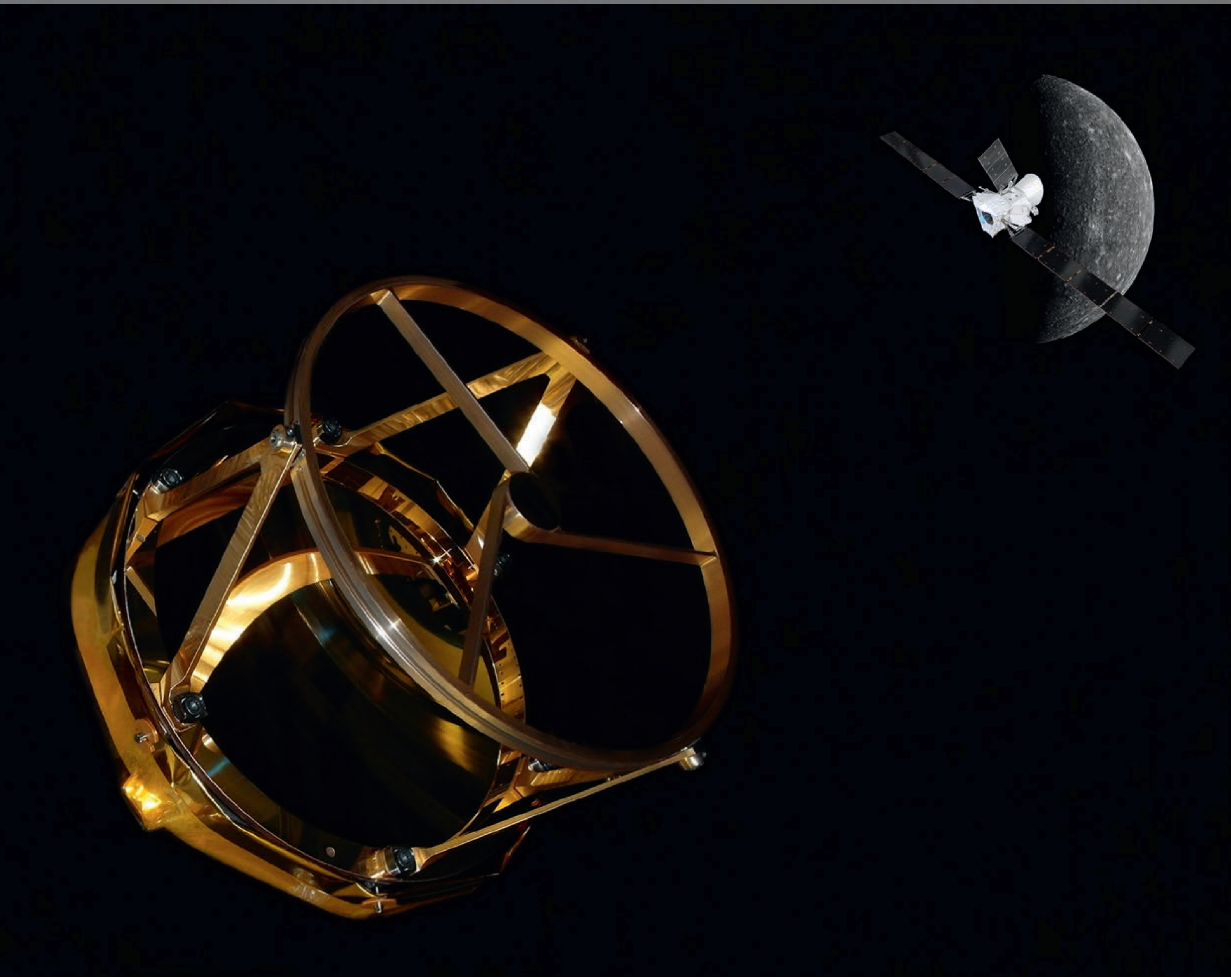
Space Research

2016 - 2018
in Switzerland



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Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
Académie des sciences naturelles

Space Research 2016–2018 in Switzerland

Report to the 42nd COSPAR Scientific Assembly
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Layout: Stephan Nyeki

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Cover Page: The BepiColombo Laser Altimeter (BELA) is one of a number of payloads onboard the BepiColombo mission to Mercury. The mission will launch from Kourou in 2018 on a 6-year flight before entering Mercury orbit. BELA will characterise and measure the figure, topography, and surface morphology of the planet with < 2 m precision. Image credits: BELA, Univ. Bern; BepiColombo spacecraft, ESA/ATG medialab; Mercury, NASA/JPL (Mariner 10 mission).

Contents

1 Foreword

The Committee on Space Research (COSPAR) is an interdisciplinary scientific organisation which is focussed on the exchange of information on progress of all kinds of space research. 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 42nd COSPAR Assembly (Pasadena, USA) 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 previous 2016 report was written when ESA's Rosetta spacecraft was in its extended mission at comet 67P/Churyumov-Gerasimenko. The mission was already clearly a major success for ESA, and the Swiss community was also proud of the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) experiment which contributed to the determination of the coma composition and density of the gas close to the nucleus. Although the mission ended in September 2016 with a semi-hard landing on the nucleus, data analysis continues with the detection of glycine being a recent highlight and further results are to be expected when more detailed analyses combining data sets from several instruments are undertaken. Swiss scientists have already taken significant steps in this direction.

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 first colour observations from in-orbit show a highly performant imager that can also support future landed missions. These will include NASA's InSight mission to Mars that will attempt to detect "Marsquakes" for the first time. Switzerland has made a contribution to the seismometer on the spacecraft. Swiss contributions to the ExoMars Rover (launch 2020) are also in development and indicate Switzerland's support for exploration of the Red Planet.

Switzerland has also contributed to the success of LISA Pathfinder. The recent detection of gravitational waves has given renewed impetus to the LISA mission which is now scheduled to fly in 2034. We expect that Switzerland will also contribute to LISA taking advantage of past experience. Switzerland has also played a significant role in the preparation of the ESA astrometry mission, GAIA, by contributing to the detection and analysis of variable celestial objects and characterising and classifying variable sources.

CLARA, a payload onboard the Norwegian NorSat-1 micro-satellite, was launched in July 2017, and is a new generation of radiometer to measure the Total Solar Irradiance (TSI). The main science goal of CLARA is to measure TSI with an uncertainty better than 0.4 $W m^{-2}$ on an absolute irradiance level. This continues the long-term involvement of Swiss institutes in studies of the Sun's output.

Looking further into the future, the Swiss space community is eagerly awaiting the operation of the first Swiss research satellite: CHEOPS, CHaracterizing ExOPlanet which was selected by ESA as a small nationally-led mission. The mission will study exoplanets using the transit method to determine radii and possibly the atmospheric structure of previously detected exoplanets. CHEOPS was adopted for construction in early 2014, designed in the last two years, and successfully passed the critical design review, giving green light for construction of the flight hardware. The instrument is now integrated on the spacecraft, and the launch is currently scheduled for early 2019. This mission is of special interest and importance to the Swiss community as it is the first Swiss science satellite.

Finally, Switzerland led the hardware development of Europe's first interplanetary laser altimeter experiment, BELA. This instrument will launch from Kourou in 2018 on a 6-year flight to Mercury where it will map the surface with <2 m precision.

As the highlights above illustrate, the Swiss space community is active and a reliable partner in space research activities. For your information and to trigger your interest, this book is a compilation of Swiss national projects related to space research. It shows broad interests in many fields with technical innovations to match.

Nicolas Thomas
President of CSR

Weblinks

COSPAR: *cosparhq.cnes.fr*
Swiss Committee on Space Research, Swiss Commission on Remote Sensing, Swiss Academy of Sciences: *naturalsciences.ch/organisations*

2 Institutes and Observatories

INTERNATIONAL
SPACE
SCIENCE
INSTITUTE

2.1 ISSI – 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

ISSI is an Institute of Advanced Studies at which scientists from all over the world are invited to work together to analyse, compare and interprete their data. Space 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 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 Univ. Bern contributes through a grant to the Director and in-kind facilities. The Space Research Inst. (IKI, RAS, Russia) and the Inst. of Space and Astronautical Sci. (ISAS, JAXA, Japan) support ISSI with an annual financial contribution.

Realisations in 2016 and 2017

In total, 131 International Team meetings, 8 Workshops, 5 Working Group meetings, and 5 Forums took place in the years 2016 and 2017. ISSI welcomes about 950 visitors annually.

Furthermore, ISSI offers a unique environment for facilitating and fostering interdisciplinary Earth Science research. Consequently ESA's Earth Observation Programme Directorate entered a contractual relationship with ISSI in 2008 to facilitate the synergistic analysis of projects of the International Polar Year, International Living Planet Teams, Workshops and Forums. The contract with the ESA Earth Science Directorate with ISSI has been extended until 2020.

ISSI jointly established with the National Space Science Center of the Chinese Academy of Sciences (NSSC/CAS) a branch called ISSI-BJ (International Space Science Institute – Beijing) in 2013. ISSI-BJ shares the same Science Committee with ISSI and uses the same study tools. Since 2014, ISSI has released together with ISSI-BJ an annual joint Call for Proposals for International Teams in Space and Earth Sciences.

ISSI is also 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. ISSI is a participant in the Europlanet Activity called "Innovation through science networking" and is working together with eight other Europlanet institutes to organise three Workshops and two strategic Forums over the

Directors

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duration of the contract which will address some of the major scientific and technical challenges of present-day planetary sciences. Europlanet 2020 RI will run until 2019.

All scientific activities result in some form of publication, e.g. in ISSI's hardcover book series *Space Sciences Series of ISSI* (SSSI), *ISSI Scientific Report Series* (SR), both published by Springer or individual papers in peer-reviewed international scientific journals. As at the end of 2017, 58 volumes of SSSI, and 15 volumes of SR have been published. Information about the complete collection can be found on ISSI's website: www.issibern.ch, in the section "Publications".

Publications

The following new volumes appeared in 2016 and 2017:

SSSI Volume 48: *Helioseismology and Dynamics of the Solar Interior,* M. J. Thompson, A. S. Brun, J. L. Culhane, L. Gizon, M. Roth, T Sekii (Eds.), ISBN 978-94-024-1033-4, 2017.

SSSI Volume 51: *Multi-Scale Structure Formation and Dynamics in Cosmic Plasmas*, A. Balogh, A. Bykov, J. Eastwood, J. Kaastra (Eds.), ISBN 978-1-4939-3546-8, 2016.

SSSI Volume 52: *Plasma Sources of Solar System Magnetospheres*, A. F. Nagy, M. Blanc, C. Chappell, N. Krupp (Eds), ISBN 978-1-4939-3543-7, 2016.

SSSI Volume 54: *The Strongest Magnetic Fields in the Universe,* V. S. Beskin, A. Balogh, M. Falanga, M. Lyutikov, S. Mereghetti, T. Piran, R. A. Treumann (Eds.), ISBN 978-1-4939-3549-9, 2016.

SSSI Volume 55: *Remote Sensing and Water Resources*, A. Cazenave, N. Champollion, J. Benveniste, J. Chen (Eds.), ISBN 978-3-319-32448-7, 2016.

Volume 58: *Integrative Study of the Mean Sea Level and its Components*, A. Cazenave, N. Champollion, F. Paul, J. Benveniste (Eds.), ISBN 978-3-319-56490-6, 2017.

SSSI Volume 59: *Dust Devils*, D. Reiss, R. Lorenz, M. Balme, L. Neakrase, A.P. Rossi, A. Spiga, J. Zarnecki (Eds.), ISBN 978-94-024-1133-1, 2017.

SSSI Volume 60: *Earth's Magnetic Field: Understanding Geomagnetic Sources from the Earth's Interior and its Environment*, C. Stolle, N. Olsen, A. D. Richmond, H. Opgenoorth (Eds.), ISBN 978-94-024-1224-6, 2017.

Scientific Reports

Volume 14: *Inventing a Space Mission – The Story of the Herschel Space Observatory*, V. Minier, R.M. Bonnet, V. Bontems, T. de Graauw, M. Griffin, F. Helmich, G. Pilbratt, S. Volonte, Results of an ISSI Working Group, ISBN 978-3-319-60023-9, 2017.

Volume 16: *Air Pollution in Eastern Asia: An Integrated Perspective*, I. Bouarar, X. Wang, G.P. Brasseur (Eds.), Results of an ISSI Team, ISBN 978-3-319-59488-0, 2017.

Other Publications

The Working Group "Carbon Cycle Data Assimilation" led by M. Scholze and M. Heimann published all their results in an interactive open-access journal of the European Geosciences Union: https://www.atmos-chem-phys.net/special_issue11_192.html.

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 21 (2015–2016) and 22 (2016–2017), which are available online (http://www.issibern.ch/publications/ar.html).

Outlook

Thirty-one new International Teams, approved in 2017 by the Science Committee, are starting their activities in the 23rd business year (2017/18). In addition, six Workshops will take place in the 23rd business year:

- Space-Based Measurement of Forest Properties for Carbon Cycle Research.

- Clusters of Galaxies: Physics and Cosmology.

- Comets: Post 67P Perspectives (in Collaboration with MiARD).

- Role of Sample Return in Addressing Major Outstanding Questions in Planetary Sciences (In Collaboration with Europlanet).

- Understanding the Relationship between Coastal Sea Level and Large-Scale Ocean Circulation.

- ExoOceans: Space Exploration of the Outer Solar System Icy Moons Oceans (in Collaboration with ESSC-ESF).

2.2 ISDC – INTEGRAL Science Data Centre

Institute

Dept. Astronomy,
Univ. Geneva (UNIGE)

In Cooperation with:

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

Prinicipal Investigator

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.

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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 Center, Science Operation Center (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 date, ISDC members have participated in about 20% of the nearly 3000 publications based on INTEGRAL data.

Past Achievements and Status

INTEGRAL was launched in October 2002 and its data are not only used for papers and PhD theses (more than 100 at present), 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 all but one double black-hole mergers detected by LIGO and detected, together with the gamma-ray monitor onboard the Fermi observatory, 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 has conducted reviews in 2010, 2012, 2014, and 2016, and concluded that fuel consumption, solar panel and battery ageing, and orbital evolution will allow the mission to be prolonged for many more years. In 2018, an operational review will ascertain the reliability of INTEGRAL for the next extension (2019–2020), for which the budget has already been approved by the ESA SPC. Further extensions 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 Center 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 performs scientific validations to report relevant "hot" discoveries in collaboration with guest observers. Several astronomer's telegrams, led 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.

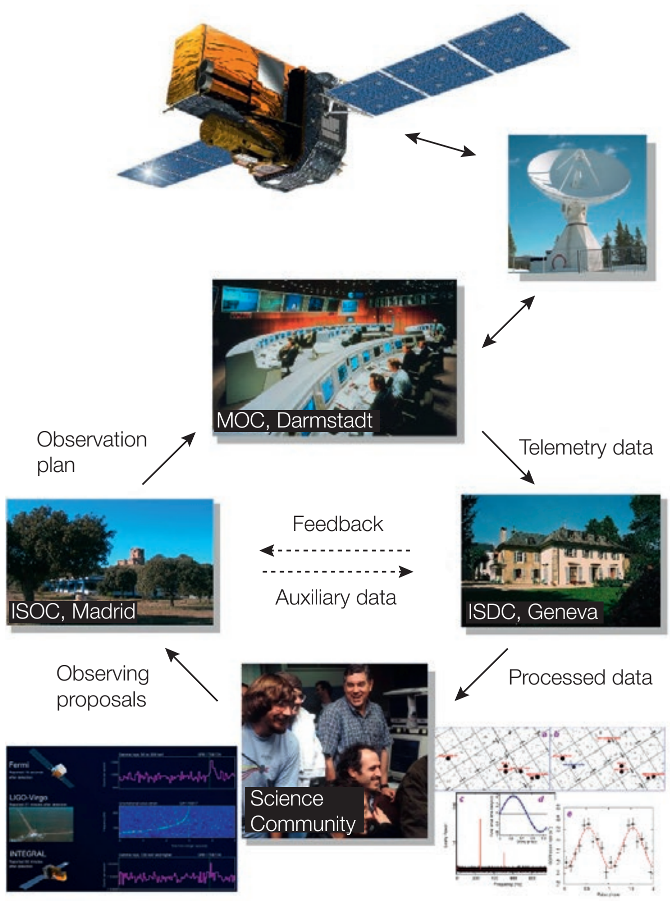
Based on an approach merging high-energy astrophysics with particle physics, astroparticle physics is rapidly developing around ISDC. Its central topics are the nature of dark matter and dark energy, the origin of cosmic rays and astrophysical particle accelerators. Research in this field involves data 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

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

2. Savchenko, V., C. Ferrigno 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.

3. Savchenko, V., C. Ferrigno 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.



Schematic view of the INTEGRAL ground segment activities.

2.3 CODE – Center for Orbit Determination in Europe

Institute

Astronomical Institute,
Univ. Bern (AIUB), Bern

In Cooperation with:

Bundesamt für Landestopographie (swisstopo), Wabern, Switzerland

Bundesamt f. Kart. u. Geodäsie (BKG), Frankfurt a. M., Germany

IAPG, Technische Universität München, Germany

Principal/Swiss Investigator

R. Dach (AIUB)

Co-Investigators

A. Jäggi (AIUB)
E. Brockmann (swisstopo)
D. Thaller (BKG)
U. Hugentobler (IAPG)

Method

Measurement

Res. Based on Existing Instrs.

GNSS data analysis and software development.

Website

www.aiub.unibe.ch

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 Institute of Astronomical and Physical Geodesy (IAPG) of the Technische Universität München, Munich, Germany. Since the early pilot phase of the IGS (21 June 1992) CODE has been running continuously. The operational processing is located at AIUB using the Bernese GNSS Software package that is developed and maintained at AIUB for many years.

Nowadays, data from about 250 globally distributed IGS tracking stations are processed every day in a rigorous combined multi-GNSS (currently the American Global Positioning System (GPS) and the Russian counterpart GLONASS) processing system of all IGS product lines (with different latencies). CODE started with the inclusion of GLONASS in its regular processing scheme back in May 2003. For five years it has been the only analysis center following this approach. In the meanwhile, other IGS analysis centers have started to follow this strategy as well.

In a seperate processing line, a fully integrated five-system solution has developed, including the established GNSS, GPS and GLONASS but also the currently developed systems, namely the European Galileo, the Chinese BeiDou, and the Japanese QZSS. The resulting solution is generated in the frame of the IGS multi-GNSS extension (IGS MGEX).

Past Achievements and Status

The main products are: i) precise GPS and GLONASS orbits, ii) satellite and receiver clock corrections, iii) station coordinates, iv) Earth orientation parameters, v) troposphere zenith path delays, and vi) 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 realisation of the International Terrestrial Reference Frame (ITRF). The daily positions of the Earth's rotation axis with respect to the Earth's crust as well as the exact length-of-day, is determined 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 antennae 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.

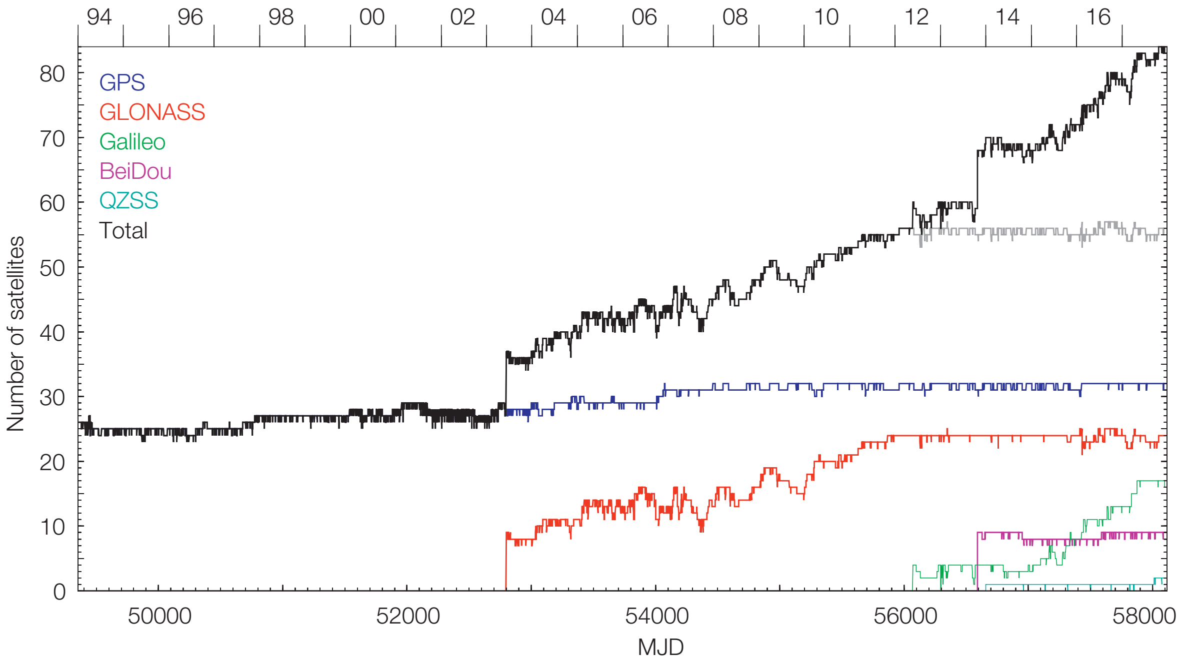
Abbreviations

CODE	Center for Orbit Determination in Europe
GNSS	Global Nav. Satellite Sys.
GPS	Global Positioning System
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema
IGS	Int. GNSS Service
ITRF	Int. Terrestrial Ref. Frame
LEO	Low Earth Orbit
QZSS	Quasi-Zenith Satellite Sys.

Publications

A list of recent publications is available at:

www.bernese.unibe.ch



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

eSPACE

Space Engineering Center

2.4 eSpace – EPFL Space Engineering Center

Mission

The EPFL Space Engineering Center (eSpace) shall contribute to space knowledge and exploration by providing world-class education, leading space technology developments, coordinating multi-disciplinary learning projects and taking EPFL's laboratory research to space.

Vision

To establish EPFL as a world renowned Center of Excellence in Space Engineering, and creating intelligent space systems in service to humankind.

Description

The Space Engineering Center (eSpace) is an interdisciplinary entity with the mission of promoting space related research and development at EPFL. eSpace was created in 2014 following a restructuring of the "Swiss Space Center". eSpace is active in three key areas: education, development projects and fundamental research. The center coordinates the minor in Space Technologies which allows master-level students to acquire extensive formal teaching in the field. These theoretical classes are complemented by hands-on multidisciplinary projects which often lead to the construction of real hardware (e.g. SwissCube, with ~200 students involved).

The center possesses expertise particularly in the field of system engineering, including Muriel Richard-Noca and Anton Ivanov as part of its senior staff, two experienced scientists who worked at NASA-JPL prior to joining EPFL. eSpace also relies on 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 to computer vision, and help take these technologies to space.

Institute

EPFL Space Engineering Center (eSpace)

Director

J.-P. Kneib

Staff

5 Scientific, 1 Admin.

Contact Information

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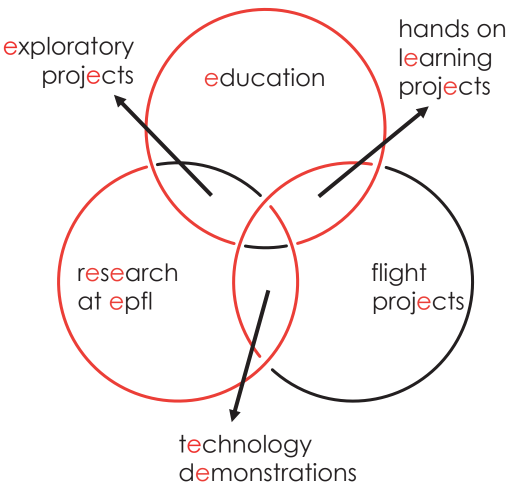
URL: http://eSpace.epfl.ch



2.5 SSA – International Space Situational Awareness

Purpose of Research

The central aim of Space Situational Awareness is to acquire information about natural and artificial objects in Earth's orbit. The growing number of so-called space debris - artificial non-functional objects - 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: i) through extending the catalogues of "known" space objects toward smaller sizes, ii) by acquiring statistical orbit information on small-size objects in support of statistical environment models, and iii) by characterising objects to assess their nature and to identify the sources of space debris.

The research is providing the scientific rationale to devise efficient space debris mitigation and remediation measures enabling sustainable outer space activities.

Past Achievements and Status

This is an ongoing international collaboration between the Astronomical Institute of the University of Bern (AIUB), the Keldish Institute of Applied Mathematics (KIAM), Moscow, ESA, and 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 Situational Awareness preparatory programme.

Publications

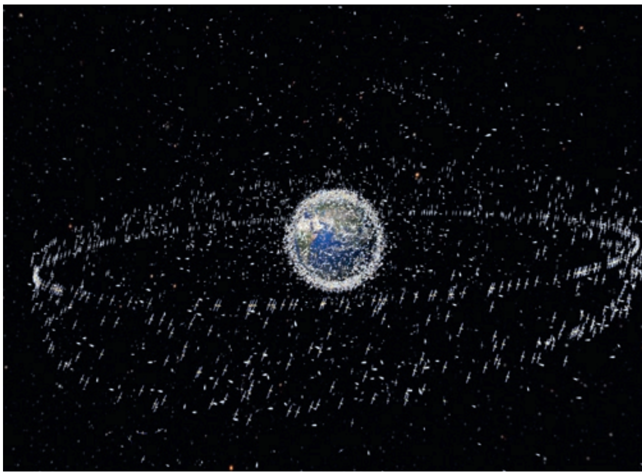
1. Šilha, J., J.-N. Pittet, T. Schildknecht, M. Hamara, (2018), Apparent rotation properties of space debris extracted from photometric measurements, *Adv. Space Res*., 61, 844-861, https://doi.org/10.1016/j.asr.2017.10.048

2. Šilha, J., T. Schildknecht, A. Hinze, T. Flohrer, A. Vananti, (2017), An optical survey for space debris on highly eccentric and inclined MEO orbits, *Adv. Space Res*. 59, 181-192, https://doi.org/10.1016/j.asr.2016.08.027

3. Vananti, A., T. Schildknecht, H. Krag, (2017), Reflectance spectroscopy characterization of space debris, *Adv. Space Res*. 59, 2488-2500, https://doi.org/10.1016/j.asr.2017.02.033

Abbreviations

SSA	Space Situational Awareness
SMARTnet	SMall Aperture Robotic Telescope network
ZIMLAT	Zimmerwald Laser and Astrometry Telescope
ZimSMART	Zimmerwald SMall Aperture Robotic Telescope



Graphical representation of the space debris population of objects >10 cm as seen from 15 Earth radii (ESA).

Institute

Astron. Inst. Univ. Bern (AIUB), Bern

In Cooperation with:

European Space Agency (ESA)
Keldish Institute of Applied Mathematics (KIAM), Moscow
International Scientific Optical Observation Network (ISON)
DLR/German Space Operation Center (GSOC)

Principal Investigators

T. Schildknecht (AIUB)

Co-Investigators

I. Molotov (KIAM), H. Fiedler (DLR)

Method

Measurement, Compilation

Observatories

Zimmerwald, Switzerland
Sutherland, South Africa
ESA, Tenerife
ISON telescopes

Website

www.aiub.unibe.ch

2.6 SSC – Swiss Space Center

Director

V. Gass (EPFL)

Staff

3 Professors
16 Scientific & Technical
2 Administrative

Board of Directors

R. Krpoun (SERI/SSO)
M. Gruber (EPFL)
D. Günther (ETHZ)

Steering Committee

M. Rothacher (ETHZ, chairman)
M. Thémans (EPFL)
U. Frei (SSO)
U. Meier (Industry rep.)
C. Schori (Industry rep.)
A. Neels (RTO rep.)
S. Krucker (Academic rep.)

Contact Information

Swiss Space Center
EPFL, PPH338, Station 13
CH-1015 Lausanne, Switzerland
Tel.: +41 21 693 69 48
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ETH Zurich, c/o Inst. Geodesy and Photogrammetry, HIL C61.3,
Stefano-Franscini Platz 5,
CH-8093 Zurich, Switzerland
Tel.: +41 44 633 30 56

Website

www.spacecenter.ch

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 2017, the Swiss Space Center welcomed four new industrial members (Synopta, MPS, Picterra, and Thales Alenia Space Switzerland), one academic institution (University of Zürich) and one RTO (EAWAG).

Apart from the founding members which constitute the BoD (SSO, EPFL, ETHZ), 32 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.

Activities 2017

During 2017, two important events were organised by the Swiss Space Center, following the request of its network.

A catalogue of Member competences entitled "Members' Profiles" was edited in March 2017. This document is available for download on the SSC website.

a) Earth Observation in Switzerland – Needs and Vision

The members of SSC's working group on Earth Observation and Remote Sensing initiated and organised a first gathering of the Swiss EO community on 16 March 2017 in Bern. The goal of the workshop was to bring Swiss Space Earth Observation and Remote Sensing (EO) together and discuss the needs and future vision of the different players.

b) Roundtable on "COTS for Space Mechanisms"

The main conclusions drawn from the roundtable included: i) There is no way around COTS (cost, planning, availability), ii) it is not possible to use COTS as is, iii) mechanical COTS very often need to be adapted to the specific application, iv) COTS require a large effort, v) one should not rush into a COTS approach with overly optimistic assumptions, and vi) the correct ratio between "traditional space-grade" and COTS must be found.

National Activities

"Mesures de Positionnement" (MdP) Call 2016

Twelve studies were selected by SERI/SSO and carried out over 15 months from November 2016 to January 2018. The main objectives of this call included the following aspects:

• To foster the development of innovative ideas and new products related to the space sector.

• To promote the collaboration between Swiss industrial and academic partners to obtain a more stable and better structured Swiss space landscape.

• To better position Swiss industry with regard to future European and worldwide activities, so as to be ready to submit competitive bids when the respective calls are published.

