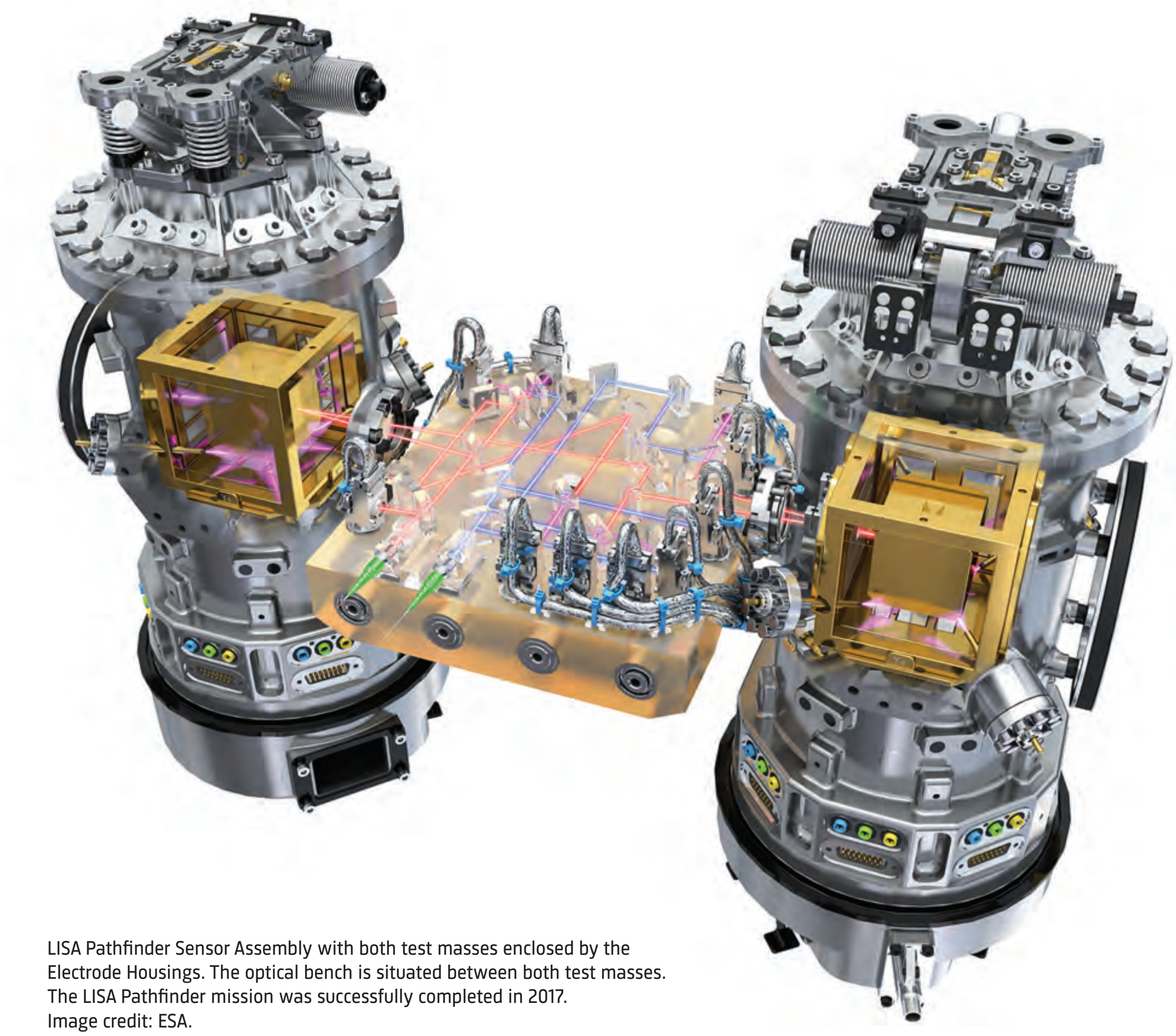
Abbreviations

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

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

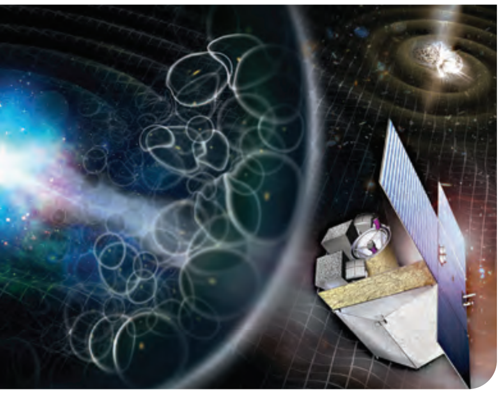


Artist's impression of the merger of two supermassive black holes during a galaxy collision.
Image credit: ESA.



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.

8.9 The Swiss Contribution to THESEUS



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

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

In cooperation with
INAF-IASF, Bologna, Italy

Principal Investigator(s)
L. Amati

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

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

Method
Measurement

Development and Construction of Instruments
Contribution to the IRT instrument, to the mission science ground segment and to the mission project office.

Industrial hardware contract to
Sauter-Bachmann, and CEDRAT Technologies

Website
www.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 ESA 5th call for M-class missions. THESEUS is designed to vastly increase the discovery space of high energy transient phenomena over the entirety of cosmic history. Its driving science goals aim to find answers to many fundamental questions of modern cosmology and astrophysics, by exploiting the unique capabilities of the mission to:

- Explore the physical conditions of the Early Universe (the cosmic dawn and re-ionisation era) by unveiling the Gamma-Ray Burst (GRB) population in the first billion years.
- To 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 because of 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 <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, also 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, and by exploiting the all-sky X-ray monitoring with 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 in the 2030s by next generation facilities such as aLIGO/aVirgo, 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 by the large facilities that will be operating in the EM domain (e.g., ELT, SKA, CTA, James Webb Space Telescope, ATHENA).

The foreseen payload of THESEUS includes the following instrumentation:

- The Soft X-ray Imager (SXI, 0.3–5 keV): a set of 2 lobster-eye telescope units, covering a total 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, allowing a FOV of up to 4 sr, a source location accuracy of ~10 arcmin at 2–150 keV and an unprecedented broad energy band.

The Swiss THESEUS team, based at the Department of Astronomy, University of Geneva, is part of the co-ordination 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 mounted in the IRT and the coordination of the mission science ground-segment design.

Time-Line	From	To
Planning	Jul. 2018	Feb. 2022
Construction	2023	2036
Measurement phase	2037	2041
Data evaluation	2037	2043

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, which involved two industry partners (Sauter-Bachmann and CEDRAT Technologies) and were successfully completed in February 2022. These activities led to the production of a first prototype of the IRT filter wheel mechanism and its positional control sensor.

The THESEUS consortium has re-submitted the THESEUS concept for the ESA M7 Medium mission call released at the end of 2021, thus looking for a future opportunity with an expected launch in 2037.

Publications

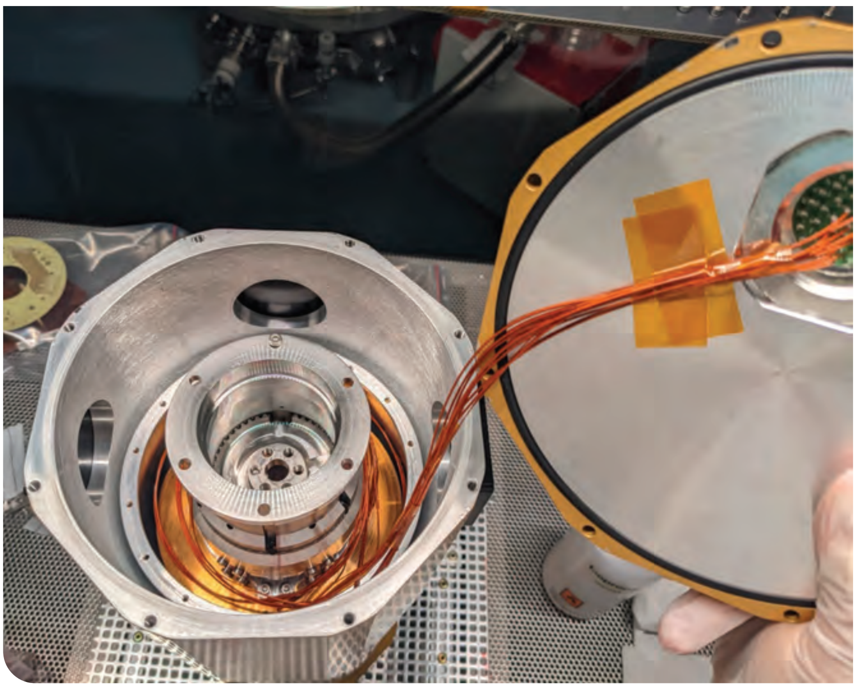
Amati L et al. (2021) **The THESEUS space mission: science goals, requirements and mission concept**, ExA, 52: 183.

Ciolfi R et al. (2021) **Multi-messenger astrophysics with THESEUS in the 2030s**, ExA, 52: 245.

Rosati P et al. (2021) **Synergies of THESEUS with the large facilities of the 2030s and guest observer opportunities**, ExA, 52: 407.

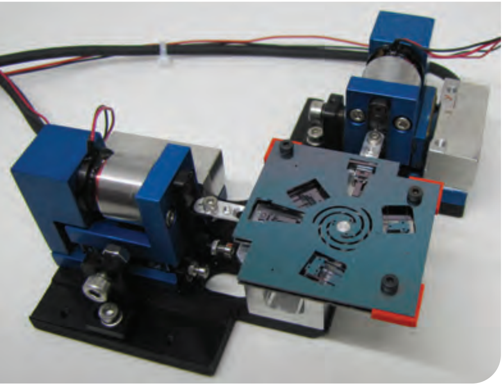
Abbreviations

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



View of the simplified IRT filter wheel prototype undergoing metrology measurements. This was realised as a proof of concept by the team at the University of Geneva in collaboration with Sauter-Bachmann (Switzerland).

8.10 The EUSO Lidar System on KLPVE (K-EUSO)



MEMS mechanism together with the supporting silicon structures that allow the inner mirror to be quickly tilted through large angles. Image credit: CSEM.

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

In cooperation with
Skobeltsyn Inst. Nuclear Physics, Moscow, Russia

Principal Investigator(s)
M. Klimov (Skobeltsyn Inst. Nucl. Phys.)

Swiss Principal Investigator(s)
A. Neronov (UNIGE)

Co-Investigator(s)
E. Bozzo (UNIGE)

Method
Measurement

Development & construction of instruments
Contribution to the Atmospheric Monitoring System of the mission science ground segment, and the mission project office.

