Vol. 15, No. 10, 2020

scnat
swiss academy of sciences

swiss academies communications

swiss-academies.ch

Space Research in Switzerland 2018 – 2020

IMPRESSUM

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

CONTACT
Prof. Dr. Nicolas Thomas • Physics Institute • University of Bern • Sidlerstrasse 5 • 3012 Bern • Switzerland • +41 31 631 44 06 • nicolas.thomas@space.unibe.ch • csr.scnat.ch

RECOMMENDED FORM OF CITATION
N Thomas, S Nyeki (2020)
Space Research in Switzerland 2018 – 2020
Swiss Academies Communications 15 (10)

EDITORS
Nicolas Thomas • Stephan Nyeki

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

LAYOUT
Stephan Nyeki, PMOD/WRC

COVER PHOTO
ESA's Characterising Exoplanet Satellite, CHEOPS, lifted off on 18 December 2019 from Europe's Spaceport in Kourou, French Guiana, on a Soyuz-Fregat launcher. CHEOPS is ESA's first mission dedicated to the study of extrasolar planets, or exoplanets. It will observe bright stars that are already known to host planets, measuring minuscule brightness changes due to the planet's transit across the star's disc. Image credit: ESA, S. Corvaja.

Edition 2020, 800 ex.
This communication can be dowloaded from csr.scnat.ch/publications.

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

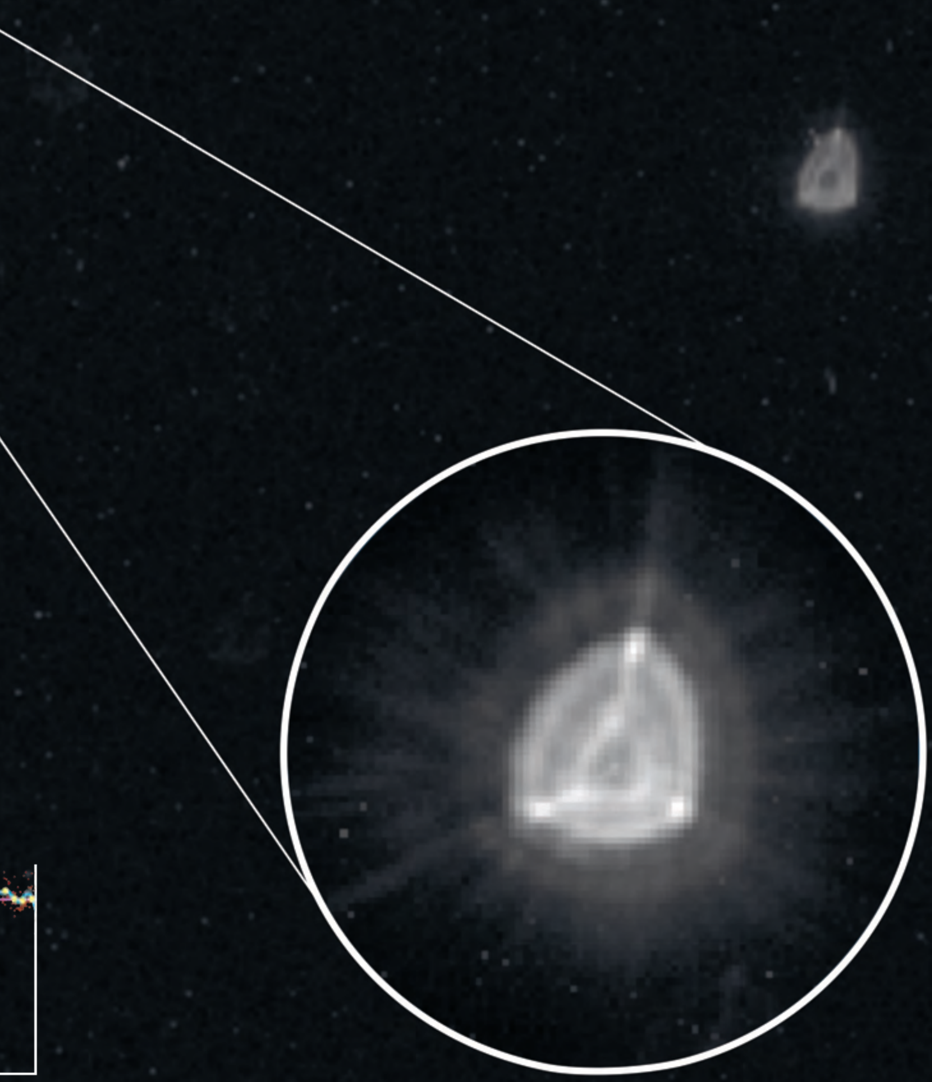
DOI: doi.org/10.5281/zenodo.3943786

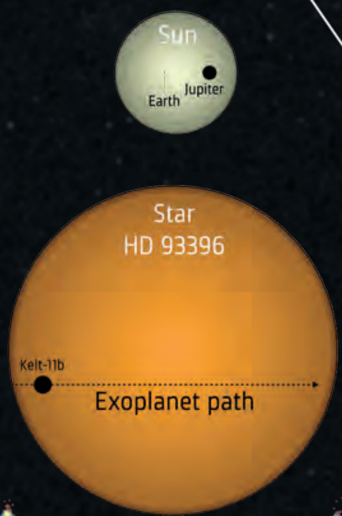
Cradle to Cradle™-certified and climate-neutral communication printed by Vögeli AG in Langnau.

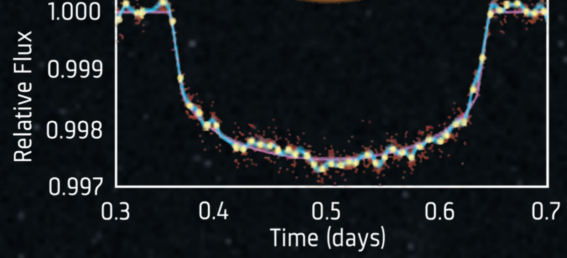
Space Research in Switzerland 2018 – 2020

First exoplanet measured by CHEOPS. During its in-orbit commissioning, ESA's CHEOPS mission observed the transit of the planet, KELT-11b, in front of its host star. HD 93396 is a subgiant yellow star located 320 light-years away, slightly cooler and three times larger than our Sun. It hosts a puffy gaseous planet, KELT-11b, about 30% larger in size than Jupiter, in an orbit that is much closer to the star than Mercury is to the Sun.

The light curve of this star shows a clear dip caused by the eight hour-long transit of KELT-11b, which enabled scientists to determine very precisely the diameter of the planet at 181,600 km, with an uncertainty just under 4300 km. The measurements made by CHEOPS are five times more accurate than those from Earth, providing a preview of the science to come from the CHEOPS mission. In this graphic, the Sun is shown as a comparison, along with the diameter of Earth and Jupiter (calculated from the mean volumetric radius). Image credits: ESA/Airbus/CHEOPS Mission Consortium.







Contents

→

1. Foreword

The Committee on Space Research (COSPAR) is an interdisciplinary scientific organisation which is focused on the exchange of information on progress of all kinds of research related to space. It was established in 1958 by the International Council for Science (ICSU) as a thematic organisation to promote scientific research in space on an international level. COSPAR's main activity is the organisation of biennial Scientific Assemblies. On the occasion of the 43rd COSPAR Assembly in Sydney, Australia, the Swiss National Committee on Space Research takes this opportunity to report on its activities to the international community.

The majority of Swiss space research activities are related to missions of the European Space Agency (ESA) and, therefore, ESA's science programme is of central importance to the Swiss science community. Within this programme, Swiss scientists and their industries have been extremely active in the past years and this is reflected in the diversity and depth of this report.

The first Swiss research satellite, CHEOPS (CHaracterizing ExOPlanets), which was selected by ESA's science programme as a small nationally-led mission, was launched in December 2019. The spacecraft and its single instrument have been commissioned and the mission has now entered its primary science phase. The mission uses the transit method to determine radii and possibly the atmospheric structure of previously detected exoplanets. The timeliness of this mission has been demonstrated by the award of the Nobel Prize for Physics to Michel Mayor and Didier Queloz from the University of Geneva for the discovery of the first exoplanet in 1995. Initial indications are that the mission will make significant discoveries in the coming years.

Switzerland, through the University of Bern, led the hardware development of Europe's first inter-planetary laser altimeter experiment, BELA. BELA forms part of a suite of experiments designed to perform geodesy experiments at Mercury from onboard ESA's BepiColombo spacecraft. The spacecraft was launched from Kourou in October 2018 on a 7-year flight to Mercury where it will perform topographic mapping of the surface with <2 metre precision.

The joint ESA/Roscosmos mission, the ExoMars Trace Gas Orbiter (TGO), was launched in March 2016 and has recently reached its primary science orbit. TGO carries the Swiss-led imaging system, CaSSIS (Colour and Stereo Surface Imaging System), which is now returning high resolution colour and stereo images of the surface of Mars in support of the spectrometers designed to measure trace gases in the Martian atmosphere (supplied by Belgium and Russia). The camera was used to image NASA's InSight lander on the surface of Mars. Switzerland has made a major contribution (through ETH Zurich) to the seismometer that has detected "Marsquakes" for the first time. Swiss contributions to the ExoMars Rover (launch 2022) are also in development and indicate Switzerland's support for exploration of the Red Planet.

ESA's Gaia Cornerstone mission passed a very significant milestone with the second data release in April 2018, which contained more than 1.5 billion objects. Switzerland is leading the analysis of variable sources, and studies more than half-a-million variable stars, compared to only ~3000 in the first data release. Switzerland also completed, in just two years, its hardware contribution for the JAXA mission, XRISM, the successor of the Hitomi mission, with a launch expected in 2022.

On 14 April 2020, the STIX hard X-ray imaging spectrometer onboard ESA's Solar Orbiter mission was successfully turned on. All 32 X-ray detectors are working beautifully. STIX observed its first solar flare on 18 May. Instrument commissioning is ongoing and expected to be completed by mid-June 2020.

For your information and to trigger your interest, this book is a compilation of Swiss national projects related to space research currently in work. A companion document entitled "A report on Space Science in Switzerland" was produced in 2019 and is available through the web site of the Swiss Academy of Science. This document provides information on the future plans of the Swiss community and shows the directions that our leading scientists would like to follow in the coming 8-10 years.

As the highlights above illustrate, the Swiss space research community is very active and a reliable partner in space research activities. Switzerland and its space science community has broad interests in many fields with technical innovation capabilities to match.

Nicolas Thomas

2. Institutes and Observatories

2.1 ISSI – International Space Science Institute

INTERNATIONAL SPACE SCIENCE INSTITUTE

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 and other advisers.

ISSI's operation mode is fivefold: International Teams, multi- and interdisciplinary Workshops, Working Groups, Visiting Scientists and Forums are the working tools 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 to the Director and in-kind facilities through a grant. The Institute of Space and Astronautical Science (ISAS, JAXA, Japan) is supporting ISSI with an annual financial contribution.

Realisations in 2018 and 2019

In total, 136 International Team meetings, 10 Workshops, and 5 Forums took place in 2018 and 2019. ISSI has welcomed to date about 950 visitors annually, of which 40% are first-time visitors.

ISSI is a part of the Europlanet 2020 Research Infrastructure (RI) project. Europlanet 2020 RI addresses key scientific and technological challenges facing modern planetary science by providing open access to state-of-the-art research data, models and facilities across the European Research Area. Thus, ISSI organised 3 Workshops: i) "Role of Sample Return in Addressing Major Outstanding Questions in Planetary Sciences" (Feb. 2018), ii) "Reading Terrestrial Planet Evolution in Isotopes and Element Measurements" (Oct. 2018), and iii) "Reading Terrestrial Planet Evolution in Isotopes and Element Measurements" (Nov. 2018) and a Forum on "Solar System - Exoplanet Science Synergies" (Feb. 2019). The peer-reviewed papers, resulting from the Workshops, are continuously published in the corresponding Topical Collections in Space Science Reviews.

The Workshop "Comets: Post 67P Perspectives" (Jan. 2018) was in collaboration with a Horizon 2020 project of the European Commission called MiARD (Multi-instrument Analysis of Rosetta Data) and included invitees from the MiARD project itself and the wider community. The Workshop provided a forum for a broad multi-disciplinary discussion of the Rosetta data set and integrated the knowledge from previous fly-bys, ground-based observations, and laboratory measurements. The peer-reviewed papers are published in the Topical Collection "Comets: Post 67P Perspectives" in Space Science Reviews.

Directors
T. Spohn (Executive Director)
A. Cazenave
R. von Steiger
J. Wambsganss

Staff
10 Scientific
6 Administrative

Contact Information
Int. Space Science Institute (ISSI),
Hallerstrasse 6,
3012 Bern, Switzerland
Tel. +41 31 631 48 96
www.issibern.ch
E-mail: firstname.name@issibern.ch

The ESSC Committee from the European Science Foundation (ESF) initiated an interdisciplinary study on "Ocean Worlds" in collaboration with the International Space Science Institute, the European Marine Board, and NAS / Space Studies Board experts. 40 Worldwide leading scientists from 11 countries gathered during the Workshop "ExoOceans: Space Exploration of the Outer Solar System Icy Moons Oceans" (Jun. 2018) to review and synthesise what is presently known on the astrobiological potential of the outer solar system. The thematic scientific papers are published in the Topical Collection "Ocean Worlds" in Space Science Reviews.

ISSI established a branch called ISSI-BJ (International Space Science Institute – Beijing) in 2013 jointly with the National Space Science Centre of the Chinese Academy of Sciences (NSSC/CAS). ISSI-BJ is sharing the same Science Committee with ISSI and is using the same study tools. ISSI releases together with ISSI-BJ annually a joint Call for Proposals for International Teams in Space and Earth Sciences. More details about ISSI Beijing and its activities can be found on www.issibj.ac.cn.

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), or individual papers in peer-reviewed international scientific journals. As of the end of 2019, 72 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 2018 and 2019, the following volumes appeared:

SSSI Volume 61: **Gamma-Ray Bursts – A Tool to Explore the Young Universe (ISSI-Beijing Book),** D. Götz, et al., (Eds.), ISBN 978-94-024-1278-9, 2018.

SSSI Vol. 62: **Jets and Winds in Pulsar Wind Nebulae, Gamma-Ray Bursts and Blazars: Physics of Extreme Energy Release**, A. Bykov, et al., (Eds.), ISBN 978-94-024-1291-8, 2018.

SSSI Vol. 63: **High Performance Clocks, with Special Emphasis on Geodesy and Geophysics and Applications to Other Bodies of the Solar System,** R. Rodrigo, et al., (Eds.), ISBN 978-94-024-1565-0, 2018.

SSSI Vol. 64: **The Delivery of Water to Protoplanets, Planets and Satellites,** A. Morbidelli, et al., (Eds.), ISBN 978-94-024-1627-5, 2019.

SSSI Vol. 65: **Shallow Clouds, Water Vapor, Circulation and Climate Sensitivity,** R. Pincus, et al., (Eds.), ISBN 978-3-319-77273-8, 2018.

SSSI Vol. 66: **Astron. Distance Determination in the Space Age (ISSI-Beijing Book),** R. de Grijs, M. Falanga (Eds.), ISBN 978-94-024-1630-5, 2019.

SSSI Vol. 67: **The Scientific Foundation of Space Weather,** D. Baker, A. Balogh, T. Gombosi, H.E.J. Koskinen, A. Veronig, R. von Steiger (Eds.), ISBN 978-94-024-1587-2, 2019.

SSSI Vol. 68: **Supernovae,** A. Bykov, et al., (Eds.), ISBN 978-94-024-1580-3, 2019.

SSSI Vol. 70: **Exploring the Earth System with Imaging Spectroscopy,** S. Förster, et al., (Eds.), ISBN 978-3-030-24909-0, 2019.

SSSI Vol. 71: **Forest Properties and Carbon Cycle Studies from Earth Observations,** K. Scipal, A. Cazenave, T. Lopez (Eds.), ISBN 978-3-030-32838-2, 2019.

SSSI Vol. 72: **Clusters of Galaxies: Physics and Cosmology,** A. Bykov, et al., (Eds.), ISBN 978-94-024-1733-3, 2019.

Furthermore, two Scientific Reports (both Open Access) appeared:

Vol. 15: **Earth Observation Open Science and Innovation,** P.P. Mathieu, C. Aubrecht (Eds.), Results of an ISSI Working Group, ISBN 978-3-319-65632-8, 2018. link.springer.com/book/10.1007/978-3-319-65633-5.

Vol. 17: **Ionospheric Multi-Spacecraft Analysis Tools,** M.W. Dunlop, H. Lühr (Eds.), Results of an ISSI Working Group, ISBN 978-3-030-26731-5, 2019. link.springer.com/book/10.1007/978-3-030-26732-2.

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 23 (2017–2018) and 24 (2018-2019).

Outlook

Thirty two new International Teams, approved in 2019 by the Science Committee, started their activities in the present business year (2019/20), and four Teams are associated with ISSI-Beijing. Furthermore, eight Workshops are scheduled for 2020 and 2021:

- Surface Bounded Exospheres and Interactions in the Solar System
- Venus: Evolution through Time
- Strong Gravitational Lensing
- Magnetic Reconnection: Explosive Energy Conversion in Space Plasmas
- Probing the Earth's Deep Interior Using in Synergy Observations of the Earth's Gravity and Magnetic Fields, and of the Earth's Rotation
- Solar & Stellar Dynamos: A New Era
- The Heliosphere in the Local Interstellar Medium
- Science Enabled by Exoplanetary Transits

ISDC

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

In cooperation with
European Space Agency
German Aerospace Centre
Istituto Nazionale di Astro., Italy
APC, France
CNRS, France
DTU Space, Denmark
Centro de Astrobiología, Spain

Prinicipal Investigator(s)
C. Ferrigno (UNIGE)

Method
Measurement

Developments
Data from the INTEGRAL gamma-ray space observatory are processed, archived and distributed to scientists worldwide together with the software to analyse them. Quick-look and automated analyses ensure the data quality and the discovery of relevant astronomical events.

Staff
About 10 scientists and software engineers, including administrative/support staff.

Contact Information
INTEGRAL Science Data Centre,
Astronomical Obs., Univ. Geneva,
1290 Versoix, Switzerland
Tel. +41 22 379 21 00
Fax +41 22 379 21 33

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 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 are 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 the present, ISDC members have participated in about 20% of the publications based on data from INTEGRAL.

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 the 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; 2017). ISDC staff led the Memorandum of Understanding with both the LIGO scientific and Virgo collaborations to look for gamma-ray counterparts of gravitational wave events. The INTEGRAL team has produced stringent upper limits on 85% of the double black-hole mergers detected by LIGO. Together with the gamma-ray monitor onboard the Fermi observatory, it found a flash of gamma-rays two seconds after the arrival on Earth of gravitational waves, originating as a result of a binary neutron star merger (Savchenko et al., 2017). This historical achievement has opened the era of multi-messenger astronomy with the subsequent observation of a kilonova in the optical, X-ray, and radio bands.

ESA conducted reviews in 2010, 2012, 2014, 2016, and 2019. They concluded that fuel consumption, solar panel and battery ageing, and orbital evolution will allow the mission to be prolonged for many more years. In 2019, an operational review ascertained the reliability of INTEGRAL until the end of 2022, for which the budget has already been approved by the ESA Science Programme Committee (SPC). Further extension requests will be based on the scientific output of the missions and budget constraints.

ISDC is an essential pillar of the mission and is currently funded by the Swiss Space Office, the University of Geneva, and ESA, with contributions from the German Aerospace Centre through the Inst. Astronomy and Astrophysics, Tübingen. ISDC counts on the contribution of about 10 software engineers and scientists who work in synergy with other space missions within the Dept. Astronomy, Univ. Geneva.

To ensure data quality and to exploit the potential of the INTEGRAL observatory, ISDC staff continuously perform scientific validations 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. During this activity, INTEGRAL managed to capture the first pulsar swinging from accretion and rotation powered emission which has been sought since evolutionary theories first appeared in 1982 (Papitto et al., 2013).

The studies performed at ISDC are mainly in the field of high-energy astrophysics. Although a significant fraction of the research topics are linked to areas in which INTEGRAL makes a significant contribution, a variety of other observation facilities, such as XMM-Newton, RXTE, Chandra, Planck, and Fermi, have so far been exploited. The science topics developed in the high-energy group span from nearby X-ray binaries up to cosmological scales, with the study of active galactic nuclei and clusters of galaxies.

Based on an approach merging high-energy astrophysics with particle physics, astroparticle physics is rapidly developing around ISDC. Its central topics are the nature of dark matter and dark energy, the origin of cosmic rays and astrophysical particle accelerators. Research in this field involves data from X-ray and gamma-ray space telescopes, as well as from ground-based gamma-ray telescopes operating at even higher energies, such as MAGIC, HESS or the future Cherenkov Telescope array.

Publications

Papitto A, Ferrigno C, Bozzo E et al. (2013) **Swings between rotation and accretion power in a binary millisecond pulsar**, Nature 501: 7468, 517-520.

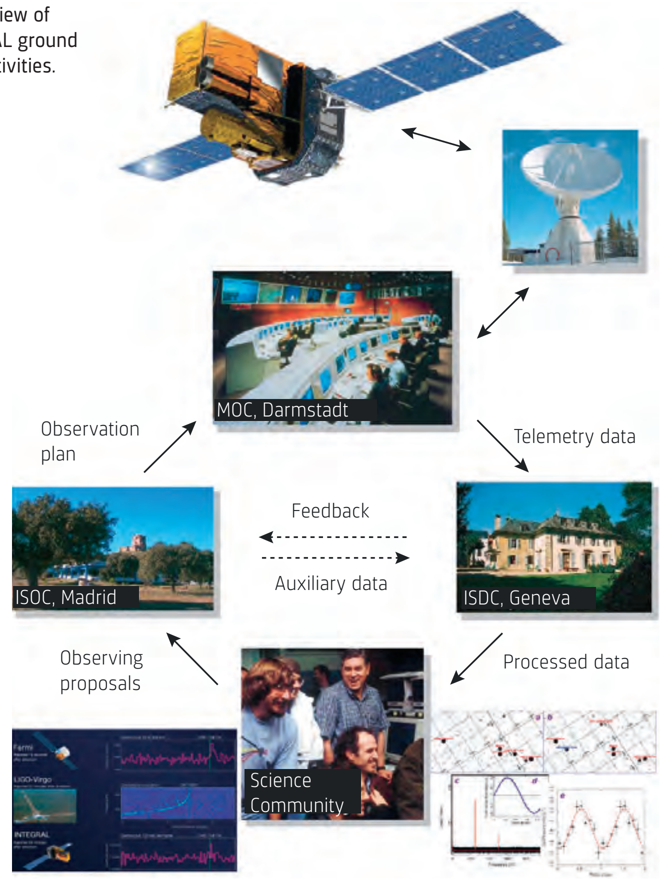
Savchenko V, Ferrigno C et al. (2016) **INTEGRAL upper limits on gamma-ray emission associated with the gravitational wave event GW150914**, Astrophys. J. Lett. 820(2): L36, 5 pp.

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 Gravitatio nal-Wave Observatory
MAGIC	Major Atmospheric Gamma-Ray Imaging Cherenkov Telescope.

Schematic view of the INTEGRAL ground segment activities.



2.3 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 280 globally distributed IGS tracking stations are processed every day. Apart from the well-known systems, such as the American Global Positioning System (GPS) and the Russian counterpart (GLONASS), the recently established European Galileo system is also considered to be a rigorous multi-GNSS processing system. When Galileo was introduced as the third global system into the operational rapid and ultra-rapid product line, CODE was the first (and is still the only) IGS analysis center with Galileo orbit and satellite clock products in their legacy product chain.

To come to this point, intensive technical developments (e.g., in order to handle the new observation types) and research (e.g., to understand the orbit of the Galileo satellites) was necessary. A similar effort is underway for the Chinese BeiDou, and the Japanese QZSS, which will hopefully soon allow their inclusion into operational IGS products chains.

Past Achievements and Status

The main products are precise GPS and GLONASS 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 for studying vertical and horizontal site displacements and plate motions, and to provide information for the realization of the International Terrestrial Reference Frame (ITRF). The daily positions of the Earth's rotation axis with respect to the Earth's crust as well as the exact length-of-day is determined for each day and provided to the International Earth Rotation and Reference Systems Service (IERS).

Apart from regularly generated products, CODE significantly contributes to the development and improvement of modelling standards. Members of the CODE group contribute or chair different IGS 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.

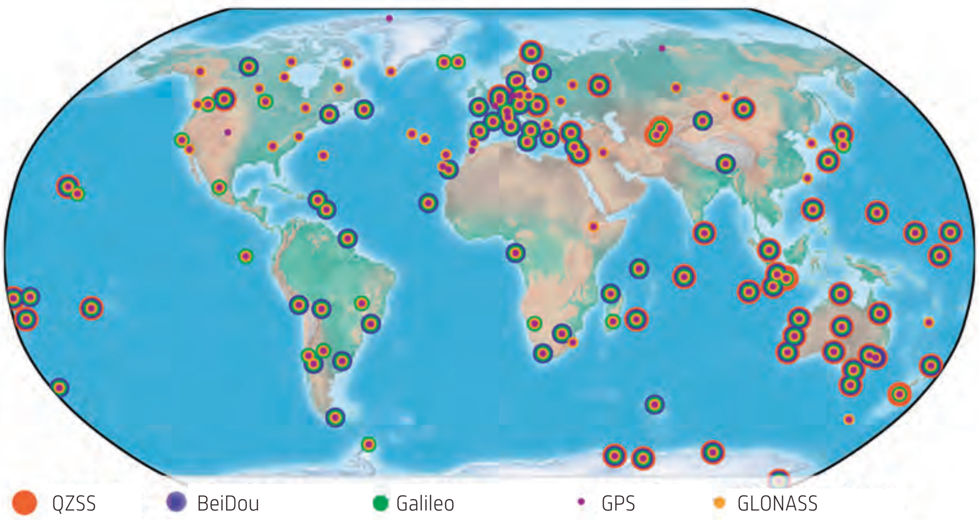
Abbreviations

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



Network with tracking capability for various GNSS used for the processing at CODE at the end of 2019.

2.4 eSpace – EPFL Space Center

eSpace EPFL Space Center

Institute
EPFL Space Center (eSpace)

Director
J.-P. Kneib

Staff
1 Director, 1 Manager, 3 Engineers, 2 Postdocs, 2 PhD, 3 Support staff

Contact Information
EPFL Space Engineering Centre
EPFL – ENT – ESC, Station 13
1015 Lausanne
Tel. +41 21 693 6948
Fax +41 21 693 6940
E-mail: espace@epfl.ch
eSpace.epfl.ch

Mission

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

The EPFL Space Center (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 minor in Space Technologies which allows master-level students to acquire extensive formal teaching 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. SwissCube satellite which was launched into space in 2008, as well as the recently selected mission, ClearSpace-1).

The center also provides guidance and support to various student-led associations on campus such as the EPFL rocket team, the Spacecraft team, Growbot hub, Callista and Space at your service.

eSpace is currently focused on the research initiative on Sustainable Space Logistics, which can include missions such as the removal of space debris, and technologies such as Relative Navigation and Space Robotics. One of the timely developments is the partnership with the eSpace's commercial spin-off, Clearspace SA, which will launch the first satellite removal mission in 2025, following the recent selection of the ClearSpace-1 mission by ESA.

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 take these technologies to space.

2.5 Research Initiative on Sustainable Space Logistics

Purpose of Research

In recent years the space industry has undergone profound changes. The drop in launch costs has been driven by many start-ups following the path of SpaceX in the launch industry, working tirelessly to transform it, similar to the beginnings of the aviation industry. At the same time, small- and nano-satellites, and the standardisation and industrialisation of satellite production enable innovative missions and business models, pushing the industry towards more commercial operation.

Finally, new long-term visions have emerged, such as settlements on the Moon or Mars which use in-situ resources (ISRU), mineral resource exploration, or deploy large infrastructures beyond low Earth orbit. These developments have in common that they relate to space logistics, and their sustainability: a new field driven by orbital dynamics, fundamentally different from Earth logistics. The objectives of the Research Initiative on Sustainable Space Logistics are:

- To initiate and support research that has the potential to drive innovation and contribute to Swiss leadership in Sustainable Space Logistics (SSL).
- To connect the EPFL and other Swiss laboratories with a background in space technology, via space logistics technology scouting.
- To identify commercial applications and opportunities from the developed research and support technology transfer.
- To develop talents and inspire new vocations.

Past Achievements and Status

The project has identified partners and is securing funding. High-level modelling has begun.

Publications

Ben Hamida S, Richard M, Kneib J-P (2019), **Towards an ontology of Sustainable Space Logistics**, European Conference for Aeronautics and Space Sciences 2019.

Chavy-Macdonald M-A, Oizumi K, Kneib J-P, Aoyama K (2020) **The cis-lunar ecosystem – a systems model and scenarios of the resource industry and its impact**, IEEE Trans. Aerospace & Electronic Systems, under review.

Chavy-Macdonald M-A (2020) **Sustainable logistics in space**, Commodities Magazine de L'Agefi, Special Edition, April 2020.

In the first instance, Sustainable Space Logistics seeks to capture the interactions and systems view of many key industry trends.

Institute
EPFL Space Center (eSpace)

In cooperation with
ESA

Principal Investigator(s)
J-P. Kneib (eSpace)

Swiss Principal Investigator(s)
EPFL

Co-Investigator(s)
M-A. Chavy-Macdonald (EPFL, eSpace)

Method
Simulation

Development of
Campaign and mission modelling, mission, system, and subsystem design, technology planning.

Website
www.epfl.ch/research/domains/epfl-space-center

2.6 SSC – Swiss Space Center

Mission

The Swiss Space Center (SSC) provides a service supporting institutions, academia and industry to access space missions and related applications, and promote interaction between these stakeholders.

Roles

- To network Swiss research institutions and industries on national and international levels in order to establish focused areas of excellence internationally recognised for both space R&D and applications.
- To facilitate access to and implementation of space projects for Swiss research institutions and industries.
- To provide education and training.
- To promote public awareness of space.

Members

In 2020, the Swiss Space Center welcomed five new industrial members. Apart from the founding members which constitute the BoD (EPFL, ETH Zurich), 39 members from each region of Switzerland representing all types of companies (large-sized, medium and start-up), academies (Swiss Federal Institutes, Universities, Universities of Applied Sciences) and RTO (CSEM, EMPA, PMOD/WRC, EAWAG) are all part of the network (Figure 1).

