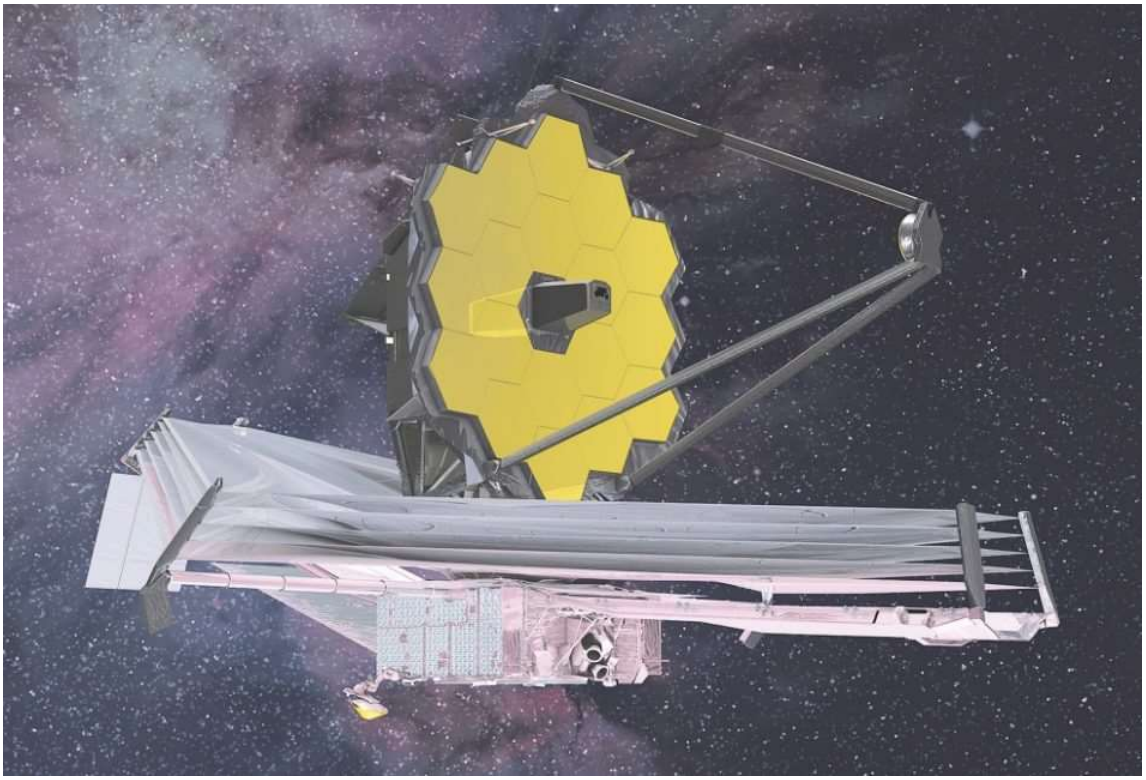
AUSTROSPACE

ANNUAL REPORT 2021



Cover picture: James Webb Space Telescope

Photo Credit: Northrop Grumman / NASA

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1 Introduction

The present AUSTROSPACE Annual Report is composed of a brief review of major space events in 2021, contributions from industrial members and research organizations about their space activities, and a current list of members with contact information.

Vienna, July 2022

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President

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Vice President and Managing Director

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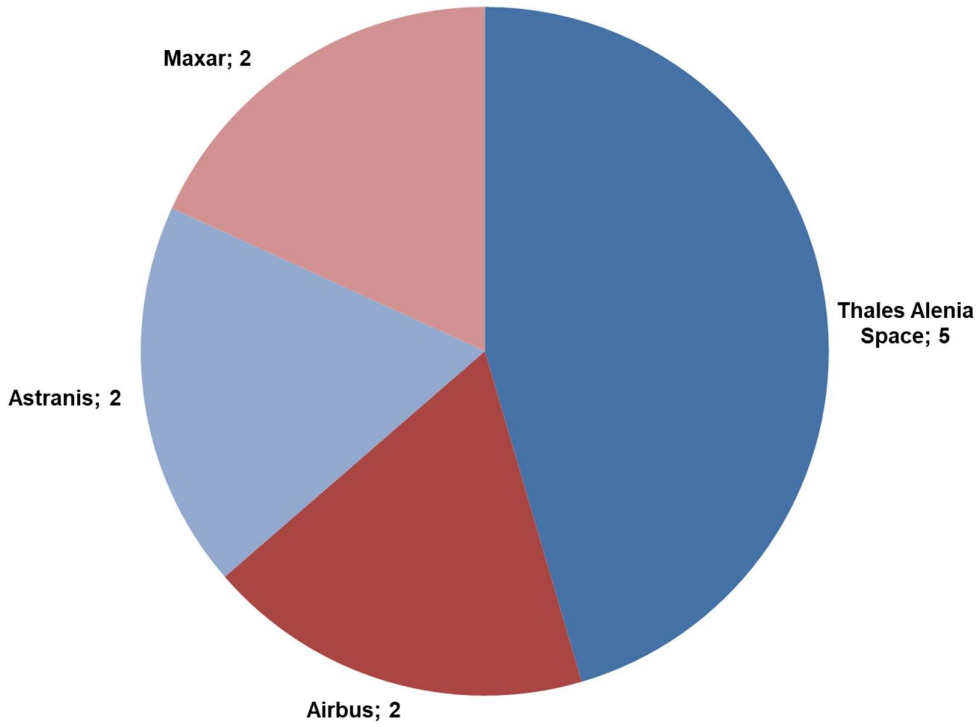
2 Year 2021 Review

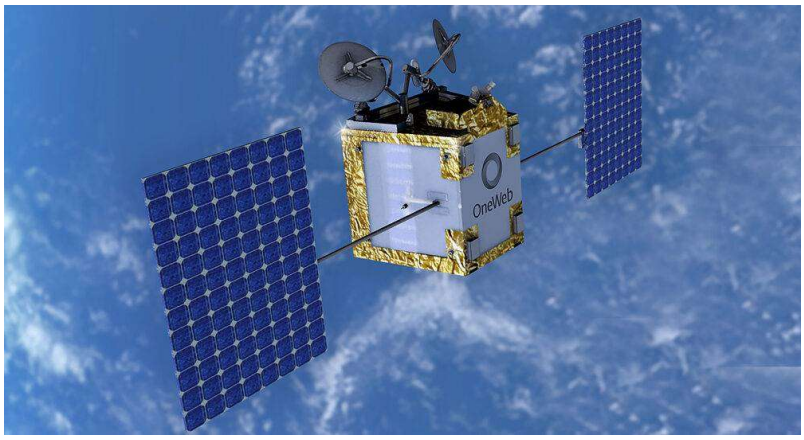
In 2021 orders for 11 geostationary (GEO) telecommunications satellites were placed worldwide, meaning a significant decline from the 23 GEOs in 2020. With 7 contracts in total, European satellite manufacturers (Thales Alenia Space (TAS): 5, Airbus: 2) confirmed their strong market position. The US competitors succeeded with 2 orders for Maxar and Astranis each, where the Astranis satellites are so-called MicroGEOs with a mass below 400 kg. The TAS contracts include 2 military communications satellites for the Italian ministry of defense (Source: Gunter's Space Page).



Commercial geostationary telecommunications satellite orders 2021 (Source: Gunter's Space Page)

However, the number of GEO orders may no longer be a useful metric of market demand, as operators seem to develop a preference for portfolios of satellites from a few hundred kilograms to several thousand kilograms. Technological breakthroughs in the area of flexible, high-throughput satellites as well as competition from constellations of small satellites in low earth orbits (LEO) make the picture even more complex.

The deployment of OneWeb, a constellation of some 650 LEO satellites in the first phase with a possible follow-on extension, has been continued with eight launches, increasing the total number of satellites in orbit to 394 at the end of 2021, including the first 6 test satellites. The satellites are delivered from a new production site in Florida jointly established by OneWeb and Airbus. Completion of the full constellation and introduction of global services is planned for 2022. In April 2021, French satellite operator EUTELSAT announced its initial investment in OneWeb. Exercising an option in September, EUTELSAT has become the second largest shareholder behind the Indian telecommunications company Bharti Global.



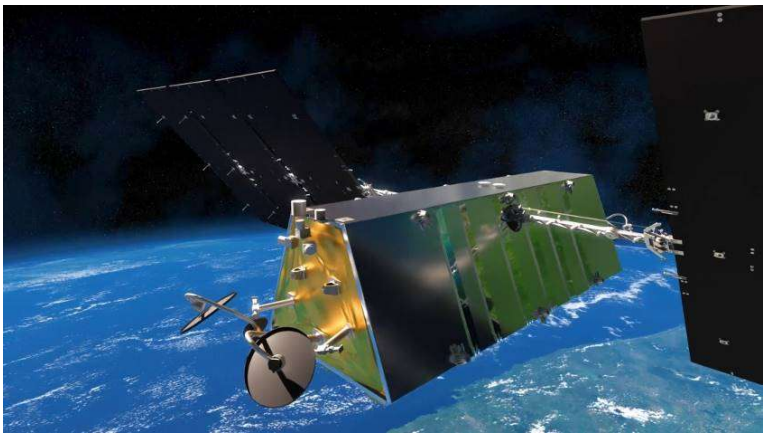
Artist's impression of OneWeb satellite (Source: OneWeb Satellites)

Competitor SpaceX had some 1.700 satellites for the much more complex Starlink network of up to 12.000 satellites in orbit at the end of the year.

Launch of 53 Starlink satellites, built by SpaceX, on Falcon 9 from Cape Canaveral (Source: NASA Kennedy Space Center)

The full network for global internet access shall be realized until 2027. Starlink services already are offered in 22 countries around the world.

In February, TAS has been selected by the Canadian satellite operator Telesat for the development of Lightspeed, a constellation of 188 LEO satellites in a combination of polar and inclined orbits. Lightspeed shall offer data rates up to 15 Gbps. Start of the development, however, has slipped further.



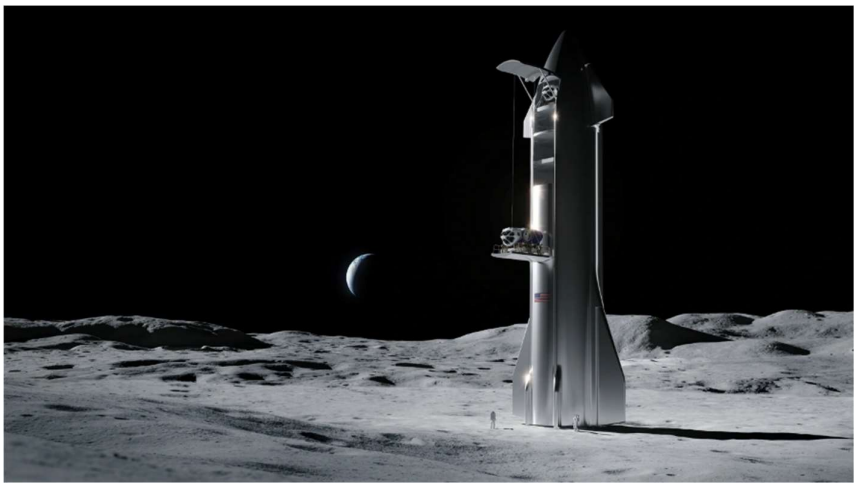
Artist's impression of Lightspeed satellite (Source: TAS)

In November, Amazon presented the planning for the first two prototype satellites of the Kuiper project. Kuiper shall eventually provide global broadband services, based on a constellation of more than 3.000 satellites. The prototypes shall be launched before the end of 2022.

Following the decision of the European Commission to speed up the development of the next generation of the satellite navigation system Galileo, the European Space Agency (ESA) signed two parallel contracts with Airbus Defence & Space (Germany) and TAS Italy during the first half of 2021. Each contract, won in an intense process of open competition, encompasses delivery of six Galileo Second Generation (G2G) satellites, the first of which are scheduled for launch in less than four years.

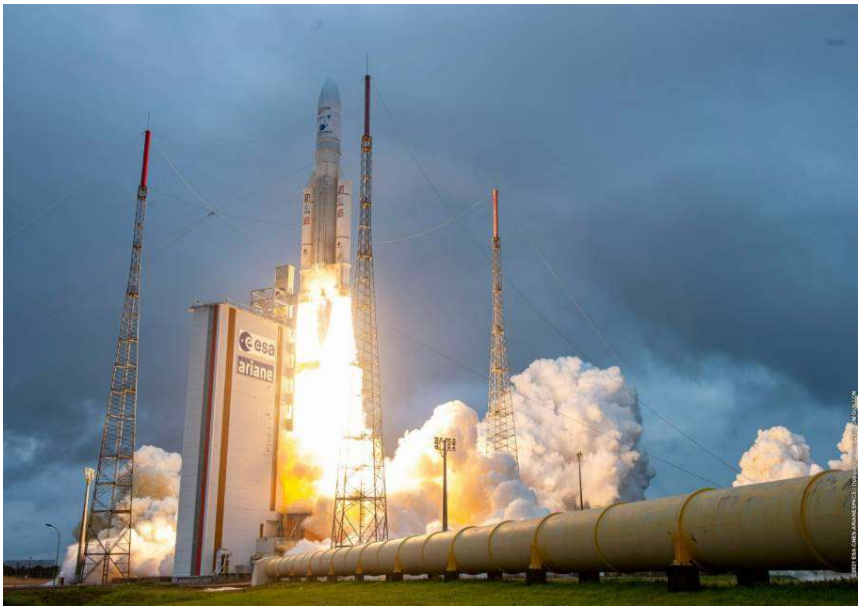
Artist's impression of TAS G2G satellites (Source: ESA)

In April, the US space agency NASA announced that SpaceX alone had won the contract to build the next moon lander for its Artemis program, which aims to return humans to the moon's surface and create a sustainable human presence.



Human Landing System for NASA's Artemis program (Source: SpaceX)

The international highlight of the space year 2021 undoubtedly was the long-expected launch of the James Webb Space Telescope (JWST) atop an Ariane 5 rocket from Europe's Spaceport in French Guiana on December 25. JWST is the next great space science observatory following Hubble, designed to answer outstanding questions about the Universe and to make breakthrough discoveries in all fields of astronomy.



Launch of James Webb Space Telescope atop Ariane 5 from Europe's Spaceport in French Guiana (Source: NASA)

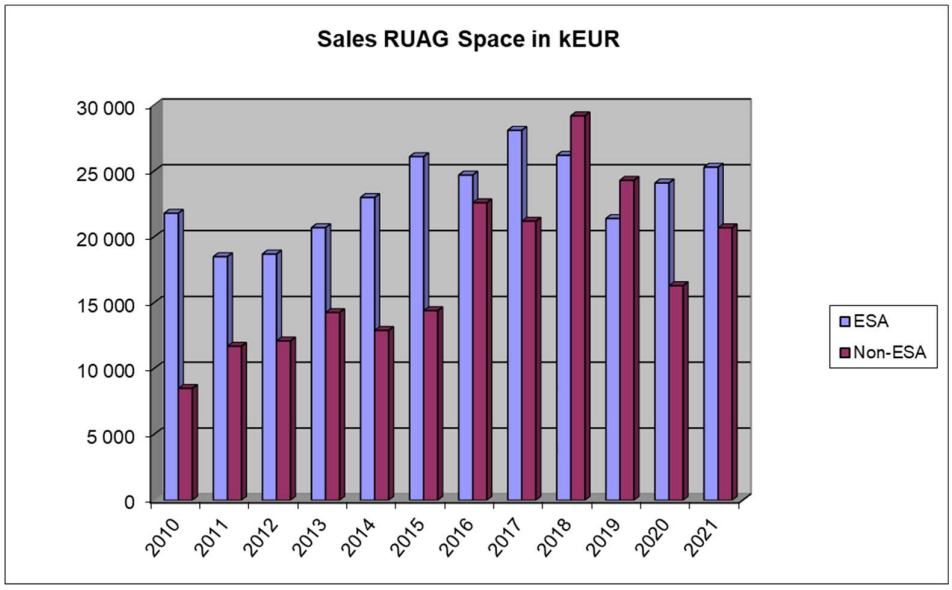
The final agreement on the regulatory and budgetary framework for the space program of the European Union has secured an institutional market with a volume of 14.8 billion EUR for the period of 2021-2027. The major program elements concern operation as well as further development of the navigation satellite system Galileo and the earth observation system Copernicus.

During an event organized on the occasion of the 30th anniversary of Austria's only manned space mission "AustroMir" in the Technical Museum Vienna, Leonore Gewessler, Federal Minister for Climate Protection, Environment, Energy, Mobility, Innovation and Technology, presented the Austrian Space Strategy 2030+ on October 1, 2021.

Federal Minister Leonore Gewessler presents the Austrian Space Strategy 2030+ (Source: APA)

The Space Strategy 2030+ establishes the guidelines for the sustainable development of the Austrian space sector in science and industry as well as for the broader use of space resources for the benefit of all citizens.

At the end of 2021 AUSTROSPACE had 21 members. The evolution of sales of the four biggest AUSTROSPACE companies is illustrated on the following pages. The figures demonstrate a rather good leverage effect of ESA projects, i.e. a sustainable growth of commercial business.


Sales RUAG Space in kEUR
30 000
25 000
20 000
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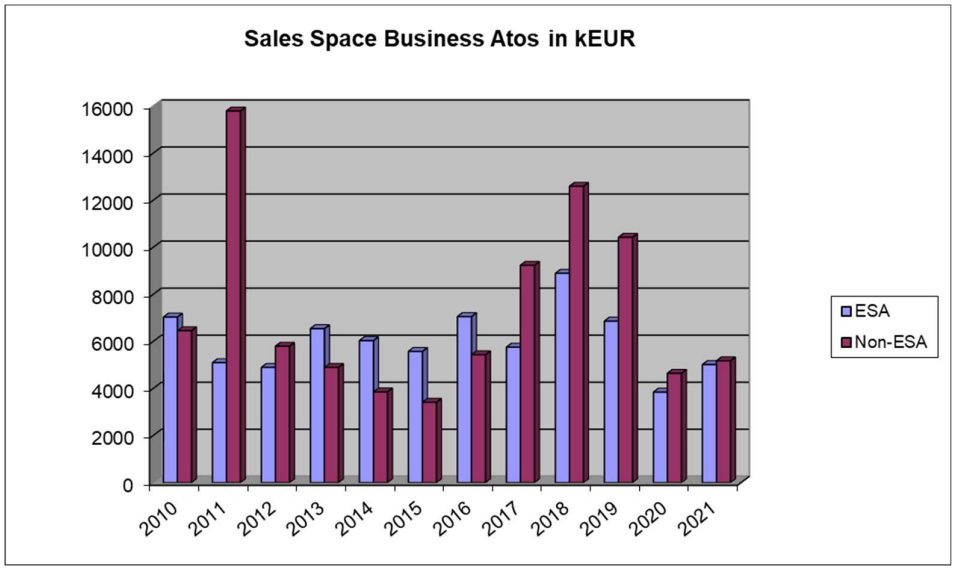
2021
ESA
Non-ESA


Sales Space Business Atos in kEUR
16000
14000
12000
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8000
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2010
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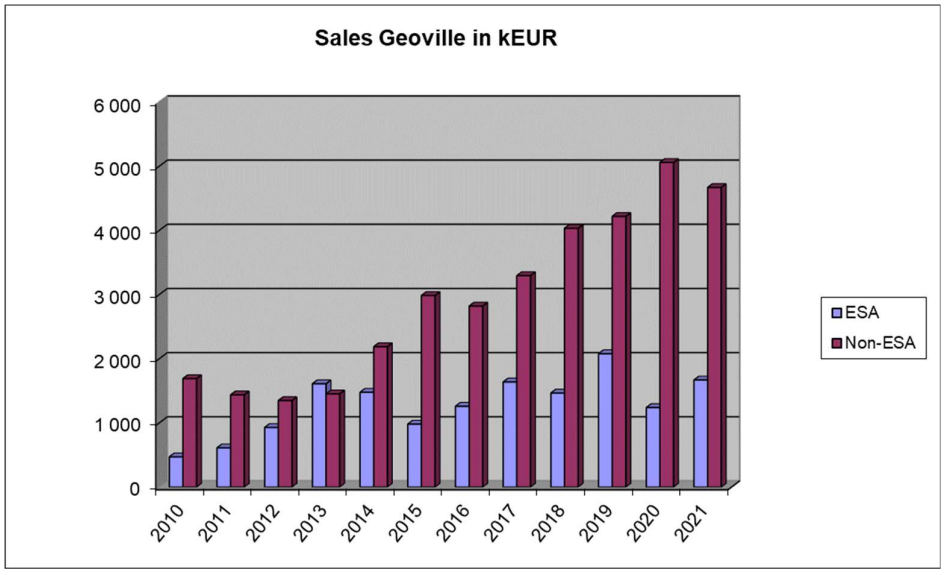
2020
2021
ESA
Non-ESA


Sales Geoville in kEUR
6 000
5 000
4 000
3 000
2 000
1 000
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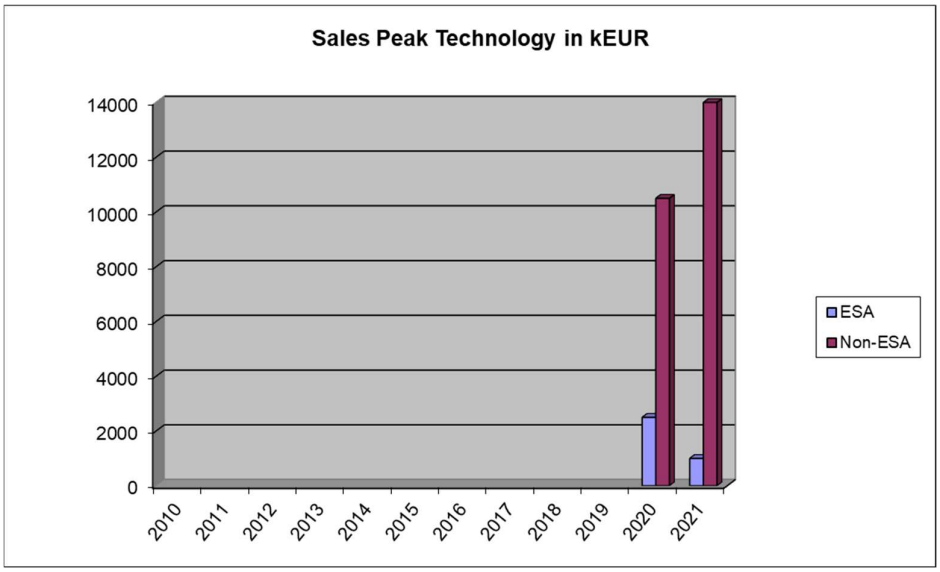
Non-ESA


Sales Peak Technology in kEUR
14000
12000
10000
8000
6000
4000
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2016
2017
2018
2019
2020
2021
ESA
Non-ESA

3 Reports of Industrial and Institutional Members

3.1 Austrian Academy of Sciences

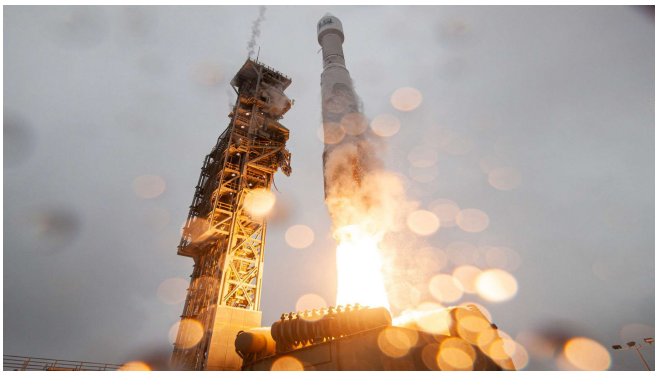
The Space Research Institute in Graz focuses on the physics of our solar system and the diversity of exoplanets. With about 100 staff members from 20 nations it is one of the largest institutes of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, OeAW).

IWF develops and builds space-qualified instruments and analyzes and interprets the data returned by them. Its core engineering expertise is in building magnetometers and on-board computers, as well as in satellite laser ranging, which is performed at a station operated by IWF at the Lustbühel Observatory. In terms of science, the institute concentrates on the physics of solar and extrasolar planets, planet-forming disks, and space plasmas.

IWF cooperates closely with international space agencies and with numerous other national and international research institutions. Tight cooperations exist with the European Space Agency (ESA).

The institute is currently involved in **23 active and future international space missions**; among these:

- The *Cluster* mission continues to provide unique data to better understand space plasma processes.
- The four *MMS* spacecraft perform multi-point measurements to study the dynamics of the Earth's magnetosphere.
- The first China Seismo-Electromagnetic Satellite *(CSES-1)* is studying the Earth's ionosphere. *CSES-2* will follow in early 2023.
- On its way to Mercury, *BepiColombo*, had its second gravity assist maneuver at Venus in August and passed by Mercury for the first time in October.
- *CHEOPS (CHaracterizing ExOPlanets Satellite)* continued nominal science operations, characterizing exoplanets around bright stars.
- ESA's *Solar Orbiter* flew by Venus in August and Earth in November to change its orbit around the Sun.
- The NASA CubeSat *CUTE (Colorado Ultraviolet Transit Experiment)* was launched in September to perform low-resolution transmission spectroscopy of transiting exoplanets at near-ultraviolet wavelengths.



***CUTE* was launched on 27 September 2021 from the Vandenberg US Airforce base in California aboard a United Launch Alliance (ULA) Atlas V rocket carrying also the *Landsat 9* mission (© ULA).**

- ESA's *JUpiter ICy moons Explorer (JUICE*, launch: 2023) will investigate Jupiter and three of its largest moons, Ganymede, Callisto, and Europa.
- The *FORESAIL-2* (launch: 2023) CubeSat will characterize the variability of ultra-low frequency waves in the inner magnetosphere.
- *SMILE* (launch: 2024) is designed to study the interaction between the solar wind and Earth's magnetosphere.
- *PLATO (*launch: 2026) is a space-based observatoryto search for planets orbiting alien stars.
- *Comet Interceptor* (launch: 2029) will characterize in detail, for the first time, a dynamically-new comet or interstellar object.

HIGHLIGHTS IN 2021

- On their journeys to the Sun and to Mercury, *Solar Orbiter* and *BepiColombo* flew by Venus in August and *BepiColombo* had its first encounter with its targetplanet Mercury in October. IWF contributed to 21 out of 58 articles on *Solar Orbiter* published in a special issue of the journal Astronomy & Astrophysics.
- Using observations by the Italian Telescopio Nazionale Galileo (TNG) on La Palma and innovative data analysis, six molecules were detectedsimultaneously in the atmosphere of an extrasolar planet for the first time. The results about the hot gasgiant HD209458b were presented in Nature.
- So-called ion cyclotron waves around Mercury were reported for the first time and published in the Geophysical Research Letters.
- An interdisciplinary volume "Reading Terrestrial Planet Evolution in Isotopes and Element Measurements" was published, which discusses how future studies of exoplanet atmospheres could change the understanding of the solar system planets.
- The Graz-Lustbühel laser station pioneered the useof a megahertz laser to determine the distances to near-Earth satellites. The results were published in the journal Optics Letters.

THE YEAR 2021 IN NUMBERS

Members of the institute published 179 papers in refereed international journals, of which 43 were first author publications. During the same period, articles with authors from the institute were cited 8726 times in the international literature. In addition, 41 talks (8 invited) and 15 posters were presented (virtually) by IWF members at international conferences. Institute members were involved in the organization of seven international meetings, e.g. EGU General Assembly and EPSC.

IWF STRUCTURE AND FUNDING

In October, Christiane Helling followed Wolfgang Baumjohann as IWF Director. Werner Magnes serves as Deputy Director.

Christiane Helling simultaneously holds a university professorship in space science at the Graz University of Technology.

Wolfgang Baumjohann hands over the signature folder to Christiane Helling (© OeAW/IWF/Scherr).

IWF now hosts eight research groups:

- **Exoplanet Weather and Climate** (Lead: Christiane Helling)
- **Exoplanet Characterization and Evolution** (Lead: Luca Fossati)
- **Planet-Forming Disks and Astrochemistry** (Lead: Peter Woitke)
- **Solar System Planetary Physics** (Lead: Helmut Lammer)
- **Space Plasma Physics** (Lead: Rumi Nakamura)
- **On-Board Computers** (Lead: Manfred Steller)
- **Space Magnetometers** (Lead: Werner Magnes)
- **Satellite Laser Ranging** (Lead: Georg Kirchner)

IWF is mainly financed by the OeAW and to a lesser extent through competitive grants from the Austrian Research Promotion Agency (FFG), the Austrian Science Fund (FWF), the European Union, and ESA.

I - NEAR-EARTH SPACE

Near-Earth space is most suitable to study fundamental space plasma processes through advanced, in-situ measurements of charged particles together with electric and magnetic fields at high cadence. In particular, multi-point spacecraft missions further our understanding of complex plasma processes by differentiating spatial structure from temporal changes. IWF has been participating in a number of near-Earth space missions from the planning and proposal phase, to the development and building of new hardware, and finally the operation and calibration of the instruments. Data taken from these missions have been extensively analyzed at IWF with different methods and by theoretical modeling to compare with the observations.

Aurora australis illuminating the Earth's upper atmosphere; photo taken from the ISS (© NASA).

New studies dealing with the interactions between solar wind and magnetosphere, the magnetosheath, and with different plasma instabilities were completed based on both the data analysis of the IWF-supported missions and theoretical studies. Among the different results one of the highlights of this year is the 3D fully kinetic particle-in-cell simulation of turbulent magnetic reconnection. The simulation showed how a turbulent, electron- to larger-scale island evolution causes an efficient cross-scale energy transfer from micro- to macro-scales, and leads to a strong electron energization within the growing magnetic islands. Such simulations provide hints for interpreting the in-situ observations of magnetic reconnection by the *Magnetospheric Multi-Scale (MMS)* mission. While magnetic reconnection operates in a small-region, its consequence can be observed in extended regions due to accelerated plasma jetting out from the reconnection region and rapid magnetic flux transport, which are detected far away from the reconnection site. *MMS* observations, with their high- temporal resolution capabilities, enabled the detection of the accelerated electrons and ions streaming from the reconnection site. The differences among species and energies of these outflowing particles, as well as among the four spacecraft, were used to determine the change in the reconnection rate and location of the acceleration site of the particles from remote observations.

This knowledge gained from near-Earth space observations contribute to understand the space plasma process applicable to other plasma environments within our solar system and beyond.

CLUSTER

ESA's *Cluster* mission is designed to study different plasma processes created by the interaction between the solar wind and the Earth's magnetosphere. This first four-spacecraft mission has been successfully operating for twenty years starting from its launch in August 2000 and is currently planned to be extended until 2024. IWF leads and/or participates in five instruments and has contributed to data archiving activities at the *Cluster Science Archives (CSA)* in addition to the science data analysis.

THEMIS/ARTEMIS

NASA's five-spacecraft mission *THEMIS (Time History of Events and Macroscale Interactions during Substorms)*, was launched in 2007. In 2010, the two outer spacecraft were sent to an orbit around the Moon and renamed *ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics MISsion)*. The inner three probes remained in their near-Earth orbit.

THEMIS studies dynamical processes, such as substorms, that cause aurora and different plasma processes in the magnetosphere and solar wind up to lunar distance. An extension of both missions has been approved until 2022. IWF is participating in processing and analyzing magnetometer data.

MMS

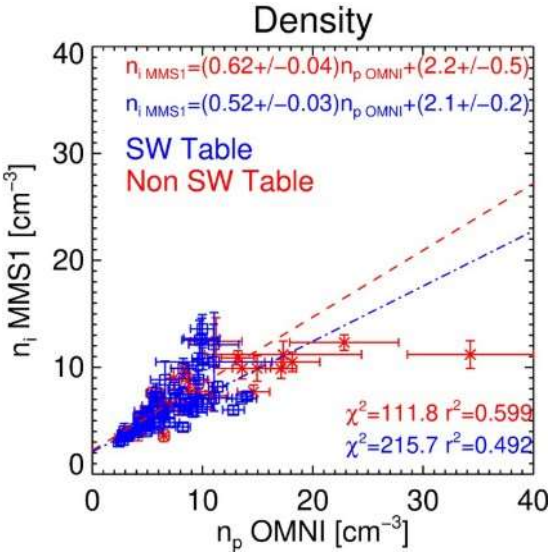
NASA's *Magnetospheric Multi-Scale (MMS)* mission, launched in 2015, explores the dynamics of the Earth's magnetosphere and the underlying energy transfer processes. Four identically equipped spacecraft carry out measurements in the Earth's magnetosphere with highest temporal and spatial measurements ever flown in space. *MMS* investigates the small-scale basic plasma processes, which transport, accelerate and energize plasmas in thin boundary and current layers. Extension of *MMS* has been approved until 2022.

IWF has taken the lead for the *Active Spacecraft POtential Control (ASPOC)* of the satellites and is participating in the *Electron Drift Instrument (EDI)* and the *Digital FluxGate magnetometer (DFG)*. In addition to the operation of these instruments and the scientific data analysis, IWF is contributing to inflight calibration activities and also deriving a new data product such as the density determined from the controlled spacecraft potential.

To enhance the usability of the *MMS* data, a dedicated study using *MMS*'s *Fast Plasma Investigation (FPI)* instrument data in the solar wind was performed. Although *MMS* is designed to investigate magnetic reconnection and other magnetosheath and magnetospheric boundary processes, *MMS's* orbit also carries the spacecraft into the pristine solar wind since 2017. In the solar wind the plasma is characterized by colder temperatures and beams in the velocity distribution function that are much narrower than in the magnetosheath, which challenge the use of plasma moment data. As the solar wind is not the main target for *MMS*, the plasma measurements from *FPI* are not optimized for that environment. To better understand the limitations of *MMS* data, a comparison was performed between the *MMS* plasma data and the *OMNI* plasma measurements. The *OMNI* measurements come from the *Wind* or the *ACE* spacecraft, which are designed for the solar wind and are a perfect reference measurement for comparison.

The results show that the ion density is underestimated by *MMS* (see figure), whereas the electron density and ion velocity are well estimated. On the other hand, the ion temperature is overestimated by up to four times the value from *OMNI*. The results presented suggest that the best practice for using *MMS* in the solar wind is that the electron density should be used as opposed to the ion density. The ion velocity can be used if spacecraft spin effects are removed. Finally, the ion temperature should not be used for the calculation of plasma parameters such as plasma beta (the ratio of thermal to magnetic pressure); *OMNI* data should be used instead of *MMS*.

Roberts et al., J. Geophys. Res., 125, e2021JA029784, 2021.



Comparison of the *MMS FPI* ion density measurement and the *OMNI* proton measurement. The blue points denote data using the *MMS* solar wind mode and red points the magnetosheath mode. χ^2 is the goodness of fit and r^2 the regression coefficient. These data show that the *FPI* density with both the solar wind and non- solar wind tables is underestimated with slopes of 0.52 and 0.62, respectively.

CSES

The *China Seismo-Electromagnetic Satellites (CSES)* are scientific missions dedicated to the investigation and monitoring of varying electromagnetic fields and waves as well as plasma parameters and particle fluxes in the near-Earth space, which are induced by natural sources on ground like seismic and volcanic events.

After the successful launch of the first satellite *CSES-1* in February 2018, the second satellite *CSES-2 i*s scheduled for launch in the beginning of 2023. It will be in the same Sun-synchronous circular low Earth orbit as *CSES-1*, with a local time of the descending node at 2 pm, but with a phase difference of 180 degrees. The combined observations of both satellites will double the detection probability of natural hazard-related events and will help to separate seismic from non-seismic events.

The *CSES* magnetometers, which are nearly identical on both spacecraft, have been developed in cooperation between the Chinese National Space Science Center (NSSC), the Institute of Experimental Physics of Graz University of Technology (TUG), and IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while IWF and TUG participate with the newly developed absolute scalar magnetometer, called *Coupled Dark State Magnetometer (CDSM).*

In 2021, the flight instrument for *CSES-2* was assembled and tested to make it ready for delivery to China in the beginning of 2022. Mandatory acceptance tests of the flight sensor included vibration and thermal cycling in vacuum.

Like in the years before, the magnetometer sensors of *CSES-1* operated continuously in good health. Ionospheric magnetic field variations at low Earth orbit (LEO) altitudes from the space based *CSES-1* magnetometer together with data from ESA's three spacecraft *Swarm* fleet were used to investigate natural hazards. In particular large earthquakes and volcanic eruptions are able to generate atmospheric waves which can propagate up to ionospheric

heights and couple thereto the ambient plasma, i.e., field- and particle-properties are modified in the satellite overflight trajectory. In terms of *CSES-1* spatio-temporal magnetic field patterns before and after the earthquakes Severo-Kurilsk (magnitude M6.5), Russia; Rio Caribe (M7.3), Venezuela; Ndoi Island (M8.2), Fiji; and Ridgecrest (M7.1), USA were analyzed. In most of the presented cases and events the statistical results, bolstered by a certain significance level, showed a change in the pattern between pre- and post-event periods.

Schirninger et al., Remote Sens., 13, 2360, 2021.

GEO-KOMPSAT-2A

GEO-KOMPSAT-2A (GEOstationary KOrea Multi-Purpose SATellite-2A) is a South Korean meteorological and environmental satellite in geostationary orbit at 128.2° East, which also hosts a space weather environment monitoring system. The Korean Meteorological Administration managed the implementation of the satellite, launched in 2018, and the necessary ground segment. The space weather observations aboard *GEO- KOMPSAT-2A* are performed by the Korean Space Environment Monitor (KSEM), which was developed under the lead of the Kyung Hee University. It consists of a set of particle detectors, a charging monitor and a four-sensor *Service Oriented Spacecraft MAGnetometer (SOSMAG)*.

The *SOSMAG* development was initiated and conducted by ESA as part of the Space Situational Awareness program and built by the *SOSMAG* consortium: IWF, Magson GmbH, Technische Universität Braunschweig, and Imperial College London. The *SOSMAG* instrument is a "ready-to-use" magnetometer avoiding the need of imposing magnetic cleanliness requirements onto the hosting spacecraft. This is achieved through the use of two high quality fluxgate sensors on an approximately one meter long boom and two additional magneto- resistive sensors mounted within the spacecraft body. The measurements of the two inner-spacecraft sensors together with the inner boom sensor enable an automated correction of the outer boom sensor measurement for the dynamic stray fields from the spacecraft.

During the third year of operation, flight data verification, in-flight calibration and operation support were continued. In parallel, the *SOSMAG* team worked on the accuracy verification of the offset calibration parameters with a period of more than one day. Via the comparison with the Tsyganenko Earth's field model it could be demonstrated that the required accuracy of 10 nT has been achieved.

SOSMAG data are publicly available via the Space Weather Service Network of ESA's Space Safety program at swe.ssa.esa.int.

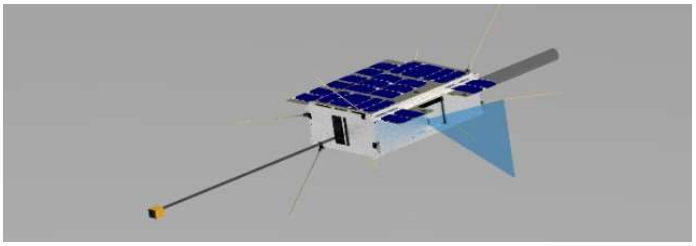
The South Korean satellite *GK-2A* in orbit around the Earth (© KARI).

FORESAIL-2

FORESAIL is a CubeSat program conducted by Aalto University in the frame of the Finnish Centre of Excellence in Research of Sustainable Space. *FORESAIL-2*, as the second mission in this program, is planned for launch into a geostationary transfer orbit (GTO) in 2023. The technology demonstration goal of this mission is to survive the harsh radiation of the Van Allen belt using low cost components and a fault- tolerant software approach. In addition, a Coulomb- drag experiment shall demonstrate safe de-orbiting from orbits with high apogee.

The characterization of the variability of ultra-low frequency (ULF) waves and their role in energizing particles in the inner magnetosphere are the core scientific objectives of *FORESAIL-2*. This shall be achieved by in-situ measurements of the magnetic field as well as relativistic electrons and protons.

In cooperation with the Institute of Electronics of Graz University of Technology, IWF contributes a miniaturized magnetometer, which will be based on a newly developed microchip for the readout of the triaxial magnetic field sensor. In 2021, the preliminary design of the magnetometer was finalized, the layout of the prototype microchip was finished and delivered to XFAB Silicon Foundries for fabrication. The development of an Engineering as well as an Interface-Verification Model was started.



Rendering of *FORESAIL-2* with the magnetometer boom in the lower left corner (© Aalto University and Foresail consortium).

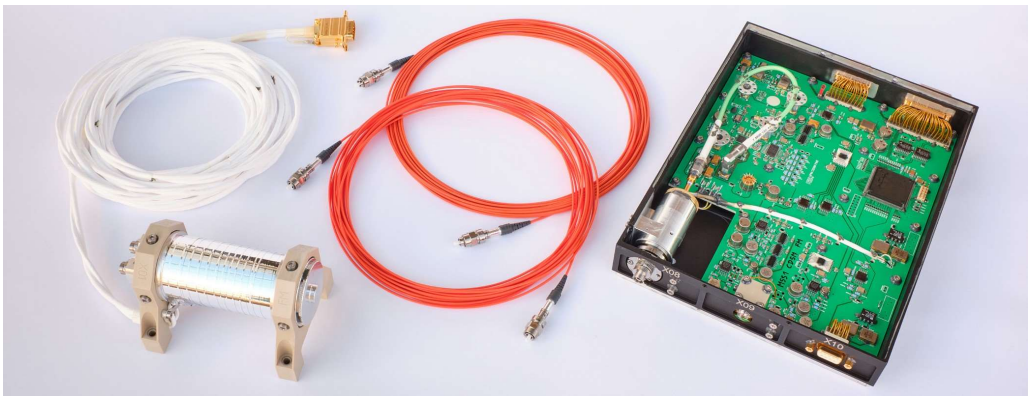
MACAO SCIENCE SATELLITE

Macao Science Satellite 1 was initiated by the State Key Laboratory of Lunar and Planetary Science at the Macau University of Science and Technology and is being implemented with support from the China National Space Administration and the local government. It is the world's first and only scientific satellite to be placed in a near-equatorial orbit to study the geomagnetic field, and specifically the South Atlantic Anomaly, from space. The launch is scheduled for the end of 2022.

The South Atlantic Anomaly is an area with a significantly weakened geomagnetic field and associated increased radiation activity. Its center lies over Brazil and its eastern coast. The inner of the two Van Allen radiation belts extends to about 700 kilometers from the Earth at the equator. In the region of the South Atlantic Anomaly, it comes much closer to Earth. Together with ESA's *SWARM* mission, launched in 2013, the South Atlantic Anomaly, which is widening and deepening, will be explored and measured in greater detail than ever before.

The scientific payload consists of a high-energy particle detector, a star tracker, a fluxgate magnetometer, and a scalar magnetometer. The sensor and sensor-related electronics of the scalar magnetometer are contributed by IWF in cooperation with the Institute of Experimental Physics of Graz University of Technology. The flight instrument is a replica of the instrument for the *CSES-2* satellite. The development of the processor and power supply electronics for the scalar magnetometer as well as its overall integration and testing are carried out by the

Harbin Institute of Technology, Shenzhen. In 2021, the flight model of the scalar magnetometer (see figure below) was assembled, tested and delivered to China.



Flight model of the scalar magnetometer before delivery to China (© *CDSM* Team / A. Pollinger, https://w.wiki/4kq5, CC BY 4.0).

SMILE

The *Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)* is a joint mission of ESA and the Chinese Academy of Sciences (CAS), scheduled for launch in 2024. It aims to complete our understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere. IWF participates in two instruments: the *Soft X-ray Imager (SXI)*, led by the University of Leicester, and the magnetometer *(MAG)*, led by CAS.

The institute, in close cooperation with international partners, contributes the instrument's control and power unit *EBOX* for *SXI*. IWF is coordinating the development and design of the Digital Processing Unit (DPU) and is responsible for the mechanical design and the tests at box level.

In addition to hardware activities, IWF is participating in the preparation of the science working group activities such as modeling and in-situ measurements.

***SMILE* DPU Board (© OeAW/IWF/Steller).**

SPACE WEATHER FOLLOW-ON

The *Space Weather Follow-On (SWFO)* mission is a joint undertaking by NASA and the National Oceanic and Atmospheric Administration (NOAA). The satellite will collect solar wind data and coronal imagery to support NOAA's mission to monitor and forecast space weather events.

The *SWFO* satellite will orbit the Sun at approximately 1.5 million kilometers from Earth in Lagrange point 1. At this point the gravitational and centrifugal forces of Sun and Earth balance each other, which makes it an ideal place for observing the Sun.

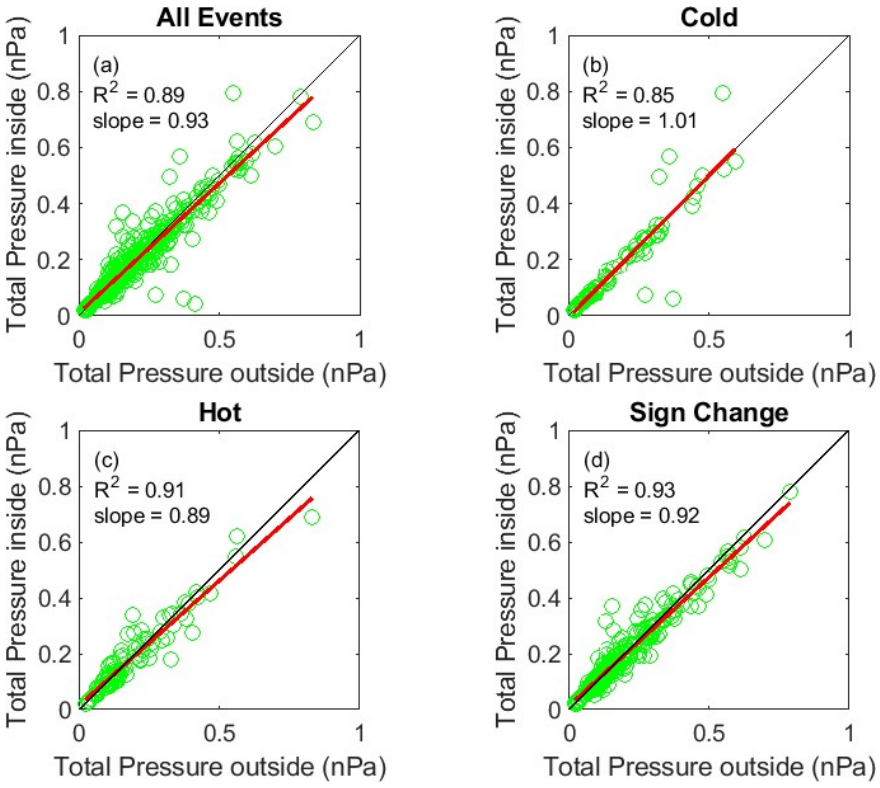
The Southwest Research Institute together with two sub-contractors at the University of New Hampshire, Durham, and IWF design, develop, integrate, and calibrate the magnetometer instrument *SWFO-MAG*. It includes two three-axis magnetometers and associated electronics to measure the vector of the interplanetary magnetic field. IWF has the lead for the Sensor Controller Board, which hosts the front-end electronics for the two fluxgate sensors. A microchip, which has originally been developed for the *Magnetospheric Multi- Scale* mission, is the central component of the front-end electronics.

The main activities at IWF in 2021 covered the testing of a breadboard model, the design and test of the Engineering and Development Unit and the support of the Critical Design Review, which was successfully passed in December.

STATISTICAL STUDY OF LINEAR MAGNETIC HOLE STRUCTURES NEAR EARTH

The *Magnetospheric Multi-Scale (MMS)* mission data for eight months in the winter periods of 2017-2019, when *MMS* had its apogee in the upstream solar wind of the Earth's bow shock, are used to study linear magnetic holes (LMHs). They are characterized by a magnetic depression of more than 50% and a rotation of the background magnetic field of less than 10°. A total of406 LMHs are found and, based on their magnetoplasmacharacteristics, are split into three categories: 1) cold,where there is an increase in density, and little changein ion temperature; 2) hot, where there is an increase in ion temperature, and a decrease in density, and 3) sign change, where at least one magnetic field component changes sign over the structure. The occurrence rate of LMHs is 2.3 per day. This is the first statistical study that shows that all LMHs are basically in pressure balance with the ambient plasma. Most of the linear magnetic holes are found in ambient plasmas that are stable against the generation of mirror-modes, but only half of the holes are mirror-mode-stable inside.

Volwerk et al., Ann. Geophys., 39, 239-253, 2021.