Industrial hardware contract(s) to
THALES Alenia Space Schweiz, CSEM Switzerland

Website
www.isdc.unige.ch/jemeuso

Purpose of Research

The KLPVE (Russian for ultra-high-energy cosmic rays) – Extreme Universe Space Observatory (K-EUSO) is a project to install a large, 2.5-meter aperture, wide field-of-view nadir-looking ultraviolet telescope on the Russian segment of the International Space Station (ISS). The telescope will image fluorescent traces of high-energy particle showers initiated by ultra-high-energy cosmic rays (UHECR) in the Earth's atmosphere developing over very short, microsecond, time-scales. The goal is to resolve the long-standing problem of the origin of UHECR, the highest energy particles known in nature.

Apart from this main goal, K-EUSO will also perform research in atmospheric science, transient atmospheric phenomena involving high-energy particles: Terrestrial Gamma Flashes (TGF), Terrestrial Electron Beams (TEB) and other Transient Luminous Phenomena (TLE) related to thunderstorms. This study will be important in the context of the problem of lightning initiation. These atmospheric phenomena form an irreducible background of transient atmospheric events on top of which the UHECR signal is detected. Research on the study of this background (and on the problems of the high-energy atmospheric physics) has already started with a prototype telescope, Mini-EUSO, which was installed at the ISS in September 2019.

K-EUSO will use the Earth's atmosphere as a giant high-energy particle detector which needs to be calibrated. The calibration will be done with a dedicated atmospheric monitoring system which will include a Light Detection and Ranging Device (LIDAR) of novel type and an infrared camera (IRCAM). The novelty of the LIDAR will be its ability to provide a 3-D picture of distribution and optical transmission properties of clouds anywhere within the 40° field-of-view of the K-EUSO telescope. This will be accomplished using a dedicated Laser Pointing System (LPS), which is being developed under Swiss leadership.

The development of the EUSO lidar system in Switzerland entered phase B2 in 2019, when a contract was signed by CSEM and THALES Switzerland to produce a bread-board of the tilting mirror system. This includes the micro electro-mechanical system (MEMS), as well as the electronics to control the movements of the mechanism, and a laser, dedicated to the functional and performance tests of the bread-board. The goal of phase B2 is to produce a working version of the concept design by the end of 2022 that can be tested against functional and performance capabilities.

The bread-board is being realised with commercial components, with the idea of progressing toward a full space-qualifiable design in phase C/D. At present, the bread-board assembly has been completed and components have passed the vibration and both Laser Induced Contamination (LIC) and Laser Induced Damage (LID) tests. The vibration test demonstrated the fragility of some silicon support structures whose design was revised in view of the next phases. The LID and LIC tests revealed no criticality with all selected materials, which are declared suitable for the long-planned operational life of the mechanism.

The control electronics boards have been designed and manufactured. The final performance tests of the unit are planned to be held after Summer 2022.

Past Achievements and Status

The mission is run by an international consortium of institutions (Joint Experiments and Missions EUSO, JEM-EUSO) led by Skobeltsyn Institute for Nuclear Physics of Moscow State University (SINP MSU), RosCosmos, the Russian Space Agency, and the Energia company, responsible for the operations of the ISS.

The project is included in the Russian Long-term and Stage programmes of applied scientific research and space experiments on the ISS, with a possible launch date from 2024 to 2025. A prototype telescope, Mini-EUSO was successfully launched in September 2019 and is currently operating onboard the ISS.

In a parallel development, the US part of the JEM-EUSO collaboration (which has restrictions on collaboration in Russian-led projects) is preparing a high-altitude, super-pressure, balloon version of the EUSO telescope (EUSO-SPB2), which will be launched in 2023 by NASA.

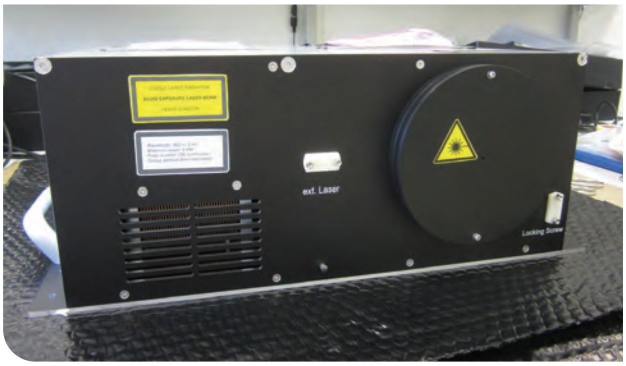
Publications

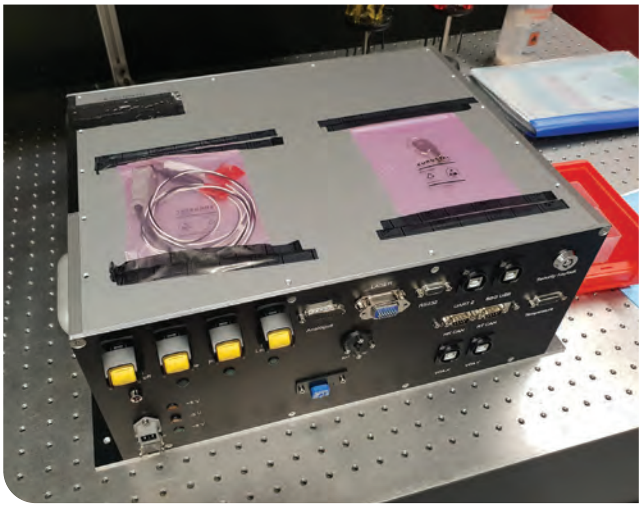
JEM-EUSO Collaboration contributions to the 37th International Cosmic Ray Conference; JEM-EUSO Collaboration, 2022, arXiv: 2201.12246

Abbreviations

EUSO	Extreme Universe Space Observatory
FWM	Filter Wheel Mechanism
JEM-EUOS	Joint Experiments and Missions EUSO
KLPVE	Russian for Ultra-High-Energy Cosmic Rays
MEMS	Micro electro-mechanical-system
UHECR	Ultra-High-Energy Cosmic Rays

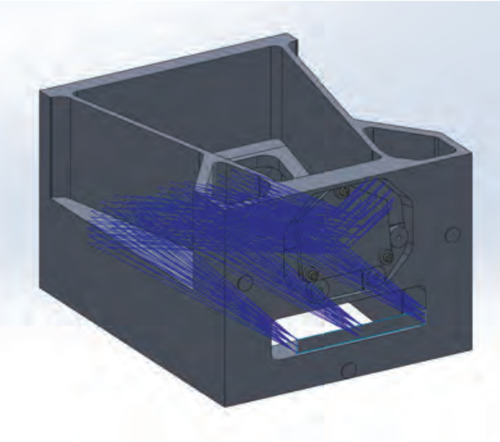
Time-Line	From	To
Planning	2010	2022
Construction	2023	2025
Measurement phase	2026	2029
Data evaluation	2026	2031





Above: laser box to be used for ground performance and functional tests of the laser pointing system bread-board (Image credit: THALES). Right: assembled control electronics to drive the mechanism movement during ground testing (Image credit: THALES).

8.11 The Swiss Contributioin to the SPICA Infrared Observatory



UNIGE design of the mechanical structure of the Grating Module Breadboard (GMBB) optics box, together with the foreseen optical design. The opening for the detector is visible.

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

In cooperation with
Netherlands Inst. Space Res. (SRON), Netherlands
Inst. Space & Astronautical Sci. (ISAS) Japan
SPICA Consortium

Principal Investigator(s)
P. Roelfsema (SRON)

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

Co-Investigator(s)
M. Audard, L. Genolet, S. Bovay (UNIGE)

Method
Measurement

Development of software for
The SAFARI Instrument Control Center and Grating Module housing.

Purpose of Research

SPICA was a project for an infrared space observatory with a 2.5m, actively cooled telescope (below 8K) and with a new generation of ultra-sensitive detector arrays. SPICA was to cover the 10 - 350 µm spectral range, capable of making deep and wide surveys to unprecedented depths in spectroscopy. SPICA was going to carry: i) SAFARI (SPICA far infra-red instrument), an infrared spectrometer operating from 34 to 230 µm (R≈250-11000), ii) B-BOP, an imaging polarimeter at 110, 220, and 350 µm, and iii) SMI, a Japanese instrument, providing imaging spectroscopy with R≈100 and full-band slit-fed spectroscopy at R≈100-2,000 from 17 to 36 µm, and R≈29,000 from 9.6 to 18 µm.

The three main goals of SPICA were: 1) To reveal the physical processes that govern the formation and evolution of galaxies and black holes over time. 2) To resolve for the first time the far-infrared polarization, and therefore the magnetic field, of star-forming regions in the Milky Way. 3) To understand the formation and evolution of planetary systems.

The University of Geneva (UNIGE) was to lead the development and operations of the SAFARI Instrument Control Center, as part of the Science Ground Segment (SGS). The Instrument Control Centers (ICCs) maintain instrument commands and develop the relevant data reduction software. In routine operations, the ICCs monitor the instrument health, carry out flight calibration and maintain the data reduction software.

In addition, UNIGE aimed to build housing structures for two of the SAFARI grating modules and the grating module thermal/mechanical suspensions to the SAFARI focal plane unit.

Past Achievements and Status

SPICA was selected as a candidate mission for the ESA M5 call and started the phase A study in 2019. Work on the SPICA Science Ground Segment definition was achieved by contributing to the Science Operations Assumption Document (SOAD), led by ESA to describe the different components and interfaces of the SGS, and by producing the SAFARI ICC Organisation and Management Plan. We further contributed to the SAFARI Observing Modes and Calibration Strategy document. On the instrument side, several iterations allowed a first design of the housing structure of the grating module to be created.

However, the participation of SPICA in the Phase A competition was abruptly terminated in late 2020. Following discussions with the Swiss Space Office and Prodex Office, a post-Phase A study of a Grating Module Breadboard (GMBB) model was agreed to be harvested from the previous work. In addition, it was decided to design a compact state-of-the-art far-infrared grating module in a collaborative study with SRON and with Taiwan. The study will allow us to position UNIGE in the field for participation in future infrared missions.

Publications

Giard M et al. (2021) **Unveiling the obscured universe with SPICA, a joint infrared space observatory**, COSPAR 43rd assembly.

Kamp I, Honda M, Nomura H, Audard M et al. (2021) **The formation of planetary systems with SPICA**, Publ. Astro. Soc. Australia, 38, 55.

Roelfsema PR et al. (2018) **SPICA – A large cryogenic infrared space telescope: Unveiling the Obscured Universe**, PASA 35: 30.