• To increase the technological maturity of ideas developed by academia and to promote competitive space products thanks to partnerships with industry.

Call for Ideas 2017 – Third Edition

Call for Ideas to Foster Low Technology Readiness Level (typically TRL 1-2; research and development studies related to space activities) was launched in March 2017. Out of nearly 20 high-quality proposals, seven projects were short-listed in a very competitive selection process.

During the implementation, the project teams studied their concepts from a space perspective and advanced on the maturity of the concepts for space applications. All projects were successfully concluded, and follow-up activities have been identified. With the second successful implementation of this project opportunity, the Call for Ideas has been consolidated and strengthened as an instrument to identify and boost space innovations in Switzerland.

Outreach to Secondary Schools

To inspire secondary school students to become the explorers of tomorrow, 1062 students, aged 11 to 16, and 100 teachers were invited to Lausanne to participate in an event with Claude Nicollier, French astronaut Jean-François Clervoy, Astrophysician Michel Mayor and Moonwalker Charlie Duke. The audience paid close attention and reacted with enthusiasm to the honor of having such legends on stage.

Outreach Event for Secondary Schools.

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

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

Purpose of Research

The Zimmerwald Geodynamics Observatory 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).

Target scheduling, acquisition and tracking, and signal optimisation may be performed fully autonomously whenever weather conditions permit. The collected data are delivered in near real-time to the global ILRS data centers, while official products are generated by the ILRS analysis centers using data from the geodetic satellites, LAGEOS and Etalon. SLR significantly contributes to the realisation of the International Terrestrial Reference Frame (ITRF), especially with respect to the determination of the origin and scale of the ITRF.

Past Achievements and Status

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 to spaceborne optical transponders such as the Lunar Reconnaissance Orbiter (LRO).

The highly autonomous management of the SLR operations by the in-house developed control software is mainly responsible for Zimmerwald Observatory evolving into one of the most productive SLR stations worldwide in the last decade. This achievement is remarkable when considering 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 for space debris with CCD cameras attached to the multi-purpose telescope.

Publications

1. Lauber, P., M. Ploner, M. Prohaska, P. Schlatter, P. Ruzek, T. Schildknecht, A. Jäggi, (2016), Trials and limits of automation: experiences from the Zimmerwald well characterised and fully automated SLR-system, Proc. 20th Int. Workshop on Laser Ranging, Potsdam, Germany, 2016.

2. Andritsch, F., R. Dach, A. Grahsl, T. Schildknecht, A. Jäggi, (2017), Comparing tracking scenarios to LAGEOS and Etalon by simulating realistic SLR observations, EGU, Vienna, Austria, 24–28 April, 2017.

3. Schildknecht, T., A. Jäggi, M. Ploner, E. Brockmann, (2015), The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Swiss National Report on the Geodetic Activities in the years 2011–2015.

Institute

Astronomical Institute,
Univ. Bern (AIUB)

In Cooperation with:

Bundesamt für Landestopographie (swisstopo), Wabern, Switzerland

Principal Investigator

T. Schildknecht (AIUB)

Co-Investigators

P. Lauber, E. Cordelli (AIUB)

Method

Measurement

Website

www.aiub.unibe.ch

Abbreviations

ILRS	International Laser Ranging Service
ITRF	International Terrestrial Reference Frame
LRO	Lunar Reconnaissance Orbiter
SLR	Satellite Laser Ranging
ZIMLAT	Zimmerwald Laser and Astrometry Telescope

3 Swiss Space Missions

3.1 CleanSpace One

Purpose of Research

The collision between the American operational satellite Iridium and the Russian Cosmos in 2009 brought a new emphasis to the orbital debris problem. Although most of the work had concentrated on avoidance prediction and debris monitoring, all major space agencies are now claiming the need for Active Debris Removal (ADR). About 23 500 debris items of sizes above 10 cm have been catalogued. Roughly 2000 of these are remains of launch vehicles, 3000 belong to defunct satellites, and the rest are either mission-generated or fragmentation debris.

The motivation behind the CleanSpace One project is to increase international awareness and start mitigating the impact on the space environment by acting responsibly and removing our "debris" from orbit. The objectives of the project are thus to demonstrate technologies related to ADR which are scalable for the removal of micro-satellites, and to de-orbit SwissCube or any similar Swiss satellite that complies with the launch constraints.

This project will contribute to the Space Sustainability and Awareness with ADR actions.

Current activities include development of the capture system, Guidance-Navigation and Control, and systems related to the rendezvous sensors and image processing.

Past Achievements and Status

The project has identified industrial partners and is in the process of securing funding.

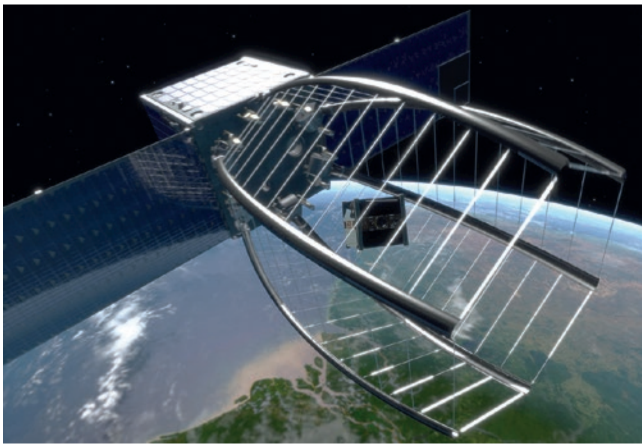
Publications

1. Richard-Noca, M., et al., (2016), Developing a reliable capture system for CleanSpace One, IAC-16-A6.5.2, 67th Int. Astronautical Congr., Guadalaraja, Mexico.
2. Chamot, B., et al., (2013), Technology Combination Analysis Tool (TCAT) for active debris removal, 6th Eur. Conf. on Space Debris, ESA/ESOC, Darmstadt, Germany.
3. Richard, M., et al., (2013), Uncooperative rendezvous and docking for MicroSats, The case for CleanSpace One, 6th Int.Conf. on Recent Advances in Space Technol., RAST 2013, Istanbul, Turkey.

Abbreviations

ADR	Active Debris Removal

Time-Line	From	To
Planning	Oct. 2017	Jul. 2019
Construction	Aug. 2019	Feb. 2022
Measurement Phase	Mar. 2022	Nov. 2022
Data Evaluation	Mar. 2022	Dec. 2022



SwissCube capture by CleanSpace One. Image credit: Jamani Caillet, EPFL.

Institute

EPFL Space Engineering Center (eSpace), EPFL

In Cooperation with:

HES-SO/HEPIA; AIUB; Fachhochschule NTB; ETHZ

Principal/Swiss Investigator

M. Richard-Noca (EPFL)

Co-Investigator

J.-P. Kneib

Method

Measurement

Development & Constr. of Instrs.

Mission design, sys. & sub-sys. design & validation, launch & flight operations.

Industrial Hardware Contract to:

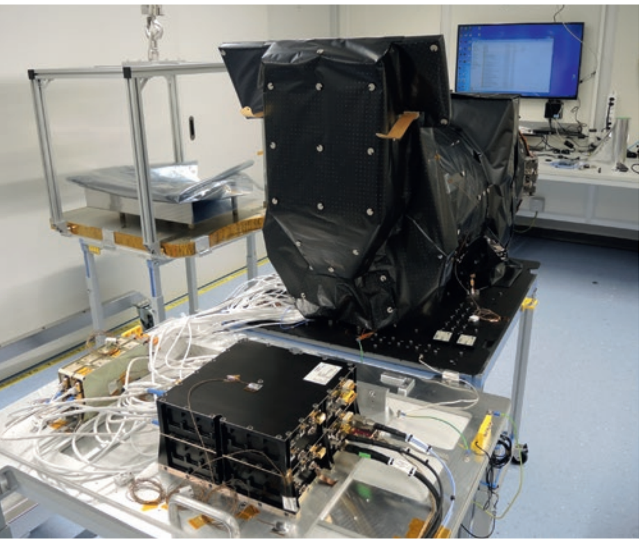
Airbus, ClearSpace SA

Method

Measurement

Website

espace.epfl.ch/CleanSpaceOne_1



The CHEOPS electronics boxes. On the right is the BEE (Back End Electronics) housing the Data Processing Unit (DPU) and the power converter. On the left, the SEM (Sensor Electronics Module) which controls the CCD as well as the temperature stabilisation of the focal plane module. Both boxes will be housed in the body of the spacecraft.

3.2 CHEOPS – Characterising ExOPlanet Satellite

Purpose of Research

CHEOPS is the first mission dedicated to search for transits of exoplanets by means of ultrahigh 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 characterization, 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.

- 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 may be addressed.

Institute

Center for Space and Habitability & Institute of Physics,
Univ. Bern (UNIBE)

In Cooperation with:

Institut für Weltraumforschung Graz, Austria
Center Spatial de Liege, Belgium
ETH Zurich, CH
Swiss Space Center, CH
Observatoire Geneve, CH
Lab. d'Astrophys. Marseille, France
DLR Inst. Planetary Res., Germany
DLR Inst. Opt. Sensor Sys., Germany
Konkoly Observatory
INAF Osserv. Astrofisico di Catania
INAF Osserv. Astro. di Padova
Centro de Astro. da Univ. do Porto
Deimos Engenharia
Onsala Space Observatory
Stockholm Univ., Sweden
Univ. Warwick, Univ. Cambridge, UK

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

At present, the CHEOPS telescope is undergoing a thorough and extensive calibration testing phase at the University of Bern which ended in April 2018.

Publications

1. Cessa, V., et al., (2017), CHEOPS: A space telescope for ultra-high precision photometry of exoplanet transits, *SPIE*, 10563, 105631.

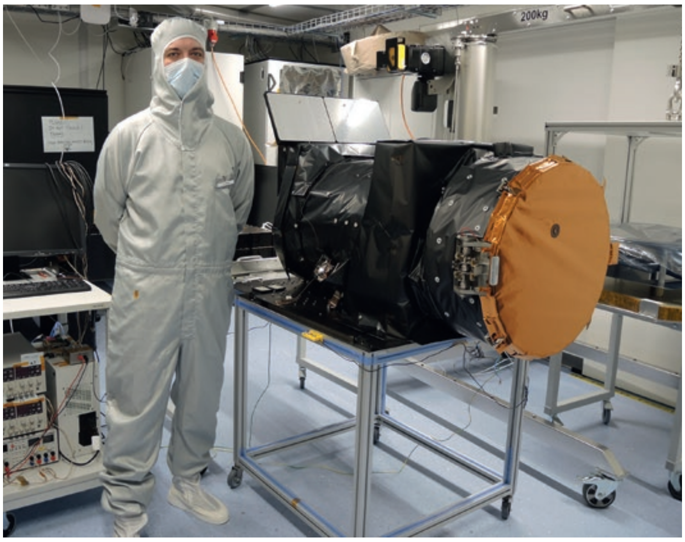
2. Beck, T., et al., (2017), The CHEOPS (CHaracterising ExOPlanet Satellite) mission: telescope optical design, development status and main technical and programmatic challenges, *SPIE*, 10562, 1056218.

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

Abbreviations

CHEOPS	CHaracterising ExOPlanet Satellite
CDR	Critical Design Review
E-ELT	European Extremely Large Telescope
EMC	Electromag. 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	Apr. 2018
Measurement Phase	2019	Mid 2022
Data Evaluation	2019	Open



The CHEOPS telescope completely assembled, integrated and ready for calibration at the University of Bern. Notice the prominent front baffle with its cover to protect the optics from dust contamination prior to launch. Also visible are the two white radiators on top which are part of the thermal stabilisation system of the read-out electronics. Standing next to the telescope is Dr. Thomas Beck, the CHEOPS system engineer.

Principal/Swiss Investigator

W. Benz (UNIBE)

Co-Investigators

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, and the CHEOPS Team

Method

Measurement

Development & Constr. of Instrs.

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

Industrial Hardware Contract to:

Almatech
Connova AG
Pfeiffer Vacuum AG
P&P
RUAG Space

Website

cheops.unibe.ch

4 Space Access Technology

4.1 ALTAIR – Air Launch Space Transportation Using an Automated Aircraft and an Innovative Rocket

The ALTAIR carrier and launcher performing the separation manoeuvre.

Institute

CMASLab, Inst. Des. Mat. & Fabr., D-MAVT, ETH Zurich, Switzerland

In Cooperation with:

ONERA, France; Bertin Technol., France; Piaggio Aerospace, Italy; GTD Sistemas de Inform., Spain; Nammo Raufoss, Norway; SpaceTec Partners, Belgium; CNES, France

Principal Investigator

N. Bérend

Swiss Principal Investigator

P. Ermanni (ETHZ)

Co-Investigators

G. Molinari (ETHZ), C. Karl (ETHZ)

Method

Simulation

Developments

Feasibility demonstration of a satellite launcher based on a semi-reusable hybrid aircraft-rocket design for low-cost, low-Earth-orbit space access.

Website

www.altair-h2020.eu

Purpose of Research

ALTAIR's strategic objective is to demonstrate the economic and technical viability of a novel European launch service for the rapidly growing small satellites market. The system is specially designed to launch satellites in the 50 – 150 kg range into Low-Earth Orbits, in a reliable and cost-competitive manner.

The ALTAIR system comprises an expendable launch vehicle built around hybrid propulsion and lightweight composite structures which is air-launched from an unmanned carrier aircraft at high altitudes. Following separation, the carrier aircraft returns to the launch site, while the rocket propels the payload into orbit, making the entire launch system partly reusable and more versatile than existing rideshare and piggyback launch solutions. ALTAIR will hence provide a dedicated launch service for small satellites, enabling on-demand and affordable space access to a large spectrum of users, from communication and Earth observation satellite operators to academic and research centers.

The key feature of the expendable rocket will be an advanced lightweight composite structure, designed around environmentally green hybrid propulsion stages. A versatile upper stage and innovative avionics contribute to mission flexibility and cost reduction, paired with novel ground system architectures. All systems are developed by exploiting multi-disciplinary analysis and optimisation techniques, and the resulting design will be supported by flight experiments to advance the maturity of key technologies.

Within the ALTAIR project, ETH Zurich will lead the development of the launcher structure, leveraging the know-how in structural design, multi-disciplinary optimisation, numerical modelling and composite materials manufacturing by CMASLab. By exploiting advanced composite materials, implementing novel and structurally optimised designs, and tailoring the composite manufacturing processes, the structural performance of the vehicle will be increased. These state-of-the-art design techniques will advance the technology of lightweight composite systems and promote the use of composite materials in launch vehicles, thereby expanding the current bounds of structural efficiency.

Past Achievements and Status

The project, funded through the EU Horizon 2020 programme, started in December 2015 and will be concluded in November 2018. Numerous design loops, involving constant improvement of the cost-per-kg performance of the launcher, have led to an effective and viable concept. The ongoing efforts are geared towards the refinement of the subsystems design, while flight tests performed on a scaled demonstrator of the entire system are planned to support the numerical analyses of the crucial captive flight phase and release manoeuvre.

Publications

1. Dupont C., et al., (2017), ALTAIR - Design & Progress on the Space Launch Vehicle Design, 7th Europ. Conf. Aeronautics & Space Sci. (EUCASS).

2. Dupont, C., et al., (2017), ALTAIR orbital module preliminary mission and system design, 7th Europ. Conf. Aeronautics & Space Sci. (EUCASS).

5 Astrophysics

5.1 Gaia Variability Processing and Analysis

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 1.7 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 is coordinated by the University of Geneva with an associated data processing center of about 60 people. The task of this coordination unit is first to statistically describe the time series and then classify the variable sources. Further specific analysis is done on a subset of sources to provide their astrophysical properties.

Past Achievements and Status

The Gaia spacecraft has been gathering data since Summer 2014. The First Data Release was made public in September 2016, in which the Gaia Data Processing and Analysis Consortium only released a small fraction of the data. In particular, variable stars were released much earlier than originally planned. We focused on Cepheid and RR Lyrae stars from the South Ecliptic pole, a region near stars of the Large Magellanic Clouds, and variability information for 3,194 stars was published of which ~10% were new. This data release was more like a showcase of the performance of Gaia.

Since late 2016, we have worked extensively on 120 billion Gaia photometric measurements to provide the first large catalogue of variable objects across the whole sky for the Second Data Release planned in April 2018. We will release classification and variability information together with time series for about half a million stars.

These catalogues are among the largest, if not the largest, ever published over the whole sky, and is the tip of the iceberg. The analysis of the first two years of data makes us confident that great science can be done with Gaia, and that the integration of the software pipelines of all Coordination Units is working under real-data conditions.

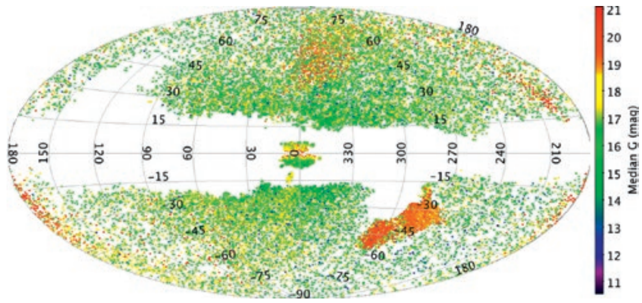
Publications

1. Gaia Collaboration, Brown, A.G.A., Vallenari, A., Prusti, T., et al., (2016), Gaia Data Release 1. Summary of the astrometric, photometric, and survey properties, *Astron. Astrophys*., 595, 2.

2. Eyer, L., Mowlavi, N., Evans, D. W., et al., (2017), Gaia Data Release 1: The variability processing & analysis and its application to the south ecliptic pole region, arXiv170203295.

3. Gaia Collaboration, Clementini, G., Eyer, L., Ripepi, V., et al., (2017), Gaia Data Release 1. Testing parallaxes with local Cepheids and RR Lyrae stars, *Astron. Astrophys*., 605, 79.

Time-Line	From	To
Planning	2006	2022
Construction	Cyclic development	2022
Measurement Phase	2014	2020
Data Evaluation	Cyclic	2022/2023



Sky distribution in Galactic coordinates of the cross-matched RR Lyrae stars from the literature, colour-coded with apparent magnitude (generally: higher means the stars are further away, though not accounting for extinction). The Magellanic clouds and Sagittarius stream are clearly visible (Image credit: ESA/Gaia/DPAC). An unrivalled catalogue of RR Lyrae stars is provided in Gaia Data Release-2.

Institute

Dept. Astron., Univ. Geneva (UNIGE)

In Cooperation with:

17 institutes in Europe, USA, Israel (more than 60 people)

Principal Investigator

ESA

Swiss Principal Investigator

L. Eyer (UNIGE)

Co-Investigators

N. Mowlavi, B. Holl, M. Audard, I. Lecoeur-Taibi, L. Rimoldini, L. Guy, O. Marchal, J. Charnas, and K. Nienartowicz, G. Jevardat de Fombelle (software co., SixSQ)

Method

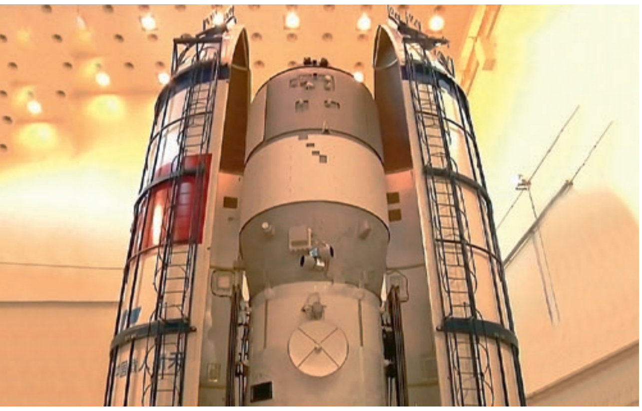
Measurement

Development of Software for

The Gaia mission

Website

www.unige.ch/sciences/astro/variability



POLAR can be seen integrated on Tiangong-2 which is attached to the "Long March" rocket just before the fairing is definitely closed.

5.2 POLAR

Institute

Data Center for Astrophysics (ISDC), Univ. Geneva

Dépt. de Physique Nucléaire et Corpusculaire (DPNC), Univ. Geneva

Paul Scherrer Institute (PSI), Villigen

In Cooperation with:

Institute for High Energy Physics (IHEP), Beijing, China

Nuclear Research Institute of Poland (NCBJ), Warsaw, Poland

Principal Investigator

S. Nan Zhang (IHEP)

Swiss Principal Investigator

N. Produit (ISDC)

Co-Investigators

M. Kole (DPNC)
Wojtek Hajdas (PSI)

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. It is dedicated to measurement of the polarisation of Gamma-Ray Bursts (GRB) in hard X-ray energies. GRBs belong to the most important subjects of contemporary astrophysics, and are linked with explosive births of black holes. The polarisation of the high energy component of the emission of these extragalactic events is one of the most important parameters to understand the GRB phenomenon. These parameters have not yet been measured with adequate statistics and controlled systematics.

POLAR is a wide field-of-view Compton polarimeter which uses light scintillation material. It covers an energy range from a few tens up to several hundred keV. The polarisation detection capability is 10 GRBs per year with a polarisation precision on the polarisation degree better than 10%.

Past Achievements and Status

After a week in space, POLAR started gathering data which was of such good quality that the Chinese authorities gradually increased the allocated data bandwidth. At its high point, the allocated bandwidth was up to ten times higher than initially foreseen. The first GRB was observed on the 28 September 2016, less than two weeks after the launch. Subsequently, GRBs were observed every 3 to 4 days.

The increase in allocated bandwidth allowed the minimum energy threshold to be drastically lowered and gave POLAR a sensitivity comparable to the FERMI GBM detector. This also allowed us to extend our research to monitoring of the Crab pulsar timing and made POLAR one of the most sensitive instruments for the search of potential electromagnetic counterparts of gravitational wave events.

Unfortunately in April 2017, after six months of excellent data, POLAR suffered a fatal flaw of the high voltage system shortly after leaving the South Atlantic Anomaly. Despite all our efforts, we were unable to switch on the power supply again, putting an end to the science exploitation of POLAR. It is still possible to communicate with POLAR, and the health status of all other instrumentation besides the high voltage system is periodically checked to raise the TRL level qualification of the other components.

During the six months of the scientific mission, we collected more data than we envisaged for the full three year mission and half the number of foreseen GRBs. The scientific data exploitation has just started. To date, several papers about the performance and the calibration of the instrument have been published.

The first GRB polarisation results will be published in mid-2018. Our Chinese colleagues have proposed a POLAR successor for the future Chinese space station. First designs and tests of the new components are currently ongoing.

Publications

1. Produit, N., et al., (2018), *Nucl. Instrum. Meth.*, A 877, 259.
2. Kole, M., et al., (2017), *Nucl. Instrum. Meth.*, A 872, 28.
3. Produit, N., et al., (2005), *Nucl. Instrum. Meth.*, A 550, 616.

Abbreviations

CSU	Tech. Engineering Center for Space Utilization
GBM	Gamma-ray Burst Monitor
GRB	Gamma-Ray Bursts
POLAR	POLAR is a compact gamma-ray polarimeter
TRL	Technology Readiness Level

Time-Line	From	To
Planning	2009	2011
Construction	2012	2014
Qualification	2014	2016
Measurement Phase	2016	2017
Data Evaluation	2017	2019

Method

Measurement

Research Based on Existing Instruments

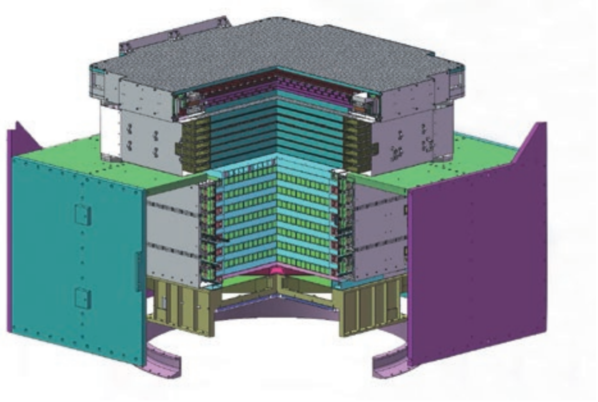
POLAR was designed, constructed and qualified by a Swiss collaboration. POLAR was launched as part of Tiangong-2 by the Technology and Engineering Center for Space Utilisation (CSU, China).

Website Addresses

isdc.unige.ch/polar/

polar.ihep.ac.cn/en/

POLAR flight model ready to be integrated on Tiangong-2 at the Jiuquan Chinese space center.



A sketch of the DAMPE payload showing the sub-detector systems.

5.3 DAMPE – DArk Matter Particle Explorer

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-converter (STK) which is made of six tracking double layers. Each consists of two layers of single-sided silicon strip detectors measuring the two orthogonal views perpendicular to the pointing direction of the apparatus.

Three layers of Tungsten plates with a 1 mm thickness are inserted in front of tracking layers 2, 3 and 4 for photon conversion. The STK is followed by an imaging calorimeter of about 31 radiation lengths thickness, made up 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, Bari, and 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 3 years of intensive effort. The final assembly was completed at the DPNC, delivered to China in April 2015 and integrated in to the satellite in May 2015. The DAMPE satellite was successfully launched on 17 December 2015. All sub-systems of DAMPE are functioning well.

The STK is performing above expectation. 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 >26 months 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 goup 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

Institute

Dépt. de Physique Nucléaire et Corpusculaire (DPNC), Univ. Geneva (UNIGE)

In Cooperation with:

INFN, Perugia, Italy
INFN, Bari, Italy
INFN, Lecce, Italy
IHEP, Beijing, China
PMO, Nanjing, China

Principal Investigator

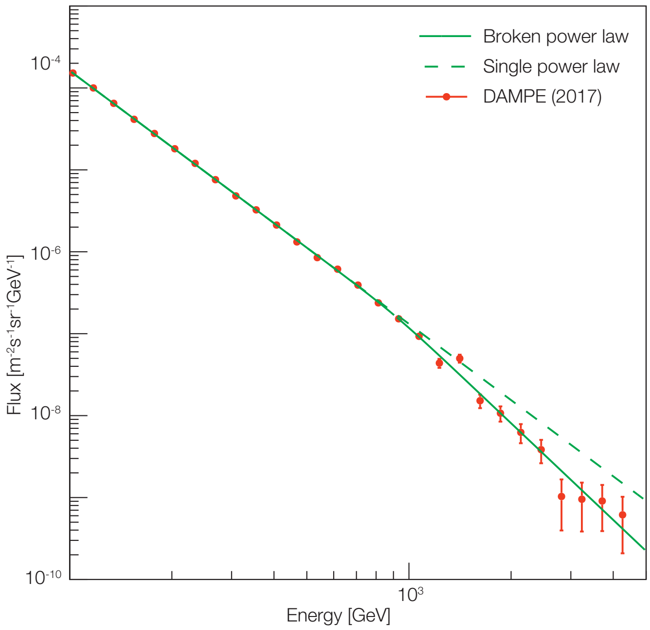
J. Chang (PMO, China)

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.

DAMPE will continue to operate for at least 3 more years. The DPNC group is involved in several major science data analysis projects, including proton and Helium flux measurements, and studies of high energy gamma-ray sources.

Publications

1. Ambrosi, G., et al., (2017), Direct detection of a break in the teraelectronvolt cosmic-ray spectrum of electrons and positrons, *Nature* 552, 63.
2. Chang, J., et al., (2017), The DArk Matter Particle Explorer mission, *Astroparticle Physics,* 95, 6–24.
3. Wu, X., et al., (2015), The Silicon-Tungsten Tracker of the DAMPE Mission, *PoS*, ICRC2015, 1192.



The Cosmic Ray Electron spectrum measured by DAMPE in the 100 GeV - 4.5 TeV range, showing the spectral break at about 1 TeV.

Abbreviations

DAMPE	DArk Matter Particle Explorer
STK	Silicon-Tungsten Tracker

Time-Line	From	To
Planning	2012	2013
Construction	2013	2015
Measurement Phase	2016	2021
Data Evaluation	2016	2025

Swiss Principal Investigator

X. Wu (UNIGE)

Method

Measurement

Industrial Hardware Contract to:

Composite Design SA, Crissier
Hybrid SA, Chez-le-Bart
Meca-Test SA, Geneva

Website

dpnc.unige.ch/dampe/index.html

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

5.4 LPF – LISA Pathfinder

Institute

Inst. Geophysics, ETH Zurich (ETHZ)

Physics Institute,
Univ. Zurich (UNIZH)

In Cooperation with:

Univ. Trento, Italy

Principal Investigators

S. Vitale (Univ. Trento)
K. Danzmann, (Albert Einstein Inst.)

Swiss Principal Investigator

D. Giardini (ETHZ)

Co-Investigators

P. Jetzer (UNIZH)
L. Ferraioli (ETHZ)
D. Mance (ETHZ)
P. Zweifel (ETHZ)

Purpose of Research

The LISA Pathfinder Mission (LPF) was a technology mission in view of ESA's planned L3 mission LISA (Laser Interferometer Space Antenna).

LPF has demonstrated the readiness of the LISA required technology including, gravitational reference sensor, laser interferometry and spacecraft platform stability. Its key objective was to test the key ideas behind gravitational wave detectors that free falling particles follow geodesics in space-time. LPF placed two proof masses (solid cubes of gold-platinum alloy, ~4.6 cm edge length, 2 kg mass) in a nearly perfect gravitational free-fall, and controlled and measured their motion with unprecedented accuracy and resolution. This has been achieved through state-of-the-art space technology and extremely careful design.

The Swiss contribution to LPF consisted of the development of a Gravitational Reference Sensor Front-End Electronics (GRS FEE) which sensed and controlled the position and attitude of the proof mass with respect to its frame and the spacecraft respectively, using ultra-stable capacitive sensing and electrostatic actuation techniques. The measurement and actuation required nanometer resolution and stability in the low-frequency band from 1 Hz down to 0.1 mHz. The GRS FEE was built fully redundant due to its criticality for the mission success.