Activities 2018 - 2020

Coordinated by the Swiss Space Center, the ESA_Lab Demonstrator Project, IGLUNA, offered students opportunities to participate in an international, collaborative project on a visionary space topic: A Habitat in Ice. In one year, 20 student teams (Figure 2) from various disciplines gathered their knowledge to design a habitat potentially suitable for an extreme environment, such as the Moon.

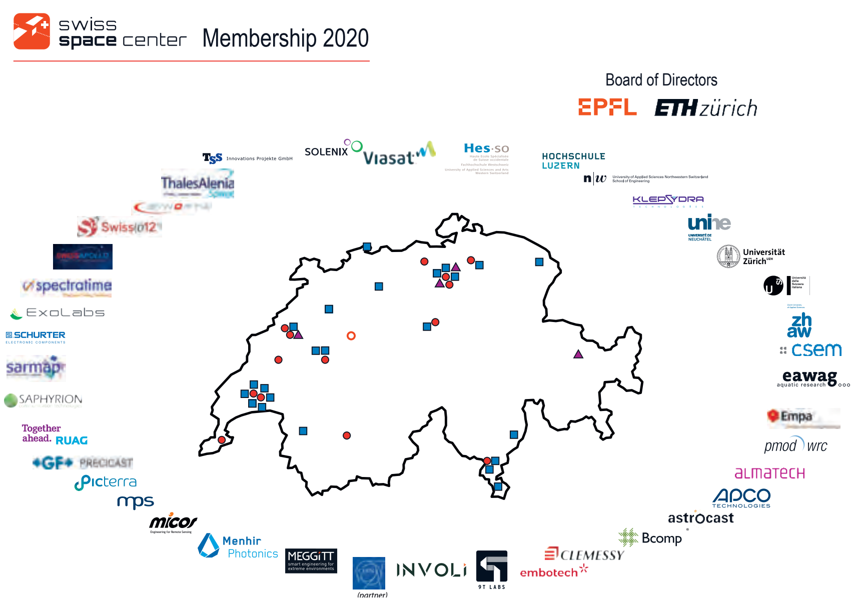


Figure 1. A catalogue of Member competences entitled “Members’ Profiles” was edited by SSC. This document is available for download on the SSC website.

Director
V. Gass (EPFL)

Staff
3 Professors
8 Scientific and Technical
2 Administrative

Board of Directors
M. Gruber (EPFL)
D. Günther (ETH Zurich)

Steering Committee
J. Binder (EPFL, Chair)
M. Rothacher (ETH Zurich)
F. Rottmeier (Industry rep.)
E. Rugi-Grond (Industry rep.)
A. Madrigal (RTO rep.)
M. Righi (Academic rep.)

Contact Information
Swiss Space Centre
EPFL, PPH338, Station 13
1015 Lausanne, Switzerland
Tel. +41 21 693 69 48
space.center@epfl.ch

ETH Zurich, HPC G32.1,
Leopold-Ruzicka-Weg 4,
8049 Zurich, Switzerland
Tel. +41 44 633 30 56

Website
www.spacecenter.ch

More than 150 students from 9 European countries designed their prototypes during the autumn semester 2018 and built their modules in the spring semester 2019. From 17 June until the full disassembly on 3 July 2019, the results came together during a field campaign inside the glacier cave of the Klein Matterhorn and an exhibition in the village of Zermatt, Switzerland (Figure 3).

Figure 2. IGLUNA 2019 exhibition during field-campaign in the village of Zermatt, Switzerland.

Figure 3. IGLUNA 2019 field campaign test-bed on a glacier at Klein Matterhorn, Zermatt, Switzerland.

IGLUNA continues to gather students from all around the world to work on a collaborative interdisciplinary project. After the positive outcome of IGLUNA 2019 as the ESA_Lab Demonstrator Project, ESA and the Swiss Space Office have engaged to support this initiative once more. Bringing it to the next level, ESA has signed a Memorandum of Collaboration (Figure 4) with the Swiss Space Center for IGLUNA to be officially coordinated as an ESA_Lab@CH Project.

Figure 4. Signing of the Memorandum of Collaboration, ESA_Lab@CH, between ESA director general Jan Wörner and SSC director Volker Gass.

Being a hub for disruptive innovation and cross-fertilisation, the ESA_Lab@ initiative creates an institutional link between ESA and universities. IGLUNA contributes to this vision and collects lessons learned for the implementation of future ESA_Labs.

IGLUNA 2020 – Space habitat and remote operations

Coordinated by the Swiss Space Center, the ESA_Lab@CH Project IGLUNA 2020 (Figure 5), as a follow-up of the 2019 campaign, again offers students opportunities to participate in an international, collaborative project with the particular twist of adding remote operations as a key requirement. During this academic year, 15 international student teams coming from 10 countries are developing their technologies on the topic of a space habitat, with the goal to install their projects on the Pilatus and operate them by remote control from the Verkehrshaus – Swiss Museum of Transport in July 2020. This inter-university project follows the first IGLUNA edition that was successfully completed last summer in Zermatt.

FIgure 5. IGLUNA 2020 participating universities and partners

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

Laser beam transmitted from the 1-meter ZIMLAT telescope to measure 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, E. Cordelli AIUB), E. Brockmann (swisstopo)

Method
Measurement

Website
www.aiub.unibe.ch

Purpose of Research

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

All these efforts have to be seen in the larger context of the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG). In order to achieve the GGOS science goals, the accuracy and amount of SLR measurements needs 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 project (ADRIOS).

Publications

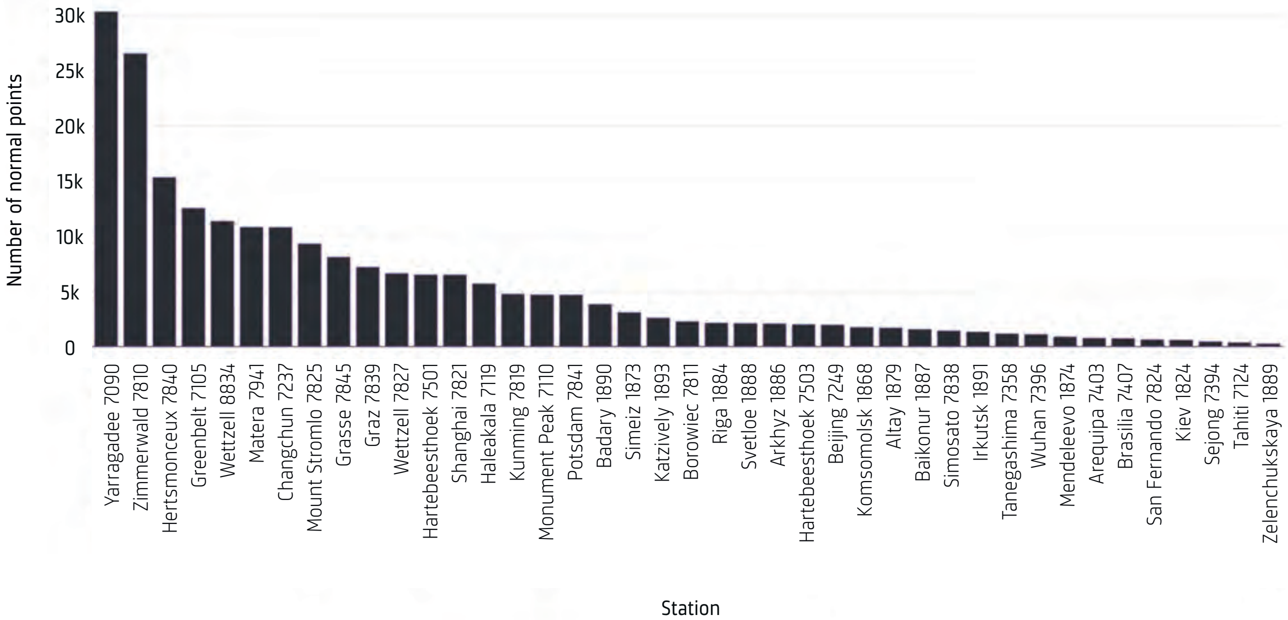
Andritsch F, Grahsl A, Dach R et al. (2020) **Simulation of tracking scenarios to LAGEOS and Etalon satellites**, J. Geod. 94: 40, doi.org/10.1007

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**.

Cordelli E, Lauber P, Prohaska M, Rodriguez J, Schlatter P, Schildknecht T (2019) **Recent developments at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald**, Proc. ESA NEO SST Conf., Darmstadt, Germany, 2019.

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" (NPT) over the period 1 February 2019 – 31 January 2020 for the geodetic satellite LAGEOS and LARES acquired in the ILRS network in 2019. 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

CHEOPS lift-off at 8:54 UT, 18 December 2019, on a Soyuz-Fregat from Kourou, French Guyana. Image credit: ArianeSpace.

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

In cooperation with
Institut für Weltraumforschung Graz, Austria
Center Spatial de Liege, Belgium
Swiss Space Center, EPFL, Switzerland
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

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, in which a wide range of science topics can be addressed.

Past Achievements and Status

- Mission selection: October 2012.
- Mission adoption: February 2014.
- Instrument CDR: December 2015.
- Ground segment CDR: January 2016.
- System CDR: May 2016.
- Flight telescope arrives at the University of Bern: April 2017
- SVT-1A: June 2017.
- SVT-1B: November 2017.
- Instrument EMC test: December 2017.
- Measurement of the center of mass, and moment of inertia: January 2018.
- Telescope ready for calibration: March 2018.
- Telescope shipped to ADS Madrid for integration: April 2018.

- Environmental tests at RUAG Space:
  July 2018.
- Satellite ready for launch, and placed in storage at ADS:
  May 2019.
- Final review before shipment to Kourou passed:
  July 2019.
- CHEOPS is successfully launched from Kourou as a secondary passenger on a Soyuz-Fregat rocket:
  18 December 2019.
- In-orbit commissioning starts:
  8 January 2020.
- Successful opening of the cover and first image taken:
  January 2020.
- 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.

Publications

Benz W, Ehrenreich D, Isaak K (2017) **CHEOPS: CHaracterising ExOPlanets Satellite, Handbook of Exoplanets**, Eds. HJ Deeg, JA Belmonte, Springer Living Ref. Work, ISBN: 978-3-319-30648-3, id.84.

Deline A, Queloz D, Chazelas B, Sordet M, Wildi F, Fortier A, Broeg C, Futyan D, Benz W (2020) **Expected performances of the Characterising Exoplanet Satellite (CHEOPS). I. Photometric performances from ground-based calibration**, Astronomy & Astrophysics 635: A22.

Hoyer S, Guterman P, Demangeon O, Sousa SG, Deleuil M, Meunier JC, Benz W (2020) **Expected performances of the Characterising Exoplanet Satellite (CHEOPS). III. Data reduction pipeline: architecture and simulated performances**, Astronomy & Astrophysics 635: A24.

Abbreviations

CDR	Critical Design Review
CHEOPS	CHaracterising ExOPlanet Satellite
E-ELT	European Extremely Large Telescope
EMC	Electromagnetic Compatibility
JWST	James Webb Space Telescope
STM	Structural Thermal Model
SVT	System Validation Test

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

CHEOPS in the clean-room at Airbus Defence and Space, Madrid, Spain, after having been declared ready to fly. Image credit: ESA.

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

Co-Investigator(s)
T. Barczy, T. Beck, M. Davies, D. Ehrenreich, M. Gillon, W. Baumjohann, C. Broeg, M. Deleuil, A. Fortier, A. Gutierrez, A. L.-d-Etangs, G. Piotto, D. Queloz, E. Renotte, T. Spohn, S. Udry, CHEOPS Team

Method
Measurement

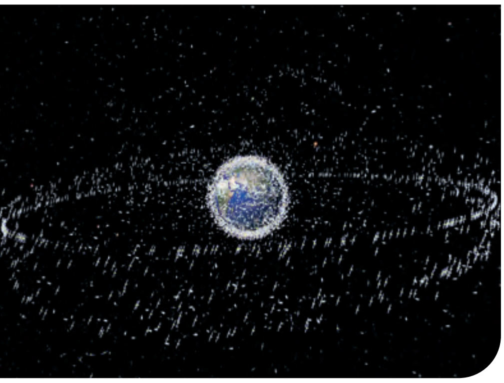
Development & construction of instrument(s)
Switzerland is responsible for the development, assembly, and verification of a 33 cm diameter telescope as well as the development and operation of the mission's ground segment.

Main industrial hardware contract(s) to
Airbus Defense & Space (ADS); Almatech; Connova AG, Pfeiffer Vacuum AG; P&P, RUAG Space

Website
www.cheops.unibe.ch

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

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), Darmstadt, 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
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 program.

An important source of space debris are fragments from on-orbit breakup events. During the past two years several severe fragmentations of upper stages took place in high-altitude orbits producing several thousand debris pieces of substantial size. The SSA / Space Safety collaboration essentially contributed to the identification and cataloguing of the resulting debris clouds. The figure on the right shows the debris clouds of three of these events.

Publications

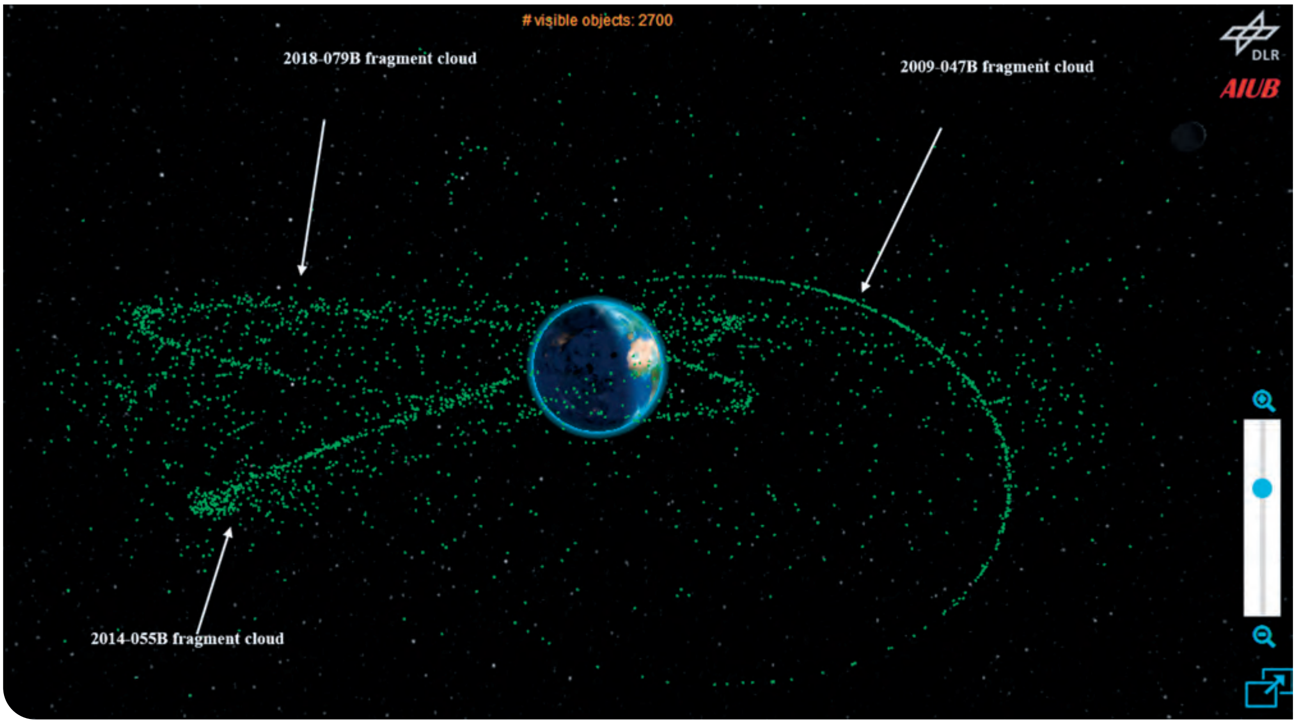
Cordelli E, et al. (2019) **Recent developments at the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald**, Proc. ESA NEO SST Conf., Darmstadt, Germany, 2019.

Cordelli E, Schildknecht T, Jäggi A, Brockmann E (2019) **The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Swiss National Report on the Geodetic Activities in the years 2015-2019**.

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.

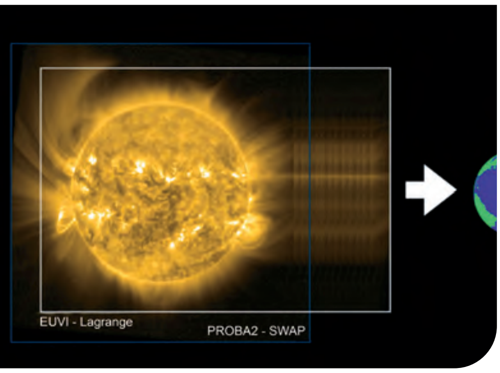
Abbreviations

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 & Astronomical Telescope
ZimSMART	Zimmerwald SMall Aperture Robotic Telescope



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

4.2 LUCI – Lagrange EUV Coronal Imager



Field-of-view of the LUCI instrument.
Image credit: Matthew West.

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

In cooperation with
ESA
Centre Spatial Liège (CSL), Liège, Belgium
Royal Observatory of Belgium (ROB), Belgium
Rutherford Appleton Lab. (RAL), UK

Swiss Scientific Contact
M. Haberreiter (PMOD/WRC)

Co-Investigator(s)
C. Kintziger, L. Jacques (CSL)
D. Berghmans, M. West, S. Gissot (ROB)
J. Hurely (RAL)
L. Harra, S. Koller, D. Pfiffner, V. Büchel, M. Gyo, P. Langer, M. Spescha (PMOD/WRC)
ESA

Method
Measurement

Development & construction of instrument(s)
LUCI to be developed and constructed under the lead of CSL.

Website
www.pmodwrc.ch

Purpose of Research

The Lagrange EUV Coronal Imager (LUCI) is an extreme UV imager on board the ESA mission within the Space Safety Programme to the Lagrange point L5. LUCI is one of the remote sensing instruments on the spacecraft and is dedicated to imaging the full solar disc and the region of the outer corona, up to 2.5 solar radii in direction towards Earth. It builds on the heritage of the SWAP (Sun Watcher using Active Pixel System detector and Image Processing) telescope on the ESA PROBA-2 satellite and the EUI telescope on Solar Orbiter.

LUCI will obtain images in the extreme ultraviolet wavelength range at 195 Å. It will provide input to generate reliable space weather forecasts and to provide new insights into solar activity and its impact on Earth. In particular, the design of LUCI, together with the side-view of the Sun-Earth line, will, for the first time, allow us to observe the onset and the early acceleration phase of Coronal Mass Ejections (CMEs) travelling towards the Earth. This is of particular importance in order to determine the arrival time of CMEs in the vicinity of Earth with higher accuracy than is currently possible. In addition, the EUV images of the Sun obtained with LUCI will allow us to improve our understanding and models of the variability of EUV radiation. The variability in the EUV range drives the temperature, density and total electron content of the Earth's upper atmosphere. As such, LUCI will provide key observations to advance our knowledge of the Earth's response to solar activity.

Past Achievements and Status

The LUCI consortium has successfully completed Phases A and B1, and is currently performing activities covered by the Pre-Development of the Front-End Electronics (FEE) and the Thermal-Mechanics (TM) of the instrument, foreseen to last until March 2021. Additional activities besides the Pre-Development are covered by the subsequent Bridging and Consolidation Phase, which are foreseen to run until June 2020 and May 2021, respectively.

The LAGRANGE mission was selected at the Space 19+ ESA Ministerial Conference in November 2019 as part of ESA's Space Safety Programme (S2P). LUCI is also expected to receive funding from PRODEX. The Prime Contractor for the mission was also chosen. The Request for Proposal is expected to come out in Q4/2020 and the start of Phase B2 is foreseen for Q2/2021. Instrument delivery is currently foreseen for the end of 2024 and the launch for 2026.

Publications

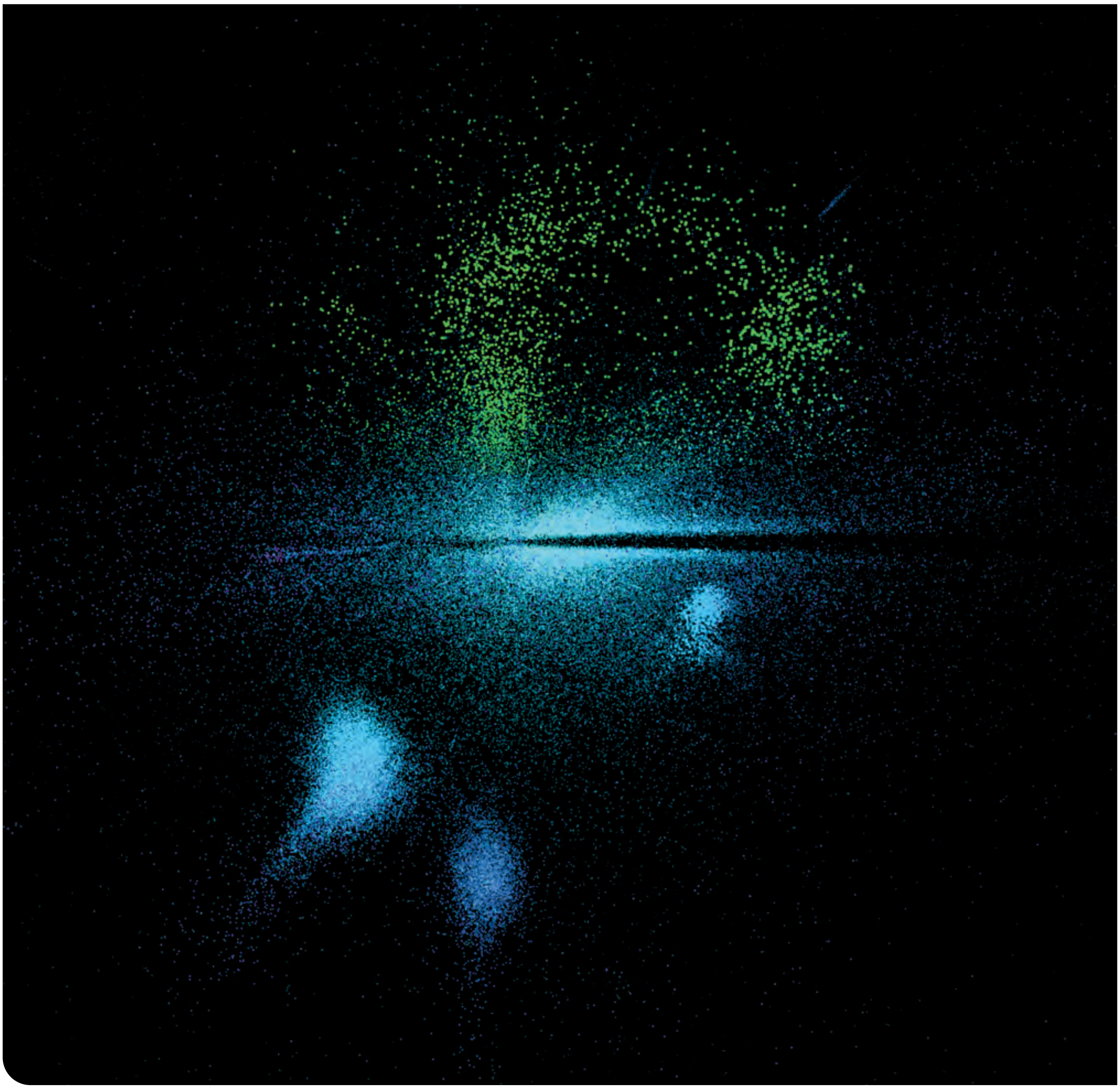
West MJ, et al. (2019) **EUV Observations of the middle corona from the L5 perspective**, AGU, Fall Meeting 2019, abstract #SH11C-3396.

West M, et al. (2019) **The EUV imager on Lagrange**, European Space Weather Week, Liege, Belgium.

Abbreviations

CME	Coronal Mass Ejection
EUV	Extreme Ultra-Violet
LUCI	Lagrange EUV Coronal Imager
S2P	Space Safety Programme

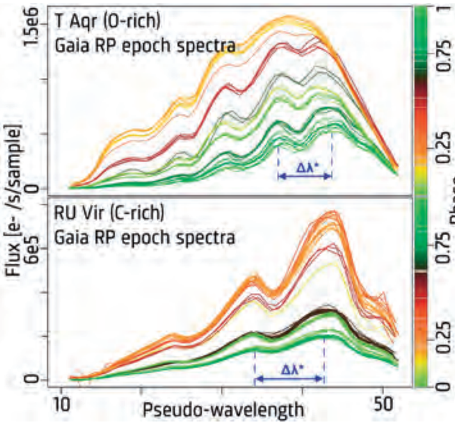
Time-Line	From	To
Planning	Feb. 2018	Feb. 2022
Construction	Mar. 2023	Dec. 2024
Measurement Phase	2026	>2033
Data evaluation	2026	>2033



The Gaia project, next article on page 22: The 3-dimensional view of the 141,000 RR Lyrae stars from the Gaia second Data Release. RR Lyrae stars are standard candles and can be used to derive distances (here used without any interstellar extinction correction). They trace the halo of our Galaxy, the Large and Small Magellanic Clouds (the two lower left clumps), the Sagittarius dwarf galaxy (lower right clump) and the associated Sagittarius stream (in green). We can also see small 'streaks' corresponding to globular clusters. The galactic plane (horizontal) is visible by its lack of detected RR Lyrae stars.

5 Astrophysics

5.1 Gaia – Variability Processing and Analysis



Gaia RP epoch spectra of two Mira stars, an O-rich (top panel) and a C-rich (bottom panel), at various phases of their pulsation cycles (pulsation periods of 203 and 425 days, respectively). The displayed spectra approximately cover the wavelength range from 640 to 1100 nm. Image credit: ESA/Gaia/DPAC, Mowlavi et al., Gaia Image of the Week 15/11/2018 (www.cosmos.esa.int/web/gaia/iow_20181115).

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

In cooperation with
17 Institutes in Europe, USA and Israel (60 people)

Principal Investigator(s)
ESA

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

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

Method
Measurement

Website
www.unige.ch/sciences/astro/variability/en

Purpose of Research

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

One of the duties of the Gaia consortium is to detect and analyse the variable celestial objects. This effort of about 60 people distributed over 17 institutes is coordinated by the University of Geneva with its associated data processing centre. The task is first to statistically describe the time-series of all two billion sources, 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.

Past Achievements and Status

The Gaia spacecraft has been gathering data since summer 2014. Two data releases were made public, in September 2016 and in April 2018. Currently, Gaia is one of the most (if not the most) important multi-epoch astronomical survey, because it provides unprecedented astrometric precision along with a homogeneous whole sky survey with nearly simultaneous measurements in astrometry, photometry, and spectroscopy. The wealth of data and their scientific impact are almost unimaginable and most astronomical fields are/will be affected in one way or another. As an example of this impact, the Gaia second data release of the 2018 summary article is the most cited article in the astrophysics literature published in that year. For the variable objects published in the first data release, we presented a showcase of 3194 variable stars in the direction of the Large Magellanic Cloud. In the second data release, some of the catalogues of variable stars that we published already represent the largest catalogues of the given sub-classes ever published, even though the number of variable stars published (half a million) represents only a small fraction of the variable objects in the sky that is going to be published by our team in the next Gaia data releases. Our Gaia Variability team produced more than 10 articles related to this last release which received in total, several hundred citations. We are currently analysing 260 billion Gaia photometric measurements, preparing the third Gaia data release with 5-10 million variables to be made public, as well as a pencil beam of 2 million time-series in a direction around a region centred on the Andromeda galaxy. The full catalogue of variable stars, a few hundred million, is planned for the fourth data release (2024 at the earliest).

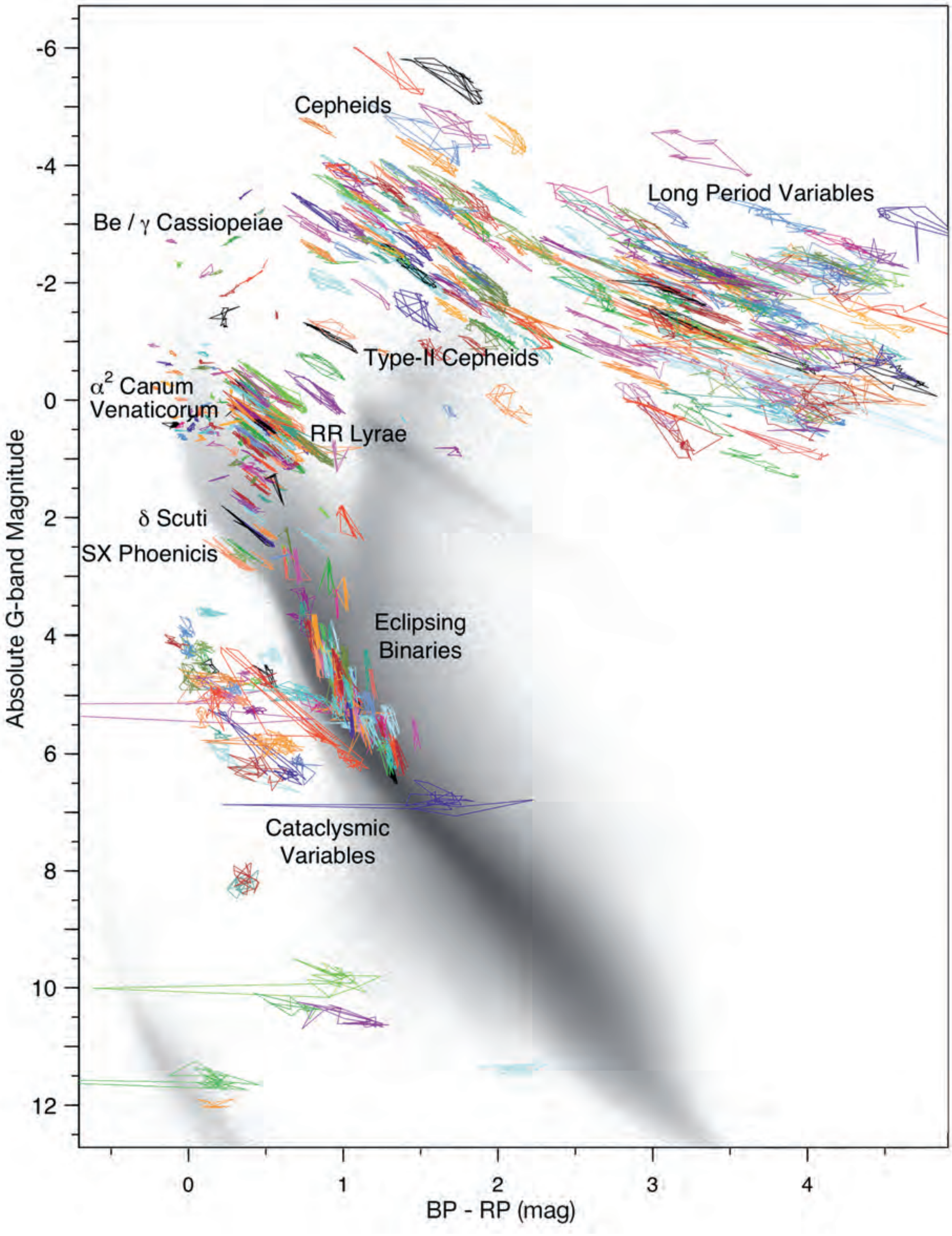
Publications

Brown A, Vallenari A, Prusti T, et al. (2018) **Gaia Data Release 2. Summary of the contents and survey properties**, Gaia Collaboration, A&A 616: 1.