8.12 The Mechanical Structure of the Telescope Optical Unit for PLATO

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 extra-solar 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. UNIBE is responsible for the design and manufacture of the Telescope Optical Unit (TOU) structure which is a key element for the stability of observations with outstanding structural thermo-optical performance.

UNIBE has significantly contributed to the engineering of the TOU and has designed a stable opto-mechanical structure, capable of withstanding the ground, launch and orbital life environment with a budget of micronic stability on the different lenses that compose the telescope. The mechanical design was fully qualified on the TOU Structural and Thermal Model (STM) at UNIBE in February 2020. The detailed definition of the telescope structural parts were realised at UNIBE while manufacturing was sub-contracted to a cluster of selected partners from Swiss and German industry. The production of the TOU mechanical parts for the Flight Models started in mid-2020 and will be finished by Q1-Q2 2023. Major milestones achieved, include:

- June 2017 Adoption at the Science Program committee (ESA).
- 2020 Payload PDR cycle, TOU STM Test Campaigns.
- 2021 Payload CDR cycle, Camera EM testing.
- 2022 PLATO Critical Milestone Review (CMR).

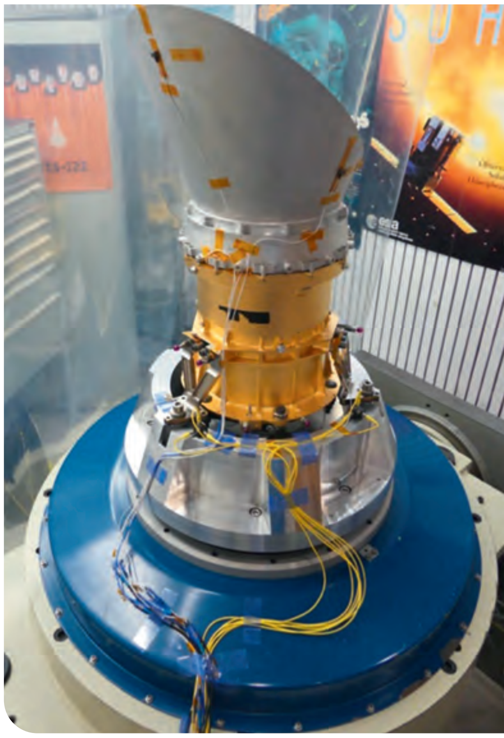
Publications

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

Abbreviations

TOU Telescope Optical Unit

Time-Line	From	To
Planning	Jun. 2017	Dec. 2030 L2 Nom. operation
Construction	2020	2025
Measurement phase	Jan. 2027	Dec. 2030/32 (+2yr extension)
Dataevaluation	Jan. 2027	open



One of the 24 PLATO Telescope Optical Units mounted on the shaker at UNIBE during vibration tests.

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)

Method
Measurement

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

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

8.13 The Swiss Contribution to eXTP

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

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

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

Method
Measurement

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

Website
www.isdc.unige.ch/extp

Purpose of Research

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 m² and 0.6 m² 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 m², 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 cm² 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 includes major research institutions from China, several European countries and the United States. The predecessor of eXTP, the XTP mission concept, was selected and funded as one of the so-called background missions in the Strategic Priority Space Science Program of the Chinese Academy of Sciences since 2011. The strong European participation has significantly enhanced the scientific capabilities of eXTP by adding the LAD and WFM instruments.

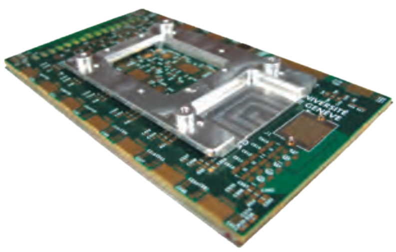
The Swiss eXTP team comprises scientists at the Particle Physics (DPNC) and Astronomy Departments of the University of Geneva. DPNC is leading the design of the front-end electronics for the LAD instrument, together with the testing and the definition of the assembly chain of the front-end electronics with the SDD detectors and ASICs.

The Astronomy Department is involved in the design of the science ground segment of the mission.

Past Achievements and Status

The eXTP mission is undergoing phase B, both in China and Europe, since the start of 2020. The DPNC team is currently involved in the construction of a LAD detection chain prototype to be completed by the end of 2022 which is required for the demonstration of the core instrument functionality. The launch date is currently planned for not earlier than 2028.

Time-Line	From	To
Planning	2017	2022
Construction	2023	2028
Measurement phase	2029	2034
Data evaluation	2029	2036



The LAD front-end electronics board prototype realised by the DPNC team.

8.14 HERD – High Energy Radiation Detection Facility

Purpose of Research

HERD is a flagship scientific experiment onboard the Chinese Space Station (CSS), where the latter is currently under construction. HERD is expected to be launched around 2027. The main science goals of HERD are precise direct cosmic ray detection up to a few PeV, Dark Matter searches, and gamma-ray astronomy. The unique feature of HERD is that it is sensitive on five of its six surfaces, allowing a large geometrical factor of ~3 m²sr to be reached.

The HERD detector consists of a central calorimeter, made of ~7500 lutetium-yttrium oxyorthosilicate (LYSO) crystal cubes (3×3×3 cm³), covered on five sides by high precision trackers, anti-coincidence and charge detectors. The DPNC's focus is on the development of the tracking detector for HERD. In particular, it is developing a large area tracker made of scintillating fibers, read out by arrays of silicon photomultipliers. This is the first time that such technology will be used in space. The Fiber Tracker (FIT) concept proposed by the group provides a flexible and robust solution to cover the larger field-of-view of HERD. In addition, the proposed tracker layout provides a cost-effective implementation of a sub-GeV gamma-ray observatory with unprecedented angular resolution using multiple tracking layers without a converter, thus opening up a new window of discovery in gamma-ray astronomy.

Past Achievements and Status

The HERD collaboration consists of more than 50 research institutes from Europe and China. The HERD mission concept has been endorsed by an international review panel jointly organised by the Chinese Manned Space Agency (CMSA) and the Italian Space Agency (ASI) in May 2018. Phase B activities are ongoing both in China and in Europe. The HERD payload is expected to be launched in 2027.

In 2018, DPNC started the Phase B project "Design and Development of the HERD Scintillating Fiber Tracker (HERD FIT)", financially supported by the Swiss Space Office within the ESA PRODEX programme. The project was successfully concluded. A FIT demonstrator was produced and space qualified. Test results obtained with particle beams at CERN show that the performance of FIT satisfies the requirement of the HERD particle tracker. As a result, FIT has now been adopted as the tracker of the HERD detector, ensuring a leading position for Switzerland in the HERD mission.

Publications

Perrina C et al. (2018) Proc. Phys. 212: 12–16.

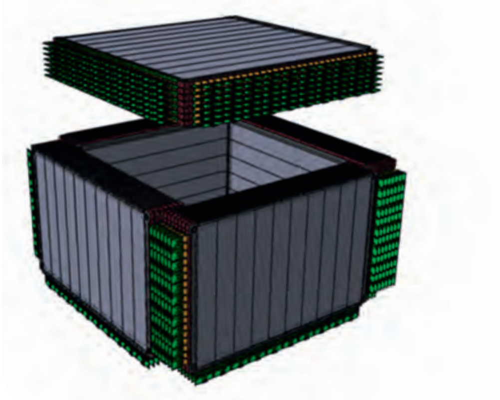
Perrina C et al. (2021) Proc. ICRC2021, https://doi.org/10.22323/1.395.0067/

Zhang S et al. (2014) Proc. SPIE Int. Soc. Opt. Eng. 9144: 91440X.

Abbreviations

FIT	Fiber Tracker
HERD	High Energy Radiation Detection Facility

Time-Line	From	To
Planning	2012	2022
Construction	2023	2027
Measurement phase	2027	2037
Data evaluation	2027	>2037



Exploded view of the Fiber Tracker (FIT) for the HERD mission under development by the University of Geneva.

Institute
Dépt. Phys. Nucl. Corp. (DPNC), Univ. Geneva, Geneva, Switzerland
École Poly. Fédérale de Lausanne (EPFL), Lausanne, 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)

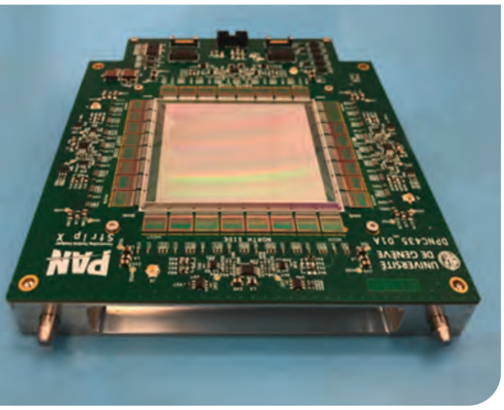
Co-Investigator(s)
C. Perrina (EPFL)

Method
Measurement

Industrial hardware contract(s) to
Composite Design Sàrl, Hauterive, Switzerland
Hybrid SA, Chez-le-Bart, Switzerland

Website
http://herd.ihep.ac.cn

8.15 PAN – Penetrating Particle Analyser



Mini.PAN tracker prototype module.

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)

Method
Measurement

Website
www.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 for studying 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 is currently funded by the EU H2020 FETOPEN programme to develop a demonstrator (Mini.PAN) in three years (2020-2022). The consortium consists of DPNC, INFN Perugia, the Czech Technical University, Prague, and CERN. Prototype components have been produced and tested with particle beams at CERN. The demonstrator is expected to be produced in 2022.

Recently, a variant of PAN called Pix.PAN, was proposed as the Ultra Relativistic Particle Detector (URPD) of a mission concept to Jupiter's radiations belts, called COMPASS, that has recently been selected by NASA for pre-Phase A conceptual studies. The conceptual study of Pix.PAN is supported by the ANC (Activités Nationales Complémentaire dans le domaine saptial) programme of the State Secretariat for Education, Research and Innovation (SERI) of the Swiss Confederation. PAN was also adopted as the main payload onboard REMEC (Radiation Environment Monitor for Energetic Cosmic rays), a mission concept that was selected for the ESA programme "Ambitious Projects (Mission Proposals) for the Czech Republic: Phase 0/A/B1 studies".

Publications

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

Abbreviations

COMPASS	Comprehensive Observation of Magnetospheric Acceleration, Source, and Sinks
PAN	Penetrating Particle Analyser
REMEC	Radiation Environment Monitor for Energetic Cosmic Rays

Time-Line	From	To
Planning	2018	2019
Construction	2020	2022

8.16 LIFE – Large Interferometer For Exoplanets

Purpose of Research

The LIFE (Large Interferometer For Exoplanets) initiative kicked-off in 2018 with the goal of developing the science, technology and a roadmap for an ambitious space mission, featuring a mid-infrared nulling interferometer to directly detect hundreds of extra-solar planets and characterise their atmospheres. A significant fraction of these objects will be exoplanets with masses, sizes and orbital periods similar to the terrestrial planets in the Solar System to investigate the atmospheric diversity among rocky worlds, quantify the fraction of potentially habitable planets, and search for indications of biological activity via atmospheric biosignature gases (such as, e.g., methane and ozone).