The LISA mission will be dedicated to measure gravitational waves - for the first time in space - and thus to enable direct observation of a broad variety of systems and events throughout the Universe. This includes: i) galactic binary systems, ii) the coalescences of supermassive black holes brought together by galaxy mergers, iii) the coalescences of stellar mass black holes months in advance to ground-based detectors, iv) the inspiral of stellar-mass black holes and compact stars into central galactic black holes (so-called EMRI), v) and to gain unique information about the behaviour, structure and early history of the Universe.

LISA will complement/enhance earth-based interferometers such as LIGO and VIRGO and will open the gravitational wave window in space measuring gravitational radiation over a broad band of frequencies, from about 0.1 mHz to 1 Hz, a band where the Universe is richly populated by strong sources of gravitational waves.

The LISA Pathfinder science operation has demonstrated proof mass free-fall well beyond the requirements for the realisation of LISA.

Past Achievements and Status

The involvement of the Institute of Geophysics, ETH Zurich, and the Institute of Physics, University of Zurich, goes back to the year 2003. A technical team from the Institute of Geophysics ETHZ established the requirements, specifications and the concept of the GRS FEE in colaboration with the international partners, in particular with the University of Trento (Principal Investigator of LPF) and Airbus Defence and Space, Friedrichshafen (Prime). It prepared the necessary specification documents for the industrial work. The industrial contract with RUAG Space and thus the development of the GRS FEE started in April 2005. Furthermore the ETHZ group supervised the development process at RUAG together with the ESA Prodex office. The GRS FEE flight hardware was delivered by RUAG to Airbus, Friedrichshafen, Germany, in December 2010.

The LISA Pathfinder mission was eventually launched on 3 December 2015 by a VEGA launcher from Europe's space port, Kourou, in French Guiana. After several progressively expanded Earth orbits using its own propulsion module, the satellite has finally reached the L1 Lagrange point, 1.5 Mio kilometer away from Earth.

The LPF satellite was controlled by the European Space Operations Center (ESOC) in Darmstadt, Germany. The Science and Technology Operations Center was located at the European Space Astronomy Center (ESAC) at Villaneuva de la Cañada in Spain and was re-located to ESOC during LISA Pathfinder operations.

The satellite and payload commissioning took place starting from December 2015 and was successfully completed by the end of February 2016. Science operations began in March 2016, and the first results were presented in June 2016. The mission was finally deactivated on 30 June 2017. The Institute of Geophysics ETHZ has been directly involved in the experiments as part of the LISA Pathfinder data analysis team as well as in the monitoring of the GRS FEE hardware during the mission.

Publications

1. Armano, M., et al., (2018), Beyond the required LISA free-fall performance: New LISA Pathfinder results down to 20 µHz, *Phys. Rev. Letts.*, 120, 061101.

2. 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.

3. Armano, M., et al., (2016), Sub-Femto-g free fall for space-based gravitational wave observatories: LISA Pathfinder results, *Phys. Rev. Letts.*, 116, 231101.

Abbreviations

EMRI	Extreme Mass Ratio Inspiral
GRS FEE	Gravitational Reference Sensor Front-End Electronics
IS FEE	Inertial Sensor Front-End Electronics
LISA	Laser Interferometer Space Antenna
LPF	LISA Pathfinder
SAU	Sensing and Actuation Units
SSU	Switching Unit

Time-Line	From	To
Planning	2003	2005
Construction	2005	2010
Measurement Phase	2016	2017
Data Evaluation	2016	open

Method

Measurement

Development and Construction of Instruments

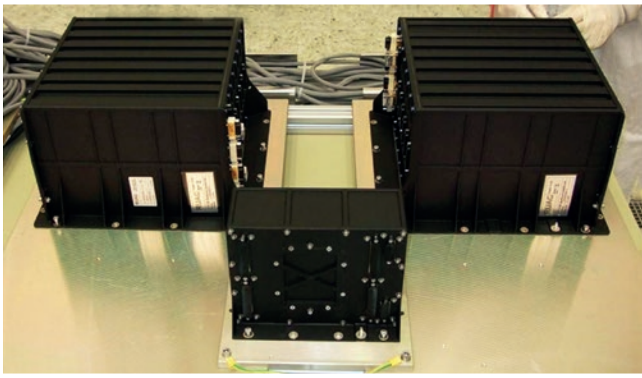
Gravitational Reference Sensor Front-End Electronics (GRS FEE) for the LISA Pathfinder mission.

Industrial Hardware Contract to:

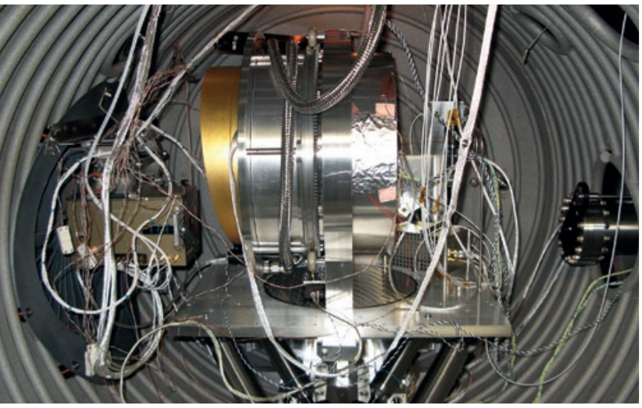
RUAG Space, Zurich
HES-SO (Haute Ecole Spécialisée de Suisse Occidentale), Sion

Website

http://spaceserv1.ethz.ch/aeil/projects-ltp.html



The IS FEE, consisting of two fully redundant Sensing and Actuation Units (SAU) and the switching unit (SSU), was designed and built by RUAG Space AG in Zurich and HES-SO in Sion (sensing and actuation boards). The Power Control Unit was developed by ASP GmbH in Salem-Neufrach. The picture shows the flight hardware without cabling, with the SAUs in the back and the SSU in front. The SSU connects the highly sensitive sensing and actuation channels from the nominal or redundant SAU to the Inertial Sensor head.



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

Institute

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

In Cooperation with:

SwRI, Austin, USA
Lockheed Martin, Palo Alto, USA
Space Res. Cen., Warsaw, Poland
Univ. New Hampshire, Durham, USA

Principal Investigator

D. McComas, Princeton Univ., USA

Swiss Principal Investigator

P. Wurz (UNIBE)

Co-Investigator

A. Galli

Method

Measurement

Development & Constr. of Instrs.

IBEX-Lo Instrument on IBEX

Industrial Hardware Contract to:

Sulzer Innotec

5.5 IBEX – Interstellar Boundary Explorer

Purpose of Research

The IBEX mission (NASA SMEX class) is designed to record energetic neutral atoms (ENAs) 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 sensors, 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 plasma physical processes at the interface between the heliosphere and the interstellar medium to be studied.

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 so that it was in resonance with the Moon which tremendously extends the orbital life-time of the spacecraft and thus allows the mission life to cover more than a solar cycle of 11 years with minimal fuel consumption.

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

Publications

1. Galli, A., P. Wurz, N. A. Schwadron, H. Kucharek, E. Möbius, M. Bzowski, J. M. Sokół, M. A. Kubiak, S. A. Fuselier, H. Funsten, and D. J. McComas, (2017), The downwind hemisphere of the heliosphere as seen with IBEX-Lo during 8 years, *Astrophys. J.,* 851, 16pp.

2. Galli, A., P. Wurz, N. A. Schwadron, H. Kucharek, E. Möbius, M. Bzowski, J. M. Sokół, M. A. Kubiak, H. Funsten, S. A. Fuselier, and D. J. McComas, (2016), The roll-over of heliospheric neutral hydrogen below 100 eV: observations and implications, *Astrophys. J.*, 821, 107, 10pp.

3. Rodríguez Moreno, D. F., P. Wurz, L. Saul, M. Bzowski, M. A. Kubiak, J. M. Sokół, P. Frisch, S. A. Fuselier, D. J. McComas, E. Möbius, and N. Schwadron, (2013), Evidence of direct detection of interstellar deuterium in the local interstellar medium by IBEX, *Astron. Astrophys.*, 557, A125, 1–13, doi: 10.1051/0004-6361/201321420.

Abbreviations

ENA	Energetic Neutral Atom
IBEX	Interstellar Boundary Explorer
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

5.6 Swiss Contribution to ATHENA

Purpose of Research

ESA has selected "The Hot and Energetic Universe" as the science theme of the second Large Mission of the Cosmic Vision programme. As a response, a large European consortium has gathered to propose and develop the ATHENA (Advanced Telescope for High Energy Astrophysics) mission, a large X-ray observatory and an evolution of former proposals: XEUS, International X-ray Observatory and ATHENA L1. Thanks to its two instruments, a large-field-of-view fast imager (Wide FIeld Imager, WFI), and a cryogenic imaging calorimeter (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 2x2 mosaic of DEPFET (depleted p-channel field-effect transistor) 512x512 pixel matrices, covering a field-of-view of 40'x40' with a time resolution better than 5 ms, while a smaller, 64x64 matrix will reach a time resolution better than 80 µs. The X-IFU will perform imaging with ~ 2 eV resolution, i.e. an improvement of a factor 50 over current imaging instruments. X-IFU uses Transition Edge Sensors and operates at cryogenic (50 mK) temperatures. This will be achieved by a complex, multi-stage mechanical cooling chain.

Switzerland is leading the development of the X-IFU Filter Wheel subsystem. This will allow optical light from bright objects (O, B stars) to be blocked, and to reduce the X-ray count rate for very bright objects in order to prevent degradation of the detector performance. The filter wheel 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, to reach optimal calibration stability. The filter wheel relies heavily on the heritage from the Swiss contribution to the JAXA ASTRO-H/Hitomi mission.

UNIGE is preparing a significant participation in the ATHENA ground-segment, both in the development phase and during scientific operations. The model under discussion involves two separate Instrument Science Centers (ISC) attached to each of the two instruments. UNIGE will play a significant role in both the X-IFU and the WFI ISCs.

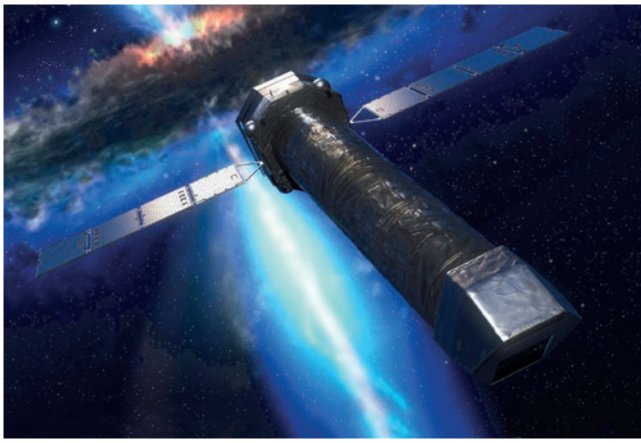
Past Achievements and Status

The ATHENA proto-consortium is currently preparing for the Preliminary Requirement Review which will be concluded by the end of 2018. A large effort has been made recently to fit the mission into the mass and budget boundary conditions. Adoption is foreseen for 2021, around the same time as the Preliminary Design Review.

Publications

1. Barret, D., et al., (2016), *Proc. SPIE*, 9905, id. 99052F.
2. Meidinger, N., (2017), *Proc. SPIE*, 10397, id. 103970V.

Time-Line	From	To
Planning		2021
Construction	2022	2026
Measurement Phase	2028	2033
Data Evaluation	2028	2040



Artist's impression of ATHENA. Image credit: ESA.

Institute

Dept. Astron. Univ. Geneva (UNIGE)

In Cooperation with:

European Space Agency (ESA)

Inst. Rech. en Astrophys. et Planét. (IRAP), Toulouse, France

Max-Planck-Institut für Extraterr. Physik (MPE), Garching, Germany

Principal Investigators

K. Nandra (MPE), D. Barret (IRAP)

Swiss Principal Investigator

S. Paltani (UNIGE)

Method

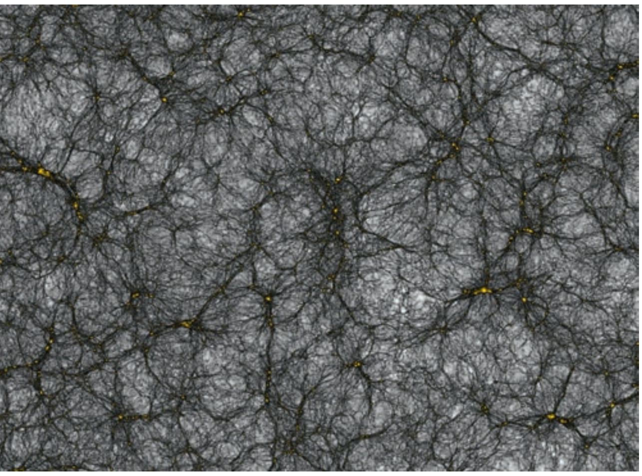
Measurement

Developments

Development and construction of the X-IFU instr. Filter Wheel subsystem. Development of data center activities for the WFI and X-IFU instruments.

Website

sci.esa.int/athena/59896-mission-summary



The Euclid Flagship simulation run on the CSCS supercomputer Piz Dain. Image credit: J. Stadel 2017.

5.7 Swiss Contribution to 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 instr. (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 in 2021.

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 participating in the coordination of the respective Science Working Groups.

On the software and algorithms level, the EPFL is active in the development of algorithms for the measurement of the galaxy shear (weak lensing) as well as the detection of strong gravitational lenses, for which it plays the role of coordinator in the so-called Shear Organisation Unit. FHNW is contributing to the so-called system team which provides the overall infrastructure binding the different components of the Euclid data centers.

UNIGE is in charge of the coordination of 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 Read-out 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.

Time-Line	From	To
Planning		2012
Construction	2012	2019(HW)/2020(SW)
Measurement Phase	2021	2027
Data Evaluation	2021	2030

Institute

École Polytechnique Fédérale de Lausanne (EPFL)

Fachhochschule Nordwestschweiz (FHNW)

Univ. Geneva, (UNIGE)

Univ. Zurich, (UNIZH)

In Cooperation with:

ESA and about 100 European institutes

NASA

>1000 astronomers and engineers worldwide

Principal Investigator

Y. Mellier, Inst. d'Astrophysique de Paris, France

Past Achievements and Status

APCO has manufactured the Breadboard Model (BM) which has been used to de-risk the mechanism development in all its critical aspects, in particular lifetime and vibration levels. All tests of the RSU BM were successfully passed, allowing the Swiss team to proceed with the Qualification Model programme, whose assembly and test campaigns are on-going. The Flight Model programme is expected to begin after Summer 2018 and to be concluded by mid-2019.

On the ground-segment side, Euclid is currently undergoing the Design Review. The ground-segment development is structured with Infrastructure Challenges and Scientific Challenges. The Swiss Science Data Center has participated in several Infrastructure Challenges; the last one, IC7, involves the deployment of the analysis pipeline on nine data centers, together with the orchestration and job distribution software. It will then re-run (part of) the Scientific Challenge 3 which goes from the raw images up to the source catalogue, in a completely distributed way.

The Science Performance Verification 2 is being conducted in parallel. SPV2's goal is to estimate whether the Euclid mission (and science ground-segment in particular) is on track to meet its scientific objectives. SPV2 is based on the Euclid Flagship Simulation which has produced the largest simulated galaxy catalogue to date. The Euclid Flagship Simulation which used a record-setting two trillion dark-matter particles, was run on Piz Daint, the third most powerful computer in the World at the end of 2017.

Publications

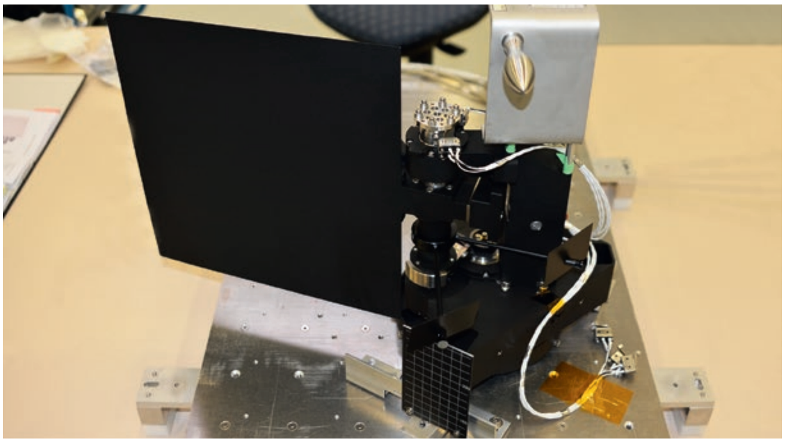
1. Laureijs, R., et al., (2011), Euclid Definition Study Report, Euclid Red Book, ESA/SRE(2011)12, eprint arXiv: 1110.3193.

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

3. 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
RSU	Read-out Shutter Unit
VIS	VISible imager



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

Co-Investigators

Swiss consortium members with lead responsibilities only:

F. Courbin (EPFL)
P. Dubath (UNIGE)
J.-P. Kneib (EPFL)
M. Kunz (UNIGE)
S. Paltani (UNIGE)
R. Teyssier (UNIZH)

Method

Measurement

Developments

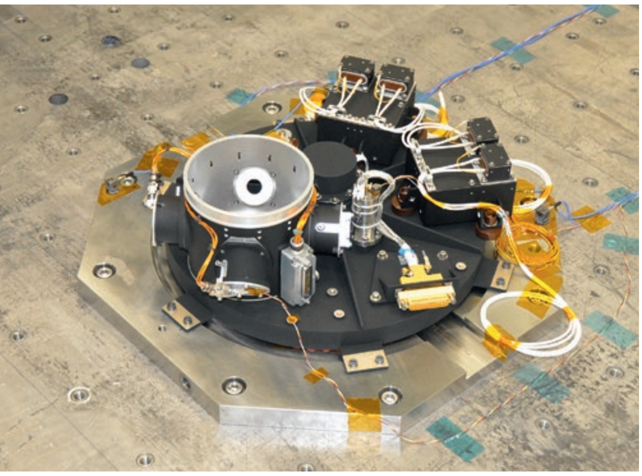
Development and construction of the Read-Out Shutter Unit (RSU) of the VIS instrument. Development of algorithms for photometric redshifts, weak and strong lensing. Euclid Flagship simulation. Development of the Swiss Euclid Science Data Center.

Industrial Hardware Contract to:

APCO Technologies
(VIS RSU Phase C/D)

Website

sci.esa.int/euclid/



The Hitomi Filter Wheel Mechanism ready for the vibration test. Image credit: Ruag Space AG.

5.8 XARM – The Swiss Contribution to the X-ray Astronomy Recovery Mission

Purpose of Research

XARM is a mission of the Japan Aerospace Exploration Agency (JAXA) planned to recover the most ambitious scientific objectives of the Hitomi mission which was successfully launched on 17 February, 2016, but experienced a failure after six weeks in operation.

Hitomi was an essential mission for high-energy astrophysics, between the current generation of facilities with XMM-Newton, INTEGRAL, Chandra and Suzaku, and ATHENA, the future Large Mission of ESA's Cosmic Vision program dedicated to the study of the hot and energetic Universe.

UNIGE participated in the Hitomi mission, together with the Dutch space research institute, SRON, by developing a filter wheel for the Soft X-ray Spectrometer (SXS). A rebuild of the Swiss contribution to Hitomi is planned for the Resolve spectrometer on XARM.

Like the SXS, Resolve uses a cryogenic silicon detector working at 50 mK, with the aim of providing outstanding energy resolution (about 4 eV) in the 0.3-10 keV energy range, while preserving some imaging capabilities and high throughput.

The purpose of the filter wheel is to select different optical elements, either to reduce the X-ray count rate or the optical load on the detector as well as to protect the detector from micro-meteorites. It also supports and commands active X-ray calibration sources which are provided by SRON, and assembled on top of the filter wheel.

The Filter Wheel consists of two separate units: the Filter Wheel Electronics (FWE) and the Filter Wheel Mechanism (FWM). For Hitomi, the control and power electronics module, the FWE, was designed by Micro-Cameras & Space Exploration and assembled and qualified by UNIGE.

The filter wheel mechanism (FWM) was built and qualified by Ruag Space, Switzerland. The Flight Models were successfully delivered to SRON and then to JAXA in Autumn 2013. Both sub-systems operated nominally after launch.

Past Achievements and Status

Despite its extremely short life, Hitomi was incredibly successful thanks to its new-generation SXS instrument. Among a handful of scientific goals, the observation of the Perseus galaxy cluster resulted in two major discoveries published in the journal *Nature*.

The first major result is related to the first direct measurement of the turbulence in the intra-cluster gas which has been found to be too low to be the main mechanism of energy

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

Institute

Dept. Astronomy,
Univ. Geneva (UNIGE)

In Cooperation with:

Netherlands Institute for Space, Research (SRON)

European Space Agency (ESA)

Principal Investigator

Japan Aerospace Exploration Agency (JAXA) transport from the central active galactic nucleus to the inner regions of the cluster.

The second result concerns the determination of the process of enrichment of the intra-cluster medium which has been found to be consistent with that in the Solar neighborhood, setting constraints on the nature of the supernova progenitors.

Both results necessitated the operation of the Filter Wheel in order to reach a sufficient level of knowledge of the energy calibration of the SXS. In addition, more than ten other papers are in the process of being published/have been published, in refereed journals.

The process to rebuild the FWE and FWM subsystems for the Resolve instrument on board XARM has just started, and the industrial contracts will be announced soon.

Publications

1. The Hitomi Collaboration, 2017, *Nature*, 551, 478.
2. Takahashi, T., et al., (2016), The ASTRO-H (Hitomi) X-ray astronomy satellite, *Proc. SPIE*, 9905, id. 99050U.
3. The Hitomi Collaboration, 2016, *Nature*, 535, 117.

Abbreviations

FWE	Filter Wheel Electronics
FWM	Filter Wheel Mechanism
JAXA	Japan Aerospace Exploration Agency
SRON	Netherlands Institute for Space Research
SXS	Soft X-ray Spectrometer
XARM	X-Ray Astronomy Recovery Mission

Swiss Principal Investigator

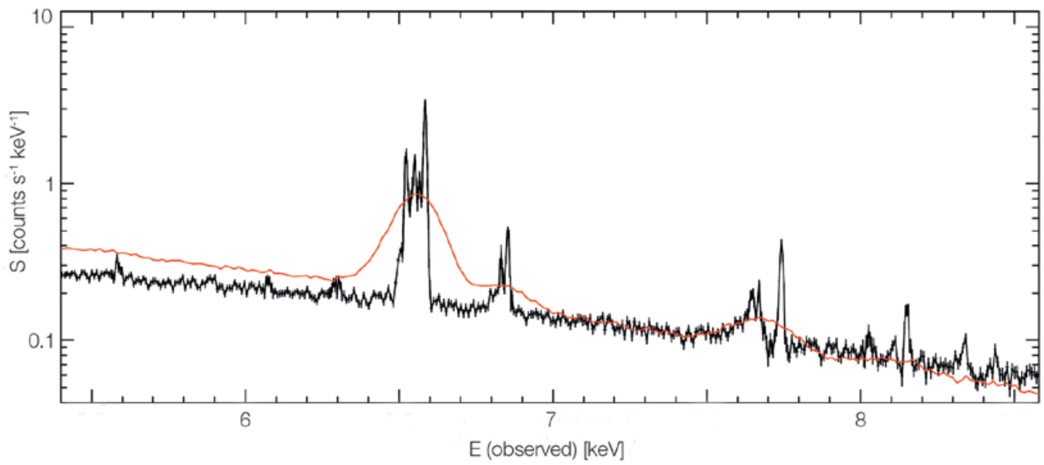
S. Paltani (UNIGE)

Method

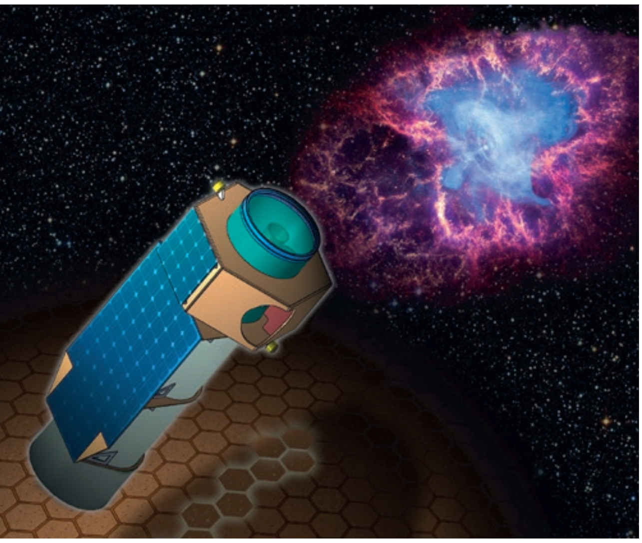
Measurement

Development and Construction of Instruments

Manufacturer of the Filter Wheel Mechanism and Electronics.



The Hitomi spectrum of the Perseus cluster (black) compared to the state-of-the-art CCD spectrum of Suzaku (red), revealing the huge step forward achieved by the SXS. Image credit: Nature.



Artist's impression of XIPE. Image credit: INAF-IAPS.

5.9 XIPE – The X-Ray Imaging Polarimetry Explorer

Purpose of Research

XIPE, the X-ray Imaging Polarimetry Explorer, is a newly proposed space mission concept competing with two other candidates for a launch opportunity in 2026 within the context of the ESA M4 call. The mission was selected in 2015 for an assessment phase study that lasted until July 2017. The down-selection of the M4 missions was expected around late 2017, but was then postponed to mid-2018.

XIPE will be entirely dedicated to measurements of X-ray polarisation from celestial Galactic and extra-Galactic X-ray sources. Polarimetric X-ray measurements are long known to be the key to probe, in-situ, the details and geometry of many poorly understood emission mechanisms, but have so far remained an undeveloped tool due to the lack of technology required to build a sufficiently sensitive instrument. XIPE will finally cover this gap and provide the possibility of performing spatially-resolved polarimetric measurements of a large sample of Galactic and extragalactic X-ray sources.

XIPE is equipped with three focusing Wolter I X-ray telescopes and the latest generation of the Gas Pixel Detectors (GPD) developed by INFN-Pisa in collaboration with INAF-IAPS. These innovative detectors permit the recording of not only the spectral, spatial and timing information of the X-ray intensity from celestial sources, but also permit recording of the two additional Stokes parameters, Q and U, thus measuring the polarisation of the X-ray emission as a function of position, photon energy and time.

The combination of the selected optics and detectors achieve an effective area of 1100 cm^2 at 2 keV (the total operating energy range is 2 – 8 keV), translating into a minimum detectable polarisation lower than 10% in 100 ks of observations for a source with the intensity of 1 mCrab.

It has been argued from theoretical considerations that X-ray radiation from many astrophysical sources must be significantly polarised because it often originates in highly aspherical emission and scattering geometries or from regions with structured magnetic fields. The wider set of observations provided by XIPE, compared to any previously flown X-ray instruments, will thus help in breaking degeneracies in the X-ray modelling of a wide range of astrophysical objects.

The induced observable polarisation can solve long-standing problems in both astrophysics and fundamental physics. For instance:

- What is the structure of magnetic fields close to the site of particle acceleration in pulsar wind nebulae, supernovae or extragalactic jets?
- Where do the seed photons for the Comptonised emission in extra-galactic jets come from?
- What is the nature of the reprocessed emission we observe from the molecular clouds in the Galactic Center?
- What is the accretion geometry in accreting X-ray pulsars?
- Can the theoretically predicted QED vacuum birefringence in the atmospheres of magnetars be confirmed?

Institute

Dept. of Astronomy,
Univ. Geneva (UNIGE)

In Cooperation with:

INAF-IAPS, Italy

Principal Investigator

P. Soffitta

Swiss Principal Investigator

S. Paltani (UNIGE)

- What is the angular momentum of accreting black holes in X-ray binaries?

- Is the theory of Loop Quantum Gravity correct? Can we detect axion-like particles that would constitute dark matter?

The Swiss XIPE team, based at the Department of Astronomy of the University of Geneva, has been in charge of the overall mission project management as well as the definition of the mission science ground segment (in collaboration with ESA).

A number of scientists from different Swiss institutions have been directly involved in the XIPE science working groups, whose tasks have been to define and shape the mission science goals.

Past Achievements and Status

XIPE has successfully completed the assessment phase which finished in July 2017 at the end of the Mission Selection Review. The XIPE consortium, under the overall coordination of the project office at the University of Geneva, has delivered over 700 pages of documentation to ESA.

In July 2017, a public presentation event of all three M4 mission candidates was organised by ESA in Paris and attended by scientists from different disciplines. At the end of March 2018, XIPE was unfortunately not selected by ESA as an M4 mission to be implemented. Nevertheless, the experience gained through this project has consolidated the leading role of the University of Geneva in coordinating the early development and ground segment design of similar missions.

Publications

1. Soffitta, P., et al., (2016), *Proc. SPIE* 9905, 990515.

2. Zane, S., et al., (2016), *Proc. SPIE* 9905, 99054H.

3. Soffitta, P., et al., (2013), *Nuclear Instr. Meth. Phys.*, 700, 99.

4. Soffitta, P., et al., (2012), *Proc. SPIE* 8443, 84431F.

5. Costa, E., et al., (2001), *Nature*, 411, 662.

Abbreviations

GPD	Gas Pixel Detector
XIPE	X-ray Imaging Polarimetry Explorer

Time-Line	From	To
Planning	Sep. 2015	Jul. 2017
Construction	Oct. 2017	Jun. 2026
Measurement Phase	Jan. 2027	Jan. 2030
Data Evaluation	open	open

Co-Investigators

T. Courvoisier
E. Bozzo (UNIGE)

Method

Measurement

Development and Construction of Instruments

Leading role in the mission science ground segment.