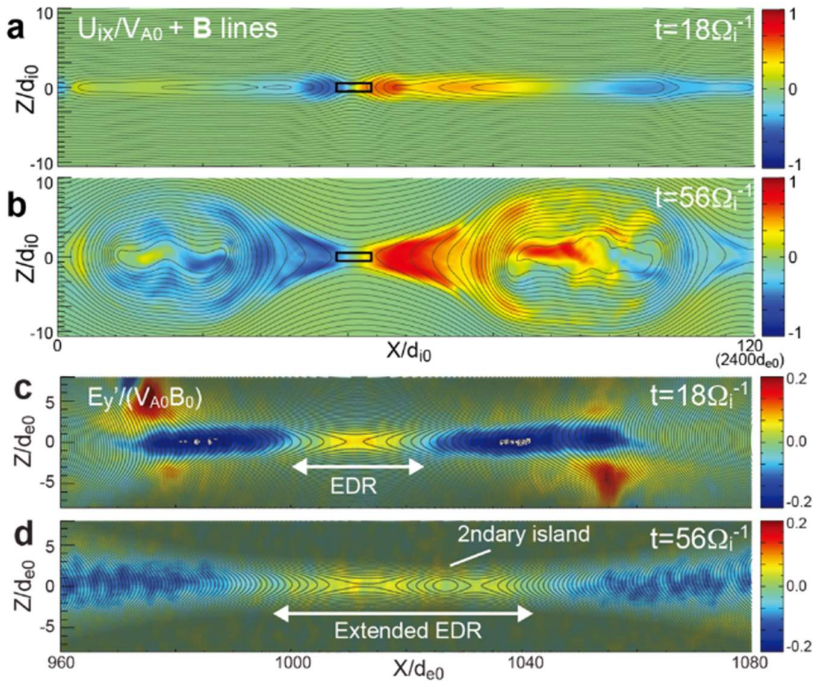


Pressure balance test across the structure of the linear magnetic holes. The total pressure is calculated at the center and outside of thestructure. (a) Relation for all structures; the black line is the identity,and the red line is a fit to the points. Pressure balances follow for (b) the cold category, (c) the hot category and (d) the sign change category. The regression coefficients and the slopes are listed in the panels.

FAST CROSS-SCALE ENERGY TRANSFER DURING TURBULENT MAGNETIC RECONNECTION

Magnetic reconnection is a key fundamental process in collisionless plasmas that explosively converts magnetic energy to plasma kinetic and thermal energy through a rapid change of magnetic field topology in a central electron-scale region called the electron diffusion region (EDR). Past simulations and observations demonstrated that this process causes efficient energy conversion through the formation of multiple macro- scale (scales larger than ion-scales) and micro-scale (sub-ion or smaller scales) magnetic islands/flux ropes. However, the coupling of these phenomena on different spatiotemporal scales is still poorly understood. Here, based on a new large-scale fully kinetic particle-in- cell simulation with a realistic, initially fluctuating magnetic field, it was demonstrated that the macro-scale evolution of turbulent reconnection involving merging of macro-scale islands reduces the rate of reconnection and accordingly extends the EDR in the reconnection outflow direction. This EDR extension leads to a repeated, quick formation of new electron-scale islands within the EDR which soon grow to larger scales and eventually merge with the macro-islands (see figure). This turbulent, electron- to larger-scale island evolution causes an efficient cross-scale energy transfer from micro- to macro-scales, and leads to a strong electron energization within the growing islands.

Nakamura T.K.M. et al., Geophys. Res. Lett., 48, e2021GL093524, 2021.



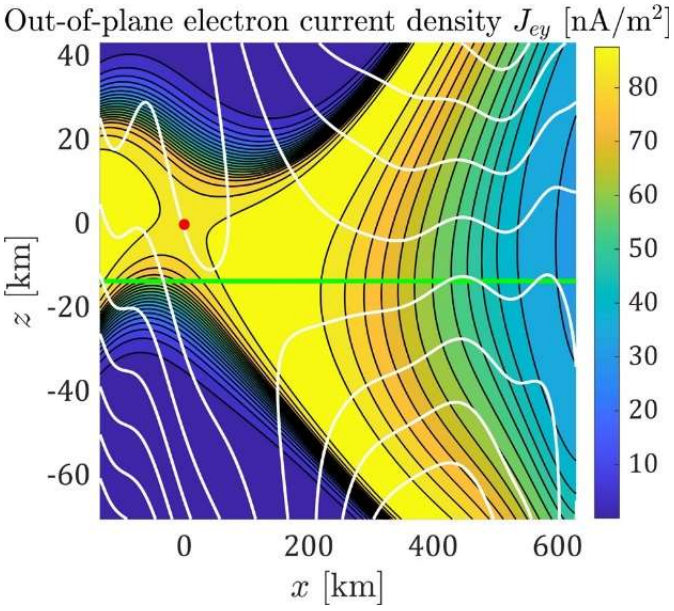
a + b: Color contours of outflow component of ion bulk velocity U_{ix}; c + d: Zoomed-in views near the EDR surrounding the most developed X-line before and after the macro-scale island merging (black boxes in a + b) of reconnection electric field E_y'. The positive E_y' in panels c + d indicates the EDR.

RECONSTRUCTION OF THE RECONNECTION KERNEL ZONE

In order to study the plasma process responsible forthe magnetic field reconfiguration and transforming magnetic energy to kinetic and thermal energy of plasma in the magnetic reconnection region, using spacecraft data such as *MMS*, it is essential to infer the location of the spacecraft relative to the reconnection region by reconstructing the current sheet based on proper assumption and modeling of the overall reconnection site.

A new analytical model for Grad–Shafranov reconstruction of two-dimensional steady-state magnetic reconnection is developed for the kernel zone (electron diffusion region, EDR). For the first time, the effects of the electron inertia are regarded explicitly in the reconstruction model of such type by implementing multi-probe data analysis. The method is applied to the *MMS* data for previously studied events. The figure plots the results of reconstruction of the EDR encounter event of 11/07/2017 in the time span of 22:34:01.70-22:34:04.92 UT. It is found that the proper accounting of these effects is of major importance for the accurate reconstruction of the out-of-plane magnetic field component and the in-plane electron velocity. The model provides a self-consistent solution of the problem, depending neither on the out-of-plane component of the electron pressure tensor divergence nor on the reconnection electric field.

Korovinskiy et al., J. Geophys. Res., 126, e2020JA029045, 2021.



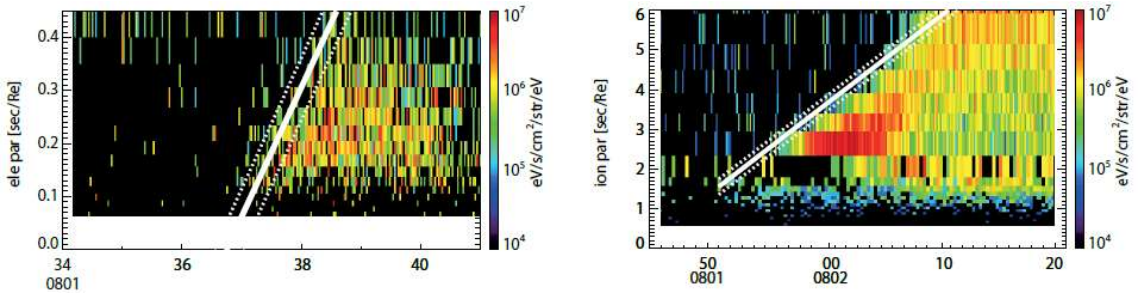
Visualization of the spatial structure of EDR obtained from the reconstruction method, for which its high accuracy is confirmed by comparing *MMS 1, 2,* and *4* data. The reconnection plane xz: the out-of-plane electron current density (color), the in-plane magnetic field lines (black contour curves), the electron in-plane streamlines (white curves), the *MMS 3* trajectory (green line), and the reconnection X-point (red dot).

REMOTE SENSING OF MAGNETIC RECONNECTION

Although magnetic reconnection is a process in which magnetic field energy is converted to particle energy in a small region, smaller than the plasma particles can complete its gyration, its signatures can be remotely detected due to the particles that are accelerated at the reconnection site and then injected along the field lines. These particle traveling along the field lines from the reconnection region can be remotely detected by spacecraft passing the separatrix region, which is the boundary between the reconnected and background field lines. The observed timing and location of these particles are expected to show differences depending on its energy and species.

Based on an observation by the four *MMS* spacecraft on 12 July 2018, the energy dispersion of the ions and electrons (see figure) is analyzed to deduce the characteristics of the remote reconnection. The remote sensing method further enabled an estimation of the reconnection electric field, which was initially 1.6-2.5 mV/m, and decreased to ~0.8 mV/m within ~20s.

Wellenzohn et al., J. Geophys. Res., 126, e2020JA028917, 2021.

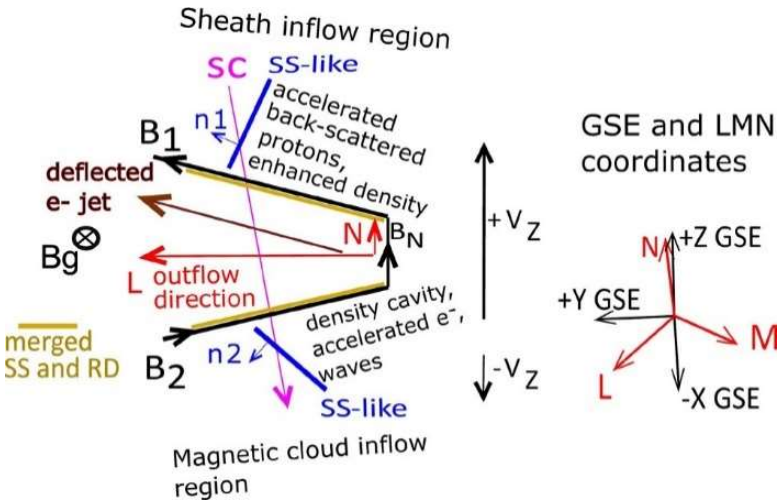


Energy dispersion of electrons (lef panel) and ions (right panel).The linear fit of the dispersion is shown as solid white line. From the energy dispersion the location and time of the electrons or ions injection can be obtained, which was estimated to be 24 R_E downtailand at 08:01:36-08:01:42 UT for this particular event.

MAGNETIC RECONNECTION WITHIN THE BOUNDARY LAYER OF A MAGNETIC CLOUD IN THE SOLAR WIND

In a multi-point study both the large-scale helical magnetic geometry of a magnetic cloud (MC) and the structure of a magnetic reconnection (MR) outflow occurring within the boundary layer of an MC are analyzed in detail. The reconnected open field lines are expected to slip over the MC resulting in extended plasma mixing. The MR outflow channel is embedded into a large-scale vertical flow shear. The geometry and the motion of the structure provided a unique possibilityto study the fluid- and kinetic-scale processes associated with MR in the solar wind. The main findings on MR include (a) first-time observation of non-Petschek-type slow-shock-like discontinuities in the inflow regions; (b) observation of turbulent Hall magnetic field associated with a Lorentz-force-deflected electron jet in the presence of a guide field (Bg); (c) acceleration of protons by reconnection electric field and their back-scatter from the slow-shock-like discontinuity in the sheath inflow region; (d) observation of relativistic electron populationnear the MC inflow boundary/separatrix; these electron populations can presumably appear as a result of nonadiabatic acceleration, gradient B drift, and via acceleration in the electrostatic potential well associated with the Hall current system; and (e) observation of Doppler-shifted ion-acoustic and Langmuir waves in the MC inflow region.

Vörös et al., J. Geophys. Res., 126, e2021JA029415, 2021.

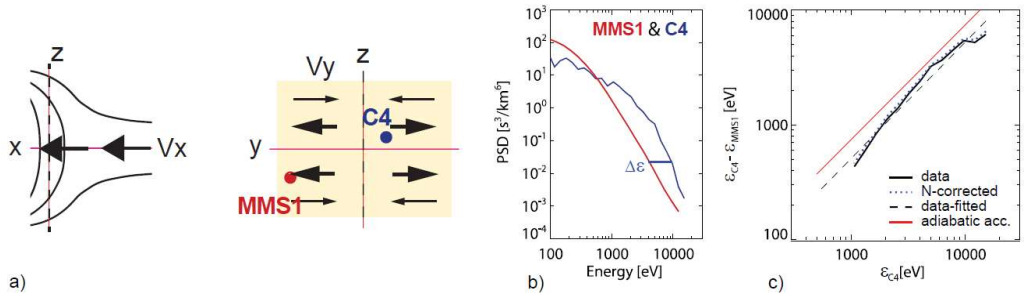


Left: Crossing of MR outflow in the LN plane. The structure is embedded into a vertical flow shear. The outflow boundaries are merged slow shocks (SS) and rotational discontinuities (RD). In the inflow regions SS-like discontinuities are developed as a consequence of interactions between the outflow and environment. Right: The reconnection LMN coordinates relative to the GSE coordinates. Here, L is the direction along the MR outflow, N is the normal direction to the current sheet and M is the "out-of-plane" direction along the MR X-line. GSE corresponds to the standard Geocentric Solar Ecliptic coordinate system.

MULTI-POINT MULTI-SCALE OBSERVATION OF A DIPOLARIZATION FRONT

In the near-Earth magnetotail localized fast flows, called bursty bulk flows (BBFs), are known to play an important role in transporting energy from the magnetotail reconnection site. These localized BBFs contain sharp enhancements in Bz (south-to-north component of the magnetic field) called dipolarization fronts (DF), which are considered an important site of energy conversion. Yet, due to its limited size in the dawn-dusk direction in a dynamic magnetotail, the study of the evolution of DFs requires multi-point multi-scale observations, where both the front and background magnetic disturbances should be monitored simultaneously. Based on 2-point *Cluster* and 4-point *MMS* measurements, the evolution of localized fast flows and DFs was obtained by also modeling the changes in the background magnetotail current sheet from the dawn and dusk side of a localized plasma flow as illustrated in panel a. The profiles of the electron energy spectra up to about 10 keV, observed by both spacecraft (panel b), showed difference in the acceleration rate (panel c), which is consistent due to adiabatic electron acceleration from a dawn-dusk localized source region in agreement with the localization of BBF.

Nakamura R. et al., J. Geophys. Res., 126, e2021JA029518, 2021.

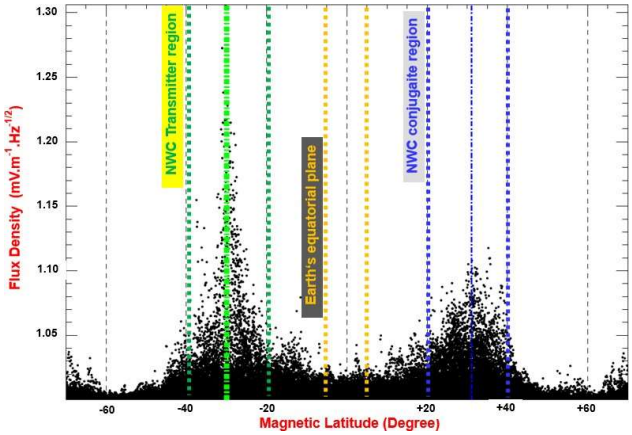


Electron observations at dipolarization front by *MMS* and *Cluster*.
a: Schematics of localized fast flow and spacecraft location relative to the flow; arrows show flow vectors in X-Z (left) and Y-Z plane (right) in Geocentric Solar Magnetospheric coordinates. *MMS* and *Cluster* are located on almost the same Y-Z plane of the localized flow at duskside and dawnside of the flow center (dashed line).
b: Electron phase space density profile at *MMS1* and *Cluster 4* observed just after the dipolarization front.
c: Comparison of differences in acceleration rate at *MMS1* and *C4* with those expected from adiabatic acceleration. The acceleration rate obtained from *MMS1* and *C4* data (black line) tends to become more deviated from adiabatic acceleration (red) for higher energy as expected from localized source region confined in the flow.

VLF SPECTRAL ANALYSIS ONBOARD THE CSES SATELLITE

China's Seismo-Electromagnetic Satellite (CSES) was launched in February 2018. It has an altitude of about 507 km in a polar and circular sun-synchronous orbit with local time nodes of 02 LT and 14 LT. The *Electric Field Detector (EFD)* was used to investigate the variations of VLF ground-based transmitter signals. This instrument has four spherical sensors deployed by booms at a distance of four meters from the satellite's body. A large frequency range is covered by the *EDF* experiment, separated into four bands: HF (18 kHz - 3.5 MHz), VLF (1.8 - 25 kHz), ELF (6 Hz - 2.2 kHz), and ULF (DC - 16 Hz). The signal emitted by the North West Cape (NWC) transmitter located in Australia at 21.5° S and 114° E was studied. The figure displays NWC flux density variation as recorded by the *CSES* satellite during four weeks in September 2019. One can see that the NWC signal is continuously detected by the *EFD/CSES* experiment. Maxima of VLF radio signals occurring each five- days have been found, when the satellite is above the NWC ground-based station. In addition, one finds VLF signal enhancements at the NWC conjugate point and amplitude signal minima when the satellite is crossing the Earth's equatorial plane. In this study, the solar radio flux at 10.7 cm, adjusted to 1 au was also considered. The degree of correlation has been calculated and found to be in the order of 5% for the three key regions but increases to 20% when all satellite latitudes are considered. The correlation between the F10.7 flux and the NWC signals was on the order of 5% for the three key regions and increases to 20% for the full dataset.

Boudjada et al., Proc. Kleinheubach Conf., 3 pp, 2021.



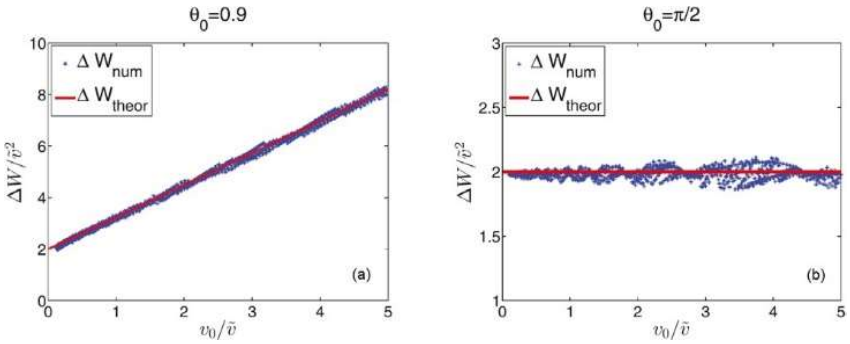
VLF flux density ($mV.m^{-1}.Hz^{-1/2}$) variation versus Earth's magnetic latitude. Three main regions have been considered: (a) above the NWC transmitter station (green-dashed box), at the NWC conjugate point (blue-dashed box), and (c) in the equatorial plane (orange-dashed box). From the figure the power radio wave heating of the ionospheric D-layers above NWC transmitter and at its conjugate point can be obtained.

TRANSIENT PARTICLE ACCELERATION BY A DAWN–DUSK ELECTRIC FIELD IN A CURRENT SHEET

The influence of a dawn-dusk electric field, E_y, on transient particles in a 1D current sheet (CS), characterized by the normal (B_z) and tangential (B_x) components of the magnetic field, was studied. The motion and energization of particles injected at the edges of the CS were investigated within the framework of a trajectory method. The analytical treatment reveals that in the case of uniform B_z and E_y, the dynamics of transient particles is described by magnetic flux conservation on specific segments of the trajectory, which allows prediction of some specific properties of the velocity space inside the CS.

Verification of the analytical treatment by means of test-particle numerical modelling demonstrates good agreement. In particular, it was shown that the CS can play the role of a converging lens that focuses particles around pitch-angle values $\theta \sim \pi$. The analysis reveals that the particle energy gain stays within the range of $\Delta W \in 2\, m[(E_y/B_z)^2, (E_y/B_z)(v_0 + E_y/B_z)]$, where m is the particle mass and v_0 is the module of the initial particle velocity. The limits of the energy gain range depend only weakly on the CS half-thickness. According to performed estimations, for the typical parameters of E_y and B_z in the stationary terrestrial magnetotail, protons with $v_0 \simeq 450$ km/s (before CS crossing) can be accelerated along the CS up to $V_x \simeq 1800$ km/s.

Sasunov et al., Phys. Plasmas 28, 042902, 2021.



Analytical ΔW_{theor} (red) and numerically simulated ΔW_{num} (blue dots) estimates of the particle energy gain in the current sheet with a half-thickness $L = v/\omega_{gyr}$, as function of the particle initial speed v_0 for different values of pitch angle θ_0. The numerical values are distributed along the analytical curve, the energy gain is a linear function of v_0 in case the pitch angel $\theta_0 < \pi/2$ (a), whereas for particles with $\theta_0 = \pi/2$ the energy gain does not depend on the initial particle energy (b).

II - SOLAR SYSTEM

IWF is involved in many international space missions, experiments and corresponding data analysis addressing solar system phenomena. The physics of the Sun and the solar wind, its interaction with the magnetospheres, upper atmospheres or surfaces of solar system planets and bodies are under investigation. Furthermore, theoretical studies related to comparative planetology and space plasma physics between solar system planets and discovered exoplanets are also carried out for understanding the early and later evolution of Venus, Earth and Mars.

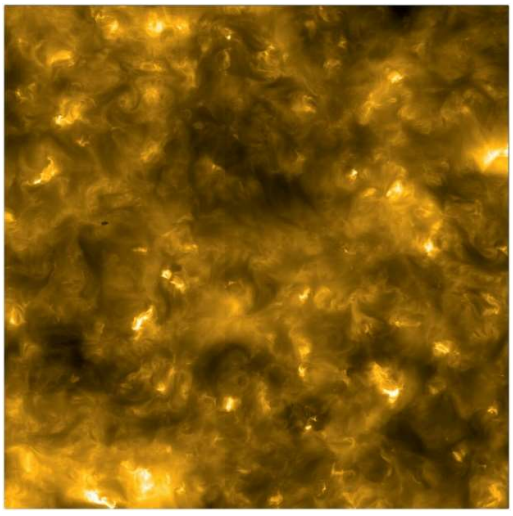


Image of the Sun's outer atmosphere, the corona, taken with the *Extreme Ultraviolet Imager* instrument onboard *Solar Orbiter* (© *Solar Orbiter*/ *EUI* Team/ESA & NASA).

SUN & SOLAR WIND

The Sun's electromagnetic radiation, magnetic activity, and the solar wind are strong drivers for various processes in the solar system.

SOLAR ORBITER

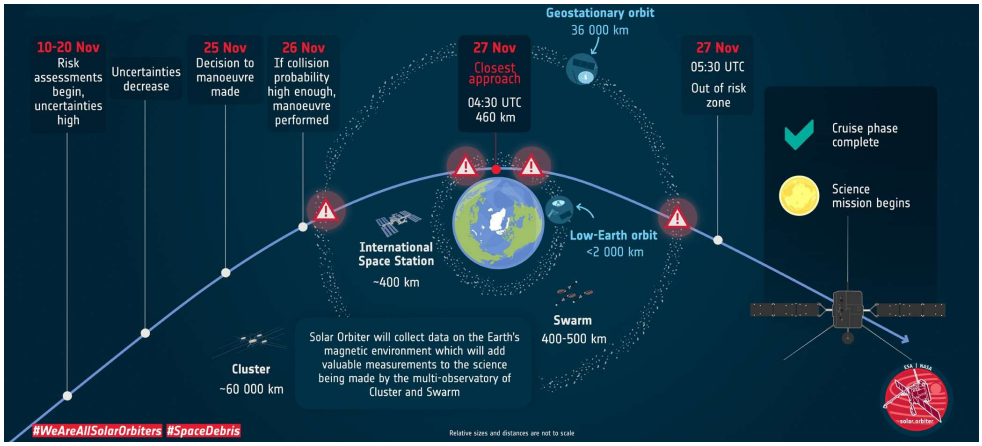
Solar Orbiter is an ESA-led space mission with NASA participation to investigate the Sun. Flying a novel trajectory, with partial Sun-spacecraft corotation, the mission studys in-situ plasma properties of the inner solar heliosphere and to observe the Sun's magnetized atmosphere and polar regions. Its operational orbit will be a high elliptical orbit with perihelion at 0.28 au.

In February 2021 *Solar Orbiter* had its frist close approach to the Sun within 0.5 au. It performed two planetary flyby maneuvers, to get onto the right course for the rendezvous with the Sun. On 9 August, it passed Venus at a distance of 7995 km. Not much later, on 27 November, the spacecraft turned the last time around the Earth with a closest approach of just 460 km.

IWF built the Digital Processing Unit (DPU) for the *Radio and Plasma Waves (RPW)* instrument and calibrated the *RPW* antennas, using numerical analysis and anechoic chamber measurements. Furthermore, the institute contributed to the fluxgate magnetometer *(MAG)*.

RPW will measure the magnetic and electric fields at high time resolution and determine the characteristics of magnetic and electrostatic waves in the solar wind from almost DC to 20 MHz. Besides the 5 m long antennas and the AC magnetic field sensors, the instrument consists of four analyzers: the thermal noise and high frequency receiver, the time domain sampler, the low frequency receiver, and the bias unit for the antennas. The control of all analyzers and the communication will be performed by the DPU.

During the two flybys at Venus and Earth, *RPW* and *MAG* were switched on to make measurements of both magnetospheres. During the Earth flyby there was a unique configuration of more than a dozen spacecraft from five missions. *Solar Orbiter, Cluster, MMS, THEMIS* and *SWARM* performed simultaneous measurements. The data processing for both flybys is still going on.



***Solar Orbiter*'s crucial Earth flyby on 27 November 2021 placed the spacecraft onto the correct orbit for its science phase to begin (© ESA).**

MERCURY

Mercury is at the center of attention because of the ESA/JAXA *BepiColombo* mission. The planet has a weak intrinsic magnetic field and develops a mini- magnetosphere, which strongly interacts with the solar wind.

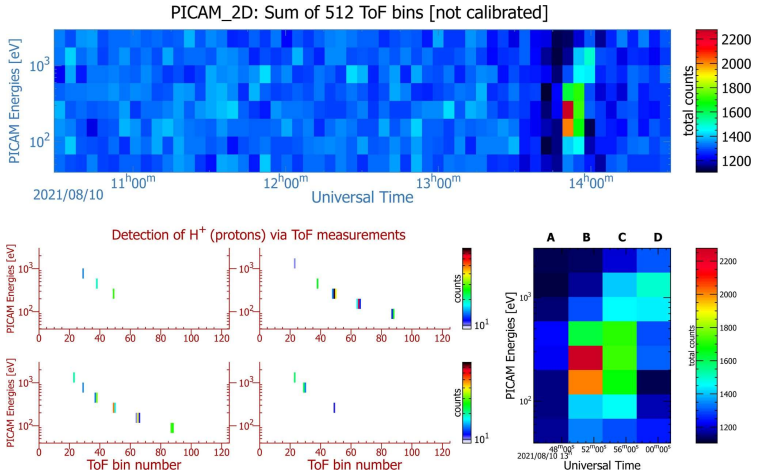
In 2021, *BepiColombo* performed two planetary flybys. It visited Venus in August and had its first encounter withits final target Mercury in October.

BEPICOLOMBO

The European-Japanese spacecraft, launched 2019,is on its way to Mercury. *BepiColombo's* trajectory is bent towards the Sun and its velocity is decreased during nine gravity-assist maneuvers (GAM) such, that the spacecraft finally can reach its Mercury orbit insertion point at the end of 2025. GAMs - also knownas flybys, swingbys or gravitational slingshots - use the gravitation of a planet or other astronomical objects to alter the path and speed of a spacecraft without using thrusters and propellant.

Two of such flybys took place in 2021. On 10 August, *BepiColombo* visited Venus for its second (and last) time. The spacecraft approached the surface of the planet as close as ~552 km, while hovering just aboveits ionosphere. And about six weeks later, on 1 October, the spacecraft flew by its targeted destination, planet Mercury, with a distance of ~200 km, for the first time.

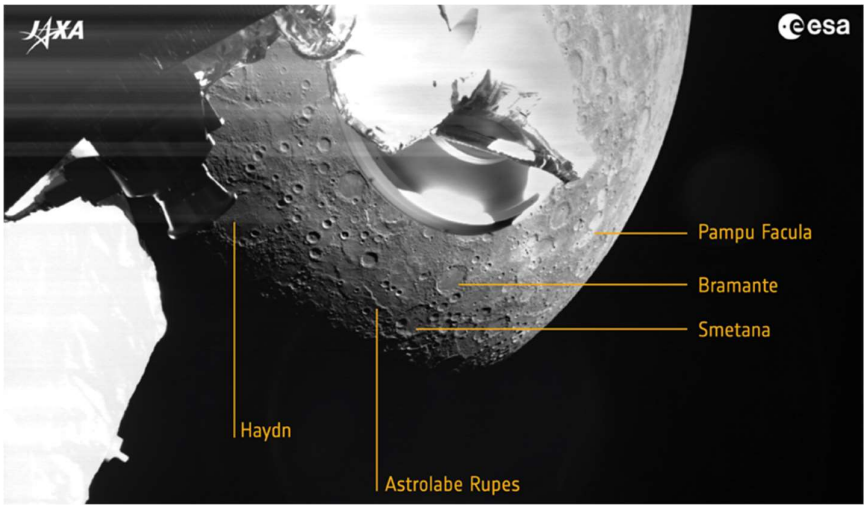
The spacecraft traveled through the dynamic magnetosphere of Mercury, looking into the properties of its various plasma regions. Many sensors, including the three payloads with an IWF hardware contribution on both the European *Mercury Planetary Orbiter (MPO)* and the Japanese *Mercury Magnetospheric Orbiter (MMO/ Mio)* took the chance for early in situ measurements. *PICAM* was operated for about 40 hours during the second Venus flyby, and for about 24 hours during the first Mercury flyby. Beside the scientific output, the operations are also always a very good occasion to fine- tune the procedures for instrument commanding and data retrieval.



An example of *BepiColombo* observations during its second Venus flyby. The top panel shows the ion spectrogram from *PICAM* at the closest approach and the bottom panels show the corresponding time-of-flight (ToF) of the ions. *PICAM* successfully detected ions species, predominantly hydrogen.

Between the two flybys, *BepiColombo* was cruising in the solar wind, and *PICAM* did a number of performance test, as well as collecting valuable scientific solar wind data. The observations by *PICAM* during both flybys, and also the cruise phase have gained high attention from the planetary scientific community, and as a result, a number of potential publications are currently in preparation.

The *MMO-MGF* (IWF PI-ship) magnetometer with its two sensors on the still stowed boom was switched on during the flybys and other campaigns for cruiseobservations and instrument check-outs. The *MPO- MAG* (IWF technical management) magnetometer with both sensors on the already deployed boom has been monitoring the magnetic field almost continuously. *MPO-MAG* data have again been widely used for scientific evaluation of magnetospheric features especially during the second Venus flyby and interesting structures of the solar wind. During the Mercury flyby, data from both magnetometers are affected by magnetic disturbances coming from the spacecraft constellation. A dedicated cleaning of the data based on combining data from both magnetometers has been initiated to make good quality data available for scientific work in 2022.



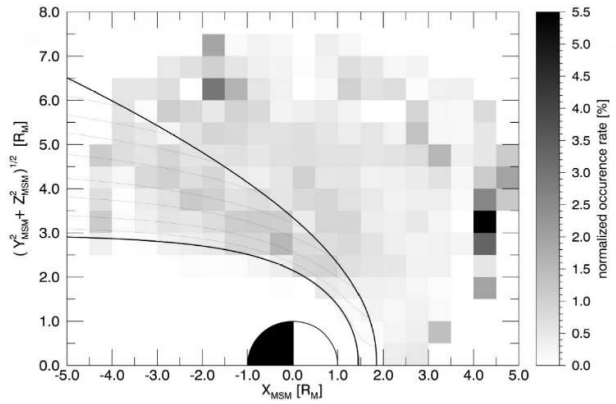
***BepiColombo* captured this view of Mercury on 1 October 2021 as the spacecraft flew past the planet for a gravity assist maneuver. This image was taken at 23:44:57 UTC by the *Mercury Transfer Module's* Monitoring Camera 3, when the spacecraft was 2687 km from Mercury. Closest approach of 199 km took place shortly before (© ESA/*BepiColombo/MTM*, CC BY-SA 3.0 IGO)**

PICK-UP IONS AT MERCURY

Mercury possesses a magnetic field, which constitutes an obstacle to the supersonic solar wind. Upstream of the planet a bow shock emerges where the supersonic solar wind is slowed down and then flows into the magnetosheath. Mercury has an exosphere, which contains species that originate from the surface and impacting micrometeoroids. These neutral particles are ionized by the UV flux of the Sun, and will thenbe picked-up by the solar wind. Because the freshly picked-up particles have a different velocity than the solar wind, the solar wind plasma becomes unstablefor the generation of plasma waves, particularly for ion cyclotron waves (ICWs). For the first time ICWsgenerated by the pick-up of H^+ at Mercury are reported. The spatial occurrence rate of the 5455 identifiedICWs is shown in the figure below in Mercury Solar Magnetospheric (MSM) coordinates. They are detected over a wide spatial range, where 73% of the observed ICWs are located in the solar wind and 27% in the magnetosheath, indicating that Mercury possesses anextended hydrogen exosphere.

From the findings it can be deduced that in the solar wind the ICWs are excited by the ion resonant beam instability and in the magnetosheath from the ring- beam. To understand the difference of their excitation, these waves should be studied on basis of plasma observations from the *BepiColombo* mission.

Schmid et al., Geophys. Res. Lett., 48, e2021GL092606, 2021a.
Schmid et al., Ann. Geophys., 39, 563–570, 2021b.



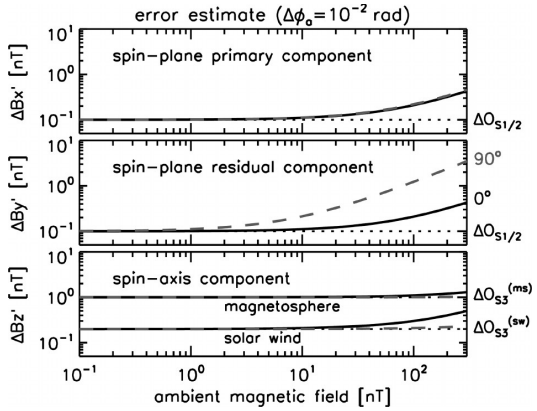
Occurrence rate of the 5455 identified ion cyclotron waves (ICWs), normalized by the *MESSENGER* dwell time. The black lines illustrate the bow shock and magnetopause obtained from the models by Slavin et al. (2009) and Korth et al. (2015). The gray lines depict the flowlines obtained from the Schmid et al. (2021b) magnetosheath plasma flow model. From the ubiquitous occurrence of ICWs around Mercury, it is therefore concluded that (1) Mercury possess an extended hydrogen exosphere and that (2) photoionization is afforded an important role in the hydrogen loss process.

ERROR ESTIMATE FOR CALIBRATED FLUXGATE MAGNETOMETER DATA IN SPACE PLASMA

The fluxgate magnetometers operate with a set of coils, often mounted on a boom extending (over several meters) from the spacecraft body to minimize the interference from spacecraft-generated fields. Like most of the other scientific instruments, the fluxgate magnetometers need to be calibrated against the standard. There are uncertainties in the magnetometer (in-flight) calibration associated with the coil properties (offset levels) and the angular deviation of sensor directions from the ideal (e.g., orthogonal) set-up. It is beneficial in space plasma observational studies to know the systematic error behavior in the (in-flight) calibrated magnetometer data.

The error estimate study was performed, finding that the magnitude of the magnetic field with respect to the offset error and the angle of the magnetic field to the spacecraft spin axis play an important role. The offset uncertainties are the major factor in a low-field environment, while the angle uncertainties (rotation angle in the spin plane, sensor non-orthogonality, and sensor misalignment to the spacecraft reference directions) become more important in a high-field environment in a proportional way to the magnetic field. The error estimate study serves as a useful tool in designing higher-precision magnetometers for future spacecraft missions as well as in developing novel data analysis methods in geophysical and solar system science.

Narita et al., Geosci. Instrum. Method. Data Syst., 10, 13-24, 2021.



In-flight calibration error of the *BepiColombo* magnetometer *MMO- MGF*. Solid curves are for the axial ambient field. Dashed curves are for the spin-plane ambient field.

VENUS & MARS

Venus and Mars are the Earth's nearest inner and outer planetary neighbors, respectively. Venus orbits the Sun at 0.7 au in 224 days, has a radius slightly smaller than the Earth, and has a very dense atmosphere. Mars orbits the Sun at 1.5 au in 687 days, has about half the radius ofthe Earth, and has a very tenuous atmosphere.

Both planets do not have an internal magnetic field, although Mars does show remnant surface magnetization, which might indicate that the planet used to have a functioning dynamo. Through the interaction of Venus and Mars with the solar wind, however, a so- called induced magnetosphere is created.

Two spacecraft made historic flybys of Venus on 9 and 10 August 2021. *Solar Orbiter* and *BepiColombo* both used the planet for gravity assists within 33 hours of each other, capturing unique imagery and data during their encounters. The *Solar Orbiter* plasma package showed clear evidence of magnetic reconnection in the far tail.

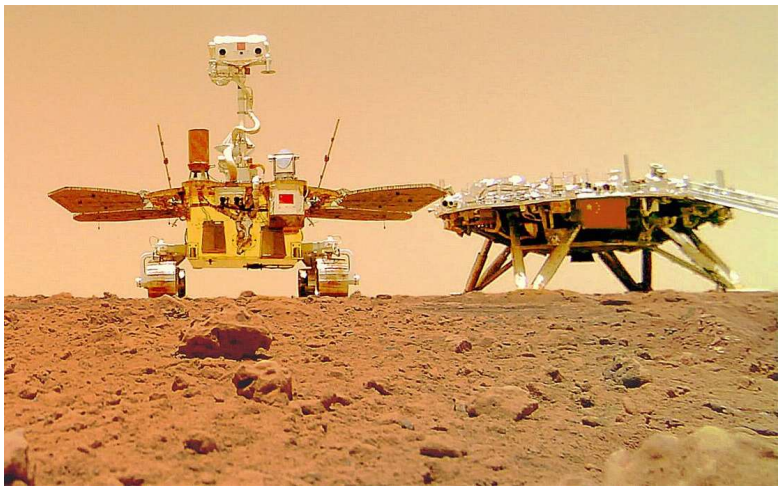
TIANWEN-1

Tianwen-1 ("questions to heaven") is China's first Mars mission, consisting of an orbiter and a rover named *Zhurong*. Before *Zhurong* only NASA has successfully landed and operated spacecraft on Mars. The mission is designed to conduct a comprehensive remote sensing of the Red Planet, as well as surface investigations. IWF contributed to a magnetometer aboard the orbiter.

Several milestone events occurred in 2021 for this mission: the successful orbital insertion on 10 February, the landing of *Zhurong* on 14 May, the magnetometer boom deployment on 25 May, and the switch-on forcontinuous operation and observations on 13 November.

Two operational modes were selected for the *Mars Orbiter MAGnetometer (MOMAG)*: 32 Hz for 120 min around periapsis and for 60 min around apoapsis, and 1 Hz for the rest of the 8-hour orbit. *MOMAG* demonstrated good performance, nevertheless preliminary measurements indicated various spacecraft magnetic effects due to the lack of a magnetic cleanliness program and the rather short 3.2 m boom. The two-sensor gradiometer formation, where the outboard sensor is located at the end of the boom and the inboard sensor at 0.9 m fromthe outboard, is used to remove the spacecraft magnetic effects in order to obtain cleaned

scientific data.



China's first Mars rover, *Zhurong*, is pictured next to its landing platform on the surface of the red planet. The rover traveled approximately 10 meters to drop off a wireless camera, then backed up into frame in order to capture this spectacular image (© CNSA).

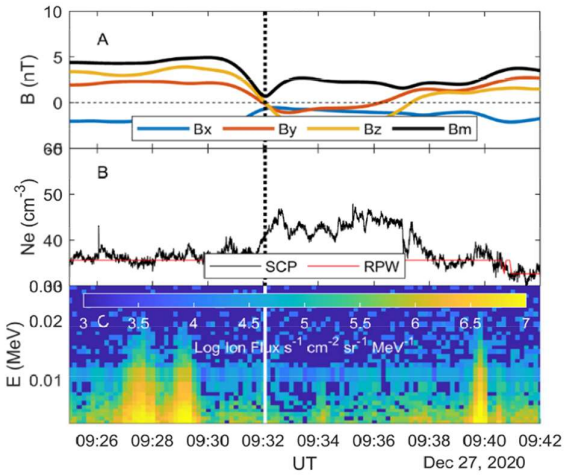
BEPI'S AND SOLO'S FIRST VENUS FLYBYS

The first of two Venus flybys that *BepiColombo* used as a gravity assist maneuver to finally arrive at Mercury, took place on 15 October 2020. After passing the bow shock, the spacecraft traveled along the induced magnetotail. The *Mercury Planetary Orbiter Magnetometer (MPO-MAG)* data were studied to investigate the structure of the induced magnetosphere. Behind the bow shock crossing, the magnetic field showed a draping pattern consistent with field lines connected to the interplanetary magnetic field wrapping around the planet: instead of pointing in a direction along the tail, the field was directed perpendicular to it. This different direction is caused by the field lines rotating away from the tail direction to remain connected with the interplanetary magnetic field direction. This flyby showed a highly active magnetotail, with e.g. strong flapping motions at a period of ~7 min. This activity was driven by solar wind conditions: Venus's magnetosphere was impacted by a stealth coronal mass ejection.

Later in the year, on 27 December, *Solar Orbiter* had its first flyby at Venus. This one took place in the opposite direction, flying along the tail towards the planet and exiting the bow shock across the north pole. Although the solar wind conditions were rather quiet, a lot of activity was observed in the tail. Using both the magnetometer data, the electron density from *RPW* and the *SpaceCraft Potential (SCP)*, and the energetic ion spectra from the *Energetic Particle Detector -Supra Thermal Electrons and Protons instrument (EPD-STEP)*, clear evidence was found for magnetic reconnection. This occurred far down the tail at ~21 RV. Closer to Venus, evidence was found for the presence of the tearing instability, which can cause reconnection. Behind the quasi-perpendicular bow shock the expected mirror modes were not found, but instead ion cyclotron waves were measured at the proton cyclotron frequency. This happened because of the relatively low plasma-beta behind the bow shock. Interestingly, these waves changed frequency further down the tail. This is interpreted as a Doppler shift of the waves, caused by the acceleration of the plasma in the magnetosheath behind the bow shock. Using the observed frequencies, it was estimated that the magnetosheath plasma was accelerated to ~180 km/s at a down-tail location of ~55 RV.

Volwerk et al., Ann. Geophys., 39, 811-831, 2021.

Volwerk et al., Astron. Astrophys., 656, A11, 2021.

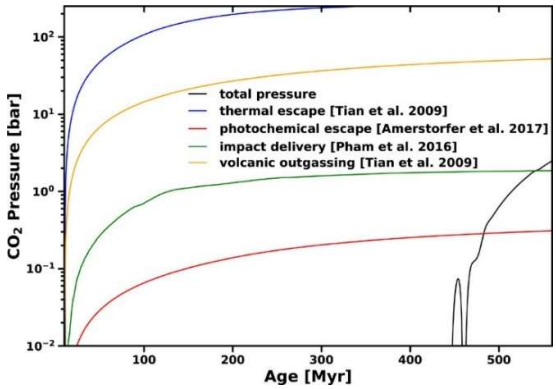


Reconnection event measured by Solar Orbiter in Venus's magnetotail. (A) The magnetic field measurements showing a very small total magnetic field at the dotted line. (B) The electron density from two instruments SCP and RPW. SCP shows a clear jump in density at the dotted line. (C) The ion flux measured by EPD-STEP showing accelerated ions on the left of the white line.

DID MARS POSSES A DENSE ATMOSPHERE DURING FIRST ~400 MYR?

The X-ray and EUV flux (together XUV) from the early Sun was significantly higher during the first 0.4 billion years (Gyr) than at present, ranging from ~20 times at ~4.2 Gyr ago to about 300 times the present value ~4.5 Gyr ago. It was already known that a CO_2- dominated atmosphere would expand significantly up to several Martian radii for such high values, thereby resulting in significant thermal escape that could erode 1 bar of CO_2 within just 10 million years for XUV fluxes ≥20 times the present value. Non-thermal escape processes would additionally put significant stress onto any existing atmosphere, even though these processes are very poorly understood for early Mars. Through reviewing the existing literature and by bringing together different sources (magma ocean and subsequent volcanic outgassing, impact delivery, etc.) and sinks (thermal and non-thermal escape) for the early Martian atmosphere, it was reconstructed whether a dense atmosphere could have existed early-on. Even the highest estimates for CO_2 sources on early Mars could not have counterbalanced atmospheric escape until ~4.1-4.0 Gyr ago. Mars, therefore, might just have always been a cold and dry planet that just episodically experienced liquid water afterwards, 4.0-3.6 Gyr ago, due to volcanic degassing and/or impact heating, when atmospheric escape diminished to much lower values.

Scherf & Lammer, Space Sci. Rev., 217, 2, 2021.



Atmospheric sources and sinks at early Mars (color lines). Black line shows a pressure scenario for which the whole Martian CO_2 inventory is outgassed continually over ~1 Gyr through volcanic degassing, contrary to most of the CO_2 being catastrophically outgassed during magma ocean solidification.

EARLY EVOLUTION OF VENUS, EARTH AND MARS

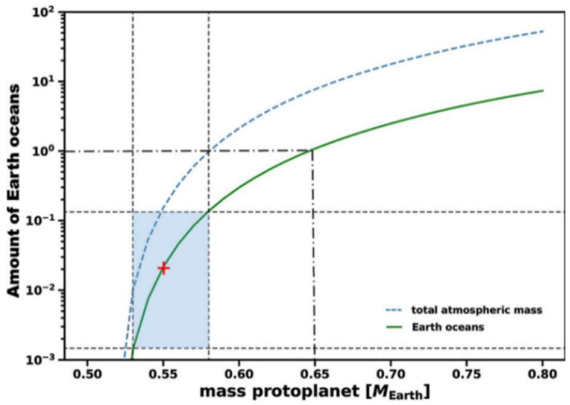
The current state of knowledge of the formation and early evolution time scales of Venus, Earth and Mars was studied, by using the latest isotopic data of various elements. Different planet formation models and isotopic data from ^{182}Hf-^{182}W, U-Pb, lithophile- siderophile elements, ^{48}Ca/^{44}Ca isotope samples from planetary building blocks, as well as reproduction attempts of atmospheric ^{36}Ar/^{38}Ar, ^{20}Ne/^{22}Ne, ^{36}Ar/^{22}Ne isotope ratios, are combined to obtain the expected solar ^{3}He abundance in Earth's interior.

By considering also, Earth's D/H seawater ratios additional light was shed on early Earth's accretion time, including a Moon-forming event at ~50 Myr after the formation of the solar system. As shown in the figure below, proto-Earth masses larger than 0.6 Earth- masses at the time when the gas disk dissipated a large amount of Earth's H_2O could have been formed from theinteraction between a primordial atmosphere and the underlying magma ocean so that left behind D/H ratios would differ largely from the measured carbonaceous chondritic value.

The results of the study support the hypothesis that the bulk of Earth's mass (≥ 80 %) most likely accreted within 10-30 Myr after the Sun's origin. From the analysis of the before mentioned isotopes, one finds that proto-Earth accreted most likely 0.5-0.6 Earth-masses during the lifetime of the protoplanetary gas disk. For Venus, the present atmospheric noble gas data are too uncertain forthe reconstruction of the planet's accretion. On the other hand, it was found that proto-Venus could have grown to its total mass before the disk dissipated.

Classic formation models for Venus, Earth and Marshave struggled to grow large planetary embryos, or protoplanets with masses as shown in the figure below, quickly from the tiniest materials within the typical lifetime of a protoplanetary disk. However, it is expected that so-called pebble accretion most likely solve this long-standing time scale controversy.

Lammer et al., Space Sci. Rev., 217, 7, 2021.



The green line shows the maximum amount of Earth oceans that could be produced from an accumulated primordial atmosphere (blue dashed line) by gas-rock interactions between the atmosphere and an underlying magma ocean. The red "+" corresponds to an accretion scenario that can reproduce Earth's present atmospheric Ar and Ne noble gas isotope ratios. In such a case, a negligible water amount of only ~2 % of an Earth ocean could have been produced with solar nebula origin.

JUPITER & SATURN

Jupiter and Saturn, the two largest planets in our solar system, both have several dozens of moons. For Jupiter, the most prominent moons are the four Galilean satellites. Callisto, Ganymede, and Europa will be visited frequently by the future *JUICE* spacecraft and the evolving trajectory of the current *JUNO* mission will allow several visits of Ganymede, Europa, and Io in the next few years. For Saturn, Titan is clearly the most prominent satellite with its dense atmosphere consisting of nitrogen and methane. However, Enceladus, with its suspected subsurface ocean is counted as a main candidate for extraterrestrial life.

In late February, *JUICE* hit a milestone when the boom for its *J-MAG* magnetometer and *Radio and Plasma Wave Investigation (RPWI)* instrument were successfully moved into place and installed at the Airbus satellite integration center facilities in Friedrichshafen, Germany. By the end of 2021 almost all scientific instruments of *JUICE* have been integrated on the spacecraft, which is undergoing extensive testing until launch in 2023.

JUICE

The launch of ESA's large mission *Jupiter ICy moons Explorer (JUICE)* had to be shifted from 2022 to 2023 due to technical reasons and delays caused by the COVID-19 pandemic. *JUICE* might arrive at Jupiter in the early 2030ies to make detailed observations of the gas giant and three of its largest moons, which are thought to have water oceans below their icy surfaces. Towards the end of the mission *JUICE* will orbit Jupiter's largest moon Ganymede.

The *Jupiter MAGnetometer (J-MAG)* is led by Imperial College London (ICL) and will measure the magnetic field vector and magnitude in the spacecraft vicinity in the bandwidth DC to 64 Hz. It is a conventional dual sensor fluxgate configuration combined with an absolute scalar sensor based on more recently developed technology. Science outcome from *J-MAG* will contribute to a much better understanding of the formation of the Galilean satellites, an improved characterization of their oceans and interiors, and will provide deep insight into the behavior of rapidly rotating magnetic bodies. IWF supplied the atomic scalar sensor *(MAGSCA)* for *J-MAG*, which was developed in collaboration with TU Graz.