Past Achievements and Status

Still being in an early study phase, LIFE has continued to build a strong international community with signficant interest in both the scientific prospects of the mission and the technological challenges. Science objectives have been formulated and a first flowdown of requirements is ongoing. A series of peer-reviewed publications show-casing the unique scientific capabilities of the LIFE mission has started to appear in Astronomy & Astrophyics (see below). The status and the TRLs of key components and technologies are currently being assessed with the goal of formulating a technology gap list and corresponding development plan in the coming months.

Significant progress was made with the Nulling Interferometry Cryogenic Experiment at ETH Zurich, where the warm pre-cursor of the cryogenic mid-infrared nulling testbed is currently being assembled. Collaborations to develop and test cryogenic deformable mirrors and mid-infrared photonic chips have been initiated and joint developments with industrial partners are being explored. ESA's Proba-3 mission, which is devoted to the demonstration of technologies and techniques for highly-precise satellite formation flying, a critical aspect of LIFE, is currently scheduled to launch in 2023. To what extent a dedicated nulling interferometry technology demonstration mission might be needed to either advance the readiness level of critical sub-systems or demonstrate the feasibility of LIFE at a descoped system level is part of the ongoing technology assessment.

A major achievement for the LIFE initiative was the outcome of ESA's "Voyage2050" process to which a White Paper was contributed. In the final recommendations from the ESA Senior Committee, the direct detection of the thermal emission of temperate terrestrial exoplanets was given very high scientific priority in ESA's future science programme and is considered as a candidate theme for a future L-class mission (L5). This provided additional visibility and substantial momentum for the LIFE initiative with more partners, both academic and industrial, expressing an interest in joining.

Publications

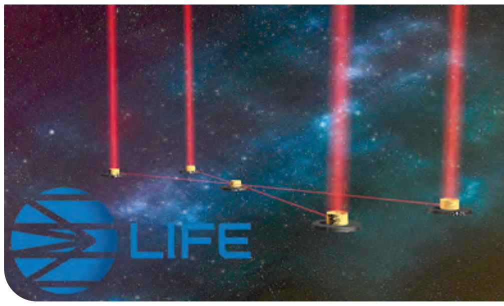
Dannert et al. (2022) 2022arXiv220300471D

Konrad et al. (2021) 2021arXiv211202054K

Quanz SP et al. (2021) 2021arXiv210107500Q

Abbreviations

LIFE Large Interferometer For Exoplanets



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 center. The present analysis assumes an X-array configuration with a baseline ratio of 6:1. The distance between the spacecraft will vary between ten and a few hundred meters depending on the target star and the minimum mirror size of the collector spacecraft is currently expected to be 1.5 m.

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)

Method
Measurement

Development & construction of instruments
LIFE is in an early mission development phase.

Website
www.life-space-mission.com

9 Earth Observation, Remote Sensing, GNSS

9.1 COST-G – Combination Service for Time-Variable Gravity Fields

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)

Method
Measurement

Website
www.cost-g.org

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 by 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). COST-G is in the frame of the Global Gravity-based Groundwater Product (G3P) initiative, which is again funded by the European Commission.

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 re-processed 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. In addition, a fitted signal model (FSM) for application in operational precise orbit determination (POD) of Low Earth Orbiters (LEO) is generated. 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.

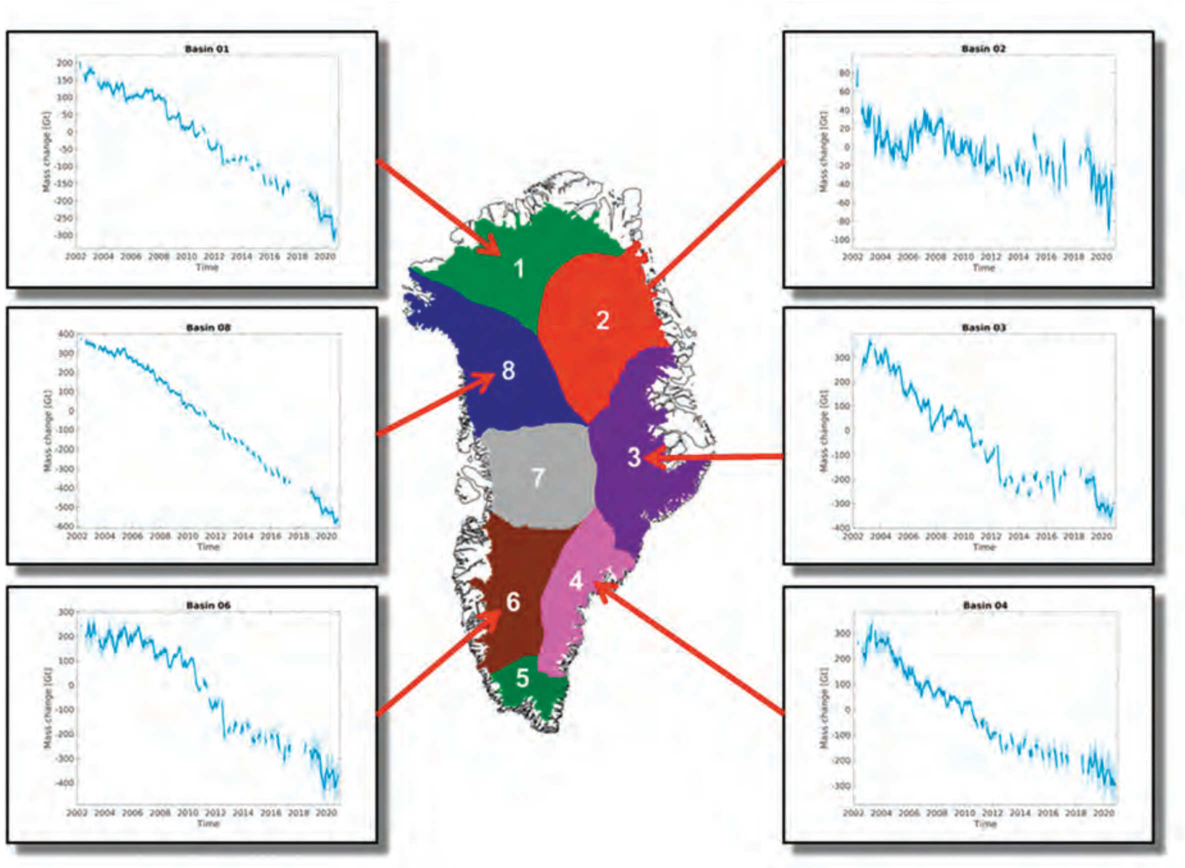
Publications

Jäggi A et al. (2020) **International Combination Service for Time-Variable Gravity Fields (COST-G)**, Intl. Assoc. Geodesy Symposia Series, doi: 10.1007/1345_2020_109

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., in review.

Abbreviations

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



GRACE-derived mass change time series for different drainage basins of the Greenland Ice Sheet computed from the COST-G combined gravity field solutions.

9.2 Copernicus Precise Orbit Determination Service

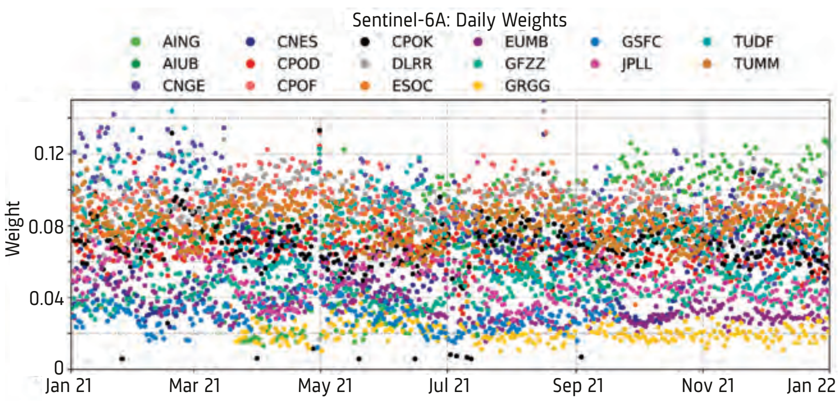
Purpose of Research

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 on 25 April 2016, respectively. The official, non-time-critical Sentinel-1 orbit solutions are expected to fulfill an accuracy requirement of 5 cm 3D 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 on 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.



Weights of Sentinel-6A orbit solutions from different centers used to compute the combined Sentinel-6A orbit solutions. Image credit: GMV.

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

In cooperation with
ESA's CPOD Quality Working Group

Principal Investigator(s)
J. Fernandez (GMV)

Swiss Principal Investigator(s)
A. Jäggi (AIUB)

Co-Investigator(s)
D. Arnold (AIUB)

Method
Measurement

Website
www.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 to 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) is contributing two solutions: i) a reduced-dynamic solution (labelled AIUB in the left-hand figure) without explicit modelling of non-gravitational forces and, ii) a fully dynamic solution (labelled AING) 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. This also holds in particular for the most recent Sentinel-6 satellite.

The AIUB solutions in particular, are making use of single-receiver ambiguity resolution techniques which are based on the GPS products of the Center for Orbit Determination in Europe (CODE). Besides precise GPS satellite orbits and clock corrections, the CODE product portfolio includes a signal-specific GPS satellite phase bias product.

Due to the demonstrated significant improvements of orbit quality when performing single-receiver ambiguity resolution, the official CPOD solution was upgraded to make use of the CODE products since Spring 2020.

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., under review.

Mao X, Arnold D, Girardin V, Villiger A, Jäggi A (2021) **Dynamic GPS-based LEO orbit determination with 1 cm precision using the Bernese GNSS Software**, Adv. Space Research, 67(2): 788–805, doi: 10.1016/j.asr.2020.10.012

Schaer S, Villiger A, Arnold D, Dach R, Prange L, Jäggi A (2021) **The CODE ambiguity-fixed clock and phase bias analysis products: generation, properties, and performance**, J. Geodesy, 95: 81, doi: 10.1007/s00190–021–01521–9

Abbreviations

CODE	Center for Orbit Determination in Europe
CPOD	Copernicus Precise Orbit Determination
CPOD QWG	CPOD Quality Working Group (CPOD QWG)

9.3 3-D Imaging of Moving Targets in SAR Images

DLR's F-SAR sensor on the Dornier DO 228 carrier platform: The antenna system is mounted at the rear of the aircraft. Image credit: DLR.