Website

www.isdc.unige.ch/xipe

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

Institute

Particle Physics Dept. (DPNC), and Dept. Astron., Univ. Geneva (UNIGE)

In Cooperation with:

IHEP, Beijing, China

Principal Investigator

S-N. Zhang (IHEP)

Swiss Principal Investigator

X. Wu (DPNC)

Co-Investigators

Stephane Paltani (UNIGE)
Enrico Bozzo (UNIGE)

Method

Measurement

Development and Construction of Instruments

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

Website

www.isdc.unige.ch/extp

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

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 simultaneous spectral-timing polarimetry studies of cosmic sources in the energy range from 0.5-30 keV (and beyond) to be studied for the first time ever.

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 offering <180 eV spectral resolution.

• The Large Area Detector (LAD) - a deployable set of 640 Silicon Drift Detectors, for a total effective area of about 3.4 m^2, between 6 and 10 keV, and spectral resolution <250 eV.

• The Polarimetry Focussing Array (PFA) - a set of two X-ray telescopes, for 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 Silicon Drift Detectors, each covering a 90° x 90° field-of-view.

The eXTP international consortium includes mostly major institutions of the Chinese Academy of Sciences and Universities in China as well as major institutions in several European countries and the United States.

The Swiss eXTP team comprises scientists at 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 definition of the chain of assembly of the front-end electronics with the SDD detectors and the ASICs. The Astronomy department is involved in the design of the science ground segment of the mission.

Past Achievements and Status

The eXTP mission has been approved by China for an extended assessment phase A and phase B, during which all interfaces between the Chinese platform/payload and the European provided payload elements will be worked out and finalised. Phase B, preceding implementation, is expected to be concluded by 2020. The launch is expected in 2025.

Abbreviations

ASIC	Application-Specific Integrated Circuit
LAD	Large Area Detector
PFA	Polarimetry Focussing Array
SFA	Spec. Focussing Array
WFM	Wide-Field Monitor

Time-Line	From	To
Planning	Jan. 2017	Dec. 2018
Construction	Jan. 2019	Dec. 2024
Measurement Phase	Jan. 2025	Jan. 2030

5.11 SPICA – Space Infrared Telescope for Cosmology and Astrophysics

Purpose of Research

SPICA is a joint European-Japanese project for an infrared space observatory with a 2.5-meter, actively cooled telescope (below 8K) and with a new generation of ultra-sensitive detector arrays. SPICA will cover the 12–350 μm spectral range, capable of making deep and wide surveys to unprecedented depths in spectroscopy. SPICA carries two instruments, SAFARI, a joint European-Canadian-US contribution, and SMI from Japan. They provide imaging and spectroscopy in different modes of operation, together with imaging polarimetry in the far infrared.

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

While the SPICA payload is primarily driven by these top-level science goals, SPICA is designed to operate as an observatory. UNIGE aims to lead the development and operations of the SAFARI Instrument Control Center (ICC). The ICCs will maintain instrument commands and develop the relevant data reduction software. In routine operations the ICCs monitor the instrument health, carry out flight calibration and maintain the data reduction software.

Past Achievements and Status

SPICA was proposed as an ESA-led mission under Cosmic Vision M5. If the mission is selected, JAXA will assume a partner Space Agency role. Within the Japanese space agency selection process for future missions, SPICA is expected to be assigned a Strategic L-class mission allocation, with an implementation schedule foreseeing launch in the late 2020s. SPICA has passed the ESA programmatic and technical screening. The M5 selection process resumed immediately after the ESA Science Programme Committee in March 2018, and SPICA was selected as one of three missions for further study.

Publications

1. Jellema, W., et al., (2017), Safari: instrument design of the far-infrared imaging spectrometer for SPICA, *Proc. SPIE*, 10563, id. 105631K.

2. Sibthorpe, B., et al., (2015), The SPICA mission, *EAS Publications Series*, 75–76, 411–417.

3. Goicochea, J. R., et al., (2013), The far-IR view of star and planet forming regions, Proc. of the SPICA's New Window on the 'Cool Universe' conference, arXiv: 1310.1683.

Abbreviations

ICC	Instrument Control Center
SAFARI	SpicA FAR-infrared Instr.
SMI	SPICA Mid-Infrared Instr.

Time-Line	From	To
Planning	2019	2022
Construction	2022	2030
Measurement Phase	2030	2035
Data Evaluation	2030	2040

The SPICA satellite (Planck configuration, 2.5m@8K telescope).

Institute

Dept. Astron., Univ. Geneva (UNIGE)

In Cooperation with:

SRON, Netherlands
ISAS, Japan
and the SPICA Consortium

Principal Investigator

P. Roelfsema (SRON)

Swiss Principal Investigator

M. Audard (UNIGE)

Co-Investigators

D. Schaerer, S. Paltani (UNIGE)

Method

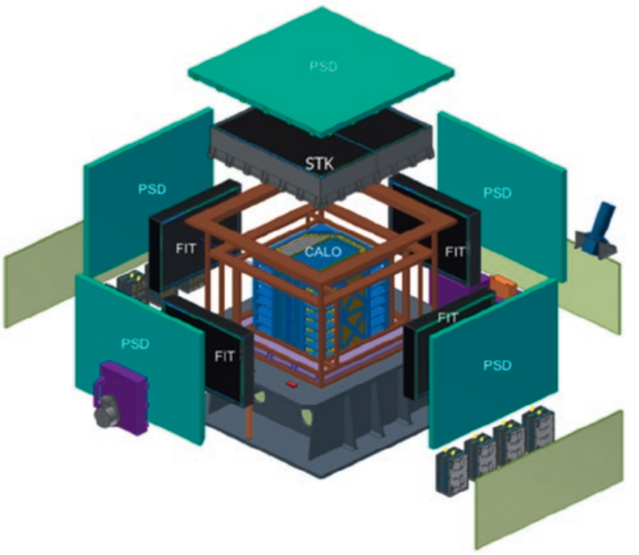
Measurement

Development of Software for

Instrument Control Center for the SAFARI instrument onboard the SPICA mission.

Website

www.spica-mission.org



Sketch of the HERD detector: the 3-dimensional LYSO calorimeter (CALO) in the center, is surrounded by the 4-sided scintillating fibre tracker (FIT) and surmounted by the silicon-tungsten tracker (STK). The tracker is encapsulated in the 5-sided plastic scintillator detector (PSD).

5.12 HERD – High Energy Radiation Detection Facility

Purpose of Research

HERD is a space mission proposed by an international collaboration to be installed onboard the future Chinese Space Station that aims to achieve the ambitious goal of performing cosmic ray measurements with 1 m^2.steradian of acceptance at PeV energies, the so -called "knee" region. It will also be an excellent detector to search for Dark Matter using electrons and photons at high energy (TeV and above).

HERD will lead to ground-breaking measurements in high energy cosmic rays that will shed new light on some of the fundamental questions concerning the Universe, such as: i) the nature of the Dark Matter, ii) the origin of cosmic rays and iii) the physics of extreme energetic processes in the Universe.

Past Achievements and Status

The main feature of the mission is a 5-side sensitive detector that allows the acceptance with a reasonable mass budget to be increased. A central calorimeter, made of ~7500 LYSO crystal cubes (3 x 3 x 3 cm^3), is covered on five sides by high precision trackers, using silicon micro-strip technology (top) and scintillating fibre technology (4 sides). The total weight of the HERD payload is about 4 tons, within a dimension envelope of 2.3 x 2.3 x 2.6 m^3.

The Geneva group is a founding member of the HERD international collaboration established in October 2012, and has been playing a major role in the HERD mission development ever since.

The Geneva group's focus is on the development of the tracking detector for HERD. In particular, it is developing a large area tracker made of scintillating fibres read out by arrays of silicon photomultipliers. This is the first time that such technology will be used in space. The Geneva group is also coordinating the activities of on-ground tests and calibrations with particle beams at CERN.

The HERD proposal is currently under review by the Chinese Manned Space Agency (CMSA) and the Italian Space Agency (ASI) which coordinates the European participation in HERD.

Publications

1. Zhang, S., et al., (2014), HERD collaboration, The High Energy cosmic-Radiation Detection (HERD) Facility onboard China's Future Space Station, *Proc. SPIE Int. Soc. Opt. Eng.* 9144, 91440X.

Abbreviations

AMI	Italian Space Agency
CMSA	Chinese Manned Space Agency
HERD	High Energy Radiation Detection Facility
LYSO	Lutetium-yttrium oxyorthosilicate

Time-Line	From	To
Planning	2012	2018
Construction	2019	2025
Measurement Phase	2025	2035
Data Evaluation	2025	2040

Institute

DPNC, Univ. Geneva (UNIGE)

In Cooperation with:

IHEP, Beiing, China
INFN, Perugia, Italy
EPFL, Lausanne, Switzerland

Principal Investigator

S-N. Zhang (IHEP)

Swiss Principal Investigator

X. Wu (DPNC)

Method

Measurement

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

Purpose of Research

THESEUS is a space mission concept developed by a large international collaboration in response to the 5th call for M-class missions by ESA. 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: a) 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 and, b) 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 future electromagnetic (EM) facilities.

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), and their association with the explosive death of massive stars. In particular, GRBs represent a unique tool to study the early Universe up to the re-ionisation era.

Besides high-redshift GRBs, THESEUS will serendipitously detect and localise, during regular observations, a large number of X-ray transients and variable sources, collecting also 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, eLISA, ET, and Km3NET. In addition, the provision of a high cadence soft X-ray monitoring capability in the 2020s together with a 0.7 m IRT in orbit will enable a strong synergy with transient phenomena observed with the large facilities that will be operating in the EM domain (e.g., ELT, SKA, CTA, JWST, ATHENA).

Past Achievements and Status

The THESEUS proposal, submitted for the ESA M5 call, was selected in mid-May 2018 as one of three missions to enter an assessment phase study that will be conducted in 2021.

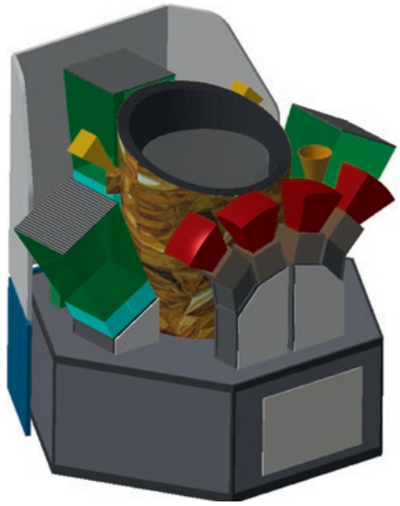
Publications

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

2. Amati, L., et al., (2017), *Adv. Space Res.* (in press; arXiv:1710.04638).

3. Stratta, G., et al., (2017), *Adv. Space Res.* (in press; arXiv:1712.08153).

Time-Line	From	To
Planning	Jul. 2018	Jul. 2019
Construction	Oct. 2019	Dec. 2027
Measurement Phase	Jan. 2028	Jan. 2031



Artist's impression of THESEUS. Image credit: INAF-IASF Bologna.

Institute

Dept. Astronomy, Univ. Geneva (UNIGE)

In Cooperation with:

INAF-IASF, Bologna, Italy

Principal Investigator

L. Amati

Swiss Principal Investigator

S. Paltani (UNIGE)

Co-Investigators

Enrico Bozzo (UNIGE)

Method

Measurement

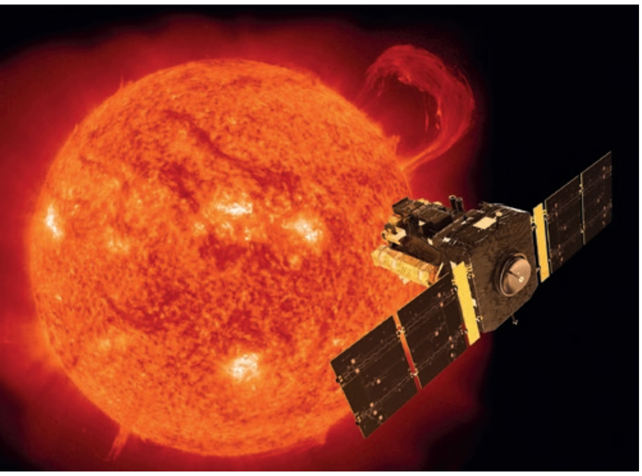
Development and Construction of Instruments

Contribution to the IRT instrument and the mission science ground segment.

Website

www.isdc.unige.ch/theseus

6 Solar Physics



VIRGO on the SoHO spacecraft. Image credit: ESA.

Institute

Physikalisch-Meteorol. Obs. Davos und Weltstrahlungszentrum (PMOD/WRC), Davos, Switzerland

In Cooperation with:

Institut Royal Météorologique de Belgique (IRMB), Brussels, Belgium

ESTEC, Noordwijk, The Netherlands

Principal Investigator

Claus Fröhlich (PMOD/WRC)

Co-Investigators

Wolfgang Finsterle (PMOD/WRC)
Werner Schmutz (PMOD/WRC)
Benjamin Walter (PMOD/WRC)

Method

Measurement

Research Based on Existing Instrs.

VIRGO/SoHO

Website

www.pmodwrc.ch/en/research-development/space/

6.1 VIRGO – Variability of Irradiance and Global Oscillations on SoHO

Purpose of Research

VIRGO provides continuous high-precision measurements of the total and spectral solar irradiance. The total solar irradiance (TSI) measurements are used to estimate a potential solar influence on terrestrial climate change.

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

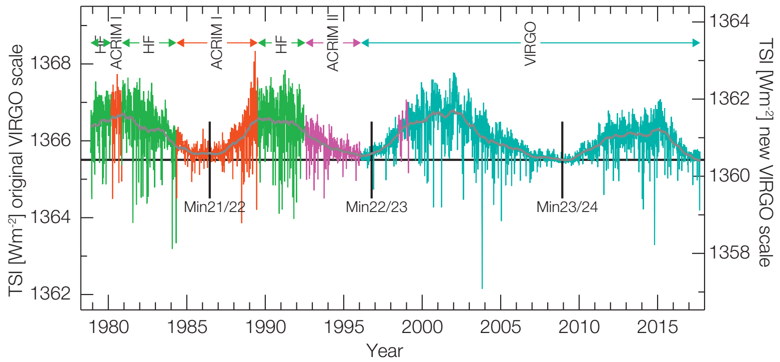
VIRGO has provided the longest continuous time series of TSI and SSI.

Publications

1. Dudok de Wit, T., et al., (2017), Methodology to create a new total solar irradiance record: Making a composite out of multiple data records, *Geophys. Res. Lett.*, doi:10.1002/2016GL071866.

2. Haberreiter, M., et al., (2017), A new observational solar irradiance composite, *JGR Space Phys.* 122, 5910, doi:10.1002/2016JA023492.

3. Fröhlich, C., (2016), Determination of time-dependent uncertainty of the total solar irradiance records from 1978 to present, *J. Space Weather Space Clim.*, 6, 11p, doi:10.1051/swsc/2016012.



The PMOD/WRC TSI composite for the indicated space experiments. The new absolute VIRGO scale is indicated on the right, and the original scale on the left.

Abbreviations

SoHO	Solar and Heliospheric Observatory
SSI	Spectral Solar Irradiance
TSI	Total Solar Irradiance
VIRGO	Variability of Solar Irradi. and Gravity Oscillations

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

6.2 Probing Solar X-Ray Nanoflares with NuSTAR

Purpose of Research

The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA Small Explorer satellite using true focusing 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 also occasionally points at the Sun.

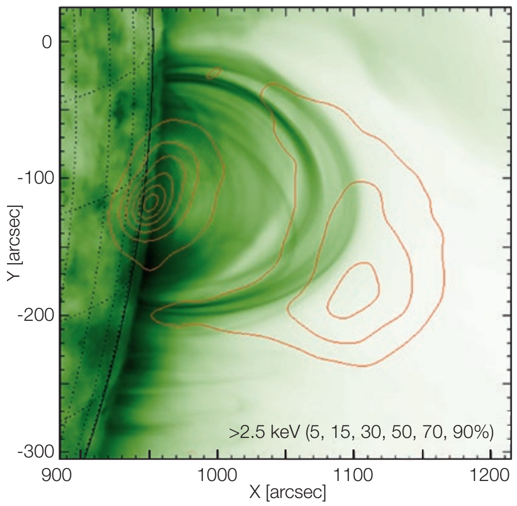
NuSTAR is 200 times more sensitive than the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), the current state-of-the-art satellite for solar hard X-ray studies. With the extraordinary increase in sensitivity provided by NuSTAR, we will be able to test the so-called "nanoflare heating"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

Past Achievements and Status

NuSTAR was successfully launched in June 2012. First solar observations were performed in September 2014, with 12 different observation runs for a total of about three days of exposure time. Future solar observations are being considered as a Target of Opportunity. The best observation conditions for our main science goal (nanoflare heating) will occur around the solar minimum (~2018–2021) at times of lowest solar activity to minimise contamination from unfocused X-rays ('ghost-rays') from outside of NuSTARs field-of-view.

Publications

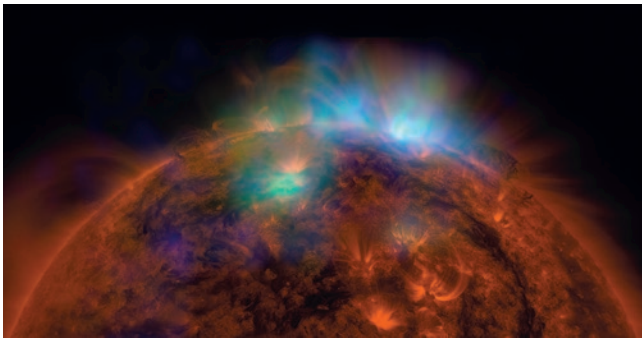
1. Fiona, A., et al., (2013), *Astrophys. J.*, 770, 103.
2. Kuhar, M., et al., (2017), *Astrophys. J. Lett.*, 835, 1, article id. 6, 8.



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

Abbreviations

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



First NuSTAR image of the Sun (NASA press release) which illustrates 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

Institute for Data Science, FHNW

In Cooperation with:

Caltech, USA; UC Santa Cruz, USA
U. Glasgow, UK; U. Minnesota, USA

Principal Investigator

F. Harrison (Caltech)

Swiss Principal Investigator

S. Krucker (FHNW)

Co-Investigator

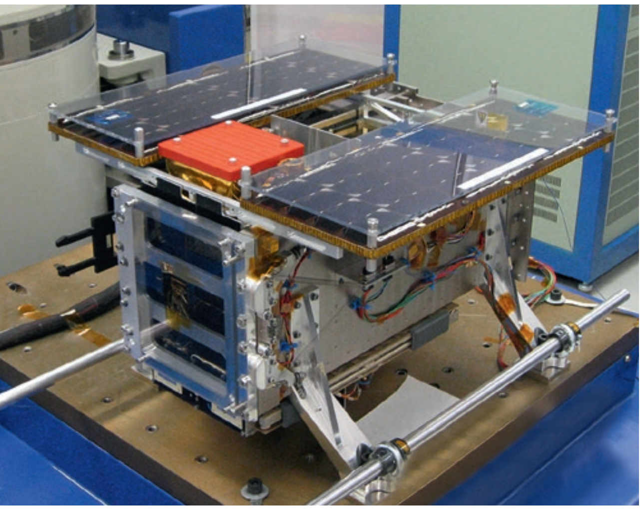
M. Kuhar (FHNW)

Method

Measurement

Research Based on Existing Instrs.

NuSTAR, launched in June 2012, is currently the leading X-ray observatory. NuSTAR's unprecedented sensitivity opens up entirely new views on astrophysical X-ray objects including our Sun.



CLARA (with red cap) mounted on the NorSat-1 structure.

Institute

PMOD/WRC, Davos
Switzerland

In Cooperation with:

Norwegian Space Center (NSC),
Oslo, Norway

LASP, Boulder CO, USA

Principal/Swiss Investigator

W. Schmutz (PMOD/WRC)

Co-Investigators

B. Anderson (NSC, Norway)

T. Leifsen (UiO, Norway)

G. Kopp (LASP, USA)

A. Fehlmann (IfA, USA)

W. Finsterle (PMOD/WRC)

B. Walter (PMOD/WRC)

6.3 CLARA – Compact Lightweight Absolute Radiometer on NorSat-1

Purpose of Research

Space Climate

The Compact Lightweight Absolute Radiometer (CLARA) CLARA is a payload onboard the Norwegian NorSat-1 micro-satellite and is a new generation of radiometer to measure the Total Solar Irradiance (TSI) which is the energy input from the Sun to the Earth. The main science goal of CLARA is to measure TSI with an uncertainty better than 0.4 $W m^{-2}$ on an absolute irradiance level and a relative stability of 5 $mW m^{-2} yr^{-1}$ (0.0004% of the TSI per year). Along with its forerunners, VIRGO and PREMOS, CLARA continues the long-term involvement of the PMOD/WRC in solar research.

Any significant long-term variation of TSI will directly translate into a change of the terrestrial climate. Solar irradiance measurements in space have been conducted since 1979 by various institutes, and have an average value of about 1361 $W m^{-2}$. During these last 36 years, TSI has varied in-phase with the 11-year solar cycle by about ±0.6 $W m^{-2}$ (±0.04%). An uncertainty of a trend of the TSI composite is difficult to assess but is of the order of 0.5 $W m^{-2}$ over the TSI composite time. It is unknown and controversially discussed in the science community whether the solar irradiance has a long-term trend and whether climate variations within the past 10,000 years are related to changes in solar irradiance (see Schmutz 2016). This is why the World Meteorological Organisation lists TSI as an essential climate variable (see GCOS Essential Climate Variables).

In view of the unknown role of suspected (and predicted) variability in solar irradiance on the terrestrial climate, it is therefore essential that monitoring of solar irradiance continues on an accuracy level that is capable of capturing any variations that could have a significant impact on the terrestrial climate. CLARA's performance will be sufficient to measure any climate-significant variation.

Radiometry

The CLARA experiment sets new standards for TSI radiometers in terms of a reduction in weight and size, without compromising accuracy and stability (Finsterle et al. 2014). The radiometer is fully characterised on the component level as well as calibrated end-to-end at the TSI Radiometer Facility (Walter et al., 2017). The measuring cadence is 30 sec which is the highest cadence of an absolute radiometer in space. This allows the study of solar irradiance variations to be extended at its high frequency end.

Past Achievements and Status

Instrument Development

One engineering and two CLARA flight units were built by PMOD/WRC. The institute was responsible for the mechanical and thermal design of the hardware, development of the electronics, and in-house manufacture. Swiss industry supported the project by: developing software, manufacturing several hardware components, running mechanical and thermal simulations, and conducting environmental testing. CLARA was assembled at PMOD/WRC and calibrated at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder Colorado, USA.

The NorSat-1 mission

The Norwegian Space Center selected the NorSat-1 mission as an affordable approach to science in space, as part of the National Space Program. NorSat-1 was launched on 14 July 2017 on a Soyuz rocket from the Baikonur Space Center, Kasachstan. The satellite is investigating solar radiation, space weather, and detecting ship traffic with an AIS transponder.

The science payload covers two aspects of scientific research focusing on the sun, including measuring solar irradiance with CLARA, and measuring electron plasma around the Earth with Langmuir probes (University of Oslo, Norway). The satellite platform has dimensions of 23x33x44 cm and was built by the University of Toronto Institute for Aerospace Studies/Space Flight Lab, Canada. Norway kindly provided payload space aboard NorSat-1 to Switzerland.

On 21 July 2017, CLARA was successfully switched on. The TSI value from these "First-Light" measurements on 25 August 2017 was measured at 1359.8 ±0.7 $\mathrm{W\,m^{-2}}$ which is very close to the predicted value. This is a pleasing verification of the robustness of the new CLARA design.

Commissioning experiments which are now finished, included measurement of the deep space background radiation, determination of the pointing sensitivity, and adjustment of the so-called CLARA shutter-delay parameter. CLARA is now operational and is continuously monitoring TSI. Incoming data are followed by PMOD/WRC scientists. At the next solar cycle minimum in about 2020, a comparison to previously observed minima might reveal a long term trend of the TSI.

Publications

1. Finsterle, W., et al., (2014), The new TSI radiometer CLARA, *SPIE,* 9264, eid. 92641S-5, doi: 10.1117/12.2069614.

2. Schmutz, W., (2016), Chapter 3.2 in: Our Space Environment: Opportunities, Stakes, and Dangers, Eds. C. Nicollier, V. Gass, EPFL Press, ISBN 978-2-940222-88-9.

3. Walter, B., et al., (2017), The CLARA/NorSat-1 solar absolute radiometer: Instrument design, characterisation and calibration, *Metrologia*, 54, 674, doi: /10.1088/1681-7575/aa7a63.

Abbreviations

CLARA	Compact Lighweight Absolute Radiometer
LASP	Lab. Atmos. Space Physics, Boulder CO, USA
NorSat-1	Norwegian Satellite
NSC	Norwegian Space Center
TRF	TSI Radiometer Facility Boulder, CO, USA
UiO	University in Oslo, Norway
UTIAS/SFL	Univ. Toronto, Inst. Aero./ Space Flight Lab., Canada

Time-Line	From	To
Planning	2013	
Construction	2014	2016
Measurement Phase	14 Jun. 2017 (launch)	open
Data Evaluation	25 Aug. 2017 (1st light)	ongoing

Method

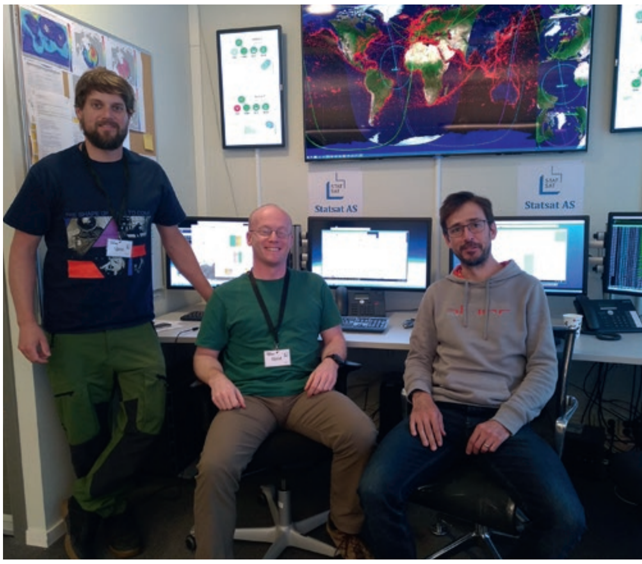
Measurement

Research Based on Existing Instrs.

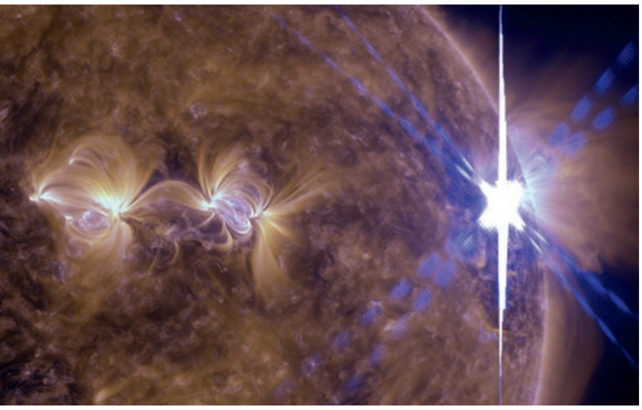
CLARA was developed and constructed by PMOD/WRC from 2013 to 2015.

Website

www.pmodwrc.ch/en/research-development/space/clara-NorSat-1



The CLARA Commissioning Team (left to right): B. Walter (PMOD/WRC), A. Beattie (UTIAS/SFL), D. Pfiffner (PMOD/WRC) in the NorSat-1 Mission Control Room, Oslo, Norway.



X6.9 flare, 9 August 2011, SDO. Image credit: NASA/SDO.

Institute

Institute for Data Science, FHNW

In Cooperation with:

Academy of Athens (AA), Greece
Northumbria Univ. (NU), UK
Trinity College Dublin (TCD), Ireland
Univ. Di Genova (UNIGEN), Italy
CNR, Italy; CNRS, France
Univ. Paris-Sud, (PSUD), France
Met. Office, UK

Principal Investigator

M. Georgoulis (RCAAM), Athens

Swiss Principal Investigator

A. Csillaghy

Co-Investigators

H. Sathiapal, M. Soldati (FHNW)

Method

Measurement

Research Based on Existing Instrs.

FLARECAST is an automated solar-flare forecasting system.

Website

www.fhnw.ch/de/die-fhnw/hochschulen/ht/institute

6.4 FLARECAST – Flare Likelihood and Region Eruption Forecasting

Purpose of Research

Solar flares are the main drivers of space weather. They may affect human assets in space and on Earth. A reliable prediction system will allow mitigation measures to be initiated on time. The three main objectives of the EU-H2020 project, FLARECAST, are:

• To understand the drivers of solar flare activity and improve flare prediction.

• To provide a globally and openly accessible flare prediction service that facilitates evolution and expansion.

• To engage in a dialogue with space-weather stakeholders, policy makers and the public on the societal benefits of reliable solar flare predictions.

FLARECAST aims to provide an advanced solar flare prediction system based on automatically extracted physical properties of solar active regions, coupled with state-of-the art flare prediction methods validated using the most appropriated forecast prediction measurements. FLARECAST forms the basis of the first quantitative, physically motivated and autonomous active-region monitoring and flare-forecasting system which is available to space-weather researchers and forecasters in Europe and around the globe.

Past Achievements and Status

FLARECAST is in its finalisation state. Flare predictors have been identified. The infrastructure for storing and processing data has been set up. Machine learning prediction algorithms have been developed and implemented.

In the mean time, more than 200 TB of data has been collected, processed and partially validated. End-user needs have been discussed with stakeholders from the fields of satellite operations, navigation, communication, defence and aviation.

Publications

1. Florios, et al., (2009), Forecasting solar flares using magnetogram-based predictors and machine learning, *Solar Physics*, 293, 28, doi: 10.1007/s11207-018-1250-4.

2. Guerra, et al., (2018), Active region photospheric magnetic properties derived from line-of-sight and radial fields, *Solar Physics*, 293, 0, doi: 10.1007/s11207-017-1231-z.