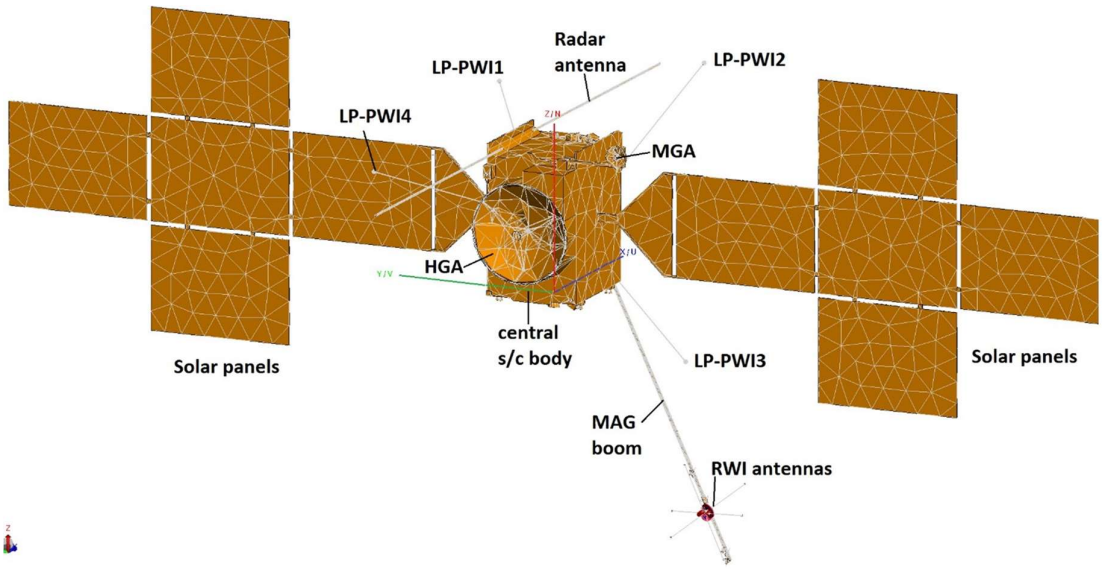
The 10.6-meter-long boom built for *JUICE's* magnetometer and *Radio and Plasma Wave Investigation (RPWI)* instruments, suspended aloft in folded configuration, being integrated to the spacecraft body in the clean room of Airbus (© Airbus, Sener).

In 2021, the *J-MAG* flight model was mounted on the spacecraft with the *MAGSCA* sensor at the tip of the *MAG* boom. Its proper function could be demonstrated during nominal testing in the integration hall as well as during an extensive thermal vacuum and balance test of the entire *JUICE* spacecraft. Furthermore, the spare model of *MAGSCA* was assembled and tested.

The *Particle Environment Package (PEP)* is a plasma package with sensors to characterize the plasma environment of the Jovian system and the composition of the exospheres of Callisto, Ganymede, and Europa. As part of the *PEP* consortium, IWF participates in the scientific studies related to the plasma interaction and exosphere formation of the Jovian satellites.

IWF was also responsible for the calibration of the radio antennas of *RPWI.* These antennas are three perpendicular dipoles mounted on the long magnetometer boom. Their reception properties have been determined using numerical methods applied to a mesh-grid model of the spacecraft, which is displayed in the figure below.

With this antenna system it will be possible to determine intensity, polarization, and incoming wave direction of Jovian radio emissions. This can only be correctly done when the antenna reception properties are well known. Therefore, the so-called effective length vectors of the radio antennas were determined for the quasi-static frequency range. In this range the antenna reception properties are constant with a toroidal antenna pattern looking similar to a donut. The changes of the effective antenna vectors as a function of the solar panel rotation were also investigated revealing angular deviations of the vectors of up to 1°. The antenna patterns at higher frequencies up to 45 MHz show multiple lobes, and direction finding with an accuracy of 2° can only be done up to a frequency of 1.5 MHz. An estimation of the influence of pulses from the *JUICE* active radar on the *RPWI* sensors revealed that these strong pulses should not do any harm to them.



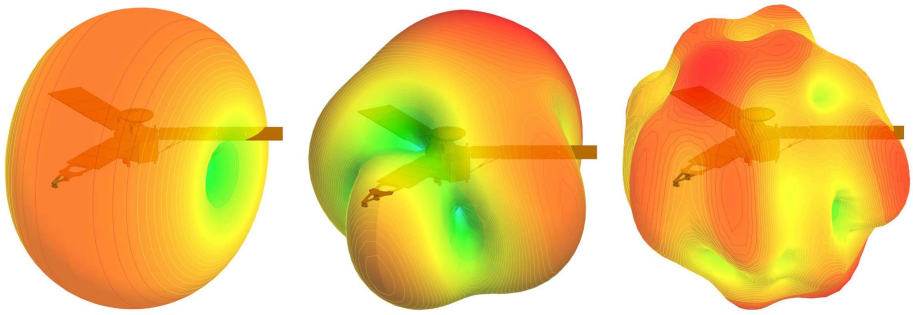
Mesh-grid model of the *JUICE* spacecraft (s/c) for numerical simulations. Most important s/c parts are annotated: *HGA* and *MGA* are the high and medium gain antennas. *LP-PWI1-4* are the L*angmuir Probes Plasma Wave Instrument*, and the antennas of the *Radio Wave Instrument (RWI)* are located on the magnetometer *(MAG)* boom.

JUNO

NASA's Juno mission is dedicated to the investigation of Jupiter's gravitational and magnetic field, its polar magnetosphere, deep atmosphere and winds, as well as core composition and mass distribution. The spacecraft entered a polar orbit around Jupiter in July 2016 and its controlled de-orbit is scheduled for 2025. One of the instruments on board is the *Radio and Plasma Wave Sensor (Waves)*, which uses a dipole antenna to measure electromagnetic field components of incident waves (Jovian radio emissions or plasma waves). The reception properties of the antenna change drastically over the instrument's frequency range from near DC to 40 MHz, so the quasi-static effective length vector cannot be used to describe the antenna system above some megahertz. Since in this frequency range the effective length vector is extremely direction- dependent, antenna gain patterns and insertion loss have been chosen as suitable properties to characterize the directional variation of the antenna sensitivity and the influence of base capacitances. These quantities were obtained by numerical computations on the basis of a suitable simulation model of the antenna system and spacecraft with all relevant features. The results can be used to evaluate observed radio wave spectra, the gain giving clues about the directions where the instrument does not see incident waves, and the insertion loss enabling a quantitative correction of wave spectra as a function

of frequency.

Sampl et al., Radio Sci., 56, e2020RS007184, 2021.



***Juno* dipole gain as function of direction of incidence of radio waves for three frequencies.**

SATURN STUDIES

The completed *Cassini* mission has provided an enormous wealth of data, which will keep scientists busy for the upcoming years. A new study used the complete *Cassini RPWS (Radio and Plasma Wave Science*) observations of Saturn Kilometric Radiation (SKR) tofind about 600 events of SKR experiencing Faraday rotation. This effect is characterized by a rotation of the semi-major axis of the SKR polarization ellipse as a function of frequency during wave propagation througha birefringent plasma medium. A statistical visibility analysis showed that elliptically polarized SKR most likely experiences Faraday rotation when it is beamed from the dawn source towards high latitudes into the noon and afternoon local time sectors.

Another study used the complete *Cassini RPWS* data to statistically analyze the polarization properties and visibility of Saturn narrowband (NB) emissions at 5 and 20 kHz. The 5 kHz NB emissions show high circular polarization only when beamed to high latitudes and are almost unpolarized in the equatorial plane. 20 kHz NB emissions are usually highly circularly polarized as they are only beamed to higher latitudes and usually donot occur at the equator.

Taubenschuss et al., Icarus, 370, 114661, 2021.

COMETS

Comets are assumed to be the left-overs of the solar system creation that have not been moulded into planetary bodies. Most of these objects reside in the Kuiper Belt (between 30 and 50 astronomical units from the Sun) and in the Oort Cloud (greater than 2000 au from the Sun). Now and then a body in these regions is nudged towards the inner regions of the solar system and as soon as it passes Jupiter's orbit, the solar irradiation is strong enough to let (sub)surface ices sublimate. This gas escapes, together with dust, and thereby creates the characteristic tails of comets. Around Christmas comet Leonard was well visible in the sky and captured by *Solar Orbiter's Heliospheric Imager*.

Image of comet Leonard captured by the *Solar Orbiter* spacecraft in December 2021 (© ESA/NASA/NRL/SoloHI).

COMET INTERCEPTOR

ESA's first F(ast)-class mission *Comet Interceptor* will, for the first time, study a so-called dynamically-new comet, i.e. a comet, which will have its first passage by the Sun after being nudged out of the Kuiper Belt or Oort Cloud. The surface composition and shape of the nucleus as well as the structure and composition of the coma will be investigated. This mission is unique, as - for the first time - there will be multiple-spacecraft simultaneously measuring in the cometary environment. *Comet Interceptor* consists of three components. A large mother spacecraft (A), which remains furthest from the nucleus, built by ESA, also serving as a relay station for the data. And two smaller spacecraft, which will have flybys much closer to the comet: B1 built by JAXA and B2 built by ESA. The launch is scheduled for 2029 and the mission will be parked at the L2 Lagrange point (up to three years) until an appropriate target has been identified. Discussions with ESA and two contractors to build the spacecraft have been ongoing in the last year and mission adoption is expected in June 2022.

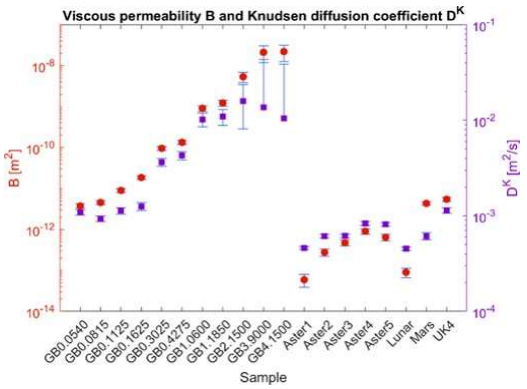
IWF is involved in two instrument packages. On spacecraft A, the institute builds the DPU for the *MANiaC (Mass Analyzer for Neutrals and ions at Comets)* instrument, which is a mass spectrometer to sample the gases released from the comet. In 2021, the prototype design of the *MANiaC* DPU was started. All electronical key components have been selected and the design is in progress. Due to the limitation in space, the elements of the DPU will be located onto two boards. The main board will contain processor, memories and FPGA and an interface board will host the driver circuitries for all external interfaces. The first prototype hardware will become available in spring 2022. In addition, the concept for the two software packets, for boot and science mode, was developed. In particular for the boot software, a detailed requirement document has been defined. Furthermore, test routines have been generated, to confirm the compliance of the quad core LEON4 processor with the high data rate during the science mode.

IWF also develops the front-end electronics for the fluxgate magnetometer, which is part of the *Dust-Field- Plasma (DFP)* package on spacecraft B2 *(BFG).* The *BFG* front-end electronics is based on the *SOSMAG* magnetometer and therefore on a previously developed microchip. It comprises most of the active electronics, which is required to amplify and digitize the magnetic field measured by a fluxgate sensor. For the *BFG* design, the electronics components outside of the microchip were adapted and matched to the miniaturized fluxgate sensor from Magson GmbH. Measurements with the bread board model showed excellent instrument performance, which allowed to finish the preliminary instrument design for the Engineering Model in the second half of 2021. Its production will start in early 2022.

GAS FLOW IN COMETARY ANALOG MATERIALS

Gas flow from its surface, originating in subsurface layers, belongs to the processes of utmost importance for the evolution of a comet. Outgassing affects the coma and the dust redistribution around the comet and influences the thermal evolution as well as mass loss of the comet. Many past studies focused on the effect of water sublimation. However, there are open questions about details of the gas flow through the porous medium, which builds the cometary surface layers. Two parameters combine the properties of the porous cometary material in a way that enables a mathematical description of the gas flux: the Knudsen diffusion coefficient D and the permeability B, which describe the molecular and the viscous flow, respectively. Both kinds of flow were investigated in laboratory measurements, using dry cometary analog materials. By simultaneous evaluation of the flow rates for a wide range of pressures, D and B could be determined forthe analog materials. In addition, glass bead samples were investigated to study the relations between pore sizes, porosity and the determined coefficients B andD in a systematic manner. The determined parameters cover a wide range of values, dependent on the pore structure of the materials (see figure). The results forthe glass beads verified relations available for packed beads of spherical grains. However, also deviations from the models were found, where the beads become non-spherical. In addition, computer simulations were applied, which indicated potential for improvements in the setup of future measurements. These were thefirst simultaneous determinations of B and D for analog materials of comets and asteroids, giving clues about further paths to better understand the gas flow through the surfaces of these space objects.

Schweighart et al., MNRAS, 504 (4), 5513–5527, 2021.



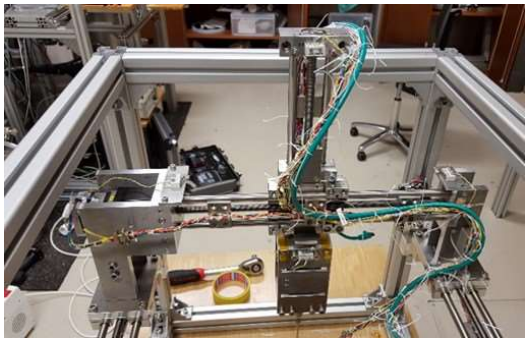
Permeability of cometary analog materials for continuous flow (B) and molecular diffusion (D) as obtained by laboratory measurements. Since the average pore size increases for larger glass beads (GB), the resistance to the gas flow decreases, resulting in higher values of B and D.

COPHYLAB

CoPhyLab started as a joint German, Swiss, and Austrian, research project between TU Braunschweig, the University of Bern, and IWF to investigate cometary processes in space simulation laboratories. Later on, the following external partners joined: MPS Göttingen, DLR Berlin, University of Stirling, Luleå University of Technology, Qian Xuesen Laboratory of Space Technology in China, and Open University. The project aims to increase the understanding of the *Rosetta* mission results by conducting selected experiments in a controlled environment. In 2021 the general laboratory setup has been finished with all the main components installed. IWF was involved in the general chamber design, the cooling

system and the light chopper for controlled illumination conditions particularly for day-night cycles. Besides the small-class gas flow experiments in Graz, IWF is also contributing to the hardware and instrument setup at the common CoPhyLab laboratory in Braunschweig. Amongst several instruments, the solar simulator mounted on the Large Chamber was contributed by IWF. The most recent addition is the sample manipulation device, which is a mobile robotic platform designed for operations inside the large thermal-vacuum chamber. The working environment is high vacuum and temperatures as low as -200 °C. It can bring sensors close or even inside the sample, mechanically interact with the sample surface and bring close-up stereo cameras to selected positions. Planned experiments are a Brazilian Disk test on icy samples and penetrometer measurements to determine the tensile and compressive strength of a processed sample.

Kreuzig et al., Rev. Sci. Instrum., 92, 115102, 2021.



Sample manipulation device before installation in the Large Chamber.

III - EXOPLANETARY SYSTEMS

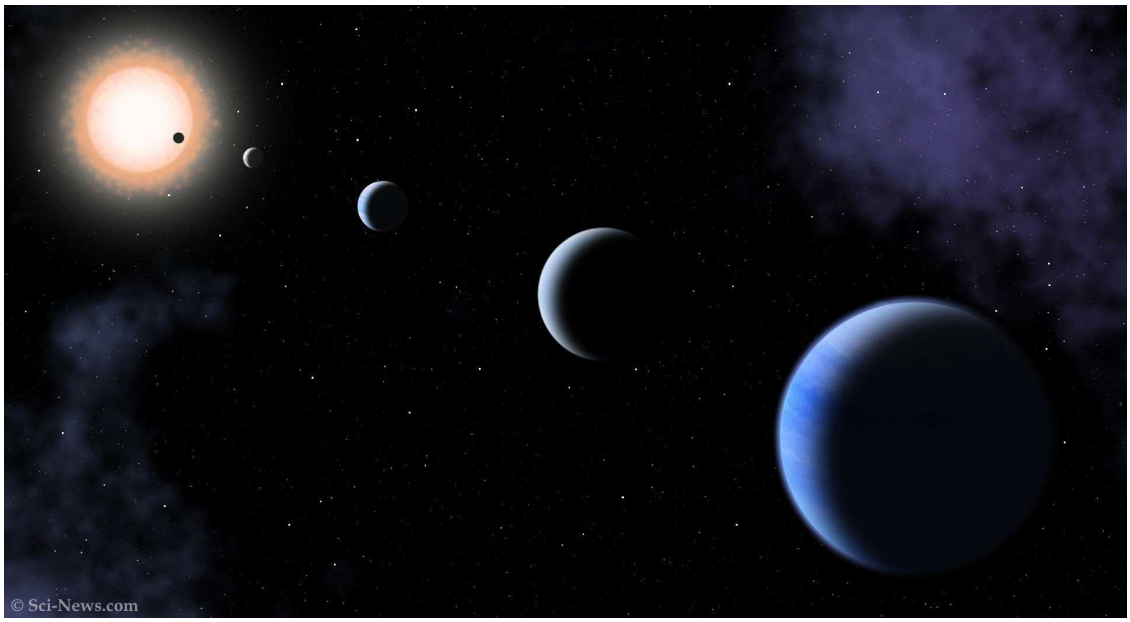
The field of exoplanet research (i.e. investigation of planets orbiting stars other than the Sun) has developed strongly in the past decades. The first exoplanet orbiting a Sun-like star, 51 Peg b, was detected in 1995. About 4500 exoplanets, most in planetary systems, are now known. Improved instrumentation and analysis techniques have led to the detection of smaller and lighter planets, particularly orbiting bright, nearby stars, which therefore enable in-depth structure and atmospheric characterization. Although hot Neptunes and (ultra-) hot Jupiters are still prime targets for atmospheric characterization, smaller planets are entering the realm of the planets for which the atmosphere can be directly probed.

The main exoplanet missions in which IWF is involved with hardware and/or science are *CHEOPS*, *CUTE*, *PLATO*, *ARIEL,* and *ATHENA*. IWF concentrates on the study and characterization of planetary atmospheres and of the star-planet interaction phenomenon using both theory and observations, focusing particularly on the analysis of planet formation, exoplanet clouds, and atmospheric mass-loss processes. The research is based on the collection and analysis of ground- and space-based observations to constrain the models, as well as on the modelling of planet and cloud formation from first principles.

An in-house developed exoplanetary atmosphere modelling tool enabling one to account for non-local thermodynamic equilibrium effects has been uniquely capable of reproducing the transmission spectroscopy observations of the hottest exoplanet known to date. In this way, it has been shown that non-local thermodynamic equilibrium effects impacting the metals in the planetary atmosphere control the temperature structure of the middle and upper atmosphere.

A one-dimensional, general, and open-source framework for exoplanet atmospheric modelling, spectral synthesis, and Bayesian retrieval has been developed. The framework has been successfully tested against the results of other similar tools and applied to interpret the observations collected for a wide range of close-in giant exoplanets. This framework has also been further upgraded to retrieve results considering the impact of a 3-dimensional geometry.

CHEOPS data collected during the first few months of science operations have been used to characterize the HD108236 planetary system. This is one of the very few multi-planet systems known to date containing at least five transiting planets and as such it provides critical information on the physics regulating the planetary mass-radius relation.



Artist's impression of the five-planet system HD108236 (© Sci-News.com).

CHEOPS

CHEOPS (CHaracterising ExOPlanet Satellite), successfully launched in December 2019, has started regular science operations in April 2020. The mission aims at studying extrasolar planets by means of ultra- high precision photometry. The main science goals are to detect transits of small planets, known to exist from radial-velocity surveys, precisely measure the radii of a large sample of planets to constrain the internal composition and atmospheric evolution of Neptune- to Earth-sized planets, study the atmospheric properties of transiting giant planets, and look for new planets particularly in already known systems.

IWF is responsible for the *Back-End-Electronics (BEE)*, one of the two on-board computers, and for controlling the data flow and the thermal stability of the telescope structure. The institute also developed and maintains the mission's signal-to-noise calculator. Within the Guaranteed Time Observations (GTO) of the *CHEOPS* consortium, IWF co-chairs the working group aiming at improving our understanding of the mass-radius relation of planets, of processes affecting planetary atmospheric evolution, and of system architecture.

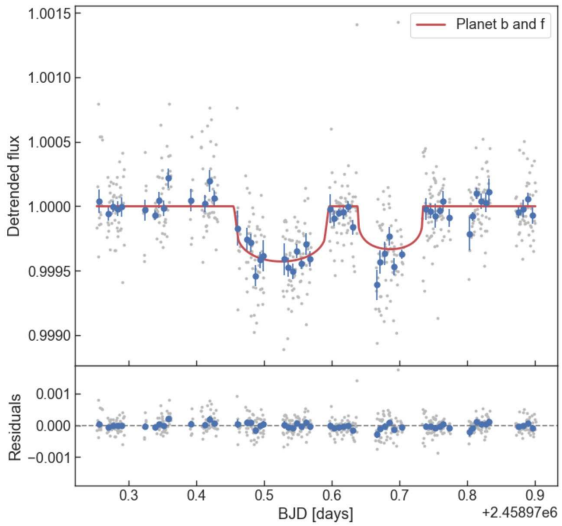
In 2021, *CHEOPS* continued nominal science operations, demonstrating that the satellite performs and ages as expected. The European consortium in charge of the majority of *CHEOPS* observing time made use of *CHEOPS* observations collected in 2020 and part of

2021 to publish nine refereed articles, among which the detection of the transit of the very long period planet v^2 Lupi d that appeared in Nature Astronomy.

One of these works has been led by IWF and presented *CHEOPS* observations characterizing the HD108236 planetary system, which hosts five transiting planets with periods ranging between 3 and 30 days and radii between 1.5 and 3 Earth radii. This is the third brightest system hosting more than three transiting planets. The stellar characterization analysis led to the determination of a stellar radius of 0.877 ± 0.008 solar radii, and stellar mass of 0.869 ± 0.049 solar masses and of an age of 6.7 ± 4.5 Gyr.

The *CHEOPS* observations led to the serendipitous detection of a fifth transiting planet, HD108236f, with an orbital period of about 29.5 days. The *CHEOPS* transit light curves (one for each planet) led also to locking the ephemerides for each planet, which is critical for enabling future further characterization observations, and to improving the planetary radii measurements by a factor of two compared to what the *TESS* satellite provided, which first discovered this system. These data were also the first direct data quality comparison between *TESS* and *CHEOPS*, which has shown the power of *CHEOPS* at significantly improving planetary radii measurements over those provided by *TESS* in a fraction of the observing time.

Bonfanti et al., Astron. Astrophys., 646, A157, 2021.



Detrended *CHEOPS* light curve showing the transits of planets b (right) and f (left). The red line shows the best fitting transit model.

CUTE

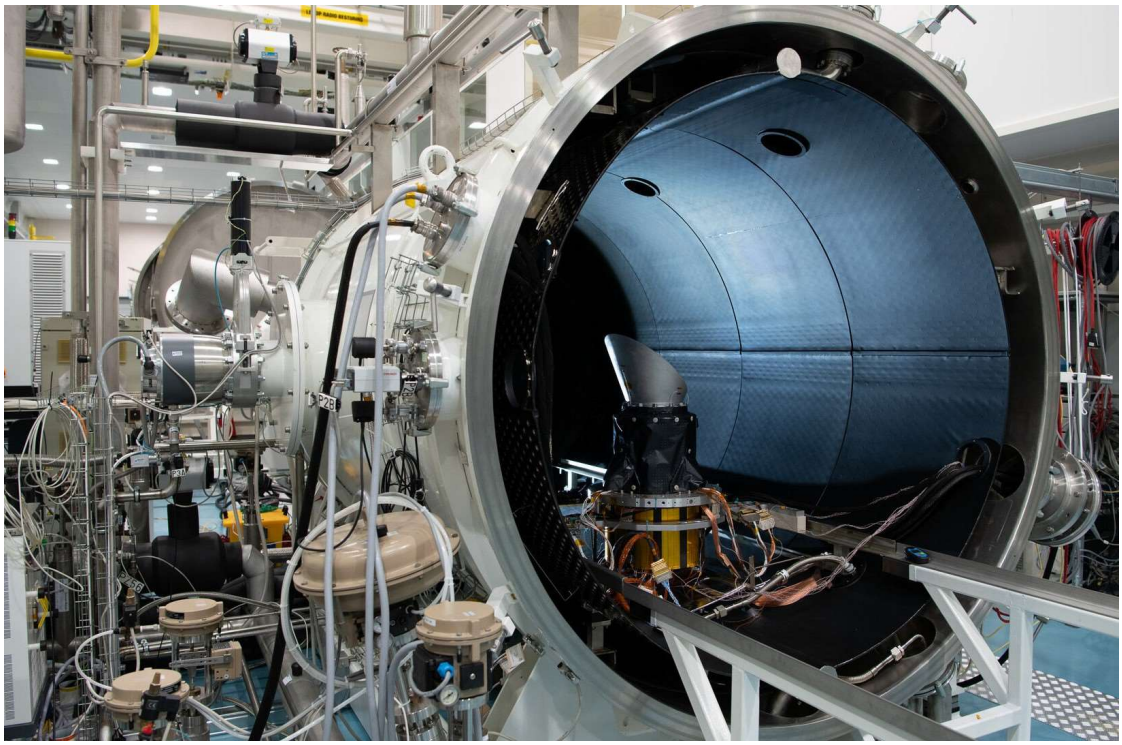
CUTE (Colorado Ultraviolet Transit Experiment) is a NASA-funded 6U-form CubeSat led by the University of Colorado that was launched on 27 September 2021 from the Vandenberg Space Force Base, in California. *CUTE* will perform low-resolution transmission spectroscopy of transiting extrasolar planets at near- ultraviolet wavelengths. It will study the upper atmosphere of short-period extrasolar planets with the aim of observationally constraining atmospheric escape processes, which are key to understand planetary evolution, and detect heavy metals, which constrain the presence and composition of aerosols in the lower atmosphere. Furthermore, *CUTE*'s continuous temporal coverage of planetary transits will allow to detect transit asymmetries, which are possibly connected with the presence of planetary magnetic fields.

IWF is the only technological contributor to the mission outside of the University of Colorado (Boulder), where *CUTE* was developed. IWF is responsible for the development of the data simulator, of the data signal-to-noise calculator, of the ground data reduction software, and of the algorithms defining the on-board data reduction software.

In 2021, IWF has defined the data reduction algorithms used on-board and finalized the development of the *CUTE* ground-based data reduction software. Commissioning of the satellite is still on-going and the first science data are awaited in early 2022.

PLATO

PLATO (PLAnetary Transits and Oscillations of stars) is ESA's third medium (M-class) mission, led by DLR. Its objective is to find and study a large number of exoplanetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. *PLATO* has also been designed to investigate seismic activity of stars, enabling the precise characterization of the host star, including its age.



Key technology for the *PLATO* spacecraft has passed a trial by vacuum to prove the mission will work as planned. This test replica of an 80-cm high, 12-cm aperture camera spent 17 days inside a thermal vacuum chamber at the ESTEC test center in the Netherlands (© ESA-Matteo Apolloni).

IWF co-leads the work package aiming at studying planetary habitability and takes part in two further workpackages (one on stellar characterization and one on planetary evolution) aiming at gaining the knowledge and preparing the tools necessary to best exploit the data. The institute contributes to the development of the I*nstrument Controller Unit (ICU)* with the development of the *Router and Data Compression Unit (RDCU)*. Launch is expected in 2026.

PLATO consists of 24 telescopes for nominal and two telescopes for fast observations. Each

telescope has its dedicated front-end-electronics, reading and digitizing the CCD content. Twelve nominal and two fast DPUs collect the data from the front-end-electronics and extract the areas of interest. The *RDCU* is a key element in the data processing chain, providing the communication between the DPUs and the *ICU*. The second task of the *RDCU* is the lossless compression of the science data. For performance reasons, the compression algorithm is implemented in an FPGA.

In 2021 all design activities have been completed and the production of the qualification model has started. The IP core for compressor and SpaceWire link has been adopted for the FPGA technology used for flight (RTAX2000). A detailed "post place and route" simulation has been performed to check for compliance with all requirements in terms of performance and timing constraints. Furthermore, long term tests with high data rate demonstrated the failure free function of the router part. The critical design review for the *RDCU* has been successfully completed.

ARIEL

ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) is ESA's fourth medium (M-class) mission, led by University College London, to be launched in 2029. It will investigate the atmospheres of several hundred exoplanets to address fundamental questions on how planetary systems form and evolve. During its four-year mission, *ARIEL* will observe 1000 exoplanets ranging from Jupiter- and Neptune- down to super- Earth-size in the visible and infrared with its meter- class telescope. The analysis of *ARIEL* spectra and photometric data will enable extracting the chemical fingerprints of gases and condensates in planetary atmospheres, including the elemental composition for the most favorable targets, with a particular focus on carbon and oxygen. Thermal and scattering properties of the atmosphere will also be studied.

ARIEL consists of a one-meter telescope feeding two infrared low-resolution spectrographs and the fine guiding sensor (FGS), working in the optical. To improve the satellite's pointing stability, the FGS provides optical photometry of the target in three broad bands that are used to control instrumental systematics, measure intrinsic stellar variability, and constrain the presence of high-altitude aerosols in planetary atmospheres. Within the *ARIEL* mission, IWF co-leads the upper atmosphere working group and is heavily involved in testing the mission's performances and advancing the atmospheric retrieval tools.

ATHENA

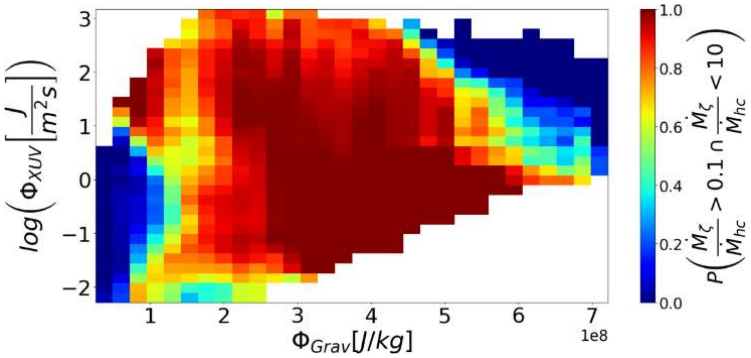
ATHENA (Advanced Telescope for High-ENergy Astrophysics), is ESA's second large (L-class) mission in the Cosmic Vision 2015-2025 plan. Its objective is to study hot gas in clusters and groups of galaxies and the intergalactic medium, to determine how ordinary matter assembles into large-scale structures. The second topic is the growth of black holes and their impact on the universe. The observations in the X-ray range of the electromagnetic spectrum will help to understand the high energetic processes close to the event horizon of black holes and provide more details for the baryonic component, locked in ultra-hot gas.

The institute will contribute to the *Wide Field Imager (WFI)* with the development of the *Central Processing Module (CPM)*. In 2021, the study concerning the processor performance has been continued. The search for efficient configuration of the level 2 cache and the efficient use of the four cores is ongoing. The technical concept for the *CPM* and the SpaceWire router has been further elaborated. All electronic components are selected and the design is ready for building the prototypes.

A CRITICAL ASSESSMENT OF THE ENERGY-LIMITED APPROXIMATION

The energy-limited atmospheric escape approach is widely used to estimate mass-loss rates for a broad range of planets that host hydrogen-dominated atmospheres as well as for performing atmospheric evolution calculations. However, its applicability has been questioned, which has called for a thorough revision of the approximation and for a comparison with sophisticated hydrodynamic models that better reproduce the physics of planetary upper atmospheres. The comparison indicated that the energy-limited approximation gives a correct order of magnitude estimate for mass-loss rates for about 76% of the planets, but there can be departures from the results of hydrodynamic simulations by up to two to three orders of magnitude in individual cases. In particular, planets for which the mass-loss rates are correctly estimated by the energy-limited approximation to within one order of magnitude have intermediate gravitational potentials (~2.5–5.5 $\times 10^8$ J kg^{-1}) as well as low-to-intermediate equilibrium temperatures and irradiation fluxes of extreme ultraviolet and X-ray radiation. However, for planets with low or high gravitational potentials, or high equilibrium temperatures and irradiation fluxes, the approximation fails in most cases. Therefore, the energy-limited approximation should not be used for planetary evolution calculations that require computing mass-loss rates for planets that cover a broad parameter space.

Krenn et al., Astron. Astrophys., 650, A94, 2021.



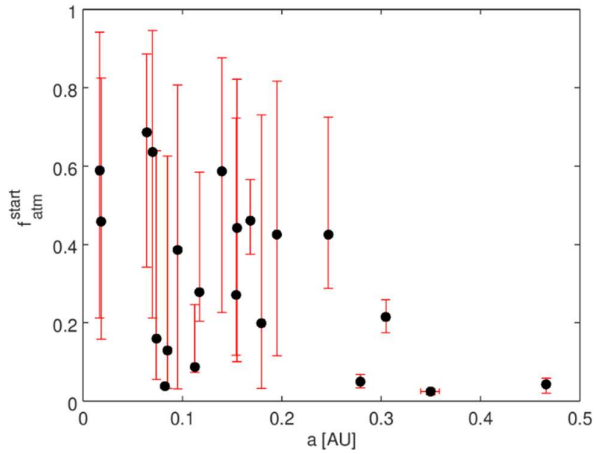
Probability of the mass-loss rate being within a factor of ten of the results given by hydrodynamic simulations as a functionof planetary gravitational potential and high-energy stellar irradiation.

CONSTRAINING STELLAR ROTATION AND SUB-NEPTUNES PLANETARY ATMOSPHERIC EVOLUTION

Planetary atmospheric evolution modelling is a prime tool for understanding the observed exoplanetpopulation and constraining formation and migration mechanisms, but it can also be used to study the evolution of the activity level of planet hosts. The PASTA (Planetary Atmospheres and Stellar roTation rAtes) code, which runs within a Bayesian framework, has been developed to model the atmospheric evolution of sub-Neptunes and super-Earths lying within a dozen systems. The Markov chain Monte Carlo scheme built inside PASTA has been used to retrieve the posterior probability density functions of the initial atmospheric mass fraction ($f_{atm,start}$) of all considered planets and the exponents of the power-law describing the rotation evolution of the host stars. Correlations have been looked for between $f_{atm,start}$ and the system parameters, but without success as a result of the large uncertainties and too small sample of exoplanets. PASTA has the potentialto provide constraints to planetary atmospheric accretion models models, particularly when considering warm sub-Neptunes that are less susceptible to mass loss compared to hotter and/or lower-mass planets. The *TESS*, *CHEOPS*,

and *PLATO* missions are going to be instrumental in identifying and precisely measuring systems amenable to PASTA's analysis and can thus potentially constrain planet formation and stellar evolution.

Bonfanti et al., Astron. Astrophys., 656, A157, 2021.

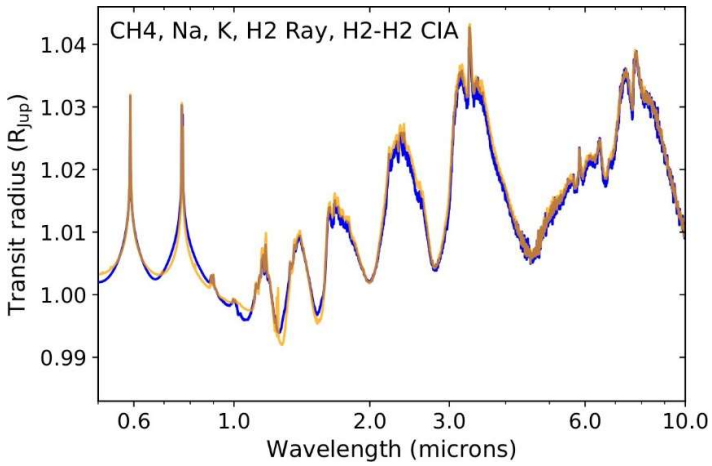


Initial atmospheric mass fractions as a function of planetary semi- major axis for the considered sample of planets.

A NEW MODELLING FRAMEWORK FOR EXOPLANETARY ATMOSPHERES

Pyrat Bay is an open-source framework developed at IWF for exoplanet atmospheric modeling, spectral synthesis, and Bayesian retrieval. The modular design of the code allows users to generate atmospheric 1D parametric models of the temperature, abundances, and altitude profiles; sample molecular cross sections from various databases; compute emission or transmission spectra considering a range of different opacities; and perform Markov chain Monte Carlo atmospheric retrievals for a given transit or eclipse dataset. The Pyrat Bay framework has been benchmarked by reproducing line-by-line sampling of molecular databases, by reproducing transmission and emission spectra produced by other comparable tools, and by accurately retrieving the atmospheric properties of simulated transmission and emission observations generated by other codes. Pyrat Bay has finally been used to perform a retrieval analysis of a population of transiting exoplanets observed by the *Hubble Space Telescope*. Consistently with previous analyses, the results indicate that the data do not enable one to distinguish whether a muted water feature is caused by clouds, high atmospheric metallicity, or low water abundance. In contrast to other comparable tools, Pyrat Bay is self- installing and it is very well documented and tested to provide maximum accessibility to the community and long-term development stability.

Cubillos & Blecic, MNRAS, 505, 2657, 2021.

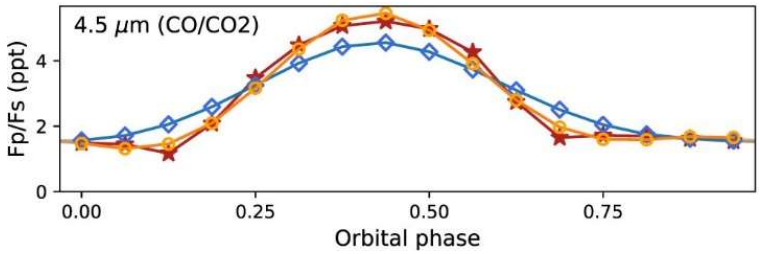


Comparison between transmission spectra computed with Pyrat Bay (blue) and petitRADTRANS (orange) considering cross sectionfor CH_4, Na, K, H_2 Rayleigh scattering, and H_2–H_2 continuum induced absorption.

LONGITUDINALLY RESOLVED SPECTRAL RETRIEVAL OF WASP-43B

Thermal phase variations of short-period planets indicate that they are not spherically symmetric: day- to-night temperature contrasts range from hundreds to thousands of degrees, rivaling their vertical temperaturecontrasts. Nonetheless, the emergent spectra of short- period planets have typically been fit using one-dimensional (1D) spectral retrieval codes that only account for vertical temperature gradients. Exoplanetresearchers have recently introduced multi-dimensional retrieval schemes for interpreting the spectra of short- period planets, but these codes are necessarily more complex and computationally expensive than their1D counterparts. An alternative has been developed, namely phase-dependent spectral observations are inverted to produce longitudinally resolved spectra that can then be fitted using standard 1D spectral retrieval codes. This scheme has been successfully tested on the iconic phase-resolved spectra of WASP-43b and on simulated observations using the open-source Pyrat Bay1D spectral retrieval framework. Furthermore, for this study the model complexity of the simulations has been taken one step further over previous studies by allowing for longitudinal variations in composition, in addition to temperature. The key result is that performing 1D spectral retrieval on longitudinally resolved spectra is more accurate than applying 1D spectral retrieval codes to disk-integrated emission spectra, despite being identical in terms of computational load.

Cubillos et al., Astrophys. J., 915, 45, 2021.

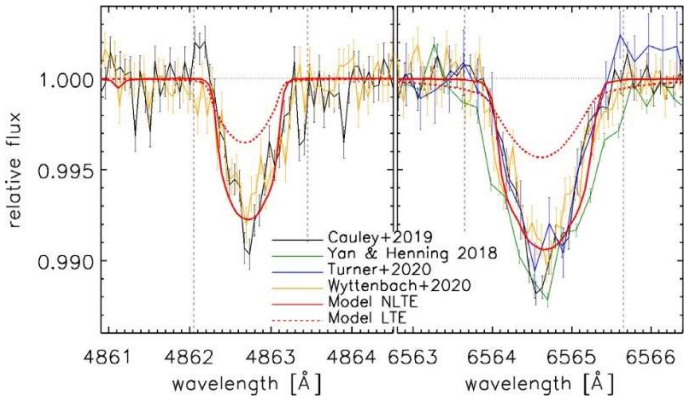


Comparison between the model flux ratios computed locally (red), disk-integrated (blue), and spatially resolved (orange) at 4.5 μm, where the spectrum is dominated by CO and CO_2 absorption. The longitudinally resolved dataset matches much better the phase curve assuming local properties at each phase than the disk- integrated dataset.

NON-LOCAL THERMODYNAMIC EQUILIBRIUM EFFECTS IN THE ATMOSPHERE OF KELT-9B

KELT-9b is the hottest exoplanet known to date. Both observational and theoretical results indicate that its atmospheric temperature in the main line formation region is a few thousand degrees higher than predicted by self-consistent models. With this in mind, the impact of non-local thermodynamic equilibrium (NLTE) effects on the atmospheric temperature profile has been tested. The Cloudy NLTE radiative transfer code has been employed to self-consistently compute the atmospheric temperature structure obtaining a profile about 2000 K hotter than obtained assuming local thermodynamic equilibrium (LTE). In particular, the higher temperature is driven principally by NLTE effects modifying the Fe and Mg level populations, affecting the thermal balance. Cloudy has been also used to generate synthetic transmission spectra finding that the NLTE model generally produces stronger absorption lines than the LTE model (up to 30%), which is largest in the ultraviolet. Furthermore, the NLTE synthetic transmission spectrum fits significantly better the observed Hα and Hβ Balmer line profiles. It can thus be used to guide future observations aiming at detecting features in the planet's transmission spectrum. Finally, these results call for checking whether NLTE effects have a similar impact also on the planetary atmospheres of cooler planets.

Fossati et al., Astron. Astrophys., 653, A52, 2021.



Observed transmission spectra of the Hα (right) and Hβ (left) Balmer lines presented in the literature compared to LTE and NLTE synthetic transmission spectra.

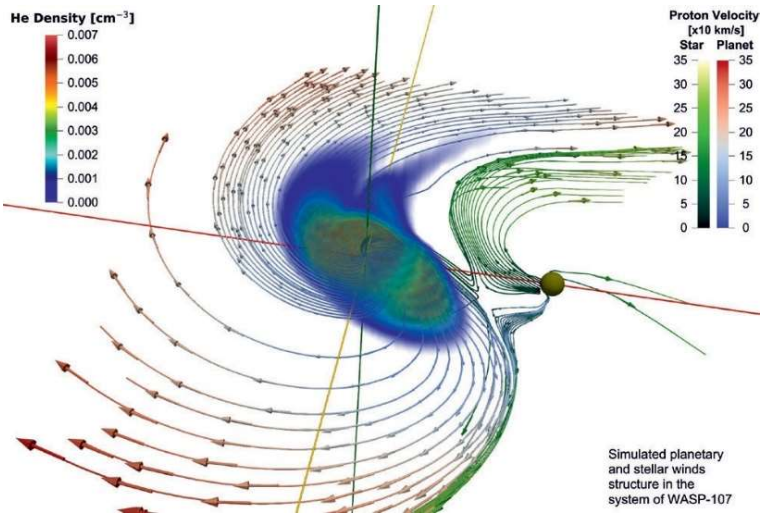
PROBING MAGNETIC FIELDS AND COMPOSITION OF ESCAPING EXOPLANETARY ATMOSPHERES

The global 3D self-consistent (M)HD modelling of the expanding upper atmospheres of WASP-107b and HD209458b interacting with stellar winds enabled simulation of their complex dynamic environments and the related observed transit absorption features of HI (Lyα), OI (1306 Å), CII (1337 Å), and HeI (10830 Å).

For WASP-107b, the observed HeI (10830 Å) absorption profiles were reproduced within the uncertainties, and the stellar high-energy flux was constrained to realistic values of 6 - 10 erg cm^{-2} s^{-1} at 1 au. The simulations revealed a solar helium abundance at the level of He/H = 0.075 - 0.15. The performed modelling demonstrates the importance of radiation pressure acting on the HeI atoms, as well as electron and atom impact processes, which were shown to influence the absorption profiles. For HD209458b, particular attention has been paid to the structure and behavior of the planetary magnetosphere and possible influence of the planetary magnetic field on the dynamics of the escaping upper atmosphere and the measured transit absorption profiles. Fitting of the simulation results to observations enabled constraining the

stellar high-energy flux and helium abundance to 10 erg cm^{-2} s^{-1} at 1 au and He/H ≈ 0.02, respectively, as well as setting an upper limit for the magnetic dipole moment of HD209458b. The latter appeared to be less than 6% of the Jovian value.

Khodachenko et al., MNRAS, 503, L23, 2021. Khodachenko et al., MNRAS, 507, 3626, 2021.

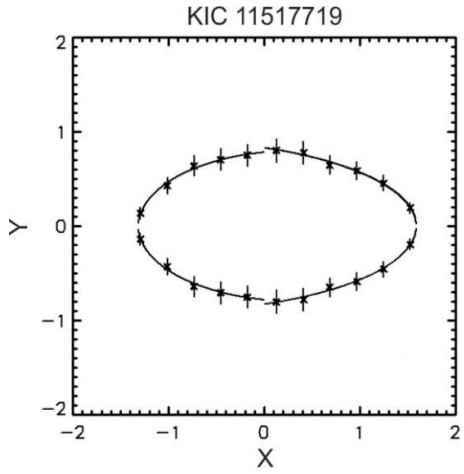


Helium 3D distribution in the atmosphere of WASP-107b. The planet is at the center of the coordinate system and moves anti- clockwise relative the star shown on the right.

PECULIAR NON-CIRCULAR SHADOWS OF SOME HOT JUPITERS FROM TRANSIT LIGHT-CURVES

The transit parameters provided by the Kepler mission enabled to look for photometric manifestations of non-spherical obscuring matter (e.g., exorings, dusts clouds, etc.) for a number of systems. Prior to this, the exoplanet parameters have been derived by fitting their transit light-curves (TLCs) assuming spherical planets and semi-major axes (calculated according to Kepler's third law), stellar radii and surface gravities. In the most typical case of a spherical transiting planet, the latter assumption does not break the consistency of the calculations. However, in the case of a non-spherical transiting planet and its non-circular shadow, the actual (i.e., obtained from the TLCs) value of the orbital semi- major axis may be inconsistent with respect to the rest of the transit parameters. The goal was to search for such inconsistencies, which manifest as differences between simulated and observed transit durations. A set of 21 hot Jupiters and 2 hot Neptunes have been investigated. The majority presented consistent transit parameters and quasi-circular shadows. However, seven objects were classified as outliers. Among them, Kepler-45b and Kepler-840b are the most intriguing because of the significant inconsistency of the parameter sets and the reconstructed elongated shadows. These finds could be interpreted in terms of dusty or aerosol contamination in the upper atmosphere or exorings.

Arkhypov et al., Astron. Astrophys., 646, A136, 2021.



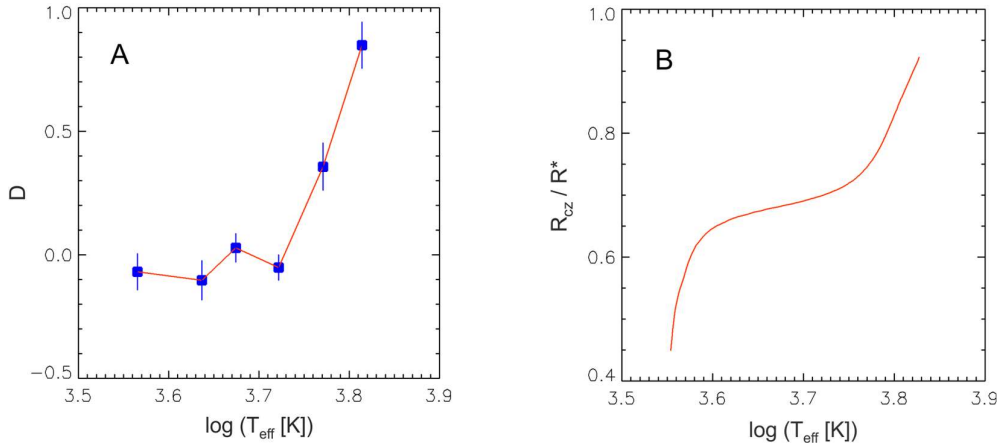
Reconstruction of elongated shadows for Kepler-840b orbiting KIC 11517719.

PROPERTIES OF RIEGER-TYPE CYCLES OF STELLAR ACTIVITY

The different driving mechanisms of Rieger cycles (a 154-day periodicity of solar flare occurrence) need verification in non-solar-like stars. Rieger-type cycles (RTCs) variability has been studied for 1726 main- sequence stars spanning a range of temperatures (T_{eff}) and rotation periods (P) employing Kepler light curves. Two kinds of the RTCs were found: 1) activity cycles with periods independent on the stellar rotation (for stars with $T_{eff} < 5500$ K) and 2) activity cycles with periods proportional to P (for stars with $T_{eff} > 6300$ K).