Institute
Remote Sensing Labs. (RSL)
Dept. Geography, Univ. Zurich, Zurich, Switzerland

In cooperation with
armasuisse, Switzerland
German Aerospace Center (DLR), Germany

Principal/Swiss Investigator(s)
D. Henke (RSL)

Co-Investigator(s)
E. Casalini, E. Méndez Domínguez, A. Damm-Reiser (RSL)

Method
Measurement

Research based on existing instruments
Airborne SAR sensor F-SAR

Website
www.geo.uzh.ch/en/units/rsl/research/SAR_Lab

Purpose of Research

Synthetic aperture radar (SAR) is a remote sensing technique capable of producing high-resolution images of the Earth's surface regardless of light and weather conditions. While the static scene of a SAR image is well-focused, the signature of a moving object (e.g., cars, trains and vessels) is often both defocused and misplaced. As a consequence, it is particularly difficult to retrieve useful information from an object, including its electromagnetic and geometric properties, and to successfully perform object recognition. Furthermore, when using conventional SAR techniques, the resulting images exhibit so-called layover effects, the superimposition of three-dimensional (3-D) structures onto the imaging plane, which makes interpreting a signature even more challenging.

3-D imaging techniques deal with all of the aforementioned issues, with the primary goal of delivering an accurate representation of a moving object. This can be achieved by combining state-of-the-art signal processing techniques, such as inverse synthetic aperture radar (ISAR), with hardware configurations equipped with multiple receiving channels. ISAR, in combination with any of the available autofocus algorithms, is particularly well-suited to deal with even the most challenging objects, including airplanes and vessels, which always present angular motions (i.e., roll, pitch and yaw). On the other hand, using one or more cross-track baselines allows interferometric phase to be exploited, and hence height information to be retrieved. In this project, these methods are refined and adapted to process common maritime objects; particular attention was paid to using a time-domain processor, the global back-projection, which is more suitable for handling strongly non-linear acquisition geometries.

Past Achievements and Status

In the past years, two-dimensional (2-D) imaging techniques were designed to handle all sorts of moving objects, ranging from cars driving on the highway to boats moving across a lake. Despite having achieved extremely high-quality products, 2-D images remain difficult to interpret, mainly due to the presence of layovered scatterers, therefore prompting the need for 3-D processing. The proposed imaging scheme was tested on data-sets acquired by F-SAR, a pulsed-SAR sensor designed by the German Aerospace Center (DLR), over Lake Constance, between the cities of Constance and Meersburg, Germany. The sensor recorded the activities of two different ferries transporting passengers and private vehicles across the lake. To fully evaluate the capabilities of the method, both the estimated motions and dimensions were compared with ground measurements.

Each moving object was observed from different viewing angles, and the resulting point clouds were merged to obtain a product with a significantly higher point density. A direct comparison of the final products with the original designs confirms that not only is it possible to accurately estimate the object dimensions, but also that the vertical structures of the moving object are somewhat preserved. More specifically, the object dimensions along the principal axes (i.e., length, width and height, respectively) were estimated with a mean percent error of 0.51%, 2.36% and 6.51%. Moreover, visual inspection of the final point clouds allows one to recognise different features of the object under analysis (e.g., the lower and upper decks), which is crucial for object recognition and classification.

Lastly, it should be highlighted that the use of a time-domain processor holds many implications: not only is it possible to process data-sets acquired with a non-linear flight-path, but the final products are also more accurate compared to the frequency-domain-based counterparts. However, this requires a higher computational complexity and, in turn, longer processing times. Future research will focus on drastically reducing the number of operations without substantially affecting the obtained performances.

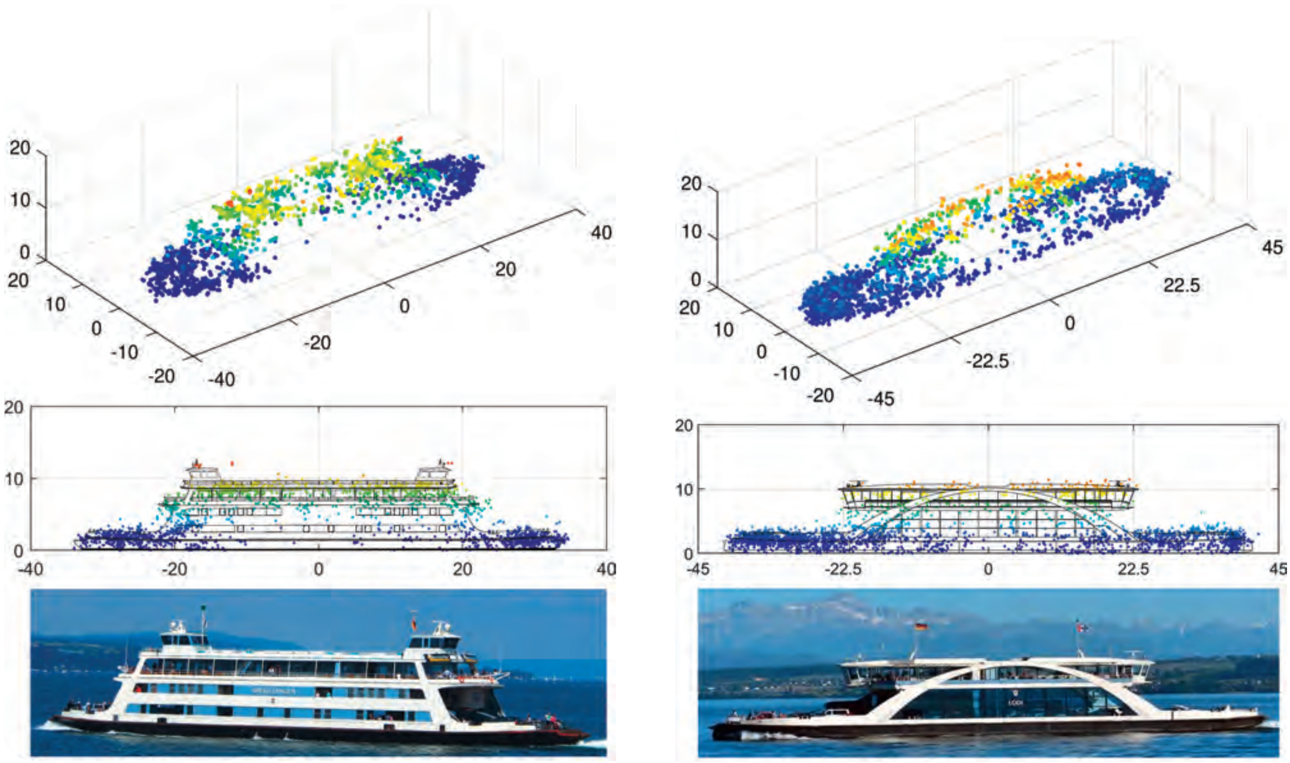
Publications

Casalini E, Fagir J, Henke D (2020) **Moving Target Refocusing with the FMCW SAR System MIRANDA-35**, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 14: 1283–1291.

Casalini E, Domínguez EM, Henke D (2021) **Multi-View Three-Dimensional Radar Imaging of Moving Targets with Time-Domain Processing**, IEEE Transactions on Geoscience and Remote Sensing 60: 1–12.

Abbreviations

ISAR	Inverse Synthetic Aperture Radar
SAR	Synthetic Aperture Radar



Objects No. 1 (left) and No. 2 (right): 3-D reconstruction (top), comparison between point cloud and design in the x-z plane (middle), and optical image (bottom).

9.4 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 (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)

Method
Measurement

Industrial hardware contract(s) to
NASA/JPL for the development of the IS sensor head in collaboration with UZH ZHAW for the development of the flight hardware and software in collaboration with UZH

Website
www.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 APEX or AVIRIS-NG until the native ARES sensors are operational.

Past Achievements and Status

The CWIS-II imaging spectrometer sensor head has been assembled at NASA/JPL and is undergoing final testing. CWIS-II is being integrated with flight hardware and software by ZHAW, forming the ARES Imaging Spectrometer (ARES-IS). Airborne imaging campaigns are currently being conducted with APEX in collaboration with VITO, and the AVIRIS_ng sensor in collaboration with NASA/JPL. It is expected that CWIS-II will enter operational service in 2023. Updates and further information can be found on the ARES web page: https://ares-observatory.ch

Abbreviations

APEX	Airborne Prism Experiment
ARES	Airborne Research Facility of the Earth System
AVIRIS-NG	Airborne Visible/Infrared Imag. Spectr. – next generation
CWIS-II	Compact Wide-Swath Imaging Spectrometer

Time-Line	From	To
Planning	2017	2018
Construction	2018	ongoing
Measurement phase	2023	ongoing
Data evaluation	2023	ongoing

AVIRIS-NG during flight operations in Summer 2021.

9.5 Arctic Weather Satellite

Purpose of Research

The Arctic Weather Satellite (AWS) mission is an ESA-funded constellation of smallsats that will be used for nowcasting in the Arctic region. For the present, a single prototype will be built and launched with an option for the full constellation of 16 satellites at a later stage. AWS carries a cross-track scanning radiometer operating in four frequency bands at 54, 89, 183 and 325 GHz, which will be used for atmospheric temperature and humidity sounding.

Since AWS is based on a constellation, the radiometer design is simplified and more compact in order to reduce the mission cost and complexity. The key feature of the quasi-optical design is that the four feeds directly illuminate the scanning mirror, without prior overlaying of the beams. However, this requires a comprehensive characterisation of each beam to allow proper corrections and pixel co-location in post-processing to be conducted. The Institute of Applied Physics (IAP), University of Bern, is performing this antenna analysis and provides consulting on potential improvements of the design and the required corrections in the Level 1B data processing.

The IAP is also designing and manufacturing both the onboard and on-ground calibration targets for the AWS mission in collaboration with the UNIBE space physics division. The onboard calibration target (OBCT) consists of a single hot target, whereas the on-ground targets (OGCT) consist of a hot, cold and variable target.

The wedge shaped OBCT is critical to the overall performance of the instrument and IAP is using an in-house developed absorber material which is optimised for thermal matching to the metal substrate, while still offering the necessary absorptivity. For both the OBCT and OGCT, IAP is conducting electromagnetic simulations, material tests, qualification tests and performance measurements.

Past Achievements and Status

The OBCT design has passed the Preliminary Design Review and absorber material property tests have been conducted showing good performance. Manufacturing of the first prototypes for the on-board target is due to be completed in Summer 2022.