3. Benvenuto, et al., (2018), A hybrid supervised/unsupervised machine learning approach to solar flare prediction, *Astrophys. J.*, 853, article id.1.

Abbreviations

FLARECAST	Flare Likelihood & Region Eruption Forecasting
HMI	Helioseismic and Magnetic Imager
SDO	Solar Dynamics Observatory

Time-Line	From	To
Measurement Phase	2016	open
Data Evaluation	2017	open

6.5 DARA – Digital Absolute Radiometer on PROBA-3

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 this could affect the climate is still a matter of debate. Continuous and precise TSI measurements are indispensable to monitor the short and long-term solar radiative emission variations. The Digital Absolute Radiometer (DARA) on the ESA PROBA-3 mission is one of PMOD/WRC's future contributions to the almost seamless series of space-borne TSI measurements since 1978.

DARA is a 3-channel active cavity electrial substitution radiometer (ESR), comprising the latest radiometer developments at PMOD/WRC to achieve long-term stability and high accuracy. 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 maintaining a fixed configuration as a "large rigid structure" in space, representing a coronagraph configuration.

Past Achievements and Status

A major part of the design and engineering tasks was conducted in 2016, including the mechanical design, development of mechanical and thermal models, electronics schematics design, components selection and the board layout. This engineering model was assembled in late 2016, and was used for first vibration tests in December 2016. The results of these tests showed the need for design adaptations to achieve stiffness improvements, higher eigenmode frequencies and less amplification of these modes.

These modifications were made in early 2017. Parallel to the re-design, a shutter mechanism life-cycle test and a radiation test (ionising radiation) with a DARA/PROBA-3 controller board were conducted. The shutter mechanism underwent four million movements under vacuum conditions. The mechanism can be considered as reliable, since none of the five test items failed or led to any other issues. The controller board was exposed to a total dose of 40 krad without any shielding. The test indicated which components are most susceptible, and consequently we will apply some spot-shielding on certain components. In addition, the aluminium housing of the instrument and the spacecraft itself will provide additional shielding against harmful radiation. By the end of 2017, the preparation for the next milestone CDR was in progress.

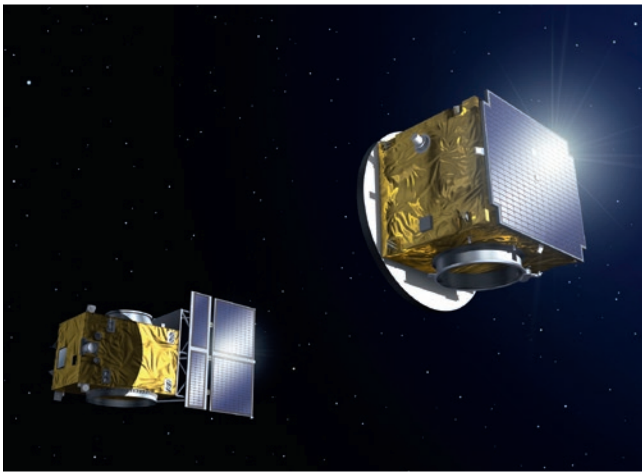
Publications

1. Walter, B., et al., (2017), *Metrologia*, 54, 674–682.

Abbreviations

CDR	Critical Design Review
ESR	Elec. Substitution Radiometer
TSI	Total Solar Irradiance

Time-Line	From	To
Planning	end of 2013	mid 2016
Construction	end of 2016 (EM)	end 2018 (EQM/FS)
Measurement Phase	late 2020	2023
Data Evaluation	2021	2024



PROBA-3 is an ESA formation-flying technology demonstration. Two satellites will fly with a 150 m separation on a highly elliptical orbit (600 x 60530 km). DARA is mounted on the front platform. Image credit: ESA.

Institute

PMOD/WRC, Davos

In Cooperation with:

ESA

Principal Investigator

W. Schmutz (PMOD/WRC)

Co-Investigators

W. Finsterle, B. Walter (PMOD/WRC)
A. Zhukov (Royal Obs. Belgium)

Method

Measurement

Development & Constr. of Instr.

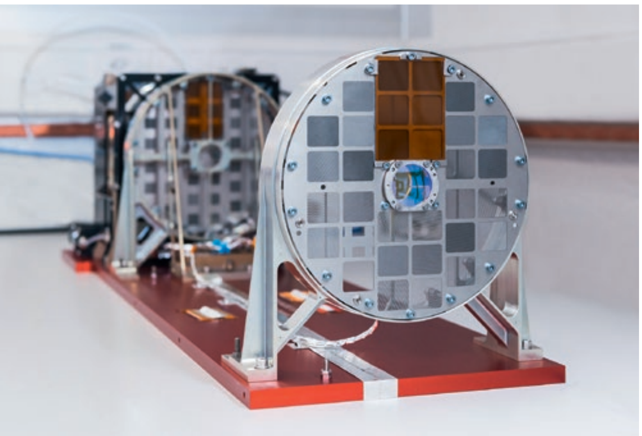
DARA is PMOD/WRC's contribution to the ESA PROBA-3 mission.

Industrial Contract to:

Almatech, Lausanne; dlab GmbH, Winterthur; else/Astorcast SA, Ecublens

Website

www.pmodwrc.ch/en/research-development/space/dara-proba-3/



The STIX Flight Model.

6.6 STIX – Spectrometer/Telescope for Imaging X-Rays Onboard Solar Orbiter

Institute

Institute for Data Science, FHNW

In Cooperation with:

SRC, PL; CEA, Sacaly, F; AIP, Potsdam, D; Czech Space Office, CZ; Univ. Graz, A; Trinity College Dublin, IRL; LESIA, F; Univ. Genova, I

Principal Investigator

S. Krucker (FHNW)

Co-Investigators

J. Sylwester (SRC), O. Limousin (CEA)
G. Mann (AIP), N. Vilmer (LESIA)
A. Vernonig (U. Graz), F. Farnik (CSO)
P. Gallagher (TCD), M. Piana (Genova)

Method

Measurement

Develop. & Constr. of Instruments

STIX is a Swiss-led instrument onboard ESA's Solar Orbiter mission.

Industrial Hardware Contract to:

Almatech; Art of Tech, AG; Syderal SA

Website

www.fhnw.ch/de/die-fhnw/hochschulen/ht/institute

Purpose of Research

STIX is a Swiss-led instrument onboard ESA's Solar Orbiter mission to be launched in Feb. 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 achieve this goal, Solar Orbiter carries a set of 10 instruments for joint observations. Through hard X-ray imaging and spectroscopy, STIX provides information about 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 provides a crucial link between the remote and in-situ instruments of Solar Orbiter.

Past Achievements and Status

In October 2012, Solar Orbiter was selected as the first medium-class mission of ESA's Cosmic Vision 2015-2025. STIX was previously selected as one of the 10 instruments onboard Solar Orbiter. The STIX Flight Model was delivered to ESA in July 2017. Launch of the Solar Orbiter mission is currently foreseen for February 2020.

Publications

1. Benz, A. O., S. Krucker, G. J. Hurford, N. G. Arnold, P. Orleanski, H.-P. Gröbelbauer, S. Klober, L. Iseli, H. J. Wiehl, A. Csillaghy, and 50 co-authors, (2012), Space telescopes and instrumentation 2012: Ultraviolet to gamma ray, *Proc. SPIE*, 8443, article id. 84433L, 15 pp.

Abbreviations

HXT	Hard X-ray Telescope
RHESSI	Reuven Ramaty High Energy Solar Spectr. Imager
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

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 observe 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.

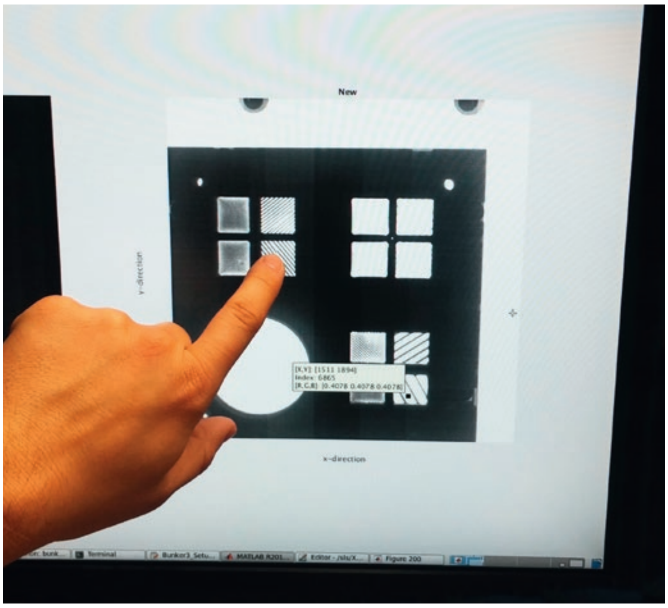
MiSolFA will use the same photon detectors as STIX, precisely quantifying the anisotropy of solar hard X-ray emissions for the first time to investigate particle acceleration in solar flares.

Past Achievements and Status

The Engineering Model of the MiSolFA gratings passed the space qualification tests with flying colors. The finalised design will be manufactured into the Qualification and Flight Models, bringing the finest X-ray gratings ever used to study the Sun, closer to launch.

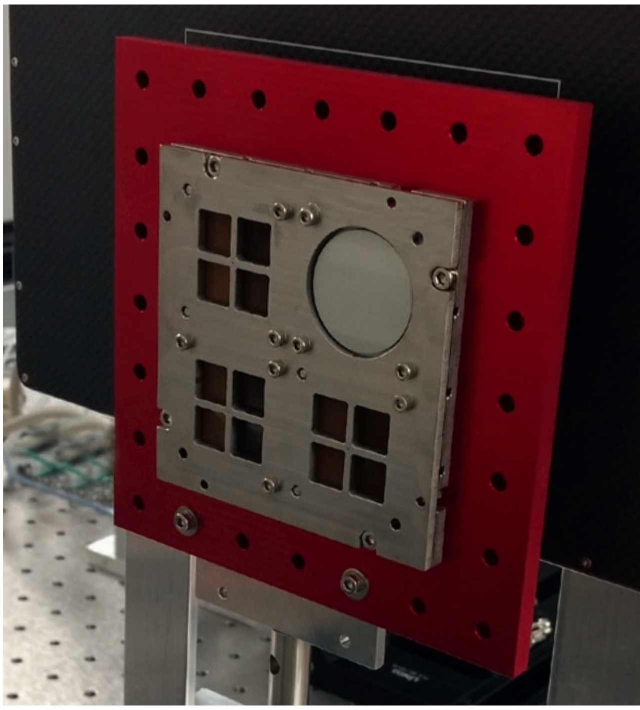
Abbreviations

MiSolFA	The Micro 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.

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



The MiSolFA Engineering Model is prepared for the first X-ray measurement of its Moiré inteference pattern.

Institute

Institute for Data Science, FHNW

Principal Investigator

D. Casadei (FHNW)

Co-Investigators

E. Lastufka, S. Krucker (FHNW)

Method

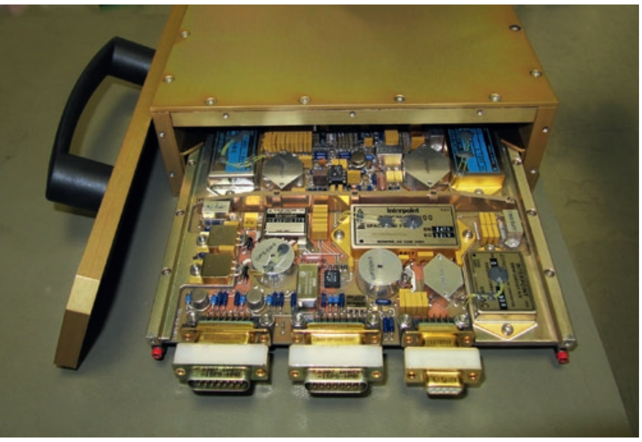
Measurement

Develop. & Construction of Instrs.

MiSolFA is a compact X-ray spectrometer that fits into a micro-satelite (30 x 20 x 10 cm, ie a 6-unit cubsat).

Industrial Hardware Contract to:

Paul Scherrer Institute (PSI)



The FM of the Low Voltage Power Supply (LVPS) for the SPICE instrument built at PMOD/WRC and as delivered to ADS.

6.8 SPICE and EUI Instruments Onboard Solar Orbiter

Institute

Physikalisch-Meteorologisches Observatorium Davos & World Radiation Center (PMOD/WRC), Davos

In Cooperation with:

SPICE and EUI consortia
Rutherford Appleton Lab. (RAL), UK
Goddard Space Flight Center (GSFC), USA
Inst. Theor. Astrophys. (ITA), Norway
Southwest Res. Inst. (SwRI), USA
Center Spatiale de Liège (CSL), Belgium
Royal Obs. Belgium (ROB), Belgium
Institut d'Optique (IO), France
Mullard Space Sci. Lab. (MSSL), UK
Inst. d'Astrophysique Spatiale (IAS), France
Max Planck Inst. Solar Sys. Res. (MPS), Germany
ESA
NASA

Principal Investigators

A. Fludra (RAL), UK (SPICE)
F. Auchère (IAS), France (SPICE)
P. Rochus (CSL), Belgium (EUI)

Swiss Principal Investigator

W. Schmutz (PMOD/WRC)

Purpose of Research

EUI is designed to investigate structures in the solar atmosphere from the chromosphere to the corona, thereby linking the solar surface and the outermost layers of the solar atmosphere that ultimately influence the characteristics of the interplanetary medium.

EUI has an instrument suite composed of a Full Sun Imager (FSI) and two High Resolution Imagers (HRI). HRI and FSI have spatial resolutions of 1 and 9 arc seconds, respectively. The HRI cadence depends on the target and can reach sub-second values to observe the fast dynamics of small-scale features.

The FSI cadence will be ~10 minutes in each passband, but can also achieve low cadences of ~10 s. The FSI works alternately in two passbands, 174 Å and 304 Å, while the two HRI passbands observe in the hydrogen Lyman α (1216 Å) and the extreme UV (174 Å).

SPICE is a high resolution imaging spectrometer operating at extreme ultraviolet (EUV) wavelengths, 70.4 – 79.0 nm and 97.3 – 104.9 nm. It is a facility instrument on the Solar Orbiter mission.

The EUV wavelength region observed by SPICE is dominated by emission lines from a wide range of ions formed in the solar atmosphere at temperatures from 10000 to 10 Million Kelvin. SPICE will measure plasma densities and temperatures, flow velocities, the presence of plasma turbulence and the composition of the source region plasma. It will observe the energetics, dynamics and fine-scale structure of the Sun's magnetised atmosphere at all latitudes.

EUI and SPICE EUI will significantly contribute to the following Solar Orbiter scientific themes:

- What drives the solar wind and where does the coronal magnetic field originate from?
- How do solar transients drive heliospheric variability?
- How do solar eruptions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

About 3 years after the launch, the spacecraft will initiate an out-of-ecliptic phase where the inclination will increase in relation to the solar equatorial plane by up to 33°. During the mission phase, the spacecraft will have the closest perihelion at 0.28 AU, while the aphelion will range from 0.78 to 1.13 AU.

Time-Line	From	To
Planning	2008	2010
Construction	2010	2017
Measurement Phase	2023	2029
Data Evaluation	2023	2030 and beyond

Past Achievements and Status

The EUI FM was delivered to Astrium Defence and Space on 9 June 2017, and the SPICE FM on 1 August 2017. The launch date of Solar Orbiter is foreseen for February 2020.

The SPICE 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 Technologies, both managed by PMOD/WRC.

Publications

1. Guerreiro, N., M. Haberreiter, V. Hansteen, W. Schmutz, (2017), Small-scale heating events in the solar atmosphere. II. Lifetime, total energy, and magnetic properties, *Astrophys. J.*, 603, id.A103.

2. Halain, J.-P., et al., (2017), EUV high resolution imager on-board solar orbiter: optical design and detector performances, Proc. SPIE, 10564, id. 105643V 6 pp.

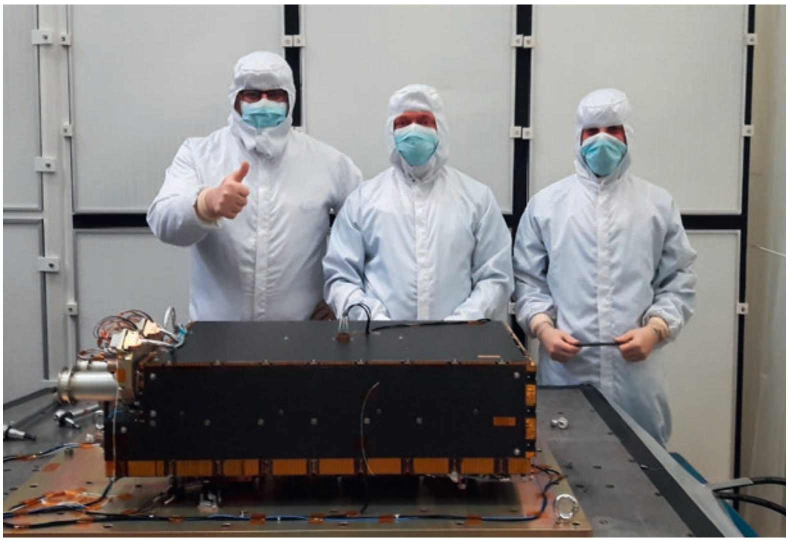
3. Caldwell, M. E., et al., (2017), The VUV instrument SPICE for Solar Orbiter: performance ground testing, Proc. SPIE, 10397, id. 1039708 13 pp.

4. Fludra, A., et al., (2016), The SPICE Spectral Imager on Solar Orbiter: Linking the Sun to the Heliosphere, COSPAR Abstract id.# D2.2-5-16.

5. Halain, J.-P., et al., (2016), The qualification campaign of the EUI instrument of Solar Orbiter, Proc. SPIE, 9905, id. 99052X 7 pp.

Abbreviations

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



The EUI flight model just after successfully passing the acceptance vibration test at CSL. From left to right: Sébastien Brunel (APCO), Manfred Gyo (PMOD/WRC) and Lionel Jacques (CSL).

Co-Investigators

SPICE:
E. Buchlin, A. Gabriel, S. Parenti, J.-C. Vial (IAS, France)
M. Carlsson (ITA, Norway)
W. Curdt, H. Peter, U. Schühle, L. Teriaca (MPS, Germany)
R. Wimmer-Schweingruber (Univ. Kiel, Germany)
M. Haberreiter (PMOD/WRC, CH)
M. Cladwell, R. Harrison, A. Giunta, N. Waltham (RAL, UK)
W. Thompson, J. Davila (GSFC, USA)
D. Hassler, C. de Forest (SWRI, USA)

EUI:
D. Berghmans, A. Zhukov, E. Buchlin, S. Parenti (IAS, France)
F. Verbeeck (ROB, Belgium)
F. Delmotte (IO, Paris-Saclay, France)
L. Harra, L. van Dreiel-Gesztelyi (MSSL), UK
U. Schühle, J. Büchner, L. Teriaca, S. Solanki (MPS, Germany)
W. Finsterle, M. Haberreiter, N. Guerreiro (PMOD/WRC, CH)

Method

Measurement

Development & Constr. of Instrs.

SPICE and EUI are part of the payload on the Solar Orbiter mission.

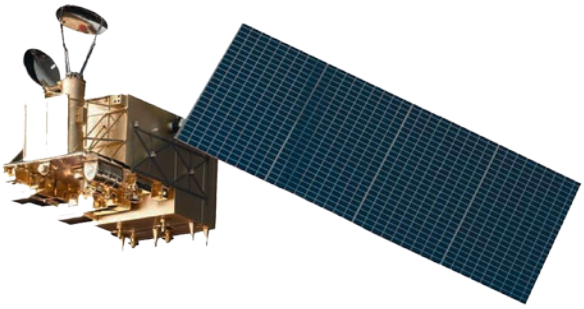
Industrial Hardware Contract to:

APCO Technologies; Almatech

Website

www.pmodwrc.ch/en/research-development/space/eui-solarorbiter

www.pmodwrc.ch/en/research-development/space/spice-solarorbiter



Artist's impression of FY-3E satellite. Image credit: CMA.

6.9 JTSIM-DARA

Joint Total Solar Irradiance Monitoring and Digital Absolute Radiometer on the Chinese FengYun-3E Satellite

Institute

Physikalisch-Meteorologisches Obs. Davos, and World Radiation Center, (PMOD/WRC), Davos

In Cooperation with:

Changchun Inst. Optics, Fine Mechanics & Physics (CIOMP), China

Principal/Swiss Investigator

W. Finsterle (PMOD/WRC)

Co-Investigators

W. Schmutz (PMOD/WRC)
B. Walter (PMOD/WRC)

Method

Measurement

Development & Constr. of Instrs.

The JTSIM-DARA experiment is a 3-channel digital absolute radiometer to measure TSI.

Industrial Hardware Contract to:

dlab GmbH, Winterthur

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/FY-3E project began in late 2015. After a successful feasibility study, a PRODEX proposal for Phase B and C/D was approved. The challenge with the JTSIM-DARA/FY-3E project lies in a different kind of industry contract, requiring an adapted approach as the Chinese collaboration is new to the community. Based on the status of the DARA/PROBA-3 mission, a Proto Flight Model (PFM) only-approach is followed. The JTSIM-DARA/FY-3E radiometer design is based on the DARA/PROBA-3 and CLARA/NorSat-1 instruments.

The manufacturing and testing of the PFM took place during 2017 and is now in the final phase. The flight electronics were fully designed, manufactured and tested at PMOD/WRC. Due to resources and complexity of some parts, the construction of the mechanics was split between PMOD/WRC and an external manufacturer. At the end of Q2 2018, the PFM will be handed over to CIOMP. A comprehensive test and qualification process is planned for Q3 2018 before the final instrument is integrated on the satellite. The launch of FY-3E is currently planned for early 2019.

Publications

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

2. Schmutz, W., et al., (2009), The PREMOS/PICARD instrument calibration, *Metrologia,* 46, S202–S206, doi: 10.1088/00261394/46/4/S13.

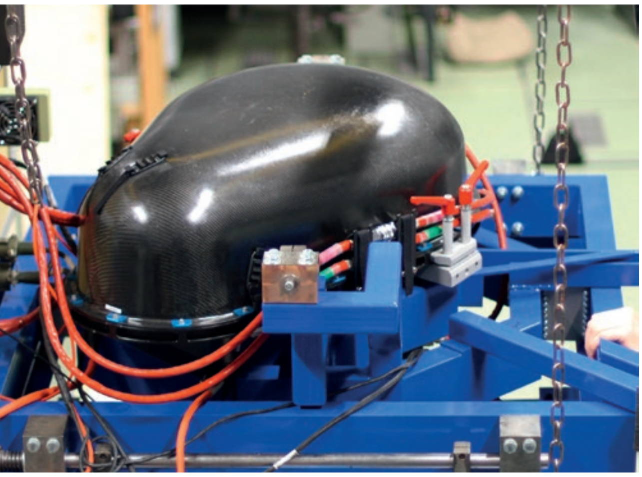
Abbreviations

DARA	Digital Absolute Radiometer
SIAR	Solar Irrad. Abs. Radiometer
TSI	Total Solar Irradiance

Time-Line	From	To
Planning	late 2013	early 2015
Construction	late 2015 (EM)	May 2018 (FM)
Measurement Phase	2019	open
Data Evaluation	2019	open

7 Earth Observation, Remote Sensing

7.1 APEX – Airborne Prism Experiment



APEX in the calibration laboratory.

Institute

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

In Cooperation with:

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

Principal/Swiss Investigator

M. E. Schaepman (RSL)

Co-Investigators

K. Meuleman (VITO), A. Hueni (RSL)

Method

Measurement

Research Based on Existing Instrs.

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.

Publications

1. Schaepman, M., et al., (2015), Advanced radiometry measurements and Earth science applications with the airborne prism experiment (APEX), *Rem. Sens. Environ.*, 158, 207–219.
2. Hueni, A., et al., (2014), Impacts of dichroic prism coatings on radiometry of the airborne imaging spectrometer APEX, *Appl. Opt.*, 53, 5344–5352.
3. Hueni, A., et al., (2013), The APEX (Airborne Prism Experiment - Imaging Spectrometer) calibration information system, *IEEE Trans. Geo. Rem. Sens.* 51, 5169–5180.

Abbreviations

APEX	Airborne Prism Experiment
PRODEX	PROg. de Dev. d'EXperiences Scient.
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

7.2 HYLIGHT – Integrated Use of Airborne Hyperspectral Imaging Data and Airborne Laser Scanning Data

Purpose of Research

The Joint Research Activity (JRA) HYLIGHT developed methodologies and tools for the integrated use of airborne hyperspectral imaging (HSI) data and airborne laser scanning (ALS) data in order to produce improved HSI and ALS vegetation information.

The developed methodologies, prototypes and tools were tested by the involved data processing facilities to improve the quality of both HSI and ALS data products for scientific users. RSL contributes by providing advanced, ray-tracing based vegetation layers from ALS data to be used in radiative transfer modelling.

HYLIGHT tools and datasets are freely available via the EUFAR toolbox and handbook. In addition, RSL provides access to HSI and ALS data gathered over the calibration supersite, Lägeren, established in the ESA STSE project '3D Vegetation Laboratory'. EUFAR (www.eufar.net) was an Integrating Activity funded by the EC 7th Framework Programme.

The activity was extended as EUFAR2 to run from 2014–2018 (24 partners). It aims to provide and improve the access to airborne facilities (i.e. aircraft, airborne instruments, data processing centers) for researchers in environmental and geo-sciences through Networking Activities (NA), Trans-national Access (TA) Activities and JRAs. The long-term objectives of EUFAR are to lay the groundwork of a European distributed infrastructure for airborne research in environmental and geo-sciences so that European scientists can obtain access to airborne facilities on "equal terms" which is most suited to their scientific objectives.

Past Achievements and Status

The EUFAR2 JRA "HYLIGHT" started in 2014 and finished in 2018. The tools can be found under http://eufar.net/cms/development-hylight-tools/

Publications

1. Morsdorf F., et al., (2018), Close-range laser scanning in forests: towards physically based semantics across scales, *Interface Focus*, 8, 10pp.

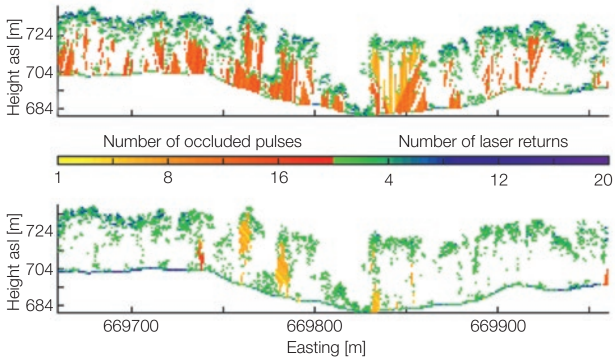
2. Kükenbrink D., et al., (2017), Quantification of hidden canopy volume of airborne laser scanning data using a voxel traversal algorithm, *Rem. Sens. Environ*. 194, 424–436.

3. Schneider, F. D., et al., (2014), Simulating imaging spectrometer data: 3d forest modeling based on lidar and in situ data, *Rem. Sens. Environ*. 152, 235–250.

Abbreviations

ALS	Airborne Laser Scanning
EUFAR2	FP-7 Integrating Activity
JRA	Joint Research Activity
HSI	Hyperspectral Imaging

Time-Line	From	To
Measurement Phase	2014	2018
Data Evaluation	2014	2018



Occlusion mapping of an ALS system in a temperate mixed forest, for "leaf-on" state (top) and "leaf-off" state (bottom).

Institute

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

In Cooperation with:

VITO, Belgium
ONERA, France
DLR, Germany
INTA, Spain
PML, UK
CVGZ, Czech Republic
TAU, Israel
TU Wien, Austria

Principal Investigator

I. Reusen (VITO)

Swiss Principal Investigator

F. Morsdorf (RSL)

Co-Investigators

A. Hueni (RSL)
M. Kneubühler (RSL)
D. Kükenbrink (RSL)
M. E. Schaepman (RSL)

Method

Simulation

Research Based on Existing Instrs.

Airborne hyperspectral sensors and laser scanners.

7.3 SPECCHIO – Spectral Information System

Institute

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

In Cooperation with:

Geoscience Australia (GA)
Australian Nat. Data Service (ANDS)
CSIRO (Australia)
OPTIMSE COST Action
Specnet Spectral Network
EcoSIS

Principal/Swiss Investigator

A. Hueni (RSL)

Co-Investigators

L. Chisholm (UoW, Australia)
M. E. Schaepman (RSL)
M. Thankappan (GA)

Method

Measurement

Development of Software

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

Website

www.specchio.ch

Purpose of Research

Scientific efforts to observe the state of natural systems over time, allowing the prediction of future states, have led to a burgeoning interest in the organised storage of spectral field data and associated metadata. This is seen as being key to the successful and efficient modelling of such systems.

A centralised system for such data, established for the remote sensing community, aims to standardise storage parameters and metadata, thus fostering best practice protocols and collaborative research. The development of a spectral information system will not only ensure the long-term storage of data but 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 have been made to the system in the past via funding provided by the Australian National Data Service (ANDS), the Swiss Commission on Remote Sensing and the EuroSpec COST Action ES0903. SPECCHIO also serves as the Spectral Information System component, fostered and developed within the working group 1 of OPTIMSE ES1309 COST Action.

SPECCHIO is installed in some 40 research institutions world-wide and is also used in teaching activities at the Remote Sensing Laboratories, University of Zurich. The Australian instance of SPECCHIO will be hosted by Geoscience Australia starting in 2018 within the framework of Digital Earth Australia.

To date, SPECCHIO is the most advanced spectral information system within the domain of Earth observing remote sensing.

SPECCHIO is also open source and has been made available as a virtual machine image in 2015 which allows anyone to run the full system on their personal laptop, thus supporting its full functionality under field conditions.