These two types of RTCs can be driven by Kelvin and Rossby waves, respectively. Rossby wave-driven RTCs correlate with the location of the tachocline, confirming the theoretical predictions. The Kelvin wave-driven RTCs do not show this correlation. Both types of wave drivers appear to coexist, leading to a joint modulation of the magnetic flux tubes, and the corresponding behavior of the activity period.

Arkhypov & Khodachenko, Astron. Astrophys., 651, A28, 2021.



Change in power index D with varying log of stellar effective temperature T_{eff} (panel A) in comparison with the location of tachocline (panel B), revealed by the models of young (0.5 Gyr) main sequence stars with the solar abundance of metals.

IV - SATELLITE LASER RANGING

In addition to routinely tracking more than 150 targets, which are equipped with laser retro-reflectors, the Satellite Laser Ranging (SLR) station of IWF is working on various international projects. Within the ESA tumbling motion project a large number of rotating space debris objects were characterized with respect to their tumbling behavior. Furthermore, range measurements to a spare *Galileo* panel were conducted at a remote location. Within a Stare and Chase experiment orbit predictions were improved during space debris tracking.

A new MHz laser has been installed at Graz SLR station and hardware and software is currently being upgraded to progress towards routine operation.

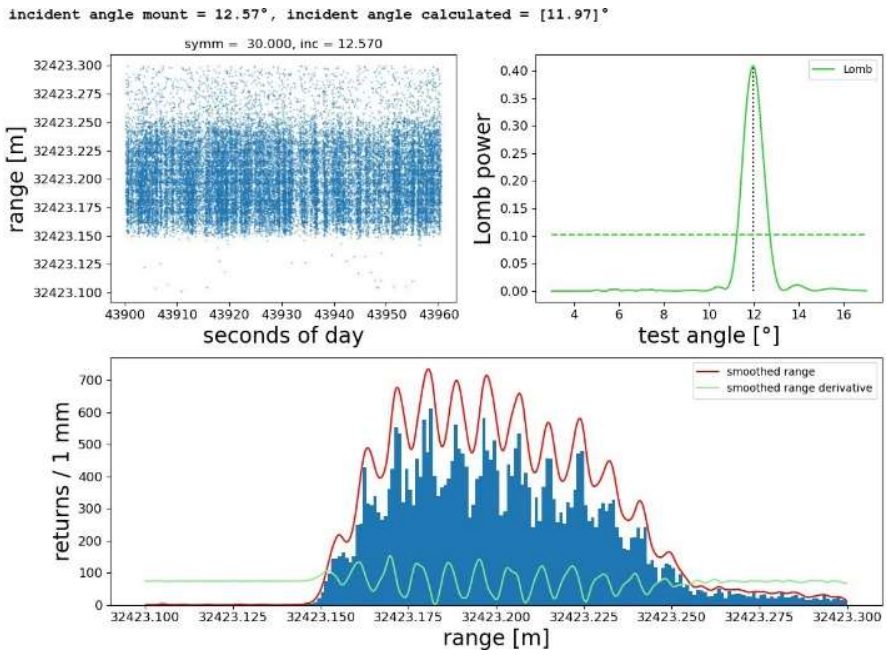
GALILEO ATTITUDE DETERMINATION

A *Galileo* in orbit validation (IOV) retro-reflector array identical to the panels mounted on the first four *Galileo* satellites was provided by ESA for laser ranging measurements at a remote location at 32.4 km distance with direct sight to the SLR station. A method is developed to measure the incidence angle on the panel by analyzing high repetition rate satellite laser ranging residuals. The panel was attached to an astronomical mount which allows the alignment of the geometrical axes to the *Galileo* panel with respect to the mount rotation axes (see figure below).

The *Galileo* IOV panel fixed on an astronomical mount and placed at a remote location located 32 km away from the SLR station Graz on a hill of 1200 m altitude.

By tilting the panel using the polar alignment screws of the mount, the panel was adjusted to point to the observatory (located 1.2° below the remote location). Fine adjustment of the panel reference orientation was done by optimizing the laser returns reflected by adjustment mirrors. A software tool was developed by which the mount/panel was rotated automatically into arbitrary positions corresponding to the desired incident/symmetry angle conditions. At the same time the nominal mount position with respect to the reference position was stored and time-tagged to be able to correlate the measurements to the laser ranging results which are also time-tagged.

Due to the hexagonal arrangement of the retro- reflectors, at given rotation angles, different rows of the retro-reflectors appear at constant distances relative to the observer. Symmetry conditions at 0°, 30°, 60° and 90° azimuthal rotation are most obvious but also intermediate symmetries exist. From the mm- precision range measurements to the panel and the statistical distribution of the returns range differences between rows down to 7 mm can be detected. Knowing the geometry of the panel, the incident angle of the laser beam on the panel can be calculated from the measurements. Data sheets are generated to analyze and visualize the results (see figure below). A range- histogram distribution (blue), a smoothed range dataset and the first derivative is calculated. The 12 peaks in the data result from the different rows at 30° azimuthal rotation while tilting the panel by 12°, corresponding to typical incident angle conditions on navigation satellites. By applying a Lomb analysis to the derivative, a most probable incident angle was derived. From the results it was concluded that the method allows to calculate the incident angle for 30° or 90° azimuthal rotation with an accuracy of 0.1°, independent of the distance to the target. Within an extensive tracking campaign approx. 100 symmetry passes of 24 different *Galileo* satellites were measured. The calculated incident angles of the *Galileo* panels will be compared to telemetry data of the respective *Galileo* spacecraft.



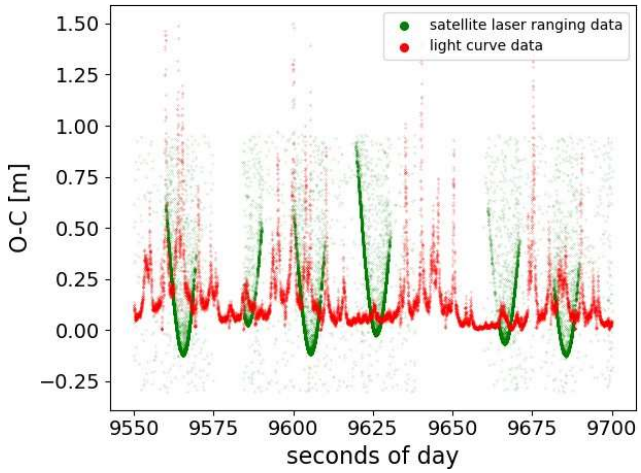
Data sheet for 30° symmetry orientation and 12° laser beam incident angle.

TUMBLING MOTION OF SPACE DEBRIS

Within the framework of the ESA project "Tumbling motion assessment for space debris objects" more than 20 different tumbling rocket bodies or defunct satellites are monitored and analyzed with respect to their tumbling behavior.

The Graz SLR station contributes by performing measurements with different measurement techniques. Besides satellite laser ranging to satellites equipped with retro-reflectors and space debris laser ranging relying on diffuse reflections of uncooperative targets, single photon light curves are recorded simultaneously. In addition to Graz' measurements, the Astronomical Institute of the University Bern gathers optical light curves, while the Fraunhofer Institute for High Frequency Physics and Radar Techniques in Wachtberg, Germany, conducts imaging radar and radar cross section measurements.

The "spin-up" of the defunct ocean topographic satellite *Jason 2* (NORAD ID: 33105) was discovered by the Graz SLR station to have occurred at the end of July 2020. Since then the tumbling behavior was monitored by IWF so far collecting 80 light curves and 60 satellite laser ranging datasets in the year 2021. Simultaneous light curve and satellite laser ranging measurements clearly show periodic signatures in both datasets (see figure). Due to the tumbling motion every 20 seconds the retro- reflector pyramid turns towards the observer and reaches its closest approach. Within one full rotation, the acceptance cone of the pyramid temporarily moves outside the observer's field of view and a gap in the SLR dataset occurs. The peaks in the light curve corresponds to sunlight reflections of the individual surfaces of the satellite and aligns well with the laser ranging measurements.

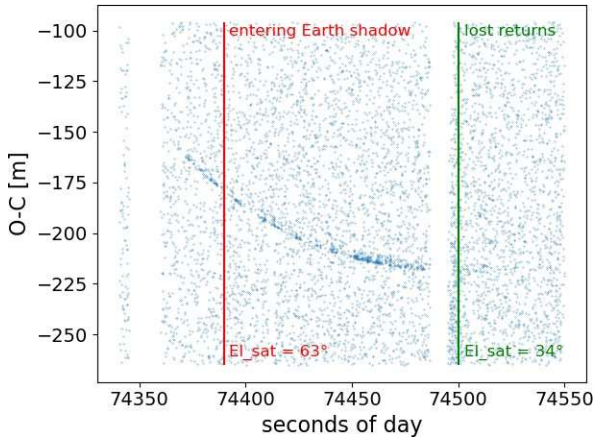


Simultaneous satellite laser ranging and light curve measurements to the defunct satellite Jason 2, clearly highlighting the tumbling behavior.

STARE AND CHASE TO SPACE DEBRIS

Together with the Comenius University in Bratislava a "Stare and Chase" tracking experiment was conducted within the project "Improvement of European capabilities for LEO objects tracking with optical passive sensors". The University of Bratislava tracked different space debris objects, acquiring a series of images (staring). From that the pointing direction was calculated via plate solving (analyzing the stellar background on the image). The observations were immediately used to improve two line element (TLE) predictions by optimizing the right ascension of the ascending node and the mean anomaly at the reference epoch. The improved TLE predictions were then transferred to the IWF server. Simultaneously, Graz started space debris laser ranging by using the non-optimized TLE prediction. As soon as Bratislava confirmed that improving the predictions was successful, Graz downloaded the predictions, implemented them into the internal tracking system and continued tracking with the improved TLE predictions.

As typical LEO satellites pass over the observing station within only a few minutes the joint experiment had to be optimized regarding coordination. The big advantage of SLR is that due to the highly accurate laser ranging data, different sets of prediction can be evaluated regarding accuracy. Using Graz SLR measurements it was possible to prove that the time bias of the predictions - the time a space object is ahead or behind its prediction – could be reduced by a factor of 4. Furthermore, using these improved predictions it was possible to conduct "blind tracking" of an upper stage SL-8 rocket body (NORAD: 7009) - without visual feedback to center the object in the field of view of the telescope (see figure).



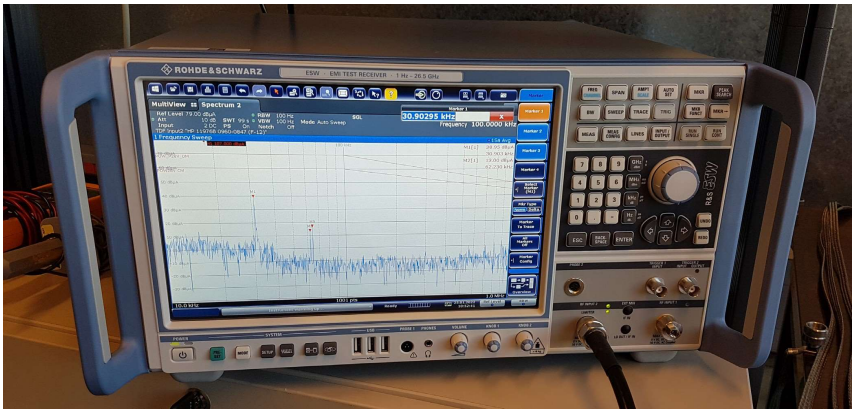
Blind tracking of an upper stage rocket body using an improved set of TLE predictions. The upper stage entered Earth shadow at an elevation of 63°. For more than 100 seconds returns could be detected afterwards.

V - NEW DEVELOPMENTS

One possible aspect to reduce costs of space exploration and hence allowing for more frequent missions is to reduce the spacecraft size and consequently the launch masses. Scientific instruments also have to decrease their resource requirements such as volume, mass, and power, but at the same time achieve at least the same performance as heritage instruments. Therefore, the development of new instrument technologies is essential for competitive and excellent space research.

NEXT GENERATION ASPOC

For future science missions, active spacecraft potential control down to < 10 V is crucial to be able to operate sensitive scientific payloads. This does not only apply to large and medium-sized spacecraft, but also to micro- and nano-spacecraft, such as CubeSats. IWF, together with FOTEC, started a two-year technology study with the goal to develop a miniaturized version (50% power, 40% mass) of the *ASPOC* instruments built for NASA's *MMS* mission, which, seven years after launch, are still operating flawlessly.



ASPOC-NG electromagnetic compatibility (EMC) test with the new EMI Test Receiver (© OeAW/IWF/Jeszenszky).

In 2021, IWF entered the assembly and test phase of the *next generation ASPOC (ASPOC-NG)* instrument. After the integration of the processor and power supply boards into the electronics box, IWF fine-tuned a specific filter module, which is necessary to keep the electromagnetic interference at a level suitable for space missions. The box assembly was followed by a functional verification of the instrument with the ion and electron test modules provided by FOTEC. In parallel, IWF continued the setup of the facilities for the unit level tests.

Concerning the onboard software for operating the unit, IWF ported the relevant parts of the *MMS* flight S/W to *ASPOC-NG*, whereby the hardware-specific abstraction layers were adapted to support the *ASPOC-NG* setup. IWF conducted the respective S/W acceptance test by means of a dedicated emitter emulation board, which allowed for simulating various emitter conditions to achieve 100% code coverage.

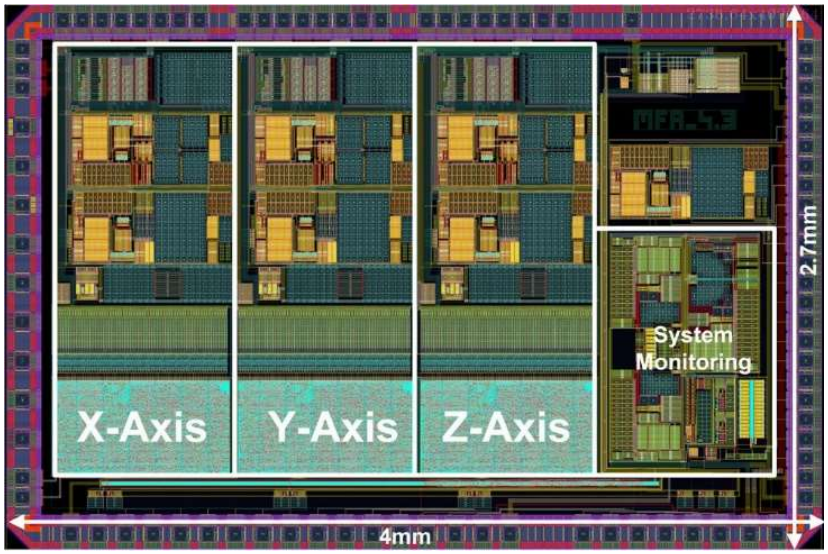
After successfully passing the test board review with ESA in July, IWF performed the unit level test with the electronics box, while FOTEC tested the prototype emitter module. ESA carefully examined the test results in the following system test readiness review, which finally resulted in the go-ahead for the last project phase.

In October, IWF handed over the *ASPOC-NG* electronics box to FOTEC for the integration of the emitter module and execution of the system level test. With support from IWF, the test activities were completed successfully right before the end of the year.

MAGNETOMETER FRONT-END ASIC

IWF and the Institute of Electronics of the Graz University of Technology (TUG) are collaborating on the next generation of the space proven Magnetometer Front-end ASIC (MFA). It features the readout electronics for magnetic field sensors which is optimized in terms of size and power consumption. The next generation Application Specific Integrated Circuit (ASIC) will overcome dynamic range limitations and be space qualified in the frame of the *FORSESAIL* mission.

Based on the evaluation results from two earlier test chips, which have contained just a single axis of the required feedback path including a high performance digital-to-analog converter (DAC), a first triple-axes feedback chip has been designed, simulated, routed and manufactured in 2021. XFAB Silicon Foundries was selected as chip manufacture because of the excellent noise performance of the transistor elements which come with a well-defined radiation characterization.



Layout of the designed chip. It contains three feedback paths including the proposed current source to compensate the ambient magnetic field within a fluxgate sensor.

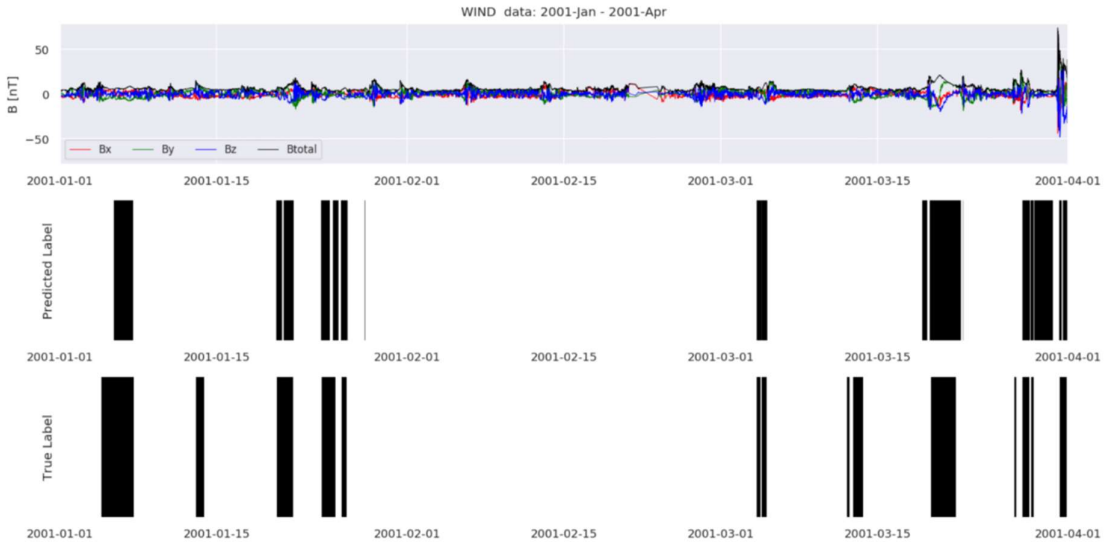
Each axis consists of a high-resolution current-steering DAC, a signal conditioning block and a fully differential current source to drive the feedback coil. The proposed current source offers an increased dynamic range and a very good low-noise performance. This results in a signal-to-noise ratio of more than 104 dB for a bandwidth of 512 Hz, requiring only a supply voltage of 3.3 V. The current source is capable of driving highly linear currents of more than 18 mA into the fluxgate sensors with an inductance of up to 9 mH while consuming 70 mW of power. An interface based on the I2S protocol was implemented for communication. Moreover, low voltage differential signaling receivers have been employed to keep the noise level low. A system monitoring block was also placed on chip to keep track of necessary environmental conditions.

The designed front-end occupies a total area of less than 11 mm^2.

MACHINE LEARNING ACTIVITIES

Funded through the European Commission's Horizon 2020 program, Europlanet 2024 Research Infrastructure (RI) provides free access to planetary simulation and analysis facilities, data services and tools, a ground- based observational network and program of community support activities. The University of Kent, UK, leads the Europlanet 2024 RI consortium, which has 57 beneficiary institutions from 25 countries in Europe and around the world, with a further 44 affiliated partners. The work package Machine Learning (ML) Solutions for Data Analysis and Exploitation in Planetary Science, led by IWF, develops ML powered data analysis and exploitation tools optimized for planetary science and integrates expert knowledge on ML into the planetary community. The goal is to build a multi-purpose toolset for ML-based data analysis that will be applicable to a range of scientific research questions in planetary science with minor or easily achievable customization efforts.

The scientific research questions range from the automatic detection of various features (e.g., bow shock and magnetopause crossings around Mercury and Earth, interplanetary mass ejections in in-situ solar wind observations - see figure - or surface features on Mars) to different classification problems (e.g., surface composition on Mercury, plasma wave emissions, or mineral identification).



Comparison of predicted and true labels for Integrated Computational Materials Engineering (ICME) detections in *Wind* data between January and April 2001. Upper panel: Magnetic field measurements by *Wind*. Middle panel: Prediction of ICMEs (black areas). Lower panel: Observed ICMEs (black areas).

VI - PUBLIC OUTREACH

IWF is actively engaged in science education and public outreach. Due to Covid-19, another year passed without visitors being guided through the labs. However, IWF continued its mission to find new ways to bring science to the public.

From 9 April to 31 October, the "Steiermark Schau" showed Styria's past, present, and future. IWF participated in the exhibition in the Folk Life Museum, where visitors could look through a microscope and discover the Styrian panther, "hidden" on a magnetometer microchip designed for NASA's *MMS* mission.

From 30 September to 4 October, the institute was part of SpaceTech 2021, a special exhibition at the Graz Autumn Fair. IWF presented its participation in the current ESA missions *CHEOPS, BepiColombo,* and *Solar Orbiter*.

IWF team at the pre-opening of SpaceTech 2021, organized on 29 September with and for representatives from industry, research and politics (© Fritz Höllerbauer).

On 2 October, IWF was invited to participate in the Austrian "Lange Nacht der Museen". Günter Kargl and Sunny Laddha presented the *CoPhyLab* project at the Vienna Museum of Science and Technology.

Throughout the year, several (online) public lectures were given. At Antares-NOe Volkssternwarte Günter Kargl reported news from NASA's *InSight* mission and Rumi Nakamura gave an overview of plasma in space. At URANIA Steiermark in Graz Luca Fossati talked about habitable worlds in the universe and Wolfgang Voller about the autumn sky. In the frame of the science program of Wiener Volkshochschulen, Günter Kargl presented the possibilities of a holiday in space and Luca Fossati explained how *ARIEL* will investigate exoplanetary atmospheres.

Luca Fossati and Günter Kargl participated in the Science Academy Niederösterreich with a workshop on satellite design. For the lecture series "Facetten der Physik" of University of Graz Günter Kargl explained the different Mars landers. As Young Science Ambassadors of OeAD, Günter Kargl and Christian Möstl held several lectures for school classes allover Austria.

Following the OeAW "Young Science Initiative", IWF participates in the project "Akademie im Klassenzimmer". Luca Fossati and Alexandra Scherr visited the Volksschule Krems-Stein, where they answered questions of the school kids ranging from aliens, along black holes to exoplanets.

After all their questions had been answered, the kids of VS Krems-Stein had fun launching rockets in the schoolyard (© OeAW/IWF/Scherr).

In the frame of OeAW's Science Bites series, Luca Fossati explained how to search for extraterrestrial life and Günter Kargl talked about how to develop instruments for missions to Mars and other planets.

Volume 8 of the OeAW comics series "Akademics" takes young readers on an exciting journey through time and the fascinating world of stars and planets to learn how Johannes Kepler unravelled their secrets some 400 years ago. Researchers from IWF acted as "scientific advisors" (www.oeaw.ac.at/akademics/sternenkunde).

Topics discussed in the space blog of the Austrian newspaper "Der Standard" were inhospitable exoplanets, nitrogen atmospheres as the basis for life, the Venus flybys of *Solar Orbiter* and *BepiColombo,* and auroral beads.

In the Servus TV show "P.M. Wissen" Magda Delva explained the differences between the Earth and its "twin" Venus. In the ORF youth magazine "Fanny's Friday Doku", Christian Möstl and Luca Fossati tried to answer the question of all questions: Are we alone inthe universe? Finally, *Rosetta's* atomic force microscope *MIDAS* was one of the main actors in "Museum AHA", ORF's knowledge show for kids by and with Thomas Brezina.

There is a lot to discover in the exhibition MISSION POSSIBLE! (© Universalmuseum Joanneum/J.J. Kucek).

End of last year, IWF started to celebrate its 50th birthday with MISSION POSSIBLE!, a hands-on special exhibition at CoSA - Center of Science Activities in Graz. In cooperation with the Children's Museum FRida&freD, a 30-meter long comic was created, on which the activities of the institute are vividly depicted. Original space instruments from IWF's 50-year history are integrated into the comic and have to be discovered. This way the visitors find out how a space mission is developed while they participate in a fictitious mission to Enceladus, one of Saturn's largest moons. The exhibition opened on 18 December 2021 and can be visited until 11 September 2022.

VII - LAST BUT NOT LEAST

On 1 January 2001 Wolfgang Baumjohann took over the management of the Department of Experimental Space Research and became the institute's director on 1 April 2004. He has led IWF for exactly 6391 days, which makeshim the longest serving IWF director. During these 17.5 years he made the institute fit for the new millennium.

Baumjohann led the institute with very clear ideas, adapted and partly reoriented it. The highest goals were always scientific excellence and a clear connection between science and instrumentation as well as a good understanding with the central administration in Vienna. The number of publications has quadrupled to around 170 per year. The citation rate has increased almost tenfold to 7100 per year. In 2011, an independent evaluation committee rated the institute as "outstanding" and "certainly at the top of its field for an institute of this size". IWF's Scientific Advisory Board described the institute repeatedly as "unique in Austria, certainly amongst the 5% best institutions of its kind internationally" and "playing a leading role in Europe and world-wide in very exciting research fields, suchas space plasma physics, (exo-)planet atmospheres and star-planet-interactions".

Werner Magnes, Christiane Helling, Wolfgang Baumjohann, Julia Fröhlich (OeAW Vienna), and Hans Sünkel during the handover ceremony at IWF on 1 October 2021 (© OeAW/IWF/Scherr).

Baumjohann has received numerous honors, which impressively demonstrate the value of his work. He is member of OeAW, the German National Academy of Sciences Leopoldina (Executive Council), the Academia Europaea, the International Academy of Astronautics, and the European Academies Science Advisory Council, Fellow of the American Geophysical Union, recipient of the Austrian Cross of Honor for Science and Art, First Class and the Styrian Medal of Honor for Science, Research and Arts, the Cardinal Innitzer Recognition Price, and was named Austrian Scientist of the Year 2014.

Baumjohann's scientific legacy includes more than 600 papers in scientific journals and four books. He is one of the most cited space scientists. Since the beginning, he was available at and for the institute almost continuously and exclusively; his commitment was enormous. During his directorship, 27 space-born instruments were designed, built, tested, launched and successfully operated in space; ten of them led by IWF with Baumjohann as Principal Investigator of the magnetometer aboard the Japanese *MMO* spacecraft of the *BepiColombo* mission.

Baumjohann has very successfully led and further developed the institute to its current high standard. IWF owes him a great debt of gratitude and wishes him many healthy years in retirement. We look forward to future, fruitful discussions and a joint exchange of ideas.

CONTACT

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3.2 AAC - Aerospace & Advanced Composites GmbH (AAC as spin-off from AIT)

The ***Aerospace & Advanced Composites GmbH (AAC) was founded in 2010*** as a spin-off from the Austrian Institute of Technology (AIT). AAC is a private company (SME) that provides research, development and engineering capabilities in materials technology and testing for industrial applications with a focus in aeronautics and space.

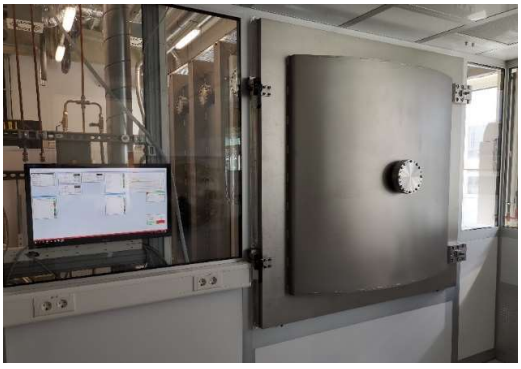
AAC integrates the staff and the facilities of AIT's former Aerospace Department and continues its aerospace research started in 1998 with the ESA-certified **Space Materials Testhouse** under ESTEC frame contract. AAC is coordinator of European and national research cooperation projects in aeronautics and space.

With its 24 employees, comprise an interdisciplinary AAC background in physics, chemistry, materials science, polymer engineering and mechanical and electrical engineering. More than one hundred research projects have been successfully concluded in the past 30 years. Based on the successful development in aerospace, AAC has extended its business to other industrial applications and will focus on three major areas:

- Polymer Composites
- Inorganic Composites
- Materials & Component Testhouse

In 2012 AAC moved to it's new premises in Wiener Neustadt, which is based on strategic decision: in this area several new research entities and one Applied University are located which provide for AAC a more prosperous growth. The infrastructure covers one building with labs and offices and a hall for heavy test equipment and polymer composite prototyping manufacturing. The increasing number of TVAC-services offered to space industry, made it reasonable to extended the liquid nitrogen supply with a nicely visible tank.

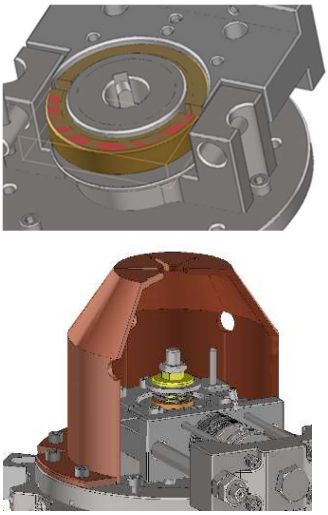
AAC facilities at TFZ in Wiener Neustadt



New "XVC" in Clean room Class 7

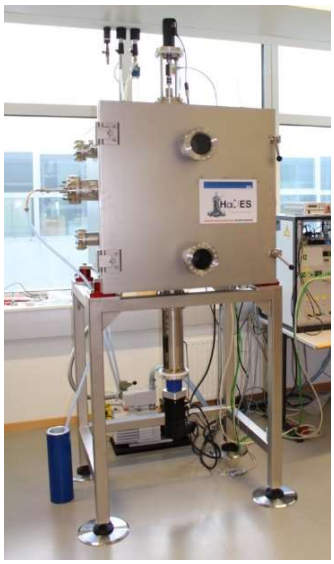
Journal bearing – Testing under TVAC

In 2021 AAC designed and built a new insert to its HADES-test chamber that enables to test journal bearings. Bushes with diameters in range from 40-50mm and width of ~15mm can be tested in ambient conditions and in thermal vacuum in a range of -80°C to 100 °C. The actuator offers torques up to 50Nm, which is also the range of measurement. The radial loading can be monitored with a load cell in excess of 10kN. In frame of a customer project two types of solid lubricated bushings were tested from -50°C up to +70°C under small oscillating motion.



New setup for journal bearings up to 50kN torque

Mechanisms that operate at low temperatures (MREP)

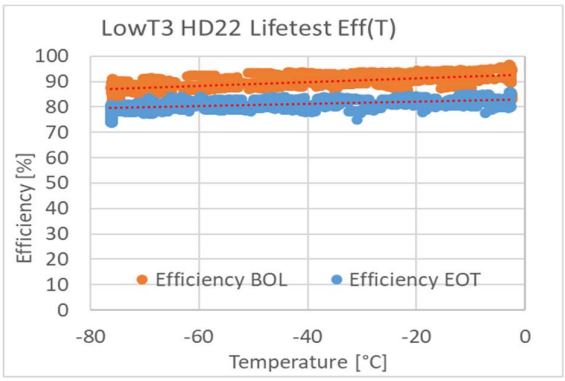


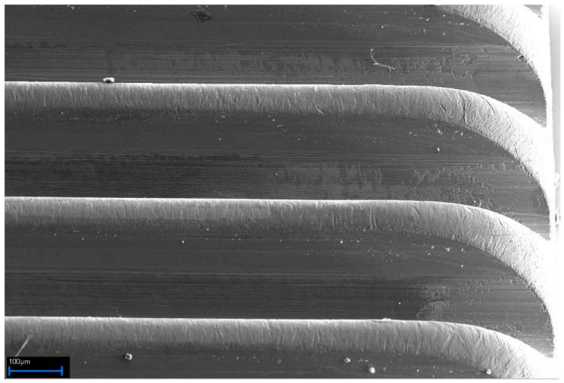
Test device HaDES

An ASAP-project under bi-lateral funding of Austria (FFG) and Germany (DLR) aimed at enhancement of torque and lifetime for solid lubricated Harmonic Drive ® gears (HDs). Together with the manufacturer Harmonic Drive SE (DE) and an Austrian supplier for heat treatments a new nitriding process was developed for PH-steels used for gears in space. The main problem was that standard nitriding processes causes formation of so called “white etching layers”, which are on PH-steels very brittle. They peel off together with the solid lubricant layer on top, which does not enable long life. The new process aims at avoiding that layer and just improving the subsurface hardness to provide a better mechanical support of the tribologically stressed surface.

In 2021 an MREP project aiming to identify a lubrication concept for “Mechanisms working at low temperatures” could be finalised taking benefit of this new process. A Harmonic Drive ® gear was equipped with newly nitrided parts, and tribological interfaces were lubricated partly with grease and solid lubricant. Before this innovation, life tests over 63.000 output revolutions under permanent thermal cycling between -80°C and -5°C led to early failures or in best case severe wear and efficiencies below 40%.

With this new components, the ***life test could be finalised without visible wear***. Moreover, at end of the test the efficiency was still over 80% over the full temperature range !





Efficiency at end of life test:

80% over full temperature range !

Toothing with nitrided surfaces after life test:

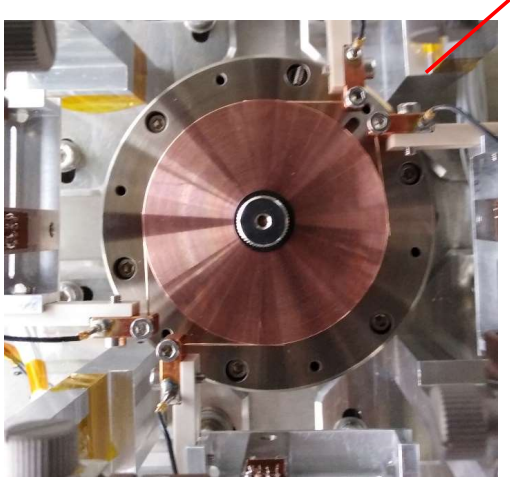
No wear at all !

Slipring - test rig "Salotte 2"

In 2021 the ESA project "ECM" was finally finished. – More than 110 tests on sliprings were done and new European materials for sliprings were identified, which could potentially replace the actual used standard material (non-European).

The facility was then used for another ESA project for root cause investigation of slipring failure. Within this project the facility was adapted to take up sliprings of a design, which is typical for flight hardware. The accuracy of the measurement systems has been improved and the software was adapted to simulate and record potential failures of a slipring.

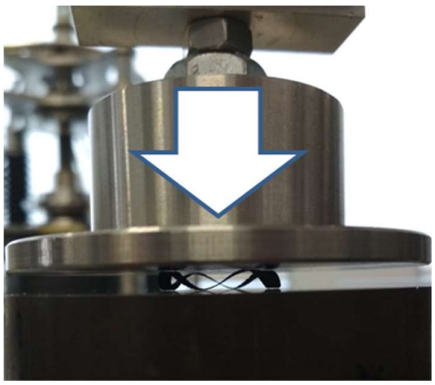
Never before gained correlations between friction forces and resistance in a sliding electrical contact have been found las year with the AAC test rig. Several mal functions in flight hardware could be explained with the newly gained data from those tests.AAC is looking forward to further test sliprings, help to improve the insight of the slipring root cause failure mechanism and become Europeans number 1 tribo-electrical test laboratory.



Test device for slip rings

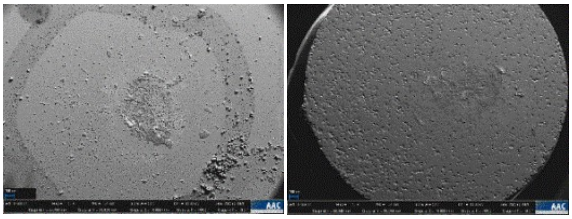
Metallic glasses – Testing on material level for applications

Bulk metallic glasses (BMG) are still an exotic kind of material. In fact, they are rapidly cooled metallic alloys. The rapid cooling “freezes” the amorphous state of the liquid and hinders crystallisation. The performance of this completely different microstructure is of interest. RHP as contractor to ESA was responsible for developing manufacturing process. AAC acting as subcontract to RHP assisted in material characterisation but also performed basic application tests. As first applications, springs and contact surfaces for hold-down and release mechanisms (HDRM) were selected. At first RHP machined wave springs, which showed in compression test at AAC reasonable elasticity. RHP also machined pins and disc which were used by AAC to investigate friction and cold welding. BMG in contact to itself showed surprisingly low adhesion in fretting tests done in launch conditions: the fretting motion was started in air, continued in low and high vacuum for a total of 15 minutes. After that, no adhesion was measured for a certain combination of BMGs. Few tests were then extended to 1500 cycles (approx. 4h net fretting), with again no adhesion. Contact surfaces were found to show hardly any wear (which is never found for contact of two “normal” metallic alloys). Hence, bulk metallic glasses may become an interesting new option for HDRMs.



Wave spring made of metallic glass

Manufactured by RHP under



Contact surface after fretting test: Metallic glass to itself shows hardly any wear !

Sales 2021: 2.0 M€
ESA Share: 0.6 M€

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3.3 Atos Convergence Creators GmbH

Atos is the global leader in secure and decarbonized digital with a range of market-leading digital solutions along with consultancy services, digital security and decarbonization offerings made available through an end-to-end partnership approach and serving a global client base. Atos' revenue in 2021 was €11 Billion. Every day 109,000 people in 71 countries are developing and implementing innovative digital solutions that address the environmental and social challenges we all face.

A net-zero pioneer in decarbonization services and products, our commitment to the future extends to carbon-neutrality for our organization as well as our clients and partners. Together, we're a force pushing the boundaries of scientific and technological excellence to ensure that everyone can live, work and thrive sustainably in a secure information space.

Worldwide number one in managed security services, and European number one in cloud (the OneCloud Advantage), cybersecurity and high-performance computing, the Atos Group provides end-to-end orchestrated hybrid cloud, Artificial Intelligence based Big data, business applications and digital workplace solutions through its Digital Transformation Factory. Furthermore, Atos is pioneering edge server and quantum technologies with the Atos Quantum Learning machine and is leading secure and decarbonized digital.

Atos supports the digital transformation of its clients across all business sectors including healthcare, energy and utilities, telecom and media, retail and transport, public sector, defense, manufacturing, financial services and insurance.

Atos is the Worldwide Information Technology Partner for the Olympic & Paralympic Games and is an SE (Societas Europaea), listed on the Paris stock exchange.

Atos operates under the main brands Atos and Atos Syntel.

The Business Practice Atos Space & Avionics (S&A) deals with Space related business and is fully integrated into the **Atos IT Solutions and Services GmbH** in Austria, with global responsibility in the respective markets. From a global Atos Group perspective, Atos Space & Avionics is part of the Business Unit Atos Aerospace Defense and Electronics, a unit established in 2018. This business unit addresses both, the commercial as well as the defense market, which broadens our S&A addressable market and creates new opportunities in the satellite defense market.

Among the Business Practises of Atos IT Solutions and Services, Space & Avionics sets tomorrow's standards developing Atos product-based customer-specific solutions for government space and ground segments as well as industry-grade solutions for commercial satellite manufacturers and satellite operators.

Atos Space & Avionics provides products, solutions and services

- For Satellite Manufacturers
  - Electrical Ground Support Equipment (EGSE)
  - Special Check-Out Equipment (SCOE)
  - RF Suitcases
- For Satellite Control
  - Ground Segment Solutions and Integration
  - Mission Control System Maintenance and Evolution
- For Satellite Operators
  - Carrier Monitoring Systems
  - Interference Localization Systems

With over 30 years of experience, Atos Space & Avionics has successfully executed far more than 200 projects for ESA, DLR, commercial satellite operators and satellite manufacturers.

In financial year 2021 Atos Space revenues reached € 10.2 million, based on commercial space markets, ESA, Galileo, FFG and DLR activities. The share of ESA sales therein accounted for € 5.02 million.

The 2021 business was mainly focused on the following topics:

- Satellite Testing
- Satellite Control
- Satellite Communication

Satellite Testing:
Electrical Ground Support and Special Check-Out Equipment (EGSE & SCOE)

Continuing to provide valuable solutions to support our customers' Assembly, Integration and Testing (AIT) processes, Atos IT Solutions and Services provided Electrical Ground Support and Special Check-Out Equipment for various institutional and commercial European, non-European and cooperation missions.

In addition to the well-renowned Radio Frequency and Power Subsystem testing solutions from Atos, more and more projects include one of our Radio Frequency Suitcase and/or Instrument respectively Payload EGSE solutions.

The ProUST product family ("Protection and Unification in Satellite Testing"), developed over the last years, co-funded by the ESA GSTP and ARTES programmes and the National ASAP programme, and its seamless integration with standard 3rd party equipment, provides the hardware and firmware core of most of our solutions.

Strong focus was again laid on the proliferation of our EGSE solutions into the global commercial and military satellite manufacturing market. Further deliveries and upgrades to the RF communication, payload and power testing equipment for Airbus OneWeb Satellites and OHB resulted from those efforts.

In former times, satellite manufacturing was a closed workshop activity. For an adversary to come close to the satellite or tamper with the satellite, he had to overcome guards, alarm systems and physical barriers. In our times of New Space and new manufacturing processes, more and more facilities have to virtually open (e.g. for remote maintenance), are therefore accessible through the internet and thus vulnerable against cyber-attacks. Test equipment is hooked up to the satellite, which means that cyber-attacks on a satellite could potentially originate from the test equipment. A specific effort has therefore been initiated to incorporate in all our EGSE offerings cyber security protections. This project in collaboration with ESA and the European Satellite manufacturers (i.e. Atos has involved Airbus Defence and Space, Thales Alenia Space and OHB in the requirements specification) started in 2020, continued in 2021 and will end in mid-2022. This project will permit Atos to offer cyber secured by design EGSEs.

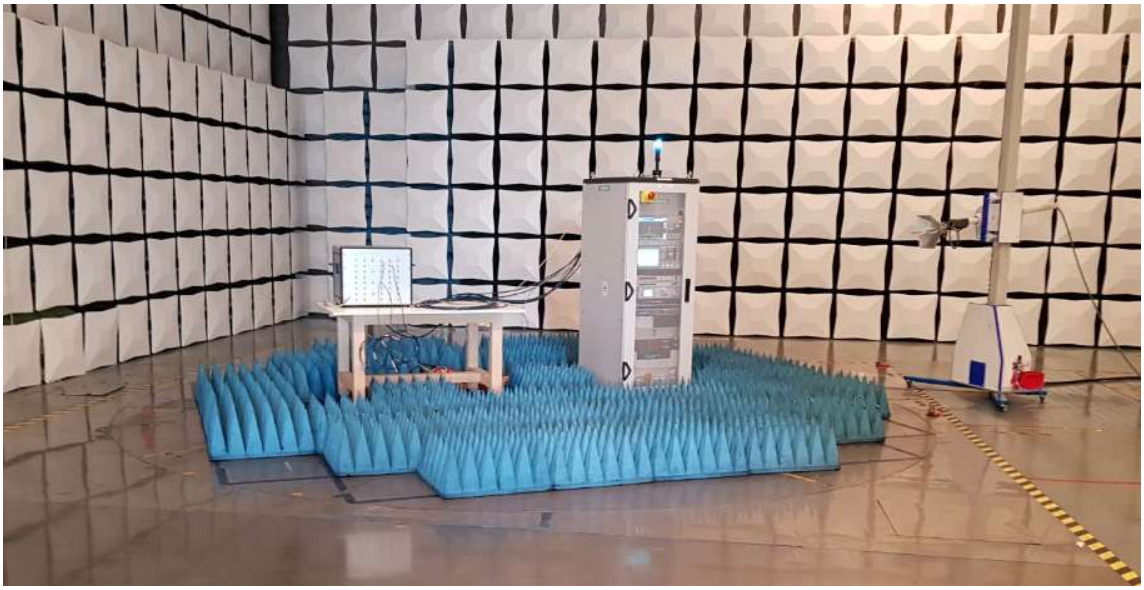
ProUST Equipment in a rack of the JUICE COMS EGSE
(Photo: Atos IT Solutions and Services)

Radio Frequency, Telemetry/Telecommand and RF Suitcase Test Systems

In 2021, the Atos RF department continued it's 'go digital' strategy. The aim is to replace expensive COTS equipment with software. In close cooperation with FFG and ESA, Atos was able to win two funding projects in this field. One is to develop an SDR modem (SDR – Software Defined Radio), the other is to develop a fully digital RF SCOE. Both together are expected to be game changers in terms of compactness and costs, and they will form the building blocks of our Ground Segment virtualization strategy. In 2021 we started the desrisking phase for the SDR modem.

Atos' mission related work in 2021 was for: OneWeb, SpaceRider, Copernicus CO2M, Earthcare, Galileo FOC + G2G, Hera, SARah, OptSat, H2Sat, C03D, Mars Sample Return, Juice, Biomass and Plato.

The GSE4 software, whose development started in 2018, is still in its rollout phase. After the successful partial usage of GSE4 in OneWeb, the second mission operated with GSE 4 was Biomass and its final rollout started in the frame of the Copernicus CO2M mission.



RF Check-Out Equipment in the FCC/EMC test chamber at TüvSüd (Photo: Atos IT Solutions and Services)

Power SCOE, Instrument and Payload EGSE Test Systems

In the Power SCOE domain Atos worked on missions such as OneWeb – mainly for the launches, SpaceRider, Hera, Copernicus CO2M and Juice. The OneWeb Power SCOE is, so far, the largest Power SCOE project for Atos Space in terms of output volume. Atos IT Solutions and Services has been delivering a total of 66 ProUST UniverSAS® power supply based solutions (see UniverSAS® product below) as per the beginning of 2021. SpaceRider, Hera and Copernicus CO2M are based on our product UniverSAS® as well.

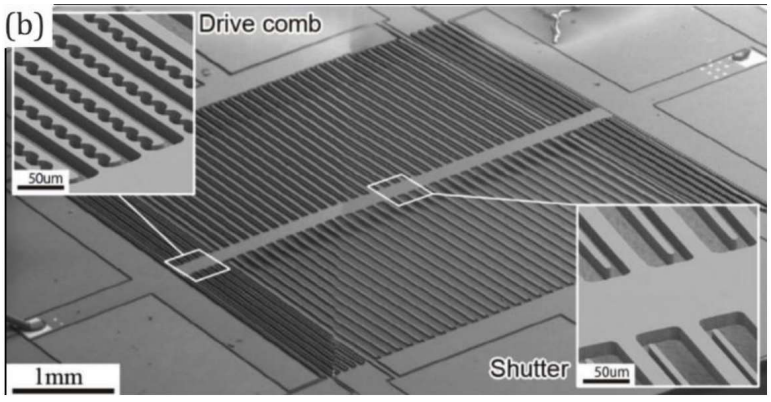
Our contribution to OneWeb generation one should offer to Atos new opportunities in the coming months, as recently mentioned in the press, ADS was awarded a contract for 15 satellites by Loft Orbital.

The Instrument EGSE projects that were started in previous years, were continued or finished, among those were Instrument EGSEs for Hera, Euclid, and Metop Second Generation, where we delivered the 3MI Instrument EGSE.

OneWeb Launch Preparation in Vostochny
(Photo: OneWeb)

Innovation: Electrostatic Voltmeter

The project aims to investigate a novel tool for the measurement of electrostatic fields at ion-thruster electrodes. In more detail, we aim for researching a fully digital, multichannel, electrostatic voltmeter for quantifying the electric potential contactless. Our goal is to surpass the shortcomings of currently available electrostatic voltmeters by realizing a modern meter design that fulfils specific user requirements for applications in satellite ion thruster management. Enhanced data storage capabilities, data analytics as well as state-of-the-art communication interfaces (Ethernet, USB) and protocols (e.g. SCPI, remote/web GUI) will be ensured.



SEM image of an example device consisting of two driving combs and the sensing area with the shutter electrodes and the fixed ones.

In 2021 Atos achieved the technology feasibility of the product.

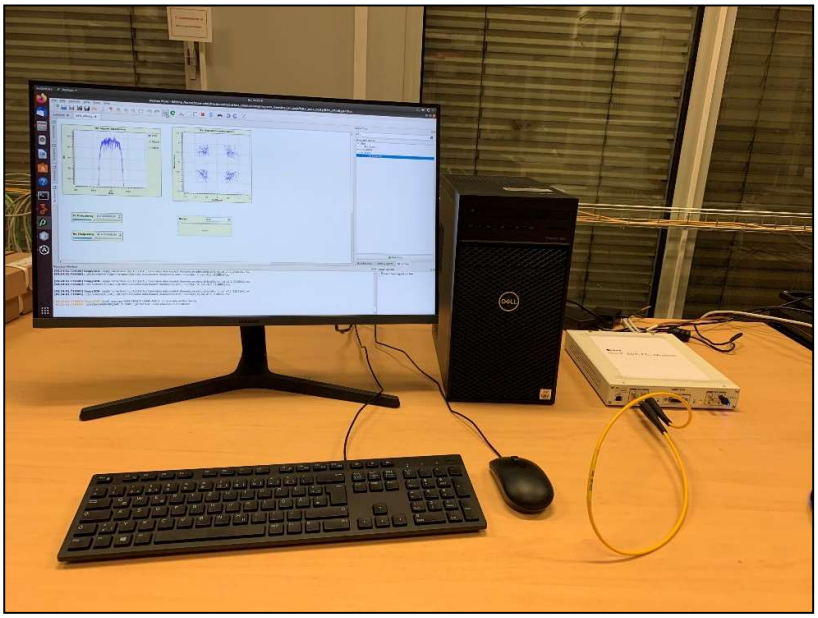
Innovation: Software defined Radio Modem

In the frame of a GSTP (initially) and now an ARTES contract, Atos is developing a modem that is mainly implemented in software (SDR – Software Defined Radio). This modem is aimed to be used in TT&C SCOEs as well as in Satellite Ground Stations.

This development was started at the end of 2019 and we finished the prototype phase in 2021.