The antenna design has been fully characterised and optimisation is in progress. Initial designs of the on-ground targets have been created and the Preliminary Design Review is scheduled for April 2022.

Abbreviations

AWS Arctic Weather Satellite
OBCT Onboard Calibration Target
OGCT On-ground Calibration Target

Time-Line	From	To
Planning	2020	2021
Construction	Apr. 2022	Dec. 2022
Measurement phase	2024	2029
Data evaluation	2024	2029

Artist's view of the Arctic Weather Satellite constellation. Image credit: ESA.

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

In cooperation with
Omnisys Instruments AB, Sweden

Principal Investigator(s)
A. Emrich (Omnisys)

Swiss Principal Investigator(s)
A. Murk (UNIBE)

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

Method
Measurement

Development & construction of instrument(s)
Development and manufacture of onboard and on-ground calibration targets, optical design and antenna simulations.

Website
www.esa.int/Applications/Observing_the_Earth/Meteorological_missions/Arctic_Weather_Satellite

9.6 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)

Method
Measurement

Development of software for
Spectral Information System for the storage of spectral field and laboratory data and associated metadata.

Website
www.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 in the organised storage of spectral field data and associated metadata. This is 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 development of a spectral information system will not only ensure the long-term storage of data but will support scientists in data analysis activities, essentially leading to improved repeatability of results, superior reprocessing capabilities, and promotion of best practice.

Past Achievements and Status

SPECCHIO remains under active development. SPECCHIO is installed in about 40 research institutions worldwide, and is well-used in research and teaching activities at the Remote Sensing Laboratories, University of Zurich.

SPECCHIO is currently being further enhanced to support CAL/VAL activities for the upcoming ESA Fluorescence Explorer Mission (FLEX) satellite and to support the storage of uncertainty budgets in the structure of uncertainty tree diagrams. SPECCHIO is also used operationally to carry out CAL/VAL for airborne imaging spectrometer campaigns with the APEX and AVIRIS-NG instruments in support of ESA satellite end-to-end simulations.

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: www.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.

Meiller C, Kuehnle H, Werfeli M, Hueni A (2020), **A calibration and validation tool for data quality analysis of airborne imaging spectroscopy data**, In: Proceedings IGARSS 2020–2020 IEEE International Geoscience and Remote Sensing Symposium, pp. 6234–6237.

Abbreviations

APEX	Airborne Prism Experiment
AVIRIS-NG	Airborne Visible / Infrared Imaging Spectrometer – Next Generation
CAL/VAL	Calibration/Validation
FLEX	Fluorescence Explorer Mission

9.7 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 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.

Screenshot from the Camaliot Android app that allows users to collect and share raw GNSS data.

Past Achievements and Status

To achieve these goals, the consortium, consisting of ETH Zurich and the International Institute for Applied Systems Analysis (IIASA), has developed an Android app for the collection of raw GNSS data from smartphones. A crowdsourcing campaign will be launched, based on the concept of citizen science. In order to cope with the large amounts of GNSS data of heterogeneous quality, new processing methods have been developed that are highly automated and robust. For this purpose, specific machine learning algorithms have been designed, trained, and applied. Based on the GNSS results, two scientific use cases are investigated, the first focusing on the determination of tropospheric parameters to support weather forecasts on Earth, and the second one focusing on the monitoring of space weather, which is important for satellite operations and communication.

Publications

Navarro V, Grieco R, Soja B (2021) **Data fusion and machine learning for innovative GNSS science use cases**, Proc. 34th Int. Techn. Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021), St. Louis, Missouri, pp. 2656–2669, https://doi.org/10.33012/2021.18115

Abbreviations

GNSS Global Navigation Satellite System
GSSC GNSS Science Support Centre

Time-Line	From	To
Planning	Mar. 2021	Aug. 2021
Construction	Sep. 2021	Mar. 2022
Measurement phase	Apr. 2022	Jul. 2022
Data evaluation	Aug. 2022	Oct. 2022

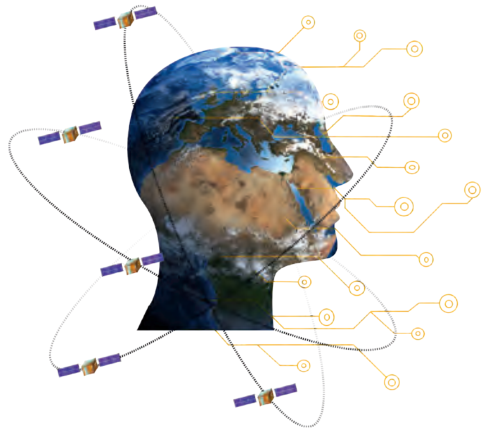


Illustration highlighting the main components of the CAMALIOT project: GNSS, machine learning, citizen science, and Earth science.

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)

Co-Investigator(s)
I. McCallum (IIASA), V. Navarro (ESA)

Method
Measurement

Research based on existing instruments
Crowdsourcing of smartphone-based raw GNSS data.

Website
camaliot.org
space.igp.ethz.ch/research/camaliot.html

9.8 CSAR on TRUTHS

Artist's impression of the TRUTHS spacecraft.
Image credit: NPL.

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

In cooperation with
National Physical Lab. (NPL), UK
Airbus Defence and Space, France
ESA

Principal Investigator(s)
N. Fox (NPL)

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

Co-Investigator(s)
N. Engler (PMOD/WRC)

Method
Measurement

Development & construction of instrument(s)
CSAR for the TRUTHS spacecraft

Industrial contract(s) to
Davos Instruments AG, Davos, Switzerland

Website
www.npl.co.uk/earth-observation/truths

Purpose of Research

The aim of the Traceable Radiometer Underpinning Terrestrial and Helio Studies (TRUTHS) mission is to establish high-accuracy, SI-traceable in-flight data, hence enabling a "calibration laboratory in space". At the heart of the TRUTHS calibration capability is the Cryogenic Solar Absolute Radiometer (CSAR) which can mimic in space, the same calibration capability and associated measurement accuracy that is delivered using this type of technology on Earth.

The TRUTHS satellite will also carry a hyperspectral imager to provide benchmark measurements of both incoming solar radiation and outgoing reflected radiation with an unprecedented accuracy. These benchmark measurements would improve our ability to estimate the radiative imbalance underlying climate change and, importantly, in a shorter time than is currently possible.

Many Earth Observation satellites are used to provide inputs and developments of models that advise policy-makers. The goal of TRUTHS is to improve the accuracy, reliability and integrity of this data through:

- Measurement of both the incoming solar and reflected (Earth/Moon) radiation with sufficient accuracy and spectral resolution to allow an order of magnitude increase in our ability to estimate the earth's radiation budget creating an SI-traceable reference data set to cross-calibrate other sensors and improve the quality of their data.
- Delivery of the first satellite to calibrate itself, which is directly traceable to SI units via a primary standard, and is in orbit.
- Absolute, high-accuracy traceable calibration for other Earth observation missions.
- Making global nadir hyperspectral observations of the Earth's reflectance.

Past Achievements and Status

NPL have developed the baseline design for CSAR/TRUTHS (Fox and Green, 2020) including a working bread-board model for CSAR (Zajiczek et al. 2017).

As part of the CSAR/TRUTHS Phase B1 engineering support, PMOD/WRC is currently reviewing the baseline design with respect to its readiness for space flight and based on experience with the ground-based CSAR, which has been in operation at PMOD/WRC since 2010.

Publications

Fox N, Green P (2020), **Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (TRUTHS): An Element of a space-based climate and calibration observatory**, Remote Sensing, https://doi.org/10.3390/rs12152400

Zajiczek L, Winkler R, Green P, Hobson T, Fox N (2017) **CEOI8 TRUTHS calibration system final report**, NPL Report M20.

Abbreviations

CSAR	Cryogenic Solar Absolute Radiometer
TRUTHS	Traceable Radiometer Underpinning Terrestrial and Helio Studies

Time-Line	From	To
Planning	2021	2022
Construction	2023	2029
Measurement phase	2029	2034
Data evaluation	2029	open

9.9 EMRP MetEOC-4

Purpose of Research

The MetEOC-4 (Metrology for Earth Observation and Climate) project is targeting the improvement of spectro-radiometric calibration methods to improve both calibration speed and accuracy. This research is paving the pathway to traceable spectral ground control point data through supporting uncertainty budgets within spectral information systems. These are key to validated airborne and satellite based products with associated uncertainty budgets.

Based on the APEX Calibration Information System, a similar system will be established to enable the operational calibration of the new ARES-IS imaging spectrometer. The Fluorescence Box (FLOX) spectro-radiometric instrument

In-situ fluorescense sensors of the Fluorescence Box (FLOX) spectro-radiometric instrument are being investigated to establish an uncertainty budget. This will support the validation of the future ESA Fluorescence Explorer (FLEX) satellite sensor.

All these efforts are geared to provide traceable measurements with uncertainty budgets, and to suppor the high-precision monitoring of the Earth System.

Past Achievements and Status

The capacity to work on uncertainty and calibration at a level applicable to National Measurement Institutes (NMIs) has been built up in past projects (MetEOC-1, MetEOC-2 and MetEOC-3). Consequently, uncertainty analysis is now applied to various sensors, enabling better calibration of sensors and estimation of uncertainties in retrieved data products.

Publications

Buman B, Hueni A, Colombo R, Cogliati S, Celesti M, Julitta T, Burkart A, Siegmann B, Rascher U, Drusch M, Damm A, **Towards consistent assessments of in situ radiometric measurements for the validation of fluorescence satellite missions**, Remote Sens. Environ., accepted.