For further information please refer to www.specchio.ch and http://optimise.dcs.aber.ac.uk/working-groups/wg1-spectral-information-system/

Publications

1. Hueni, A., L. Chisholm, L. Suarez, C. Ong, and M. Wyatt, (2012), Spectral information system development for Australia, in Geospatial Sci. Res. Symp. Melbourne, Australia.

2. Hueni, A., T. Malthus, M. Kneubuehler, and M. Schaepman, (2011), Data exchange between distributed spectral databases, *Computers & Geosci.*, 37, 861–873.

3. Hueni, A., J. Nieke, J. Schopfer, M. Kneubühler, and K. Itten, (2009), The spectral database SPECCHIO for improved long term usability and data sharing, *Computers & Geosci.*, 35, 557–565.

7.4 FLEX – FLuorescence EXplorer Mission

Purpose of Research

The FLuorescence EXplorer satellite mission will map Sun-Induced chlorophyll Fluorescence (SIF) emitted by vegetation on a global scale. SIF is the most direct measurement of photosynthesis at scale.

The Key objectives of FLEX are to measure several properties of emitted SIF signals, including:

- SIF emitted around the two oxygen absorption features O2-A and O2-B,
- SIF emissions at the two emission peaks at 685 and 740 nm,
- Total fluorescence integrated over the full emission spectrum, and
- The individual contributions from photosystem I and II.

The FLEX mission will have significant implications for ecosystem research and food security in the context of environmental change. SIF is a complementary measurement of vegetation status and health, and offers new pathways to assess, e.g., ecosystem functioning, gas and energy exchanges of terrestrial ecosystems as well as biodiversity.

Past Achievements and Status

In November 2015, FLEX was selected for implementation as an outcome of ESA's user consultation meeting in Krakow, Poland. After several preparatory studies in the frame of Phase 0 of ESA's Earth Explorer 7 and Phase A/B1 of ESA's Earth Explorer 8 activities, FLEX has now entered Phase B2.

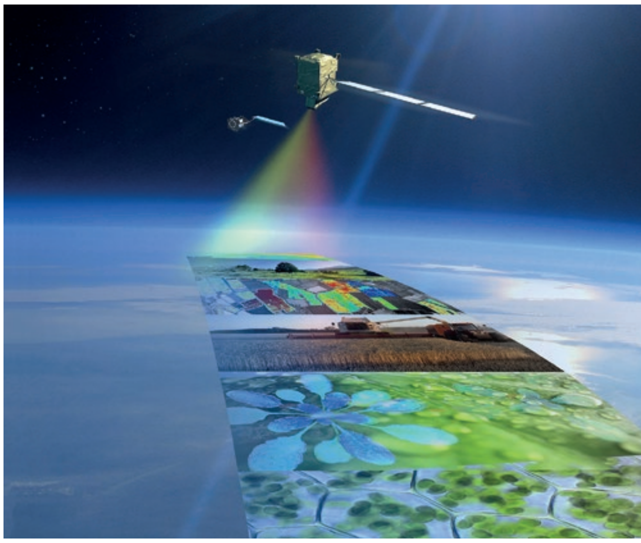
At the beginning of 2016, the FLEX Mission Advisory Group (MAG) was established. Together with eight other experts from European countries as well as Canada, Alexander Damm (Univ. Zurich, Zurich, Switzerland) became a member of the MAG advisory group. The launch of FLEX is foreseen for 2022.

Publications

1. Drusch, M., et al., (2017), The FLuorescence EXplorer Mission Concept-ESA's Earth Explorer 8, *IEEE Trans. Geosci. Rem. Sens.* 55, 1273–1284.
2. ESA, (2015), Report for Mission Selection: FLEX. ESA SP-1330/2 (2 volume series), ESA, Noordwijk, The Netherlands.
3. Rascher, U., et al., (2015), Sun-induced fluorescence – a new probe of photosynthesis: First maps from the imaging spectrometer HyPlant, *Global Change Biology*, 21, 4673–4684.

Abbreviations

FLEX	FLuorescence EXplorer Mission
FLORIS	Fluorescence imaging Spectrometer
MAG	Mission Advisory Group
SIF	Sun-Induced chlorophyll Fluorescence



Mission concept of ESA's 8th Earth Explorer Mission, FLEX. Image credit: ESA/ATG medialab.

Institute

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

In Cooperation with:

ESA, Netherlands
Univ. Valencia, Spain
Forschungszent. Jülich, Germany
CNR, Inst. Biometeorology, Italy
Lab. Met. Dyn., France
P&M Technologies, Canada
Univ. Twente, Netherlands
Univ. Milano Bicocca, Italy

Principal Investigator

J. Moreno

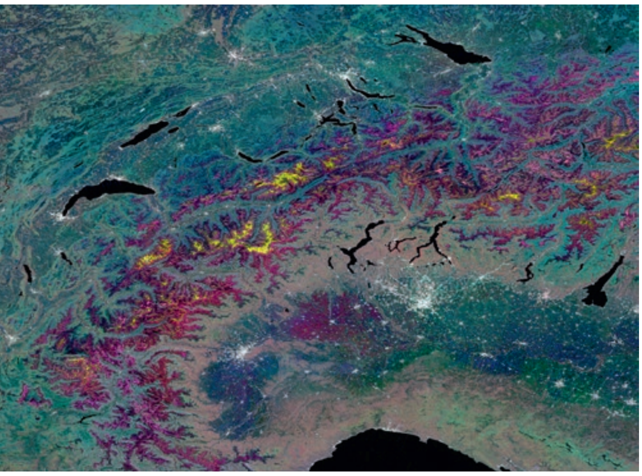
Method

Measurement

Development of Software

Development of tandem satellite FLEX/Sentinel-3, incl. FLORIS.

7.5 Wet Snow Monitoring with Spaceborne SAR



The image shows composite backscatter images from the Sentinel-1A/B radar satellites of the European Alps - the composite backscatter values were calculated using data from 6-day periods. Red is from early Jan. 2017, green from late April, and blue from late June. Dry snow shows up brightly, while melting snow returns low backscatter, hence the highest mountains appear yellow (red+green), as they only began melting in June.

Institute

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

In Cooperation with:

European Space Agency (ESA)

Canadian Space Agency (CSA)

WSL Institute for Snow and Avalanche Research (SLF)

Principal/Swiss Investigator

D. Small (RSL)

Co-Investigators

C. Rohner (RSL)

A. Schubert (RSL)

Purpose of Research

The University of Zurich Remote Sensing Laboratories (UZH-RSL) works with ESA and other partners to develop a novel spaceborne SAR image product whereby many of the effects of topography on radar image brightness are modelled and corrected before estimating the backscatter coefficient at each image coordinate.

The new type of product offers several benefits. Comparisons of backscatter from image acquisitions made from differing orbital tracks become possible. Flattening the terrain-induced effects on radar brightness enables significantly more frequent revisits to a specific point on the Earth, in particular, given the availability of a wide swath mode such as C-band Sentinel-1, Radarsat-2 SCN & SCW, L-band ALOS PALSAR WB (wide beam), or the wide ScanSAR modes from the X-band sensors CosmoSkymed, TSX, TDX, and PAZ.

Use of the new products enables a great improvement in temporal resolution, a parameter of critical importance in land-cover monitoring to lower the probability of missing events of brief duration. Data-rich time-series can be built up for a chosen area much more quickly from a single sensor given a wider variety of tracks (even combinations of ascending and descending passes), and especially to integrate backscatter measurements from a diversity of sensors.

Each sensor is typically characterised by the single orbital repeat period chosen at launch and the set of beam modes on offer. Building algorithms that are open to multiple sensors therefore implies by necessity, openness to differing tracks, modes, and nominal incident angles.

Not being open to multiple tracks, triggers (in the absence of terrain-flattening) incompatibility with meaningful short-term comparisons or quick revisits when monitoring large regions. Only terrain-flattened backscatter, a product we call terrain-flattened gamma nought, offers the possibility of combining data from multiple SAR sensors acquired over rolling terrain.

The ESA Sentinel-1 radar satellites, the first of which was launched in April 2014, are acquiring regular images of Europe at a resolution of 20 m. RSL has been generating composite backscatter images of the European Alps as well as other regions to test a new method for snow-melt monitoring.

Given the complex topography of the Alps in Switzerland, construction of backscatter time-series requires rigorous radiometric calibration that accounts for track-dependent terrain-induced effects. If a standard terrain-flattened backscatter product could be offered by ESA, this would simplify interpretation of SAR imagery not only in Switzerland, but throughout the world.

Time-Line	From	To
Planning	ongoing	
Construction	-	-
Measurement Phase	2014	ongoing
Data Evaluation	2015	ongoing

Past Achievements and Status

A terrain-normalisation method for SAR imagery covering steep terrain has been developed and tested using data from major spaceborne SAR sensors. Further tests are under way using data from Sentinel-1, Radarsat-2, and TerraSAR-X. In the case of wide-swath C-band data covering Switzerland, seasonal trends are established (see image on left). Springtime melting in the Swiss Alps is clearly visible: terrain-flattened backscatter makes monitoring of the snow melt theoretically possible with multiple observations per week using Sentinel-1 data.

The companion satellite to Sentinel-1A, Sentinel-1B, was launched in April 2016. We were able to show that C-band sensors can monitor forest phenology, given accurate geometric and radiometric calibration. Deciduous and coniferous forest can be classified with terrain-flattened C-band backscatter.

Wet snow measurements have been evaluated qualitatively and are being compared with state-of-the-art operational methodologies. Harmonised data acquisition strategies for the different spaceborne SAR sensors are being coordinated through the World Meteorological Organisation Polar Space Task Group (WMO-PSTG).

Abbreviations

PALSAR	Phased Array L–band Synthetic Aperture Radar
SAR	Synthetic Aperture Radar
SCN	RADARSAT ScanSAR Narrow
SCW	RADARSAT ScanSAR Wide
TSX/TDX/PAZ	TerraSAR–X satell. (X–band)

Publications

1. Rüetschi M., M. Schaepman, D. Small D., (2018), Using multitemporal Sentinel-1 C-band backscatter to monitor phenology and classify deciduous and coniferous forests in Northern Switzerland, *Remote Sensing*, 10(55), 30p.

2. Schubert A., N. Miranda, D. Geudtner, D. Small, (2017), Sentinel-1A/B combined product geolocation Accuracy, *Remote Sensing*, 9(607), 16p.

3. Small D., (2011), *IEEE Trans. Geosci. Rem. Sens.*, Aug. 2011, 49(8), pp. 3081–3093.

Method

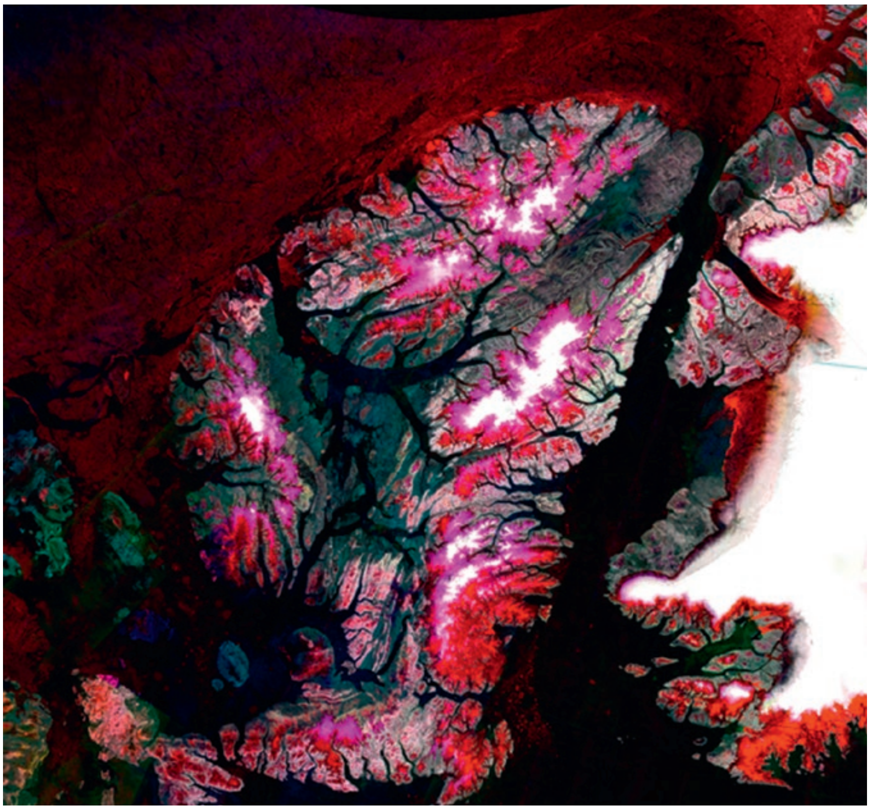
Measurement

Research Based on Existing Instrs.

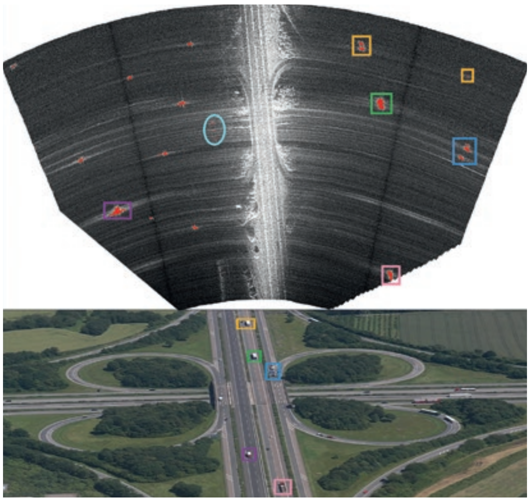
Sentinel-1, Radarsat-2
TerraSAR-X, Cosmo-Skymed

Website

www.geo.uzh.ch/en/research-groups/David-Small.html



The image shows melting in the Canadian high arctic, with coverage of Ellesmere Island and northwestern Greenland. Three radar 2-day composites from Sentinel-1A and 1B are superimposed as an RGB overlay. The red channel comes from 11–12 May 2017, green from 8–9 August 2017, and blue from 15–16 July 2017. The ice caps were initially dry and cold in May, but began to progressively melt in early to mid–July, causing lower backscatter in their margins, and therefore appearing in red tones.



Exo-clutter processing: Upper panel: geocoded focussed SAR image with moving target indications. Lower panel: optical ref. image.

Institute

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

In Cooperation with:

armasuisse (CH);
Fraunhofer Inst. High Freq. Physics and Radar Tech. (FHR), Germany;
German Aerospace Center (DLR), Germany

Principal/Swiss Investigator

D. Henke (RSL)

Co-Investigators

E. Casalini (RSL), E. Meier (RSL)
M. E. Schaepman (RSL)

Method

Measurement

Research Based on Existing Instrs.

Airborne SAR sensors.

Website

www.geo.uzh.ch/en/units/rsl/Research/SAR_Lab.html

7.6 Moving Target Tracking in SAR Images

Purpose of Research

Ground Moving Target Indication (GMTI) in synthetic aperture radar (SAR) data addresses the task of extracting information about moving objects. SAR-GMTI allows moving objects to be indicated while simultaneously imaging the area of interest and works independently of weather conditions and daytime.

However, since SAR was originally developed for use in static scenes, the problem of extracting information from moving objects is a challenging task which has evolved over the last decade and demands state-of-the-art processing techniques, such as Along-Track Interferometry (ATI), displaced-phase-center antenna, Space-Time Adaptive Processing (STAP), and exo-clutter processing techniques or temporal tracking algorithms. In this project, these methods are refined and adapted to innovative SAR technologies such as Frequency-Modulated Continuous-Wave (FMCW) SAR systems which have become increasingly popular in the last years due to their particular features.

Past Achievements and Status

In 2016 and 2017, various data-sets were recorded with the Fraunhofer FHR MIRANDA35 sensor which is an FMCW SAR system in the Ka-band. A test site for the 2016 SAR-GMTI campaign was chosen with traffic flows on a highway outside the city of Koblenz, Germany. Different SAR-GMTI methods were tested and compared to evaluate the performance of each of the specific techniques of FMCW SAR systems.

More specifically, ATI processing yielded a detection rate of 60.4% and a false alarm rate of 21.4%. Vice-versa, exo-clutter processing reached a detection rate of 97.8%, whereas the false alarm rate was quantified at 12.3%.

To properly interprete such results, several considerations must be kept in mind. The signatures of moving targets are frequently displaced on bright stationary targets, thus making their detection a much more challenging task. ATI, for instance, is substantially affected by such scenarios, whereas exo-clutter processing is not.

To tackle this problem, two-dimensional filtering techniques (i.e., STAP) will be implemented and adapted for FMCW SAR systems. This is now possible as the new 2017 data were collected with an innovative multichannel sensor.

Publications

1. Henke, D., et al., (2018), Moving target tracking in SAR data using combined exo-and endo-clutter processing, *IEEE Trans. on Geosci. Rem. Sens.*, 56, 251-263.

2. Casalini, E., D. Henke, and E. Meier, (2016), GMTI in circular SAR data using STAP, In IEEE Sensor Signal Processing for Defence (SSPD).

Abbreviations

ATI	Along-Track Interferometry
FMCW	Frequency-Modulated Continuous-Wave
GMTI	Ground Moving Target Indication
SAR	Synthetic Aperture Radar
STAP	Space-Time Adaptive Processing

7.7 Calibration Targets for MetOp-SG Instruments MWS and ICI

Purpose of Research

The second generation of the Meteorological Operational Satellite (MetOp-SG) programme is a series of polar orbiting satellites to provide atmospheric remote sensing observations for numerical weather prediction. Two of the instruments to be flown on MetOp-SG are the Microwave Sounder (MWS) and Ice Cloud Imager (ICI). The state-of-the-art MWS instrument includes radiometers between 23 GHz and 230 GHz for measuring atmospheric temperature and humidity profiles. The novel ICI instrument includes radiometers between 175 GHz and 668 GHz for imaging and profiling of 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 Inst. Applied Physics (IAP) is responsible for the electromagnetic design and the experimental verification of the on-board calibration targets of MWS and ICI. These targets have a pyramidal shape with a tapered profile and multi-layer absorber coating which were optimised to provide the best trade-off between a high temperature uniformity and a low microwave reflectivity.

The IAP is also working on the development of the on-ground calibration targets for the ICI instrument which will be used prior to launch for verification of the radiometric performance of ICI at instrument and satellite level. The two on-ground targets have to provide a cryogenic and an accurately controlled variable brightness temperature under thermal-vacuum conditions. Since they have to meet more challenging performance requirements than the flight targets, a wedged cavity design has been selected and optimised using physical optics simulations.

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. Delivery of the first flight models and of the ground support equipment is scheduled by the end of 2018.

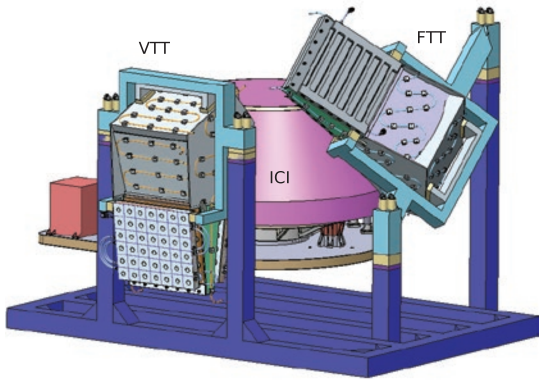
Publications

1. Schröder, A., et al., (2017), Electromagnetic design of calibration targets for MetOp-SG microwave instruments, *IEEE Trans. THz Sci. Technol.*, 7, 677–685.
2. Schröder, A., et al., (2017), Brightness temperature computation of microwave calibration targets, *IEEE Trans. Geo. Rem. Sens.*, 55, 7104–7112.
3. Kotiranta, M., et al., (2017), 5th Work. Adv. RF Sens. & Rem. Sensing Instrs., ESTEC, Noordwijk, NL.

Abbreviations

ICI	Ice Cloud Imager
MetOp	Met. Operational Satellite
MWS	Microwave Sounder

Time-Line	From	To
Planning	2013	2015
Construction	2016	2018
Measurement Phase	2018	2019
Data Evaluation	2018	2019



CAD model of the ICI on-ground calibration targets.

Institute

Inst. Appl. Phys., Univ. Bern (UNIBE)

In Cooperation with:

TK Instruments, UK
Airbus Space and Defence, UK
Airbus Space and Defence, Spain
IABG, Germany
ESA

Swiss Principal Investigator

A. Murk (UNIBE)

Co-Investigators

A. Schröder, M. Kotiranta

Method

Measurement

Developments

Development of on-board and on-ground calibration equipment.

Industrial Hardware Contract to:

TK Instrs., UK
IABG, Germany

Website

www.iapmw.unibe.ch

7.8 EGSIEM – European Gravity Service for Improved Emergency Management

Institute

Astronomical Institute,
Univ. Bern (AIUB)

In Cooperation with:

EGSIEM Consortium

Swiss Principal Investigator

A. Jäggi (AIUB)

Co-Investigators

U. Meyer

Y. Jean

Andreja Sušnik

Method

Measurement

Website

http://egsiem.eu/

Purpose of Research

Earth observation satellites yield a wealth of data for scientific, operational and commercial exploitation. However, the redistribution of environmental mass is not yet part of the standard Earth observation data products to date. These observations, derived between 2002 and 2017 from the Gravity Recovery and Climate Experiment (GRACE), and from 2018 onwards by GRACE-FO (Follow-on), deliver fundamental insights into the global water cycle.

Changes in continental water storage control the regional water budget and can, in extreme cases, result in floods and droughts that often claim a high toll on infrastructure, economy and human lives. The aim of the European Gravity Service for Improved Emergency Management (EGSIEM) was to provide consolidated mass redistribution products and to demonstrate that gravity products open the door for innovative approaches to flood and drought monitoring and forecast.

The timeliness and reliability of information is the primary concern for any early-warning system. EGSIEM has increased the temporal resolution from one month, typical for GRACE products, to one day and provided gravity field information within 5 days (near real-time).

Early warning indicators derived from these products were demonstrated to have the potential to improve the timely awareness of potentially evolving hydrological extremes and may help in the scheduling of high-resolution follow-up observations as performed at centers such as the Center for Satellite Based Crisis Information (ZKI, operated by the German Aerospace Center). EGSIEM has unified the combined knowledge of the entire European GRACE community and has established a total of three prototype services:

1) A scientific combination service.

2) A near real-time service.

3) A hydrological/early warning service.

Past Achievements and Status

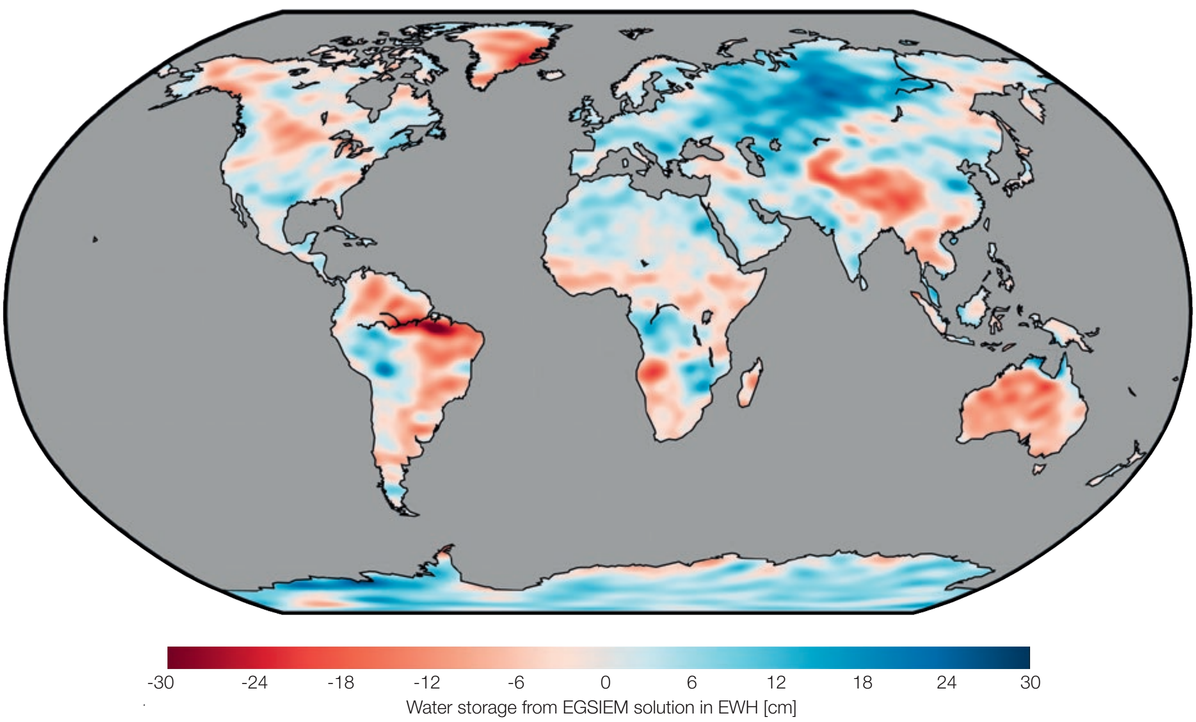
Starting in January 2015, EGSIEM received funding from the European Commission (EC) for three years until the end of 2017. EGSIEM unified the knowledge of the entire European GRACE community to pave the way for a long awaited standardisation of gravity-derived products. Combining the results obtained from different analysis centers of the EGSIEM consortium, each of which performing independent analysis methods but employing consistent processing standards, has significantly increased the quality, robustness and reliability of these data. The successful work of the scientific combination service will be continued after the EC-funded prototype phase as the International Combination Service for Time-variable Gravity Field Solutions (COST-G) under the umbrella of the International Association of Geodesy (IAG). Specifically, COST-G will be the Product Center for time-variable gravity fields of IAG's International Gravity Field Service (IGFS). The near real-time and hydrological services will be continued on a best effort basis as soon as GRACE-FO data becomes available.

Publications

1. Jäggi, A., M. Weigelt, F. Flechtner, A. Güntner, T. Mayer-Gürr, S. Martinis, S. Bruinsma, J. Flury, S. Bourgogne, H. Steffen, U. Meyer, Y. Jean, A. Sušnik, A. Grahsl, D. Arnold, K. Cann-Guthauser, R. Dach, Z. Li, Q. Chen, T. van Dam, C. Gruber, L. Poropat, B. Gouweleeuw, A. Kvas, B. Klinger, J.-M. Lemoine, R. Biancale, H. Zwenzner, T. Bandikova, A. Shabanloui, (2018), European Gravity Service for Improved Emergency Management (EGSIEM) - from concept to implementation. *J. Geodesy*, submitted in March 2018.

Abbreviations

EGSIEM	European Gravity Service for Improved Emergency Management
GRACE	Gravity Recovery And Climate Experiment
GRACE-FO	GRACE Follow-On



Post-processed grids of equivalent water heights for hydrological applications for an example month (January 2008).

7.9 Copernicus Precise Orbit Determination Service

Institute

Astronomical Institute, Univ. Bern (AIUB)

In Cooperation with:

ESA's CPOD Quality Working Group

Principal Investigator

J. Fernandez

Swiss Principal Investigator

A. Jäggi (AIUB)

Co-Investigator

D. Arnold

Method

Measurement

Website

www.copernicus.eu

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.

Artist's impression of the Sentinel-1A satellite. Image credit: ESA.

Past Achievements and Status

Starting with Sentinel-1A, the rigorous orbit comparisons revealed a systematic radial offset between various orbit solutions of about 3 cm. Due to the different parameterisation and orbit models used for the orbit determination by the different QWG members, this systematic orbit offset was identified as erroneous information in the satellite geometry despite the lack of any independent orbit validation techniques onboard Sentinel-1A.

Based on the corrected geometry, long-term comparisons have been performed, and the consistency between the orbit solutions was assessed to be well within the required orbital accuracy of 5 cm 3D RMS.

Similar comparisons are currently being performed for all other Sentinel satellites. For Sentinel-3, it is possible to not only use the Global Positioning System (GPS) but also other satellite tracking techniques such as Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) and Satellite Laser Ranging (SLR) to compute and validate the precise orbit solutions of the CPOD Service.

Adopting a refined strategy for generation of the GPS carrier phase data of the Sentinel-3 GPS receiver, has recently allowed half-cycle ambiguities in GPS data to be handled that have so far inhibited ambiguity-fixed orbit solutions. Based on single-receiver ambiguity resolution techniques, improved orbit precision from about 9 to 5 mm standard deviation was demonstrated due to the availability of independent SLR data. With respect to altimetry, the improved orbit precision will be beneficial for the global consistency of sea surface height data.

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

Publications

1. Peter, H., et al., (2017), Sentinel-1A – First precise orbit determination results, *Adv. Space Res.*, 60(5), 879–892, doi: 10.1016/j.asr.2017.05.034.

2. Montenbruck, O., S. Hackel, A. Jäggi, (2017), Precise orbit determination of the Sentinel-3A altimetry satellite using ambiguity-fixed GPS carrier phase observations. *J. Geodesy*, doi: 10.1007/s00190-017-1090-2, in press.

Abbreviations

CPOD Service	Copernicus Precise Orbit Determination Service
CPOD QWG	CPOD Quality Working Grp.
DORIS	Doppler Orbitogr. & Radio-positioning Int. by Satellite
SLR	Satellite Laser Ranging

7.10 EMRP MetEOC-3

EMRP
European Metrology Research Programme
Programme of EURAMET

Metrology for Earth Observation and Climate

Institute

Remote Sensing Labs. (RSL), Univ Zurich, Zurich, Switzerland

In Cooperation with:

National Physical Lab. (NPL), UK

Principal Investigator

N. Fox (NPL)

Swiss Principal Investigator

A. Hueni (RSL)

Co-Investigator

M. E. Schaepman (RSL)

Method

Measurement

Research Based on Existing Instrs.