In 2021, a technology desrisking phase was then started.

The figure below shows the current prototype of the SDR Modem.



First Prototype of SDR Modem
(Photo: Atos IT Solutions and Services)

Innovation: Green Platform SCOE and Configurable Source and Sink (CSAS) Power Supply (GSTP)

The motivation of this innovation project was to include in our portfolio a novel, agile power supply with high energy efficiency, promising form factor and flexibility to cover all power-related functions of an EGSE, all with a cost-effective in-house solution. The GSTP co-funded activity, started in early 2014, was – at the beginning of 2017 – about to provide such an EGSE building block as part of the ProUST product family.

New product: ProUST UniverSAS® 2.1

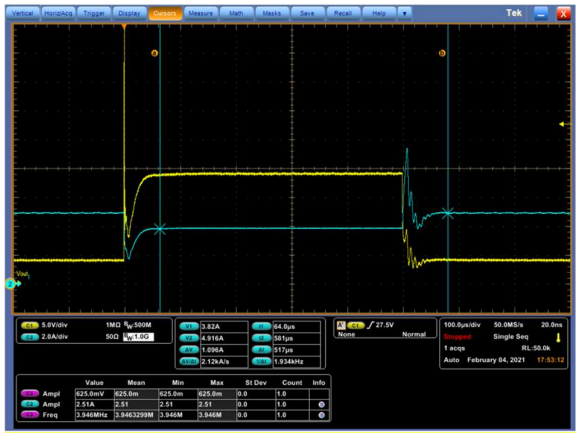
The new product resulting from learnings of the ProUST CSAS study and going towards the development of an operational product is **ProUST UniverSAS®**.

ProUST UniverSAS® 2.1 (Photo: Atos IT Solutions and Services)

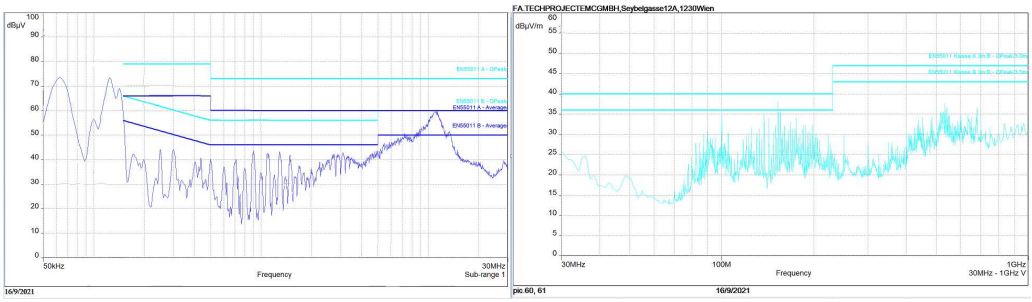
In 2021, UniverSAS® version 2.1 development was started.

Major work performed in 2021:

- Integration of the full device and CE and UL certification at a power of 17kW as a standalone product.
- univerSAS® Master/Slave functionality
- Synchronization across multiple devices
- Sequential Switched Shunt Regulator (S3R) mode up to 12,5 kHz – a first in a switched power supply
- SAS/BS/BCE Ripple and Spikes reduction
- Current measurement accuracy improvement
- Battery capacity management – establishing the capacity of the battery (very important not only for Space applications)
- Battery Simulation with configurable dynamic battery models
- Dynamic load profile simulation on top of static load profile simulation
- Temperature Protection
- Zero Level Protection
- Self-Calibration
- Hot redundancy



ProUST UniverSAS® 2.1 S3R Measurements (Photo: Atos IT Solutions and Services)



Successful conductive (left) and radiated (right) EMC measurements of ProUST UniverSAS® 2.1

UniverSAS® is a true game-changing technology. It is complementing the product portfolio of ProUST SLP and ProUST FE in the EGSE/SCOE area, and it paves the way for a new generation of AIT solutions.

Satellite Control:
Ground Segment Systems and Mission Control Software

Also, in the year 2021, the main focus of Atos Space activities in the Ground Segment Systems and Mission Control Software domain was in the following area:

- Evolution of generic Mission Control and EGSE SW architectures and building blocks
- Performance Evaluation and Improvements of the ESA Common Core developments
- New Ground Segment Test Automation Tools, Processes and Techniques

ESA Main Control Room (Photo: ESA)

Various studies have been and are being performed together with ESOC Operations, to cover offline and near-real-time data analysis, new ground segment test automation in the mission control context, as well as several aspects of ground station SW interfaces.

Atos Space is part of the European initiative to design a new EGSE SW and Mission Control SW core, both being represented in the ESA Common Core activities as well as in industry-driven showcase projects. These activities show the close synergy between EGSE SW and Mission Control SW.

Satellite Communication:
Carrier Monitoring and Geolocation Systems

In 2021 we have continued our research and development activities to apply Artificial Intelligence / Machine Learning algorithms to address the more and more increasing complexity in satellite communication. New satellite technologies like high throughput satellites (HTS) and satellite constellations in low earth orbit (LEO) offer reduced latency, higher bandwidth at lower costs to acquire and launch, plus a higher refresh cycle that supports rapid technology insertion as programs and technology evolve.

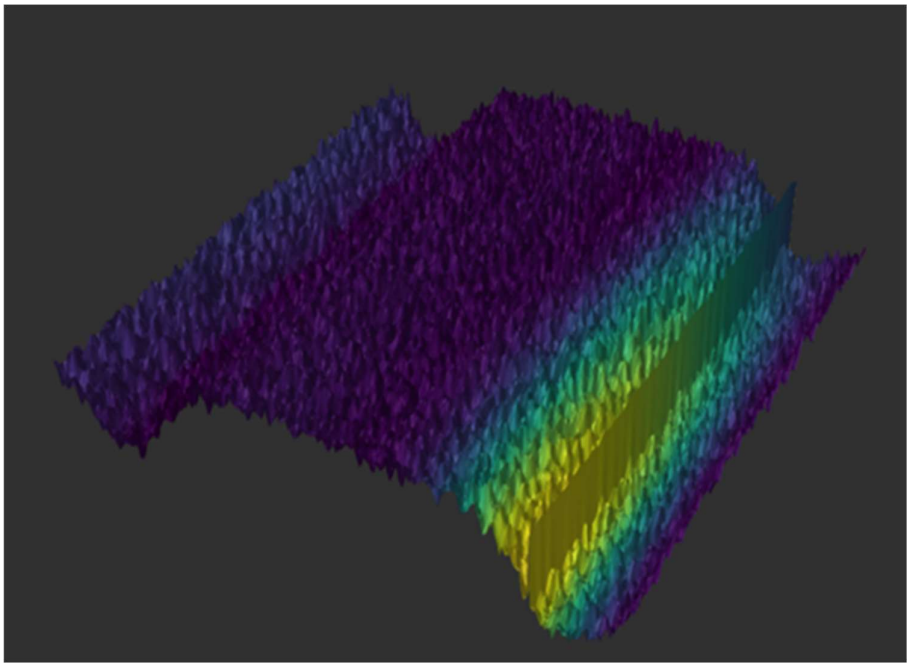
However, it is expected that the deployment of LEO constellations will significantly escalate interference issues in GEO networks. This is caused when a LEO satellite crosses the path between a GEO ground station and a GEO satellite. The availability of the usable frequency spectrum for satellite communication is limited, therefor GEO and LEO operators may sometimes share the same frequency band (mainly Ku/Ka-band). Different technologies have been developed to avoid conflicts (interferences) between GEO and LEO satellites, like changing frequency band or switching off payloads when crossing the equator. However, its questionable if these technologies will work 100% reliably on all LEO constellations.

In case thousands or even ten-thousands of LEO satellites will orbit the earth, it will be impossible to manually identify and classify interferences and take the appropriate steps to get rid of them.

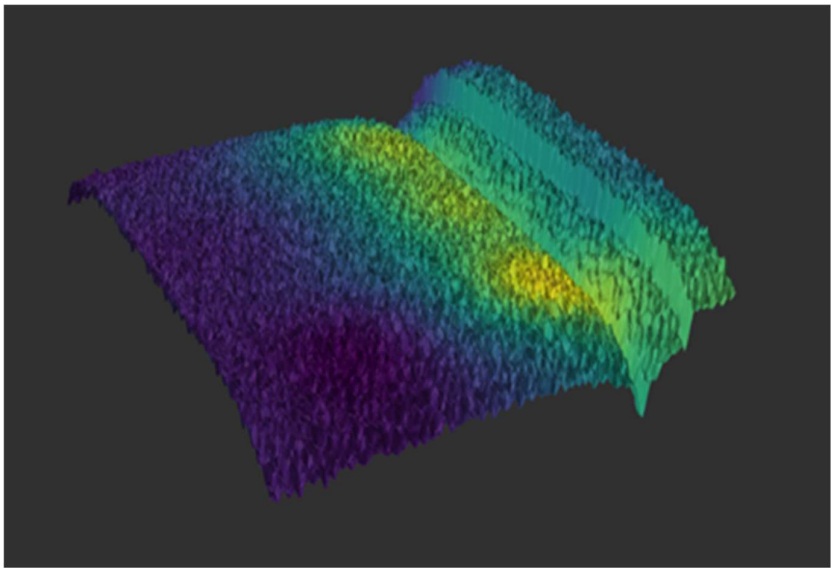
In 2021 we have therefor developed in the frame of the ARTES C&G program a prototype to demonstrate the capability of AI/ML algorithms to detect and classify satellite interferences.

Satellite interferences can be recognized by comparing the shape of an interference free signal spectrum with a spectrum affected by interference. It is comparable with face recognition in images or videos and in fact after investigating different AI models, it turned out that AI models which are optimized for pattern recognition will also have a very high success rate in identifying interferences in spectrum shapes. Since different interference sources (e.g. CW, GSM, LTE) will show different shapes it is also possible to classify the type of interference.

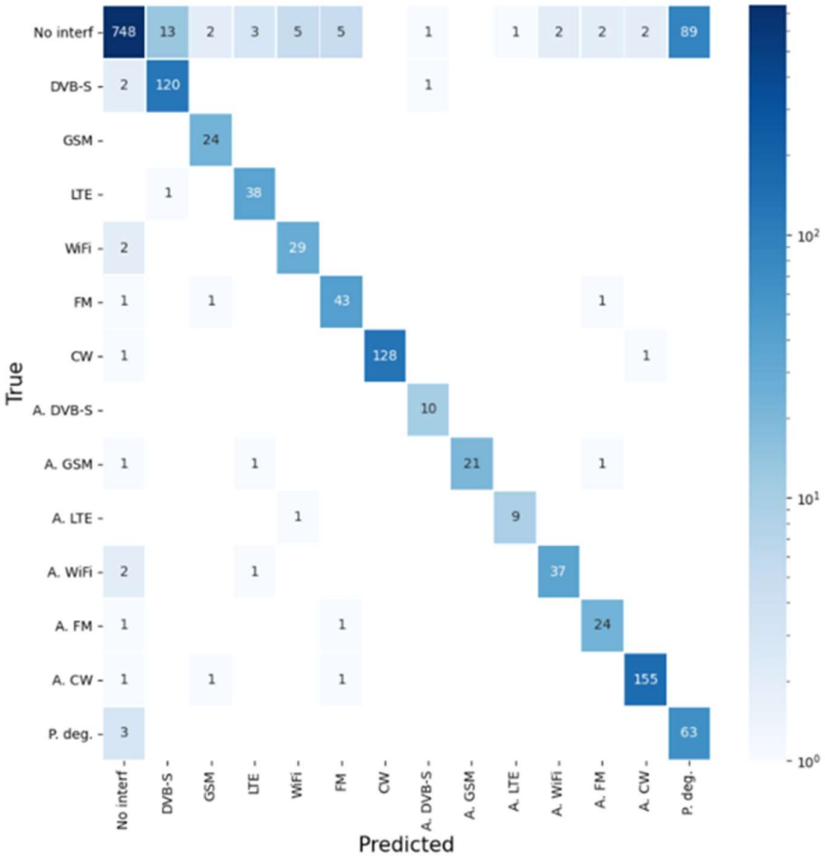
The following example shows the result of the interference detection model for a CW interferer:



Also, power degradations due to bad weather situations can be identified as the following example shows:



The following confusion matrix shows the overall performance of the chosen AI model for different interference types. For signal type classification we could reach a success rate of about 98%:



The research has proven that AI can help addressing interference. It is able to enable automatic identification of interference situations via spectrum analysis, predict satellite link quality degradation caused by bad weather scenarios, and enable interference detection in complex satellite environments.

As a next step this prototype will be further developed towards a real product fully integrated into our carrier monitoring system.

Sales 2021: 10.2 M€
ESA Share: 5.02 M€

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3.4 ENPULSION GMBH

Despite the aftermath of the COVID pandemic on supply chains, ENPULSION demonstrated a high level of resilience in anticipating possible delivery difficulties at an early stage, also allowing the production scale up to go forward. 11 new employees joined the company this year, from all walks of life and with different qualifications across departments.

Up to 250 thrusters were delivered to international customers and many more deliveries are under way. ENPULSION signed a contract with Danish satellite manufacturer Gomspace and British RAL Space to support the ESA SCOUT-1 Earth Observation mission with the delivery of state-of-the-art thrusters, to be launched in 2024. The constellation will be composed of 3 CubeSats and will become the first “climate mission” of its kind, aiming to study and quantify processes and variability in the tropical upper troposphere and stratosphere and their impact on climate change.

In July 2021, ENPULSION reached another milestone with 25 thrusters on the same flight, the SpaceX´s Transportation-2 rideshare mission, with 88 satellites onboard.

ENPULSION also successfully passed the certification process ISO 9001 audit 2021, restating the high quality of ENPULSION´s products. The ISO 9001 sets out criteria for a quality management system and is the only standard that can be certified to within the 9000 ISO standards family.

Sales 2021: 6.1 M€
ESA Share: 0.53 M€

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3.5 EODC: Earth Observation Data Centre for Water Resources Monitoring GmbH

What we do

The EODC (https://www.eodc.eu) is a public-private partnership (PPP) between the Vienna University of Technology, the Austrian Meteorological Service ZAMG, the companies GeoVille Information Systems GmbH and Cloudflight Austria GmbH, and several private individuals. The mission of the EODC is to work together with its shareholders and multi-national partners from science, the public and private sectors in order to foster the use of earth observation (EO) data.

The EODC maintains and provides a cloud computing environment including a high-performance computing environment for the Earth Observation (EO) ground segment for deriving geophysical parameters and land cover properties from Sentinel-1 (synthetic aperture radar), Sentinel-2 (high-resolution optical imaging), Sentinel-3 (land) and other EO missions. The EODC has the following broad spheres of service provision:

- Cloud Computing
- High Performance Computing
- Sentinel Data Provision and Products
- EO Software and Services

With its federated activities EODC is part of the current WEkEO DIAS and the European Science Cloud (EOSC). Moreover, EODC is active in the ESA project openEO platform and within several Copernicus services.

Project highlights in 2021

The Austrian Space Applications Programme

LandStatsEO
LandSTATSeo has two primary objectives. Initially, to further develop the EODC platform to allow user enabled on-boarding to specialised EO service solutions. Secondly, to support and empower national statistical offices to access ready-to-use statistical information on land dynamics derived through the Copernicus satellite data, assess the impact within current data gathering workflows and motivate the operational implementation of EO derived statistical products for their reporting obligations on national and international (i.e. SDG reporting) level. Specifically, the project intends to develop and verify: 1) IT solutions for end user-based activated API services, and 2) a suite of statistical information streams on land cover dynamics, developed with, and for, non-EO experts, that can be readily integrated into public authority workflows to significantly enhance reporting capacities, with a specific focus on SDG obligations.

DWC Radar
The goal of the DWC-Radar project is to exploit the first-time availability of five contemporary C-band radar instruments in space (three Metop ASCAT instruments, two Sentinel-1 Synthetic Aperture Radar (SAR) sensors) to retrieve soil moisture (SM) and rainfall (RF) estimates at 1km resolution to support Phase 0 activities for G-Class, demonstrating scientific algorithms and data products, and highlighting known strengths and weaknesses of this ground-breaking technology. Furthermore, the project will demonstrate the high practical utility of this technology

by using the developed sub-daily SM and improved RF data as input for three applications targeted by G-Class, namely irrigation water use mapping, flood forecasting and landslide risk assessment. The data records and three use cases will be tested and validated over the larger Mediterranean region, which is particularly vulnerable to climate change, and the main target area of G-Class. The data records of sub-daily backscatter, SM, and RF will be made publicly available through a visualization tool at the Earth Observation Data Centre for Water Resources Monitoring. The results of DWC-Radar will directly feed into the ESA EE10 Phase 0 activities closely interacting with the G-Class Science Team, addressing science requirements for G-Class and providing algorithms for sub-daily SM and RF documented in two separate Algorithm Theoretical Baseline Documents.

ACube4Floods
The ACube4Floods project is striving to extract the maximum information from Sentinel-1 & Sentinel-2 time series by applying change detection- and machine learning algorithms to analysis-ready Sentinel data cubes. By capturing also smaller-scale flood events, ACube4Floods will help the project's pilot users, most importantly the Austrian Ministry for Sustainability and Tourism and the Federal Ministry of Defense, to enhance disaster resilience, through better preparedness, response, inventory, and recovery.

AI4SAR
The usability of Synthetic Aperture Radar (SAR) satellite data depends on the correct interpretation of the underlying scatter mechanism, where current modelling approaches perform poorly or fail. Within the proposed project AI4SAR, different state-of-the-art artificial intelligence (AI) algorithms based on unsupervised, active and knowledge-based learning are further developed to find a data-driven solution for this impressive challenge. The AI-based separation of different scattering mechanisms then allows optimised SAR despeckle filtering, interferometric phase preservation, SAR-to-optical matching, and in general advanced SAR processing. The AI4SAR developments will be demonstrated with the help of different use cases in the fields of forest monitoring, deformation monitoring and ground control point transfer.

ESA

DHR ESA Missions - Operations of a Data Hub Relay – Austria
The purpose of the Data Hub Relay (DHR) is, under overall ESA coordination and responsibility, to facilitate the bulk delivery of Sentinel data products from the ESA operated collaborative data hub towards the ESA member state collaborative GS mirror archives. The Data Hub Relays establish a distributed dissemination network in order to avoid bottlenecks / saturation in the dissemination and potentially to establish an overall load balancing scheme towards the collaborative ground segments. The ESA Missions Data Hub Relay Service (ESA-DHR) will further enrich the data offering of the Data Hub collaborative service (currently limited to Sentinel data and EODC's current SMOS activity) with ESA heritage and scientific mission data.

CCI+ - Climate Change Initiative Extension (CCI+) Phase 1 New R&D on CCI ECVs: Soil Moisture
The objective of the CCI+ Phase 1 soil moisture project is to continue the successful achievements of CCI on the research, development and qualification of pre-operational

soil moisture ECV products and processing systems, with the goal of transferring developments made into operational production outside (currently C3S). The production system hosted at EODC allows for the merging of the different sensor-specific Level 2 soil moisture datasets (retrieved surface soil moisture) into combined products.

openEO platform
The openEO Platform is a project built on top of the H2020 project openEO. It brings openEO to production and offers data access and data processing services to the EO community, see https://openeo.cloud/.

EU – Copernicus

C3S - Copernicus Climate Change Service (C3S): Land Hydrology and Cryosphere
The service focuses on Terrestrial ECV's in the land hydrology and cryosphere domain and will operationally produce and deliver, or broker access to a suite of Climate Data Records (CDRs) and Intermediate Climate Data Records (ICDR) for the ECV variables of Soil Moisture, Glaciers, Lakes, and Ice Sheets.

GFM - Sentinel-1 based global flood monitoring system of Copernicus Emergency Management Service
Using EO data from the Sentinel-1 suite of satellites, linked with the state-of-the-art flood detection models, the GFM service will produce near real time flood monitoring products within 8 hours of the satellite observation. The products will be integrated within the current Copernicus EMS European Flood Awareness System (EFAS) and the EC and ECMWF's Global Flood Awareness System (GloFAS).

EU – H2020

C-SCALE - Copernicus - eoSC AnaLytics Engine
The C-SCALEproject aims to federate European EO infrastructure services, such as the Copernicus DIAS and others. The federation shall capitalise on the European Open Science Cloud's (EOSC) capacity and capabilities to support Copernicus research and operations with large and easily accessible European computing environments. That would allow the rapid scaling and sharing of EO data among a large community of users by increasing the service offering of the EOSC Portal. By making such a scalable Big Copernicus Data Analytics federated services available through EOSC and its Portal and linking the problems and results with experience from other research disciplines, C-SCALE will help to support the EO sector in its development and furthermore will enable the integration of EO data into other existing and future domains within EOSC.

Sales 2021: 5.5 M€
ESA Share: 0.42 M€

CONTACT:

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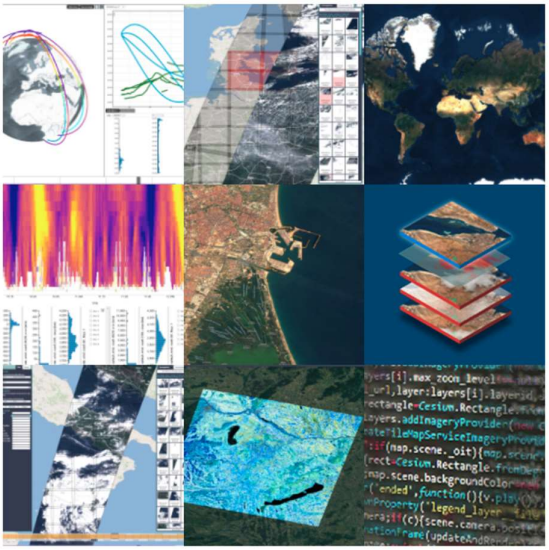
3.6 EOX IT Services GmbH



VIEW THE WORLD
THROUGH OUR EYES

Overview

EOX IT Services GmbH (EOX) is a geospatial engineering and service company based in Austria, a non-startup, founder-managed business. It creates software and tools to allow people to consume geospatial data in the cloud and on the Web. The company focuses on getting the most value out of the vast amount of the data acquired by Earth observation satellites. EOX furnishes software and cloud infrastructure services to selected customers in geoscience and European government organizations.

EOX is among the main ESA contractors in Austria and has successfully carried out more than 60 engineering and operations projects for ESA. In recent years, the client base has been expanding to customers stemming from private industry sectors, non-space public organizations and research institutes interested in engineering, consultancy and in the new data product services provided by EOX. The Sentinel commodity product series “EOxCloudless”, which currently includes Sentinel-1 and -2 global product offerings has opened the doors for EOX to a wide consumer market.

EOX has a fourteen-year long record of space software projects building components of Earth Observation satellite payload ground segments most of them including (sophisticated) geospatial Web GUI implementations together with adequate server infrastructure functions including data cubes, as can be checked on the company’s home page https://eox.at. EOX is also a provider of high-throughput processing lines for production of exploitation-ready satellite data which are used in viewing and analysis downstream applications. EOX has gained special expertise related to the deployment of processing lines and data access software functionality on cloud-based ICT infrastructures like on Copernicus DIAS, AWS, and GCP.

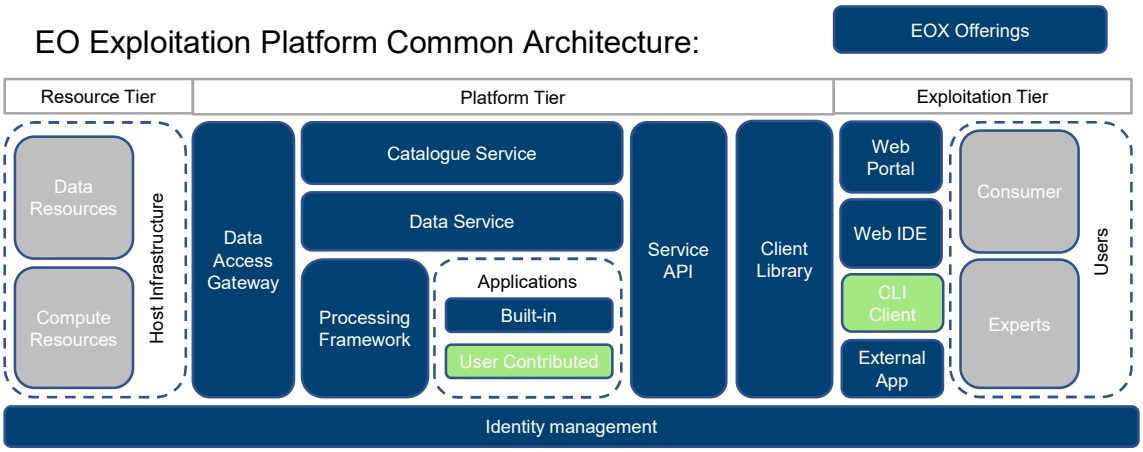
EOX is strongly committed towards utilizing and contributing to Open Source Software for example via the EOX GitHub organization. EOX is further committed to comply to and improve Open Standards particularly those of the Open Geospatial Consortium (OGC). EOX is an active promotor of such standards and offers related consultancy and implementation services.

At present, EOX employs 21 full-time, permanent staff and, in addition, temporary co-workers including master students and stagiaires. Administrative processes are to a good deal outsourced to external professionals.

Under the following headlines the 2021 highlights are reported.

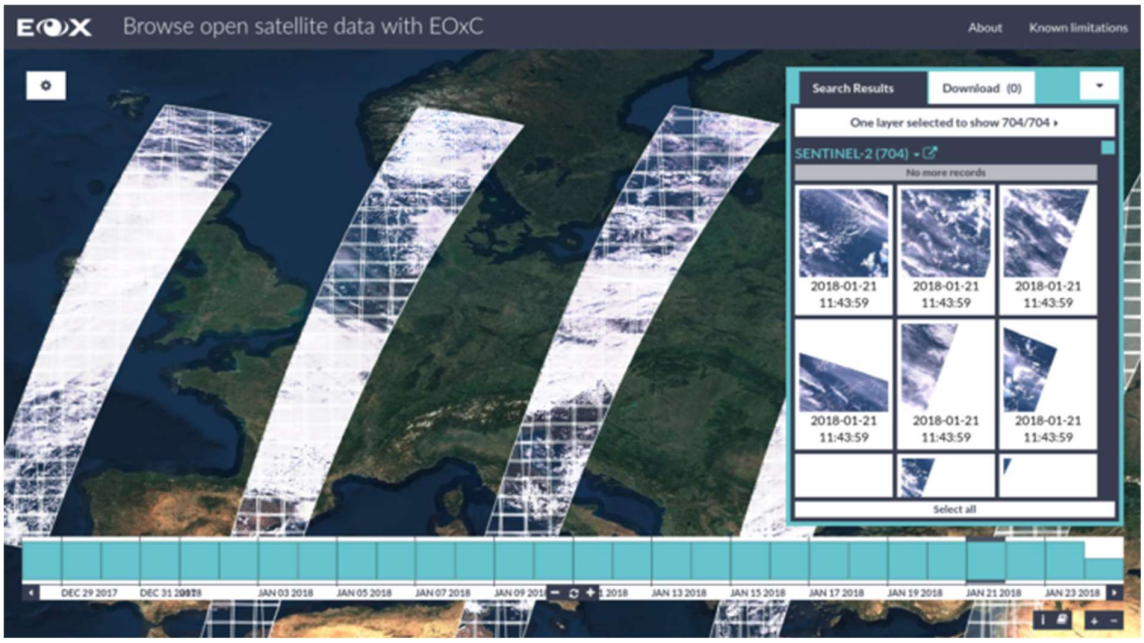
Technology

EOX is full-stack technology provider for the handling of big data from Earth observation (EO) satellite missions. The following figure shows the modules in the system architecture for which EOX delivers software technology. The entire chain from the satellite data resources to the end-consumer system is offered. Due to the modularity of the solutions and the support of industry-standard interfaces, subsets of the functionality can be used as “plug and play” components for integration into custom system architectures.



The following illustrates some of these components.

EOxC - the ultimate HTML-5 client for search in and download from big data EO archives.



This client software allows to view spatio-temporal distribution of EO datasets in an EO data archive, apply filters and automatically refresh results. It includes a shopping-cart mechanism and lets users download selected data either as files using a browser, via URL-list or metalink file. EOxC supports industry-standard interface specifications as defined by OGC.

Example instances of EOxC are running as part of Mundi Copernicus Data and Information Access Service (DIAS) [1] and PRISM Data Access Service (PASS) [2]. The software is provided by EOX as Free and Open Source Software (FOSS) [3].

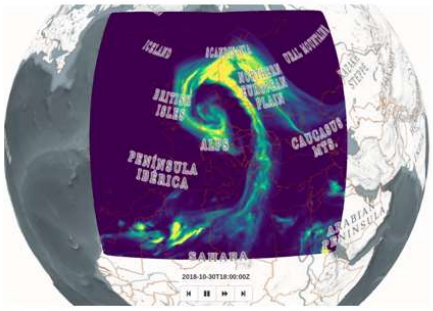
[1] https://mundiwebservices.com/geodata/S2_MSI_L2A

[2] https://vhr18.pass.copernicus.eu/ [3] https://github.com/eoxc/eoxc

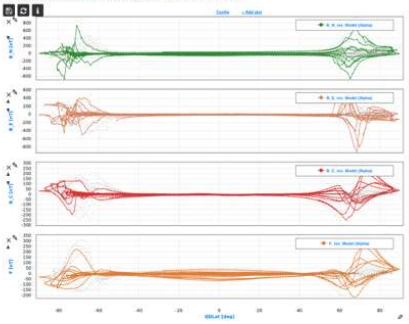
plotty & graphly - Interactive graphics and high-end plotting in Web browser

These are two examples of JavaScript libraries developed and maintained by EOX allowing developers to build complex Web portals for interactive visual analytics of EO and auxiliary data. Both libraries are FOSS [4], [5].

plotty
WebGL colorscale rendering



graphly
WebGL based graph library



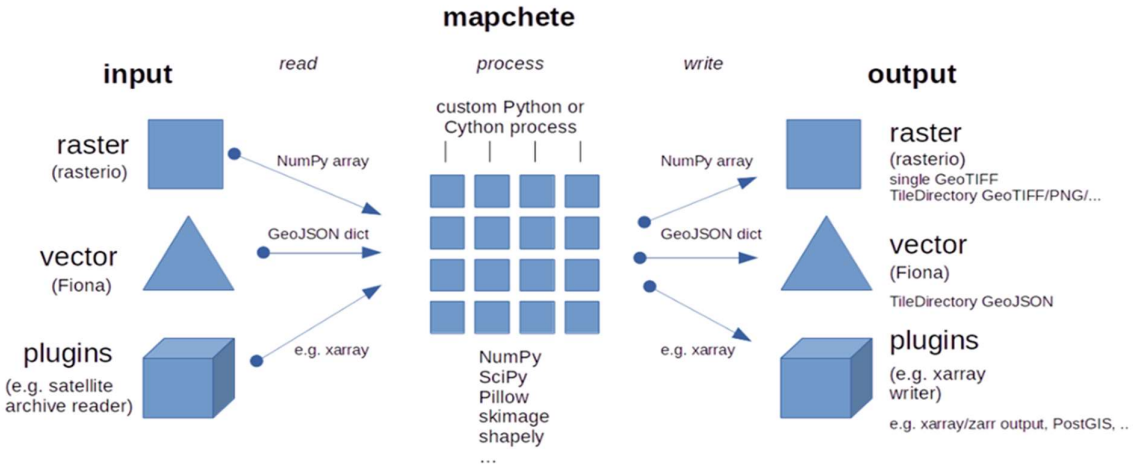
Example instances of graphly and plotty are being used in VirES for Swarm [6], VirES for Aeolus [7] and TOP [8] services.

[4] http://santilland.github.io/plotty/ [5] https://eox-a.github.io/graphly/

[6] https://vires.services/ [7] https://aeolus.services/ [8] http://top-platform.eu/

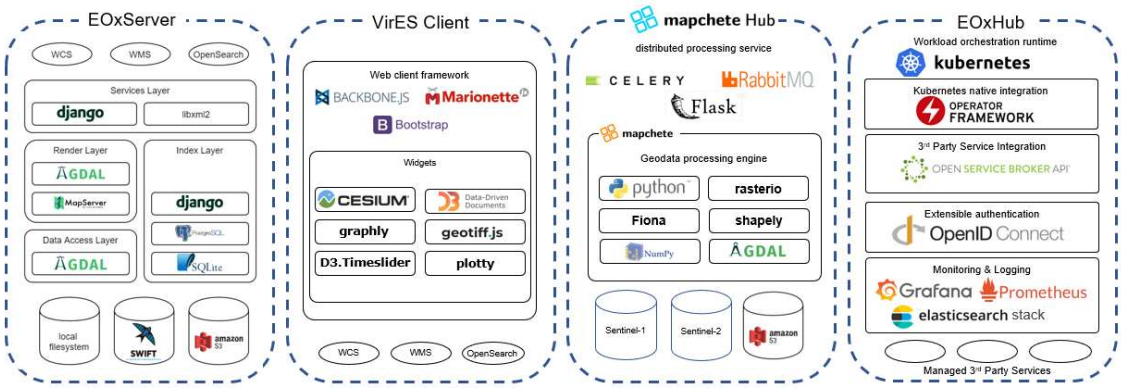
mapchete - Cloud-enabled workflow management for high-throughput satellite data processing.

This software package is used by EOX as the workhorse for large volume EO data processing tasks such as for the generation of EOxCloudless products (see below).



Software zoo - EOX excels in know-how about EO-relevant FOSS and its integrability. Four examples of the many software elements integrated in EOX-provided packages are shown in

the following figure: EOxServer [9], the nucleus of EOX data access technology; VirES Web client framework [10] as it is used in [6] and [7]; and the above-described mapchete package. The “home” of EOX FOSS is at [11].



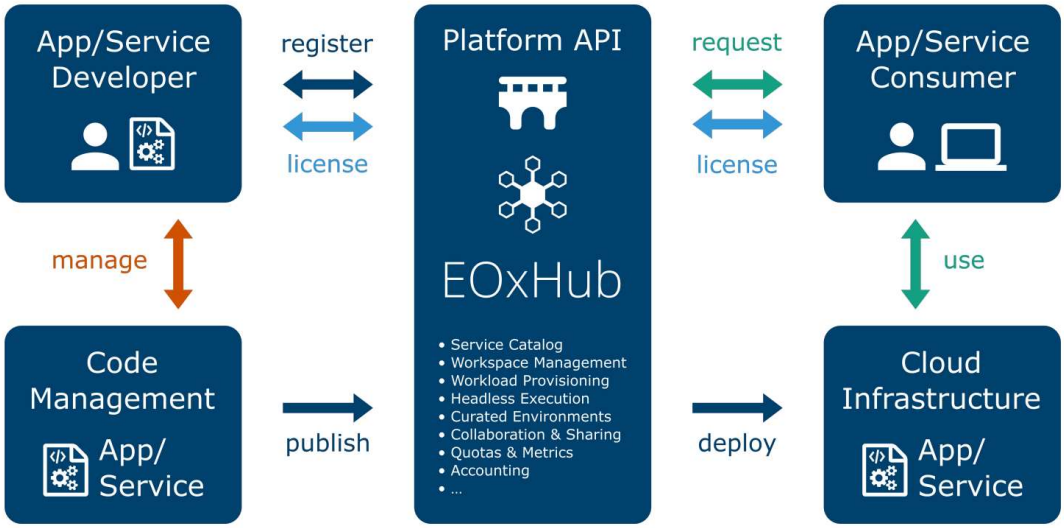
[9] https://ows.eox.at [10] https://github.com/ESA-VirES [11] https://github.com/eox-a

Services

DevOps Services - EOX masters different cultures and tasks of software development and operations under one roof to the satisfaction of its customers: software engineering; IT infrastructure & cloud management; deployment; operations; customer/user support. E.g. EOX’ principal customer ESA requires both ECSS and Agile approaches to be applied in the same project and in a unique blend.

EOxHub – Business-enabling, scalable cloud deployment and operations of “EO as a Service”

Under this label EOX offers a Kubernetes-based, multi-tenant, self-service environment. It is a workflow- and service- orchestration platform which is operated by EOX as a central hub (“marketplace”) for EO products used by customers who want to offer solutions to their user base; and by sellers who want to promote their applications or data.

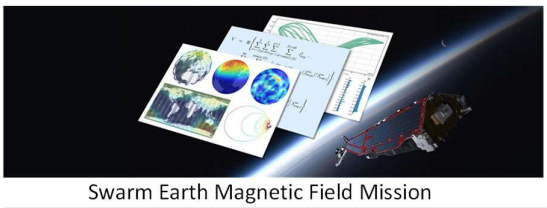


Through EOxHub [12] also optimal data access strategies (e.g. those implemented in Euro Data Cube [13]) are offered in a pluggable and unified way.

[12] https://hub.eox.at/ [13] https://eurodatacube.com

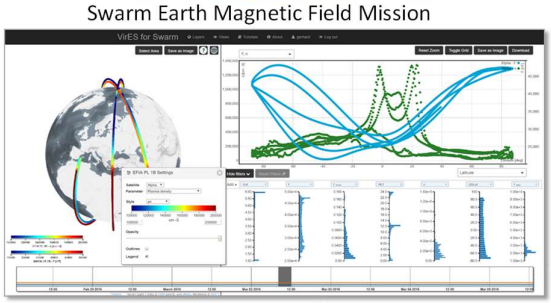
Virtual Research Environments

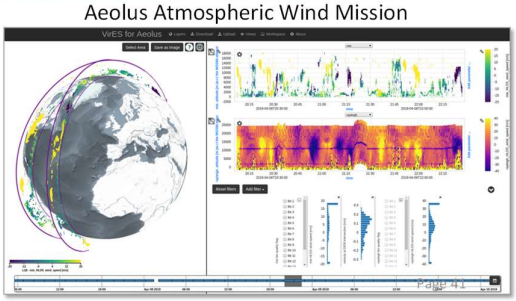
The VirES family of services [14], [15] operated by EOX for ESA are providing operational interactive user services for the Earth Explorer missions Swarm, launched into space on 22 November 2013, and Aeolus, launched into space on 22 August 2018.



Swarm Earth Magnetic Field Mission

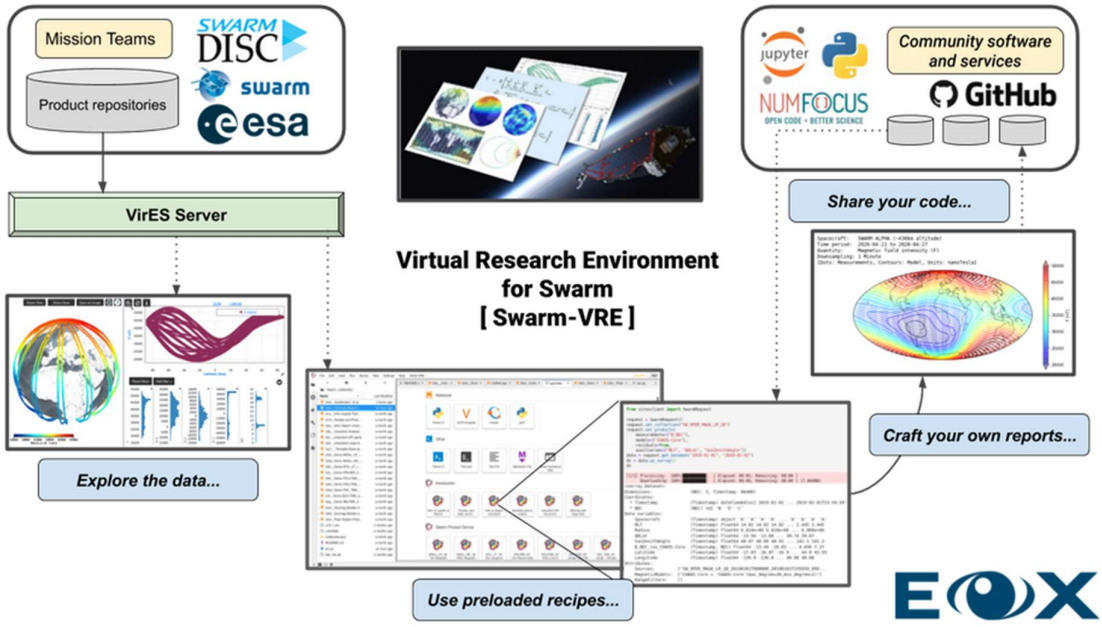
Aeolus Atmospheric Wind Mission





EOX is continuously synchronizing the entire Swarm and Aeolus mission data archives and provides data access to them via VirES Server. Besides the direct access via the dedicated Web GUI for data exploration, a workflow which supports flexible scientific data analysis and

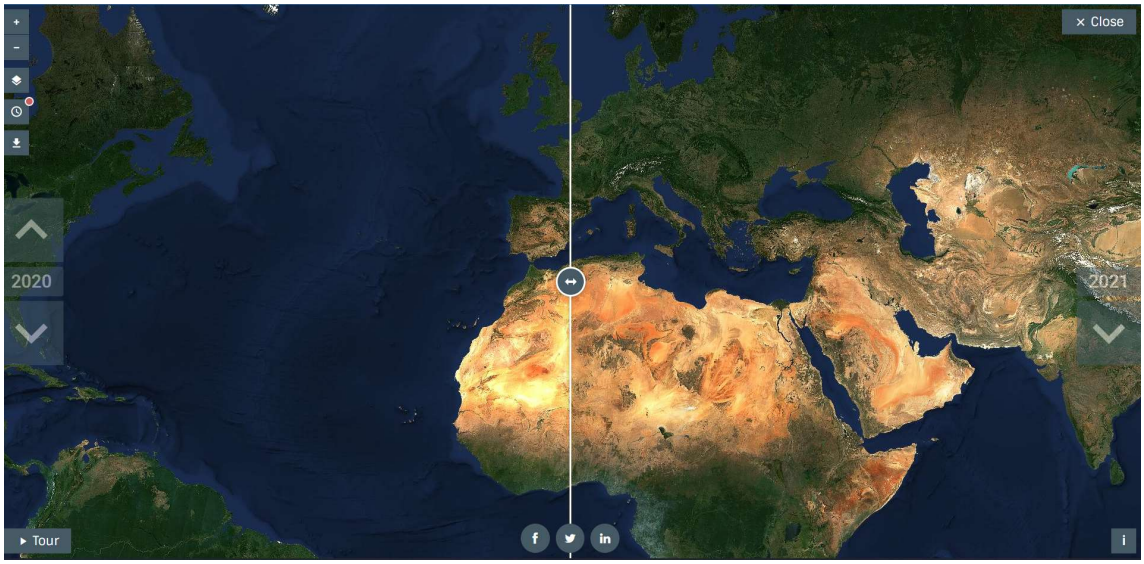
collaboration by code sharing using Jupyter Notebooks has been implemented, as shown in the following figure [16].



[14] https://vires.services [15] https://aeolus.services
[16] https://eox.at/2019/01/using-python-interface-of-vires-in-eox-jupyter-platform/

Open Geospatial Data

Sentinel-2 cloudless - EOX was the first company to produce a global, cloud free mosaic from Sentinel-2 [17]. The target was to create a pure visual product to be used for mapping applications as a background layer. A special algorithm eliminates clouds from a time stack of data on a pixel by pixel basis to reduce significantly disturbing borders between Sentinel-2 scenes. To apply this algorithm globally, a the mapchete processing platform was created by EOX which can handle hundreds of Terabytes.



Sentinel-2 cloudless – https://s2maps.eu by EOX IT Services GmbH (Contains modified Copernicus Sentinel data 2020 & 2021)

Using its own processing platform, EOX offers to create mosaics tailored to customer needs. The mosaics are not limited to the visible bands (red, green, blue) but can also contain any of the other Sentinel-2 bands (e.g. NIR) available. Also, the input time range used can be chosen to let the customer get a mosaic containing data from exactly the desired time range. Additional metadata can be appended to trace each pixel's source reflectance value. Other value-adding processing steps can be applied on customer input.

"**EOxMaps**" is EOX' contribution to open data offering global topographic online maps [18].

Multiple geospatial data layers (OpenStreetMaps, various global and regional Digital Elevation Models, global landcover data) are being uniquely combined in a global database which is used for generation of various cartographic products.

Apart from the motivation to create beautiful maps one of the main drivers is to split background from overlay layers to enable embedding data properly in between. The reason is that both background and overlay provide spatial context in different ways. The background (e.g. Terrain Light) provides an idea of land usage and topography while the overlay adds labels and line features like borders or streets to provide more detailed information.

All maps are provided free-of-charge as Web Map Tile Service (WMTS) and Web Map Service (WMS) layers in simple lat lon projection also known as WGS84 or EPSG:4326 or pseudo-mercator projection also known as Google projection, EPSG:3857, or EPSG:900913. Special customers, such as ESA, are served by EOX via the provision of dedicated instances of the map services.

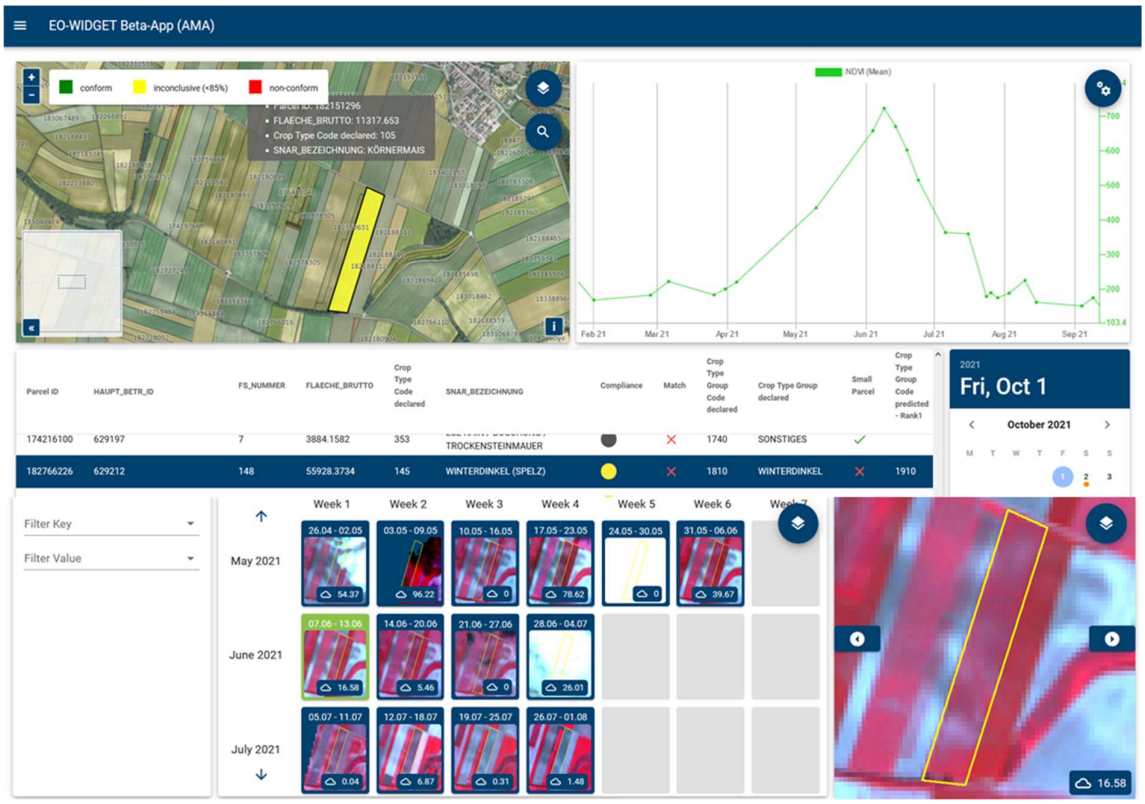
[17] https://s2maps.eu [18] https://maps.eox.at

The URLs to include the open maps in tools like QGIS, Leaflet or OpenLayers are:

[19] WMTS https://tiles.maps.eox.at/wmts/1.0.0/WMTSCapabilities.xml
[20] WMS https://tiles.maps.eox.at/wms?service=wms&request=getcapabilities

Domain Application Products

EOX offers **Agricultural Area Monitoring** solutions based on satellite EO data to support expert judgment and decision making compliant with the EU Common Agricultural Policy (CAP). The following diagramme shows the “Parcel Explorer” user interface for crop type validation which is an example from a number of tools [21] which EOX provides to Paying Agencies in EU Member States for assessment of farmer applications for subsidies.



Sales 2021: 2.2 M€
ESA Share: 1.8M€

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3.7 Fachhochschule Wiener Neustadt – University of Applied Sciences Wiener Neustadt (& research company FOTEC)

The University of Applied Sciences Wiener Neustadt together with its research subsidiary FOTEC Forschungs- und Technologietransfer GmbH was involved in a series of R&D projects for ESA and other customers. Details of some projects are given below.

Nanosatellite Development and Testing

In 2021, FOTEC and the FHWN started the FFG-funded project *DEEP* with the goal to increase FOTEC's testing and analysis capabilities specifically for nano and micro satellites. Particular attention was paid to the plasma plume of an electric thruster and its interaction with the environment as well as to the thermal interaction of such a thruster with the satellite. So-called Digital Faraday Cups (DFCs) were developed which allow the precise measurement of the ion beam current density distribution. Compared to conventional Faraday cups with the conditioning and measurement electronics located outside the vacuum chamber, DFCs feature integrated electronics and therefore reach noise floor levels of several magnitudes better. Obtained knowledge shall also be used to develop a new syllabus to be implemented in the curriculum of Aerospace Engineering at the FHWN.