Eyer L, Rimoldini L, Audard M, et al. (2019) **Gaia Data Release 2. Variable stars in the colour-absolute magnitude diagram**, Gaia collaboration, A&A 623: 110.

Holl B., Audard M, Nienartowicz K, et al. (2018) **Gaia Data Release 2. Summary of the variability processing and analysis results**, A&A 618: 30.

Time-Line	From	To
Planning	2006	up to 2027
Construction	cyclic dev.	up to 2026
Measurement Phase	2014	up to 2024
Data Evaluation	cyclic	up to 2027



The motion of individual stars in the Colour-Magnitude Diagram by connecting the measured colour (BP-RP) and absolute magnitude (G) at different observation times. The movement of individual variable stars is shown by lines of different colour, on a backdrop of non-variable stars in grey. This is the first time such a comprehensive plot has been compiled.

5.2 POLAR – Gamma Ray Burst Polarisation

Tiangong-2 ready for launch by a Long March rocket at the Jiuquan Satellite Launch Center, China, on the day of the launch. Image credit: N. Produit.

Institute
Obs. de Genève, Geneva, Switzerland
Dépt. Phys. Nucl. Corp. (DPNC), Univ. Geneva, Geneva, Switzerland
Paul Scherrer Institute (PSI), Villigen, Switzerland

In cooperation with
Inst. High Energy Phys. (IHEP), Beijing, China
Nucl. Res. Inst. Poland (NCBJ), Warsaw, Poland

Principal Investigator(s)
S. Nan Zhang (IHEP)

Mission Manager
N. Produit (Obs. de Genève)

Co-Investigator(s)
N. Produit, X. Wu, M. Kole (DPNC), W. Hajdas (PSI)

Method
Measurement

Research based on existing instruments
POLAR was designed, constructed, qualified, calibrated and operated by a Swiss collab. Launched as part of Tiangong-2, it was destroyed by de-orbiting on 19 July 2019.

Industrial hardware contract(s) to
Art of Technology, Zürich

Website
www.astro.unige.ch/polar/polar.ihep.ac.cn/en

Purpose of Research

POLAR is a compact polarimeter that was launched on 15 September 2016 at 14:04 UTC on the Tiangong-2 Chinese space laboratory. Gamma Ray Bursts (GRBs) are cosmological astronomical events linked with the explosive creation of black holes. Recently, GRBs were connected to gravitational waves.

POLAR is a wide field-of-view Compton polarimeter. It took data in space in science mode for six months and monitored 55 GRBs. Measurements from POLAR have been published in the first large catalogue of GRB polarisation with a controlled systematic error.

Past Achievements and Status

POLAR took more than 3 TB of data during its six months of science activity in space. The data consists of a list of time-tagged energy depositions in one or several of the 1600 plastic scintillator bars. The time accuracy of each event is 62 ms. The absolute time calibration (provided by GPS) was shown to be better than 1 ms by using GRB triangulation and the Crab pulsation phase.

The detector was carefully ground-calibrated and we have demonstrated that this calibration was maintained during the launch and flight.

Measuring polarisation requires a very precise knowledge of the detector performances that we gather by building a very precise Monte Carlo simulation code. This code was certified by comparing data taken with a polarised ground-source of gamma rays. The Monte Carlo simulation was also shown to correctly predict the flight data. We studied in detail the method of polarisation measurement analysis using very advanced Baesian statistical tools. We showed that previous “state of the art” analysis methods were lacking important systematic corrections that could explain the tension seen in the corpus of existing GRB polarisation measurements.

POLAR data was analysed during 2018, 2019 and 2020. The polarisation of a dozen GRBs have been analysed in great detail. POLAR has shown that contrary to previous assumptions, GRBs are overall not strongly polarised. But surprisingly when examining a single pulse, it has been observed that a strong rotational polarisation exists. This rotation averages the polarisation degree to a very low value. This behaviour was not expected and requires a much larger detector to see if this is a general feature of all GRBs.

The detector was also used to study the spectrum and the polarisation of the Crab, and was used to demonstrate the possibilities of pulsar navigation.

The excellent scientific results have convinced the Chinese space authorities to propose to Switzerland that a successor to POLAR is flown on the Chinese space station in 2024. We have accepted this opportunity and an improved detector called POLAR-2 is in the design stage.

Publications

Burgess JM, Kole M, et al. (2019) Astronomy & Astrophysics 627: A105.

Kole M, et al. (2017) Nucl. Instrum. Meth. A 872: 28.

Li HC, et al. (2019) J. High Energy Astrophysics 24: 15-22.

Produit N, et al. (2005) Nucl. Instrum. Meth. A 550: 616.

Produit N, et al. (2018) Nucl. Instrum. Meth. A 877: 259.

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

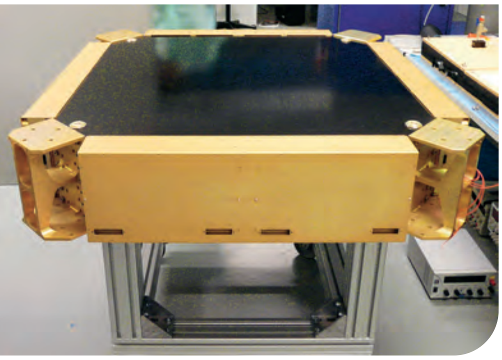
Abbreviations

CSU	Tech. and Engineering Centre for Space Utilization
GRB	Gamma-Ray Bursts
POLAR	POLAR is a compact gamma-ray polarimeter
TG2	The second Chinese space laboratory, Tiangong-2

Time-Line	From	To
Planning	2009	2011
Construction	2012	2014
Qualification	2014	2016
Measurement Phase	2016	2017
Data Evaluation	2017	2020

POLAR Flight Spare on display at the Chinese National Museum in Beijing in front of a life size model of TG2. Merlin Kole and Nicolas Produit can be seen in the picture. Image credit: N. Produit.

5.3 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), Perugia; Bari; Lecce, Italy
Inst. High Energy Phys.(IHEP), Beijing, China
GSI 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
www.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 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 the construction of the STK was completed 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 still 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 four 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.

First results, published in *Nature* (Ambrosi et al., 2017), concerned the most precisely measured CRE spectrum in the multi-TeV range, 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.

The cosmic ray proton spectrum up to 100 TeV energy was recently published in *Science Advances* (An et al., 2019). This measurement (see Figure opposite) revealed, for the first time, direct evidence of spectral softening at 10 TeV, which was previously only hinted at indirectly by other experiments. The DPNC group is a key contributor to this analysis.

The initial operation period of DAMPE was three years, but given the excellent working condition of the detector, and the interesting new spectral features observed in electron and proton fluxes, the mission has been extended for at least three more years, to the end of 2021. The DPNC group is involved in several data analysis projects, including extending the electron flux measurement to 10 TeV, the Helium flux measurement, anisotropy studies and pulse studies.

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

Publications

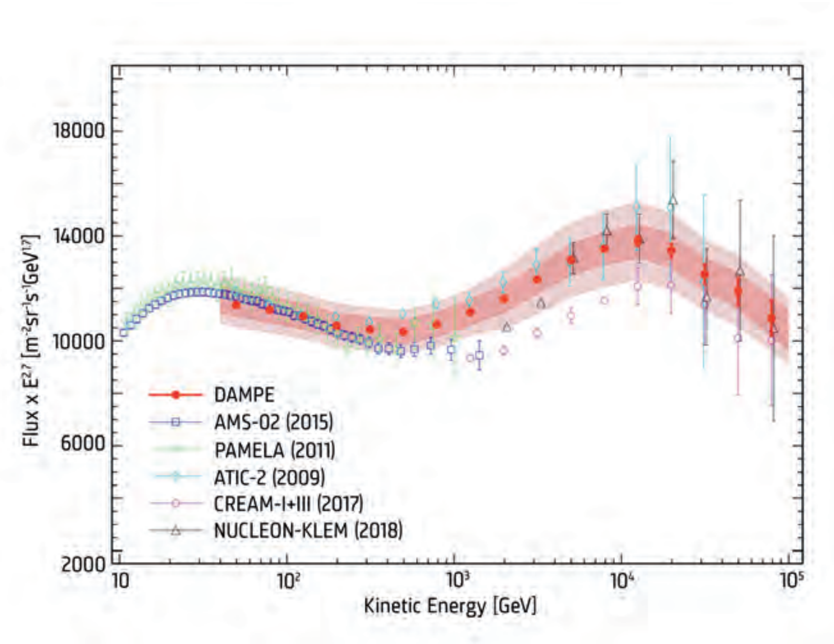
Ambrosi G, et al. (2017) **Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons**, Nature 552: 63.

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.

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

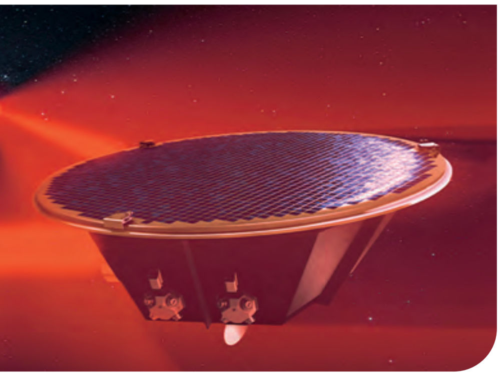
Abbreviations

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



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

5.4 LISA – Gravitational Reference Sensor Front-End Electronics



Artist's impression of a Laser Interferometer Space Antenna (LISA) mission concept spacecraft.

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

In cooperation with
European Space Agency
Univ. Trento, Italy
Albert Einstein Inst.,
Max Planck Inst. 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. Mance (ETH Zurich)
Jan ten Pierick (UNIZH)

Method
Measurement

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

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. LISA builds on the success of LISA Pathfinder (LPF), which recently completed its mission after twenty years of technology development.

The Swiss contribution to LPF consisted of the development of the Inertial Sensor Front-End Electronics (IS FEE), which sensed and controlled the position and the attitude of the test masses with respect to their frame. IS FEE was based on ultra-stable capacitive sensing and electrostatic actuation. The sensing and actuation required nanometer resolution and stability in the low-frequency band from 1 Hz down to 0.1 mHz. The IS FEE was built fully redundant due to its criticality for the mission success.

The LISA mission consists of three identical spacecraft which will form an equilateral triangle in a heliocentric orbit following the Earth and maintaining a mutual spacecraft-to-spacecraft distance of 2.5 million kilometres. The Gravitational Reference Sensor (GRS) is the core of the LISA instrument. It hosts the test masses that are the free-falling reference for the measurement of the gravitational waves.

The LISA GRS FEE is the sensing and control electronics for the GRS. GRS FEE is the Swiss Contribution to LISA. It is based on 100 kHz 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), small actuation forces (several nN), a test mass acquisition/accelerometer mode with "wall-to-wall" sensing (4 mm), and larger (µN) forces. The sensing and actuation function for the LISA GRS requires ultra stable performances 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 in its Phase A (2019-2020). ETH Zurich is establishing the instrument requirement specifications and developing the design concept. The GRS FEE Phase A study is being conducted together with the LISA Instrument and LISA System Phase A studies which have already completed the Mission Consolidation Review (2019) and will end with the Mission Formulation Review in 2021.

The ESA LISA Phase 0 Instrument study was performed from April 2017 until November 2017 focussing on the spacecraft and the payload part of the mission. The Mission Definition Review was completed in November 2017.

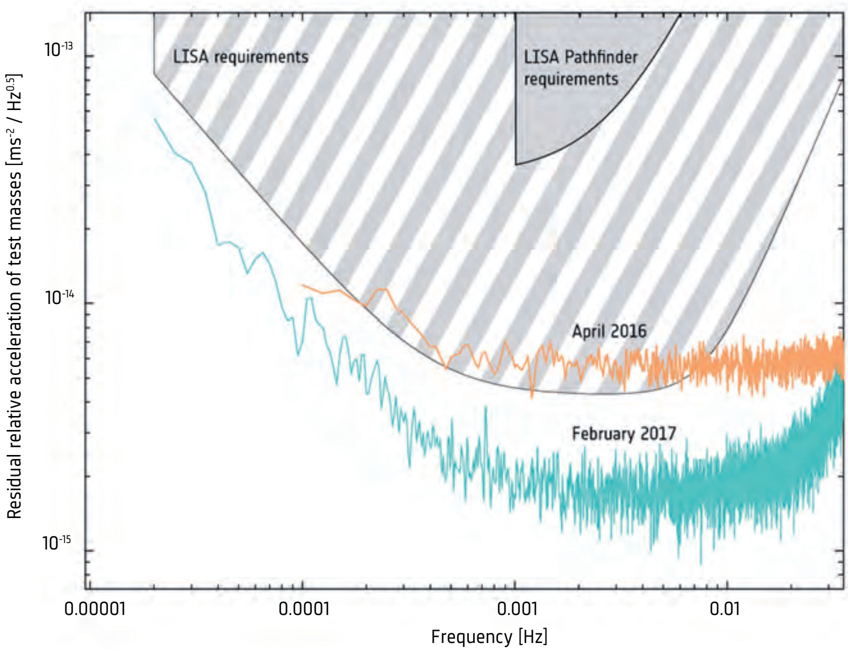
Time-Line	From	To
Planning	2019	2021
Construction	>2021	
Measurement Phase	>2030	
Data evaluation	>2030	

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. (2018) **Beyond the required LISA free-fall performance: New LISA Pathfinder results down to 20 μHz**, Phys. Rev. Lett. 120: 061101.

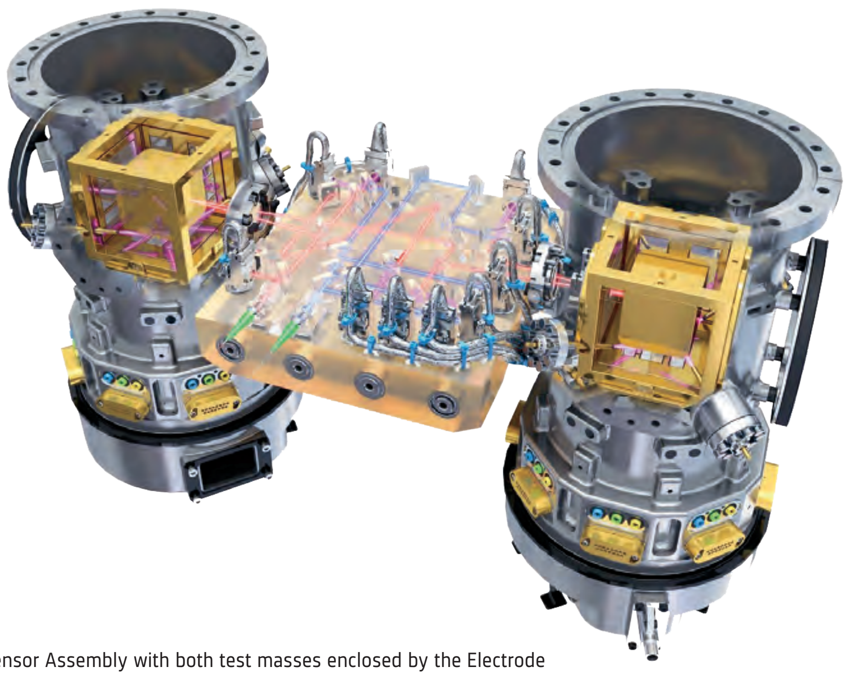
Armano M, et al. (2020) **Analysis of the accuracy of actuation electronics in the laser interferometer space antenna pathfinder, accepted for publication**, Rev. Sci. Instr., 2020.



ASD of parasitic differential acceleration of LPF test masses as a function of the frequency. Source: Phys. Rev. Lett. 120, 061101.

Abbreviations

FEE	Front-End Electronics
GRS	Gravitational Reference Sensor
IS	Inertial Sensor
LISA	Laser Interfer. Space Antenna
LPF	LISA Pathfinder



LPF inertial Sensor Assembly with both test masses enclosed by the Electrode Housings. The optical bench is situated between both test masses.

5.5 ATHENA – The Swiss Contribution

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 (UNIGE)

Method
Measurement

Developments
The X-IFU Filter Wheel mechanism, as well as the corresponding control electronics and filters. Development of the thick filter for soft X-ray suppression for the WFI instrument. Development of data centre activities for the WFI and X-IFU instrument science centres.

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 (covering the agency plans for space exploration in the period 2015-2025). 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 x 2 mosaic of large-area DEPFET (depleted p-channel field-effect transistor) active pixel sensor matrices covering a field-of-view of 40' x 40', together with a single smaller gateable DEPFET sensor matrix optimised for the high count-rate applications and achieving a time resolution of 80 µs. The X-IFU uses Transition Edge Sensors, operated at cryogenic (50 mK) temperatures 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.

The science of ATHENA will fit nicely within the long-established expertise at the UNIGE in the analysis and interpretation of X-ray data on both Galactic and extra-Galactic sources. Consequently, ATHENA has been the top priority of the high-energy group of the Department of Astronomy for about two decades. The group is involved in the science exploitation of several current and future X-ray missions, such as INTEGRAL, XMM-Newton, NuSTAR, HITOMI, XRISM, eXTP, THESEUS, and Strobe-X. Compared to these missions, ATHENA will provide complementary and revolutionary data, exploiting a unique combination of high sensitivity and fine spectral resolution.

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 radioactive 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 X-IFU Filter Wheel development at UNIGE relies heavily on our heritage from the Swiss contribution to the JAXA ASTRO-H/Hitomi and XRISM missions.

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 consolidated its position in both the X-IFU and WFI Instrument Science Centers (ISCs). These centers will cover a number of critical 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.

Past Achievements and Status

The Athena mission has successfully completed its phase A study with the closure of the Mission Formulation Review (MFR) at the end of 2019. A preliminary design of the ATHENA/X-IFU filter wheel was developed by UNIGE during phase A. The ATHENA/X-IFU Filter Wheel will be more than a factor two larger in size than the HITOMI/XRISM filter wheel (710 mm in diameter compared to 300 mm for HITOMI/XRISM) and a factor of three in mass (about 10 kg compared to 3 kg for HITOMI/XRISM).

The increase in size and mass is driven by the uniquely large X-ray telescope onboard ATHENA that will require filters as large as 160 mm in diameter (to be compared with the 80 mm required for HITOMI/XRISM). Phase B1 started at the beginning of 2020 and will last until mid-2021, where the mission adoption is expected pending the success of the System Requirement Review (SRR). Phase B2 will start in 2022 and will be concluded at the end of the same year with the Preliminary Design Review (PDR). The construction of the different instruments and sub-system models will start in 2023, leading to a launch date currently set for mid-2031.

Publications

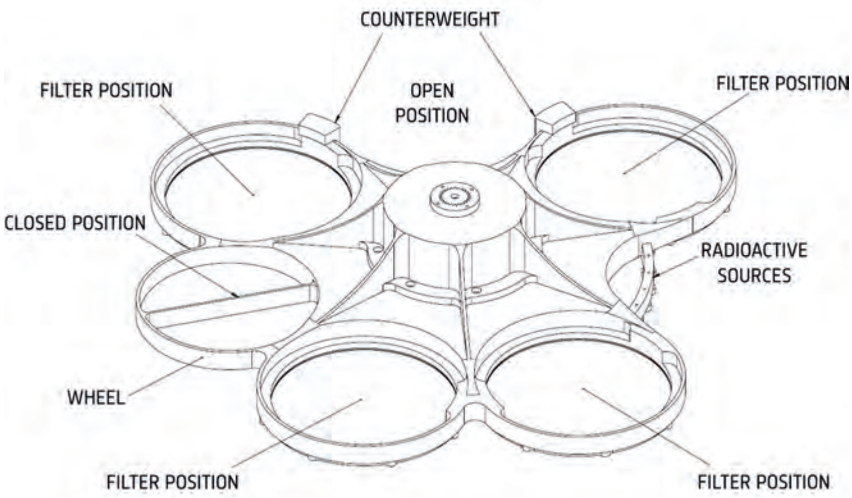
Barret D, et al. (2018) Proc. SPIE 10699: id. 10699G.

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

Abbreviations

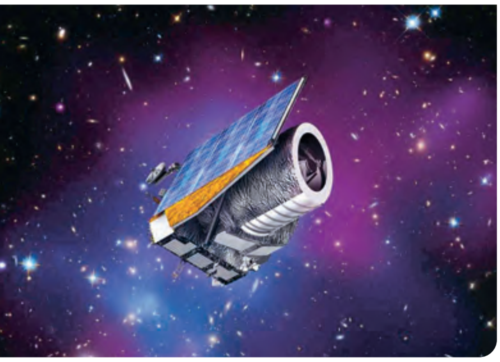
ATHENA	Advanced Telescope for High-Energy Astrophysics
ISC	Instrument Science Centre
JAXA	Japan Aerospace Exploration Agency
WFI	Wide-Field Imager
X-IFU	X-ray Integral FIeld Unit

Time-Line	From	To
Planning	2019	2021
Construction	2022	2031
Measurement Phase	2031	2036
Data evaluation	2031	2041



Current design of the ATHENA/X-IFU Filter Wheel, as developed by UNIGE, at the end of 2019. The wheel hosts seven filter positions (including a position dedicated to the radioactive sources). The large size (710 mm diameter) has necessitated the development of a complex shape, in order to save weight.

5.6 Euclid – The Swiss Contribution



Artist's impression of the Euclid spacecraft. Image credit: ESA/C. Carreau.

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 RSU of the VIS instr. Development of algorithms for photometric redshifts, weak and strong lensing. Development of infrastructure and processing software.

Industrial Hardware Contract to
APCO Technologies SA
(VIS RSU Phase C/D)

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 energy and dark matter, 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 2022.

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 which integrates the data centres distributed in Europe into a uniform processing system.

UNIGE is in charge of the so-called Photometric-Redshift Organisation Unit (OU-PHZ) and leads the development of algorithms and software for the determination of photometric redshifts, which is a central component of one of the main science goals of Euclid, 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 also develops the Readout Shutter Unit (RSU), a cryogenics shutter for the VIS instrument which it has started to design and is now being 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 Qualification Model (QM), Flight Model (FM) and Flight Spare (FS) were manufactured by APCO Technologies, under the lead of UNIGE. The FM successfully passed all acceptance campaign tests and was delivered to Airbus for assembly on the spacecraft and to commence system level tests (pending the closure of a Non-Conformance Report.

On the ground-segment side, Euclid is currently undergoing a series of scientific challenges with increasing complexity and increasing representativity of the Euclid processing. The Scientific Challenge 4/5/6 has been completed, and served as the basis for the Design Review which took place at the end of last year. The challenges involved all the Euclid science data centres, including the Swiss Science Data Centre at UNIGE.

The Infrastructure Abstraction Layer developed at FHNW played an essential role in the distribution and processing of the pipelines. Scientific Challenge 5 included the first version of the photometric pipeline developed by OU-PHZ at UNIGE.

Further developments of the Scientific Challenges will include more refinements of the Euclid pipeline, in particular the photometric-redshift pipeline, and the first version of the strong-lens detection pipeline led by EPFL. These challenges will use more and more realistic end-to-end simulations including mock galaxy catalogues developed by the Cosmo-Sim-SWG led by UNIZH.

Publications

Cropper M, et al. (2016) **VIS: The visible imager for Euclid**, Proc. SPIE, 9904, Article ID. 99040Q.

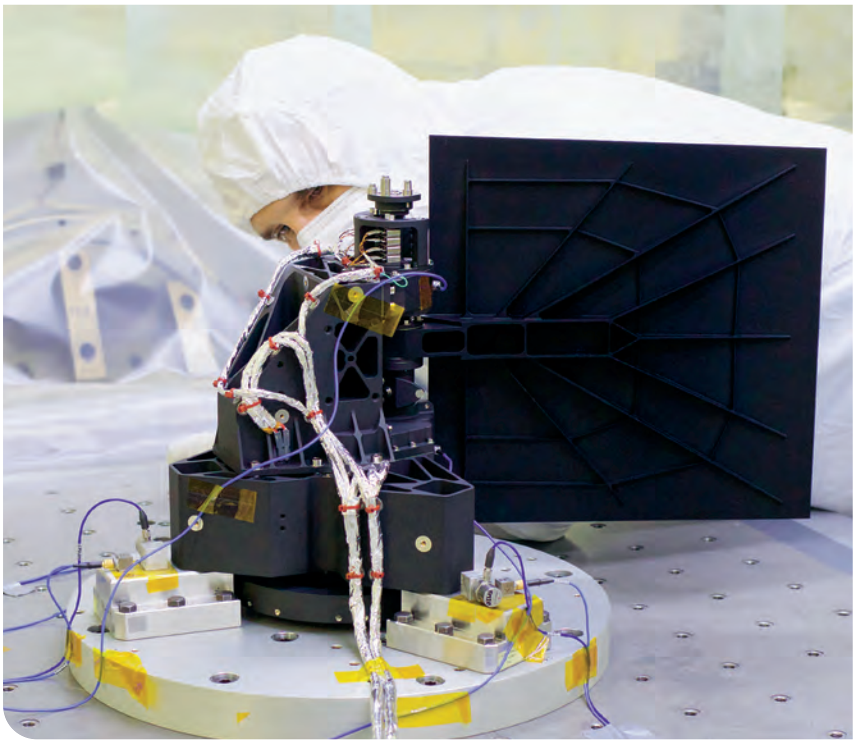
Laureijs R, et al. (2011) **Euclid Definition Study Report**, Euclid Red Book, ESA/SRE(2011)12, eprint arXiv: 1110.3193.

Potter D, et al. (2017) **PKDGRAV3**, Comp. Astrophys. Cosmol. 4: 2, doi:10.1186/s40668-017-0021-1

Abbreviations

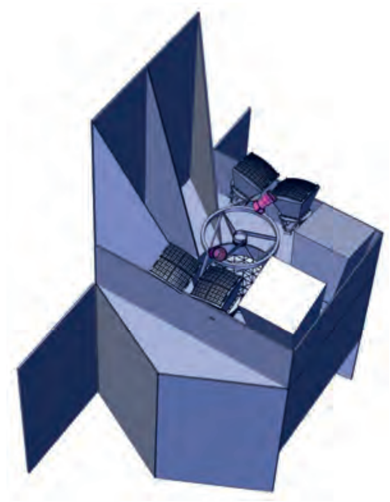
NISP Near-Infrared Spectrometer Photometer instrument
OU-PHZ Photometric-Redshift Organisation Unit
RSU Read-out Shutter Unit
SWG Science Working Group
VIS VISible imager

Time-Line	From	To
Planning		2012
Construction	2012	2020 (HW)/ 2020 (SW)
Measurement Phase	2022	2028
Data evaluation	2022	2031



The VIS RSU Breadboard Model. Image credit: APCO Technologies SA.

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



THESEUS mission concept after the Concurrent Design Facility study. Image credit: ESA CDF.

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)
Enrico Bozzo (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.

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 next decade.

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 an all-sky X-ray monitoring of extraordinary grasp and sensitivity carried out at high cadence. THESEUS will be able to locate and identify the electromagnetic counterparts to sources of gravitational radiation and neutrinos which will be routinely detected in the late '20s / early '30s by next generation facilities such as aLIGO/aVirgo, LISA, the Einstein Telescope, and Km3NET. In addition, the provision of a high cadence soft X-ray monitoring capability in the 2020s 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, JWST, 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 up to 4 sr FOV, a source location accuracy of ~10 arcmin in 2-150 keV and an unprecedented broad energy band.

The Swiss THESEUS team, based at the Department of Astronomy of the University of Geneva, is part of the coordination team over-viewing all engineering and scientific activities around THESEUS. The University of Geneva is hosting part of the mission project office and the mission website. The other responsibilities of the Swiss team cover the development of the cryo filter-wheel mechanism mounted in the IRT and the coordination of the mission ground-segment design.

Time-Line	From	To
Planning	Jul. 2018	Jun. 2021
Construction	Oct. 2021	2031
Measurement Phase	Jan. 2032	Jan. 2035
Data evaluation	2032	2040

Past Achievements and Status

THESEUS is one of the three M5 mission candidates currently undergoing a competitive phase A to be concluded in mid-2021, with the down-selection of a single mission (during the Mission Selection Review) to be implemented and launched in 2032. THESEUS has so far successfully completed its phase 0 with the Mission Formulation Review in December 2018 and it is now undergoing a second review, the Mission Consolidation Review (MCR), to be completed by April 2020. All requested documentation for the MCR has been delivered by the THESEUS teams to ESA under the coordination of the Swiss team and the project office. No criticality has been raised and the mission has so far achieved a solid baseline configuration, allowing its planned science objective to be met with a large margin.

Publications

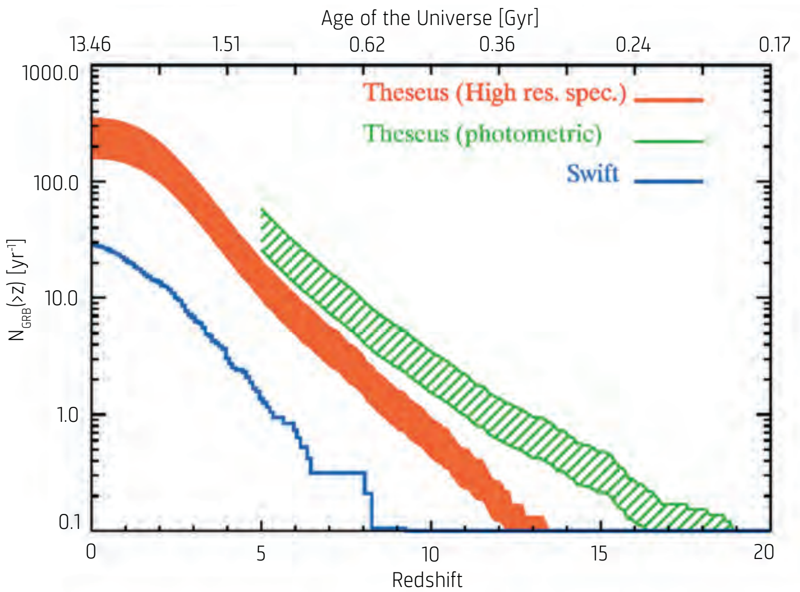
Amati L, et al. (2017) **The THESEUS Workshop** 2017, arXiv:1802.01673.