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 to:

NASA/JPL

Website

www.meteoc.org

Purpose of Research

The Earth's climate is changing. The scale of impact on future society remains uncertain and with it, government's ability to confidently take necessary mitigation/adaptation in a timely manner. A key limitation is the performance of forecasting models and the quality of the data that drive them. Remote sensing from space is the main method of obtaining the global data needed.

The harshness of launch and environment of space severely limits accuracy and traceability. MetEOC-3 will improve pre-and post-launch calibration/validation (Cal/Val) of observations (land, ocean and atmosphere) to enable trustworthy information on the state-of-the-planet to be delivered to policymakers.

Key aspects to validate 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 providing traceable measurements with uncertainty budgets, and 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 established in past projects (MetEOC-1 and MetEOC-2).

Consequently, the APEX Raw to Radiance Processor has been updated to produce uncertainty cubes for imaging cubes acquired in flight. These uncertainty cubes contain the radiometric uncertainties for all pixels of the image cubes and can be used to inform probabilistic models to allow optimised estimates.

Publications

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

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

Abbreviations

APEX	Airborne Prism Experiment
CWIS	Compact Wide-Swathe Imaging Spectrometer
EMRP	European Metrology Research Programme
MetEOC	Metrology for Earth Observation and Climate
SPECCHIO	Spectral Information System

7.11 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 4-year 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 University of Zurich group will keep operating the APEX airborne imaging spectrometer and also coordinate European flight missions with NASA/JPL airborne sensor systems.

These efforts are designed to maintain airborne operational capabilities, keep the scientific momentum of airborne spectroscopy, and prepare the user community for the type of data to be expected from the upcoming ARES sensor suite.

Abbreviations

APEX	Airborne Prism Experiment
ARES	Airborne Research Facility for the Earth System
hpPC	high-performance Photogrammetric Camera
IS	Imaging Spectrometer
LiDAR	Light Detection and Ranging

Time-Line	From	To
Planning	2017	2018
Construction	2018	2020
Measurement Phase	2020	open
Data Evaluation	2020	open

ARES during air operations.

Institute

Remote Sensing Labs. (RSL), Univ Zurich, Zurich, Switzerland

In Cooperation with:

ETHZ; Inst. Math., UZH; IAC, ETHZ; IAS, ETHZ; IGP, ETHZ; EMPA; EAWAG; EPFL ENAC; UniFr; UniL

Principal Investigator

M. E. Schaepman

Co-Investigators

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

Method

Measurement

Development & Constr. of Instrs.

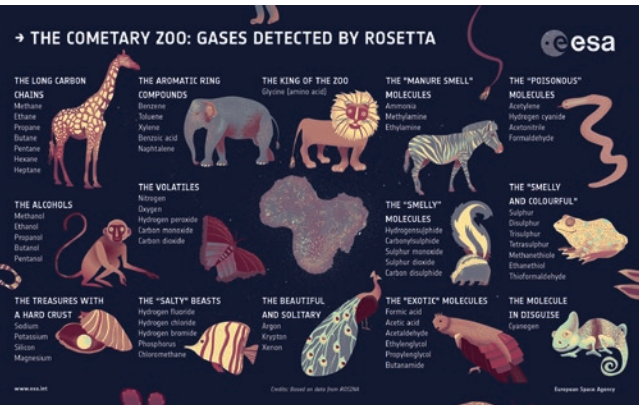
ARES is an airborne research facility.

Industrial Hardware Contract to:

NASA/JPL (develop. IS with UZH)

8 Comets, Planets

8.1 ROSINA – Rosetta Orbiter Spectrometer for Ion and Neutral Analysis



The ROSINA Zoo of volatile species detected by Rosetta/ ROSINA in coma of comet 67P/Churyumov-Gerasimenko (Image Credit: ESA, more details: http://blogs.esa.int/ rosetta/2016/09/29/the-cometary-zoo/).

Institute

Institute of Physics,
Univ. Bern (UNIBE)

In Cooperation with::

ESA; MPS;
TUB; BIRA;
CESR; IPSL;
LMM; UMich., (USA);
SwRI, USA

Principal Investigator

K. Altwegg (UNIBE)

Co-Investigators

H. Balsiger, E. Kopp
M. Rubin, P. Wurz

Method

Measurement

Industrial Hardware Contract to:

Contraves (Ruag) Space
APCO
Montena etc.

Website

www.space.unibe.ch/

Purpose of Research

In September 2016, the European Space Agency's Rosetta mission came to its conclusion. The final plunge of the spacecraft onto comet 67P/Churyumov-Gerasimenko (hereafter 67P) marked the end of a two-year thorough investigation of the comet. As part of the payload, the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) monitored the volatile species in the coma of the comet. ROSINA contained two complementing mass spectrometers and a pressure sensor (Balsiger et al., 2007).

ROSINA was dedicated to the analysis of cometary material, and to obtain insight into the physical and chemical conditions at the time of formation in our early solar system.

Crucial measurements included the isotopes of hydrogen in water which indicated that comets such as 67P are most likely not the origin of the majority of water on Earth (Altwegg et al., 2015; 2017a). The isotopes of the noble gas xenon, on the other hand, indicated that the terrestrial atmosphere could indeed be partially of cometary origin (Marty et al., 2017).

In other species, comet 67P also showed remarkable differences in its isotopic composition compared to solar abundances (Calmonte et al., 2017; Rubin et al., 2017) which in turn indicates that the early solar system was rather inhomogeneous in the region where the comet formed. ROSINA detected many species for the first time in comets, including molecular oxygen (Bieler et al., 2015), nitrogen (Rubin et al., 2015), and halogens (Dhooghe et al., 2017).

In addition, the comet is very rich in organics (Altwegg et al., 2017b) and contains many elements and molecules relevant to life as we know it (Altwegg et al., 2016; Fayolle et al., 2017) – material that could have been brought to Earth through impacts in the early days of the solar system (Marty et al., 2016).

Past Achievements and Status

The active part of the mission is now finished. ROSINA collected numerous mass spectra and current work includes data archiving, i.e. the assimilation of these data into ESA's Planetary Science Archive and NASA's Planetary Data System. In the meantime, science investigations are ongoing.

Abbreviations

ROSINA	Rosetta Orbiter Spectrometer for Ion and Neutral Analysis

Time-Line	From	To
Planning	1995	1996
Construction	1996	2002
Measurement Phase	launch 2004, asteroid flyby's 2008 & 2010	
Comet phase	2014	2016
Data Evaluation	2014	ongoing

Publications

1. Altwegg, K., et al., (2015), Cometary science. 67P/Churyumov-Gerasimenko, a Jupiter family comet with a high D/H ratio, *Science*, 347, 1261952.

2. Altwegg, K., et al., (2016), Prebiotic chemicals-amino acid and phosphorus-in the coma of comet 67P/Churyumov-Gerasimenko, *Sci Adv.*, 2, e1600285.

3. Altwegg, K., et al., (2017a), D_2O and HDS in the coma of 67P/Churyumov–Gerasimenko, *Phil. Trans. Royal Soc. A, Math., Phys. Eng. Sci.*, 375.

4. Altwegg, K., et al., (2017b), Organics in comet 67P – a first comparative analysis of mass spectra from ROSINA–DFMS, COSAC and Ptolemy, *Monthly Notices Royal Astronom. Soc.,* 469, S130–S141.

5. Balsiger, H., et al., (2007), Rosina - Rosetta orbiter spectrometer for ion and neutral analysis, *Space Sci. Rev.* 128, 745–801.

6. Bieler, A., et al., (2015), Abundant molecular oxygen in the coma of comet 67P/Churyumov-Gerasimenko, *Nature*, 526, 678–681.

7. Calmonte, U., et al., (2017), Sulphur isotope mass-independent fractionation observed in Comet 67P/Churyumov-Geras. by Rosetta/ROSINA, *Monthly Notices Royal Astronom. Soc.*, 469, S787–S803.

8. Dhooghe, F., et al., (2017), Halogens as tracers of protosolar nebula material in comet 67P/Churyumov-Gerasimenko, *Monthly Notices Royal Astronom. Soc.*, 472, 1336–1345.

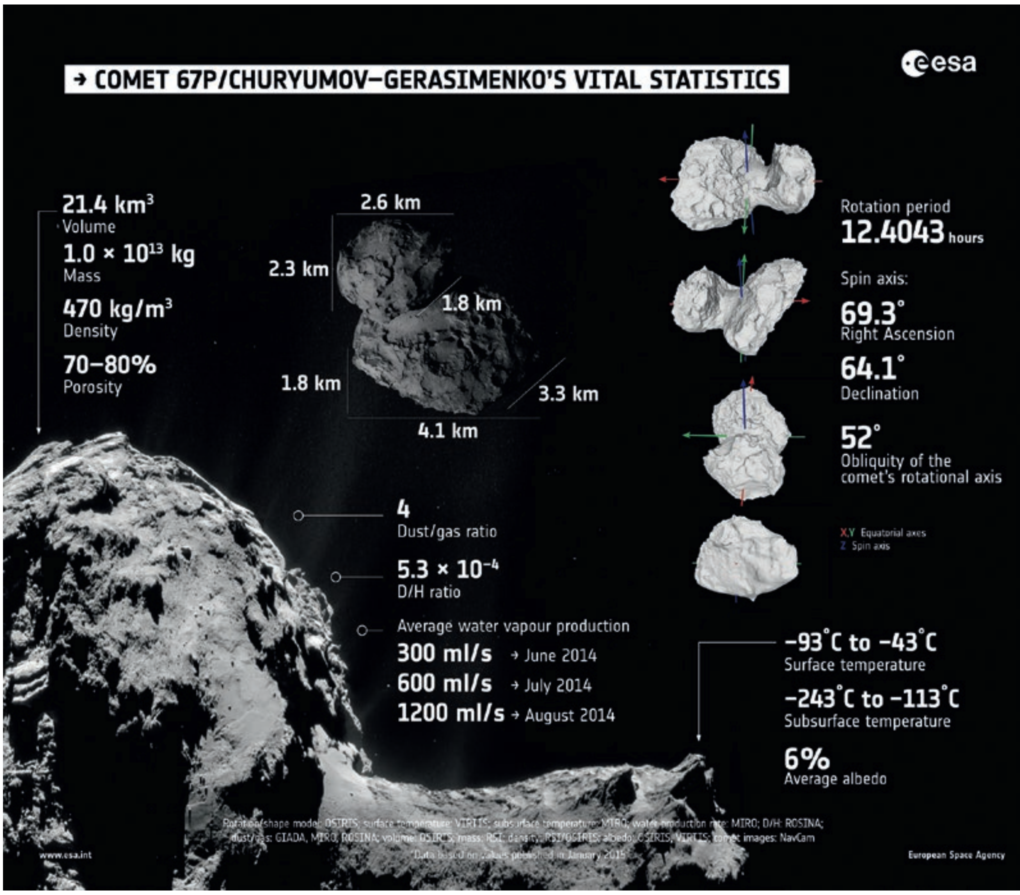
9. Fayolle, E., et al., (2017), Protostellar and cometary detections of organohalogens, *Nature Astron.*, 1, 703–708.

10. Marty, B., et al., (2016), Origins of volatile elements (H, C, N, noble gases) on Earth and Mars in light of recent results from the ROSETTA cometary mission, *Earth Planet. Sci. Lett*. 441, 91–102.

11. Marty, B., et al., (2017), Xenon isotopes in 67P/Churyumov-Gerasimenko show that comets contributed to Earth's atmosphere, *Science*, 356, 1069.

12. Rubin, M., et al., (2015), Molecular nitrogen in comet 67P/Churyumov-Gerasimenko indicates a low formation temperature, *Science*, 348, 232–235.

13. Rubin, M., et al., (2017), Evidence for depletion of heavy silicon isotopes at comet 67P/Churyumov-Gerasimenko, *Astron. Astrophys.*, 601, A123.



Vital statistics of comet 67P/Churyumov-Gerasimenko (Image Credit: ESA, more details: http://sci.esa.int/rosetta/55304-comet-67p-vital-statistics/).

InSight Mars lander with open solar arrays during assembly and integration at Lockheed Martin.

Institute

Inst. Geophysics,
ETH Zurich (ETHZ)

In Cooperation with::

Inst. Physique du Globe,
Paris, France

Imperial College,
London, England

MPS, Göttingen,
Germany

Jet Propulsion Lab.,
Pasadena, USA

Center National d'Études Spatiales
(CNES), Toulouse, France

Principal Investigator

P. Lognonné
(Inst. Physique du Globe, Paris)

Swiss Principal Investigator

D. Giardini (ETHZ)

8.2 Seismometer Instrument for the NASA InSight Mission

Purpose of Research

The SEIS instrument (Seismic Experiment for Interior Structure) onboard the NASA Mars mission InSight (Interior exploration using Seismology, Geodesy, and Heat Transfer) will advance the planetary seismometry beyond the Viking experiments with a much higher sensitivity over a broader frequency band. SEIS will measure seismic waves travelling through the interior structure and composition of the planet Mars. The 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.

2. Determine the present level of tectonic activity and impact rate at Mars.

• Measure the magnitude, rate and geographical distribution of internal seismic activity.

• Measure the rate of meteorite impacts on the surface.

The InSight Lander will carry three instruments to the surface of Mars to take the first-ever in-depth look at the planet's 'vital stats': its pulse, or internal activity, as measured by the SEIS instrument; its temperature as measured by the HP3 instrument; and its reflexes as measured by the RISE instrument. Together, the data will provide essential clues about the evolution of not just Mars, but also all the terrestrial planets. 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 is in charge of the Electronics Box which consists of all electronics including the modules of the partners. It provides:

• The acquisition electronics which continuously acquires the seismic sensor outputs 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 instrument.

The SEIS acquisition and control electronics are redundantly built as SEIS is the InSight core instrument, providing most of the scientific return, and is therefore mission critical. It was built by Syderal SA (Switzerland), and was delivered to CNES (Toulouse, France) for the SEIS instrument integration.

Building on the expertise and infrastructure of the Swiss Seismological

Service at ETH, the Earthquake Monitoring group is taking the lead role in the Marsquake Service that will build a catalogue of seismic events from SEIS data. The Marsquake Service will include 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, itself a critical target for the InSight mission, and provide key input for the development of Martian crustal and deep-structure models. The group will adapt advanced single-seismometer analytic techniques developed for applications on Earth to make them suitable for characterising Martian seismicity. Furthermore the Seismology and Geodynamics group of the Institute of Geophysics has an active research team engaged in modelling 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 FSW validation. The QM was integrated on the lander to support the ATLO (Assembly, Test and Launch Operations) process. Simu-SEIS is used to validate FSW 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.

Publications

1. Dandonneau, P-A., et al., (2013), The SEIS InSight VBB Experiment, 44th Lunar and Planetary Sci. Conf.
2. Böse, M., et al., (2017), *Phys Earth Planet. Int.*, 262, 48–65, doi:10.1016/j.pepi.2016.11.003.
3. Khan, A., et al., (2016), *Phys. Earth Planet Int.*, 258, 28–42, doi:10.1016/j.pepi.2016.05.017.
4. Ceylan, S., et al., (2017), *Space Sci. Rev.*, doi:10.1007/s11214-017-0380-6.
5. Clinton, J. F., et al., (2017), *Seis. Res. Lett.*, doi:10.1785/0220170094, 2017.

Abbreviations

ATLO	Assembly, Test and Launch Operations
FSW	Flight Software
SEIS	Seismic Exp. Interior Struct.

Time-Line	From	To
Planning	2010	2012
Construction	Sep. 2012	Mar. 2015
Measurement Phase	Nov. 2018	Oct. 2020
Data Evaluation	Nov. 2018	> 2020

Co-Investigators

J. Clinton, D. Mance, P. Zweifel

Method

Measurement

Development and Construction of Instruments

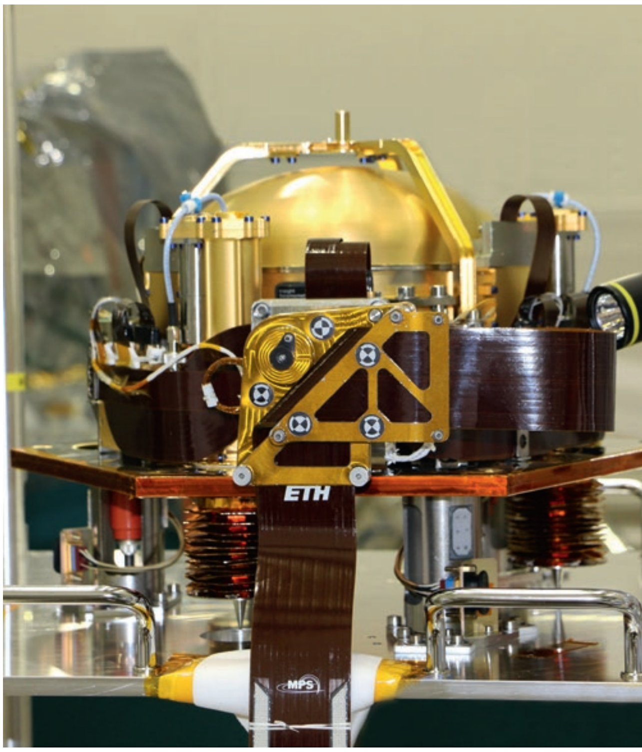
Electronics box, including instrument power conditioning and acquisition, and control electronics for SEIS on-board NASA's InSight mission.

Industrial Hardware Contract to:

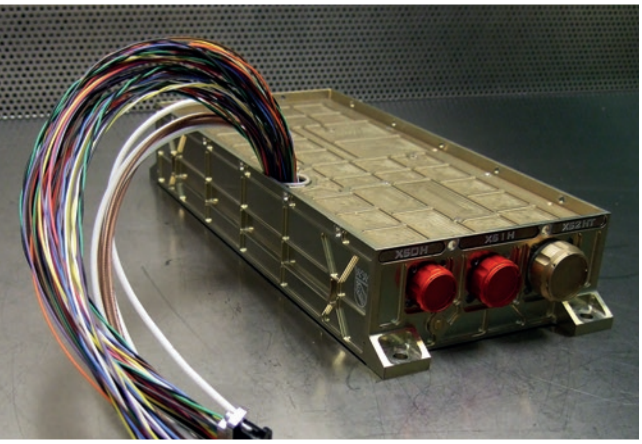
Syderal SA (Switzerland)

Website

www.insight.ethz.ch/home



SEIS sensor assembly during integration at CNES.



LASMA Engineering Model.

Institute

Space Res. & Planet., U. Bern (UNIBE)

In Cooperation with:

Inst. Sp. Res., IKI, Moscow, Russia, (G. Managadze, A. Chumikov)

Principal Investigators

G. Managadze, P. Wurz (Co-PI, UNIBE)

Swiss Principal Investigator

P. Wurz (UNIBE)

Co-Investigators

M. Tulej, R. Fausch

Method

Measurement

Development & Constr. of Instrs.

LASMA instrument for direct meas. of elemental composition of solid materials.

Industrial Hardware Contract to:

WaveLab Engineering AG; Montena Technology SA; nanoTRONIC GmbH

Website

www.space.unibe.ch

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

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 which is part of the scientific payload of both landers, will perform direct elemental analysis of soil samples collected in the vicinity of the spacecraft landing site as well as from the sub-surface by means of a drill (Luna-Resurs only). Elemental and isotopic analysis will be performed on 12 soil samples.

Past Achievements and Status

The spacecraft is currently under development while the LASMA instrument was delivered for integration onto the spacecraft in Autumn 2017.

The launch of Luna-Glob is foreseen in early 2020, and Luna-Resurs will launch in 2022. The LASMA instrument is a copy of the same instrument that was part of the Phobos-Grunt mission.

Publications

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

2. Wurz, P., D. Abplanalp, M. Tulej, M. Iakovleva, V. A. Fernandes, A. Chumikov, and G. Managadze, (2012), Mass spectrometric analysis in planetary science: Investigation of the surface and the atmosphere, *Sol. Sys. Res.*, 46, 408–422.

3. Rohner, U., J. Whitby, P. Wurz, and S. Barabash, (2004), A highly miniaturised laser ablation time-of-flight mass spectrometer for planetary rover, *Rev. Sci. Instr.*, 75(5), 1314–1322.

Abbreviations

LASMA	Laser Ablation Mass Spectrometer

Time-Line	From	To
Measurement Phase	2020	2020
Data Evaluation	2020	2022

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

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, a gas chromatograph and a Neutral Gas Mass Spectrometer (NGMS) which is provided by the University of Bern.

Past Achievements and Status

The Luna-Resurs spacecraft and scientific instruments are currently under development. Launch of Luna-Resurs is foreseen in 2022. The Proto Flight Model (PFM) of the NGMS was finished at the end of 2017, and the flight spare model will be finished in mid-2018. The NGMS design is based on an earlier design used for stratospheric research.

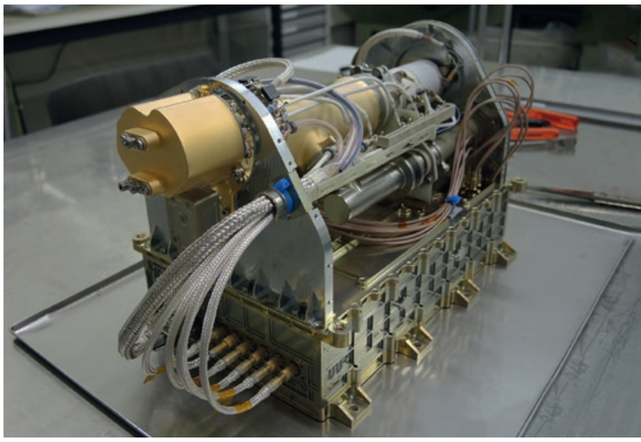
Publications

1. Hofer, L., P. Wurz, A. Buch, M. Cabane, P. Coll, D. Coscia, M. Gerasimov, D. Lasi, A. Sapgir, C. Szopa, and M. Tulej, (2015), Prototype of the gas chromatograph – mass spectrometer to investigate volatile species in the lunar soil for the Luna-Resurs mission, *Planet. Sp. Sci.*, 111, 126–133.
2. Wurz, P., D. Abplanalp, M. Tulej, and H. Lammer, (2012), A neutral gas mass spectrometer for the investigation of lunar volatiles, *Planet. Sp. Sci*, 74, 264–269.
3. Abplanalp, D., P. Wurz, L. Huber, I. Leya, E. Kopp, U. Rohner, M. Wieser, L. Kalla, and S. Barabash, (2009), A neutral gas mass spectrometer to measure the chemical composition of the stratosphere, *Adv. Space Res.*, 44, 870–878.

Abbreviations

NGMS	Neutral Gas Mass Spectrometer
PFM	Proto Flight Model

Time-Line	From	To
Planning	Sep. 2010	Jun. 2011
Construction	Jul. 2011	Jun. 2018
Measurement Phase	2022	2022
Data Evaluation	2022	2024



NGMS Flight Model of Luna-Resurs.

Institute

Space Res. & Planet., U. Bern (UNIBE)

In Cooperation with:

Inst. Sp. Res., IKI, Moscow, Russia, (M. Gerasimov, A. Sapgir, D. Rodinov)
Univ. Pierre, Marie Curie, Paris, France (M. Cabane, D. Coscia)

Principal Investigators

M. Gerasimov, P. Wurz (Co-PI; UNIBE)

Swiss Principal Investigator

P. Wurz (UNIBE)

Co-Investigators

M. Tulej, R. Fausch

Method

Measurement

Development & Constr. of Instrs.

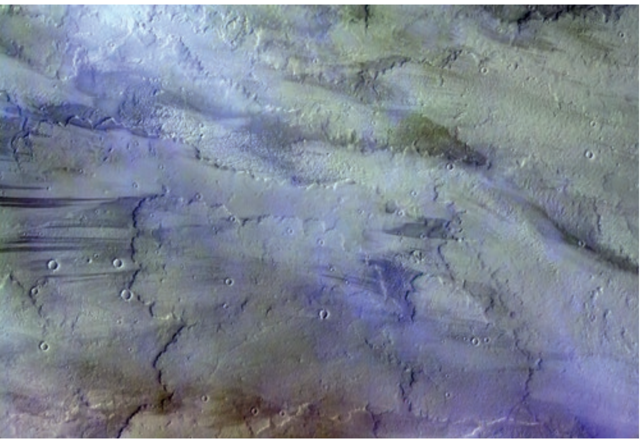
NGMS to measure volatiles.

Industrial Hardware Contract to:

EMPA, Dübendorf

Website

www.space.unibe.ch



Clouds over lava flows on Mars are seen in this false-colour composite image from CaSSIS. Image credit: ESA/CaSSIS/Roscosmos

Institute

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

In Cooperation with:

Astronomical Obs., Padova, Italy
Space Res. Center, Warsaw, Poland

Swiss Principal Investigator

N. Thomas (UNIBE)

Co-Investigators

24 scientists from Europe and US

Method

Measurement

Development & Constr. Instrs.

The University of Bern developed and built CaSSIS with parts supplied by Italy, Poland and Hungary.

Industrial Hardware Contract to:

RUAG (now Thales-Alenia Space Switzerland) in Zurich

Website

www.cassis.unibe.ch/

8.5 CaSSIS – The Colour and Stereo Surface Imaging System

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.

• Image and analyse surface features possibly related to trace gas sources and sinks in order to better understand the broad range of processes that might be related to trace gases. The science team will compile and prioritise a list of observation targets needed to test specific hypotheses concerning active surface processes on Mars. We will begin to address this objective early in the mission, prior to new trace-gas discoveries from EMTGO. Unusual or changing colours indicate active processes, perhaps linked to methane formation or release.

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

• Search for and help certify the safety of new candidate landing sites driven by EMTGO discoveries. The discovery of methane has helped stimulate exploration plans in Europe and the U.S. A portion of NE Syrtis Major has recently been approved for priority MRO coverage as a candidate landing site; this site is at the margin of the Syrtis Major methane plume. It is likely that a pair of NASA/ESA landers in 2020 will also consider methane areas for landing sites. At the ‘Habitability and Landing Sites’ workshop, the surfaces associated with methane plumes were identified as high priority exploration targets. However, the best locations will presumably be found by EMTGO, and MRO/HiRISE may or may not be able to certify new landing sites post 2018/9. CaSSIS cannot identify meter-scale hazards, but it can provide the 5 m scale slope information needed to complete certification of thousands of locations imaged by HiRISE (but not in stereo). CaSSIS will therefore play a role in defining new landing sites.

Past Achievements and Status

The instrument has been shown to be fully functional in Mars orbit. The TGO has just completed its aerobraking phase and is now ready for its prime mission. During orbit capture and the initial manoeuvres, data were taken demonstrating the capabilities and calibration of the instrument.

Publications

1. Thomas, N., and 60 colleagues, (2017), *Space Sci. Rev.*, 212, 1897–1944.

2. Roloff, V., and 24 colleagues, (2017), *Space Sci. Rev.*, 212, 1871–1896.

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

8.6 SERENA/STROFIO on BepiColombo

Composition of Crust, Exosphere, Surface Evolution, Formation and Evolution of Planet Mercury

Purpose of Research

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

The launch of BepiColombo is foreseen in late 2018 (launch window spans from 5 October to 29 November) and the transfer to Mercury will take until late 2025. Thus the data phase will start in late 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 by developing two mass spectrometers. One mass spectrometer is on the BepiColombo Mercury Magnetosphere Orbiter (MMO) spacecraft to perform Energetic Neutral Atom (ENA) imaging of the interaction of the solar wind with the magnetosphere of 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.

Past Achievements and Status

The BepiColombo spacecraft are currently under development and have a launch scheduled in late 2018. Scientific instruments were delivered for integration on the spacecraft in Autumn 2014, while the calibration of flight spare instruments is ongoing.

Publications

1. Pfleger, M., et al., (2015), 3D-modeling of Mercury's solar wind sputtered surface-exosphere environment, *Planet. Sp. Sci.*, 115, 90–101.

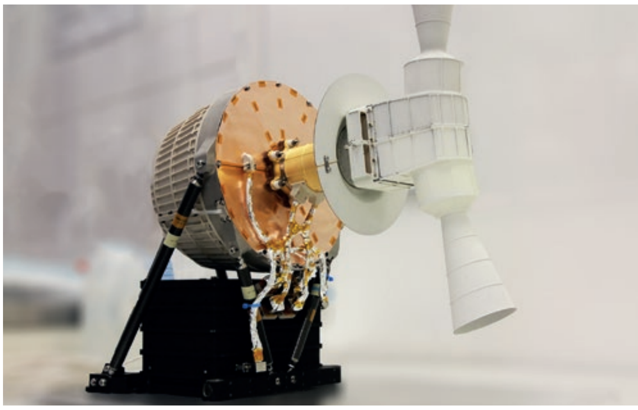
2. Wurz, P., et al., (2010), Self-consistent modelling of Mercury's exosphere by sputtering, micro-meteorite impact and photon-stimulated desorption, *Planet. Sp. Sci.*, 58, 1599–1616.

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

Abbreviations

ENA	Energetic Neutral Atom
MMO	Mercury Magnetosph. Orb.
MPO	Mercury Planetary Orbiter
MPPE	Mercury Plasma Part Exp.
SERENA	Search Exopheric Refilling & Emitted Nat. Abundances
STROFIO	Start from a Rotating Fleld mass spectrOmeter

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



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

Institute

Space Res. & Planet., U. Bern (UNIBE)

In Cooperation with:

Inst. Fisica Sp. Interpl., Rome, Italy (S. Orsini, A. Milillo)
SSRI, Sweden (S. Barabash, M. Wieser)
SwRI, San Antonio, USA, (S. Livi)

Principal Investigators

S. Orsini, S. Barabash

Swiss Principal Investigator

P. Wurz (UNIBE)

Co-Investigators

A. Vorburger, D. Gamborino

Method

Measurement

Research Based on Existing Instrs.