The Aerospace Engineering department of the FHWN is developing a new concept of a thermal vacuum chamber which will allow to conduct thermal vacuum testing for electric propulsion systems during operation.

Nina Mühlich is setting up the Digital Faraday Cups on the diagnostic boom in FOTEC's large vacuum chamber (Source: FOTEC)

FOTEC is continuously improving their low thrust measurement test stands and in particular the µN torsion-based thrust balance. Within the *FOS-Sens-Add* project funded by Land NÖ new optical displacement sensors are developed and evaluated to reduce the noise floor and the response time of the system.

Electric Propulsion

FOTEC has continued the development and assessment of FOTEC's IFM Nano Thruster, which was first in-orbit demonstrated in 2018, in the frame of the *Sci-FIT* project funded by the science directorate of ESA. Advanced in-house developed diagnostic systems, such as the thrust balance, plasma diagnostics or mass efficiency test stand, are used to characterize the thruster in detail. This helps to verify the challenging requirements posed by future scientific or Earth observation missions on the one hand, but also helps to identify gaps for future delta developments on the other hand.

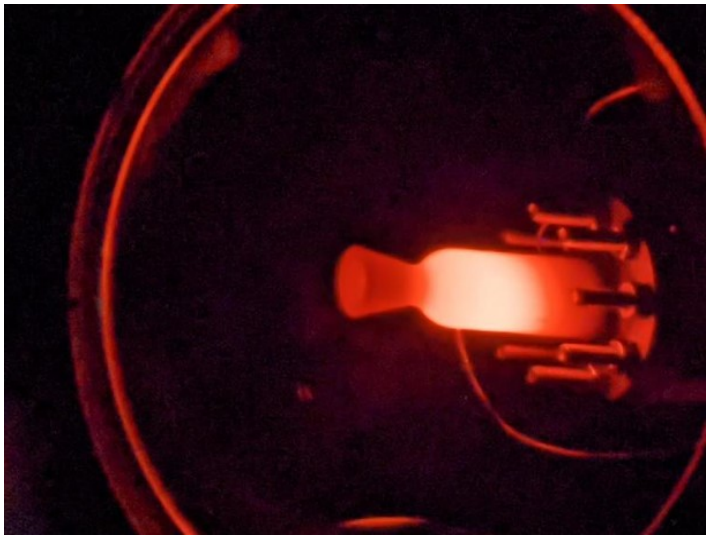
For NASA's and ESA's upcoming *Next Generation Gravity Mission (NGGM)*, FOTEC's FEEP thruster is one of the electric propulsion candidates to either perform drag compensation of the spacecraft or to allow fine pointing.

Field Emission Electric Propulsion (FEEP) based ion thrusters do not only emit ions but also neutral particles at lower velocity. Since indium is used as propellant, it is crucial to know the distribution of these neutrals. As conventional Quartz Crystal Microbalance cannot be used on FOTEC's diagnostic boom, new digital QCMs are being developed within the project *QUITE moving* funded by FFG. This activity will help FOTEC to build up a diagnostic system to scan and characterize the beam of neutrals of a FEEP thruster.

To avoid a positive charge accumulation on the surface of the satellite, FEEP ion emitters have to be operated always in parallel with an electron emitter. FOTEC is currently investigating two alternatives to the heritage neutralizers that are based on thermionic technology. In particular, FOTEC is involved in the H2020 project *NEMESIS* where electride coatings are evaluated and is working on the FFG-funded *TESSA* project, where electron emission based on planar semiconductor technology is investigated.

Chemical Propulsion

The ESA GSTP de-risk project *HACat* (Hexaluminate catalyst), with the project partners Lithoz (AUT, additive manufacturing of ceramic catalyst support structure) and IC2MP (FRA, Pt-coating of ceramic catalyst support structures), was started in May 2021. The main objective of this project is the development of a chemical propulsion system that uses a Platinum coated ceramic catalyst and reaches a thrust level of 1 N in less than 100 ms. As a base material for the catalyst the ceramic Lanthanum Hexaluminate (LHA) is used, which has higher thermal shock resistance compared to for example Magnesium oxide, Cordierite or Silicon nitride. Several important milestones were achieved in 2021, the synthesis of the LHA powder, additive manufacturing of the catalyst support structure and the Pt-coating. Finally, first hot firing tests inside a vacuum chamber could have been done.



Initial hot firing tests of the HTP thruster in the vacuum chamber using the Pt-coated LHA catalyst (Source: FOTEC)

Based on the outcome of the ESA GSTP de-risk project HACat, a project called *CP/EP Thruster Development* was started in October 2021. This activity has a total budget of 2.85 Mio. EUR and is funded by the government of Lower Austria, ESA is also involved and supports the development as a technical supervisor. The main objectives are a 1N-monopropellant HTP thruster up to qualification level, concepts and initial prototypes of a hybrid solution that combines chemical and electrical propulsion and a 10N-bipropellant HTP-based thruster up to PDR level. The last objective is optional considering the remaining project resources. It is planned to finish the development until December 2025 and to start with the commercialization in cooperation with space industry.

Sales 2021: 3.45 M€
ESA Share: 0.85 M€

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3.8 GeoVille Information Systems and Data Processing GmbH

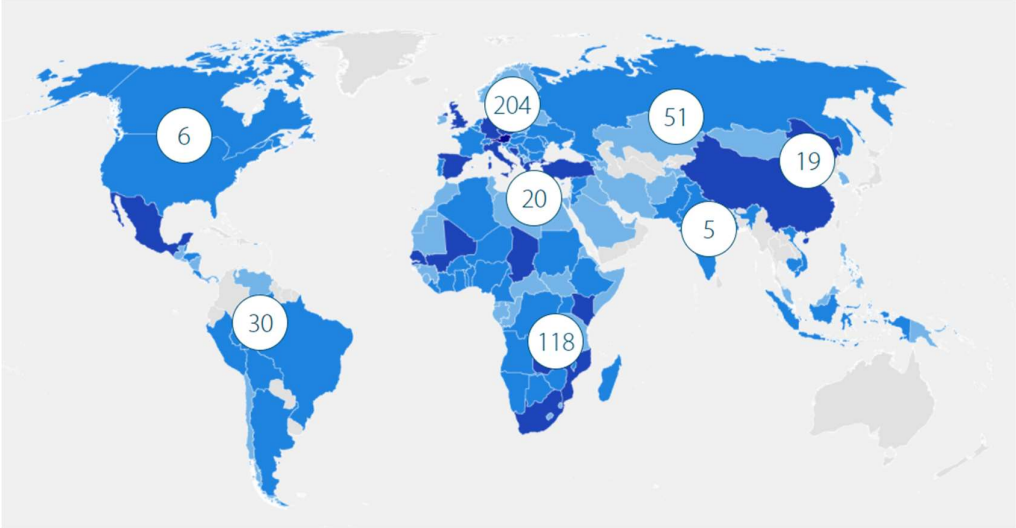
WHAT WE DO

GeoVille provides a wide range of value-added services derived from Earth observation data and GIS applications. Our mission is to provide turnkey geospatial intelligence solutions enabling efficient client operations and management. We aim at optimising the value of our spatial insights, thereby generating benefits and advances for our clients through reliable information.

OUR CLIENTS

We have a global clients' base in 139 countries world-wide. Our clients are international institutions, NGOs, public authorities, and commercial customers.

International Institutions	Financial Institutions	Public Authorities	Private companies
European Environment Agency, European Space Agency, European Union, IFAD, United Nations Programmes	Asian Development Bank, European Investment Bank, EuropeAid, World Bank	Various ministries and agencies for environment, agriculture, forestry, research, water and energy commissions	Agriculture, Financial Sector, Consulting, Construction, Oil & Gas, Telecommunication, etc.



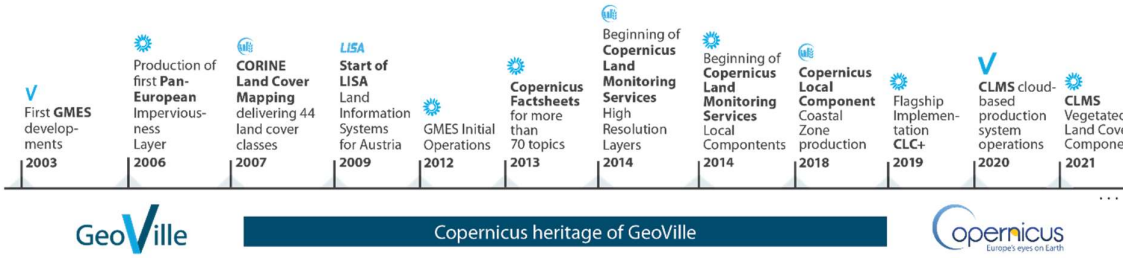
Realised projects worldwide (excl. global projects)

20 YEARS OF COPERNICUS EXPERIENCE

GEOVILLE'S HERITAGE OF COPERNICUS LAND MONITORING SERVICES: From early 'GMES' R&D projects to years of operational services

Copernicus, the EU's Earth Observation programme, is looking at our planet and its environment and supports public authorities, the private sector, and Europe's citizens with satellite-derived environmental and security-related information. Managed by the European Commission, Copernicus provides accurate, timely and easily accessible information to help decision-makers to take appropriate action.

GeoVille plays a key role in Copernicus services for land applications, related to both land cover/use data production, and monitoring solutions for emergency management. We have performed many projects and commercial activities related to and building upon Copernicus services, covering the full value-adding chain from data production to operational land monitoring solutions as well as targeted capacity building and promotion for expert authorities and the public at large.



GeoVille started early adopter and development activities in the frame of GMES Global Monitoring for Environment and Security initiative, financed by the European Commission through the R&D framework programmes RP5, 6 and 7, as well as the European Space Agency through dedicated GMES Service Elements.

By 2006, GeoVille has built up leading expertise in land monitoring focused on the mapping of imperviousness and soil sealing and has lead the first ever implementation of a pan-European 'Fast Track Service' High-Resolution layer (HRL) tendered out by the European Environment Agency, followed up by its first update for 2009. In 2007, GeoVille supported the development of a transition concept for Copernicus/GMES to become an operational programme. In this year, GeoVille also became part of the CORINE Land Cover Mapping activities, which delivers an inventory of land cover of 44 classes for the reference years 1990, 2000, 2006, 2012 and 2018.

With the Land Information System Austria (LISA), GeoVille developed the conceptual precursor of the EAGLE data model as object-oriented, multi-resolution LC/LU data repository for multiple user instances from various domains such as spatial planning, agriculture, forestry and natural resource management. Since then, a series of national implementations have been successfully achieved by GeoVille. In 2012 GeoVille joined the

developments of the GMES Initial Operations (GIO), which was earmarked as a component of the Land service to operate “a multi-purpose service component” and led the HRL on Imperviousness.

To raise awareness among the public and decision-makers for the benefits of the Copernicus programme, and, in more general, for the Earth observation sector, GeoVille joined a team of experts to deliver the so-called “Copernicus Briefs”. These 71 factsheets provided concise overviews of various satellite based applications highlighting their benefits for Europe’s decision makers and public.

Starting in 2014, the European Environment Agency (EEA) has initiated the mapping of five high resolution layers (HRLs) on land cover characteristics through the new, fully operational Copernicus Land Monitoring services (CLMS), namely 1) Imperviousness, 2) Forest, 3) Grassland, 4) Wetland and Water bodies and 5) Small woody features. All layers cover the EEA-39 area and are updated regularly (every 3 years). Since then, GeoVille has acquired and solidified a unique CLMS product heritage and expertise, as leading producer of the CLMS pan-European HR Layers Water &Wetness and Imperviousness, as well as production partner of the Small Woody Features and Grassland products.

Following the production of the Pan-European Layers, the EEA has commissioned the production of the local component of the CLMS, that are Urban Atlas, Riparian Zones, Natura2000 and Coastal Zones. These local layers provide specific and more detailed information on different hotspot areas across Europe. GeoVille is production partner of the Natura2000, Riparian Zones and Coastal Zones products.

Next to the Copernicus Land Monitoring Services (CLMS), GeoVille has also been active in the Copernicus Emergency Management Service (CEMS). CEMS supports all actors involved in the management of natural or manmade disasters by providing geospatial data and images for informed decision making and constantly monitors Europe and the globe for signals of an impending disaster. The Joint Research Center (JRC) of the European Commission is responsible for most CEMS and GeoVille has been able to join several developments and implementations, such as the JRC Risk & Recovery mapping in 2016, the JRC Sentinel-2 Global Mosaic in 2017 and most recently the developments of the JRC Global Flood Monitoring in 2020.

In 2019, the EEA has introduced a new era of land monitoring products, the so called CLC+ suite of products (2nd generation CORINE Land Cover - CLC+), enabled by the predevelopments of the Austrian Land Information System (LISA). The CLC+ complements and extents the suite of currently existing CLMS products to better align with increasing requirements for European Land Cover Land Use (LC/LU) monitoring and reporting obligations. The CLC+ portfolio includes four components:

- the CLC+ Backbone: detailed wall to wall geometric vector reference layer with basic thematic content (18 classes) and a 12-class 10m spatial resolution raster product
- the CLC+ Core: consistent multi-use grid-based Land Cover/Land Use (LC/LU) hybrid data repository

- and the CLC+ Instances: tailored LC/LU products, on a 100m grid level, based on an on-demand combination of available (EAGLE harmonized) LC/LU information (e.g. LULUCF, CAP2020, etc.)

Two out of those three components (CLC+ Backbone, CLC+ Core) have already been started and are currently implemented by GeoVille and its partners.

End of 2021 a new Copernicus Layer has been initiated – the High Resolution Layer - Vegetated Land Cover Component (VLCC), which will address for the first time ever the monitoring of agricultural and other vegetated surfaces.

The VLCC will be implemented by GeoVille, together with the main partners GAF (Germany) and VITO (Belgium):

NEW PROJECTS

OUR NEWEST COPERNICUS ADDITION

High Resolution Layer - Vegetated Land Cover Component (VLCC)

The new HRL Vegetated product suite (HRL VLCC) will represent one of the future four major groups of European HRLs (besides HRL Non-Vegetated, Cryo-/Hydrosphere and Small Woody Features) as part of the pan-European Copernicus Land Monitoring Service (CLMS) component for the EEA-39 countries. It consists of the HRL Forest, HRL Grassland, HRL Crop Types, and their derived or ancillary layers. With the HRL VLCC, the European Environment Agency (EEA) will fill the current gap of agricultural monitoring within the CLMS portfolio, while ensuring the time series continuity of the existing products previously produced within HRL Forest and HRL Grassland.

To improve the applicability, the HRL VLCC will increase the update frequency for status layers from 3 years to yearly updates, while change layers will keep the same 3-yearly update frequency, to ensure comparability of the change time series.

The HRL VLCC product supports related environmental policy actions of the EU, such as the Good Agricultural and Environmental Conditions (GAEC) requirements as well as measures aiming at the “Greening of the Common Agricultural Policy” (CAP). Further, the HRL VLCC is expected to support food security measures, and facilitate downstream services, such as crop growth and yield modelling, drought monitoring etc.

Contract Value: 2150K €

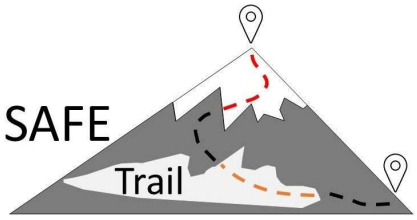
ESA EO APPLICATIONS

RAMONA: Rangeland Monitoring for Africa

RAMONA is a project of the ESA EO-Africa programme with the aim to develop and demonstrate a EO-based rangeland monitoring system at a continental scale. The project will provide an increased capacity in evaluating and responding to spatiotemporal fluctuations in forage biomass availability and quality to aid to livelihood decisions and thus human wellbeing. The service will report on rangeland extent, type and carrying capacity which in turn directly quantifies land degradation and biodiversity loss across African rangelands.

Contract Value: 290K €

SAFETrail



Tourism represents one of the main sources of income for local populations in the Alps. The pressures arising from tourism in the Alps are manifold. The heterogeneous concentration of Alpine tourism in space and time, results in a spatial and temporal concentration of environmental impacts. Recreational and tourism activities, such as hiking, mountain biking and horse riding affect alpine vegetation in high mountain areas are not only causing disturbances in natural ecosystems but affect as-well the fragile alpine vegetation.

SAFETrail is a project of the ESA EO-Alps initiative and aims to proof the feasibility for the provision of near-real-time EO services to support the better management the tourism activities in high mountain areas of the Alps in a sustainable manner.

Contract Value: 215K €

The Austrian Research Promotion Agency – KIRAS Programme

gAIa: Development of hazard indication maps for landslides from consolidated inventory data

In the context of anticipated climate change, meteorologists expect an increase in extreme weather events in Austria, which may serve as precursors of gravitational mass movements such as landslides. Landslides represent a safety risk for people and infrastructure, and often cause great damage. Consequently, their detection is crucial to be able to act promptly and to avert potential damage at an early stage. A high-quality and complete data inventory is an essential prerequisite for a better understanding of landslides and for the creation of maps, risk analyses or the development of an early warning system.

Thus, the aim of gAIa is to utilize methods of modern artificial intelligence (AI) to provide policymakers with this essential basis for decision-making. More specifically, within gAia we will harmonize and fuse heterogeneous data sources and model the occurrence probability of landslides. In this way, circumstances, which may lead to landslides, can be detected and the extended data inventory used to provide improved hazard risk maps.

Contract Value: 174K €

Boosting access to satellite data

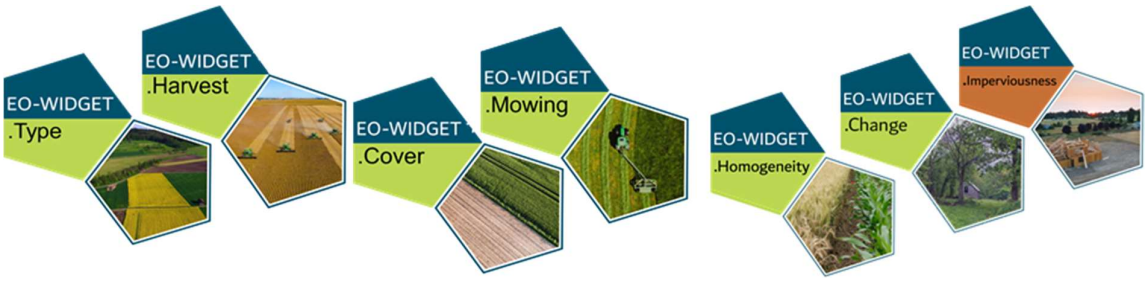
EARTHSTREAMER

With the launch of EarthStreamer at the end of 2021, GeoVille has kicked-off a new era of serving big Earth observation data between high-performance computing infrastructures, servers, and end-user devices. EarthStreamer provides a services to tackle the big-data challenges of digital platforms –significantly reducing the sizes of digital-archives and overcome limitations of network bandwidth to exchange data. By taking advantage of cutting-edge streaming technologies and adapting it to the needs of the Earth observation industry, EarthStreamer provides a revolutionary solution to store and disseminate satellite derived data over standard networks and commodity hardware. All this comes with a stack of well proven technology which serves Petabytes of data daily into the life of billions of users. A solution capable to build upon todays and future satellite data archives and connect them all around the world. The EarthStreamer technologies are a self-funded development by GeoVille.

PROGRESS ON CAP AREA MONITORING IN AUSTRIA

ESA InCubed Activity Update

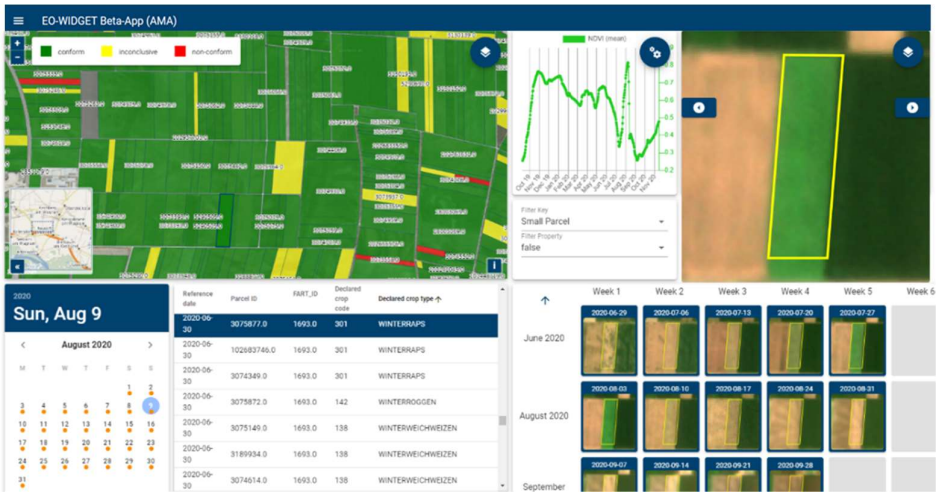
EO-WIDGET- Agricultural Area Monitoring Services



Within the ESA InCubed co-funded project EO-WIDGET, GeoVille, together with EOX IT Services GmbH, established and operates a service package dedicated to European Paying agency and their suppliers. The consortium provides customers with EO-based agricultural area monitoring products via dedicated IT mechanisms and visualisation via easy-to-onboard mini-applications – so called widgets. These services allow for fast access to the products, reports and validation tools to specific information products, that allow to monitor, assess, and report on various agricultural practices and regulatory obligations in the framework of CAP Monitoring – these products are commonly referred to as Checks-by-Monitoring Services.

The new INVEKOS directive (Article 10) of the Area Monitoring System (AMS) extends the reporting requirements for reliable observation, tracking and assessment of agricultural activities and practices with three priority products. These priority products assess the presence and development of sealed or other non-agricultural areas on a parcel level over the

entire growing season. This is the first step of the Member State to validate the eligibility of the claimed area by the farmer. EO-WIDGET is the first development activity in Europe that directly corresponds to these new directive and is able to serve the needs of Paying Agencies across Europe and their incumbent suppliers with new ways of implementing Checks by Monitoring (CbM) and Area Monitoring System (AMS) via commodity services. The consortium is working closely with our pilot customer, the Austrian Paying Agency AMA, to develop and implement products and services in fulfilment of the new regulations.



Public demo for EO-WIDGET (GeoVille, EOX)

Sales 2021: 6.34M €
ESA Share: 1.67M €

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LinkedIn: linkedin.com/company/geoville-information-systems-gmbh

3.9 Joanneum Research Forschungsgesellschaft mbH

JOANNEUM RESEARCH is dedicated to Space research and technology since 1978. The Institute for Information and Communication Technologies (DIGITAL) is focusing on the following competence areas

- Satellite communications and navigation
- Microwave propagation and radar technology
- Development of space-qualified hard- and software
- Verification and optimisation of systems and services in field trials
- Remote sensing
- Processing of data from active and passive space- and airborne sensors
- Space robotics

JOANNEUM RESEARCH is a highly recognised partner in large number of projects by the European Space Agency ESA, the European Union, international and national space industry and research establishments as well as foreign national space agencies such as NASA, ASI and DLR. Prototypes are developed into commercial products in collaboration with national and international industry. Successful examples are a monitoring service for forest damage assessment, a satellite channel emulator, a satellite signal monitor, contributions in the field of vision-based navigation and autonomy of space probes operating on planetary surfaces, and 3D vision operations for the NASA Mars 2020 Mastcam-Z instrument, as well as activities to prepare for the 3D vision capabilities of the ExoMars 2022 panoramic camera system. Developed systems are validated and optimised in field trials.

Communications & Navigation Technologies

W-Cube

On 24 June 2021, the first-ever satellite with a W-band radio transmitter on board was launched. The objective of this mission, funded under the ARTES Advanced Technology programme, is to improve our understanding of the atmospheric effects in the propagation of radio signals at such a high frequency band. The mission's success will help pave the way for future operational telecom services in W-band.

After the successful launch of the spacecraft from Cape Canaveral, Florida, USA, and deployment in a 550-km-altitude sun-synchronous orbit the spacecraft is transmitting beacons at 75 and 37,5 GHz and is operating as expected.

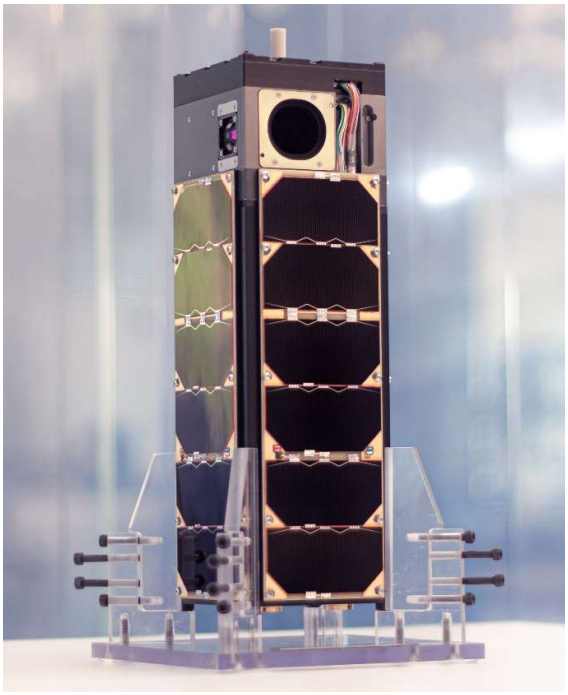
The launch marks the beginning of a two-year campaign of measurement collection, where continuous-wave radio signals will be routinely received and processed on the ground – in order to build a better picture of the atmospheric channel propagation statistics. This will be carried out at the JOANNEUM RESEARCH facilities, in Graz, Austria. The research group "Space and Communication Technology" is leading the European consortium who designed, manufactured and built the spacecraft and associated ground segment for this mission. JOANNEUM RESEARCH already had valuable expertise in this field having been heavily involved in the Alphasat Q/V-band experiment (characterizing atmospheric propagation in that frequency band).

JOANNEUM RESEARCH leads a strong consortium of companies which made it possible to be the **world's first** to transmit in 75 GHz from a LEO Satellite. Europe keeps with this project its leading position in wave propagation for satellite communication.

As part of this consortium, Kuva Space have designed, assembled and tested the spacecraft to make sure it withstands the rigours of the launch and of the space environment. Kuva Space will also monitor the health of the spacecraft and run operations using the ground station they have set-up at their premises in Espoo, Finland.

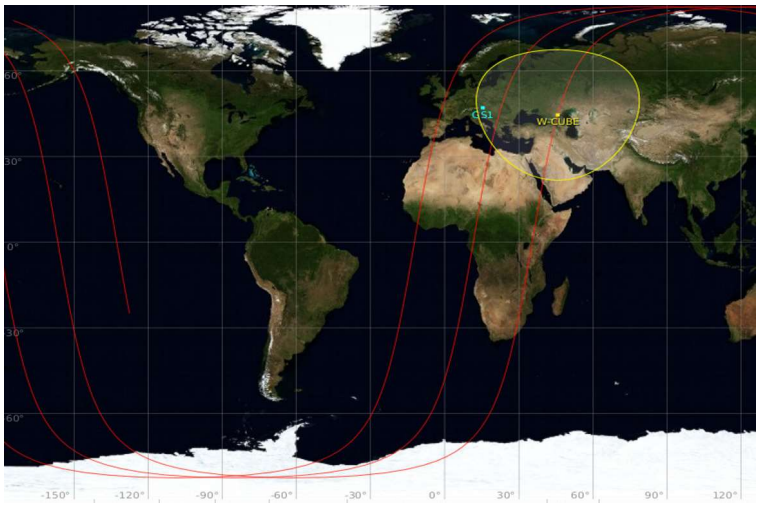
The payload developed by VTT, in Helsinki, Finland, includes the frequency beacons that generate the signals transmitted to the ground station. Amplifiers and frequency converter came from Fraunhofer Institute for Applied Solid State Physics, in Freiburg im Breisgau, Germany.

Portuguese Luis Cupido Technologies have developed the ground antenna, including the tracking system and JOANNEUM RESEARCH implemented the 4-channel beacon receiver and analysis software to perform statistical analysis and to extract a channel model out of the data.



The 3U CubeSat was launched on the Falcon 9 Transporter 2 rideshare mission (Image credit: Kuva Space)

Final assembly of the 75/37,5 GHz beacon receiving antenna on top of the roof of the JOANNEUM RESEARCH building in Graz/ Steyrergasse



The W-Cube Satellite is 5-6 times/24h in the visibility of Graz and allows then wave propagation measurements

a. A low-cost 40-element GNSS antenna array

Antenna arrays are more and more used for Global Navigation Satellite Systems (GNSS) applications. There are various aspects and use cases, which benefit from an antenna array like interference detection and mitigation, GNSS signal quality monitoring and estimation of unknown code chip sequences. Whereas previous activities usually rely on a smaller number of antennas, this project concentrated on a quite large array using 40 antenna elements. Considering such big number of antennas and sampling units, economical considerations are not to be neglected. Hence, the number of antennas was a compromise of costs and achievable passive gain. Fortunately, the constantly decreasing prices of even high performance SDR platforms allow low-cost solutions.

For the selection of suitable low- to medium-cost commercial off-the-shelf (COTS) components a thorough market survey was done. The criteria for selecting an antenna model was a reasonably homogenous pattern down to an elevation of 25 deg. This allows evaluating also satellites at lower elevations with increased gain. The requirements for the sampling platform were a quantization of the ADC of 12 bit or more, and a sampling rate high enough to cover at least most of the E1 band.

The most promising antenna models and SDR platforms were procured and tested in the laboratory. In the end, a Tallysman VSE6137 antenna and a BladeRF 2.0 micro xA4 software-defined radio board were chosen. Finally, a system design was worked out and a system was set up out of 40 antenna elements, 20 dual-channel BladeRF 2.0 software-defined radio (SDR) boards, 20 low-end recording PCs, network infrastructure, a high-end processing PC, power supply and temperature cooling. For synchronization, the BladeRF 2.0 offers a synchronisation input for external clocks to control the sampling. In addition, it provides a synchronization output. Using both sync input and output, all 20 dual-channel sampling units were controlled by a single GPS disciplined oscillator as external clock. This saved a lot of money compared

to a “1 by 20 signal splitter”. However, it does not solve the issue of data stream synchronization, which needs to be done additionally by calibration or purely by software using GNSS signals.

Since electromagnetic interference was expected, for electromagnetic shielding, the SDR platforms were individually put into aluminium cages, allowing air circulation for thermal reasons. Unfortunately, this was not sufficient. Depending on the geometric configuration, a decrease of 20 dBHz and more could be observed in the CN0 values making signal tracking (nearly) impossible. Numerous investigations and tests followed to find the source of interference. Different shielding material and different system design were tested. The source could be identified to be the SDR platform but the component on the SDR platform causing the interference could not be figured out. In the end, the electromagnetic interference (EMI) issue could successfully be solved by separating antennas and SDR units with 40 pieces of 12-meter cables and moving the SDR units indoors behind concrete walls.

Investigations of the data quality were performed using elaborated GNSS software-defined receivers like the open-source GNSS-SDR, SX3 and MUSNAT. It had to be found out that a GNSS-specific AGC functionality needed to be implemented, otherwise, the performance of the different antennas / channels was arbitrary.

In the end, the system is working. It allows the simultaneous collection of IQ sample data of 40 antennas with a sampling rate of 35 MSPS (5.600 MBytes/s) and any kind of post-processing. By applying specific beamforming techniques in post-processing, the antenna can act as an omni-directional high-gain GNSS antenna to investigate GNSS signals. In general, such a setup allows performing multiple research activities in the field of controlled reception pattern antennas (CRPAs), direction finding, beamforming networks, signal quality monitoring and blind chip sequence estimation, and localization based on signals of opportunity (SoO).

Final antenna platform with 40 elements

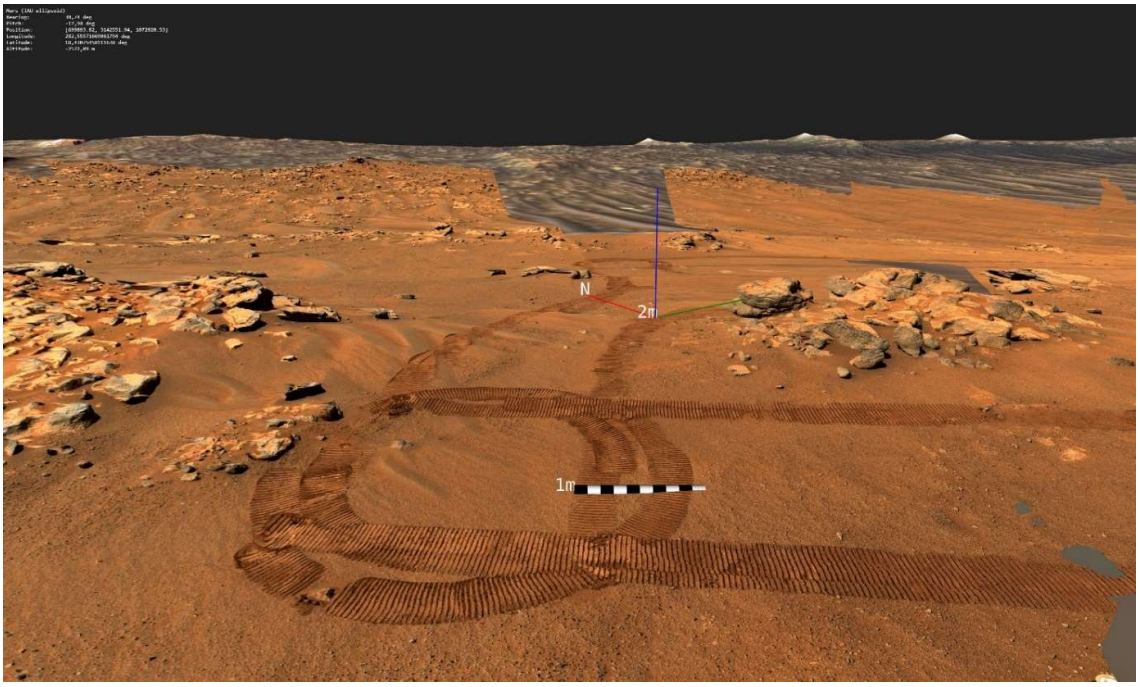
Space Robotics Vision / Space Science & Exploration

Mars 2020 Mastcam-Z 3D Vision

The NASA Mars 2020 *Perseverance* Rover mission landed on Mars on 18th February 2022 to undertake the next key steps in our understanding of Mars' potential as a habitat for past or present life. Among other instruments, Perseverance carries Mastcam-Z, a stereoscopic zoomable multispectral camera coordinated by Arizona State University. Gerhard Paar from JOANNEUM RESEARCH is one of about a dozen international Mastcam-Z Co-Investigators (Co-Is).

Within the framework of an ESA PRODEX contract, JOANNEUM RESEARCH and VRVis, with scientific support of the Austrian Academy of Science (ÖAW; Prof. Christian Koeberl and his team), have started to cover 3D vision building blocks (3D vision processing PRoViP and visualization – PRo3D) in 2021 and to assemble 3D models, data fusion products and visualizations from Mastcam-Z stereo pairs at various scales (Figure) for further geologic interpretation during the mission in the operational timeframe.

The Austrian team is embedded in daily operations and contributes to the regular publication waves of the mission (with about a dozen publication participations already in 2021), emphasizing on impact science, aeolian and geologic analysis, as well as provision of outreach data products.



PRo3D screenshot of annotated Mars 2020 Sol 182 Mastcam-Z Scene 8200 (34mm focal length) PRoViP stereo reconstruction, overlaid on HiRISE satellite-based RGB-textured Digital Terrain Model (DTM).
Credits: NASA/JPL/CalTech/ASU/MSSS/USGS/JR/VRVis

ExoMars PanCam 3D Vision

The joint ESA/Roscosmos ExoMars Rover Mission was scheduled for launch in summer 2022 and landing on the Red Planet in spring 2023 to search for signs of past and present life on

Mars. One important scientific sensor is the panoramic imaging system *PanCam*, mounted on the Rover Mast. It consists of a wide-angle multispectral stereo pair (Wide-Angle Camera, WAC) and a high-resolution monoscopic camera (High-Resolution Camera, HRC). Main objectives during its 218 sols (Martian days) nominal operational phase are the provision of context information to detect, locate and measure potential scientifically interesting targets, localize the landing site, geologically characterize the local environment, and observe experiments. Gerhard Paar from JOANNEUM RESEARCH is Co-I for PanCam and the ExoMars Close-Up Imager CLUPI.

The three-dimensional (3D) PanCam vision processing toolchain "PRoViP" is an essential component of mission planning and scientific data analysis. Standard ground vision processing products will be digital terrain maps, panoramas, and virtual views of the environment. In 2021, the main processing components as provided by the PanCam 3D Vision Team under JOANNEUM RESEARCH coordination (ASAP-15 Contract) were delivered to the Rover Operations Control Center (ROCC) at ALTEC in Turin / I. The processing tools were used in ExoMars design simulations with images from the Mastcam instrument of the Mars Science Laboratory (MSL) mission, see Figure.

Particular emphasis is given to visualization for geological interpretation (PRo3D tool), which is under further development by the Austrian research entity VRVis.

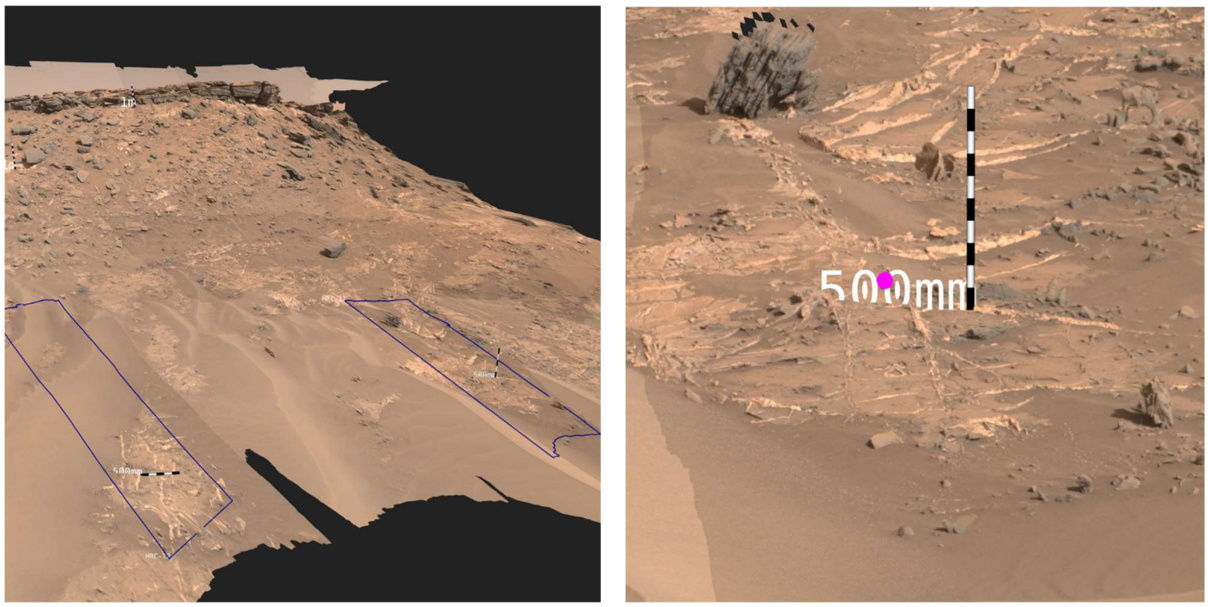


Image data as prepared by JR and VRVis for ExoMars Design Simulations in Autumn 2021. Images were rendered using PRo3D on PRoViP 3D vision processing products from MSL Mastcam stereo image sequences. Left: Simulated ExoMars PanCam WAC image with PanCam HRC footprints from another Rover position indicated. Right: Simulated PanCam HRC image. Credits: NASA/JPL/CalTech/ASU/MSSS/JR/VRVis

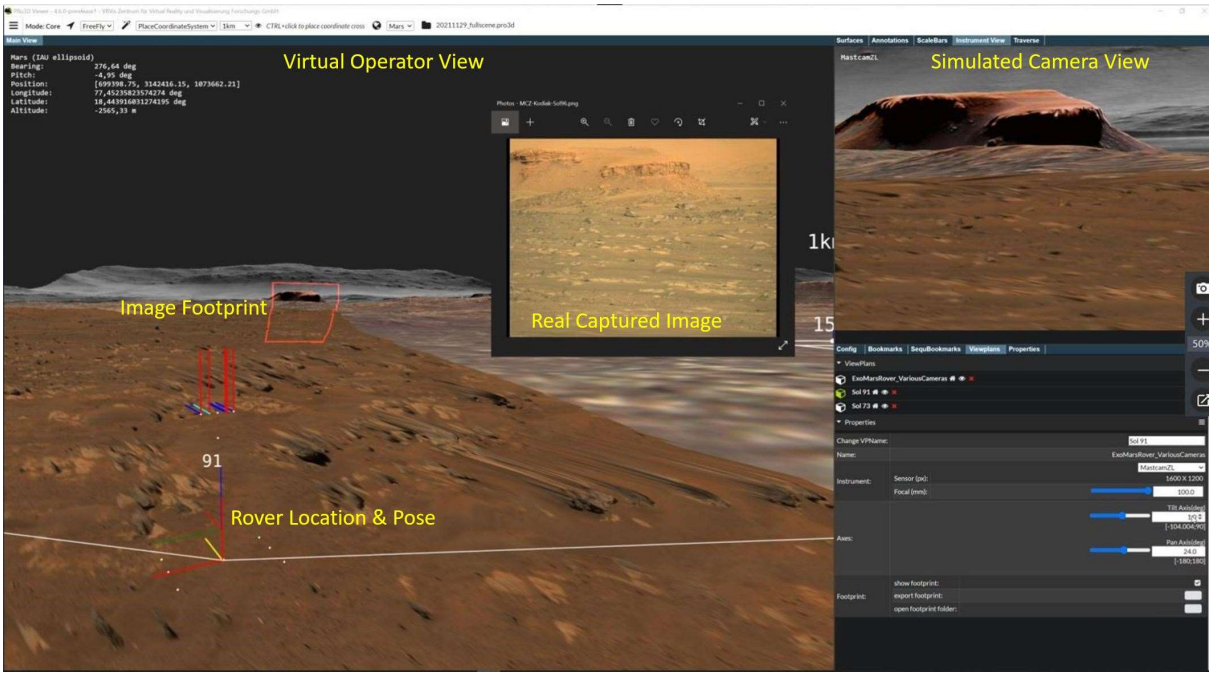
ExoMars NavCam/LocCam 3D vision processing

The ExoMars-2022 Rover *Rosalind Franklin* will be controlled from Turin in Italy, where the Rover Operations Control Centre (ROCC, provided by ALTEC/Thales Alenia Space Italy) is located. To plan the Rover's daily operations, in particular to avoid dangerous morphological formations (cliffs, rocks, dunes etc.) during its ride on our outer neighbour planet's desert

surface and to select the next scientifically interesting targets, a precise 3D model of its surrounding is needed. JOANNEUM RESEARCH is providing the software to generate such 3D models based on daily images from the Rover's navigation and localization cameras (NavCam & LocCam) for the so-called "tactical" planning. The processing components are developed in high synergy with PanCam 3D vision processing, with emphasis on fast and robust 3D vision products' delivery and embedding in the mission environment to allow scientific and engineering tactical decisions being taken within minutes after data downlink receipt. Deliveries in 2021 led to first end-to-end successful processing testing in the ROCC processing environment.

WIBSTAC - Tactical Rover Planning by Intelligent Wide-Baseline Stereo

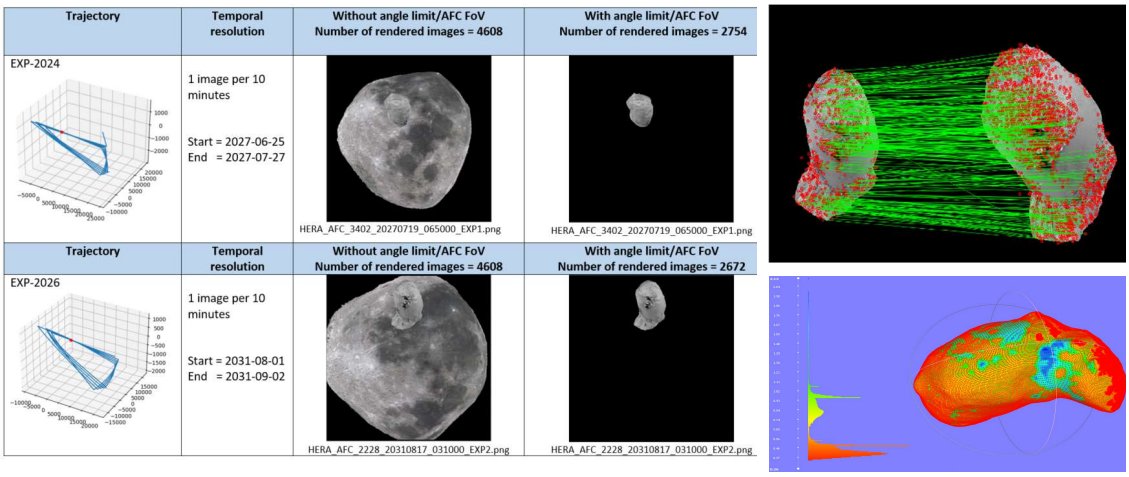
Contemporary rovers (e.g. the MSL rover Curiosity or Mars 2020 Perseverance) are able to travel more than 100m per day, a distance that cannot be covered by any on-board stereo vision sensor for planning a safe path on Earth or on-board prior to travelling. With proper selection of imagery acquired, coupled with rover motion, a technique called "wide baseline stereo" (WBS) will lead to much longer ranges to be covered by 3D mapping using on-board rover vision sensors, and therewith considerably enhance the capability of strategic planning. The WIBSTAC project, starting in September 2021 in cooperation between JOANNEUM RESEARCH, VRVis, SLR Engineering and ALTEC (Turin), deals with the planning, selection, processing and visualization of images taken at different rover positions and/or by different vision instruments, to enhance the working distance of 3D vision from such sensors both for operational and scientific purposes such as Rover path selection, science campaign planning, or geologic analysis of distant regions. In 2021, the required processing and visualization functions were designed, and building blocks such as a large-distance view planner (Figure) were implemented.



PRo3D View Planner first version for WIBSTAC. It allows a simultaneous view of the 3D scene for a virtual operator, the simulated camera view, and the embedding of rover locations and annotation of image footprints, based on a fused representation of 3D reconstruction from rover stereo image scenes (close-range) and satellite Digital Terrain Model (far-range). Credits: NASA/JPL/CalTech/ASU/MSSS/USGS/JR/VRVis

HERA 3D Vision

In 2019, JOANNEUM RESEARCH and Austrian Partner VRVis had started their developments for vision-based tactical 3D reconstruction of the double Asteroid system Didymos for the HERA Asteroid mission to support the spacecraft's rendezvous with Didymain and its moon Dimorphos. In 2021, the 3D vision processing chain and tools for scientific visualization (Figure) were delivered. Virtual views based on the spacecraft trajectories as planned for the approach to the asteroids were used to verify a photogrammetric chain that allows the seamless three-dimensional modelling of the asteroid bodies in all phases of the proximity operations. Further components of the 2021 delivery emphasized on enhancements for change visualization and the simulation of the latest approach scenarios (Figure).



Simulation, 3D reconstruction and visualization building blocks for HERA 3D vision. Left: Different approach and imaging scenarios and simulated images. Top right: Correspondences calculated from different views, as needed to gain camera positions & orientations, as well as for 3D reconstructions. Bottom right: Visualization of simulated change.

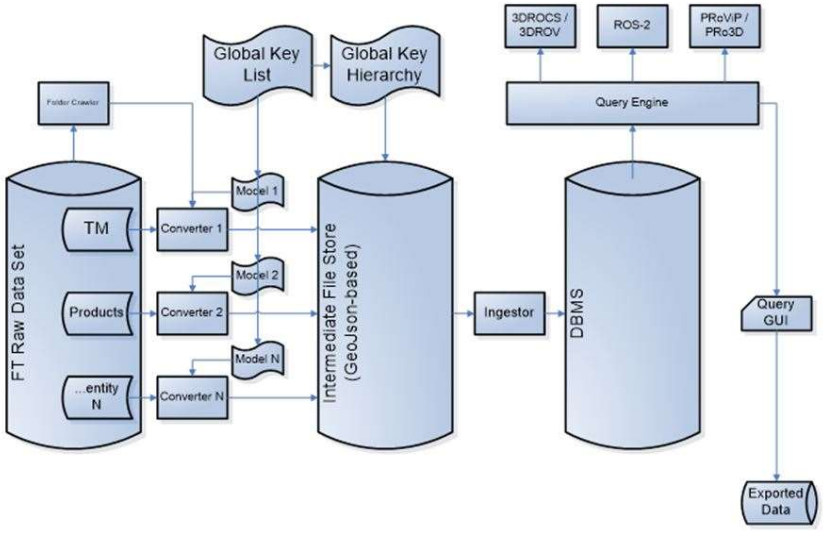
ADE: Autonomous Decision Making in Very Long Traverses

The Horizon 2020 SPACE Project "ADE" (Autonomous Decision Making) dealt with Rover autonomy in terms of navigation, planning and science decisions. JOANNEUM RESEARCH settled the "ground truth" infrastructure for the validation of specific ADE navigation components by building a high-fidelity 3D simulation framework that allows realistic renderings of images from real environments in various scales that are combined to a multi-scale 3D model.