Amati L, et al. (2018) Adv. Space Res. 62: 191.

Stratta G, et al. (2018) Adv. Space Res. 62: 662.

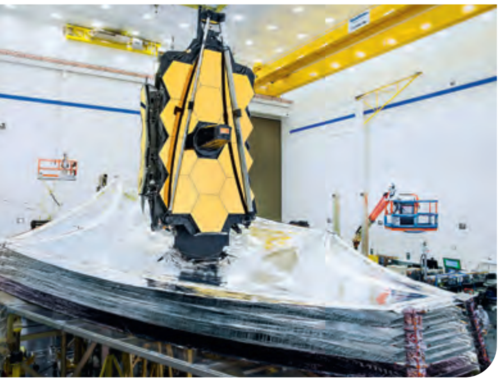
Abbreviations

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



Cumulative distribution of GRBs as a function of the redshift as obtained by the THESEUS predecessor Swift in 10 yrs (blue line) and the prediction for THESEUS (including uncertainties on the GRB population models) in just 3 yrs of operation, for redshifts obtained either from high-resolution spectroscopy (red band) or low-resolution spectrophotometry (green) band.

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



The James Webb Space Telescope. Image credit: Chris Gunn/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

Website
www.jwst.nasa.gov

Purpose of Research

The James Webb Space Telescope (JWST) will be the next big space telescope and the successor of the famous Hubble Space Telescope. JWST has a 6.5m deployable primary mirror that will passively cool to 50 K behind a very large sun-shield in order to provide unprecedented sensitivity for the wavelength range between 0.6 and 28 μm. 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 mid-infrared range between 5 and 28 μm. MIRI provides imaging, coronagraphy, long-slit low-resolution spectroscopy and mid-resolution integral field spectroscopy.

The JWST will be exceptionally powerful for the study of the end of the "Dark Ages" of the universe by detecting first light objects. It will detect and observe the very first galaxies seen at $z>10$ and their evolution until present. In addition, it will study complex processes in star and planet formation and provide indicators for the search for 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 2011. The instrument was then formally delivered to NASA in 2012. Thereafter, 3 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 worlds largest cryogenic facility.

JWST is now fully assembled after the telescope was combined with the sunshield and the space bus. The last tests have been conducted at the time of writing, and shipment to French Guyana is planned for end 2020/early 2021.

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

ISIM	Integrated Science Instruments Module
MIRI	Mid-Infrared Instrument

Time-Line	From	To
Planning	2001	2021
Construction	2006	2021
Measurement Phase	2021	2031
Data evaluation	2021	2031

5.9 SPICA – The Swiss Participation in the Infrared Observatory

Purpose of Research

SPICA is an infrared space observatory with a 2.5-m, actively cooled telescope (below 8K). It will cover the 10-350 µm range, capable of making deep and wide surveys to unprecedented spectroscopic depths. SPICA will carry SAFARI, an infrared spectrometer (34-230 µm) at R≈250-11000, B-BOP, an imaging polarimeter at 110, 220, and 350 µm, and SMI, a Japanese instrument, that will provide imaging spectroscopy at R≈100 and full-band slit-fed spectroscopy at R≈100-2,000 (17-36 µm), and R≈29,000 (9.6-18 µm). SPICA will provide spectroscopic capabilities at a high sensitivity of 2-15E-20 Wm^{-2} (5 sigma/1hr), about two orders of magnitude deeper than Herschel. The three main goals of SPICA are:

- To reveal the physical processes that govern the formation and evolution of galaxies and black holes over time.
- To resolve for the first time the far-infrared polarisation, and hence the magnetic field, of star forming regions in the Milky Way.
- To understand the formation and evolution of planetary systems.

While the SPICA payload is primarily driven by these top-level science goals, it is designed to operate as an observatory. UNIGE aims to lead the development and operations of the SAFARI Instr. Control Center (ICC). The ICCs will maintain instrument commands and develop the relevant data reduction software. The ICCs monitor the instrument health, conduct flight calibration and maintain the data reduction software. UNIGE will also build the housing structures for two of the SAFARI grating modules and the grating module thermal/mechanical suspensions for the focal plane unit.

Past Achievements and Status

SPICA was proposed as an ESA-led mission under Cosmic Vision M5. It was selected in May 2018 for Phase A with a foreseen launch in 2032. JAXA will assume a partner Space Agency role. UNIGE participates in the SPICA Science Ground Segment working group that defines the way data will be transmitted, received, processed and delivered during operations. As lead institute for the SAFARI ICC, UNIGE is in charge of providing the input from the SAFARI ICC to the Science Operations Assumption Document to be delivered for the Mission Selection Review planned in April 2021. In addition, the SAFARI ICC delivered its organisation and management plan. UNIGE is also designing the grating module housing structure to fit the requirements set by the SAFARI system team (e.g., size, mass, resonance frequency, material). The ICC and grating module documents and study were provided at the end of March for the Mission Consolidation Review, an intermediate step before the final selection. Work in 2020 will focus on the consolidation of the instrument design, in particular taking into account the new SPICA vertical configuration decided in January 2020.

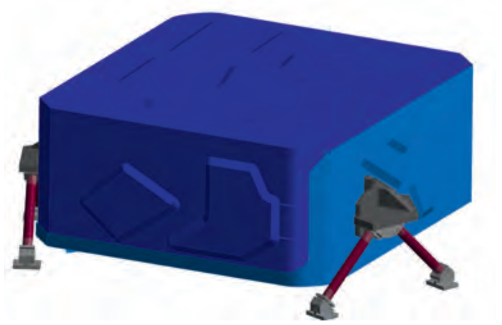
Publications

Jellema W, et al. (2017) Proc. SPIE 10563: id. 105631K 8pp.

Roelfsema PR, et al. (2014) Proc. SPIE 9143: id. 91431K, 11pp.

Roelfsema PR, et al. (2018) PASA 35: 30.

Time-Line	From	To
Planning	2019	2023
Construction	2024	2032
Measurement Phase	2032	2035



SAFARI grating module housing with the magnetic shielding and the thermo-mechanical suspensions.

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)

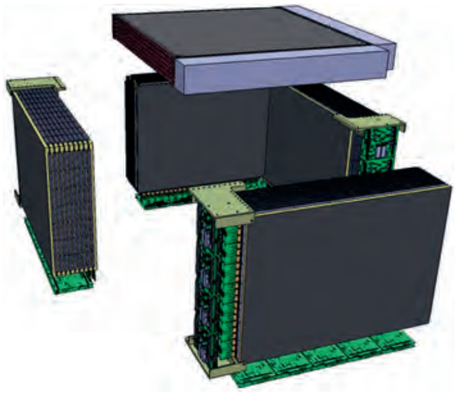
Co-Investigator(s)
M. Audard, L. Genolet, S. Paltani (UNIGE)

Method
Measurement

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

Website
www.spica-mission.org

5.10 HERD – High Energy Radiation Detection Facility



Exploded view of the Fiber Tracker (FIT) for the HERD mission.

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

In cooperation with
École Poly. Fédérale de Lausanne (EPFL), Lausanne, Switzerland
Inst. High Energy Phys. (IHEP), Beijing, China
Istit. Naz. di Fisica Nucleare (INFN), Perugia, Italy
Inst. Cosmos Sci. Univ. Barcelona (ICCUB) Barcelona, Spain

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

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

Method
Measurement

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

Purpose of Research

HERD is a flagship scientific experiment on board the China Space Station (CSS), which will be constructed in 2020-2022. HERD is expected to be launched around 2025. 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 m^{2}sr to be reached.

The HERD detector consists of a central calorimeter, made of ~7500 lutetium-yttrium oxyorthosilicate (LYSO) crystal cubes (3x3x3 cm^3), 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

A HERD Joint Working Team (JWT) representing more than 10 institutes from China, Italy, Switzerland, Spain and Germany was set up in 2017 to coordinate Phase A studies. In April 2018, the JWT submitted the HERD proposal to a review jointly organised by the Chinese Manned Space Agency (CMSA) and the Italian Space Agency (ASI), which resulted in a full endorsement of the mission by an international review committee in May 2018. The DPNC group started the Phase B project "Design and Development of the HERD Scintillating Fiber Tracker (HERD FIT)" in 2018, supported financially by the Swiss Space Office within the ESA PRODEX programme. The project is currently in its final phase.

FIT is made of fiber mats, 6-fiber layers thick and 97.83 mm wide, each read out by 3 MPPC-128 silicon photomultiplier arrays. Two types of mat are needed: a long one (100 cm), and a short one (70 cm). The baseline layout has 5 double (X-Y) tracking layers on the top, and 9 double layers on the side. The front-end readout Application-Specific Integrated Circuit (ASIC) is being designed by ICCUB. All technical aspects to build a FIT demonstrator have been solved. Test results with particle beams at CERN show that the FIT detectors have a very good performance, compatible with the requirement of the HERD particle tracker. In Dec. 2019, the HERD collaboration adopted the fiber tracker technology as the only tracker baseline 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. (2019) Proc. ICRC2019, https://pos.sissa.it/358/122/

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

Time-Line	From	To
Planning	2012	2020
Construction	2021	2025
Measurement Phase	2025	2035
Data Evaluation	2025	>2035

5.11 XRISM – The Swiss Contribution to the X-Ray Imaging Spectroscopy Mission

Purpose of Research

The X-Ray Imaging Spectroscopy Mission (XRISM, formerly XARM) is a mission of the Japan Aerospace Exploration Agency (JAXA), and is 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 X-ray astrophysics, between the current generation of telescopes and ATHENA, ESA's future Large Mission dedicated to the study of the hot and energetic Universe. UNIGE participated in the Hitomi mission with the Dutch space research institute, SRON, by developing a filter wheel for the Soft X-ray Spectrometer (SXS). The Swiss contribution to XRISM consists of a rebuild of this sub-system.

Resolve uses a cryogenic silicon bolometer working at 50 mK, providing outstanding energy resolution (about 5 eV) in the 0.3-10 keV energy range, with imaging capabilities and high throughput. The purpose of the filter wheel is to optimise the science observations by reducing the X-ray count rate or the optical load on the detector, and to protect the detector from micro-meteorites. It also supports and commands active X-ray calibration sources provided by SRON and is assembled on top of the filter wheel.

Past Achievements and Status

Despite its extremely short life, Hitomi was incredibly successful thanks to its new-generation SXS instrument. A single observation of the Perseus galaxy cluster resulted in several important results, including two major discoveries published in the journal *Nature* related to the direct measurement of turbulent motion in the intra-cluster gas, and to the origin of metals in this gas. These 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 onboard XRISM was performed by industry, SYDERAL SWISS SA and RUAG Space AG, respectively.

The program has been successfully completed, and the sub-systems have been delivered to SRON and JAXA.

Publications

Takahashi T, et al. (2016) **The ASTRO-H (Hitomi) X-ray astronomy satellite**, Proc. SPIE, 9905, id. 99050U.

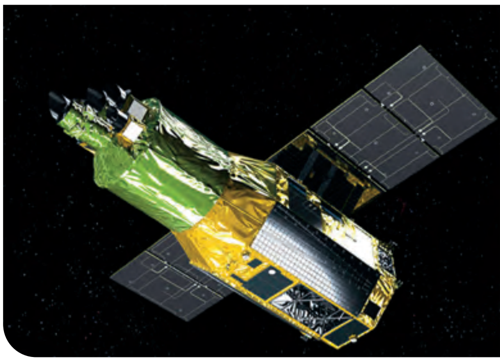
The Hitomi Collaboration (2016) **The quiescent intracluster medium in the core of the Perseus cluster**, Nature 535: 117.

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

Abbreviations

FWE	Filter Wheel Electronics
FWM	Filter Wheel Mechanism
SXS	Soft X-ray Spectrometer

Time-Line	From	To
Planning	2017	2017
Construction	2018	2019
Measurement Phase	2021	2026
Data evaluation	2021	2031



3D rendering 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.

Website
www.astro.unige.ch/xrism

5.12 eXTP – The Enhanced X-Ray Timing and Polarimetry Mission

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)
Stephane Paltani (UNIGE)
Enrico 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 m^2 and 0.6 m^2 at 2 keV and 6 keV, respectively, equipped with Silicon Drift Detectors (SDDs) offering <180 eV spectral resolution.
– The Large Area Detector (LAD): a deployable set of 640 SDDs, with a total effective area of ~3.4 m^2, at 6-10 keV, and spectral resolution <250 eV.
– The Polarimetry Focussing Array (PFA): a set of two X-ray telescopes, with a total effective area of 250 cm^2 at 2 keV, equipped with imaging gas pixel photoelectric polarimeters.
– The Wide-Field Monitor (WFM): a set of three coded mask wide-field units, equipped with position-sensitive SDDs, each covering a 90° x 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, has been 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 from the DPNC and Astronomy departments of the University of Geneva. The DPNC is leading the design of the front-end electronics for the LAD instrument, together with the chain of assembly definition of the front-end electronics with the SDD detectors and the Application-Specific Integrated Circuits (ASIC). The Dept. Astronomy is involved in the design of the science ground segment of the mission.

Past Achievements and Status

The eXTP mission has been undergoing phase B, both in China and Europe, since the start of 2020. The most important interfaces between the payload elements and the spacecraft have been fixed. The status of the European payload element development has been reviewed by a commission of experts organised by ESA, and successfully passed this review in late 2019 before entering phase B. The launch is expected in 2027.

Publications

Zhang S, et al. (2019) Sci. China Phys., Mech. Astron. 62: 29502.

Time-Line	From	To
Planning	Jan. 2017	Dec. 2021
Construction	Jan. 2022	Dec. 2026
Measurement Phase	Jan. 2027	Dec. 2031
Data Evaluation	Jan. 2027	Dec. 2035

5.13 PAN – Penetrating Particle Analyser

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, penetrating particles cannot be shielded effectively. PAN can monitor the flux and composition of these particles precisely and continuously, thus providing real-time radiation hazard warning and long-term radiation health risk for human space travellers. Once developed, PAN can become a standard device for deep space human bases and for deep space exploration and commercial spacecrafts, or as part of a space weather advance warning system permanently deployed in space.

Past Achievements and Status

Particles with energies above 100 MeV/n are highly penetrating, thus the only viable detection technique is with a magnetic spectrometer. PAN aims to fill the current observational gap in deep space radiation monitoring, proposing a modular spectrometer suitable for long-distance missions. The PAN project addresses this vision with several advanced technologies:

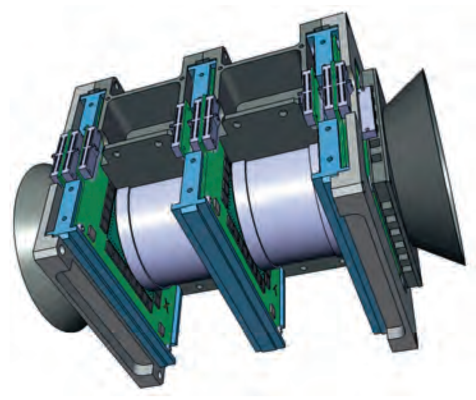
- Fine pitch (25 µm) and thin (150 µm) silicon strip detectors read-out by low noise ASICs, to reach a position resolution of 2 µm.
- Low mass magnetic spectrometer instrumented with a tracker using the aforementioned thin silicon detectors to reach unprecedented energy resolution for energetic particles in the 100 MeV/n - 5 GeV/n range in deep space.
- High-rate detection technology using low-power hybrid active pixel detectors, allowing energetic particles during even the strongest solar events to be measured.
- Fast Time-Of-Flight detector based on plastic scintillator with silicon photomultiplier readout, for both timing and charge measurements.

PAN was presented at both the ESA and NASA science workshops for the Lunar Gateway. Currently, it is 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 Tech. Univ. and CERN.

Publications

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

Time-Line	From	To
Planning	2018	2019
Construction	2020	2022



Sketch of the Mini.PAN instrument.

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

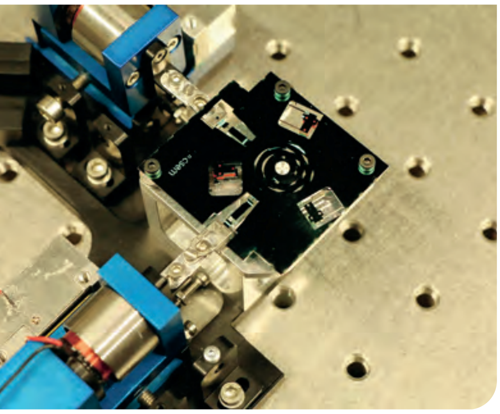
In cooperation with
Istit. Naz. di Fisica Nucleare (INFN), Perugia, Italy
Czech Technical Univ. of Prague, Prague, Czech Republic
CERN, Switzerland

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

Method
Measurement

Website
www.pan-space.eu

5.14 KLPVE – Extreme Universe Space Observatory (K-EUSO)



MEMS mechanism together with the supporting silicon structures that allow the inner mirror to quickly tilt by large angles. Photo taken during the MEMS mirror assembly at CSEM. Image credit: CSEM.

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

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

Principal Investigator(s)
M. I. Panasyuk (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 to the mission science ground segment, and to the mission project office.

Industrial hardware contract(s) to
THALES Switzerland

Website
www.isdc.unige.ch/jemeuso

Purpose of Research

The KLPVE, the Extreme Universe Space Observatory (K-EUSO), is a project to install a large, 2.5 m aperture, wide field-of-view, nadir-looking UV telescope on the Russian segment of the 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, whiuch develop over very short time-scales. of microseconds.

K-EUSO will use the Earth's atmosphere as a giant high-energy particle detector which will need to be calibrated. Such calibration will be done with a dedicated atmospheric monitoring system which will include a novel lidar and infrared camera (IRCAM). The novelty of the lidar will be its capability to provide a 3D picture of distribution and optical transmission properties of clouds anywhere within a 40° wide field-of-view of the K-EUSO telescope. This will be done using a dedicated Laser Pointing System (LPS) developed under Swiss leadership.

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 including a mechanical envelope hosting a functional laser and all the control electronics. The goal of phase B2 is to produce a working version of the concept design by the end of 2020 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 core part of the mechanism has been vibrated and tested to verify its compliance against the Laser Induced Contamination (LIC) and Laser Induced Damage (LID) issues. The control electronics boards have been designed and produced, and it is expected that performance tests of the unit will be carried out in late 2020.

Past Achievements and Status

The mission has been developed by an international consortium of institutions (Joint Experiments and Missions EUSO, JEM-EUSO) led by the Skobeltsyn Inst. Nuclear Physics, Moscow State Univ. (SINP MSU), RosCosmos, the Russian Space Agency, and the Energia company, responsible for the ISS operations. The project is included in the Russian Long-term and Stage programmes of applied scientific research and space experiments on the ISS, with a foreseen launch date of 2023-2024. 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, to be launched in 2022-2023 by NASA.

Publications

Adams J, et al. (2015) **The atmospheric monitoring system of JEM-EUSO instrument**, Exp. Astron. 2015: 40, 45.

Adams J, et al. (2015) **The JEM-EUSO mission: An introduction**, Exp. Astron. 2015: 40, 3.

Time-Line	From	To
Planning	2010	2020
Construction	2021	2023
Measurement Phase	2024	2028
Data evaluation	2024	2030

5.15 PLATO – The Mechanical Structure of the Telescope Optical Unit

Purpose of Research

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

Past Achievements and Status

After successful adoption in June 2017, the development of ESA's PLATO mission began with a launch planned for December 2026. The PLATO payload, which encompasses a total of 26 cameras, will analyse the stability of the photometric signal of stars to detect Earth-like planets in an unprecedented field-of-view of 2200 deg^2.

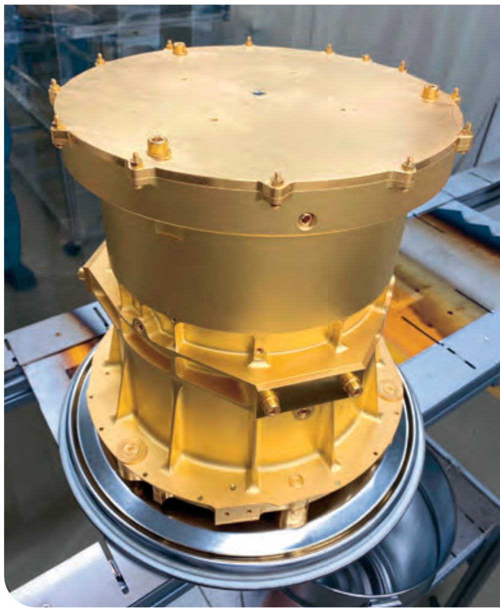
The requirement of photometric stability is a key technical challenge. UNIBE is responsible for the design and manufacturing of the telescope and optical mounting structure, as well as key elements for the stability of the observation with outstanding structural thermo-optical performance. The involvement of UNIBE in PLATO is mainly devoted to designing a stable structure and optical mounts, which are capable of withstanding the launch and space environment with a budget of micrometer stability. The engineering of the telescope's opto-mechanical groups were fully qualified in February 2020.

The concept design and detailed definition of the telescope structural parts were realised at UNIBE while the manufacturing was subcontracted to a cluster of selected partners from the Swiss and German industries. Three concept models (breadboard prototype) were built and successfully tested in 2019. Production of the STM and EM began in parallel and is nearing completion. They will be used for the mechanical, thermal, functional and performance qualification of the PLATO camera system. As part of the validation campaign of the STM camera model, the Telescope Optical Unit (TOU) is being constructed at UNIBE. Major milestones include:
- Q1/Q2 2018: SC/Payload Co-Engineering, System SRR
- Q3/Q4 2018: Payload and S/S PDR, S/C SRR
- Q1/Q2 2019: TOU S/S PDRs, DMBB (Development Breadboard) Manufacturing
- Q1/Q2 2020: TOU S/S PDRs close-out, DMBB Test Campaigns, CAM STM/EM

Publications

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

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



From concept to reality: The TOU tube (in process Model), one of the structural parts of the PLATO telescope, designed and produced under the responsibility of UNIBE.

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

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

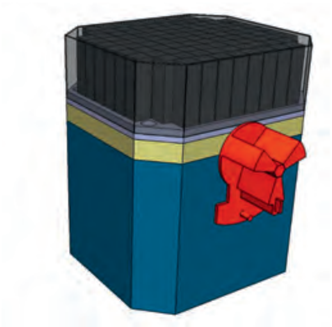
Swiss Principal Investigator(s)
W. Benz (UNIBE)

Method
Measurement

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

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

5.16 POLAR-2 – The Follow-up to POLAR



Sketch of the POLAR-2 instrument.

Institute
Dépt. Phys. Nucl. Corp. (DPNC), 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 (DPNC)

Method
Measurement

Development & construction of instruments
POLAR-2 will be more sensitive than POLAR and will study the polarisation of transient events in gamma-rays.

Website
www.unige.ch/dpnc/index.php?cID=888

Purpose of Research

The POLAR-2 project is a follow-up of the successful POLAR project which collected data during 6 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.

The first results of POLAR were recently published in the *Nature Astronomy* journal, which indicate 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 better precision are required in the future. Furthermore, 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 both providing high precision polarisation measurements as well as detecting very weak GRBs.

An international collaboration, led by the DPNC group and consisting of leading members of the POLAR collaboration and new members from the Max Planck Institute for Extraterrestrial Physics (MPE), proposed the POLAR-2 instrument with the required capabilities based on recent advances in the field. It is foreseen that POLAR-2 will answer several fundamental questions regarding the origin of GRBs by performing polarisation measurements during two years of operation. 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

A proposal regarding the POLAR-2 instrument was submitted in 2018 for the Call for Experiments on board the China Space Station (CSS) issued by the UN Office for Outer Space Affairs (UNOOSA) and China's Manned Space Agency (CMSA), and was selected in June for implementation. 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. In the current plan, POLAR-2 will be launched to the CSS in 2024.

Publications

Burgess JM, Kole M, et al. (2019) Astronomy & Astrophysics 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

CMSA	China's Manned Space Agency
CSS	Chinese Space Station
GRB	Gamma-Ray Bursts
UNOOSA	UN Office for Outer Space Affairs

Time-Line	From	To
Planning	2018	2019
Construction	2020	2024
Measurement Phase	2024	>2026
Data Evaluation	2024	>2026

5.17 LIFE – Large Interferometer For Exoplanets

Purpose of Research

LIFE (Large Interferometer For Exoplanets) is a project initiated in 2017 and officially kicked-off in 2018 to develop the science, technology and a roadmap for an ambitious space mission that will allow humankind, for the first time, to detect and characterise the atmospheres of dozens of warm, terrestrial extrasolar planets.

Thanks to NASA's Kepler mission and dedicated, long-term exoplanet searches from the ground, we know that rocky exoplanets are ubiquitous in the Milky Way and most likely also in the immediate solar neighbourhood.

Detecting the nearest planets, understanding the (atmospheric) diversity of other worlds and searching for indications of habitability and biological activity is a cornerstone of 21st century astrophysics and will provide us with a new perspective on our place in this vast Cosmos.

Past Achievements and Status

After an official kick-off meeting in 2018, LIFE is currently in a first study phase.

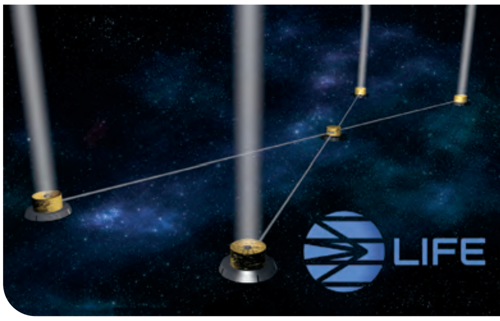
The main activities in this phase include:
- Community building by generating interest in the science and technology development and expanding the team of collaborators.
- Formulating a first set of clear science objectives for the mission.
- Deriving a first set of major science requirements based on the science objectives.
- Assessing the current status and maturity of key technologies required for the mission and drafting a technology development roadmap.
- Inititating a new laboratory experiment at ETH Zurich to demonstrate the nulling technique under cryogenic conditions.
- Seeking funding opportunities for technical as well as scientific work which are related to the LIFE project.

Publications

Quanz SP, Kammerer J, Defrère D, Absil O, Glauser AM, Kitzmann D (2018) **Exoplanet science with a space-based mid-infrared nulling interferometer**, SPIE, 10701, 107011I

Abbreviations

LIFE	Large Interferometer For Exoplanets



Artist's impression of a possible concept for the Large Interferometer For Exoplanets (LIFE) mission.

Institute
ETH Zurich, Zurich
Switzerland

In cooperation with
LIFE Consortium

Principal/Swiss Investigator(s)
S. Quanz (ETH Zurich)

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

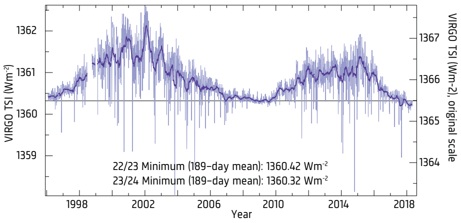
Method
Measurement

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

Website
www.life-space-mission.com

6 Solar Physics

6.1 VIRGO – Variability of Irradiance and Global Oscillations



The latest version of the manually de-trended Total Solar Irradiance (TSI) time-series.

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 data base 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, shown in the above figure. A new method for correcting sensor degradation based on machine learning algorithms is currently being tested by the ETH Zurich. The figure below illustrates the corrected time-series. Of particular interest is the long-term trend of the TSI. The current version shows only a minimal difference between the two solar cycles with minima in 1996, 2009 and 2018. The new version indicates a slight decrease over the 24 years.

Publications

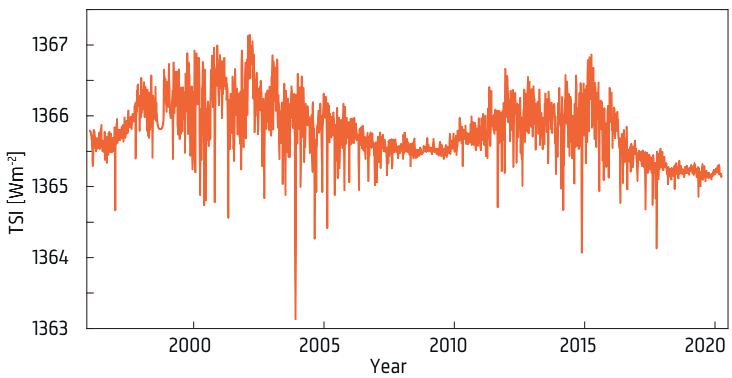
Amazo-Gómez EM, et al. (2020) **Rotation periods from the inflection point in the power spectrum of stellar brightness variations: II. The Sun**, arXiv:2002.03455

Jain K, Tripathy SC, Hill F (2018) **The Sun's seismic radius as measured from the fundamental modes of oscillations and its implications for the TSI variations**, ApJ 859: L9, doi:10.3847/2041-8213/aac327

Abbreviations

SoHO	Solar and Heliospheric Observatory
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradiance and Gravity Oscillations

Time-Line	From	To
Measurement Phase	1996	ongoing
Data evaluation	1996	ongoing



First draft version of the VIRGO TSI time-series detrended with the machine learning algorithm developed by the ETH Zurich.

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/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)
B. N. Andersen (NSC, Norway)

Method
Measurement

Research based on existing instruments
VIRGO experiment on the SoHO spacecraft

Website
www.pmodwrc.ch

6.2 NuSTAR – Probing Solar X-ray Nanoflares

Purpose of Research

The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA Small Explorer satellite using true focussing optics and pixellated X-ray detectors to achieve unprecedented sensitivity in the medium-to-hard X-ray band (2-80 keV). While NuSTAR is an astrophysics mission, it occasionally also points at the Sun.