Trim SA, Mason K, Hueni A (2021) **Spectroradiometer spectral calibration, ISRF shapes, and related uncertainties,** Applied Optics 60(18): 5405–5417, http://ao.osa.org/abstract.cfm?URI=ao-60-18-5405

Petibon F, Czyż EA, Ghielmetti G, Hueni A, Kneubühler M, Schaepman ME, Schuman MC (2021) **Uncertainties in measurements of leaf optical properties are small compared to the biological variation within and between individuals of European beech,** Remote Sensing of Environment, 264: 112601, https://www.sciencedirect.com/science/article/pii/S0034425721003217

Abbreviations

APEX	Airborne Prism Experiment
ARES-IS	Airborne Research Facility of the Earth System Imaging Spectrometer
EMRP	European Metrology Research Programme
FLEX	ESA Fluorescence Explorer
FLOX	Fluorescence Box Spectro-Radio metric Instrument
MetEOC	Metrology for Earth Observation and Climate

EMRP
European Metrology Research Programme
Programme of EURAMET
Metrology for Earth Observation and Climate

Institute
Remote Sensing Labs. (RSL)
Dept. Geography, Univ. Zurich, Zurich., Switzerland

In cooperation with
National Physical Lab. (NPL)
UK

Principal Investigator(s)
N. Fox (NPL)

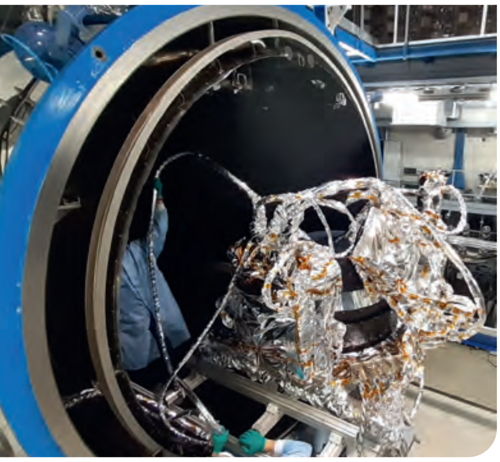
Swiss Investigator(s)
A. Hueni (RSL)

Method
Measurement

Research based on existing instruments
Tests of new spectral and combined spectro-radiometric calibration methods. Establishment of uncertainty budget support within spectral databases (SPECCHIO system). Uncertainty budget estimate for the FLOX instrument. Calibration support for new ARES-IS imaging spectrometer.

Website
www.meteoc.org

9.10 Calibration Targets for MetOp-SG Instruments MWS and ICI



Installation of ICI on-ground calibration system with an engineering model of the ICI instrument in a thermo-vacuum chamber at IAPB, Germany. Image credit: IABG.

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
ESA

Swiss Principal Investigator(s)
A. Murk (UNIBE)

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

Method
Measurement

Development & construction of instrument(s)
Development of onboard and on-ground calibration equipment

Industrial hardware contract(s) to
TK Instruments, UK
IABG, Germany

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 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 using physical optics antenna simulations.

Past Achievements and Status

The RF performance of the three ICI On-Board Calibration Target (OBCT) flight models and one flight spare were tested at IAP during 2020. They were delivered to Airbus Defence & Space (Spain) in June 2021. For the MWS OBCT, only the two first flight models were fully characterised and delivered to Airbus Defence & Space (UK) in 2020/2021, while the final RF tests of FM3 and the flight spare are still pending.

The ICI OGCT system was delivered in 2020 and was successfully used for a first calibration campaign with the engineering model of the ICI instrument. The launch of the first MetOP-SG-A satellite with MWS is scheduled for 2024, while ICI on MetOP-SG-B will not be launched before 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 et al. (2019) **Optical Design and Electromagnetic Verification of the On-Ground Calibration Target for the Ice Cloud Imager on Metop-SG, Workshop on Advanced RF Sensors and Remote Sensing Instruments**, ESTEC.

Schröder A et al. (2017), **Electromagnetic design of calibration targets for MetOp-SG microwave instruments**, IEEE Trans. THz Sci. Technol. 7: 677–685, http://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	2022

9.11 APEX – Airborne Prism Experiment

Purpose of Research

ESA's Airborne Imaging Spectrometer APEX (Airborne Prism Experiment) was developed under the PRODEX (PROgramme de Développement d'EXpériences scientifiques) programme by a Swiss-Belgian consortium and entered its operational phase at the end of 2010 (Schaepman et al., 2015). It collects spectral data in the VNIR–SWIR range from 385 nm to 2500 nm. APEX is designed to collect imaging spectroscopy data at a regional scale, serving as a data source to answer questions in Earth System Sciences, and to simulate, calibrate and validate optical airborne and satellite-based sensors.

Past Achievements and Status

The Remote Sensing Lab. (RSL) at the University of Zurich is responsible for: i) the scientific management of the project, ii) added value within the calibration chain of the APEX instrument, iii) the product generation, and iv) for extending and maintaining the Processing and Archiving Facility. The latter is a universal, database-driven system which supports the processing and distribution of all APEX raw data acquisitions. Sophisticated information technology tools are used for a versatile processing system, which is designed to be persistent throughout the operational phase of the instrument.

The processing and archiving facility is being continuously updated to allow the reprocessing of data acquired since 2009 using the latest processing algorithms. In parallel, RSL manages the flights for Swiss partners within Switzerland and occasional special campaigns with partner institutes abroad. General operations are carried out by our partner organisation, VITO, Belgium.

APEX is currently being phased out and will be replaced with the new imaging spectrometer within the Airborne Research Facility of the Earth System (ARES). The APEX data archive is planned to be made open-source to support airborne spectroscopy research in Switzerland and world-wide.

Publications

Hueni A et al. (2013) **The APEX (Airborne Prism Experiment – Imaging Spectrometer) calibration information system**, IEEE Trans. Geo. Rem. Sens. 51: 5169–5180.

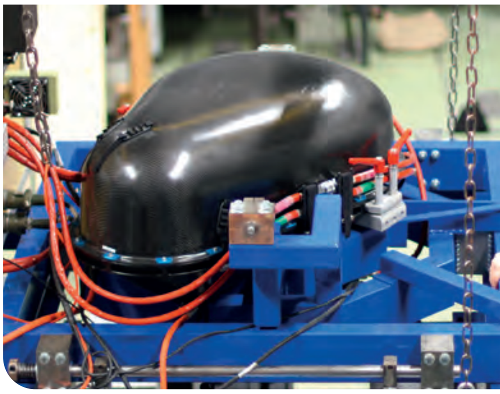
Hueni A, et al. (2014) **Impacts of dichroic prism coatings on radiometry of the airborne imaging spectrometer APEX**, Appl. Opt. 53: 5344–5352.

Schaepman M et al. (2015) **Advanced radiometry measurements and Earth science applications with the airborne prism experiment (APEX)**, Rem. Sens. Environ. 158: 207–219.

Abbreviations

APEX	Airborne Prism Experiment
ARES	Airborne Research Facility of the Earth System
ENMAP	Environmental Mapping and Analysis Programme
EOEP	Earth Obs. Envelope Prog.
PRODEX	Programme de Developement d'Experiences Scientifiques
SWIR	Short Wave Infrared
VNIR	Visible and Near-Infrared

Time-Line	From	To
Planning	1997	2000
Construction	2002	2010
Measurement phase	2009	ongoing
Data evaluation	2009	ongoing



APEX in the calibration laboratory.

Institute
Remote Sensing Labs. (RSL)
Dept. Geography, Univ. Zurich
Zurich, Switzerland

In cooperation with
ESA/PRODEX
ESA/Earth Observation Envelope Programme (EOEP)
Vlaamse Instelling voor Technologisch Onderzoek (VITO), Belgium

Principal/Swiss Investigator(s)
M. E. Schaepman (RSL)

Co-Investigator(s)
B. Bomans (VITO)
A. Hueni (RSL)

Method
Measurement

Research based on existing instruments
Use of the APEX instrument: calibration experiments and research flights.

Website
www.apex-esa.org

10 Life Science

10.1 CaSiPaC – Calcium Signalling during Parabolic Flight in Chondrocytes

CaSiPaC mission logo.
Image credit: Hochschule Luzern.

Institute
Inst. Medical Eng., Space Biology Group, Lucerne Univ. Appl. Sci. & Arts (HSLU) Hergiswil, Switzerland

In cooperation with
M. Böhmer, Goethe Univ., Frankfurt am Main, Germany

Principal/Swiss Investigator(s)
S. Wüest (HSLU)

Co-Investigator(s)
G. Cerretti, C. Follonier, K. F. Rattenbacher-Kiser, J. L. Wadsworth, T. Bradley, D. Schiffmann, S. Maranda, R. Kummer, C. Zumbühl, S. von Arx, S. Ammann, A. Hammer, D. A. Ricciardi, F. Strobl, R. Berkane, A. Stolz, E. H. K. Stelzer, E. Schleiff, M. Egli, F. Ille (HSLU)

Method
Measurement

Development & construction of instrument(s)
Two different hardware devices were developed for parabolic flights. One allowed irradiating live cells with UV light, which express a fluorescent calcium indicator. The other was a commercial plate reader adapted for parabolic flights.

Website
www.hslu.ch/spacebio

Purpose of Research

Articular cartilage separates the bones in articulating joints (e.g. hips, knees, shoulder, etc.) and allows for almost effortless movement. The predominant cell types found in articular cartilage are termed chondrocytes and are responsible for building, maintaining, and degrading the tissue. An active lifestyle and adequate mechanical stimulation are essential for cellular health and tissue maintenance. However, to date, the molecular mechanisms on how chondrocytes (cartilage cells) integrate mechanical forces into a cellular response (mechano-transduction) are not fully understood. Our aim is, therefore, to better understand the effects of mechano-transduction on cartilage degeneration and regeneration.

Among other mechanisms, mechano-sensitive ion channels are thought to play a key role in mechano-transduction. Ion channels are a major contributor to the cell's electrical potential across the cell membrane (membrane potential). Previous experiments have shown that the membrane potential could be gravity-dependent. In this experiment, we studied alterations in membrane potential and, in particular, the conc. of free calcium in chondrocytes in response to altered gravitational conditions during parabolic flights. Calcium is a common signalling molecule for several cellular processes and is thought to enter the cell through mechano-sensitive ion channels.

Past Achievements and Status

We used two techniques to measure the cellular free calcium. On one hand, an engineered fluorescent protein was introduced into the cells. In the presence of calcium and UV light, the signal colour changed, therefore allowing the detection of elevated cytosolic free calcium. We developed a novel hardware, which allowed the irradiation of numerous samples at specific time points during a parabolic flight.

On the other hand, a commercial plate reader and specific fluorescent dyes were used. The cells were stained with two different fluorescent dyes pre-flight. They indicate either changes in cytosolic free calcium concentration or membrane potential change. The fluorescent signal was then recorded in real-time during the flight.

Publications

Hammer A et al. (2022) **Biomedicines** 10(1):138. https://doi.org/10.3390/biomedicines10010138

Wuest SL, et al. (2022) **Acta Astronautica** 193: 287–302, https://doi.org/10.1016/j.actaastro.2022.01.016.

Time-Line	From	To
Planning	Mar. 2020	Jun. 2020
Construction	May 2020	Oct. 2020
Measurement phase	Oct. 2020	May 2021
Data evaluation	Nov. 2020	Jan. 2022

Zero Gravity during the 75th ESA Parabolic Flight Campaign. Image credit: Novespace.

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 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 a long-duration mission at the International 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.

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: ESA access to 76th ESA partial gravity Parabolic Flight Campaign December 2021: The effect of partial gravity on spinal stiffness.