For the visualization component, the VRVis Planetary Robotics 3D Viewer (PRo3D) was used. Further JOANNEUM RESEARCH activities in ADE after a successful field trial in Germany were the support and annotation of science training data, the definition of the test scenario, the evaluation of tests and the collection of the final data set.

DIARY

The DIARY (fielD trIal dAta pRocessing sYstem) study und ESA contract is a cooperation between JOANNEUM RESEARCH and EOX IT Services GmbH. DIARY is establishing a framework to provide the required tools for the archiving of data sets generated as a result of field trials and simulations. The archive will allow the later usage of such data for customer applications in a well-organized way (Figure).



DIARY concept. Raw data sets from space exploration field trials (FT) such as instrument telemetry (TM), data products and meta data are converted into data schemes that can be understood by a generic concept, to be ingested into a Data Base Management System (DBMS). This allows queries to search for data in an organized way and collect / export it for applications that use the data for testing and validation.

Outlook for 2022

The participation in the Mars 2020 mission with 3D vision data processing and visualization for the Mastcam-Z instrument will go on with JR, VRVis and ÖAW until the end of 2022. In 2022, further testing of processing and visualization assets will be elaborated by JOANNEUM RESEARCH and VRVis for ExoMars PanCam, and for the ExoMars ROCC (Rover Operations Control Centre) the 3D vision data processing for the NavCam and LocCam engineering rover camera systems for tactical mission planning will be finalized, tested and deployed in its next generation. This also includes further maintenance and calibration of the “Mars Terrain Simulator (MTS)” 3D vision system. The WIBSTAC project will realize its main 3D vision processing and visualization components for exploiting wide baseline stereo configurations, to be utilized in Mars 2020 and ExoMars operations. Scientific processing and visualization contributions for the HERA 3D vision framework will be defined until mission operations, with an activity start still in 2022. A novel approach for data provenance (following up the history and story of mission science data) emphasizing the HERA case will be started to investigate in a separate ESA activity. Within the DIARY field trials archiving activity, the testing phase will start using trials data from the Sample Fetching Rover (SFR) development.

Sales 2021: 3.29 M€
ESA Share: 1.48 M€

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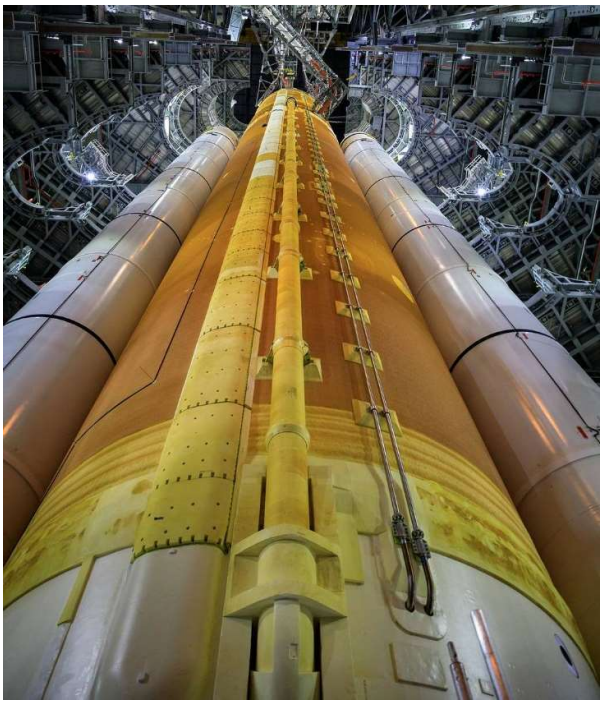
3.10 Magna Steyr Fahrzeugtechnik AG & Co KG Aerospace

SLS (Space Launch System) – Propulsion Systems Lines & Flexible Joints

The cooperation with The Boeing Company for the manufacturing of propulsion system Components for NASA's Space Launch System (SLS) was successfully continued in 2021. Additional contract awards for propulsion systems equipment were successfully secured and further Flight Hardware deliveries completed. Flight hardware is now in manufacturing for SLS core stages #3 to #6.

The first Core Stage with Magna's hardware on board was shipped in the meanwhile to Kennedy Space Center (KSC) in Florida, where the first full stack of SLS was successfully performed to be ready for its inaugural flight in 2022.

The development of components for SLS Exploration Upper Stage (EUS) was continued which contribute to use the full potential of this powerful launch system.



Source: NASA

AVIO Vega Evolution

In 2021 Magna completed the development and process qualification for the manufacturing of the M10 engine lines for LOX and LCH4, concluding with a successful Manufacturing Readiness Review (MRR). Subsequently the first prototype shipset of engine lines has been manufactured and successfully delivered to Avio for further integration onto the DM1 engine. This engine is foreseen to undergo extensive hot-fire testing at Avio's test facility in Sicily, Italy in 2022.
A follow-on activity was started for the development support and manufacturing of engine lines for the DM2 and DM3 protoype engines.

In parallel the development for the Liquid Propulsion Module (LPM) propellant lines was kicked off, starting with a trade-off face to define the basic layout and to make the material selection for the needed pipework. This is the first launcher program, where Magna's patented Aluminium Feed Lines technology is considered for realization. This gives the customer an option for designing a low mass propellant system.

Source: ESA


Source: Avio

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3.11 OHB Digital Solutions GmbH

Field of Work

OHB Digital Solutions GmbH's main activities comprise GNSS quality assurance and GNSS signal simulation, in particular the development and combination of navigation, telecommunications and information technologies as well as services for a wide variety of applications in the context of satellite-based navigation systems. With the know-how of the company's team members, we develop solutions, services and applications according to customer and market needs.

Field of Expertise

Topics of work include technical consultancy, system design and analysis, machine learning, software development, project preparation and management, business development as well as marketing and development strategies for new products and services.

International Partners

The expertise of the company team members is perfected by a tremendous pool of experts within the OHB group of companies. Furthermore, the company has access to a dense network of European partners, being active in all relevant fields of technology. Universities, research centres, industry as well as small and medium-sized enterprises work tightly together with OHB Digital Solutions. The company is a reliable and experienced partner of EU organizations related to the space industry such as ESA, GSA or Horizon 2020.

Our Customers

- Governmental agencies
- Industry (automotive, precise farming, tolling, off-road vehicles, geodesy, ...)
- Manufacturer of navigation devices (tracker, leisure, sports, personal devices, ...)
- Drones and unmanned flying devices
- Manufacturer of timeserver
- Defense sector

Our offices

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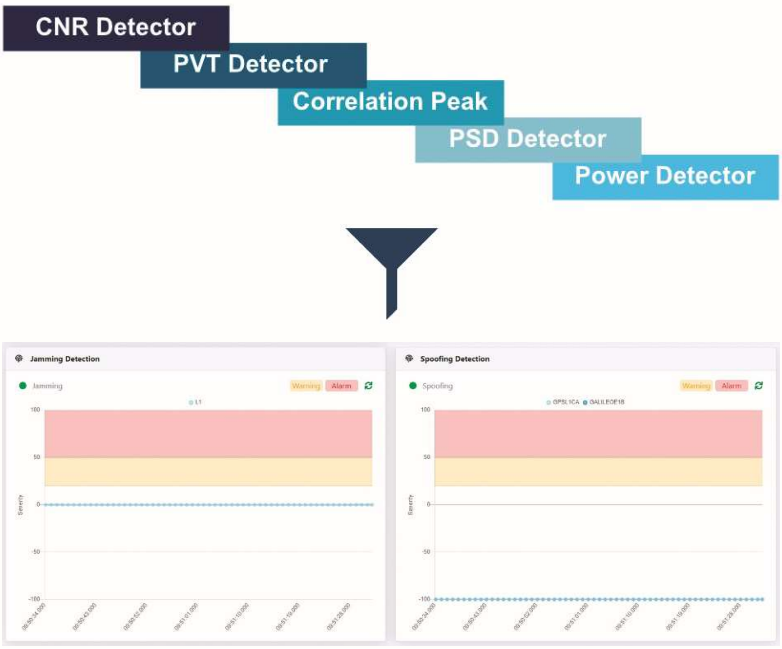
GNSS Quality Assurance

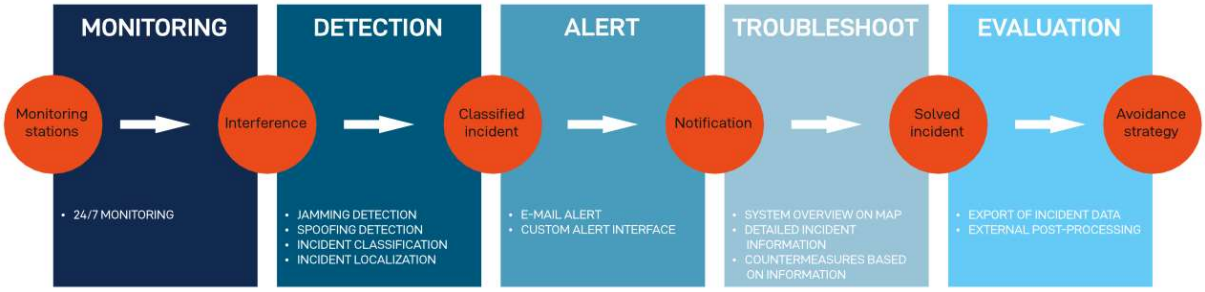
Global Navigation Satellite Systems (GNSS) positioning and timing services form the backbone of many applications and markets. Civilian GNSS services are free of charge and globally available but insufficiently protected against unintentional and even intentional disturbances. OHB Digital Solution researches for more than 20 years on how to provide means to monitor and augment the GNSS services with GNSS quality assurance. For many applications, it's not only precision that matters, but predominantly integrity too! OHB's knowledge and experience in GNSS quality assurance are available in many different forms in our GIDAS product family.

The core and heart behind the GNSS interference detection & analysis system (GIDAS) product family is OHB's knowledge of and experience with a multitude of different radio frequency interference detection techniques. We built up our experience in the course of more than 80 research projects, measurement campaigns and permanent on-site installations within the last two decades. Each available detection technique operates best in a very distinct working range, only with the smart combination of a wide range of different techniques a robust determination of either jamming or spoofing is possible reliably.

1. Multiple detection techniques (no extensive list)
2. Weighted combination of multiple techniques to improve robustness
3. Simple to read and interpret decision metrics for jamming and spoofing



On this foundation, the GIDAS product family is built to support our customers in reliable GNSS applications and operations. OHB Digital's core concept of safe and integer GNSS navigation foresees a multiple layer approach.



By constantly monitoring the GNSS signals, GIDAS is capable to detect, classify and even localize a radio frequency interference source in near-real-time. A wide range of GNSS users takes the ubiquity and free availability for granted, without considering the vulnerability of GNSS leading to misleading navigation or undetected failure. Awareness of the presence of GNSS interference is the first step of mitigation. As every customer application comes with its very distinct requirements OHB offers GIDAS features in different shapes. But all GIDAS product derivatives have one thing in common – the rock-solid experience of OHB in dealing with GNSS interference.

GIDAS EMBEDDED algorithms
The heart and core of GIDAS. Our knowledge regarding GNSS interference detection poured into source code, forming a C++ library to be directly integrated into customer solutions.

GIDAS EMBEDDED micro controller
We bring our knowledge directly to customer platforms. By supporting selected microcontrollers, GIDAS algorithms can run side-by-side with customer applications on existing hardware platforms.

GIDAS EMBEDDED analytics
GIDAS Analytics is a software suit for detailed post processing of digital I/Q signals. This is the best way to use our knowledge for your R&D or product development.

GIDAS MONITORING CENTER local
The monitoring center is the core entity of any permanent installation of GIDAS. It hosts a central database, the web-based user interface, and alarming interfaces.

GIDAS MONITORING CENTER nationwide
Having multiple GIDAS installations distributed nationwide requires one central dashboard to monitor, configure and maintain the system. The generation of nationwide interference reports has never been easier.

GIDAS MONITORING SENSOR stationary
The monitoring sensors form the eyes and ears for the GIDAS system. A stationary monitoring sensor is composed of a dual-module GNSS antenna and a receiving unit with a small form factor.

GIDAS MONITORING STATION mobile
Applications such as the enforcement of GNSS-based tolling systems require mobile units mounted on the rooftop of vehicles to monitor GNSS interference on the move.

GIDAS MONITORING STATION portable
For full autonomous operation, GIDAS is also available in a portable, full sustaining form factor. GIDAS portable includes everything to monitor GNSS signals everywhere you have to.

GIDAS adds to the operational safety of many different GNSS reliant applications. OHB's GIDAS is already operational in ports and airports, to help to secure GNSS navigation. The GIDAS product family addresses system manufacturers equally as end customers with a requirement on reliant GNSS positioning or timing. We bring our knowledge to your platform, product, service, or operation.

A first step of safe GNSS applications is the awareness of present threats – GIDAS detects, classifies, localizes and alerts if GNSS is about to be disturbed and makes therefore your GNSS-dependent application more robust and reliable.

Acknowledgement: **GIDAS** was carried out under a program of and funded by the European Space Agency. The view expressed herein can in no way be taken to reflect the official opinion of ESA.

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Sales 2021: 1.3 M€
ESA Share: 0.8 M€

3.12 Peak Technology GmbH

Peak Technology GmbH has developed its core competence towards the design and manufacturing of composite overwrapped pressure tanks and carbon/hybrid structures for launcher and satellite industry striving to become a market leader in this sector. With its roots as supplier for almost all Formula 1 Teams in the motorsports industry, Peak Technology is focusing on high-end technology and market competitive products for the aerospace industry.

Vega / Vega-C
Since the successful qualification of the aerothermal cover and the igniter cases for the Zefiro9 and Zefiro40 Stage for Vega & Vega-C launcher, we have started in 2021 the series production of these components.

Aero Thermal Cover

Igniter Case for Zefiro9

Vega-E
Starting in 2020 with the development of helium tanks for the upcoming Vega E launcher we will finalize PDR in 2022. This lightweight high-pressure tank is going to be responsible for the pressurization in the fuel lines of the newly developed upper stage.
Next to the helium tanks we started in 2021 a co-engineering together with AVIO for the Engine Thrust Frame for the Vega-E upper stage.

Composite Overwrapped High-Pressure Tank

Astris Kick Stage for Ariane6
In 2021 we were finally selected from Ariane Group for the development of the Helium high pressure tanks for the new Astris Kickstage for Ariane6.

Ariane 6 Astris Kick Stage

Sales 2021: 15 M€
ESA Share: 1.0 M€
Commercial Space: 6.5 M€

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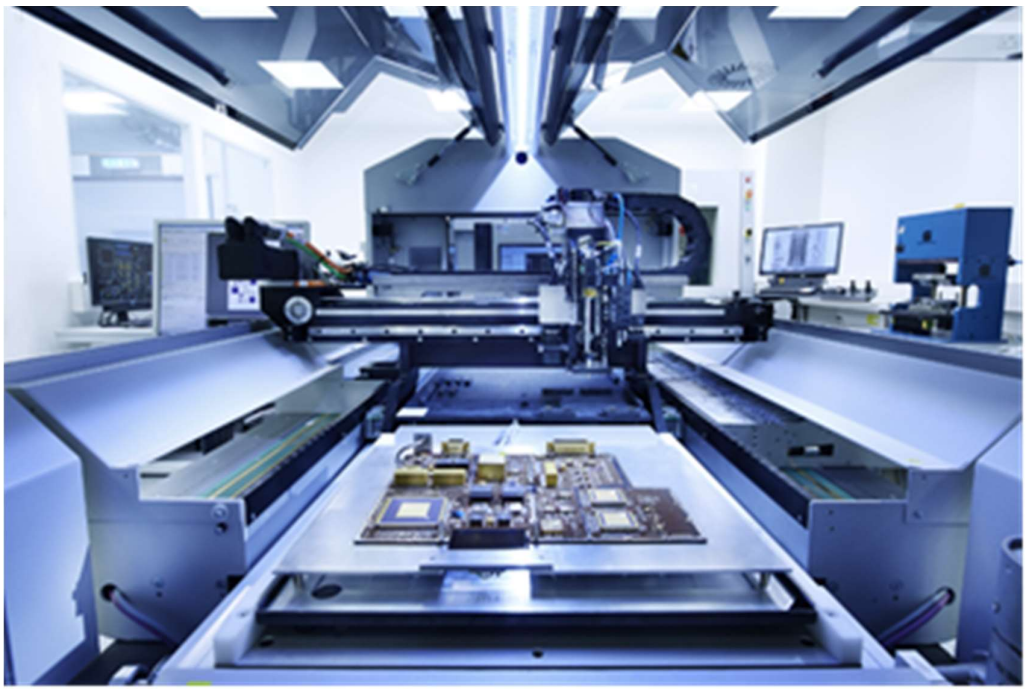
3.13 Ruag Space GmbH (Beyond Gavity Austria GmbH from May 1, 2022)

RUAG Space GmbH (RSA) belongs to Swiss RUAG International since 2008. The company is part of the RUAG Space Division, which employs around 1.600 people in Switzerland, Sweden, Austria, Finland, Germany and USA, thus forming the largest independent space product supplier in Europe. RSA, with some 230 employees the largest space company in Austria, has started its operations in 1983. The product portfolio comprises on-board electronics, mechanisms and thermal hardware as well as mechanical ground support equipment.



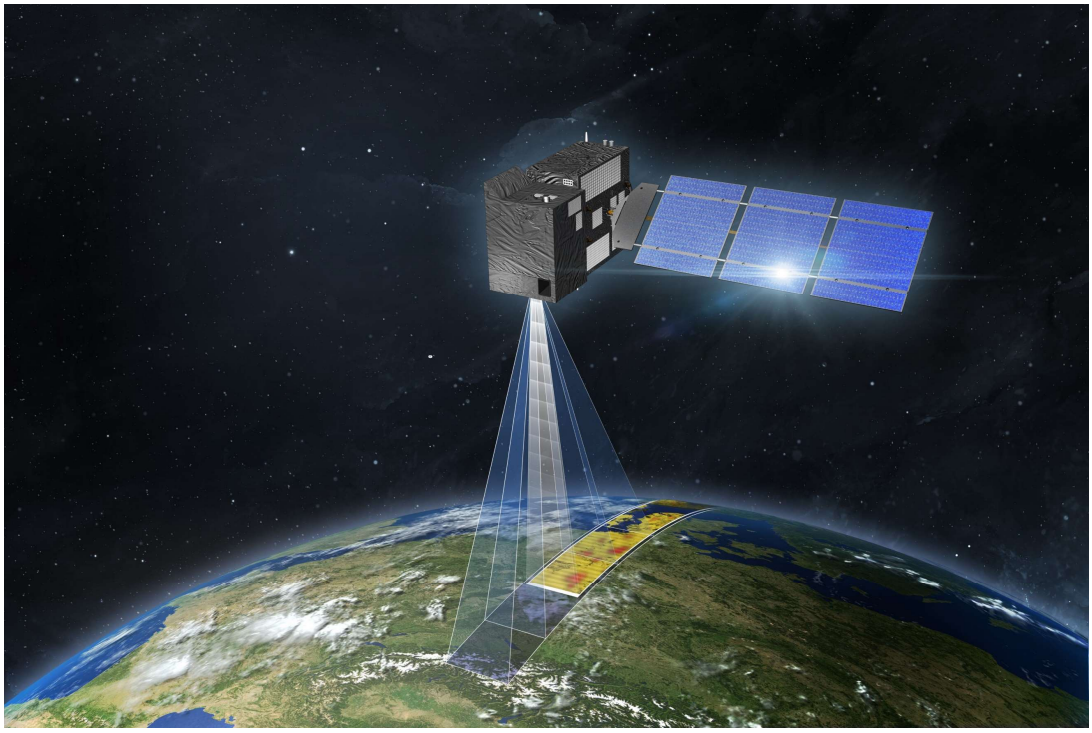
Products of high strategic importance for RSA are Global Navigation Satellite System (GNSS) Precise Orbit Determination (POD) Receivers. GNSS POD uses high-quality carrier and code measurements of a dual-frequency receiver on-board of a satellite, to achieve measurement of its position with an accuracy of a few centimeters in on-ground processing.



Automated assembly of Navigation Signal Processor

As of December 2021, 22 flight models of the first product generation have been delivered, of which 20 are operating in orbit. This includes all Sentinel A&B satellites of the joint ESA/EU Copernicus program and the NASA mission ICESat-2.

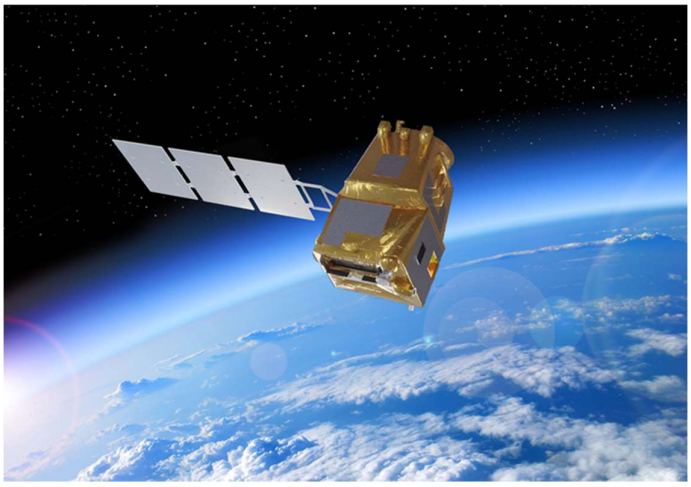
Building upon this dual-frequency GPS expertise and heritage, a next generation multi-constellation GNSS Receiver (PODRIX), incorporating Galileo signal processing capability, has been qualified in 2016. Orders for 50 flight models could be booked until end of 2021, and 36 units have been delivered already. The new receiver will fly on the Sentinels 1, 2, 3 C&D as well as on the German reconnaissance satellites SARah and OptSat developed by OHB. The latest orders include two of Europe's Copernicus new high-priority satellite missions: Carbon Dioxide Monitoring (CO2M) and CRISTAL. The CO2M mission will be the first to measure how much carbon dioxide is released into the atmosphere specifically through human activity.



Copernicus Carbon Dioxide Monitoring (CO2M) mission (source: ESA)

The new generation receiver already made its successful in-orbit premiere aboard the sea-level monitoring satellite Sentinel-6 Michael Freilich launched in November 2020. In Europe, the RSA market share for dual-frequency receivers exceeds 90%. Several contracts from South Korea and the first order from Canada demonstrate the strong market position also outside Europe.

With the development of lower cost GPS & Galileo single-frequency receivers for low earth orbit (LEORIX) as well as geo-stationary orbit satellites (GEORIOX) the product portfolio has been extended. LEO receivers were delivered to customers in Europe, the US, South Korea and the United Arab Emirates already. The most recent success is an order for the Copernicus Land Surface Temperature Monitoring (LSTM) mission, which will carry a high spatial-temporal resolution thermal infrared sensor to provide observations of land-surface temperature. The mission responds to priority requirements of the agricultural user community for improving sustainable agricultural productivity at field-scale in a world of increasing water scarcity and variability.



Copernicus Land Surface Temperature Monitoring (LSTM) mission (source: ESA)

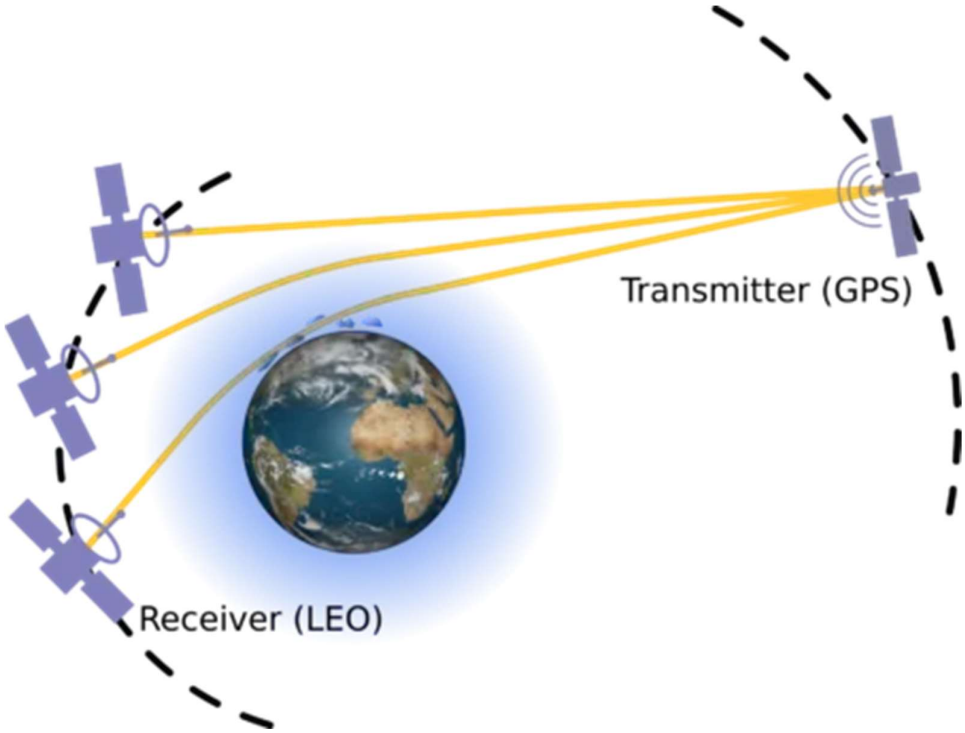
A remarkable success in the US institutional market was the selection of the RSA receiver for NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission to be launched in the 2022-2023 timeframe. The decision of the Goddard Space Flight Center (GSFC) in favor of RSA against domestic competitors was a real breakthrough and a strong indicator of the excellent position with this product in the global space market. This has been confirmed with the recent receiver order from Ball Aerospace for the Weather System Follow-on – Microwave (WSF-M), which represents the next-generation operational environmental satellite system for the US Department of Defense.

Weather System Follow-on – Microwave (WSF-M) environmental satellite (source: Ball Aerospace)

The GEO version (GEORIX), successfully qualified in 2018, will find its first applications in the new all-electric telecom platform Electra of OHB as well as in the satellite of a US customer.

RSA GNSS Receiver product family

RSA GNSS Receiver Modules also form the basis of the advanced radio occultation (RO) instrument of the Metop Second Generation satellites. RO uses GNSS signals to provide vertical profiles of temperature, pressure and humidity at high resolution. A total number of 26 flight units has been delivered in the frame of this contract.



Radio occultation for atmospheric sounding (source: EODC)

GNSS related electronics products contributed roughly one quarter to the RSA total sales in 2021.

In the current ESA/EUMETSAT Metop Second Generation meteorological satellite development program RSA contributions, besides the RO GNSS Receivers, comprise an Antenna Pointing Drive Electronics and electronics modules for a Remote Interface Unit.

Important contracts concern PLATO, the PLAnetary Transits and Oscillations of stars mission of ESA, which shall be launched in 2026 to find and study extrasolar planetary systems, with a special emphasis on rocky planets around Sun-like stars and their habitable zone – the distance from a star where liquid water can exist on a planet's surface. RSA will supply the Antenna Deployment and Pointing Mechanism Electronics, the Payload Accurate Thermal Control Unit and electronics modules for a Remote Terminal Unit.

Artist's impression of PLATO (source: ESA)

Another ESA mission relying on proven RSA electronics is Hera. Named after the Greek goddess of marriage, Hera will be humankind's first probe to rendezvous with a binary asteroid system – a little understood class making up around 15% of all known asteroids. RSA will supply the Solar Array Drive Electronics (SADE) for the spacecraft.

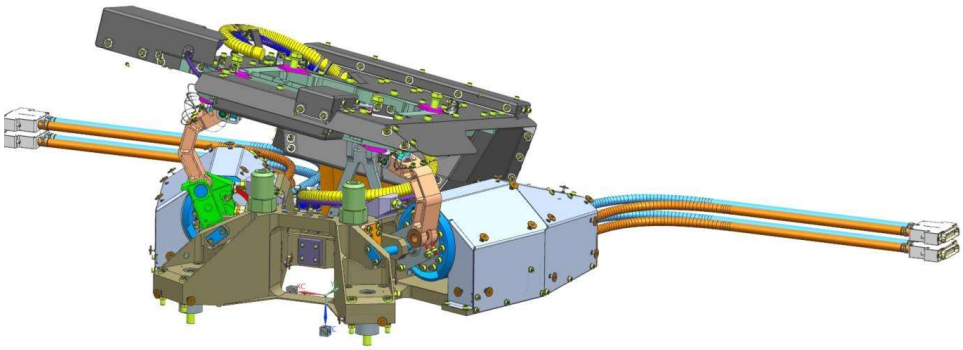
In the frame of the evolution of the European satellite navigation system into its second generation, RSA participates in the development of a Galileo Test Bed.

The strategic teaming agreement with TTTech concerning the development of high-performance data network space electronics based on TTTech's Time-Triggered Technology has resulted in first contracts with two prime contractors for NASA's Lunar Orbital Platform – Gateway (LOP-G). The customers are Maxar Technologies, responsible for the Power and Propulsion Element (PPE) and Northrop Grumman, leading the development of the Habitation and Logistics Module (HALO).

Artist's impression of Lunar Orbital Platform – Gateway (source: NASA)

In a consortium of RSA, TU Graz and Seibersdorf Laboratories the development of the ESA-funded nanosatellite mission PRETTY (Passive Reflectometry and Dosimetry) has advanced. RSA acts as Prime contractor and designer of the passive reflectometer, TU Graz is responsible for design and integration of the satellite and Seibersdorf Laboratories provides the dosimeter payload. The RSA payload processes direct and indirect GNSS signals reflected by ice or water and shall contribute to climate change research.

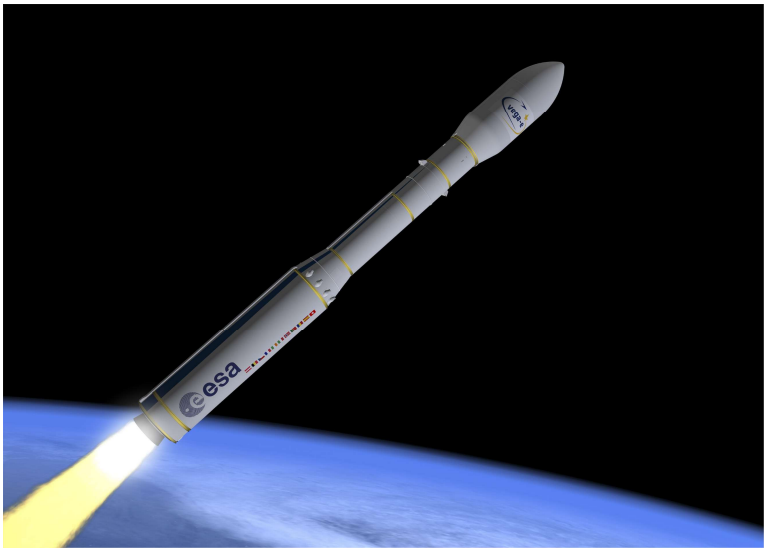
In the product segment Mechanisms, the development of an Electric Propulsion Pointing Mechanism (EPPM) concept optimized for volume production, and targeting the satellite constellation market, has advanced. The first application of the new product, now named APPMAX2 (Advanced Electric Propulsion Pointing Mechanism 2 Axes), will be Galileo Second Generation (G2G) satellites of Thales Alenia Space (TAS).



Conceptual design of APPMAX2 for G2G satellites of TAS1

[1]*This conceptual design has been produced under funding of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union and/or ESA.*

A contract signed with Avio, the prime contractor for the development of the new European Vega-E rocket, concerns supply of the Gimbal Joint for the thrust vector control of the upper stage. The gimbal joint enables steering of the stage along its flight path.



Artist's view of Vega-E (source: ESA)

A significant contribution to the 2021 sales in the mechanical area came from several major orders of the Mechanical Ground Support Equipment (MGSE) for the integration and transport of satellites. These orders include a container and a trolley for the Plato spacecraft of ESA, three satellite containers for the US satellite builder Ball Aerospace and a large satellite container as well as a multi-purpose trolley for NASA's Jet Propulsion Laboratory (JPL). The prestgious contracts with the two US customers underline the company's strong position with these products in the biggest space market.

RSA Satellite Transport Container

Sales of thermal insulation products reached about one third of total RSA sales. Significant contributions came from the ESA projects Juice, Metop Second Generation, Meteosat Third Generation (MTG) and Sentinel-5. With the supply of thermal insulation to OneWeb RSA has established a good position in the emerging mega-constellation market, based on significant improvements in logistics and production processes.

Dispenser with 36 OneWeb spacecraft, protected by RSA Thermal Insulation, on Fregat upper stage at Vostochny Cosmodrome (source: Arianespace)

Of big strategic relevance is the entry of the launcher thermal insulation market in the frame of the Ariane 6 development. In 2021 production of the first flight models of high-temperature thermal protection has commenced.

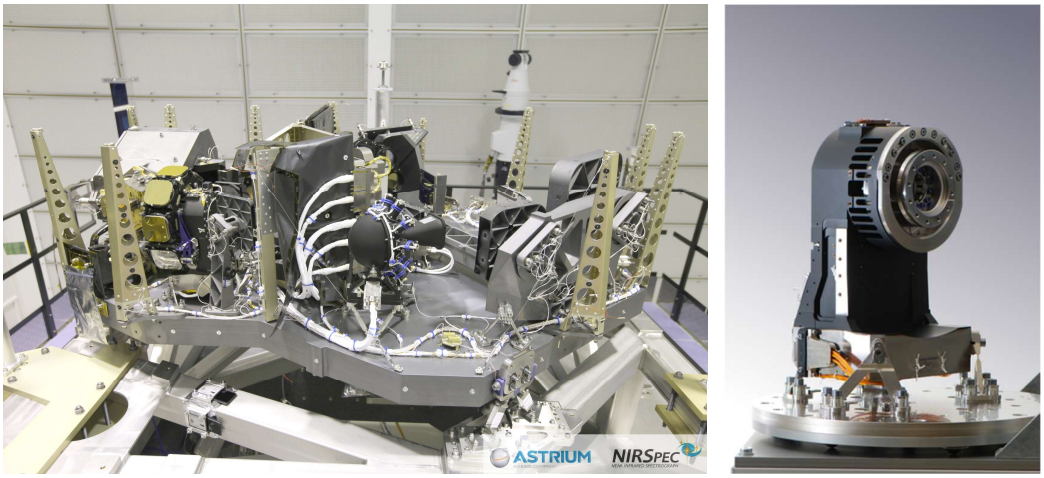
Sales in the area of cryogenic insulation for terrestrial applications, a spin-off of the company's space business, increased in 2021 and contributed 11% to the total company sales.

Production of Cryogenic Thermal Insulation in Berndorf (source: Martin Steiger)

The international highlight of the space year 2021 was the long-expected launch of the James Webb Space Telescope (JWST). On 25 December JWST lifted off on an Ariane 5 from Europe's Spaceport in French Guiana on its exciting mission to unlock the secrets of the Universe.

James Webb Space Telescope lift-off on Ariane 5 from Europe's spaceport in French Guiana (source: ESA)

RSA has provided major elements to the development of this next great space science observatory following Hubble. The company has supplied two high-precision mechanisms for the Near-Infrared Spectrograph (NIRSpec) instrument, the major contribution of ESA and Europe to the observatory, as well as thermal insulation for the communication antenna of the spacecraft.

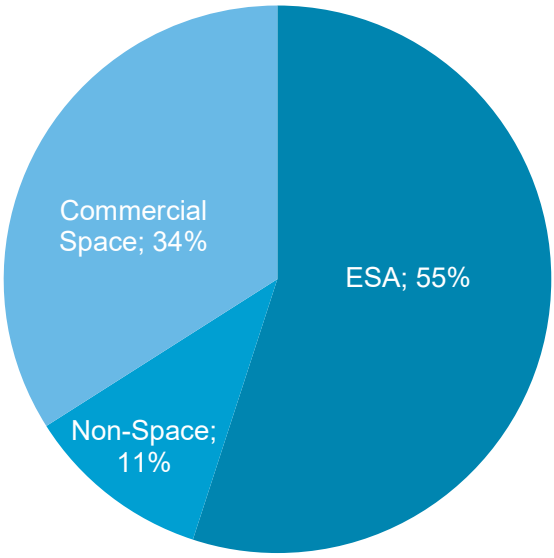


NIRSpec instrument (source: ESA) and RSA high-precision mechanism

Throughout the integration, testing and launch preparation of JWST, an RSA ultra-high capacity rollover fixture has enabled convenient access to the various spacecraft subsystems.

James Webb Space Telescope on RSA Multi-Axis Rollover Fixture in clean room at Europe's spaceport (source: ESA)

RSA total sales increased by 14% compared to 2020, mainly due to growing success in US programs. The non-ESA share reached 45%.



Sales 2021: 46.0 M€
ESA Share: 25.3 M€

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3.14 Seibersdorf Labor GmbH

Seibersdorf Labor GmbH, under its brand name Seibersdorf Laboratories, offers high-quality laboratory analyses and measurement technologies. The Seibersdorf Laboratories are located at the Tech Campus Seibersdorf and employed more than 160 staff and trainees in 2021. Seibersdorf Laboratories focus their space activities to space radiation and its effects to humans, electronic components, systems and materials. The activities cover the following topics:

- Space weather studies and services for aerospace dosimetry
- Radiation hardness assurance of EEE components
- Developments of radiation sensors and detectors
- Space radiation shielding developments

In the following, we present our space related public projects and studies carried out during 2021:

AVIDOS	Aviation dosimetry service in space weather context
PRETTY	Passive reflectometry and dosimetry on-board CubeSat space mission
CORHA	Radiation screening of COTS components and verification of COTS radiation hardness assurance approach

In their inhouse testing facility TEC-Laboratory at the Tech Campus Seibersdorf, we offer EN ISO IEC 17025 accredited services for radiation hardness assurance testing of electronic components and systems. Seibersdorf Laboratories organised in 2021 a special edition of its 6th RADHARD Symposium which focused on laser testing and covered the following topics:

- Principals of Laser Testing for Radiation Hardness Assurance
- Practical Aspects and Potential of Laser Testing
- Overview on State-of-the-Art Laser Testing Technology
- Discussions with Laser Testing Experts and Laser Testing System Providers

Furthermore, Seibersdorf Laboratories coordinated the European conference RADECS 2021 on Radiation and its Effects on Electronic Components and Systems in Vienna as a combined presence and online event with great success.

In addition, we conducted projects and offered services for the European and international aerospace industry.

AVIDOS - AVIATION DOSIMETRY IN SPACE WEATHER CONTEXT

Introduction

Space weather is a collective term for phenomena in the solar system that can have an impact on life and technical infrastructure on Earth and in space. Extreme events (so-called solar storms) have a variety of adverse effects, e.g., on navigation systems, radio communication, power supply, and pose an increased radiation hazard for aircraft passengers and astronauts. For the latter, the main concern are so-called Ground Level Enhancements – particularly strong events that lead to temporarily enhanced radiation doses measured on the ground. It is therefore of interest to establish systems that constantly monitor the radiation environment.

The European Space Agency (ESA) in the frame of its Space Situational Awareness (SSA) Programme (2009 - 2019) established Space Weather Service Network that provides public, industry, government and research institutes with high-quality scientific observations, results and models in the space weather domain. This effort is continued under ESA's current Space Safety Programme that aims at mitigating and preventing the impact of hazards from space.

As space weather can impact various business sectors, it is in focus also in other international organisations. An example the International Civil Aviation Organization (ICAO) which is interested in space weather information tailored to aviation sector.

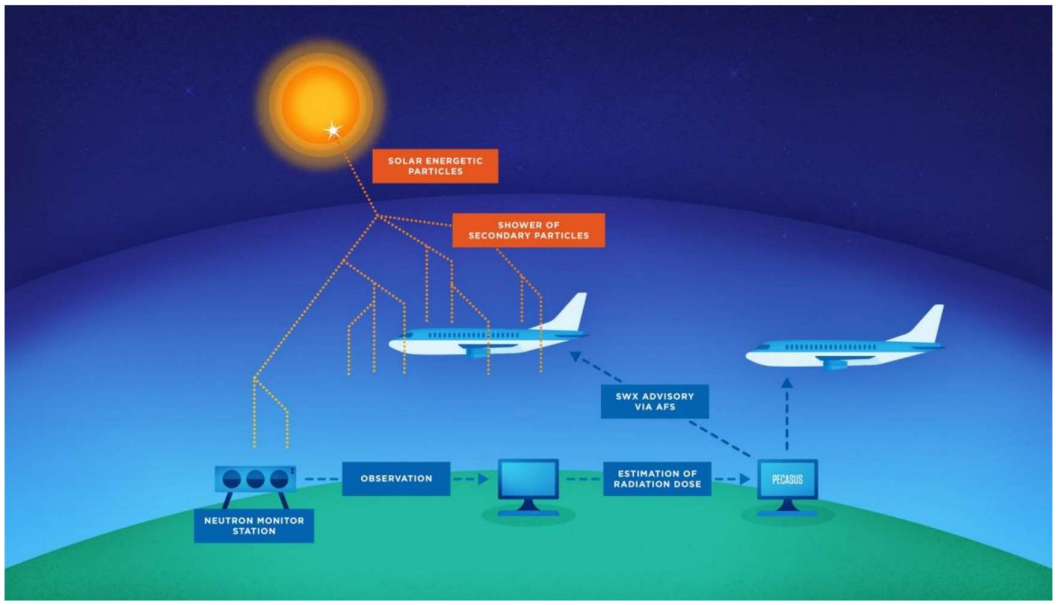

Figure: Schema for radiation-related space weather advisories as implemented in PECASUS (pecasus.eu). Observations from Neutron Monitor station serve as input to AVIDOS for real-time assessment of radiation dose. Based on this and other data space weather advisories are issued to inform civil aviation about elevated radiation levels.

Methods and Results

Seibersdorf Laboratories has contributed with the ESA's Space Weather Service Network (http://swe.ssa.esa.int) with aviation dosimetry service AVIDOS. AVIDOS is an informational and educational online software for an assessment of cosmic radiation exposure of passengers and aircrew at civil flight altitudes. In 2021, we released version 3.0 (http://swe.ssa.esa.int/web/guest/avidos-federated). AVIDOS 3.0 has revised and re-programmed using newest programming technologies the Graphical User Interface what makes is easily accessible via majority of modern web-browsers. AVIDOS 3.0 has a new functionality: an internal database that allows users storing and managing their data.

Seibersdorf Laboratories is part of the PECASUS consortium (Partnership of Excellence for Civil Aviation Space Weather User Services), that forms a global space weather information service center for ICAO. PECASUS delivers information on space weather that has the potential to affect communications, navigation and the health of passengers and crew. One of the main components that addresses radiation issues within PECASUS is our AVIDOS service. For that service, Seibersdorf Laboratories have developed methods that coupled with ground-based measurements form a neutron monitor station, provide in real-time a global map of radiation doses at a large set of altitudes in a format requested by ICAO.

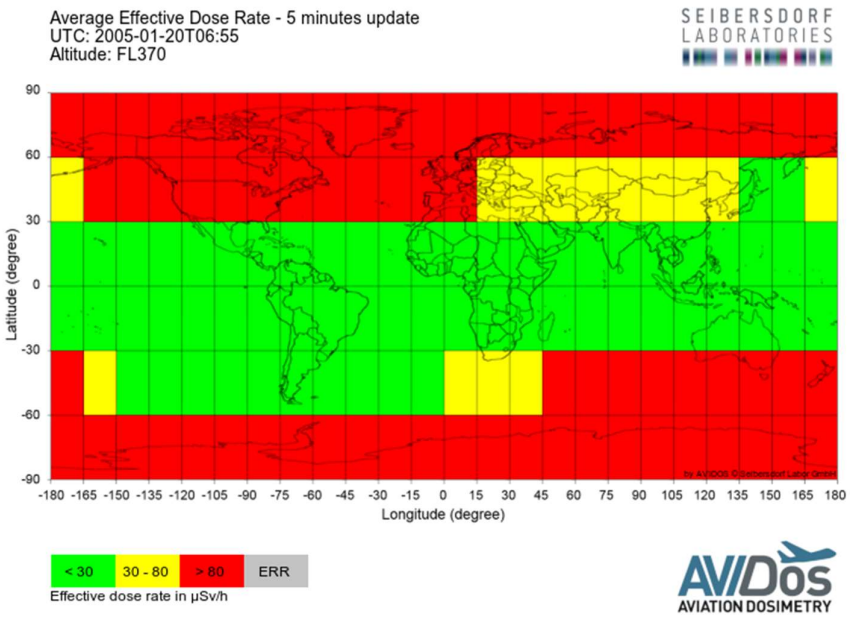

Figure: World map of average effective dose rate, *E*, for GLE69 on 20th of January 2005 at 6:55 UTC as nowcasted by AVIDOS. Green blocks $E < 30$ µSv/h, yellow: 30 µSv/h $< E <$ 80 µSv/h, red: $E > 80$ µSv/h.

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Acknowledgements

Seibersdorf Laboratories' space weather activities are supported by ESA, the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), the Austrian Aeronautics and Space Agency (ALR) as part of the Austrian Research Promotion Agency (FFG). Authors acknowledge all PECASUS partners, the SSCC team, neutron monitor station in Oulu, Finland, http://cosmicrays.oulu.fi, NMDB – Neutron Monitor Database http://www.nmdb.eu, and ANEMOS service http://swe.ssa.esa.int/web/guest/anemos-federated.

PRETTY - PASSIVE REFLECTOMETRY AND DOSIMETRY

Introduction

PRETTY is an ESA CubeSat space mission on Passive Reflectometry and Dosimetry (PRETTY), which is coordinated by RUAG Space (Beyond Gravity) and carried out in collaboration with Seibersdorf Laboratories and Graz University of Technology. The PRETTY CubeSat platform hosts two scientific payloads: A passive reflectometer, exploiting signals of opportunity for passive bistatic radar measurements and a reference dosimeter system, for continuously assessing the ionizing dose on-board the PRETTY spacecraft. Seibersdorf Laboratories is responsible for the reference dosimeter system. After completion of Phase B, PRETTY Phase C/D for design finalization, system assembly, and integration was successfully initiated. Currently, the dosimeter payload is undergoing its final tests before being integrated into the satellite. The launch of the PRETTY 3U CubeSat into a low-Earth sun-synchronous orbit is scheduled for Q4 2022.

Objectives

The objectives for the proposed radiation dosimeter payload are:

- To assess the radiation mission dose during the whole CubeSat space mission
- To assess the radiation dose rate at three geographic regions of interest with elevated radiation levels: the South Atlantic Anomaly (SAA), the North Pole and the South Pole Region
- To provide a technology demonstration of a reference dosimeter system based on a RADFET radiation sensor on-board CubeSat

The assessment of the radiation mission dose and dose rate during the whole satellite's space mission is a main objective for the radiation sensor payload. The radiation sensor will provide information regarding total ionizing dose deposited in electronic components. For non-laboratory conditions like the one during the proposed CubeSat space mission, we will additionally carry out a technology demonstration regarding the influence and possible correction of temperature and ELDRS effects in RADFET. The novelty of this proposal for a reference dosimeter system based on RADEFT is that we will take into account the fading effect due to temperature fluctuations as well as the ELDRS sensitivity.

Total Ionizing Dose Detection

Radiation environment at CubeSat orbits (typically sun-synchronous, 400-600 km altitude and >95° inclination) is composed of several components like trapped radiation particles such as electrons and protons, solar and galactic cosmic radiation. Radiation sensors are used on-board satellites in almost every space mission. Due to mass, size, and power restrictions, dosimeter systems for CubeSat missions must be small and optimised with regard to their technical specifications.

The dosimeter payload of the PRETTY spacecraft will operate two different types of radiation integrating sensors that provide information regarding total ionizing dose (TID) deposited in electronic components that are: (1) MOSFET optimized for radiation sensitivity (RADFET) and (2) floating gate dosimeters (FGDOS). Seibersdorf Laboratories will characterize the sensors in terms of dose rate and temperature dependency to develop a novelty and unique reference dosimeter system for space radiation. Further, the Seibersdorf dosimeter system will compare shielded and un-shielded conditions to discriminate dose contribution from different radiation particles. The RADFET is a well-known radiation sensor and is used to assess the accumulated dose over the PRETTY space mission. The FGDOS is a new development together with CERN

and shows a dose rate resolution, which allows in-orbit dose rate mapping as a function of time and location.

To increase the reliability of the dosimeter payload and to improve the power budget of the satellite, the dosimeter payload interface for the PRETTY satellite was fundamentally revised. Instead of the originally intended I2C and SPI communication with the satellite experimental processing platform (SEPP), the dosimeter will be directly connected to the on-board computer (OBC) of the PRETTY satellite. The communication with the OBC is established via CAN, with I2C as backup with 100% redundancy. Additionally, the dosimeter payload will be designed to operate using the on the CubeSat Space Protocol (CSP), a network-layer delivery protocol designed for nanosatellites such as CubeSats.

Single Event Effect Assessment

In addition to the above described highly recommended risk mitigation, Seibersdorf Laboratories has further investigated available measurement circuitry and identified a solution to further increase the scientific value of the dosimeter payload, by supplementing observation data from accumulated total-dose with the in-orbit detection of single event effects (SEE). SEE are caused by single, energetic particles that lead to a broad variety of soft to fatal errors in electronic devices. These effects pose a high risk to every space mission, as an impact by an energetic proton or heavy ion in the sensitive area of any electronic device can happen from day one of a space mission, eventually ending the mission due to a fatal impact on the system.