NuSTAR is 200 times more sensitive than RHESSI, the current state-of-the-art satellite for solar hard X-ray studies. With the extraordinary increase in sensitivity provided by NuSTAR, we will be able to test the so-called "nanoflare heating" theory predicting that many tiny explosions seen in X-rays provide enough energy to keep the solar atmosphere at its extraordinary hot temperature in the million degree range.

Past Achievements and Status

NuSTAR was successfully launched in June 2012. First solar observations were performed in September 2014, and currently there are about 20 individual solar observing runs. Observations under best conditions were recently recorded on 20 February 2020, and data are currently being analysed to search for evidence of "nanoflare heating".

Publications

Harrison FA, et al. (2013) Astrophys. J. 770: 103.

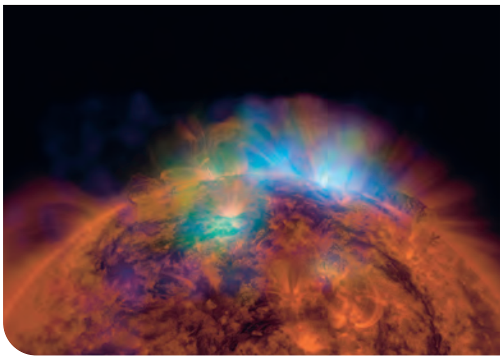
Kuhar M, et al. (2017) Astrophys. J. Lett. 835: 1, id. 6.

Kuhar M. et al. (2018) Astrophys. J. 856: L32.

Abbreviations

NuSTAR	Nuclear Spectroscopic Telescope Array
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager

Time-Line	From	To
Measurement Phase	2012	open
Data evaluation	2014	open



First NuSTAR image of the Sun (NASA press release): The NuSTAR image is represented by bluish colors superposed on an extreme UV image (around 171 Å) taken by SDO/AIA shown in red. While the EUV image represents 'cold' coronal plasma around 1 MK, the NuSTAR image outlines the location of the hottest plasma (typically 4-5 MK during non-flaring times).

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

In cooperation with
Caltech, USA
UC Santa Cruz, USA
Univ. Glasgow, UK
Univ. Minnesota, USA

Principal Investigator(s)
F. Harrison (Caltech)

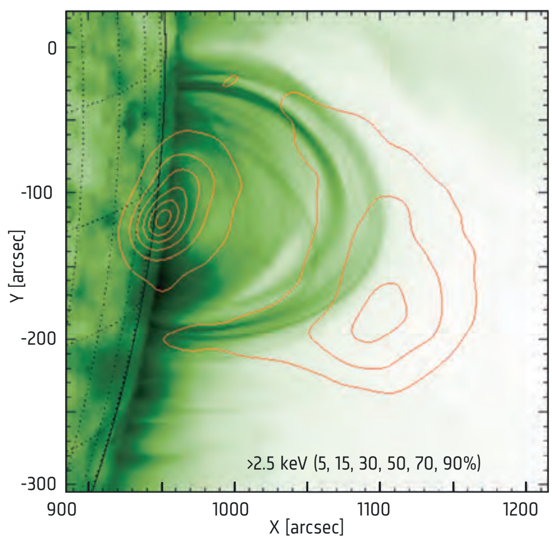
Swiss Principal Investigator(s)
S. Krucker (FHNW)

Co-Investigator(s)
M. Kuhar (FHNW)

Method
Measurement

Research based on existing instruments
NuSTAR's unprecedented sensitivity in the hard X-ray band opens up entirely new views on astrophysical X-ray objects including our Sun.

Website
www.astro-helio.ch/project/nustar



Flare loops as seen with NuSTAR, above 2.5 keV, are shown on an extreme UV 171 Å image. The NusTAR image was taken a full day after the flare onset revealing that the release of magnetic energy was still ongoing even well after the flare peak time.

6.3 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
Lab. Atmos. Space Physics (LASP), Boulder, USA

Principal Investigator(s)
W. Schmutz (until 2019; PMOD/WRC)
W. Finsterle (from 2020; PMOD/WRC)

Co-Investigator(s)
M. Haberreiter, L. Harra, M. Gyo, S. Koller, D. Pfiffner (PMOD/WRC)
B. N. Andersen (NSC, Norway)
G. Kopp (LASP, USA)
T. Leifsen (UiO, Norway)
B. Walter (SLF, Switzerland)

Method
Measurement

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

Website
www.pmodwrc.ch

Purpose of Research

CLARA is a new generation of radiometers to measure the Total Solar Irradiance (TSI), which is the energy input from the Sun to the Earth. The CLARA instrument onboard the Norwegian micro-satellite NorSat-1 is PMOD/WRC's latest operational absolute TSI radiometer, ensuring the continuous measurement of this essential climate variable (ECV).

For a correct evaluation of the Earth's energy budget, it is key to measure TSI with the highest possible accuracy and precision from space. The main science goal of CLARA is to measure TSI with an uncertainty better than 0.4 Wm^{-2} on an absolute irradiance level and a relative stability of 5 $mWm^{-2}yr^{-1}$ (0.0004% of the TSI per year). Along with PMOD/WRC's earlier instruments, VIRGO and PREMOS, CLARA continues the long-term involvement of PMOD/WRC in solar research.

Currently, there is a lot of scientific debate about any possible long-term variation of TSI, specifically the long-term change between the Maunder Minimum and the current level of TSI. If the TSI does vary on long-term scales, it will have a direct effect on the terrestrial climate. Solar irradiance measurements in space have been conducted since 1979 by various institutes, and have an average value of about 1361 Wm^{-2} (Prša, A. et al., 2016). During these 40 years, TSI varied in phase with the 11-year solar cycle by about ±0.6 Wm^{-2} (±0.04%). Despite various attempts, it is difficult to determine a long-term trend, i.e. a change between subsequent solar minima in the TSI composite, even more so the uncertainty of such a trend. However, in the early 20th century both TSI and the temperature of the Earth increased. At the same time, this phase can be considered as not yet being significantly influenced by anthropogenic climate change.

The study by Egorova et al. (2018) indicates that the early 20th century warming on Earth could be caused by a concurrent increase in TSI. This study further indicates that a strong secular trend in TSI between the Maunder Minimum and the present is possible. This hypothesis still needs to be independently confirmed, but it clearly indicates the importance of continuing to monitor TSI from space.

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, 1360.18 Wm^{-2} (Walter et al., 2018) confirmed TSI values from the TIM/SORCE, PREMOS/PICARD and VIRGO/SoHO missions.

In May 2018, the satellite experienced a spinning-wheel failure. Subsequently the platform and operation teams had to develop a new pointing scheme so that CLARA could be pointed to the Sun to conduct solar measurements. During this time, the satellite platform was not fully stabilised and CLARA was not operational. Thanks to the efforts of the NorSat-1 teams, reasonable pointing was restored with two reaction wheels, and CLARA saw its second "First Light" on 8 November 2019.

As was to be expected, the fine-pointing performance of the platform with the two reaction wheels is now limited. Therefore, the recent TSI data need to be carefully filtered using the available pre-flight cavity alignment measurements as well as the pointing information onboard NorSat-1.

In addition to its primary mission goal, CLARA started taking measurements of the Earth's outgoing radiation at the end of 2019, which is, due to the NorSat-1 orbit, only possible on the night-side of Earth. These measurements will serve as a technical demonstration and will pave the way for future absolute radiometers to determine Earth's Energy Imbalance.

Abbreviations

CLARA	Compact Lightweight Absolute Radiometer
NorSat-1	Norwegian satellite
TRF	Total Solar Irradiance Radiometer Facility
TSI	Total Solar Irradiance
UiO	University in Oslo, Norway

Publications

Egorova T, Rozanov E, Arsenovic P, Peter T, Schmutz W (2018) **Contributions of natural and anthropogenic forcing agents to the early 20th century warming**, Frontiers in Earth Science Vol. 6: id.206, doi: 10.3389/feart.2018.00206

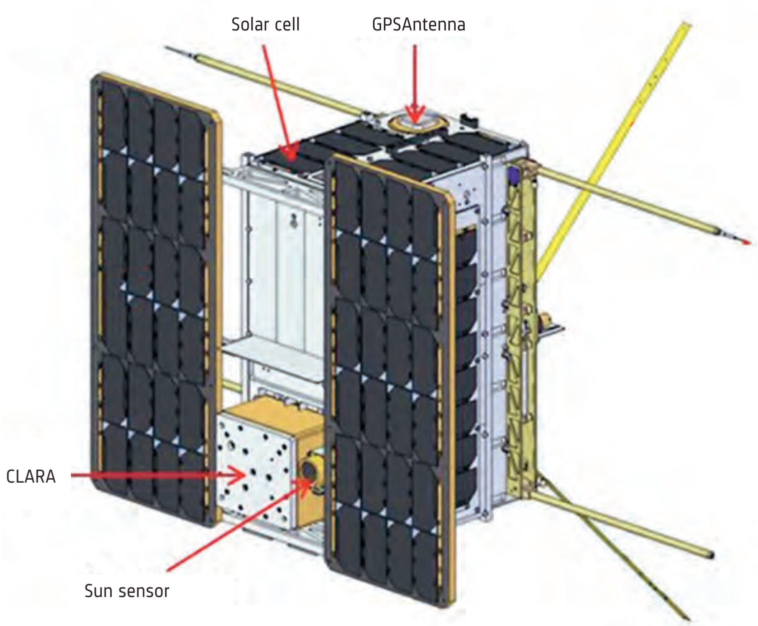
Haberreiter M, Finsterle W, Schmutz W, et al. (2020) **Latest TSI Measurements from NORSAT-1 / CLARA**, Sun Climate Symposium, Tucson, USA,

Prša A, Harmanec P, Torres G, et al. (2016) **Nominal Values for Selected Solar and Planetary Quantities: IAU 2015 Resolution B3**, The Astronomical Journal 152(2): id. 41, 7 pp., doi: 10.3847/0004-6256/152/2/41

Walter B., P-L Levesque, G Kopp, et al. (2017) **The CLARA/NORSAT-1 solar absolute radiometer: instrument design, characterization and calibration**, Metrologia 54, p. 5, doi: 10.1088/1681-7575/aa7a63

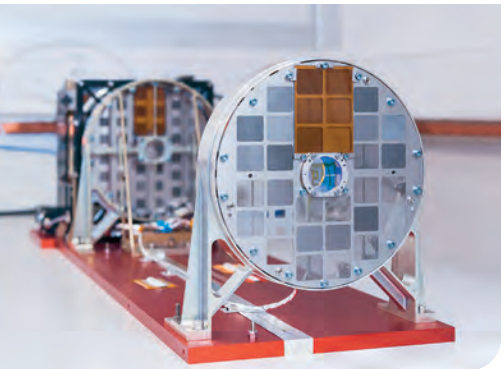
Walter, B., B. Andersen, A. Beattie, et al. (2018) Proc. IAU, 2020, pp. 358-360, doi: 10.1017/S1743921319004617

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



Payload on NorSat-1, illustrating CLARA with the Sun sensor.

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



The STIX Flight Model before delivery to ESA in 2017.

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. Vernonig (Uni Graz); P. Gallagher (TCD) N. Vilmer (LESIA); M. Piana (Univ. Genova)

Method
Measurement

Industrial contract(s) to
Almatech Lausanne; Art of Technology; SYDERAL SWISS SA, Switzerland,

Development & construction of instruments
STIX is a Swiss-lead instrument onboard ESA's Solar Orbiter mission.

Website
www.stix.i4ds.net

Purpose of Research

STIX is a Swiss-led instrument on board ESA's Solar Orbiter mission launched on 9 February 2020. STIX is a hard X-ray imaging spectrometer based on a Fourier-imaging technique similar to that used successfully by the Hard X-ray Telescope (HXT) on the Japanese Yohkoh mission, and related to that used for the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) NASA SMEX mission.

Solar Orbiter is a joint ESA-NASA collaboration that will address the central question of heliophysics: How does the Sun create and control the heliosphere? To achive this goal, Solar Orbiter carries a set of 10 instruments to perform joint observations.

Through hard X-ray imaging and spectroscopy, the 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 which include:

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

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

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 on board Solar Orbiter.

The STIX Flight Model was delivered to ESA in July 2017, and Solar Orbiter was succesfully launched on 9 February 2020. The commissioning of STIX will start on 14 April 2020 and will last for two months, followed by a cruise phase where STIX will not be operational. The STIX nominal science mission will start after completion of the cruise phase in October 2021. STIX science research at the Fachhochschule Nordwestschweiz (FHNW) is supported by the Swiss National Science Foundation (SNSF).

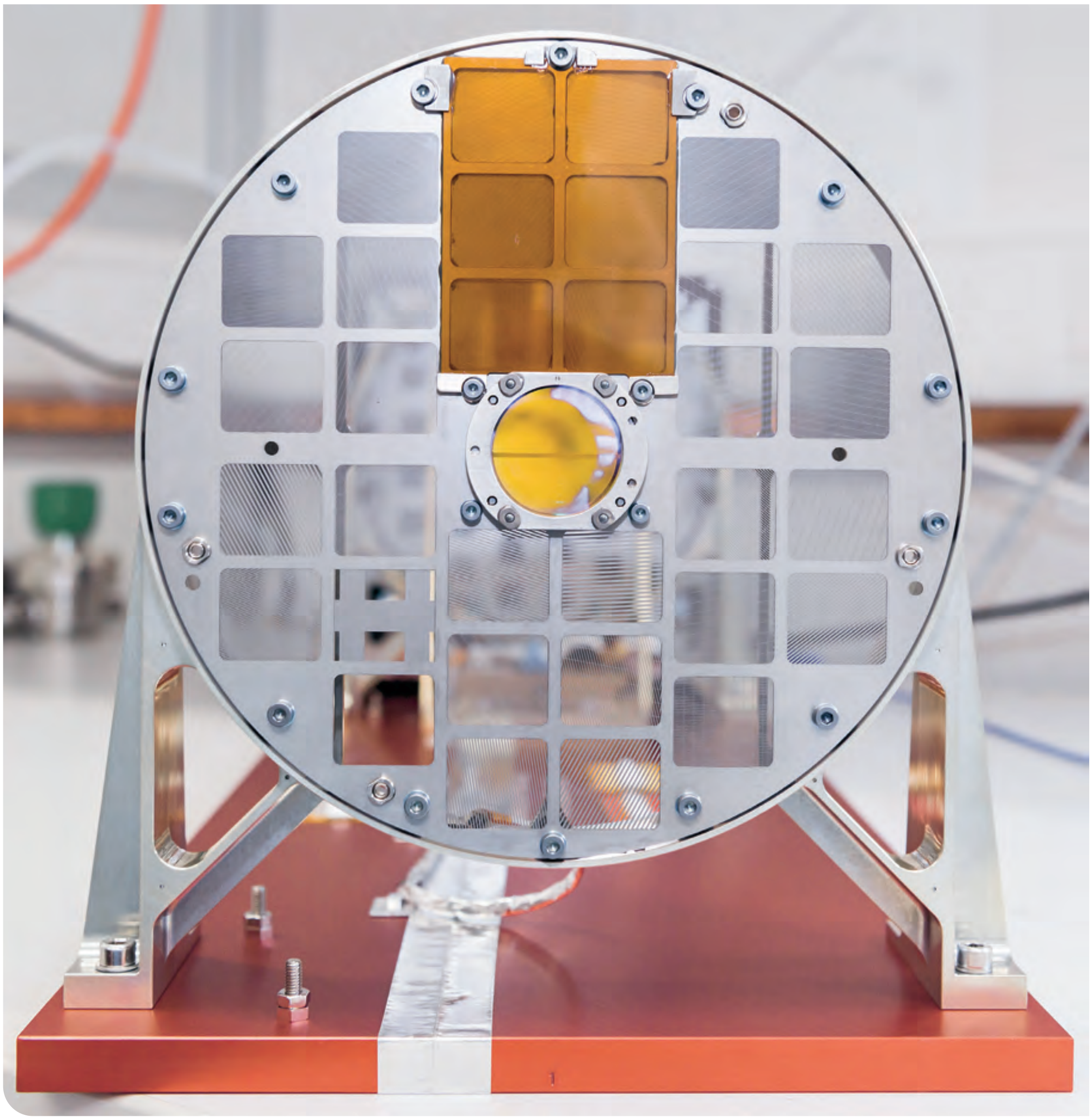
Publications

Krucker S, et al. (2020) Astronomy & Astrophysics, in press.

Abbreviations

HXT	Hard X-ray Telescope
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
SMEX	Small Explorers (NASA mission)
STIX	Spectrometer/Telescope for Imaging X-rays

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



Close-up view of the STIX Flight Model.

SOLAR PHYSICS

6.5 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. Sonnensystemforschung (MPS), Germany
University of Oslo (UiO), Norway

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

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

Purpose of Research

Both EUI and SPICE are key instruments for the Solar Orbiter mission. The mission's over-arching goals are to understand how the Sun creates and controls the heliosphere. Solar Orbiter was successfully launched on an Atlas V from Cape Canaveral on 9 Feb. 2020. Following commissioning, the mission will enter its cruise phase. During that time there will be five checkout windows for the remote sensing instruments for calibration purposes. Towards the end of 2021, the nominal science phase will begin.

EUI is designed to understand the dynamics and structure of the Sun through different layers of the solar atmosphere. It is an instrument suite with three telescopes- the Full Sun Imager (FSI) and two High Resolution Imagers (HRI). The two HRIs will image the solar atmosphere in the chromospheric Lyman alpha band and the coronal 17 nm band with a resolution of 0.5''. At the perihelion position, this corresponds to a pixel resolution of 110 km. The field-of-view of the FSI is large enough to image the region where the streamers fade into the solar wind (see Rochus et al., 2019).

SPICE is designed to understand the composition, temperature, turbulence and density of the plasma that ends up in the solar wind. It is an imaging spectrometer that operates at EUV wavelengths from 70.4 nm - 79 nm and 97.3 nm - 104.9 nm. Both EUI and SPICE will significantly contribute to the goals of the Solar Orbiter mission which are:

- What drives the solar wind and where does the coronal magnetic field originate?
- How do solar transients drive heliospheric activity?
- How do solar eruptions produce energetic particles?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

A key element of the orbit choice is to get close in to the Sun in order to measure the solar wind as it flows past the spacecraft and observe the source of the solar wind on the disk. It is known that the solar wind fluctuations diminish the further away from the Sun the measurements are made, so it is vital to get in close to correlate the dynamics on the Sun to that seen in the solar wind. The spacecraft will slowly increase its inclination out of the ecliptic plane by up to 33°. This will provide the first ever view of the solar poles by telescopes. The poles are important regions in the Sun as they explain the solar activity cycle, and hence this latter part of the mission lifetime is also key. It is unknown how the magnetic fields in the poles behave.

Past Achievements and Status

Both the EUI and the SPICE flight models were delivered to Airbus DS in 2017. Thereafter, integration occurred at Stevenage before shipping to Germany for spacecraft-level testing. The spacecraft was shipped to the US in autumn 2019 for integration into the Atlas V. The mission successfully launched in February 2020.

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 started successfully and both EUI and SPICE have been switched on, and have taken calibration data with the doors closed.

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

Auchère F, et al. (2019) **Coordination within the remote sensing payload on the Solar Orbiter mission**, https://doi.org/10.1051/0004-6361/201937032

Rochus P, et al. (2019) **The Solar Orbiter EUI instrument: The Extreme Ultraviolet Imager**, https://doi.org/10.1051/0004-6361/201936663

SPICE consortium (2019) **The Solar Orbiter SPICE instrument: An extreme UV imaging spectrometer**, https://doi.org/10.1051/0004-6361/201935574

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

The Solar Orbiter PIs, project scientists and national agency visitors at the launch pad the morning of the launch (9th February 2020) at the Kennedy Space Center, Cape Canaveral.

Co-Investigator(s)

SPICE

E. Buchlin, A. Gabriel, S. Parenti, J.-C Vial, M. Javier, E. Pariat (France)
M. Carlsson, V. Hansteen (Norway)
W. Curdt, H. Peter, U. Schühle, L. Terica, R. Wimmer-Schweingruber, S. Solanki (Germany)
M. Haberreiter (Switzerland)
M. Caldwell, R. Harrison, A. Giunta, N. Waltham, Sarah Matthews, G. Del Zanna, R. von Fay Siebenburgen (UK)
W. Thompson, J. Davila, D. Hassler, C. de Forest, P. Chamberlain, P. Young (USA)
J. Dudik, P. Heinzel (Czech)

EUI

P. Rochus, A. Zhukov, F. Cerbeeck, K. Stegen, M. Mierla, S. Poedts, L. Rodriguez, T. van Doorsselaere (Belgium)
E. Buchlin, S. Parenti, F. Delmotte (France)
L. van Driel-Gesztelyi, S. Matthews, D. Long, N. Labrosse, Duncan MacKay (UK)
U. Schühle, J. Büchner, L. Terica, S. Solanki, T. Wiegelmann, E. Marsch (Germany)
M. Haberreiter (Switzerland)
D. Seaton (USA)
D. Williams (ESA)

Method

Measurement

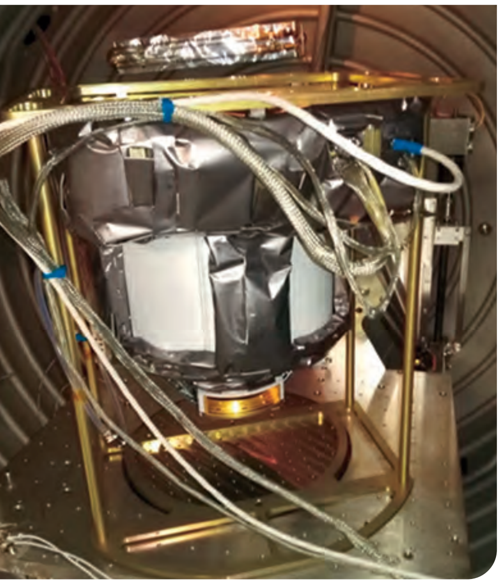
Industrial hardware contract(s) to

APCO technologies
Almatech

Website

www.pmodwrc.ch

6.6 SWA – Solar Wind Plasma Analyser on Solar Orbiter



Heavy Ion Sensors (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 will be used 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)) that will measure the ion and electron bulk properties (including density, velocity, and temperature) of the solar wind. This will allow characterisation of the solar wind at a distance of between 0.28 and 1.4 AU from the Sun, with an increasing inclination of 25° relative to the solar equator.

During the extended mission, additional Venus gravity assist manoeuvres will allow the orbital inclination of Solar Orbiter to increase to about 34°. In addition to determining the bulk properties of the wind, SWA will provide measurements of solar wind ion composition for key elements.

Time-Line	From	To
Planning	2007	2010
Construction	2010	2020
Measurement Phase	Mar. 2020	Dec. 2027
Data evaluation	Mar. 2020	2030

Past Achievements and Status

We calibrated the Heavy Ion Sensor (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 successfully launched on 10 February 2020 at 04:03 UTC from Cape Canaveral and is on its trajectory to close proximity to the Sun.

Publications

Wurz P, Ipavich FM, Galvin AB, Bochsler P, Aellig MR, Kallenbach R, Hovestadt D, Grünwaldt H, Hilchenbach M, Axford WI, Balsiger H, Bürgi A, Coplan MA, Geiss J, Gliem F, Gloeckler G, Hefti S, Hsieh KC, Klecker B, Lee MA, Livi S, Managadze GG, Marsch E, Möbius E, Neugebauer M, Reiche KU, Scholer M, Verigin MI, Wilken B, (1998), **Elemental composition of the January 6, 1997, CME**, Geophys. Res. Lett. 25: 2557-2560.

Wurz P, Bochsler P, Paquette JA, Ipavich FM (2003) **The calcium abundance in the solar wind**, Astrophys. J. 583: 489-495.

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

6.7 MiSolFA – The Micro Solar-Flare Apparatus

Purpose of Research

Operating at the same time as the STIX instrument on the ESA Solar Orbiter mission, during the next solar maximum (~2023), MiSolFa and STIX will have the unique opportunity to look at the same flare from two different directions: Solar Orbiter will be very close to the Sun with a significant orbital inclination, while MiSolFA will be in a near-Earth orbit.

MiSolFA will use similar photon detectors as STIX, precisely quantifying the anisotropy of solar hard X-ray emission for the first time to investigate particle acceleration in solar flares.

Time-Line	From	To
Planning	2015	2019
Construction	2020	2023
Measurement Phase	2023	2024
Data evaluation	2023	open

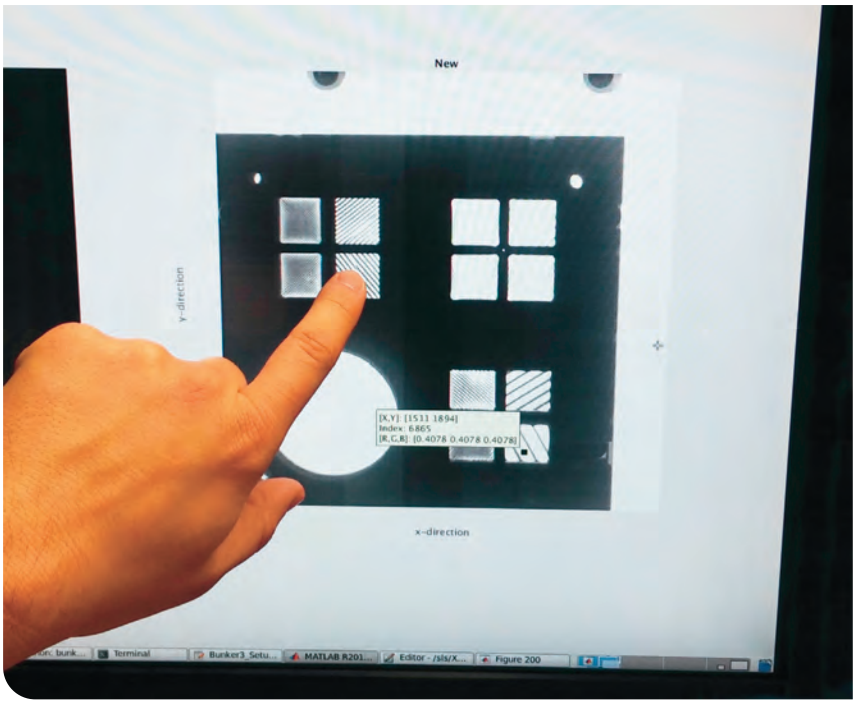
Past Achievements and Status

The Engineering Model (EM) of the MiSolFA gratings passed the space qualification tests with flying colours. The final design will be built into the Qualification and Flight Models, bringing the finest X-ray gratings ever used to study the Sun, closer to launch.

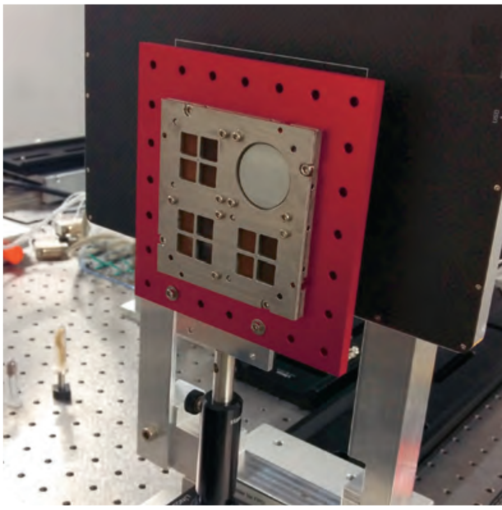
A proposal to obtain funding for the Cubsat platform is currently under evaluation by NASA.

Abbreviations

EM	Engineering Model
MiSolFA	Mirco Solar Flare Apparatus
STIX	Spectrometer/Telescope for Imaging X-rays



Success! The first X-ray images of the Moiré pattern show clear dark and bright stripes from coarse and fine gratings alike.



The MiSolFA EM is shown during the first X-ray measurement of its Moiré interference pattern. When operating in space, MiSolFA will allow the size and location of solar flare X-ray sources to be determined.

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

In cooperation with
A. Meuris, Commissariat à l'Énergie Atomique (CEA), France
S. Christe, Goddard Space Flight Center (GSFC), USA

Principal Investigator(s)
D. Casadei (FHNW)

Co-Investigator(s)
E. Lastufka (FHNW), S. Krucker (FHNW)

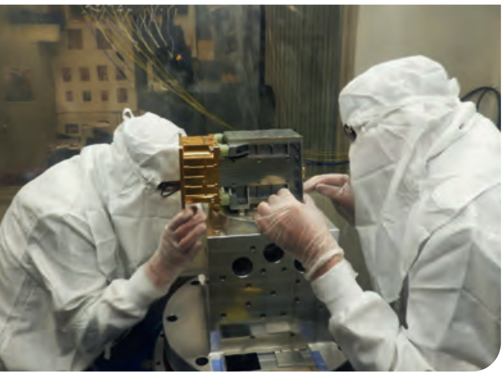
Method
Measurement

Development & construction of instruments
MiSolFA is a compact X-ray imaging spectrometer that fits within a micro-satelite (30x20x10 cm, a so-called 6-unit cubsat).

Industrial Contracts to
Paul Scherrer Institute (PSI), Switzerland

Website
www.misolfa.i4ds.net

6.8 DARA – Digital Absolute Radiometer on PROBA-3



The DARA EQM/FS at the vibration testing facility at the University Bern. Two engineers from PMOD/WRC are preparing the instrument for the tests.

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

In cooperation with
European Space Agency (ESA)

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

Co-Investigator(s)
W. Finsterle (PMOD/WRC)
J.-P. Montillet (PMOD/WRC)
G, Kopp, Lab. Atmos. & Space Physics (LASP), USA
A. Zhukov, Royal Observatory Belgium (ROB), Belgium

Method
Measurement

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

Website
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 mission (Project for On-Board Autonomy) 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 will guarantee 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. This will effectively represent 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 eccentric orbit which has a duration of 19 hrs 38 mins.

Past Achievements and Status

The instrument development is essentially complete with some of the qualifications and the final interface test between the DARA Engineering Qualification Model / Flight Spare (EQM/FS) and ADPMS (Qinetiq), still pending. The EQM/FS hardware was ready in 2019 and tested in front of the Sun. The DARA flight model (FM) is nearly complete at the time of writing in early 2020. Next, the FM will be calibrated in front of the Sun at PMOD/WRC. A calibration campaign at the TSI Radiometer Facility (TRF) at LASP in Boulder, Colorado is foreseen in Q4 of 2020.

The delivery of the FM is planned for the end of 2020. The overall schedule of PROBA-3 has constantly slipped over the years with the launch always being about two years in the future. At present, the launch is scheduled for mid-2022.

Publications

Walter B, et al. (2017) Metrologia 54: 674-682.