PI: ESA access to 74th ESA partial gravity Parabolic Flight Campaign December 2020: The effect of partial gravity on spinal stiffness.

PI: ESA access to 71st ESA Parabolic Flight Campaign June 2019: The effect of changing gravity on spinal stiffness.

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.

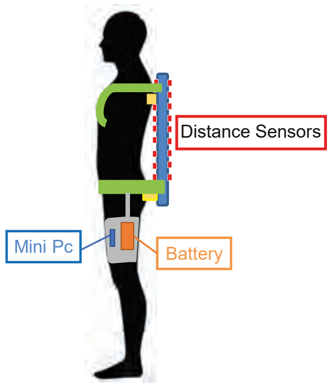
Swanenburg J, et al. (2018) **Spinal stiffness in prone and upright postures during 0 – 1.8 g induced by parabolic flight**, Aerospace Medicine and Human Performance 89(6): 563–568.

Swanenburg J, et al. (2020) **Microgravity and hypergravity induced by parabolic flight differently affect lumbar spinal stiffness**, Frontiers in Physiology 11: 562557.

Abbreviations

ISS International Space Station

Time-Line	From	To
Planning	Jun. 2021	Dec. 2021
Construction	Jan. 2022	Oct. 2022
Measurement phase	Oct. 2022	Jun. 2023
Data evaluation	Jul. 2023	Dec. 2023



Spinal curvature backpack.

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

Principal/Swiss Investigator(s)
J. Swanenburg (UNIZH)

Co-Investigator(s)
M. Egli (HSLU)

Method
Measurement

Development & construction of instruments
The spinal curvature is measured with the 'Spinal curvature backpack', which contains an array of distance sensors that measure the distance between the backpack and the human back.

Websites
www.spacehub.uzh.ch/en/research-areas/space-life-science/spinal-health.html

www.balgrist.ch/forschung/forschergruppen/chiropraktische-medizin/jaap-swanenburg-phd

10.3 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

Principal Investigator(s)
J. Swanenburg (UNIZH), M. Egli (HSLU)

Co-Investigator(s)
D. A. Green (ESA), F. Ille (HSLU), R. Sutter (Balgrist)

Method
Measurement

Research based on existing instruments
Measurements of lumbar spinal motor control, ultrasonic examination of the lumbar intervertebral discs (IVD) and studies on isolated IVDs, cultivated under simulated microgravity

Websites
www.spacehub.uzh.ch/en/research-areas/space-life-science/spinal-health.html

www.balgrist.ch/forschung/forschergruppen/chiropraktische-medizin/jaap-swanenburg-phd

Purpose of Research

Exposing humans to microgravity has severe implications on their health. Low back pain, for example, emerges in flight and substantially impairs the performance of the astronauts. It is assumed that microgravity induces a swelling of the lumbar intervertebral discs (IVD), which causes the low back pain . New reports are claiming, however, that mechanisms involved in stabilising the spinal cord might be the main reason for the pain, rather than the disc swelling.

In addition, an important topic that has not yet been extensively addressed is the motor control challenged that astronauts suffer when exposed to different spine loading/unloading. For maintaining the balance of the upright body and the ability to adapt to changes in gravity and/or additional loading, a healthy motor control of the spine is essential. It is obvious that gravity plays a key role in this spinal motor control system. Last but not least, it has been shown that movement kinematics change in response to a decrease of microgravity but more research is needed to explain the processes behind those changes.

This project will investigate the microgravity-induced changes on the human spine to understand in more detail the above-mentioned knowledge gaps. Measurements of lumbar spinal motor control (stiffness and motion patterns) and ultrasonic examination of the discs (with and without load) of astronauts will be performed before and after the mission.

To understand the results and corroborate the findings, the science team will also perform a Ground Reference Experiment that will culture IVDs from cow tail in a microgravity simulator, a Random positioning machine (RPM). IVD from the cow tail is an excellent model for human IVDs because it very closely represents the physiological and physical properties in humans. There are several studies showing that the IVDs of astronauts degenerate while in space. By investigating isolated bovine IVDs that have experienced similar microgravity exposure, similar to those of astronauts, a more profound knowledge of potential degenerative processes on tissue as well as cell level can be obtained.

Past Achievements and Status

We have participated in multiple ESA Parabolic Flight Campaigns (PFC), including: 76th ESA PFC in December 2021, 74th ESA PFC in December 2020, and 71st ESA PFC in June 2019.

Publications

Swanenburg J, et al. (2018) **Spinal stiffness in prone and upright postures during 0 – 1.8g 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	Lumbar Intervertebral Discs
RPM	Random positioning machine

Time-Line	From	To
Planning	Jun. 2019	Dec. 2020
Construction	Jan. 2021	Sep. 2021
Measurement phase	Oct. 2021	Dec. 2023
Data evaluation	Jun. 2023	Apr. 2024

11 Swiss Space Industries Group

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 becoming stronger and private initiatives are creating increasing impact, 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, 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 about five billion euros. Switzerland contributes around 170 million francs annually. As a result, funds flow into research and enable Swiss scientists to participate in significant ESA missions, while the manufacturers benefit as suppliers to the research sector or directly through contracts awarded by ESA.

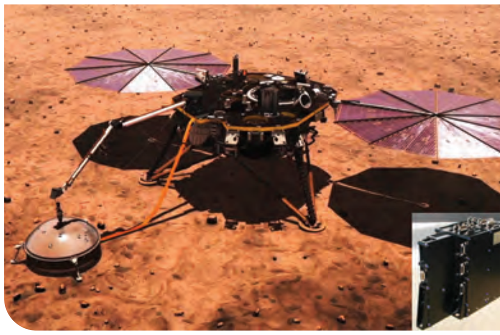
European and Swiss Collaboration

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, 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, MetOp or Electra, the space astrometry mission Cheops or the Sentinel satellites for Copernicus, Europe's Global Monitoring for Environment and Security system, are just some examples of important space programmes in which Swiss manufacturers have played a major role. There is hardly a current European mission which 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 membership. The ability to compete inter-



Insight SEIS Electronics Image credit: Syderal Swiss.

Contact
Swiss Space Industries Group (SSIG)

President
O. Henin
SYDERAL SWISS SA

Secretary General
R. Keller (SSIG)

Swissmem
Pfingstweidstr. 102,
PO Box, 8037 Zurich,
Switzerland
www.swissmem.ch/ssig

SSIG Members

3D PRECISION SA, www.3dprecision.ch

Altmatech SA, www.almatech.ch

APCO Technologies SA
www.apco-technologies.com

Art of Technology AG, www.art-of-technology.ch

Blösch AG, www.bloesch.ch

Clearspace SA, www.clearspace.today

Clemessy (Switzerland) AG, www.clemessy.ch

Coactum SA, www.coactum.ch

Cosylab Switzerland GmbH, www.cosylab.ch

CSEM, www.csem.ch

FAES-PWR ESTECH AG, www.estech.ch

Fisba AG, www.fisba.ch

Franke Industrie AG, www.industech.ch

General Atomics Synopta GmbH, www.ga-synopta.ch

icotec AG, www.icotec-medical.com

nanoTRONIC GmbH, www.nanotronic.ch

Orolia Switzerland SA, www.orolia.com

RUAG Schweiz AG / RUAG Space, www.ruag.com/space

SAPHYRION Sagl, www.saphyrion.ch

Schurter AG, www.schurter.ch

SpacePharma SA, www.space4p.com

SpacePNT Sarl, www.spacepnt.com

SYDERAL SWISS SA www.syderal.swiss

Thales Alenia Space Schweiz AG, www.thalesgroup.com

ViaSat Antenna Systems SA, www.viasat.com

WEKA AG, www.weka-ag.ch

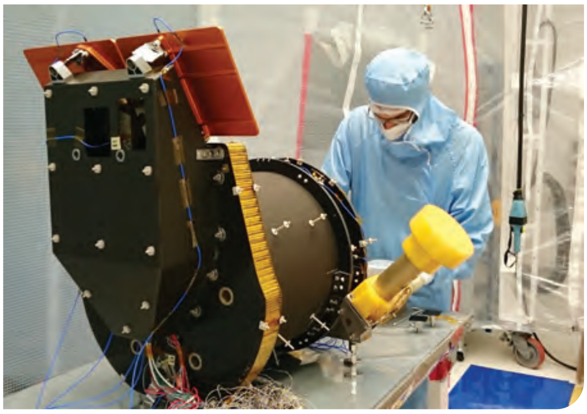
nationally is not a matter of course, it must be worked on. Having a location that is able to compete is the basis of success. Swissmem is committed to Swiss companies and the qualities of Switzerland as a center of industry and research. Continuous groundwork has made Swissmem into a center of strategic commercial and employer skills. This allows the association to represent the concerns of the sector to politicians, national and international organizations, 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, and components for propulsion engines 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.



Final assembly of the CHEOPS Telescope Structure developed by Almatech.

12 List of Authors

Marc Audard	Univ. Geneva, Geneva
Willy Benz	WP/PI, Univ. Bern, Bern
Enrico Bozzo	Univ. Geneva, Geneva
Valeria Büchel	PMOD/WRC, Davos
John Clinton	ETH Zurich, Zurich
Rolf Dach	AIUB, Bern
Laurent Eyer	Univ. Geneva, Geneva
Luigi Ferraioli	ETH Zurich, Zurich
Carlo Ferrigno	Univ. Geneva, Geneva
Wolfgang Finsterle	PMOD/WRC, Davos
Andrea Fischer	ISSI, Bern
Adrian Glauser	ETH Zurich, Zurich
Margit Haberreiter	PMOD/WRC, Davos
Louise Harra	PMOD/WRC, Davos
Daniel Henke	RSL, Univ. Zurich, Zurich
Andreas Hueni	RSL, Univ. Zurich, Zurich
Adrian Jäggi	AIUB, Bern
Jean-Luc Josset	SEI, Neuchatel
Raoul Keller	Swissmem, SSIG
Säm Krucker	FHNW, Windisch
Axel Murk	IAP, Univ. Bern, Bern
Stéphane Paltani	Univ. Geneva, Geneva
Sascha Quanz	ETH Zurich, Zurich
David Rodriguez	EPFL, Lausanne
Martin Rubin	Univ. Bern, Bern
Thomas Schildknecht	AIUB, Bern
Werner Schmutz	PMOD/WRC, Davos
Benedikt Soja	ETHZ Zurich, Zurich
Jaap Swanenburg	Univ. Zurich, Zurich
Nicolas Thomas	WP/PI, Univ. Bern, Bern
Xin Wu	Univ. Geneva, Geneva
Simon Wüest	HSLU, Hergiswil
Peter Wurz	WP/PI, Univ. Bern, Bern