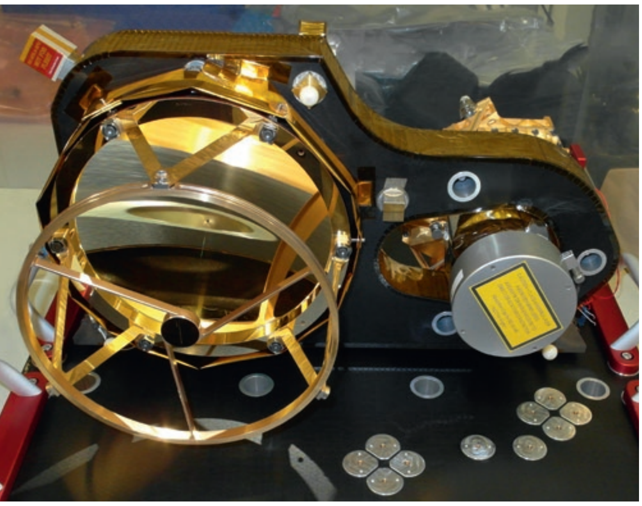
SERENA and MPPE instruments.

Industrial Hardware Contract to:

EMPA, Rekolas, Sulzer Innotec, SWSTech AG

Website

www.space.unibe.ch



The BepiColombo Laser Altimeter (BELA) flight model.

8.7 BELA – BepiColombo Laser Altimeter

Institute

Space Research and Planetology, Univ. Bern (UNIBE)

In Cooperation with:

DLR, Berlin, Germany

MPS, Göttingen, Germany

IAA, Granada, Spain

Principal Investigators

N. Thomas (Co-PI)

H. Hussmann (Co-PI)

Swiss Principal Investigator

N. Thomas (UNIBE)

Co-Investigators

30 leading geophysicists from Europe

Purpose of Research

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

• The figure parameters of Mercury to establish accurate reference surfaces.

• The 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.

• The surface roughness, local slopes and albedo variations, also in permanently shaded craters near the poles.

BELA will form an integral part of a larger geodesy and geophysics package, incorporating radio science and stereo imaging. Although stand-alone instruments in their right, only the synergy between these will make full use of present-day technology and scientific capability.

The synergy will cover the problems of planetary figure and gravity field determination, interior structure exploration, surface morphology and geology, and extend into the measurements of tidal deformations. The reference surfaces and the geodetic network will provide the coordinate system for any detailed exploration of the surface: geological, physical, and chemical.

The topography is needed to develop digital terrain models that allow quantitative explorations of the geology, the tectonics, and the age of the planet surface. The topography is further needed for a reduction of the gravity field data because topographical contributions to gravity must first be removed before using gravity anomalies for the investigation of sub-surface structures.

The use of topography together with gravity data will constrain, by an admittance analysis between the two and with the help of a flexure model for the lithosphere, lithosphere and crust properties. Examples here would include the lithosphere elastic thickness (essential for the reconstruction of the thermal history of Mercury) and the crustal density (essential for the construction of a Hermean internal model).

In addition to the moments of inertia which will be provided by the radio science experiment, the tidal deformations measured by BELA and the radio science instrument will place further constraints 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

Time-Line	From	To
Planning	2004	2008
Construction	2008	2016
Measurement Phase	2024	2027
Data Evaluation	2024	2028

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 by using a time-of-flight electronics within an electronics box which also houses the instrument computer and power supply.

Past Achievements and Status

The flight model has been delivered to ESA and is integrated on the spacecraft. The instrument has passed flight acceptance review. Performance analyses indicate excellent results should be obtained with the present instrument status.

Publications

1. Gunderson, K. and N. Thomas, (2010), BELA receiver performance modeling over BepiColombo mission lifetime, *Planet. Sp. Sci.*, 58, 309–318.
2. Seiferlin, K., et al., (2007), Design and manufacture of a lightweight reflective baffle for the BepiColombo laser altimeter, *Opt. Eng.*, 46, 043003-1.
3. Thomas, N., et al., (2007), The Bepi Colombo Laser Altimeter (BELA): Concept and baseline design, *Planet. Sp. Sci.*, 55, 1398–1413.

Abbreviations

BELA	BepiColombo Laser Altimeter

Method

Measurement

Development & Constr. Instrs.

UNIBE developed and built BELA with parts from Germany and Spain.

Industrial Hardware Contract to:

RUAG Space (now Thales-Alenia Space), Switzerland

Syderal SA, Switzerland

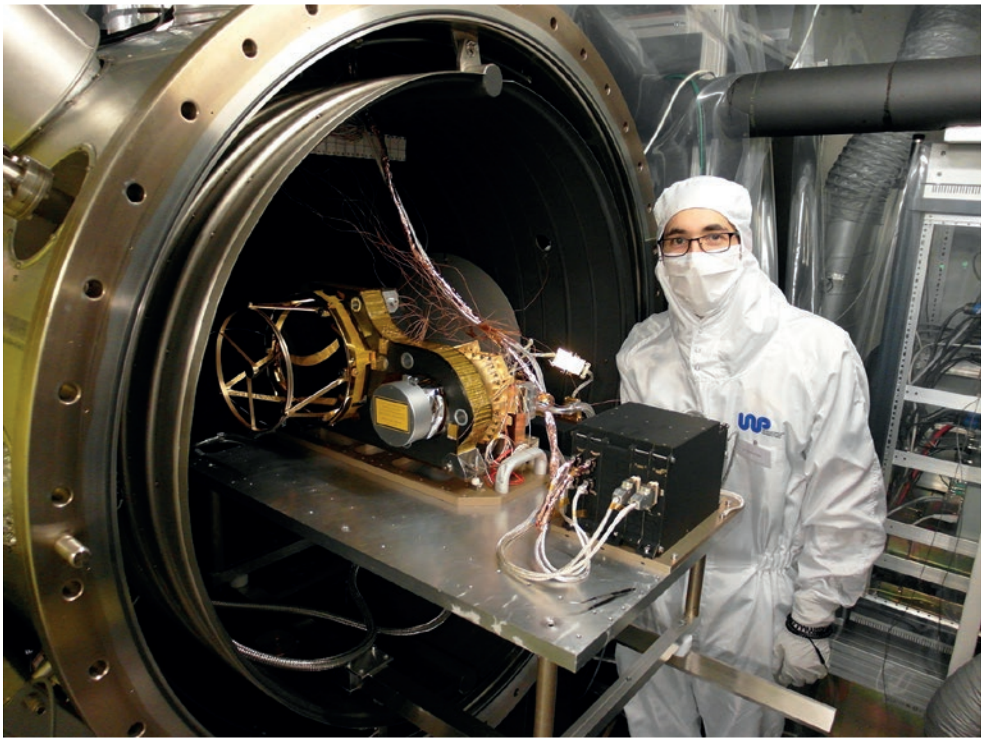
FISBA Optik, Switzerland

Cassidian Optronik, Germany,

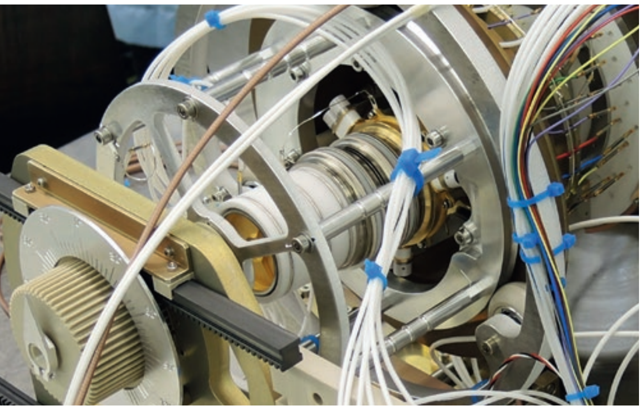
CRISA, Spain

Website

www.bela.space.unibe.ch



The picture shows PhD student, Julian Gouman, with the BELA Engineering Qualification Model in the thermal vacuum chamber at the Univ. Bern.



NIM prototype model for PEP/JUICE, mounted in calibration setup.

8.8 PEP – Particle Environment Package on JUICE

Institute

Space Res. & Planet., U. Bern (UNIBE)

In Cooperation with:

SSRI, Kiruna, S; J. H. Univ., Laurel, USA; MPS, Göttingen, D; FMI, Helsinki, Fi; Univ. Wales, Aber., UK

Principal Investigators

S. Barabash (PI, SSRI)
P. Wurz (Co-PI, UNIBE)

Swiss Principal Investigator

P. Wurz (UNIBE)

Co-Investigators

A. Galli, N. Thomas,
M. Tulej, A. Vorburger

Method

Measurement

Development & Constr. of Instrs.

NIM instr. for PEP experiment.

Industrial Hardware Contract to:.

EMPA Dübendorf

Website

www.space.unibe.ch

Purpose of Research

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

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. 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, while the University of Bern is the Co-PI institution for this experiment. The development of the PEP experiment and the NIM instrument are ongoing.

Publications

1. Vorburger, A., and P. Wurz, (2018), Europa's ice-related atmosphere: The sputter contribution, Icarus, 311, 135–145.

2. Plainaki, C., T. Cassidy, V. Shematovich, A. Milillo, P. Wurz, A. Vorburger, L. Roth, A. Galli, M. Rubin, A. Blöcker, P. Brandt, F. Crary, I. Dandouras, D. Grassi, P. Hartogh, X. Jia, A. Lucchetti, M. McGrath, V. Mangano, A. Mura, S. Orsini, C. Paranicas, A. Radioti, K. Retherford, J. Saur, and B. Teolis, (2018), Towards a global unified model of Europa's tenuous atmosphere, *Sp. Sci. Rev.*, 214, 40, 71 pp.

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

4. Vorburger, A., et al., (2015), Monte-Carlo simulation of Callisto's exosphere, *Icarus*, 262, 14–29.

Abbreviations

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

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

8.9 SWI – Submillimeter Wave Instrument on JUICE

Purpose of Research

The JUpiter ICy moons Explorer (JUICE) is an L-class mission of the ESA Cosmic Vision 2015–2025 programme to investigate Jupiter and its Galilean satellites as planetary bodies and potential habitats for life.

The Submillimeter Wave Instrument (SWI) on JUICE will study the chemical composition, wind speeds and temperature variability of Jupiter's atmosphere as well as the exosphere and surface properties of its icy moons.

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

The Institute of Applied Physics (IAP) is responsible for the optical design of the instrument and the development of the optical components in the receiver unit. This includes the corrugated feed horn of the 600 GHz receiver, several focusing reflectors, a polarising beam splitter and in particular, the on-board blackbody calibration target. In addition, IAP is conducting the radiometric performance tests of the SWI Receiver Unit.

Past Achievements and Status

The optical design of the SWI instrument has been finalised and the effects of misalignment, manufacturing errors and thermoelastic distortions were analysed. A demonstration model of the SWI receiver unit has been manufactured and tested.

The Instrument Preliminary Design Review was successfully passed in April 2017, and the JUICE mission is scheduled for launch in 2022.

Publications

1. Jacob, K., et al., (2018), Design, manufacturing and characterization of conical blackbody targets with optimized profile, *IEEE Trans. THz Sci. Technol.* 8, 76–84.

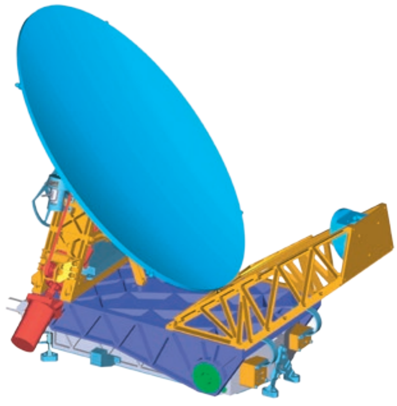
2. Kotiranta, M., et al., (2018), Optical design of the Submillimeter Wave Instrument on JUICE, Int. Symp. Space THz Technol., Pasadena, CA, USA.

3. Jacob, K., et al., (2016), Design of the Calibration Target for SWI on JUICE, IRMMW-THz Conf., Copenhagen, DK.

Abbreviations

JUICE	Jupiter Icy Moons Explorer
SWI	Submillimeter Wave Instrument

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



CAD model of the SWI telescope and receiver unit.

Institute

Inst. Appl. Phys., Univ. Bern (UNIBE)

In Cooperation with:

MPS, Göttingen, Germany
Omnisys Instruments, Sweden
LERMA, France; RPG, Germany
NICT, Japan; CBK, Poland

Principal Investigator

P. Hartogh (MPS)

Swiss Principal Investigator

A. Murk (Co-I, UNIBE)

Co-Investigators

M. Kotiranta, K. Jacob

Method

Measurement

Development & Constr. of Instrs.

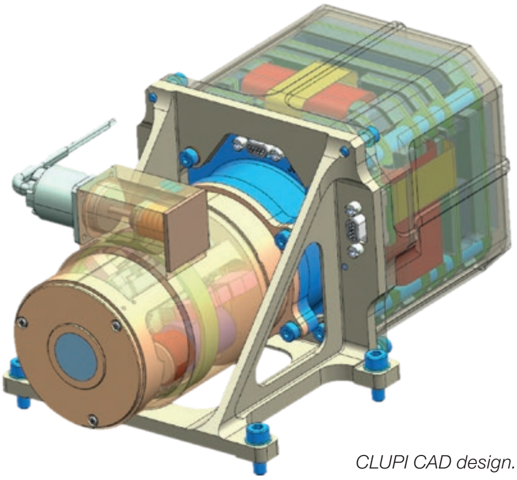
Optics design, optical components and calibration unit for the SWI instr.

Industrial Hardware Contract to:

Micos Engineering, CH

Website

www.iapmw.unibe.ch



CLUPI CAD design.

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

J.-L. Josset (SEI)

Co-Investigators

T. Bontognali, M. Josset, S. Gasc
(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

8.10 CLUPI – CLose-Up Imager for ExoMars Rover 2020

Purpose of Research

CLUPI, part of the Pasteur Payload on board the ESA ExoMars Rover 2020, 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:

  1) Identification of the lithologies,

  2) Identification of eventual structures/textures (primary or secondary alteration features) that could provide information to interpret habitability.

- Identification of bio-signatures:

  1) Observation of structural features.

  2) Observation of carbon (EXM looking for carbonaceous bio-signatures) concentrations.

CLUPI is a miniaturised, low-power, efficient, and highly adaptive imaging system with a mass under 1 kg. It has specific micro-technical innovations regarding its sensor and focus mechanism.

The imager can focus from ~10 cm to infinity (~16 µm per pixel at 20 cm from the target), where colour imaging is 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 to increase the scientific return. A calibration target is used to colour calibrate images during science operations.

CLUPI will be housed on the rover drill box, and use mirrors to observe with three different fields-of-view. Taking advantage of both the rover's mobility and the drill's degrees of freedom, 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: 1) obtain geological information on rock texture and structure, possible alterations, etc., 2) allow the geological history of targets to be established, and 3) appraise the potential preservation of biosignatures.
- Drilling area observation.
- Drilling operation observation: 1) to monitor the process, 2) observe the generated mound of fines with potential colour and textural variations, and 3) to obtain information on the mechanical properties of the soil.
- Drill hole observation (with deposited fines).
- Drilled core sample observation collected by the drill up to 2 m below the Martian surface.

Past Achievements and Status

CLUPI is currently passing the CDR in March 2018 of its development. The Flight Model will be delivered to the mission after the science calibration planned in December 2018.

Abbreviations

CDR	Critical Design Review
CLUPI	CLose-Up Imager ExoMars

Publications

1. 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.

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

Time-Line	From	To
Planning	2003	2010
Construction	2011	2018
Measurement Phase	2021	2022
Data Evaluation	2021	2024

Method

Measurement

Development & Constr. of Instrs.

High-resolution imaging instrument for colour close-up observation of Martian rocks, surfaces, and samples.

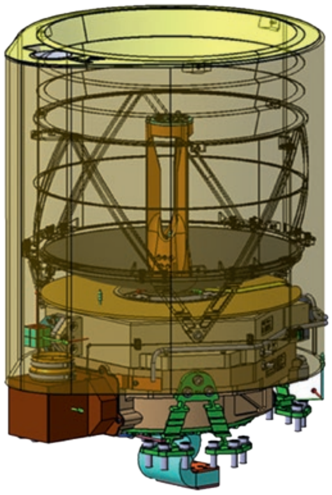
Industrial Hardware Contract to:

TAS-CH; CSEM; Fisba AG; Petitpierre SA; Syderal SA; e2v (funded by CNES)

Website

www.space-x.ch/

Illustration of the ExoMars Rover 2020. Image credit: ESA.



Schematic of GALA that is slated to fly on ESA's JUICE mission to the Jovian system. The Univ. Bern contributes to the rangefinding electronics.

Institute

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

In Cooperation with:

DLR Institute for Planetary Research, Berlin-Adlershof, Germany
Chiba Inst. Technology, Japan
Instituto de Astrofisica de Andalucia (IAA), Granada, Spain

Principal Investigator

H. Hussmann

Swiss Principal & Co-Investigator

N. Thomas

Method

Measurement

Industrial Hardware Contract to:

Thales-Alenia Space Switzerland (to be confirmed).

Website

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

8.11 GALA – Ganymede Laser Altimeter

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, the laser pulse energy, and the pulse shape. These three quantities are the only immediate science results from the GALA 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 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 development is currently in Phase B.

Abbreviations

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

Time-Line	From	To
Planning	2012	2017
Construction	2018	2020
Measurement Phase	2025	2033
Data Evaluation	2031	2035

8.12 MiARD – Multi-Instrument Analysis of Rosetta Data

Purpose of Research

The University of Bern has received support from the European Union's H2020 programme to analyse Rosetta data from several instruments in a joint framework known as MiARD. The specific goals of the MiARD programme are:

• To refine the 3D topography of specific areas on the nucleus at the highest possible resolution and accuracy, and to quantify topographic changes.

• To model the gas and dust flow fields by combining multiple data sets.

• To assimilate available information on the structural and chemical nature of the first 30 cm of the nucleus surface layer.

• To assess the physico-chemical representativeness of the Philae landing site with respect to the rest of the comet.

• To derive an updated model of the development of gas and dust activity triggered by different volatiles when the comet is approaching the Sun (including quantifying any heterogeneity and its source(s)).

• To constrain solar nebula models and cometesimal formation schemes with the derived 67P composition and isotopic ratios.

• To provide additional information to support assessment of risks to the Earth and interplanetary spacecraft from comets and cometary dust.

• To review and further develop a scientific scenario for the return of pristine material to Earth by incorporating lander and remote-sensing data.

Past Achievements and Status

The programme has developed a new shape model of the nucleus, has defined the regions on a 3D model for presentation to scientists and the general public, and has developed fits to the gas and dust distributions around the nucleus at specific times in the mission. The programme will be completed in August 2018 with a review of future mission concepts.

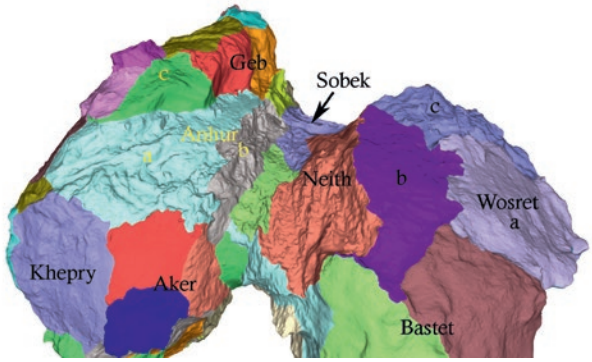
The MiARD programme has resulted in more than 10 publications arising directly from the additional EC funding (six are currently in press).

Publications

1. Preusker, F., et al., (2017), The global meter-level shape model of comet 67P/Churyumov-Gerasimenko, *Astron. Astrophys*. 607, L1.

2. Gerig, S-B., et al., (2018), On deviations from free-radial outflow in the inner coma of comet 67P/Churyumov-Gerasimenko, *Icarus*, accepted.

Time-Line	From	To
Planning	2015	2015
Construction	-	-
Measurement Phase	-	-
Data Evaluation	2016	2018



A 3D digital terrain model of the nucleus of 67P. The regional unit definition made by the Univ. Bern through the MiARD project (EC funding) has been overlaid on the 3D model. Some of the major regions are marked.

Institute

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

In Cooperation with:

Max-Planck-Inst. for Solar System, Research, Goettingen, Germany
DLR Inst. Plan. Res., Berlin, Germany
Lab. d'Astrophys., Marseille, France
Open Univ., Milton Keynes, England
Heriot-Watt Univ., Edinburgh, Scotland
ISSI, Bern, Switzerland
Amanuensis GmBH, Bern, Switzerland

Principal/Swiss Investigator

N. Thomas

Co-Investigators

E. Kuehrt, R. Rodrigo, L. Jorda, P. Hartogh, I. Wright, J. Whitby

Method

Simulation

Res. Based on Existing Instrs.

MiARD has resulted in more than 10 publications.

Website

www.miard.eu

9 Life Science

9.1 Yeast Bioreactor Experiment

Network biology of stress responses and cell flocculation of *Saccharomyces cerevisiae* grown under microgravity conditions.

Institute

Inst. Med. Eng., Lucerne School Eng & Archit., Lucerne Univ. of Appl. Sci. & Arts (HSLU), Hergiswil, CH

In Cooperation with:

Vrije Univ.; Lab. Structural Biology; Dept. Bioeng. Sci.; Brussels, Belgium

Lab. Protein Biochem. & Biomolec. Eng., (L-Probe), Univ. Gent, Belgium

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

Principal Investigator

R. Willaert (Vrije Univ.)

Swiss Principal Investigator

M. Egli (HSLU)

Co-Investigators

B. Devreese (Univ. Gent)
P. Van Dijck (KU Leuven & VIB)

Method

Measurement

Industrial Hardware Contract to:

RUAG Space, Nyon

Website

www.hslu.ch/spacebio

Purpose of Research

The project is focused on the effect of microgravity on the physiology of *S. cerevisiae*. Studies conducted in a simulated microgravity environment have shown a disturbed cell physiology. The expression of a significant number of genes was changed when yeast cells were cultured for 5 generations or 25 generations under simulated microgravity.

The relevance of gravity on *S. cerevisiae* cell-cell and cell-surface interactions is best shown by the fact that *S. cerevisiae* cells grow in clusters under microgravity compared to cells grown on Earth. In addition, it was found that continuous cultivation of *S. cerevisiae* in microgravity had an influence on the bud scar positioning, a critical factor in cell adhesion and invasion.

In the proposed experiment different *S. cerevisiae* strains will be used to investigate the effect of microgravity on non-interacting and cell-cell interacting (flocculation) yeast growth, and on induced stress responses by applying a 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, i.e. 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 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 particular space bioreactor. The use of a continuous cultivation mode (chemostat) gives defined and controlled conditions over time (i.e. growth at one specific growth rate), permitting the repetition of an experiment without having different starting conditions except for the elapsed microgravity time, and easily interpretable results.

The hardware will monitor and control growth parameters such as temperature, flow rate and 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's status is a delta B phase where scientific requirements for the hardware development are established. The hardware is now being constructed by RUAG Nyon.

Time-Line	From	To
Planning	2013	2014
Construction	2014	2020
Measurement Phase	2020	2021
Data Evaluation	2021	2022

9.2 Calcium-Dependent Current Recordings During the 2nd Swiss Parabolic Flight Campaign

Purpose of Research

Living organisms adapt to mechanical loads. However, it is not fully understood how biological cells sense and respond to such loads. Among other mechanisms, mechano-sensitive ion channels are thought to play a key role in allowing cells to transduce mechanical forces. Indeed, previous experiments performed under microgravity have shown that gravity affects the gating properties of ion channels.

In this project, a method was developed which allows a calcium-dependent current in native *Xenopus laevis* oocytes to be recorded under microgravity conditions during a parabolic flight.

Past Achievements and Status

By using a custom made "OoClamp" hardware , a 3-voltage-step protocol was applied to provoke a calcium-dependent current. This current increased with extracellular calcium concentration and decreased by applying extracellular gadolinium. The "OoClamp" hardware was validated by comparing the results of the 3-voltage-step protocol to results obtained by control experiments by applying the well-established two-electrode voltage clamp (TEVC) technique.

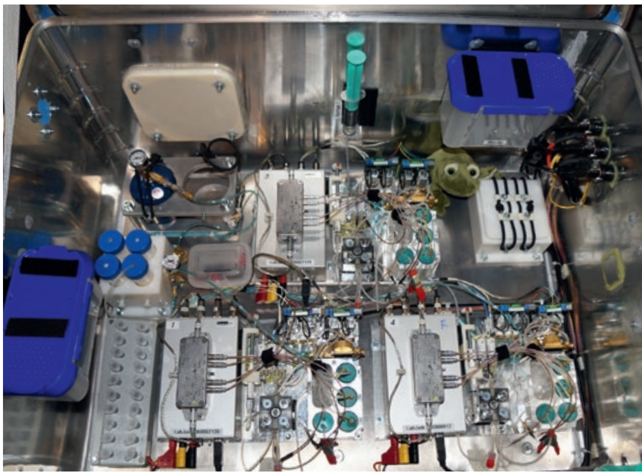
In the context of the 2nd Swiss Parabolic Flight Campaign, we tested the OoClamp and the method. The set-up and experiment protocol worked well during the parabolic flight. According to the data gathered, it appears that the calcium-dependent current is smaller under microgravity than under 1 g conditions. However, a conclusive statement was not possible due to the small sample size.

Publications

Wüest, S. L., C. Roesch, F. Ille, M. Egli, (2017), Calcium dependent current recordings in Xenopus laevis oocytes in microgravity, *Acta Astronautica*, 141, 228-236.

Time-Line	From	To
Planning	Jan. 2016	Jun. 2016
Construction	Jun. 2016	Oct. 2016
Measurement Phase	Oct. 2016	Oct. 2016
Data Evaluation	Jun. 2016	Dec. 2016

HSLU Team in the A310 during the 2nd Parabolic Flight Campaign.



Experimental set-up during the 2nd Swiss Parabolic Flight Campaign.

Institute

Institute of Medical Engineering,
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Method

Measurement

Website

www.hslu.ch/spacebio


One of our researchers enjoying a moment of microgravity onboard the Airbus.

9.3 Focal Adhesion Characterisation During Parabolic Flight Campaign

Institute

Inst. Med. Eng., Lucerne Univ. of Appl. Sci. & Arts (HSLU), Hergiswil, Switzerland

In Cooperation with:

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Method

Measurement

Research Based on Existing Instruments

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

Website

www.hslu.ch/spacebio

Purpose of Research

Focal adhesions are large, multi-protein structures in adherent cells. They represent the key anchor points between the cells and their surrounding. Focal adhesions consist of clustered trans-membrane integrin receptors connecting the extracellular matrix on one side with a wide range of cytosolic proteins on the other side.

They not only physically connect the cells with their surroundings, but also play a role in relaying alot of other information involving a wide range of signalling pathways. Because of their direct link to the cytoskeleton, however, they play an important role in sensing and reacting to mechano-sensory effects such as gravitational perturbations.

Our goal is to investigate the effect of these gravitational perturbations, including micro and hypergravity, as experienced during parabolic flights onboard an Airbus A310, on focal adhesion characteristics. We are especially interested in studying these effects in chondrocytes (found in cartilage tissue) since this is the main focus of our research.

To do so, we are looking at the localisation of various proteins involved in focal adhesions. With our research we hope to contribute to a better understanding of how gravitational dynamics are sensed by cells and what effects they have on them.

Past Achievements and Status

We were able to successfully conduct our experiment during the spring parabolic flight campaign organised by the German Aerospace Center (DLR) in March 2018. At present, our samples are being processed and analysed. In the past, we have studied similar effects on different cell types using various microgravity platforms.

In addition to other parabolic flights on the Airbus A310, our samples have flown with the Swiss armed forces on fighter jets (prolonged duration of microgravity compared to the Airbus A310) and looked at the effect of simulated microgravity using random positioning machines. We hope to be able to publish our results in the near future.

Abbreviations

DLR — German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)

Time-Line	From	To
Planning	2017	2018
Construction	2017	2018
Measurement Phase	2018	2018
Data Evaluation	2018	2018

10 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 three 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,

To run the new out-of-autoclave process for payload fairings, RUAG has invested in a state-of-the-art manufacturing hall in Emmen, Switzerland.

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RUAG Schweiz AG, 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 SA, www.syderal.ch

Synopta GmbH, www.synopta.ch

Thales Alenia Space Schweiz AG,
www.thalesgroup.com/en/global/activities/space

ViaSat Antenna Systems SA, www.viasat.com

WEKA AG, www.weka-ag.ch

representatives of employees and the public. Apart from this, Swissmem offers companies numerous practice-oriented services which help them to maintain their ability to compete and to successfully meet new challenges.

The Specialists: SSIG, Swiss Space Industries Group

SSIG (Swiss Space Industries Group) is organised as a technology group within Swissmem. SSIG includes companies that are significantly involved in the wide-ranging, competitive Swiss space technology environment. These manufacturers and engineering companies play a prominent role in the broadly faceted, competitive Swiss space industry, and develop solutions for all areas of space business, including: structures for rockets, satellites, space transporters, and components for propulsion engines and scientific instruments. Our companies participate in various ESA projects and earn themselves a merited high place in the fiercely competitive 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 in SSIG currently engage ~900 employees in the Space sector, but thousands of other professionals are also indirectly connected. Many of them 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 those companies concerned, 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.

APCO Technologies is in charge of the Structure and Thermal Subsystem of the Sentinel 2 Multi Spectral Instrument of the Copernicus programme.

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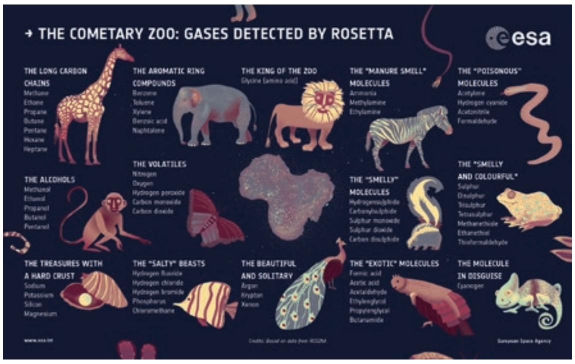

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