Abbreviations

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

Time-Line	From	To
Planning	end 2013	mid 2016
Construction	end 2016 (EM)	end 2020 (EQM/FS)
Measurement Phase	2022	2024
Data evaluation	2022	

6.9 JTSIM-DARA on FY-3E

Purpose of Research

Continuous and precise TSI measurements are indispensable to evaluate the influence of short and long-term solar radiative emission variations on the Earth's climate. The JTSIM-DARA absolute radiometer on the FY-3E mission is one of PMOD/WRC's future contributions to the almost seamless series of spaceborne TSI measurements since 1978.

The JTSIM-DARA/FY-3E experiment is a cooperation with the Chinese 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 in Davos, 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 SIAR radiometer designed by CIOMP.

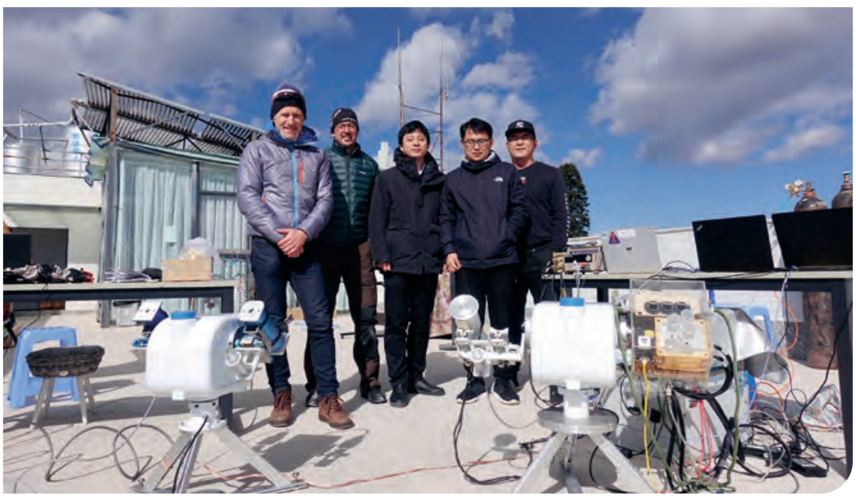
Past Achievements and Status

The JTSIM-DARA TSI radiometer proto flight model has been manufactured, calibrated and delivered to CIOMP (China) for integration on the JTSIM solar tracking frame and FY-3E satellite.

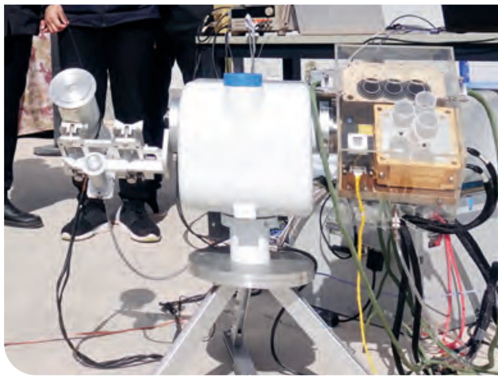
Abbreviations

DARA	Digital Absolute Radiometer
FY-3E	FengYun 3E
JTSIM	Joint TSI Monitor
SIAR	Solar Irradiance Absolute Radiometer
WRR	World Radiation Reference

Time-Line	From	To
Planning	2014	2015
Construction	2015	2018
Measurement Phase	2021	open
Data evaluation	2021	



JTSIM-DARA (right-hand side of tracker on the right) were calibrated against WRR traceable reference radiometers from 1 - 15 Dec. 2019 at the Gemini Observatory in Ruahnping (Yunnan Province, China).



JTSIM-DARA during calibration in China.

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 (ex-PMOD/WRC)
J.-P. Montillet (PMOD/WRC)

Method
Measurement

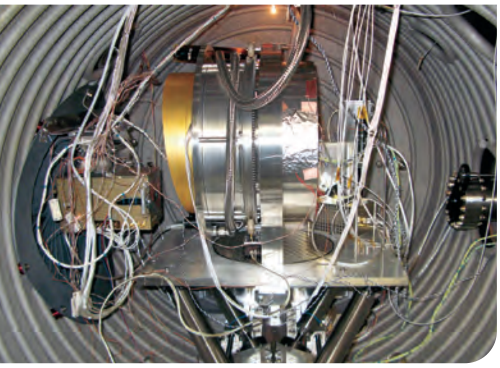
Development & construction of instrument(s)
DARA TSI radiometer

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

Website
www.pmodwrc.ch

7 Heliospheric Physics

7.1 IBEX – Interstellar Boundary Explorer



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

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 tremendously extends the orbital lifetime of the IBEX spacecraft and thus allows the mission to cover more than a solar cycle of 11 years with a minimal fuel consumption.

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

Resources on the IBEX spacecraft are sufficient to continue operations for several more years. Operations are planned to enable an overlap with the Interstellar Mapping and Accelaration Probe (IMAP) spacecraft of NASA to be launched in the second half of 2024.

Publications

Galli A, Wurz P, Schwadron NA, Kucharek H, Möbius E, Bzowski M, Sokół JM, Kubiak MA, Fuselier SA, Funsten H, McComas DJ (2017) **The downwind hemisphere of the heliosphere as seen with IBEX-Lo during 8 years**, Astrophys. J. 851: 16pp, doi: 10.3847/1538-4357/aa988f

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**, Astronomy & Astrophysics 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	Jan. 2005	May 2006
Construction	Jun. 2006	Aug. 2008
Measurement Phase	Oct. 2008	ongoing
Data evaluation	Oct. 2008	ongoing

7.2 IMAP – Interstellar Mapping and Acceleration Probe

Purpose of Research

The 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 the solar wind plasma 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. Measured energy distributions of ENAs, solar wind supra-thermal tails, pickup ions, and energetic particles disclose the physical processes that control the acceleration of suprathermal particles at 1 AU and within the heliosheath.

IMAP was selected by NASA in 2018, with a scheduled launch in October 2024. 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 participates in the IMAP-Lo camera covering 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 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

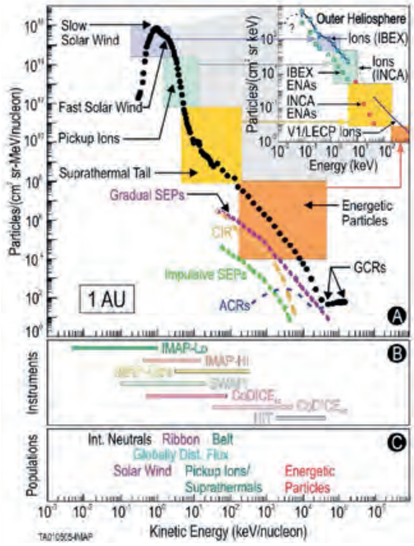
Wurz P, (2000), **Detection of Energetic Neutral Particles**, in The Outer Heliosphere: Beyond the Planets, (eds. K. Scherer, H. Fichtner, and E. Marsch), Copernicus Gesellschaft e.V., Katlenburg-Lindau, Germany, 251-288.

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	Dec. 2024	2029
Data evaluation	Dec. 2024	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.



Caption text: see end of article.

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

In cooperation with
Princeton University, Princeton, USA
Southwest Research Institute, Austin, USA
Univ. New Hampshire, Durham, USA
Los Alamos National Laboratory, USA

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

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

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

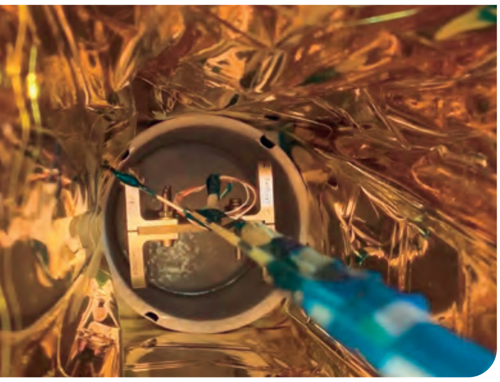
Method
Measurement

Development & construction of instruments
We participated in the ion-optical design, development, and the manufacturing of the IMAP-Lo ENA camera. Moreover, we will perform the entire IMAP-Lo calibration with ENAs over the full energy range, and for all species of interest.

Website
www.map.princeton.edu

HELIOSPHERIC PHYSICS

7.3 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 aluminium) at ZHAW. Image credit: ZHAW.

Institute
Inst. Data Science,
Fachhochschule Nordwestschweiz (FHNW),
Windisch, 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 contract(s) to
Kögl Space, Switzerland
Space Acoustics, Switzerland

Website
www.astro-helio.ch/project/sxi
sci.esa.int/smile/59138-science-objectives

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 (CAS). 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

SXI has successfully past the Preliminary Design Review (PDR) in 2019. In collaboration with Swiss Industry, FHNW is currently manufacturing the Structural Thermal Model of the SXI radiator.

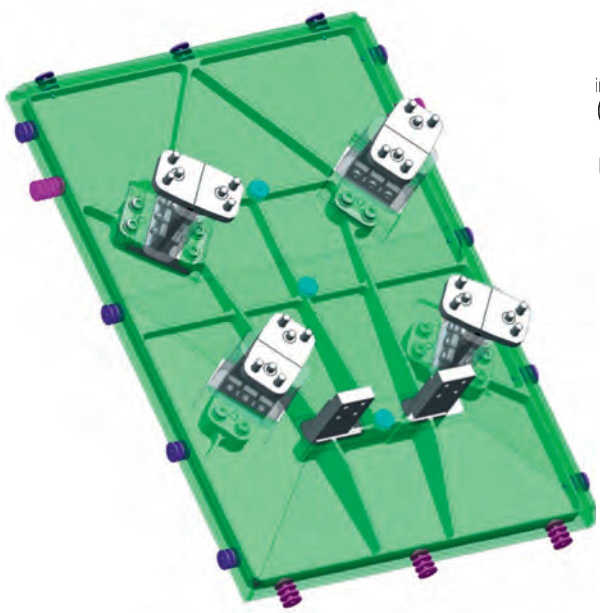
Publications

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

CAS	Chinese Academy of Sciences
SMILE	Solar wind Magnetosphere Ionosphere Link Explorer
SXI	Soft X-Ray Imager

Time-Line	From	To
Planning	2017	2020
Construction	2021	2023
Measurement Phase	2024	2027
Data evaluation	2024	2027



Current design of the SXI radiator as seen from the instrument side. The radiator (shown in green) is mounted to the instrument in four places (light grey), and there are two narrow cold fingers connecting the radiator directly to the SXI detectors.

7.4 SMILE – Solar Wind – Magnetosphere Interaction

Purpose of Research

The Solar wind Magnetosphere Ionosphere Link Explorer (SMILE) mission is a joint mission between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS). 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.

In particular, SMILE will investigate the dayside interaction and plasma reconnection processes taking place there. It will investigate the substorm cycles arising from disturbances of the magnetosphere by the solar wind, and it will investigate magnetic storms resulting from coronal mass ejections hitting the magnetosphere.

We are participating with the Light Ion Analyser (LIA) instrument to investigate the interaction of the solar wind and magnetosheath under various conditions.

Past Achievements and Status

The LIA instrument is currently under development, and is based on instruments we developed earlier for the Magnetosphere-Ionosphere-Thermosphere mission (MIT) as well as the Chinese Mars Exploration Mission.

Abbreviations

LIA	Light Ion Analyser
MIT	Magnetosphere-Ionosphere-Thermosphere mission
SMILE	Solar Wind Magnetosphere Ionosphere Link Explorer

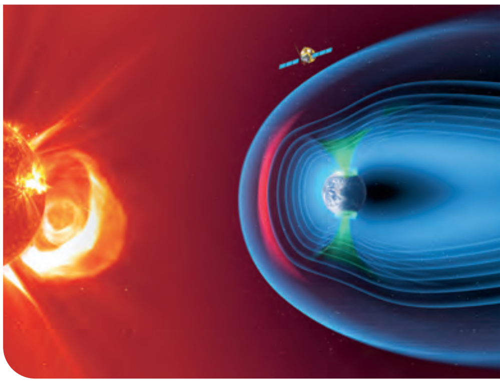
Publications

Fuselier SA, Funsten HO, Heirtzler D, Janzen P, Kucharek H, McComas DJ, Möbius E, Moore TE, Petrinec SM, Reisenfeld DB, Schwadron NA, Trattner KJ, Wurz P (2010) **Energetic neutral atoms from the Earth's subsolar magnetopause**, Geophys. Res. Lett. 37: 13101, doi:10.1029/2010GL044140

Petrinec SM, Dayeh MA, Funsten HO, Fuselier SA, Heirtzler D, Janzen P, Kucharek H, McComas DJ, Möbius E, Moore TE, Reisenfeld DB, Schwadron NA, Trattner KJ, Wurz P (2011) **Neutral atom imaging of the magnetospheric cusps**, J. Geophys. Res. 116: A7, CiteID A07203, doi: 10.1029/2010JA016357

Wurz P, Balogh A, Coffey V, Dichter BK, Kasprzak WT, Lazarus AJ, Lennartsson W, McFadden JP (2007) **Calibration Techniques**, in Calibration of Particle Instruments in Space Physics, (editors M. Wüest, D. S. Evans, R. von Steiger), ESA Communications, ISSI Scientific Report, SR-007, 117-276.

Time-Line	From	To
Planning	2015	2017
Construction	2017	2022
Measurement Phase	2023	
Data evaluation	2023	



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

Institute
Physics Institute, 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)

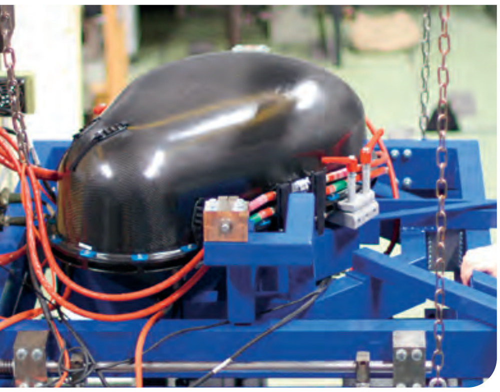
Method
Measurement

Development & construction of instruments
Light Ion Analyser (LIA)

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

8 Earth Observation, Remote Sensing

8.1 APEX – Airborne Prism Experiment



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 APEX during extensive measurement campaigns in the calibration home base and during airborne imaging campaigns to support Earth System Sciences.

Website
www.apex-esa.org

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

RSL is responsible for a number of tasks, including: i) the scientific management of the project, ii) added value within the calibration chain of the APEX instrument, iii) generation of products, and iv) to extend and maintain the Processing and Archiving Facility. The latter is a universal, database driven system supporting 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 was used in 2018 in an ESA campaign to support the development of the upcoming CHIME satellite system.

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
CHIME	Copernicus Hyperspectral Imaging Mission
SWIR	Short Wave Infrared
VNIR	Visible and Near-Infrared

Time-Line	From	To
Planning	1997	2000
Construction	2002	2010
Measurement Phase	2011	ongoing
Data evaluation	2011	ongoing

8.2 SPECCHIO – Spectral Information System

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 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. Major contributions were made to the system in the past year to allow the efficient storage and processing of tower-based spectroradiometric instruments delivering contineous data streams during daylight hours and to support the handling of uncertainty vectors and traceability chains.

SPECCHIO is installed in some 40 research institutions world-wide 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 calibration/validation activities for the upcoming ESA FLEX satellite. It is also used operationally to carry out calibration/validation for airborne imaging spectrometer campaigns with the APEX and AVIRIS-ng instruments.

The Australian instance of SPECCHIO will be hosted by Geoscience Australia starting in 2020 within the framework of Digital Earth Australia.

SPECCHIO is at present the most advanced spectral information system within the domain of Earth observing remote sensing. SPECCHIO is also open source and was made available in 2015 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, Nieke J, Schopfer J, Kneubühler M, Itten K (2009) **The spectral database SPECCHIO for improved long term usability and data sharing**, Computers & Geosciences 35: 557-565.

Hueni A, Malthus T, Kneubuehler M, Schaepman M (2011) **Data exchange between distributed spectral databases**, Computers & Geosciences 37: 861-873.

Hueni A, Chisholm L, Suarez L, Ong C, Wyatt M (2012) **Spectral information system development for Australia**, in Geospatial Science Research Symposium, Melbourne, Australia.

Abbreviations

APEX	Airborne Prism Experiment
AVIRIS-ng	Airborne Visible / Infrared Imaging Spectrometer - Next Generation
FLEX	Fluorescence Explorer Mission

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

In cooperation with
Geoscience Australia (GA)
SENSECO COST Action
EcoSIS
MetEOC (EMPIR)

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

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

Purpose of Research

Ultra-precise inter-satellite ranging, as performed for more than 15 years 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 system Earth from space. Continued meanwhile by its Follow-On mission (GRACE-FO), a growing 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 noise and sometimes also in terms of signal. In the frame of the European Gravity Service for Improved Emergency Management (EGSIEM) initiative, 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.

The Combination Service of Time-Variable Gravity Fields (COST-G) continues the activities of the scientific combination prototype service of the EGSIEM initiative. COST-G aims to realise a long-awaited standardisation of gravity-derived mass transport products under the umbrella of the International Association of Geodesy (IAG).

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 will operationally provide consolidated monthly global gravity models with improved quality, robustness, and reliability both in terms of spherical harmonic coefficients and thereof derived grids of surface mass changes by combining solutions or normal equations from COST-G analysis centers. The COST-G analysis centers are adopting different analysis methods but apply agreed-upon consistent processing standards to deliver time-variable gravity field models, e.g. from GRACE or GRACE-FO low-low satellite-to-satellite tracking (ll-SST) or from non-dedicated data such as GPS high-low satellite-to-satellite tracking (hl-SST) or Satellite Laser Ranging (SLR). 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.

COST-G has provided a first release of combined GRACE monthly gravity fields covering the entire GRACE time period between April 2002 and June 2017. In addition, COST-G also provides combined monthly gravity fields from data of the Swarm mission as an operational product in the frame of an ESA initiative. Combined monthly gravity fields from data of the GRACE-FO mission are planned to be released on an operational basis in the course of the year 2020.

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

Publications

Jäggi A, et al. (2019) **European Gravity Service for Improved Emergency Management (EGSIEM) – from concept to implementation**, Geophys. J. Intl. 218: 1572-1590.

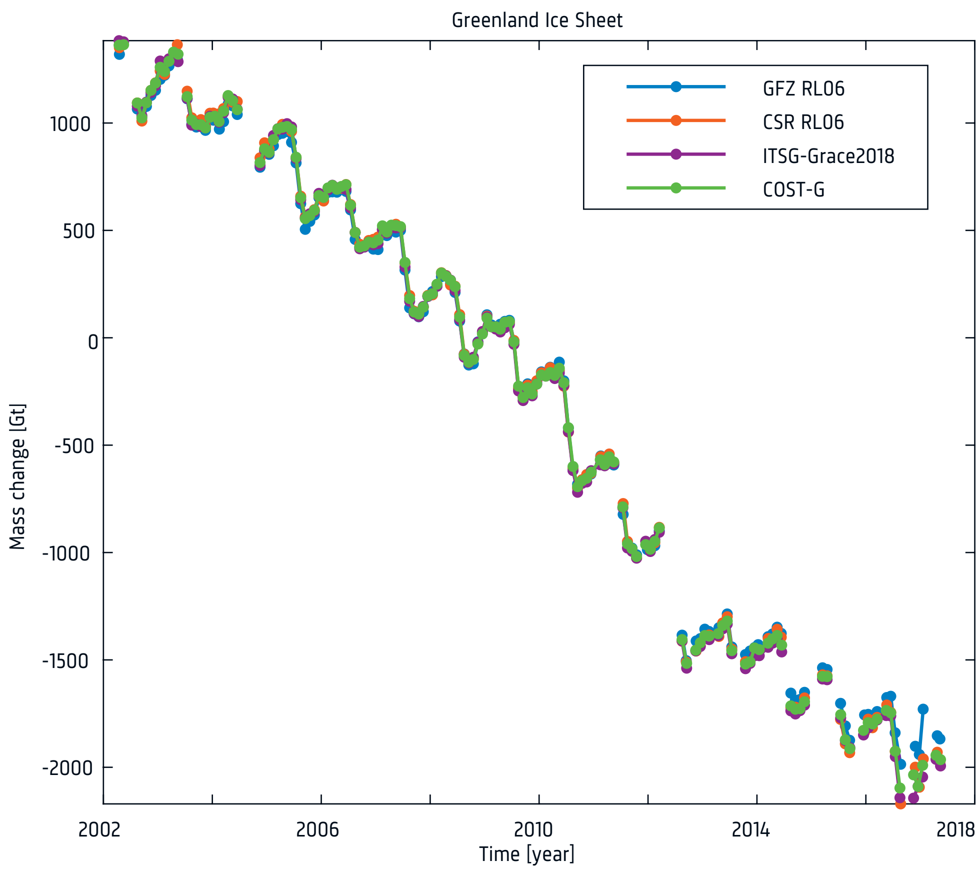
Jäggi A, et al. (2020) **International Combination Service for Time-Variable Gravity Fields (COST-G)**, Intl. Assoc. Geodesy Symposia Series, in press.

Meyer U, et al. (2019) **Combination of GRACE monthly gravity fields on the normal equation level**, J. Geod. 93: 1645-1658.

Jean Y, et al. (2018) **Combination of GRACE monthly gravity field solutions from different processing strategies**, J. Geod. 92: 1313-1328.

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 the entire Greenland Ice Sheet (GIS) computed from gravity field solutions from different institutions and from the COST-G combined solution. Further analyses confirm a reduced noise level of the COST-G mass change time-series. For the entire GIS, but also for the majority of the individual GIS drainage basins, the COST-G mass change time-series show the lowest noise of all solutions used for the combination.

8.4 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 on 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.

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 and 3A/B, 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.

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

In cooperation with
ESA's CPOD Quality Working Group

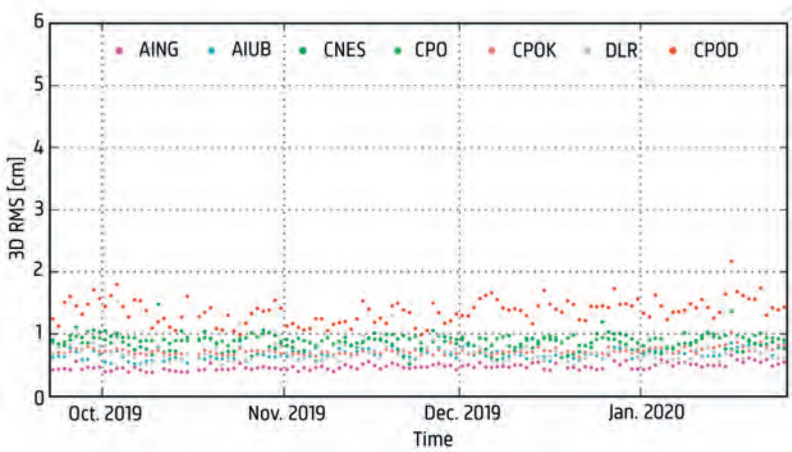
Principal Investigator(s)
J. Fernandez (GMV)

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

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

Method
Measurement

Website
www.copernicus.eu



Sentinel-3B Orbital Comparisons 3D RMS (cm); External solutions vs. combined solution.

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, to Satellite Laser Ranging (SLR).

The Astronomical Institute of the University of Bern (AIUB) is contributing two solutions, a reduced-dynamic solution without explicit modelling of non-gravitational forces (see solution labelled AIUB in the figure on the opposite page) and a fully dynamic solution relying on a more detailed force model (solution labelled AING). The RSR analyses confirm that the quality of the delivered AIUB solutions is among the best of all solutions contributing to the CPOD QWG.

The AIUB solutions are in particular making use of single-receiver ambiguity resolution techniques which are based on the GPS products of the Center for Orbit Determination in Europe (CODE) hosted at AIUB. Besides precise GPS satellite orbits and clock corrections, the CODE product portfolio includes a new 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 has been upgraded to make use of the CODE products since spring 2020.

Artist' impression of the Sentinel-3B satellite. Image credit: ESA.

Publications

Montenbruck O, Hackel S, Jäggi A (2018) **Precise orbit determination of the Sentinel-3A altimetry satellite using ambiguity-fixed GPS carrier phase observations**, J. Geodesy. 92: 711-726.

Schaer S, Villiger A, Arnold D, Dach R, Prange L, Jäggi A (2020) **The CODE ambiguity-fixed clock and phase bias analysis products and their properties and performance**, J. Geodesy., submitted.

Abbreviations

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

8.5 EMRP MetEOC-3 / EMPIR MetEOC-4

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)

Co-Investigator(s)
M. E. Schaepman (RSL)

Method
Measurement

Research based on existing instruments
Improvement of the APEX sensor model and test of new spectral calibration methods. Establishment of uncertainty budget support within spectral databases (SPECCHIO system). Calibration support for new CWIS-II imaging spectrometer (built in collaboration with NASA/JPL).

Industrial hardware contract(s) to
NASA/JPL

Website
www.meteoc.org

Purpose of Research

Key aspects to validated airborne and satellite based products with associated uncertainty budgets include:

- Improvement of spectro-radiometric calibration methods to improve both calibration speed and accuracy.
- Paving the pathway to traceable spectral ground control point data through supporting uncertainty budgets within spectral information systems.

Based on the APEX Calibration Information System, a similar system will be established to enable the operational calibration of the new CWIS-II imaging spectrometer. All these efforts are geared to provide traceable measurements with uncertainty budgets, supporting 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 and MetEOC-2; Metrology for Earth Observation and Climate). This capacity will be used in the upcoming MetEOC-4 project once more to further work towards the support of uncertainty in processing and storage systems such as the SPECCHIO spectral information system.

An in-situ instrument designed to measure sun-induced plant fluorescence will be used as a case study to implement automated uncertainty estimates in spectral information systems. FLoX spectroradiometers are currently being deployed on mainly existing flux towers to serve as a validation network for the upcoming ESA FLEX (Fluorescence Explorer) satellite mission.

The SPECCHIO system is being updated to automatically ingest, process and quality control diurnal data provided by the FLoX instruments. Uncertainty budgets defined at the instrument level will enable the propagation of uncertainty within the system and aid probabilistic calibration and validation methods.

Publications

Hueni A, Schlaepfer D, Jehle M, Schaepman ME (2014) **Impacts of dichroic prism coatings on radiometry of the Airborne Imaging Spectrometer APEX**, Appl. Opt. 53: 5344-5352.

Hueni A, Damm A, Kneubuehler M, Schläpfer D, Schaepman M (2017) **Field and airborne spectroscopy cross-validation – some considerations**, IEEE J. Selected Topics Appl. Earth Obs. Remote Sensing 10: 1117-1135.

Abbreviations

APEX	Airborne Prism Experiment
CWIS-II	Compact Wide-Swath Imaging Spectrometer
EMRP	European Metrology Research Programme
FLEX	Fluorescence Explorer
FLoX	Fluorescence Box instrument
Flux tower	Observation station to track CO_2 exchange
MetEOC	Metrology for Earth Observation and Climate
NMI	National Measurement Institute
SPECCHIO	Spectral Information System

8.6 ARES – Airborne Research Facility for the Earth System

Purpose of Research

ARES is an airborne research facility to predominantly 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.

Past Achievements and Status

The CWIS-II imaging spectrometer sensor head is currently under construction at NASA/JPL. Airborne imaging campaigns are currently being conducted with the APEX sensor in collaboration with VITO and the AVIRIS_ng sensor with NASA/JPL. It is expected that CWIS-II will enter operational service in 2021-2022. Further information is on the ARES webpage: https://ares-observatory.ch

Abbreviations

APEX	Airborne Prism Experiment
ARES	Airborne Research Facility for the Earth System
AVIRIS-ng	Airborne Visible / Infrared Imag. Spectr. - next generation
CWIS-II	Compact Wide-Swath Imaging Spectrometer
VITO	Vlaamse Instelling voor Techn. Onderzoek (VITO), Belgium

Time-Line	From	To
Planning	2017	2018
Construction	2018	2021
Measurement Phase	2022	-
Data evaluation	2022	-

ARES during air operations.

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)

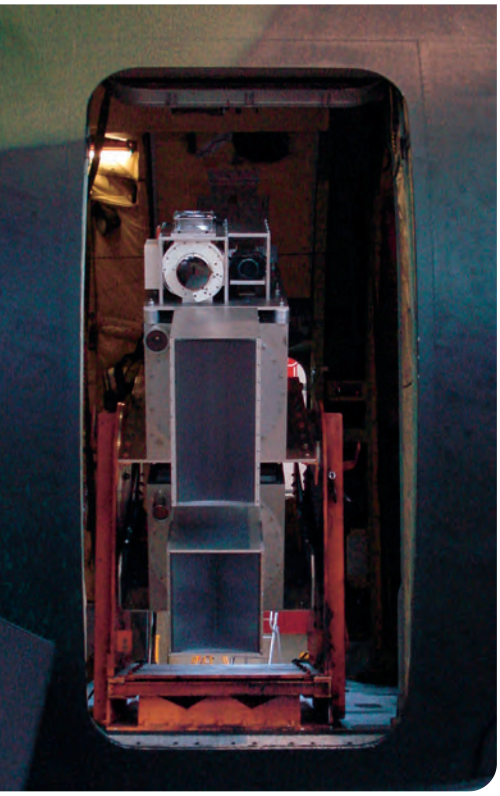
Co-Investigator(s)
A. Hueni (RSL), R. Furrer (UZH)
S. Seneviratne (IAC), N. Buchmann (IAS)
K. Schindler (IGP), B. Buchmann (EMPA)
A. Wüest (EAWAG), M. Hoelzle (UniFr)
R. Veron (EPFL ENAC), G. Mariethoz (UniL)

Method
Measurement

Industrial hardware contract(s) to
NASA/JPL for the development of the IS in collaboration with UZH

Website
www.ares-observatory.ch

8.7 SARCD – Synthetic Aperture Radar Tomography for Change Detection Applications



MEMPHIS sensor installed onboard a C-160 Transall airplane

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

In cooperation with
armasuisse, Switzerland

Fraunhofer Inst. High Frequency Physics & Radar Techniques (FHR), Germany

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

Co-Investigator(s)
E. Méndez Domínguez (RSL)
D. Small (RSL)

Purpose of Research

Information on 3D structures expands the scope of change detection applications in urban studies, human activity and forest monitoring. Traditionally, 3D change detection is performed only with LiDAR data or optical images after photogrammetric processing. However, these methods do not exploit the potential of 3D information contained in synthetic aperture radar (SAR) imagery, mainly due to the limited availability of data: SAR sensors provide 3D images by extension of the synthetic aperture in elevation. This configuration, known as tomographic SAR (TomoSAR), generates a 3D point cloud that allows the analysis of both, backscatter and height information.

TomoSAR also permits to resolve layover and detect multiple scatterers within the resolution cell. In order to perform change detection with 3D SAR imagery, we designed a three-stage method complementing the properties of 2D and 3D very high resolution SAR imagery to combine advantages of both 2D only SAR approaches, and well-established LiDAR methods to improve SAR change detection tasks.

Past Achievements and Status

In 2012 and 2013, various data-sets were recorded with Fraunhofer FHR's MEMPHIS sensor, a pulsed SAR system at Ka-band. The sensor was equipped with four receiving antennas, enabling single-pass multi-baseline cross-track interferometry. The data sets were acquired over Hinwil (Switzerland) and Memmingen (Germany). The 3D images were focused after tomographic processing of the signals recorded with the four receiving antennas in single-pass mode. The method consisted of three stages:

First, we detected changes caused by targets with low vertical extent using a 2D approach that exploits both single-look and multisquint processing mode to reduce errors caused by presence of image artifacts while detecting changes at the resolution space of the single-look images.

Second, we detected changes caused by tall objects using 3D images. To derive the corresponding change map we combined information of the difference in backscatter and height by means of a conditional random field.

In the third stage, we computed a final 3D change map derived after fusing the maps from the two previous stages. After labelling a synthetic ground truth, we performed quality assessment of the proposed method and some other existing approaches.

In global terms, numerical evalution showed that the kappa coefficient improved by a factor 2.1 in comparison to established 2D methods and by a factor 1.7 in comparison to common 3D approaches. When backscatter and height differences were exploited by means of a conditional random field, kappa further improved by a factor 1.2 in comparison to that obtained when exploiting the backscatter difference only.

This work provides first references demonstrating the performance of tomographic SAR data acquired in medium density urban areas for change detection purposes.

Publications

Méndez Domínguez E, Magnard C, Meier E, Small D., Schaepman ME, Henke D (2019) **A back-projection tomographic framework for VHR SAR image change detection**, IEEE Trans. Geosci. Remote Sensing 57: 4470-4484.

Méndez Domínguez E, Small D, Henke D (2019) **Synthetic aperture radar tomography for change detection applications**, Joint Urban Remote Sensing Event (JURSE), Vannes, France, 22-24 May 2019.

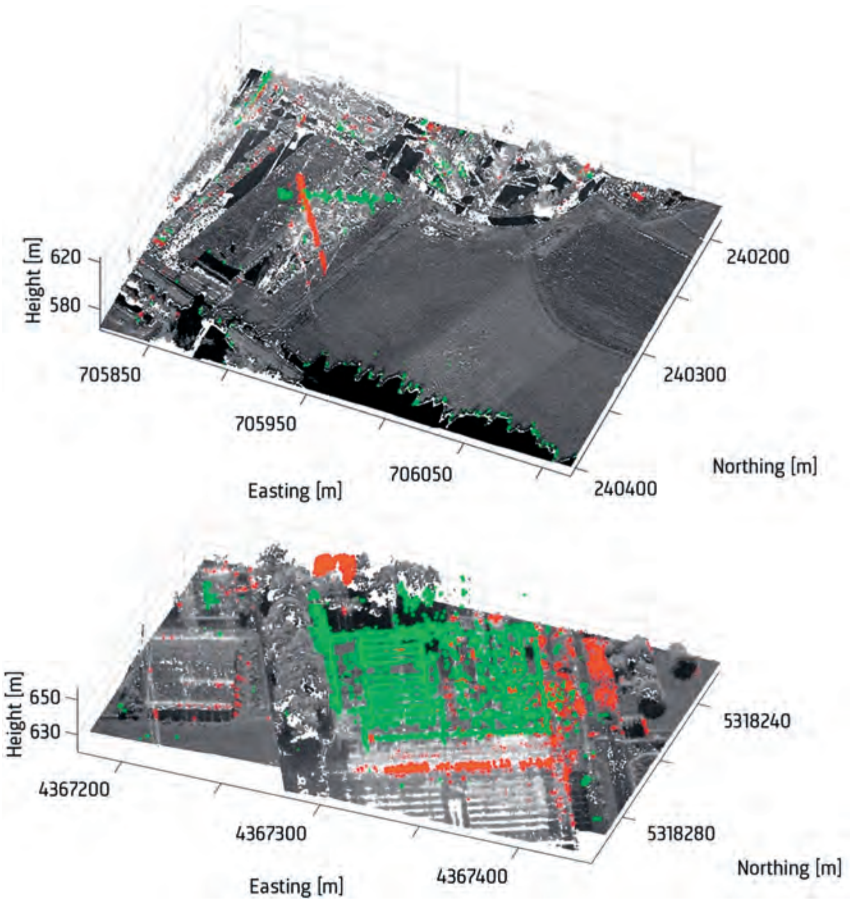
Abbreviations

MEMPHIS	Multi-frequency Experimental Monopulse High- resolution Interferometric SAR
SAR	Synthetic Aperture Radar
TomoSAR	Tomographic Synthetic Aperture Radar

Method
Measurement

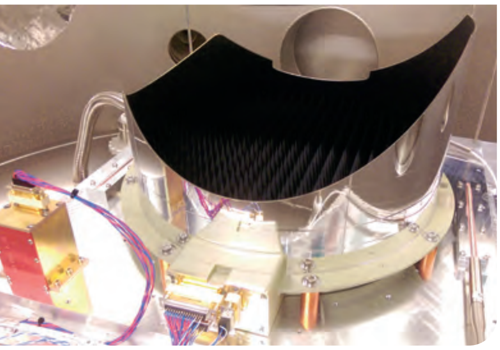
Research based on existing instruments
Airborne SAR sensors

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



Detection of the movement of a crane (top) and the construction of a new building (bottom) using SAR tomography. Change map overlaid on the reference 3D amplitude SAR image. Green voxels: incoming targets. Red voxels: leaving targets.

8.8 MetOp – Calibration Targets for MWS and ICI Instruments



MWS on-board target in the thermal calibration facility at TK Instruments, UK.

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

In cooperation with
TK Instruments, UK
Airbus Space and Defence, UK and Spain
IABG, Germany

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

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

Method
Measurement

Development & construction of instrument(s)
Development of on-board 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 two on-ground blackbody calibration targets for ICI. They will be used to verify the radiometric performance of ICI prior to launch by providing scenes with an either cryogenic or variable brightness temperature. These on-ground targets are designed as wedged cavities matched to the ICI antenna design, allowing the performance of the on-board calibration targets to be exceeded.

Past Achievements and Status

The Critical Design Reviews (CDR) of the on-board and on-ground calibration targets were successfully passed in January and April 2018, respectively. The RF performance of the on-ground calibration targets was successfully characterised in 2019. The engineering (EM) and proto-flight (PFM) models of the MWS and ICI on-board targets were also successfully tested in 2019, with further testing in 2020. The first two launches of the MetOP-SG programme are currently foreseen in 2021 and 2022.

Publications

Murk A, et al. (2019) 6th Workshop on Adv. RF Sensors & Rem. Sensing Instr., ESTEC, Noordwijk, NL.

Schröder A, et al. (2017), IEEE Trans. THz Sci. Technol. 7: 677-685.

Time-Line	From	To
Planning	2013	2015
Construction	2016	2018
Measurement Phase	2018	2020

ICI on-ground calibration targets during integration at IABG, Germany.

9 Comets, Planets

9.1 ROSINA Analysis and Data Archiving

Research and Status

The Rosetta spacecraft spent 2 years in the close vicinity of comet 67P/Churyumov-Gerasimenko before the mission ended on 30 September 2016 with a soft landing on the comet's surface. During that time, ROSINA carried out a wealth of measurements, the analysis of which is ongoing. The abundance of data continues to reveal key aspects about the nature of the comet's near-nucleus gas environment and the ices contained in its nucleus (Rubin et al., 2019). For instance, a sizeable number of organic, oxygen-bearing molecules have been identified in the coma of the comet (Schuhmann et al., 2019).

A recent and remarkable finding reveals the presence of ammonium salts and explains the deficiency of nitrogen in comets observed to date (Altwegg et al., 2020). As with many other investigations, these conclusions were supported by accompanying laboratory calibrations using the flight spare instruments of ROSINA (Hänni et al., 2020). Furthermore, Schroeder et al., (2019) reported no statistically significant difference in the deuterium-to-hydrogen ratio in the water originating from the two lobes of the comet (see Figure). This is consistent with both parts having formed in the same region in the protoplanetary disc before their collisional merger.

All these results bear witness to the richness of the ROSINA dataset. The analysis is ongoing and there are still numerous key questions to be addressed. The ROSINA datasets have therefore been fully incorporated into ESA's Planetary Science Archive and NASA's Planetary Data System. All measurements, from raw format to higher level data products, including densities of individual gases measured throughout the whole mission, are now freely available to all interested amateurs and experts around the world at the following web address: https://archives.esac.esa.int/psa.

Publications

Altwegg K, et al. (2020) **Evidence of ammonium salts in comet 67P as explanation for the nitrogen depletion in cometary comae**, Nature Astronomy: 1-8, https://doi.org/10.1038/s41550-019-0991-9

Hänni N, et al. (2019) **Ammonium salts as a source of small molecules observed with high-resolution electron-impact ionization mass spectrometry**, J. Phys. Chem. A 123 (27), https://doi.org/10.1021/acs.jpca.9b03534

Rubin M, et al. (2019) **Elemental and molecular abundances in comet 67P/Churyumov-Gerasimenko**, Monthly Notices of the Royal Astronomical Society 489: 594-607, https://doi.org/10.1093/mnras/stz2086

Schroeder IR, et al. (2019) **A comparison between the two lobes of comet 67P/Churyumov-Gerasimenko based on D/H ratios in H_2O**, MNRAS 489: 4734-4740, https://doi.org/10.1093/mnras/stz2482

Schuhmann M., et al. (2019) **Aliphatic and aromatic hydrocarbons in comet 67P/Churyumov-Gerasimenko seen by ROSINA**, Astronomy & Astrophys., https://doi.org/10.1051/0004-6361/201834666

Abbreviations

ROSINA Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

Time-Line	From	To
Planning	1995	1996
Construction	1996	2002
Measurement Phase	2014	2016
Data evaluation	2014	ongoing

Rosetta OSIRIS Wide Angle Camera image of comet 67P/Churyumov-Gerasimenko on 9 Sep. 2016. Image credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA.

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)

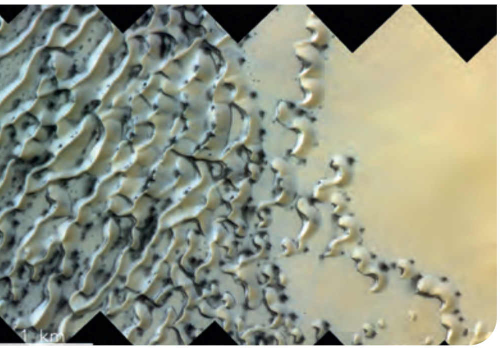
Co-Investigator(s)
H. Balsiger (UNIBE), J.-J. Berthelier (LATMOS), C. Briois (CNRS), M. Combi (UMich), B. Fiethe (TUB), S. Fuselier (SwRI), T.I. Gombosi (UMich), K.C. Hansen (UMich), E. Kopp (UNIBE), A. Korth (MPS), U. Mall (MPS), H. Rème (CNRS), M. Rubin (UNIBE), H. Waite (SwRI), P. Wurz (UNIBE)

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

9.2 CaSSIS – The Colour and Stereo Surface Imaging System



CaSSIS image of defrosting sand dunes on Mars. As northern spring begins, dunes of sand near the north pole of Mars began to thaw. They are pictured here in late May 2019 by the CaSSIS instrument on ESA's ExoMars Trace Gas Orbiter.

Institute
Space Res. & Planetary Sci., Inst. Phys., 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, J.J. Wray 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

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

CaSSIS is onboard ESA's ExoMars Trace Gas Orbiter (EMTGO) mission 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 compiles and prioritises lists of observation targets needed to test specific hypotheses concerning active surface processes on Mars. Unusual or changing colours indicate active processes, perhaps linked to methane formation or release. The stereo capability is being used to derive 3D information about the surface structure in key places on Mars.

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 in order 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 United States. CaSSIS will play a role in characterising and defining new landing sites.

Past Achievements and Status

The instrument has been shown to be fully functional in Mars orbit and has acquired over 10,000 images to date. These include stereo pairs from which digital terrain models at high resolution have been constructed.

The full colour observations are also revealing details of the surface and are being used to characterise future landing sites such as Oxia Planum and Jezero Crater.

Publications

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.

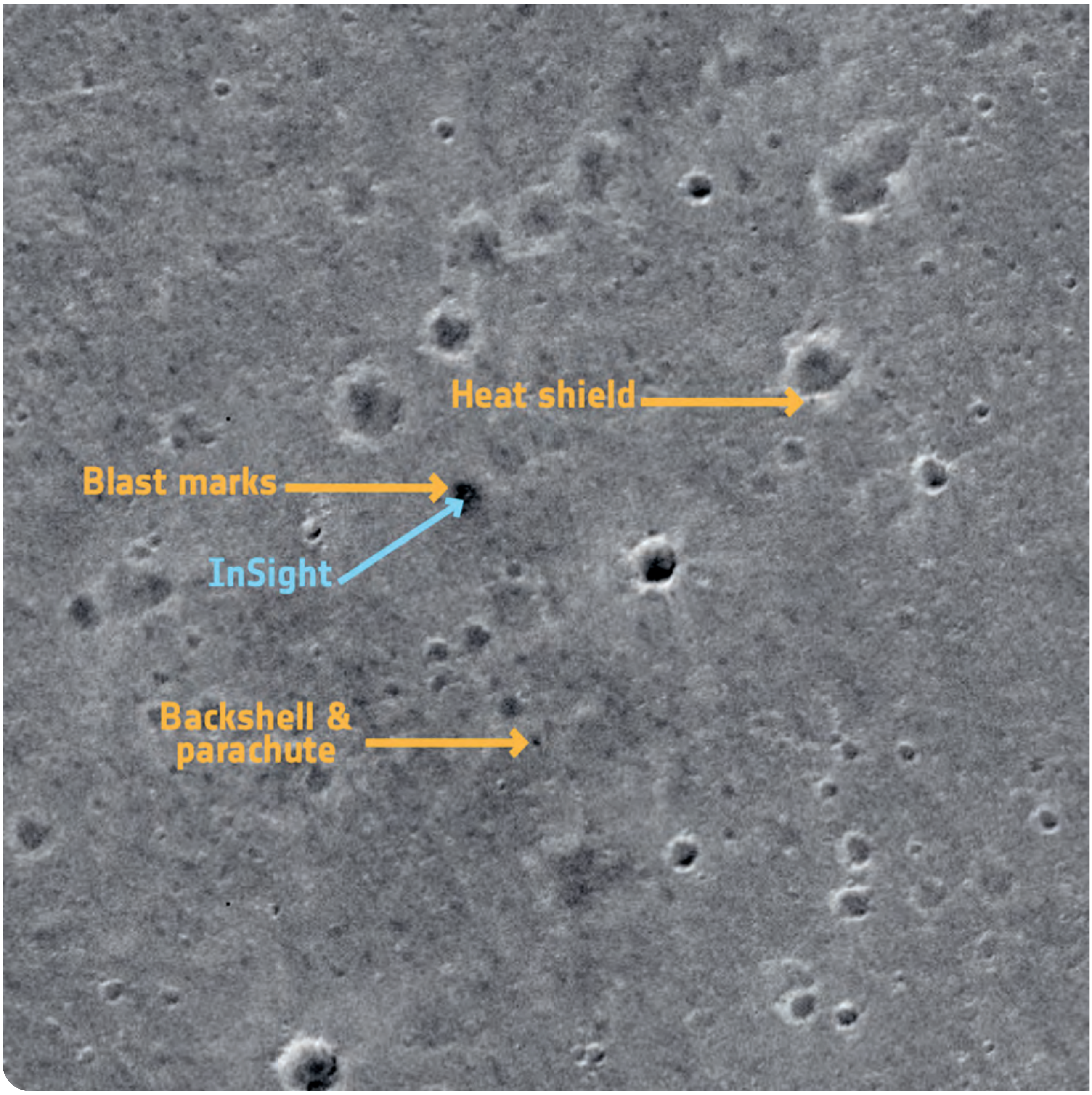
Roloff V., and 24 colleagues (2017) **On-ground performance and calibration of the ExoMars Trace Gas Orbiter CaSSIS Imager**, Space Science Reviews 212: 1871-1896.

Becerra P, Sori MM, Thomas N, Pommerol A, Simioni E, Sutton SS, Tulyakov S, Cremonese G (2019) **Timescales of the climate record in the south polar ice cap of Mars**, Geophys. Res. Letts. 46: 7268.

Abbreviations

CaSSIS	The Colour and Stereo Surface Imaging System
EMTGO	ExoMars Trace Gas Orbiter

Time-Line	From	To
Planning	Apr. 2010	Oct. 2013
Construction	Oct. 2013	Nov. 2015
Measurement Phase	Apr. 2018	>2020
Data evaluation	2018	>2022



The CASSIS image shows a panchromatic channel image of the InSight landing site on Mars. NASA's InSight Lander arrived on the surface of Mars on 26 November 2018. The InSight mission is designed to study the interior of Mars and includes a seismometer experiment to which ETH Zurich contributed. An area of about 2.25 km x 2.25 km in the Elysium Planitia region is shown in the image. A dark apron of material was produced when the lander fired its retro rockets just before touchdown. The colour capability of the CaSSIS image shows InSight as a brighter dot in the centre of the dark patch, while the bluish coloured solar panels of InSight stand out against the red colour of Mars. The heat shield, released by InSight just before landing, and the backshell, used to protect the lander during descent, are also marked. Image credit: ESA/Roscosmos/CaSSIS.

9.3 CoCa and MANiaC for Comet Interceptor

Preliminary design of the CoCa camera system.

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

In cooperation with
DLR Inst. Planetary Res., Berlin, Germany
Lab. d'Astrophysique, Marseille, France
Inst. de Astro. de Andalucia, Spain
Wigner Inst., Budapest, Hungary
DLR Inst. for Aerodynamics & Flow Technology, Göttingen, Germany
Inst. Weltraumforschung, Graz, Austria

Principal/Swiss Investigator(s)
N. Thomas (CoCa, UNIBE),
M. Rubin (MANiaC, UNIBE),

Co-Investigator(s)
H. Michaelis (DLR), L. Lara (IAA), L. Jorda (LAM), A. Kereszturi (RCAES), M. Grabe (DLR), U. Mall (MPS), M. Steller (IWF) and others.

Method
Measurement

Development & construction of instrument(s)
Work on both expts, has started and initial designs are being prepared for approval by ESA.

Website
www.cometinterceptor.space

Purpose of Research

The European Space Agency (ESA) has recently selected Comet Interceptor as its first F-class mission (capped at 150 MEuro). The mission is due to be launched as a secondary payload together with Ariel.

Comet Interceptor will be sent to a Lagrangian point (L2) and wait until a Dynamically New Comet (DNC) or an interstellar object enters the inner Solar System. The spacecraft will then be sent to the object, deploy two sub-spacecraft from ESA and the Japan Aerospace Exploration Agency (JAXA), and perform a fast fly-by.

CoCa (Comet Camera) and MANiaC (Mass Analyser for Neutrals in a Coma) are two of the principal instruments onboard the main spacecraft. Both instruments will be built by a consortium led by the University of Bern in an approach designed to minimise costs while maximising the scientific return.

The specific goals of the programme include the following:

- To image the nucleus of a DNC with CoCa.
- To obtain the chemical composition of a DNC's ices with MANiaC.

The information from the Comet Interceptor mission will be compared to the detailed observations obtained at 67P/Churyumov-Gerasimenko and at 1P/Halley.

The aim will be to search for physical and chemical signatures that could reveal the properties of different comet reservoirs.

Past Achievements and Status

Phase A is just starting with adoption of the mission targeted for late 2021 or early 2022.

Initial designs for the two instruments have been performed and detailed precise requirements are now being developed. These will take into consideration the spacecraft capabilities and provisional spacecraft design.

A preliminary design drawing of the CoCa camera system is shown on the left. The telescope is based upon that used for CaSSIS while the detector and read-out will be derived from the JANUS instrument on ESA's Jupiter and Icy Moons Explorer (JUICE) mission.

Publications

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

Abbreviations

CoCa	Comet Camera
DNC	Dynamically New Comet
JANUS	Jovis, Amorum ac Natorum Undique Scrutator
JUICE	Jupiter and Icy Moons Explorer
MANiaC	Mass Analyser for Neutrals in a Coma

Time-Line	From	To
Planning	2020	2022
Construction	2023	2026
Measurement Phase	2028	2032
Data evaluation	2031	2035

9.4 MINPA – Mars Ions and Neutral Particles Analyser

Purpose of Research

The Mars Global Remote Sensing Orbiter and Small Rover mission, also known as Huoxing-1, is a mission currently implemented by China to send a spacecraft to Mars (Huoxing simply means Mars in Chinese).

The mission consists of an orbiter, a lander and a rover. The mission is planned to be launched in July 2020. 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 Subsurface Radar (OSR).
- Mars Ion and Neutral Particle 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	2020	
Data evaluation	2021	

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.

Charge conversion technology, developed by the University of Bern, is used for the registration of ENAs with the ionised particles being analysed by the ion optical system of the ion measurement.

MINPA has been successfully built and calibrated.

Publications

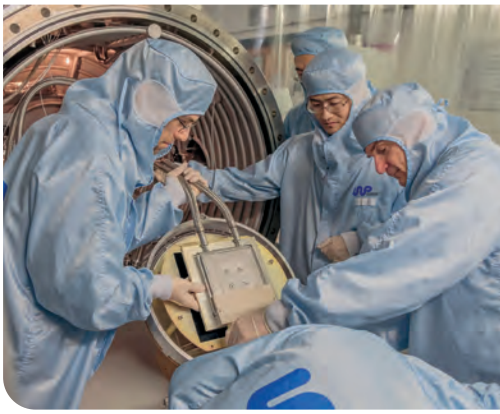
Galli A, Wurz P, Barabash S, Grigoriev A, Gunell H, Lundin R, Holmström M, Fedorov A (2006) **Energetic hydrogen and oxygen atoms at the nightside of Mars**, Space Science Rev. 126: 267-297.

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)

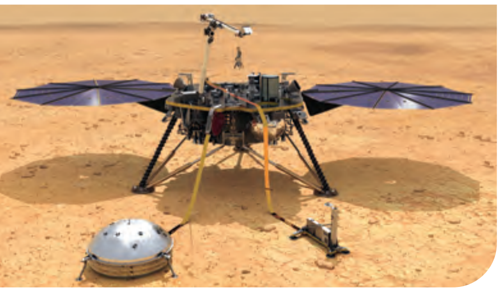
Co-Investigator(s)
A. Galli (UNIBE)

Method
Measurement

Development & construction of instrument(s)
Mars Ions and Neutral Particles Analyser (MINPA)

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

9.5 SEIS – InSight Seismic Experiment for Interior Structure



Artistic impression of Insight on its landing site.
Image credit: NASA

Institute
Inst. Geophysics, ETH Zurich
Zurich, Switzerland

In cooperation with
Inst. Physique du Globe, Paris, France
Imperial College, London, England
MPS, Göttingen, Germany
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, D. Mance, J. ten Pierick, P. Zweifel

Method
Measurement

Development & construction of 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

InSight's main objective is to improve our knowledge of the earliest history of the processes that shaped Mars. To this end it is studying the size, thickness, density and overall structure of the planet's core, mantle, and crust. The InSight Lander has deployed three instruments on the surface of Mars to take the first-ever in-depth look at the planet's internal activity. The three instruments are:

– The SEIS instrument for measuring seismic waves of Martian earthquakes.
– The HP3 instrument to quantify the heat flow from the planet's interior to its surface.
– The RISE experiment for calculating the wobbly rotation of the planet.

The SEIS instrument (Seismic Experiment for Interior Structure) is measuring seismic waves travelling through the interior structure and composition of the planet Mars. The main science objectives are defined as follows:

– Understand the formation and evolution of the terrestrial planets through investigation of the interior structure and processes of Mars.
– Determine the size, composition, and physical state (liquid/solid) of the core.
– Determine the thickness and structure of the crust.
– Determine the composition and structure of the mantle. Determine the present level of tectonic activity and the impact rate at 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 consists of the sensor assembly, the wind shield, a tether, and the acquisition and control electronics. The sensor assembly comprises of two 3-axial sensor assemblies mounted on a levelling mechanism: a 3-axis very broad-band (VBB) oblique seismometer, and an independent 3-axis short period (SP) seismometer.

The Institute of Geophysics (ETH Zurich) was in charge of the Electronics Box which consists of the data acquisition and control electronics. It includes:

– The acquisition electronics which continuously acquires the seismic sensor output channels and a set of housekeeping signals.
– The control electronics which control the instrument's levelling mechanism as well as the sensor configuration and re-centering.
– The power conditioning electronics for the whole SEIS instrument.

As SEIS is an InSight core instrument, the electronic box is considered mission critical. It was manufactured by SYDERAL SWISS SA (Switzerland), and was delivered to CNES (Toulouse, France) for integration with the SEIS instrument.

The Swiss Seismological Service (SED) and the Seismology and Geodynamics Group (SEG) at the Institute of Geophysics are responsible for the Marsquake Service that is building a catalogue of seismic events from SEIS data. The Marsquake Service includes both automatic and reviewed event detection and the characterisation of local seismicity and teleseismic events as well as meteor impacts. The goal of this service is to create a comprehensive high-quality event catalogue for Mars, a critical target for the InSight mission, and provide key input for the development of Martian crustal and deep-structure models. The group is developing dedicated analytical techniques for the characterisation of the Martian seismicity. Furthermore, the SEG and the Exploration and Environmental Geophysics Group (EEG) at the Institute of Geophysics have active research teams engaged in modelling and characterising the planetary structure.

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 hardware simulator (Simu-SEIS) were delivered to CNES and JPL/Lockheed Martin. The ELM is used in the Spacecraft Test Lab for flight software validation. The QM was integrated on the lander to support the ATLO (Assembly, Test and Launch Operations) process. Simu-SEIS is used to validate flight software with respect to certain instrument processes (sensor re-centering and levelling). The integration and test of the instruments on the spacecraft was successfully completed in March 2018. The spacecraft was moved from Lockheed Martin to the launch pad in Vandenberg, California. A final check-up of the instrument was performed at the end of 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 Mars earthquakes.

Publications

Banerdt WB, Smrekar SE, Banfield D, et al. (2020) **Initial results from the InSight mission on Mars**, Nat. Geosci. 13, 183-189, https://doi.org/10.1038/s41561-020-0544-y

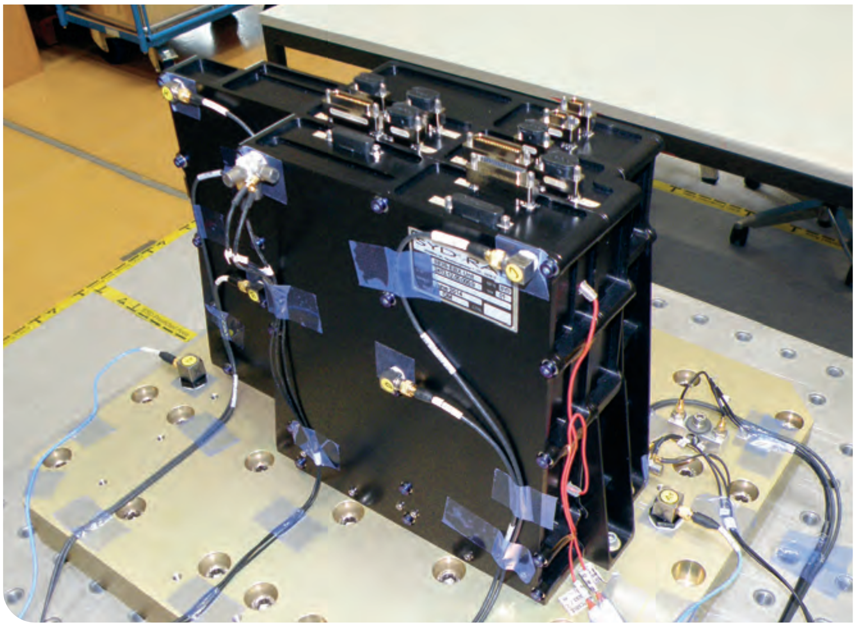
Giardini D, Lognonné P, Banerdt WB, et al. (2020) **The seismicity of Mars**, Nat. Geosci. 13: 205-212, https://doi.org/10.1038/s41561-020-0539-8

Lognonné P, Banerdt WB, Pike WT, et al. (2020) **Constraints on the shallow elastic and anelastic structure of Mars from InSight seismic data**, Nat. Geosci. 13: 213-220, https://doi.org/10.1038/s41561-020-0536-y

Abbreviations

Ebox	Electronics box
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
QM	Qualification Model
SEIS	Seismic Experiment for Interior Structure
Simu-SEIS	Hardware simulator

Time-Line	From	To
Planning	2010	2012
Construction	2012	2018
Measurement Phase	2018	>2020
Data evaluation	2018	>2020



SEIS Ebox QM Random Vibration Tests.

9.6 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 (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 CLosue-UP Imager (CLUPI), part of the Pasteur Payload on board 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 interprete 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 dril, 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 2m below the Martian surface.

Past Achievements and Status

The CLUPI Flight Model development will be achieved by the end of 2020, including complementary tests and software update.

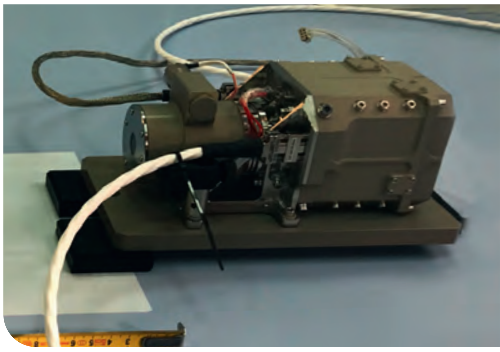
Time-Line	From	To
Planning	2003	2010
Construction	2011	2020
Measurement Phase	2023	2024
Data evaluation	2023	2026

A science validation phase with operation preparation is planned until the launch which has been recently postponed to August - September 2022 with an arrival on Mars in April 2023.

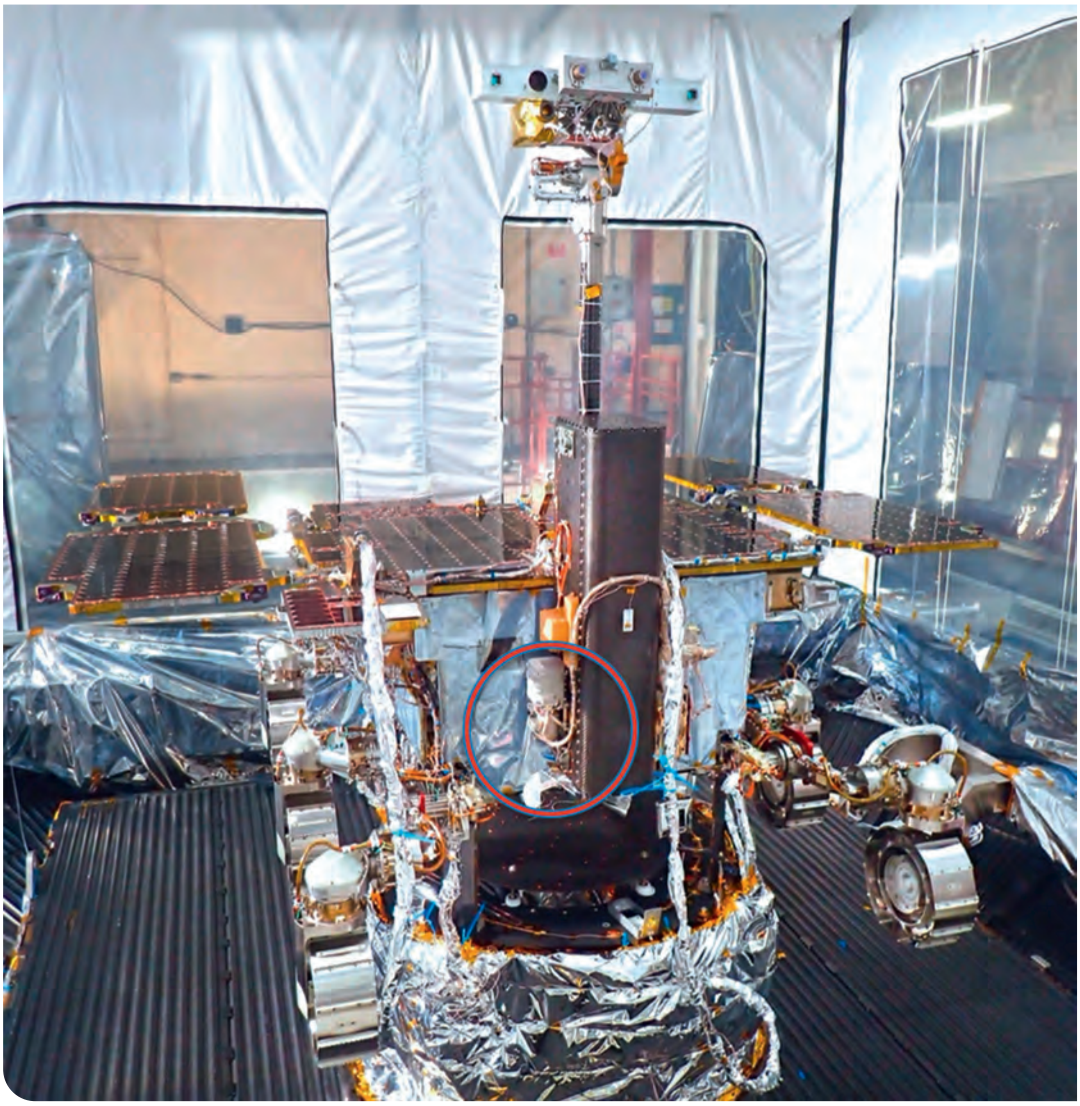
Publications

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.

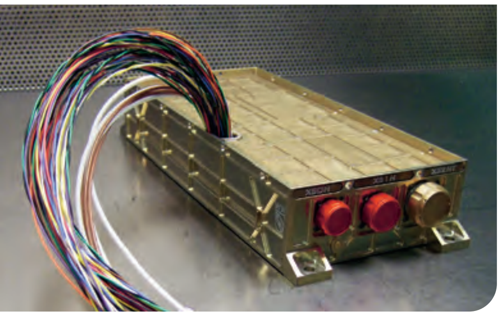


CLUPI Flight Model: Testing at ESA/Estec during imaging of a Martian meteorite.



CLUPI (in the circle) on the ExoMars Rover 2022 during tests. Image credit: Airbus.

9.7 LASMA – The Chemical Composition of Lunar Soils on Luna-Glob and Luna-Resurs



LASMA Engineering Model.

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

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

Principal Investigator(s)
G. Managadze (IKI)
P. Wurz (Co-PI, UNIBE)

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

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

Method
Measurement

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

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

Website
www.en.wikipedia.org/wiki/Luna-Glob
www.en.wikipedia.org/wiki/Luna_27

Purpose of Research

The Russian Space Agency will launch two lunar landers to land near the lunar South and North Poles, Luna-Glob and Luna-Resurs. 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). Elemental and isotopic analysis will be performed on 12 soil samples.

Past Achievements and Status

The spacecraft is currently under development, and the LASMA instrument has been delivered for integration on the spacecraft in Autumn 2017.

The launch of Luna-Glob is forseen for early 2022, and Luna-Resurs will launch in 2025. The LASMA instrument is a copy of the LASMA instrument that was part of the Phobos-Grunt mission.

Abbreviations

LASMA	Laser Ablation Mass Spectrometer

Time-Line	From	To
Measurement Phase	2022	2022
Data evaluation	2022	2024

Publications

Rohner U, Whitby J, Wurz P, Barabash S (2004) **A highly miniaturised laser ablation time-of-flight mass spectrometer for planetary rover**, Review Scientific Instruments 75(5): 1314-1322.

Tulej M, Riedo A, Neuland MB, Meyer S,Lasi D, Piazza D, Thomas N, Wurz P (2014) **A miniature instrument suite for in situ investigation of the composition and morphology of extraterrestrial materials**, Geostand. Geoanal. Res. 38: 441-466.

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.

9.8 NGMS – Volatiles in Lunar Soils from on Luna-Resurs

Purpose of Research

The Russian Space Agency will launch a lunar lander to land near the lunar South Pole, Luna-Resurs. The gas-chromatography mass spectrometer complex, GC-MS, which is part of the scientific payload of this 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 consists of a thermal differential analyser to release volatile material from the soil sample, a gas chromatograph for chemical pre-separation, and a mass spectrometer (NGMS), for detailed chemical analysis. NGMS is provided by the University of Bern.

Past Achievements and Status

Luna-Resurs spacecraft and scientific instruments are currently under development. Launch of Luna-Resurs is forseen for 2025. The Proto-flight model (PFM) of the NGMS was finished by the end of 2017, the flight spare model (FS) was finished in late 2018. The NGMS design is based on an earlier design used for stratospheric research.

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

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

GC-MS	Gas chromatography mass spectrometer
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. Tulej (UNIBE)
R. Fausch (UNIBE)

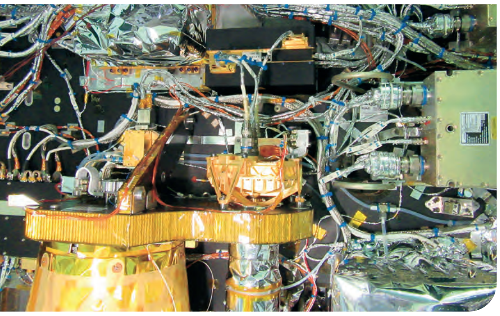
Method
Measurement

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

9.9 BELA – BepiColombo Laser Altimeter



BELA integrated in flight configuration on the spacecraft

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

In cooperation with
DLR Institute for Planetary Res. (DLR), Berlin-Adlershof, Germany
Max-Planck-Inst. Sonnensystemforsch. (MPS), Katlenburg-Lindau/Göttingen, Germany
Instituto de Astrofisica de Andalucia (IAA), Granada, Spain

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

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

Co-Investigator(s)
30 leading 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; CRISA, Spain

Website
www.bela.space.unibe.ch

Purpose of Research

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

- 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 lithosphere and crust properties by an admittance analysis between the two and with the help of a flexure model for the lithosphere. 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 time-of-flight electronics within an electronics box which also houses the instrument computer and power supply.

Past Achievements and Status

The instrument was successfully integrated on the spacecraft and launched in 2018. The post-launch commissioning was fully successful and the spacecraft is now on its way to Mercury. A paper describing the instrument in detail is being prepared for Space Science Reviews.

Abbreviations

BELA BepiColombo Laser Altimeter

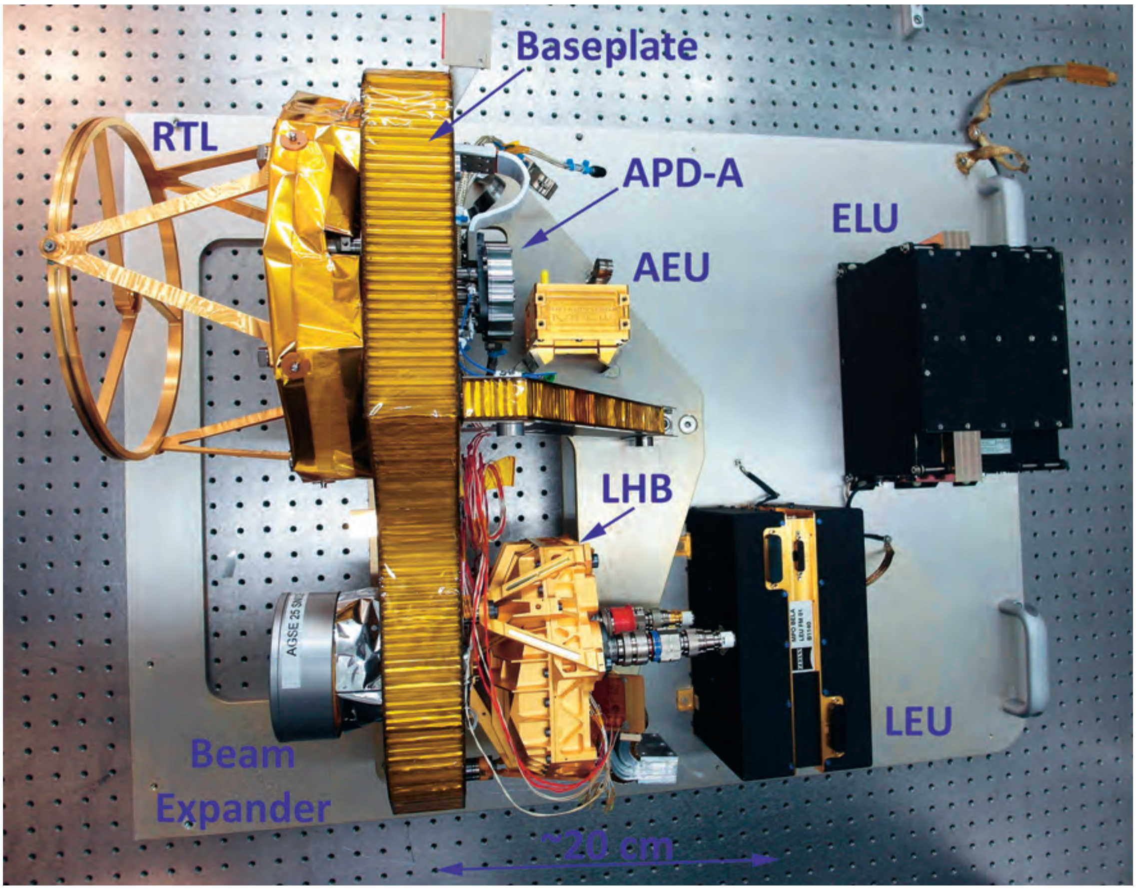
Publications

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.

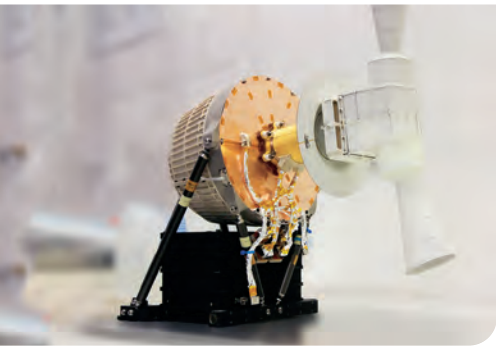
Thomas N, et al., (2007) **The BepiColombo Laser Altimeter (BELA): Concept and baseline design**, Planetary and Space Science 55: 1398-1413.

Time-Line	From	To
Planning	2004	2008
Construction	2008	2016
Measurement Phase	2025	2027
Data evaluation	2025	2028



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.

9.10 STROFIO and MPPE – Analysing the Exosphere from Onboard BepiColombo



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

Institute
Space Res. & Planet., 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 (UNIBE), D. Gamborino (UNIBE)

Method
Measurement

Development & construction of instrument(s)
Participation in two instruments: SERENA/ STROFIO on MPO, and MPPE on MMO

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

Website
www.serena.iaps.inaf.it
www.sci.esa.int/web/bepicolombo
www.solarsystem.nasa.gov/missions/bepicolombo/in-depth

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.

BepiColombo was successfully launched on 20 October 2018, and is on the way to Mercury, with the transfer taking until late 2025. Thus the dataphase will start late in 2026, at the earliest, 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 with the development of two mass spectrometers. One mass spectrometer is on the BepiColombo/Mercury Magnetospheric Orbiter (MMO) spacecraft to perform Energetic Neutral Atom (ENA) imaging of the space around Mercury. The second instrument is on the BepiColombo/Mercury Planetary Orbiter (MPO) spacecraft 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, set for BepiColombo.

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

Past Achievements and Status

The BeiColombo spacecraft is on its way to Mercury, with an expected arrival in late 2025.

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

Wurz P, Lammer H (2003) **Monte-Carlo simulation of Mercury's exosphere**, Icarus 164: 1-13.

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
MPPE	Mercury Plasma Particle
MPO	Mercury Planetary Orbiter Experiment
SERENA	Search Exopheric Refilling and Emitted Natural Abundances
STROFIO	Start from a Rotating FIeld mass spectrOmeter

9.11 PEP and NIM on JUICE

Purpose of Research

The European Space Agency selected the 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) will measure the chemical composition of the neutral atmospheres of the icy moons and their thermal ion population. From the composition of the atmospheres we will derive the composition of the surfaces of these moons, and that in turn will provide information on the chemical and physical processes during the formation of Jupiter and its moons from the protoplanetary disc.

JUICE is scheduled for launch in May 2022 and will arrive in the Jupiter system in 2030.

Past Achievements and Status

The JUICE mission is currently in the implementation phase. The JUICE mission was adopted by ESA in November 2014, and the industrial prime was selected in July 2015. PEP is one of the 10 selected science experiments for the JUICE missions.

The Swedish Institute for Space Physics is the PI institution, and the University of Bern is Co-PI institution for this experiment. The PEP experiment and the NIM instrument development are ongoing with delivery to the spacecraft planned for late 2020.

Publications

Galli A., Vorburger A, Wurz P, Pommerol A, Cerubini R, Jost B, Poch O, Tulej M, Thomas N (2017) **0.2 to 10 keV electrons interacting with water ice: radiolysis, sputtering, and sublimation**, Icarus 291: 36-45.

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

Abbreviations

JUICE	Jupiter and Icy Moons Explorer
NIM	Neutral and Ion Mass spectrometer
PEP	Particle Environment Package
PFM	Proto-Flight Model

Time-Line	From	To
Planning	Oct. 2012	Feb. 2014
Construction	Mar. 2014	Jun. 2021
Measurement Phase	Jan. 2030	Jul. 2033
Data evaluation	Jan. 2030	2036

PFM of the NIM spectrometer of the PEP experiment on the ESA JUICE mission. Electronic box is on the left, sensor is in the middle.

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)

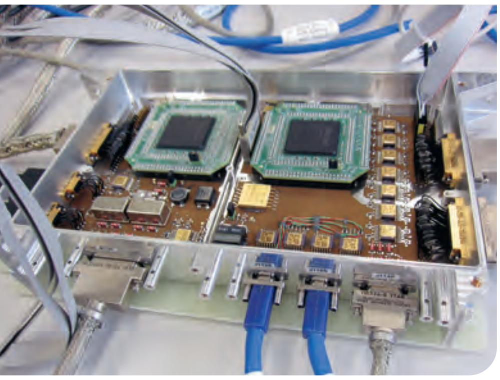
Method
Measurement

Development & construction of instrument(s)
NIM and PEP on JUICE

Industrial hardware contract(s) to
EMPA Dübendorf

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

9.12 GALA – Ganymede Laser Altimeter on JUICE



The Range Finder Module (RFM) test-board.

Institute
Space Res. & Planet., Phys. Inst., 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)
N. Thomas (UNIBE)

Method
Measurement

Industrial hardware contract(s) to
Thales-Alenia Space, Switzerland
SYDERAL SWISS SA, 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 JUICE mission. The University of Bern will contribute the rangefinder electronics to the laser altimeter system. This will be a derivative of the BELA rangefinder which has been successfully implemented for BepiColombo. The rangefinder will mostly be constructed by industry.

The rangefinder measures the time-of-flight of the laser pulse, as well as 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 Range Finder Module (RFM) 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 instrument is currently in Phase C/D. The RFM flight unit is at the time of writing being tested by DLR after system integration in the instrument electronics unit.

Abbreviations

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

Time-Line	From	To
Planning	2012	2017
Construction	2018	2021
Measurement Phase	2025	2033
Data evaluation	2031	2035

9.13 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 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, University of Bern, 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, the Institute of Applied Physics is conducting radiometric performance tests of the SWI receiver unit.

Past Achievements and Status

Building of optical hardware for the instrument structural thermal model and engineering model (EM) was completed in 2019 and the performance of the 600-GHz channel of the receiver unit EM was characterised. A Martin-Puplett Interferometer was developed to allow radiometric tests of the instrument in a thermal-vacuum chamber. Optical hardware for the instrument flight model was delivered to the Max Planck Institut für Sonnensystemforschung (MPS) in the first quarter of 2020.

The instrument critical design review was passed successfully in April 2019, and the JUICE mission is scheduled for launch in 2022.

Abbreviations

EM	Engineering Model
JUICE	Jupiter and Icy Moons Explorer
SWI	Submillimeter Wave Instrument

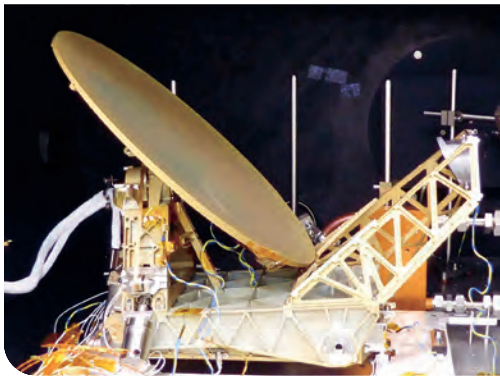
Publications

Jacob K, et al. (2019) **Transmission and reflection characterization of polarizing beam splitters at submillimeter wavelengths**, IEEE Trans. THz Sci. Technol. 9: 3, 272-281.

Jacob K, et al. (2019) **Radiometric performance of the 530 to 625 GHz receiver unit of the submillimetre wave instrument on JUICE**, Int. Symp. Space THz Technol., Gothenburg, Sweden.

Kotiranta M, et al. (2018) **Optical design and analysis of the Submillimeter-Wave Instrument on JUICE**, IEEE Trans. THz Technol. 8: 6, 588-595.

Time-Line	From	To
Planning	2010	2012
Construction	2013	2020
Measurement Phase	2030	2033
Data evaluation	2030	2036



Engineering model of SWI Telescope and Receiver Unit in the thermal vacuum chamber at 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

10 Life Science

10.1 Yeast Bioreactor Experiment

Institute
Inst. Medical Eng., School Eng. & Architecture,
Lucerne Univ. Appl. Sci. & Arts (HSLU)
Hergiswil, Switzerland

In cooperation with
Vrije Univ. Brussel, Lab. Structural Biology,
Dept. Bioeng. Sci., Brussels, Belgium

Ghent Univ., Lab. Protein Biochem. Biomol. Eng.,
Ghent, Belgium

KU Leuven & VIB, Dept. Molec. Microbiol.,
Lab. Molecular Cell Biology,
Leuven, Belgium

Principal Investigator(s)
R. Willaert (Vrije Univ. Brussel)

Swiss Investigator(s)
M. Egli (HSLU)

Co-Investigator(s)
B. Devreese (Univ. Gent)
P. Van Dijck (KU Leuven & VIB)

Method
Measurement

Industrial hardware contract(s) to:
RUAG Space, Nyon

Website
www.hslu.ch/de-ch/technik-architektur/forschung/kompetenzzentren/bioscience-and-medical-engineering/weltraumbiologie

Purpose of Research

The goal of the project is to investigate the effect of microgravity on physiological functions of the yeast cell strain, Saccharomyces cerevisiae. Previous studies conducted in a simulated microgravity environment have shown a change of a significant number of genes. Furthermore, S. cerevisiae grows in clusters under microgravity whereas that is not the case when cultivated on the ground.

In the proposed experiment, S. cerevisiae will be used to investigate the effect of microgravity on yeast growth and induced stress responses by applying heat as well as osmotic shock in microgravity.

An integrative-experimental approach will be used to assess the effect of microgravity. Therefore, various -omics technologies, such as, fluxomics, transcriptomics, proteomics and genomics, and specific cell analysis methods will be used to analyse the samples.

A network biology model for S. cerevisiae will be set-up in addition, to process the -omics data. This will lead to insight into how gravity influences global regulation of energy metabolism, (stress) signalling transduction pathways, transcriptional regulatory networks, gene regulatory networks, protein-protein interaction networks, and metabolic networks.

Yeast cultivation will be performed in a custom-made space bioreactor that allows continuous cultivation. This hardware will monitor and control growth parameters such as temperature and flow-rate, as well as monitor pH, oxygen and carbon dioxide levels which are necessary to achieve a steady-state and stable growth. The samples will be automatically withdrawn, treated (shock), filtrated and fixed.

Past Achievements and Status

The project is currently in the delta B phase where scientific requirements for the hardware development are established. Further details can be found on our website:

www.hslu.ch/de-ch/technik-architektur/forschung/kompetenzzentren/bioscience-and-medical-engineering/weltraumbiologie

Time-Line	From	To
Planning	2013	2014
Construction	2015	2022
Measurement Phase	2023	2024
Data evaluation	2025	2026

10.2 COW – Cartilage ExpOsed to Weightlessness

Purpose of Research

Chondrocytes are the sole resident cells found in articular cartilage, which line the articulating bones in joints and allow effortless movements. Chondrocytes are responsible for cartilaginous matrix synthesis, maintenance, and degradation. Since these cells are frequently exposed to mechanical loading patterns, it is generally believed that chondrocytes require mechanical stimuli for adequate cartilage homeostasis. However, to date, the molecular mechanisms of cellular force sensing (mechanotransduction) are not fully understood. Among other mechanisms, the cytoskeleton and mechanosensitive ion channels are thought to play a key role. The cytoskeleton is involved in many cellular functions, including proliferation, migration, and differentiation and largely determines the mechanical properties of a cell. Mechanosensitive ion channels allow the exchange of ions, such as calcium, across the cell membrane and are known to respond to mechanical forces.

Past Achievements and Status

In the context of the 3rd Swiss Parabolic Flight and the 71st ESA Parabolic Flight, we measured the fluidity of the cell membrane and the voltage across the cell membrane, termed membrane potential. We noticed that the membrane fluidity in primary articular chondrocytes is gravity dependent. The membrane properties are known to greatly influence the function of membrane proteins, including ion channels. We also found that the membrane potential, which is largely determined by ion channels, is also changed under altered gravity conditions. Because the membrane potential change was fast in response to altered gravity, it is reasonable to assume that ion channels could serve as a sensor for mechanosensation.

Throughout the 71st ESA Parabolic Flight, we examined if the cytoskeleton in primary articular chondrocytes changes during the course of a parabolic flight. For this we developed a novel hardware which allowed us to chemically fix cells at 7 time points over the course of a 31-parabola flight. The samples were subsequently stained for two protein members of the cytoskeleton (microtubules and vimentin) and microscopic images were acquired.

Time-Line	From	To
Planning	Aug. 2017	Jul. 2018
Construction	Jan. 2018	Mar. 2019
Measurement Phase	Jun. 2018	May 2019
Data evaluation	Jun. 2019	present

Simon Wüest floating in weightlessness during the 3rd Flight Campaign. Image credit: R. Sablotny.

Institute
Inst. Medical Eng. School Eng. & Architecture, Lucerne Univ. Appl. Sci. & Arts (HSLU)
Hergiswil, Switzerland

In cooperation with
F. Kohn, Univ. Hohenheim
Stuttgart, Germany

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

Co-Investigator(s)
M. Egli (HSLU)
F. Ille (HSLU)
C. Giger-Lange (HSLU)

Method
Measurement

Website
www.hslu.ch/spacebio

10.3 The Effect of Changing Gravity on Spinal Stiffness

Measurements in microgravity during the 71st ESA Parabolic Flight Campaign 2019. Image credit: Novespace.

Institute
Balgrist University Hospital, Integrative Spinal Research ISR, UZH Space Hub, Univ. Zürich (UNIZH), Zurich, Switzerland

Principal Investigator(s)
J. Swanenburg (UNIZH)

Co-Investigator(s)
P. Schweinhardt (UNIZH)
A. Langenfeld (UNIZH)

Method
Measurement

Research based on existing instruments
The sampling was performed on existing hardware from previous parabolic flight campaigns.

Website
www.innovation.uzh.ch/en/cluster/space-aviation/spacehub/Topics/Space-Life-Science/Spinal-Health.html

Purpose of Research

Everything on Earth is subject to gravity or gravitation. With every movement we make, we have to overcome the force of gravity. Therefore, the human body is optimally adapted to this constant force. Astronauts experience various changes / adaptations of their body in weightlessness. These have to some extent, effects on their health. More than half of astronauts suffer from back pain, just like the population back on Earth. The exact cause of back pain in astronauts is still unknown. A better understanding of the spine stabilisation mechanisms under normal gravity, hypergravity and weightlessness could be an important step towards solving the back-pain problem for astronauts.

The objective of this study was to determine the response of the lumbar spinal motor control caused by the change from earth to hyper-, and microgravity conditions. This was accomplished by measuring lumbar motor control changes during different gravity conditions obtained during parabolic flights. Lumbar spinal motor control was assessed by measuring spinal stiffness of the L3 vertebra. In addition, muscle activity of the erector spinae, multifidi, transversus abdominis, and psoas muscles was recorded using surface electromyography (EMG). Two distance sensors were used to assess lumbar curvature.

Past Achievements and Status

The 71st ESA parabolic flight campaign with the Airbus A310 ZERO-G took place from 20 to 24 May 2019 in Bordeaux, France. During each flight (3 in total), 30 parabolas were flown. Our team was represented by six test persons. Two subjects were measured one after the other during each flight. We were able to successfully measure all six participants. All systems worked well, and there were no adverse events.

First preliminary results show an increased spinal stiffness during microgravity and decreased stiffness during hypergravity. We observed an increase in spinal stiffness in microgravity, an increase in multifidi muscle activity, and a flattening of the lumbar curvature. Hypergravity led to a decrease in spinal stiffness, an increase in activity of all muscles, and flattening of the lumbar curvature.

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, Meier ML, Langenfeld A, Schweinhardt P, Humphreys BK (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.

Abbreviations

EMG Electromyography

Time-Line	From	To
Planning	2016	2016
Construction	2017	2018
Measurement Phase	2019	2019
Data evaluation	2019	2020

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.

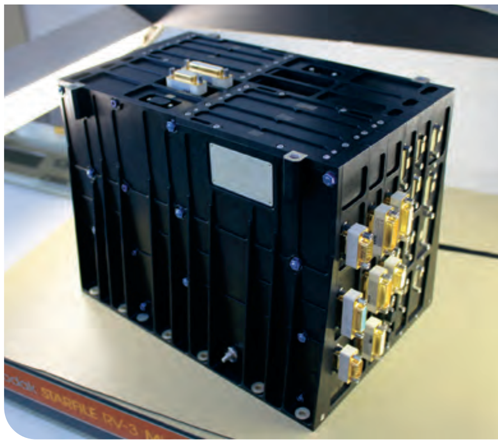
ESA coordinates and promotes the development of European space technology and ensures that the investment made goes to the lasting benefit of all Europeans. The EU aims to utilise the benefits of its space policy in its security, environment, transport, economic and social policy. ESA has an annual budget 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.

Swiss Collaboration

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 internationally is not a matter of course, it must be worked on. Having a location that is able to compete is the basis of success. Swissmem is committed to Swiss companies and the qualities of Switzerland as a 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



IASI-Ng MDE. Image credit: SYDERAL SWISS SA.

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

Clemessy (Switzerland) AG, www.clemessy.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

GF Casting Solutions, www.gfcs.com

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

shirokuma GmbH, www.shirokuma-gmbh.ch

SWISSto12 SA, www.swissto12.ch

SYDERAL SWISS SA, www.syderal.swiss

Synopta GmbH, www.synopta.ch

Thales Alenia Space Schweiz AG,
www.thalesgroup.com

ViaSat Antenna Systems SA, www.viasat.com

WEKA AG, www.weka-ag.ch

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 European 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.

OPTEL-μ® - the Thales Alenia Space Switzerland optical communcation down-link terminal for small satellites.

12 List of Authors

Marc Audard	Univ. Geneva, Geneva
Willy Benz	WP/PI, Univ. Bern, Bern
Enrico Bozzo	Univ. Geneva, Geneva
Rolf Dach	AIUB, Bern
Emanuelle David	EPFL, Lausanne
Marcel Egli	HSLU, Hergiswil
Laurent Eyer	Univ. Geneva, Geneva
Luigi Ferraioli	ETH Zurich, Zurich
Carlo Ferrigno	Univ. Geneva, Geneva
Wolfgang Finsterle	PMOD/WRC, Davos
Andrea Fischer	ISSI, Bern
Volker Gass	SSC, EPFL, Lausanne
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
Nicolas Produit	Geneva Obs., Geneva
Martin Rubin	Univ. Bern, Bern
Thomas Schildknecht	AIUB, Bern
Werner Schmutz	PMOD/WRC, Davos
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