To quantify the threat of single event effects, the TID dosimeter payload shall be extended by a single event upset (SEU) assessment system. The SEU assessment system will be based on SRAM memories and is carried out as collaboration with CERN. The integration of two SRAMs with well-different energy response allows to discriminate SEU contribution of low and high linear energy transfer (LET) particles. Further, the measurements allow to compare and finally validate widely used space radiation environment and SEU rate prediction models using the characterization data of the memories and calculated flux and fluence data of the space radiation environment. The measurements are representative for other silicon-based electronic systems e.g., during reliability testing of electronic components, in particular commercial off-the-shelf (COTS) components on-board CubeSat.

Summary and Conclusion

Seibersdorf Laboratories proposes a TID reference dosimeter for technology demonstration under non-laboratory conditions, on-board the planned CubeSat mission PRETTY (Passive Reflectometry and Dosimetry). The dosimeter will assess the radiation mission dose and dose rate during the whole CubeSat space mission and the dose rates at geographic regions of interest with elevated radiation levels - data that can be linked to damaging effects in electronic devices. Further, it will provide a technology demonstration of a dosimeter system concept based on RADFET and FGDOS radiation sensor on-board CubeSat. Further, the updated dosimeter design features a SEU assessment system, based on two commercial, but radiation characterized SRAM, realized in collaboration with CERN. Seibersdorf Laboratories will provide a reliable radiation hardness assurance testing of electronic components on-board future CubeSat missions by using the developed reference dosimeter system. The updated dosimeter system approach was successfully approved by ESA. Currently, the dosimeter payload is tested against its requirements before it is integrated into the PRETTY satellite before launch.

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Acknowledgements

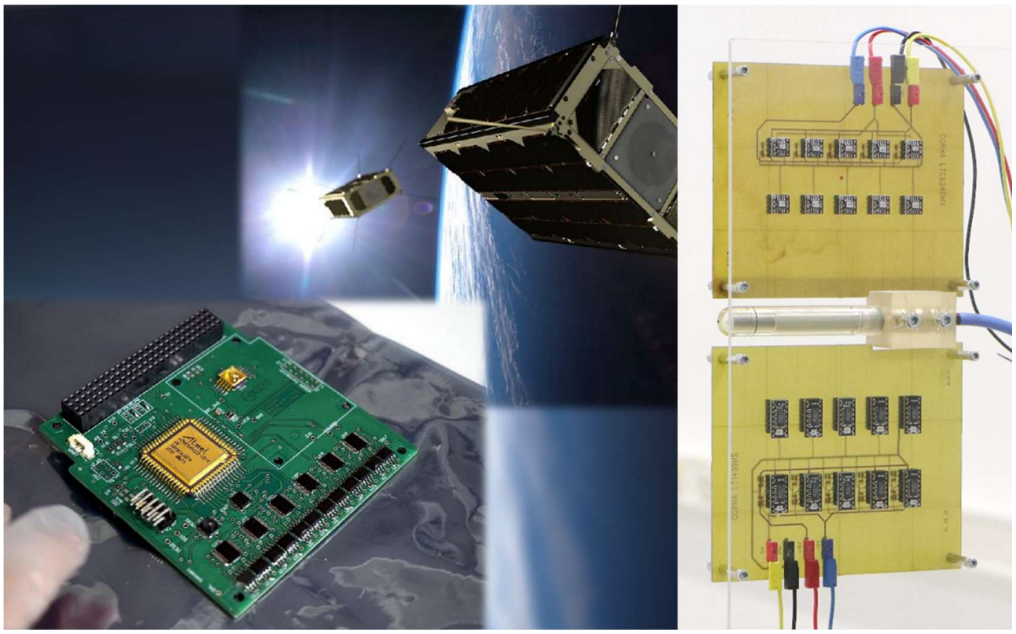
The Phase C/D study for the PRETTY mission is funded by ESA GSTP Program under the ESA Contract No. 4000129499/19/NL/AS, coordinated by the European Space Agency (ESA).

CORHA - RADIATION SCREENING OF COTS COMPONENTS AND VERIFICATION OF COTS RHA APPROACH

Introduction

Commercial off-the-shelf (COTS) components offers great benefits especially when considering aspects such as high performance, low costs, and rapid availability. However, COTS components come also with some serious disadvantages such as lack of traceability, packaging constraints, radiation sensitivity and questions regarding board level and component level testing, obsolescence, cost increase due to up-screening and others. Therefore, the use of COTS components requires expert knowledge and comprehensive risk management. In this context, it is of crucial importance that RHA for COTS is implemented already in the early phases of the project development and that there is an awareness for the need of a suitable risk management strategy.

The experimental activities undertaken within the scope of the Radiation Screening of COTS Components and Verification of COTS RHA approach (CORHA) project coordinated by ESA aims to address problems of using COTS components within the view of radiation hardness assurance.



Objectives

The objective of the study is to evaluate COTS technologies available on the market with respect to their TID response and to their susceptibility for SEE. A comprehensive set of relevant COTS components is used for the experimental work.

The gathered data together with a review of existing standards and the most recent scientific and technical literature, shall serve as a base for the formulation of an ad-hoc RHA approach for COTS components. The applicability of existing models that calculate proton and heavy ion upset rates will be investigated based on the gathered data.

Within the scope of the experimental work, exposures to Co-60 gammas and to either high-energetic protons and/or heavy ions are performed according to test method standards for semiconductor devices as defined in ESCC Basic Specifications No. 22900 and ESCC 25100.

Method and Results

The strategy for selection of the COTS components used for the present work is based on the following considerations:

- to have a set of test devices covering a wide range of component types
- to comprise various technologies
- to maximize the number of tested parts
- to ensure that the selected parts have delivery times of less than three months to follow the requirements given by the project schedule

The table below presents the component types that are considered most relevant for testing within the scope of the CORHA project:

Table: List of parts scheduled for testing.

Component Type	Part	DESCRIPTION	Manufacturer
Memory	MT28EW256ABA	128Mb Embedded NOR Flash Memory, single bit per cell	Micron
Memory	CY14V101PS	1-Mbit (128k x 8) Quad SPI nvSRAM with Real Time Clock (NVM is SONOS)	Cypress
Memory	MB85RS256TY	256K (32 K x 8) Bit SPI FRAM	Fujitsu
Memory	CY15B102QN	ExcelonTM- 2-Mbit (256K x 8) Serial (SPI) F-RAM	Cypress
Microcontroller	STM32F103	Microcontroller, standard version	ST Microelectronics
Microcontroller	STM32L152	Microcontroller, low power version	ST Microelectronics
Operational Amplifier	LT1499HS	10MHz, 6V/µs, Dual/Quad Rail-to-Rail Input and Output Precision C-Load Operational Amplifier	Linear Technology
Operational Amplifier	LTC6240	CMOS Operational Amplifier	Linear Technology
Multiplexer	CD74HC4051	Hi-Speed CMOS 8-Ch MUX	Texas Instruments
Multiplexer	ADG5408TCPZ-EP	HV Latch-up proof 8 Channel MUX	Analog Devices
ADC	ADC128S102	500 ksps to 1Msps, 12-Bit A/D Converter	Texas Instruments
Operational Amplifier	MAX44248ASA+TCT-ND	36V, Precision, Low-power, 90µA Operational Amplifier	Maxim Integrated

All the TID exposures are performed in the radiation standard laboratory of the Seibersdorf Laboratories using the TEC-Laboratory. The heavy ion testing is scheduled to be performed at the Heavy Ion Facility (HIF) of the Université catholique de Louvain (UCL), while the proton testing is scheduled to be performed at the PIF of the Paul-Scherrer-Institute (PSI) and at the Proton Therapy Center Trento.

Status of the Test-Progress

The table below presents an overview on all the test activities planned within the CORHA project. Also, the test status is shown that is either (1) test performed – indicated in green, (2) test scheduled – indicated in blue or (3) test not to be performed – indicated in black. It is noted, that scheduling of the proton SEE tests depends on the results of the respective heavy ion tests, as proton tests are only performed for parts that are susceptible to heavy ions with an LET of less than 15 MeV·cm^2·mg^{-1}. This is, since protons may induce secondary short range heavy ions that have a LET of maximum 15 MeV·cm^2·mg^{-1}.

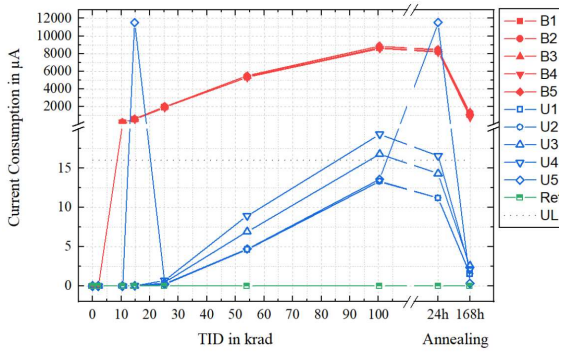
Due to the COVID-19 situation, significant amount of the heavy ion and proton tests, had to be shifted to 2021 as travelling was only possible to a very limited extend. In fact, only one heavy ion campaign could be realized in September 2020. This led to a significant delay of the project schedule.

Component	Status – TID Test	Status – HI SEE Test	Status – p$^+$ SEE Test
MT28EW128AB	performed 2020	performed 2021	performed 2021
CY14V101PS	performed 2020	performed 2021	performed 2021
MB85RS256TY	performed 2020	performed 2021	performed 2021
CY15B102QN	performed 2020	performed 2021	performed 2021
STM32F103RGT6	performed 2020	performed 2021	performed 2021
STM32L152RET6	performed 2020	performed 2021	performed 2021
LT1499HS	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm^2·mg^{-1}
LTC6240	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm^2·mg^{-1}
CD74HC4051	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm^2·mg^{-1}
ADG5408TCPZ-EP	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm^2·mg^{-1}
ADC128S102	performed 2020	performed 2021	performed 2021
MAX44248ASA	performed 2021	performed 2021	performed 2021

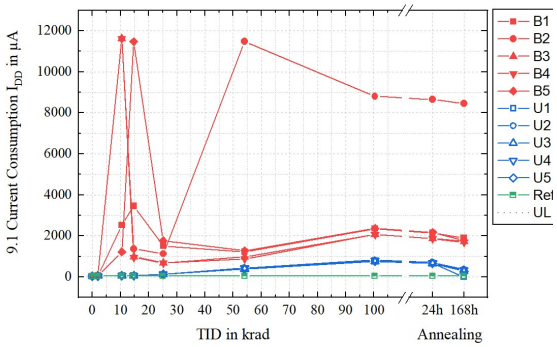
Exemplarily Result: TID response of two COTS Multiplexer

Within the CORHA study, all TID exposure tests are performed in the TEC-Laboratory, an ISO/IEC 17025 accredited Co-60 irradiation facility operated by the Seibersdorf Laboratories. Exemplarily presented are the TID testing results of two COTS multiplexer (CD74HC4051, ADG5408TCPZ-EP). The exposures have been performed according the ESCC 22900. For each device type, a total of eleven components were randomly selected from one single lot of 100 components, resulting in five samples for biased configuration, five for unbiased configuration and one as non-irradiated reference. The DUTs are exposed in six dose steps at a constant dose rate of 2.4 krad$_{(Si)}$/h to a target TID dose of 100 krad$_{(Si)}$. Subsequent to the TID exposure two annealing steps are performed that are (1) a 24 hours room temperature annealing step and (2) a 168 hours elevated temperature aging step.

A total of 70 and 71 device parameters are characterised and exemplified for two COTS multiplexer CD74HC4051 and ADG5408TCP-EZ respectively. The following diagrams show the degradation of the current consumption for the two devices.



Degradation of the current consumption of the CD74HC4051 COTS multiplexer as a function of dose.



Degradation of the current consumption of the ADG5408TCPZ-EP COTS multiplexer as a function of dose.

The table below presents for both biased and unbiased devices, an overview on the TID testing performance of two COTS multiplexers (CD74HC4051, ADG5408TCPZ-EP). A green cell colour indicates that all biased (B) or unbiased (U) devices are within the specification limits, a dashed letter indicates that all but one tested devices are within the specification limits, otherwise the cell is marked red.

	CD74HC4051																	ADG5408TCPZ-EP															
	Applied Dose in krad												Annealing					Applied Dose in krad												Annealing			
Symbol	2		11		15		25		54		100		24h R.T.		168h 100°C		Symbol	2		11		15		25		54		100		24h R.T.		168h 100°C	
$r_{ON0-7}(V_{ISmax})$	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	$r_{ON1-8}(V_{Smax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$r_{ON0-7}(V_{ISmin})$	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	$r_{ON1-8}(V_{Smin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$\Delta r_{ON}(V_{ISmax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$\Delta r_{ON}(V_{Smax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$\Delta r_{ON}(V_{ISmin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$\Delta r_{ON}(V_{Smin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$I_{OFF0-8}(V_{ISmax}, V_{OSmin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$I_{OFF1-9}(V_{Smax}, V_{Dmin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$I_{OFF0-8}(V_{ISmin}, V_{OSmax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$I_{OFF1-9}(V_{Smin}, V_{Dmax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$I_{ON0-7}(V_{ISmin}, V_{OSmin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$I_{ON1-8}(V_{Smin}, V_{Dmin})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
$I_{ON0-7}(V_{ISmax}, V_{OSmax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	$I_{ON1-8}(V_{Smax}, V_{Dmax})$	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{IH0-3}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	I_{INH0-3}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{IL0-3}	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	I_{INL0-3}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_{IH0-3}	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	V_{INH0-3}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_{IL0-3}	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	V_{INL0-3}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{CC}	B	U	B	U	B	Ū	B	U	B	U	B	U	B	U	B	U	I_{DD}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
TTT	B	U	B	U	B	Ū	B	U	B	U	B	U	B	Ū	B	Ū	I_{SS}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
																	TTT	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U

An analysis of the available data indicates that the CD74HC4051 can withstand TID levels of greater than 100 $krad_{(Si)}$ without breaking or loosing functionality, however the truth table test (TTT) of the biased parts failed after the 24 hours room temperature annealing.

For both devices a significant number of parameters exceed the specification limits - some already at very low TID levels. For the investigated dose levels and device parameters, the CD74HC4015 can withstand 2 $krad_{(Si)}$ without showing any parameter degradation that

exceeds the defined specification limit while the ADG5408TCPZ-EP showed severe parameter degradation already at this dose level including a fail of the TTT of the biased parts.

After application of the final dose of 100 krad(Si), we performed 24h annealing at room temperature and 168h annealing/accelerated aging at an elevated temperature of 100°C. After annealing, the parameter degradation for the CD74HC4051 multiplexer recovered partially while no annealing effect was observed for the ADG5408TCPZ-EP.

Summary and Conclusion

Twelve commercially available parts that are: four memories, two microcontrollers, three operational amplifiers, two multiplexers, and one analog to digital converter, have been identified to be relevant for COTS during the ESA CORHA project. The experimental activities undertaken within the scope of the present project will serve as baseline data that is to be used for the formulation of an ad-hoc RHA approach for commercial parts. This is of importance as currently no universal RHA standards are available that are dedicated to COTS. Although the standard document ECSS-Q-ST-60-15C applies also to COTS, the application of this standard to small satellites that are flying COTS devices turns out to be not practical for technical and/or financial reasons. For this reason, RHA for COTS is handled on a case-to-case base and thus is realized as tailored RHA solution for each specific application. The unfavourable situation of lacking dedicated RHA standards for COTS needs to be addressed promptly by providing standards that regulate testing of COTS components to facilitate the achievement of significant test results. The present project concludes the numerical and experimental investigations by formulating an ad-hoc RHA approach for COTS.

Publications

Michael Wind, Christoph Tscherne, Marta Bagatin, Simone Gerardin, Lukas Huber, Alessandro Paccagnella, Marc Poizat, Peter Beck, *Testing of COTS Multiplexer in the Framework of the ESA CORHA Study*, Data Workshop Presentation, Radiation Effects on Components and Systems Conference, RADECS 2021, Vienna, September 2021

Michael Wind, Peter Beck, Lukas Huber, Marcin Latocha, Christoph Tscherne, *Space Radiation Environments at LEO, MEO, GEO and their Effects on Components and Systems*, RADHARD Symposium 2020, Online Conference, ISBN (Print) 978-3-902780-18-8, ISBN (Ebook) 978-3-902780-19-5, Seibersdorf Laboratories, Seibersdorf, Nov 2020.

Peter Beck, Marta Bagatin, Simone Gerardin, Marcin Latocha, Alessandro Paccagnella, Christoph Tscherne, Michael Wind, Marc Poizat, *ESA Study on Radiation Testing of COTS Components to Verify a COTS RHA Approach*, Oral Presentation, RADHARD Symposium 2020, online conference, Nov 2020.

Simone Gerardin, Marta Bagatin, Alessandro Paccagnella, Peter Beck, Christoph Tscherne, Michael Wind,Marc Poizat, *Total Ionizing Tests on Non-volatile Memories For Small Satellites*, Oral Presentation, RADHARD Symposium 2020, online conference, ISBN (Print) 978-3-902780-18-8, ISBN (Ebook) 978-3-902780-19-5, Seibersdorf Laboratories, Seibersdorf, Nov 2020.

Christoph Tscherne, Patrick Schmidt, Michael Hofbauer, Christian Laa, Andreas Dielacher, Michael Wind, Thomas Panhofer, Heinz Fragner, Horst Zimmermann, Peter Beck, *SEELAS - Comparison of Laser and Heavy Ion Radiation Testing*, Oral Presentation, RADHARD Symposium 2020, online conference, ISBN (Print) 978-3-902780-18-8, ISBN (Ebook) 978-3-902780-19-5, Seibersdorf Laboratories, Seibersdorf, Nov 2020.

Christoph Tscherne, Michael Wind, Marta Bagatin, Simone Gerardin, Marcin Latocha, Alessandro Paccagnella, Marc Poizat, Peter Beck, *Testing of COTS Operational Amplifier in*

the Framework of the ESA CORHA Study, Data Workshop Presentation, Radiation Effects on Components and Systems Conference, RADECS 2020, online conference, Oct-Nov 2020.

Christoph Tscherne, Michael Wind, Marcin Latocha, Peter Beck, *Characterization of a Certified Exposure Facility for Total Ionizing Dose Testing of Electronic Components*, Poster Presentation, 2020 IEEE Nuclear and Space Radiation Effects Conference, NSREC 2020, online conference, Nov-Dec 2020.

Acknowledgements

The project is carried out within the scope of the Radiation screening of COTS components and verification of COTS RHA approach (CORHA) project (ESA contract number: 4000126049/18/NL/KML) coordinated by the European Space Agency (ESA).

RADHARD SYMPOSIUM 2021

Introduction

On May 18, 2021, Seibersdorf Laboratories organized their **6th RADHARD-Symposium**.

The mission of the RADHARD Symposium is to provide, in addition to the RADECS Conference, a forum for the exchange of practical experience in the field of radiation hardness assurance, which is important for industrial applications as well as for research and science. Our vision is that the RADHARD Symposium will provide a venue with plenty of room for communication, initiate new joint projects, and invite this year's upcoming RADECS Conference 2021 in Vienna, Austria.

The **6th RADHARD-Symposium** in 2021 was, due to COVID Pandemic, organised online, with topics on:

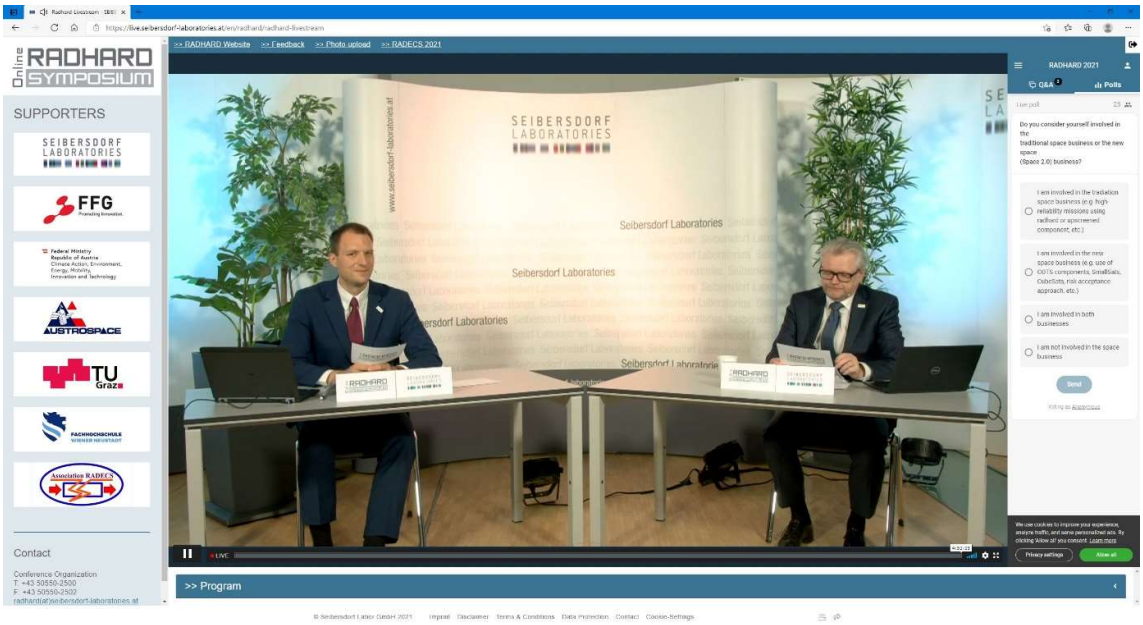
- Principals of Laser Testing for Radiation Hardness Assurance
- Practical Aspects and Potential of Laser Testing
- Overview on State-of-the-Art Laser Testing Technology

The RADHARD Symposium is aimed at space system integrators, manufacturers of electrical and electronic equipment, industry, research and science as well as students interested in radiation and its effects on components and systems. International experts present new results and give a comprehensive overview of the current situation. We encourage students to present their early research work on radiation hardening effects and discuss with radiation hardening experts from research and industry.

Online RADHARD SYMPOSIUM

May 18th, 2021

SEIBERSDORF LABORATORIES



The 6th RADHARD Symposium 2021 overview

- More than 100 participants from 17 Countries
- Keynote: Fundamentals of Laser Testing
- Keynote: Laser Testing – Airbus Needs and Desirable Test Option for the Future
- Three Q&A Sessions with Questions and Answers about the Lectures

Further information is provided at: www.radhard.eu.

Book of Abstracts

The book of abstracts is available for download online at RADHARD 2021 - Book of Abstracts (seibersdorf-laboratories.at) Reference: ISBN (Print) 978-3-902780-20-1 ISBN (Ebook) 978-3-902780-21-8

Figure: Book of Abstracts 6th RADHARD Symposium 2021

Organizers and Supporters

The RADHARD Symposium 2021 was organized by Seibersdorf Laboratories and supported by the Austrian Research Promotion Agency (FFG), the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, AUSTROSPACE and in cooperation with Graz University of Technology, the University of Applied Sciences Wiener Neustadt and the RADECS Association.

Acknowledgements

Seibersdorf Laboratories would like to thank all participants, organizers, and supporters for their outstanding contribution to a successful RADHARD Symposium 2021.

RADECS 2021 CONFERENCE IN VIENNA

Introduction

On behalf of the Association on Radiation and its Effects on Components and Systems, RADECS, Seibersdorf Laboratories organized the 2021 RADECS Conference, which was held September 13-17, 2021, at the Hotel Savoyen in Vienna, Austria.

RADECS 2021 was organized as a hybrid conference. Both online and on-site registered participants were provided with the following conference items:

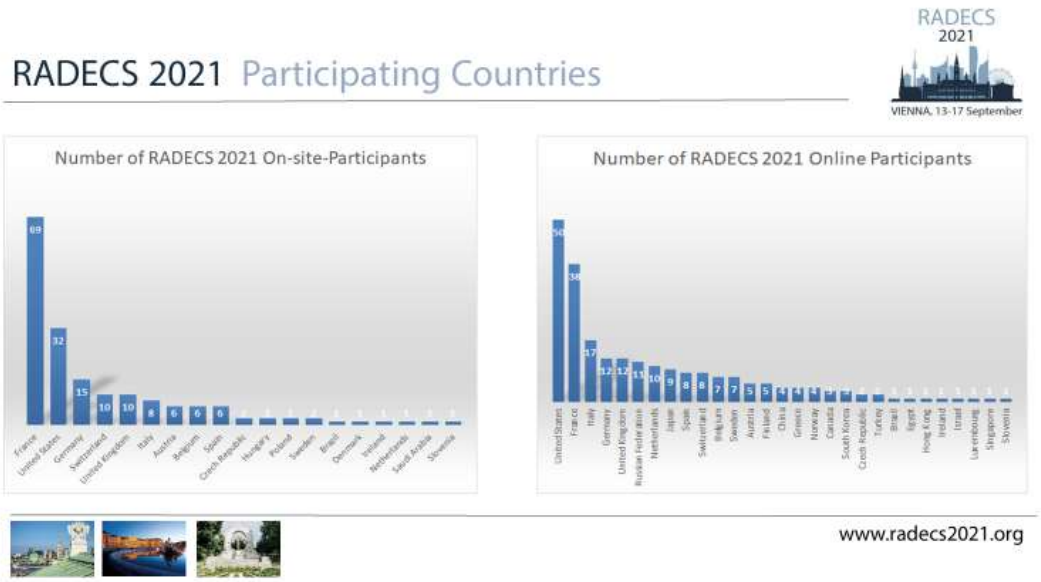
- **Short Course** as live streams and videos on demand,
- **Technical Sessions** as live streams and videos on demand,
- **Poster Session** both, as on-line meetings, and onsite sessions,
- **Data Workshop** both, as on-line meetings, and onsite sessions,
- **Exhibition** both, as on-line meetings, and onsite sessions,
- **Invited Talks** both, speakers were on-line and onsite

The conference theme of RADECS 2021 was: “Committed to Safety and Sustainability in Space”, with a view to future space missions and applications, and the use of space for the entire global community. This edition of the RADECS Conference was organized by Seibersdorf Laboratories in collaboration with CERN and partners. The conference features a technical program dedicated to the latest developments and experimental observations. The technical program was based on critically reviewed presentations describing nuclear and space radiation effects on electronics and photonic materials, devices, circuits, sensors, and systems.

Very important for RADECS was the close collaboration link to the industry, which supported the conference. New features of RADECS 2021 included support for online streaming of lectures to keep in touch with attendees from around the world during these challenging times, as well as online attendance by industry exhibitors. In addition, all attendees did have access to all booked lectures via the Internet for an additional month.

Outstanding invited talks were given by internationally recognized personalities on 2000 years of architecture in Vienna, on a success story of an Austrian space spin-off, current insights on climate & space, on the new European network RADNEXT on radiation hardness research and test facilities, and a talk on the reliability of nanosatellite missions. The exhibition chairs had gathered a panel of 27 international exhibitors. Companies working in areas related to the field of radiation effects, microelectronics, design, tests and space application did exhibit their products and services.

To get students involved in the community a support program was established gratefully supported by RADSAGA, the RADECS Association and the RADECS 2021 Conference. In particular the Jean Marie Palau Award was created for this purpose in the past.



The RADECS Conference 2021 overview

- 405 participants (36% Newcomers) from 19 Countries
- 27 Exhibitors on-site and online
- 24 Session Chairs, 5 Invited Speakers, and 2 Industrial Exhibit Chairs
- Further information is provided at: https://www.seibersdorf-laboratories.at/en/radecs-2021

Conference Booklet

The book of abstracts is available for download online at https://www.seibersdorf-laboratories.at/en/radecs-2021/conference/conference-booklet

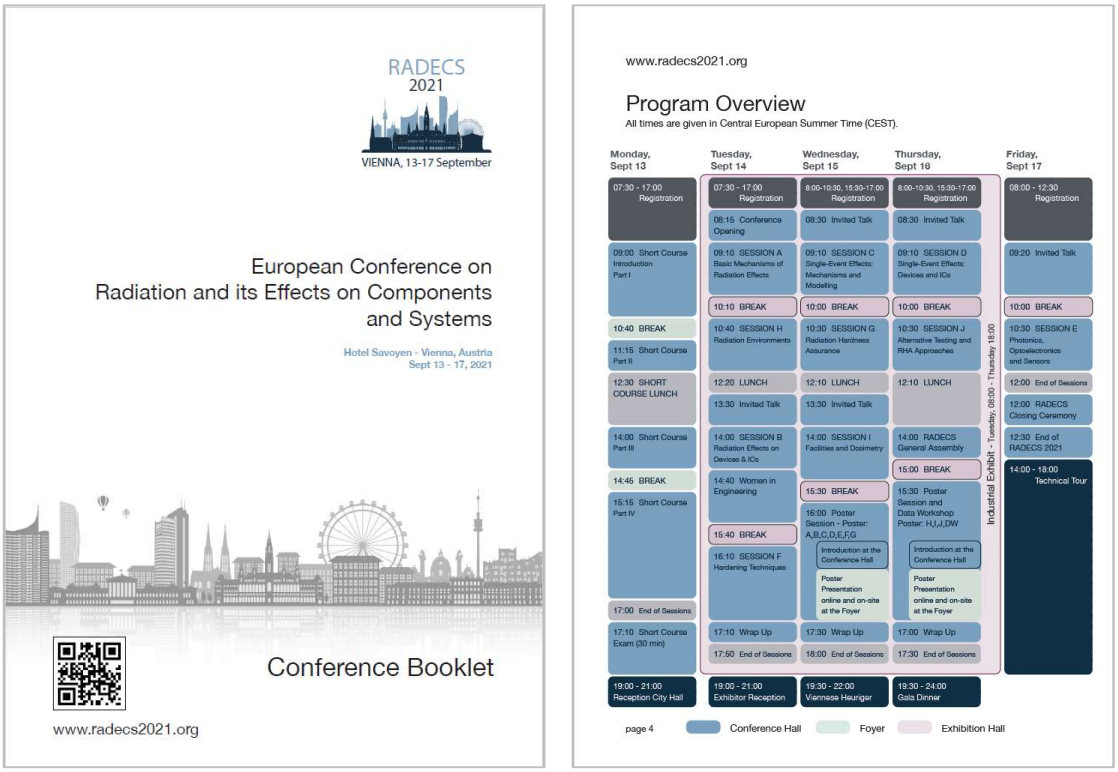


Figure: Conference Booklet of RADECS 2021

Sales 2021 (space projects): 0.6 M€

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3.15 TTTech Computertechnik AG

Leading global supplier of dependable networking solutions and modular safety platforms. The company's products simplify and reduce development cycles while enhancing the reliability of networked electronic systems in transportation and industrial automation markets. The company was established in 1998. The TTTech Group employs more than 2500 employees worldwide of which the majority works in engineering and development departments (with a focus on software development). The Group is headquartered in Vienna, Austria. TTTech Auto AG is its largest subsidiary and works mainly on software platforms for advanced driver assistance systems enabling also future autonomously driving cars.

TTTech Aerospace is the business unit within TTTech Group which is dedicated to the global aerospace markets. It operates in Europe, North America (with offices in two states) and Asia (with offices in Japan and China). In 2021 the revenue from space programs again exceeded the busines unit's sales related to aeronautics programs.

European Space Activities 2021

Completion of the ECSS standardization of Time-Triggered Ethernet for use in space applications was a key milestone for the technology developed by TTTech and introduced to programs like the Ariane 6 launch system or the NASA Gateway. In parallel our ESA GSTP activity for the qualification of key TTEthernet avionics elements – space-grade TTEthernet switches and network interface cards (see picture to the right) was executed reaching the preliminary design review at the end of the year. These elements are developed in close cooperation with RUAG Space GmbH which is also responsible for all manufacturing aspects. This large project will remain active until 2023.

TTTech's bids for the switches and network interface cards needed for ESA's Gateway modules "International Habitat" and "ESPRIT Refueling Module" were successful and the related projects started in the second half of the year. Thales Alenia Space (TAS) is the prime contractor for both modules. This also offers the opportunity to work with TAS on the use of the same building blocks in other space applications like Earth observation.

TTTech continued to support Airbus Defence and Space on the dispensable European Service Module which powers the NASA Orion Crew Vehicle, key to the Artemis 1 mission scheduled for 2022.

Outside Europe

Both our US offices were highly active in the Artemis/Gateway program driven by large contracts with Maxar and Northrop Grumman Space Systems for central elements of the PPE and HALO avionics including integration of the flight computer for the latter (an integrated avionics unit is depicted below – on its own and as held by ESA DG Josef Aschbacher during the International Space Symposium). Major milestones were achieved during the year. Our collaboration with NASA JSC focusses on software, software integration and software verification. TTTech exhibited at the International Space Symposium and also participated in the IAC 2021 in Dubai and took the opportunity to join the Austrian trade organization in a visit to the UAE Space Agency.

Several attractive projects with non-traditional actors also continued.

Revenue

Total European space revenue grew to Euro 2.1 million with an ESA share of 1.9 million. Clearly outnumbered by sales in the other regions (mainly North America) which more than tripled in comparison to 2020 and exceeded Euro 16 million. Further growth in 2022 is expected on the basis of TTTech's strong cooperation with RUAG Space for the NASA Gateway and other deep space missions.

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3.16 Graz University of Technology (TU Graz)

Graz University of Technology has been very active in a variety of space technology, space science and space experiments since 1969.

The current activities by the Institute of Communication Networks and Satellite Communications, the Institute of Geodesy, the Institute of Experimental Physics and the Institute of Electronics focus on satellite communications, satellite navigation, satellite geodesy, remote sensing, the development of space-qualified hard- and software and small satellite missions, including operations of nanosatellites.

Institute of Communications Networks and Satellite Communications

Satellite Communications Activities

In 2021 the EU HORIZON 2020 project EO-ALERT (Next Generation Satellite Processing Chain for Rapid Civil Alerts) was successfully completed. Contrary to conventional Earth Observation satellites, EO-ALERT aimed at on-board processing of high resolution optical and Synthetic Aperture Radar (SAR) images with very fast delivery of products to the end users. The consortium was led by DEIMOS (Spain) with OHB Italia, DLR (Germany), Politecnico di Torino (Italy) and TU Graz as partners.

The main applications of this new system are

- Disaster management and emergency response (e.g. floods, fires, earthquakes, oil slicks, ..)
- Forecasting (e.g. extreme weather nowcasting)
- Monitoring and security (e.g. maritime smuggling, illegal fishing, illegal immigration, …)

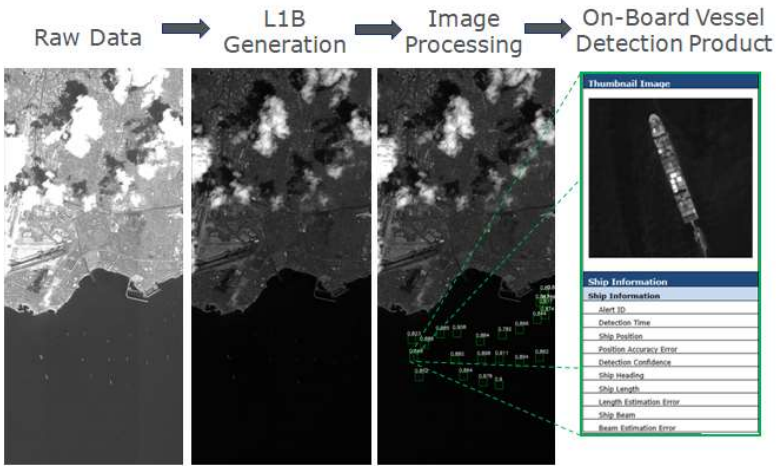
Using powerful field-programmable arrays (FPGAs) for the on-board processor alerts can be generated on-board and provided to end users such as emergency and relief teams globally in less than 5 minutes from acquisition to delivery. Current latencies of Earth Observation civil emergency products are between 20 minutes to several hours. Timely Earth Observation products can save lives and property.

TU Graz was responsible to develop the communications concept for transfer of bulk data (SAR and optical images) and alerts. A versatile communications hardware/software emulator of the communications system was developed in cooperation with the SME Unitel IT Innovationen in Graz.

This system was extensively tested together with the processor test bench by OHB Italia demonstrating that the requirements of global delivery of bulk data within 30 minutes and alerts in less than 5 minutes could be achieved.
The company ADDVALUE made an engineering model of a novel transceiver available which allowed to test the alert transfer via a real satellite link (INMARSAT) possible.

Ship Detection, classification and positioning was tested using Terrasar-X (SAR) and DEIMOS-2 (optical) payload data.

This demonstrated that worldwide persistent real-time Earth Observation disaster management services are achievable now.



Example of a ship alert

Test of the INMARSAT IDRS Terminal

Nanosatellites

The Institute is currently involved in three nanosatellite missions:

- TUGSAT-1/BRITE-Austria
- OPS-SAT (ESA)
- PRETTY (ESA)

The BRITE Mission is a true success story. Launched in 2013 TUGSAT-1 has exceeded the design lifetime by more than a factor of 4 and is continuing to deliver high-quality science data to the BRITE Executive Science Team. A very large number of peer-reviewed papers in renowned astrophysical journals (including “Science Astronomy”) stemmed from the analysis of the data of asteroseismical observations of massive luminous stars.

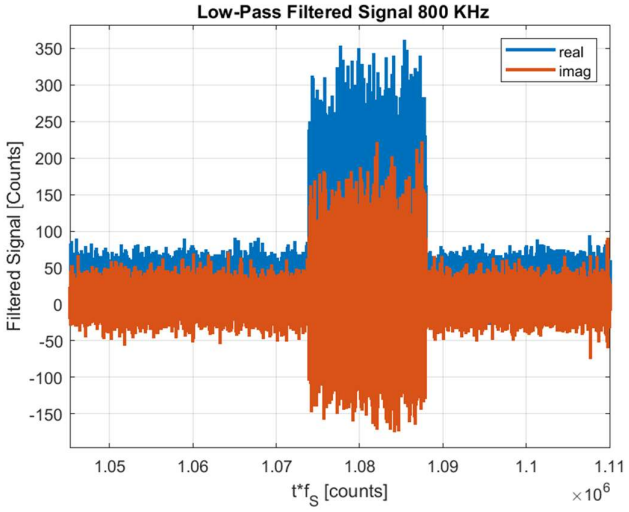
Nanosatellite Mission OPS-SAT

OPS-SAT is an ESA’ nanosatellite mission to demonstrate and validate new operational concepts and to carry out hardware and software experiments in space using flexible programmable on-board subsystems. OPS-SAT, a 3U CubeSat, was developed under the technical lead of the Institute of Communication Networks and Satellite Communications with partners from Austria (Unitel IT Innovationen and MAGNA STEYR), Poland, Denmark and Germany under an ESA contract within the GSTP program.

OPS-SAT Spacecraft

In 2021 the Institute carried out a very successful campaign for radio interference monitoring from Space using the Software-defined Radio Payload on board of OPS-SAT, together with the Austrian Armed Forces, AUSTROCONTROL and the Radio Regulation Office. Interference in the UHF band due to radars and jamming in the GNSS band could be clearly detected and localised.

GNSS jamming and spoofing is becoming an increasing problem. Using space-borne receivers localisation is possible with small and low-cost paylaods.



Radar Interference Signal captured by the SDR Payload in the 430 MHz band

SDR Receiver

Nanosatellite Mission PRETTY (Passive Reflectometry and Dosimetry)

PRETTY is a nanosatellite mission with the objective to demonstrate and validate passive reflectometry in space. PRETTY includes an SDR payload similar to the software-defined radio on OPS-SAT. Direct and ground-reflected GNSS signals are received by the spacecraft. By correlation the time difference is measured realising a precise altimeter. Reflecting surfaces such as glaciers and sea waves can be surveyed by a low-power and compact payload. PRETTY is expected to provide valuable contributions to climate research. The radiation environment in LEO orbit is measured by a novel dosimeter developed by Seibersdorf Laboratories. The spacecraft is currently assembled in the clean room of TU Graz.

PRETTY is foreseen to be launched in Q4/2022 on board of a VEGA.

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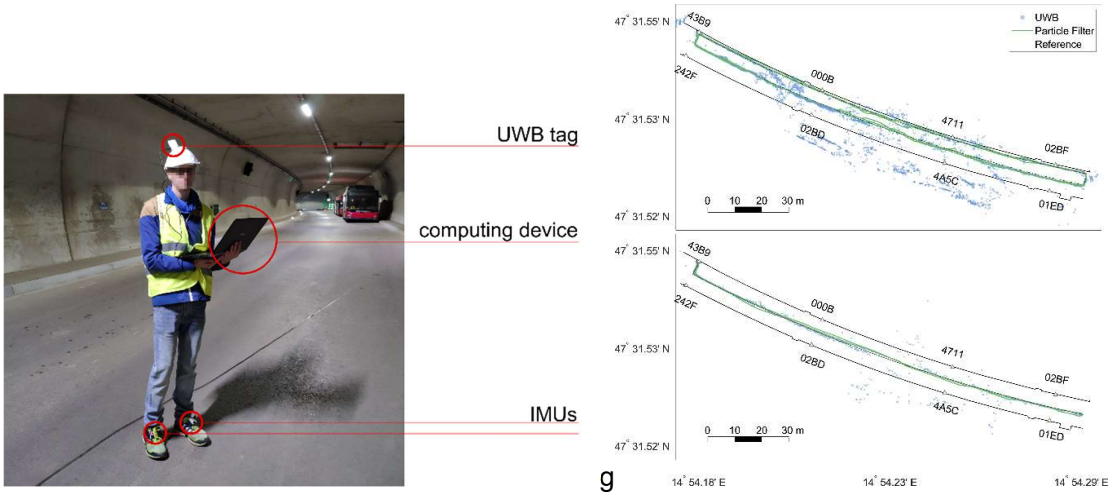
Institue of Geodesy- Working Group of Navigation

The Working Group of Navigation at the Institute of Geodesy (ifG) at Graz University of Technology puts its focus on satellite-based positioning and navigation systems. In the field of satellite-based positioning the team focuses on robust and precise positioning algorithms and methods for Global Navigation Satellite Systems (GNSS) using software-defined GNSS radios (SDRs). Currently a special focus is on GNSS interference detection, classification, and countermeasures. In addition, the working group is working on exploiting other RF space-based signals (so called signals of opportunities) from LEO satellites for positioning. Currently the working group is involved in GNSS interference detection activities together with the Austrian government as well as working on deriving position information from actual satellite mega constellations like Starlink or OneWeb. In the field of navigation, the working group seeks for the best possible sensor integration of complementary navigation sensors. This topic has been investigated successfully for the last decades. Extensive expertise and know-how in the integration of different navigation sensors (e.g., GNSS, inertial sensors, magnetometers, barometers, LIDAR, stereo cameras, UWB, WiFi, BLE, etc.) was built up in numerous national and international research project. In recent years, there has been increased research in the area of interior positioning for pedestrians as well as autonomous robots and vehicles. Within the various research projects, the Institute has acquired a great deal of know-how in the area of evaluating and integrating a wide variety of sensor data and position filtering (Kalman and particle filters) in recent years.
On October 1st, 2021, Univ.-Prof. Philipp Berglez succeeded Univ.-Prof. Bernhard Hofmann-Wellenhof as Professor of Navigation. He strengthens the team and contributes his more than 15 years of expertise in the area of Global Navigation Satellite Systems (GNSS), especially in the fields of software-based GNSS signal processing and GNSS interference.

NIKE BLUETRACK - Sustainable Interdisciplinarity in Complex Underground Operations - BLUE Force TRACKing

Carrying out complex operations in underground structures (e.g., tunnels, subway stations) poses a major challenge, as operations are made more difficult due to the lack of/poor lighting and smoke. An essential prerequisite for successfully managing an operation is the reliable localization of the own forces (i.e., blue force). This is much more challenging underground, as Global Navigation Satellite Systems (GNSS) can only be used at the entrance. The focus of this project is the development of an easily portable navigation solution for the precise location of one's own forces in complex underground operations. In a particle filter, information from a foot-mounted inertial navigation system (INS) is fused with distance measurements from ultra-wideband (UWB) and data from 3D tunnel models into a position solution. The required UWB infrastructure and map information are generated during use. The latest research, within the FFG-funded research project, focuses on using machine learning techniques to enhance the underground positioning.



NIKE BLUETRACK equipment and test measurement results in a tunnel at Zentrum am Berg

Research Projects ANTON and ANDREA

The FFG-funded research projects ANTON and ANDREA aim at automating composting by means of satellite-based navigation technologies (GNSS). Within the project ANTON ("Autonomous navigation for tracked compost turners"), a robust and reliable navigation module for an autonomous compost turner was successfully developed, tested, and demonstrated with a prototype at a real composting site. The key innovation lies in the sensor fusion tailored to tracked compost turners. By fusing data from multiple sensors, specific motion characteristics of tracked vehicles such as slippage can be included in the motion models. The use of a dual-antenna GNSS-RTK receiver allows to determine a cm-level accurate position and a highly precise heading in real-time. To increase the robustness of the system, the GNSS observations are fused with measurements from an Inertial Measurement Unit, a stereo camera, and rotary encoders of the machine in an Error-State Kalman Filter.
The project ANDREA ("Automated GNSS-based data and process management for composting plants") aims at developing a concept for an automated management system for composting that reduces the measurement and documentation effort for compost producers. In the project, the temperature measurements that are required by the Compost Regulation shall be carried out directly by a compost turner and georeferenced by means of GNSS-based trajectory determination. The measurements will then be mapped in a management system for composting, which should give compost producers a better overview of the rotting process.

Autonomous driving compost turner in action.

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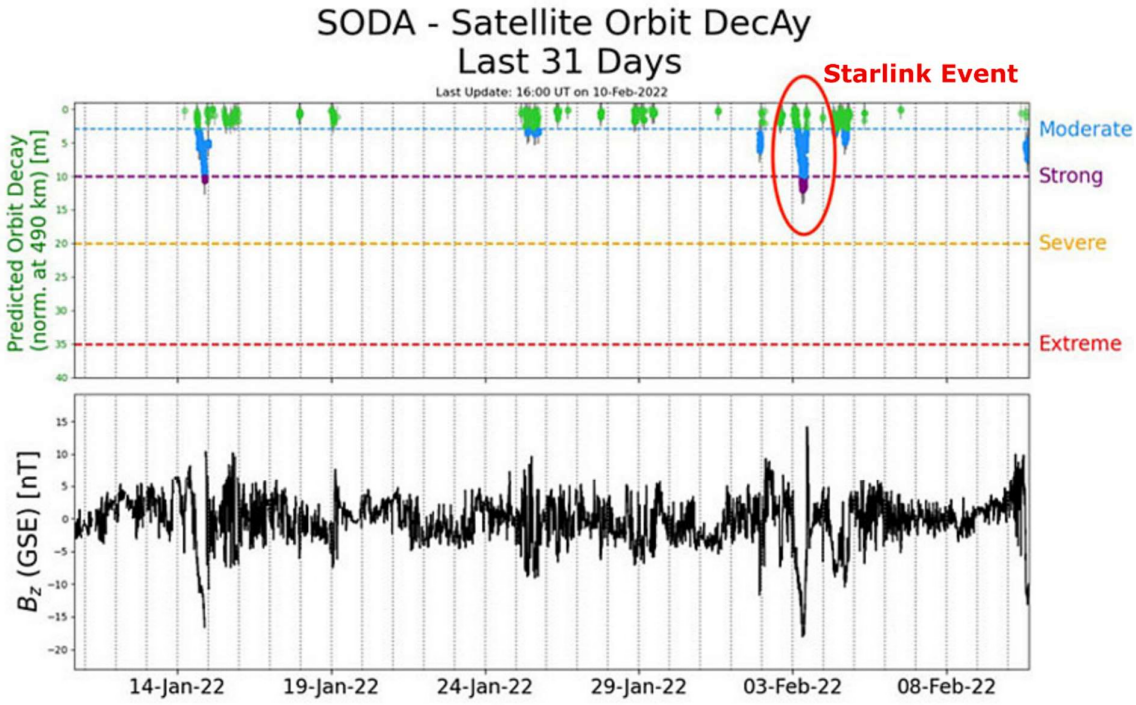
SODA - a service to forecast space weather effects on LEO satellites

Geomagnetic storms occur rather consistently in accordance with the 11-year solar cycle and have effects on near-Earth space and down to the Earth's ground level. Different kinds of solar events have the capability to trigger atmospheric disturbances and subsequently influence the trajectories of Earth orbiting satellites. The strongest disturbances of the space environment are primarily caused by interplanetary coronal mass ejections (ICMEs). The service SODA (Satellite Orbit DecAy) is a joint project with the Heliospheric Physics Research Group at the University of Graz and implemented in the ESA Ionospheric Weather SSP program/Ionospheric Weather Expert Service Centre (I-ESC). The aim of the service is to forecast the impact of space weather effects triggered by ICMEs on low Earth orbiting (LEO) satellites. The basis for the service is a thoroughly analysis of a large sample of about 300 ICMEs, which occurred during the GRACE mission duration between 2002 – 2017. The examinations are carried out in view of how the solar events relate to the orbit decay of the satellites. The key principle are correlations between the interplanetary magnetic field of ICMEs and the variation of the neutral density in the thermosphere. For SODA, the former observations are made by the DSCOVR spacecraft located at the Lagrange point L1. The neutral density estimates are based on accelerometer measurements as well as on kinematic orbit information of the twin-satellite mission GRACE. Our findings indicate that strong magnetic field variations in the Bz component trigger geomagnetic storms, which lead to an

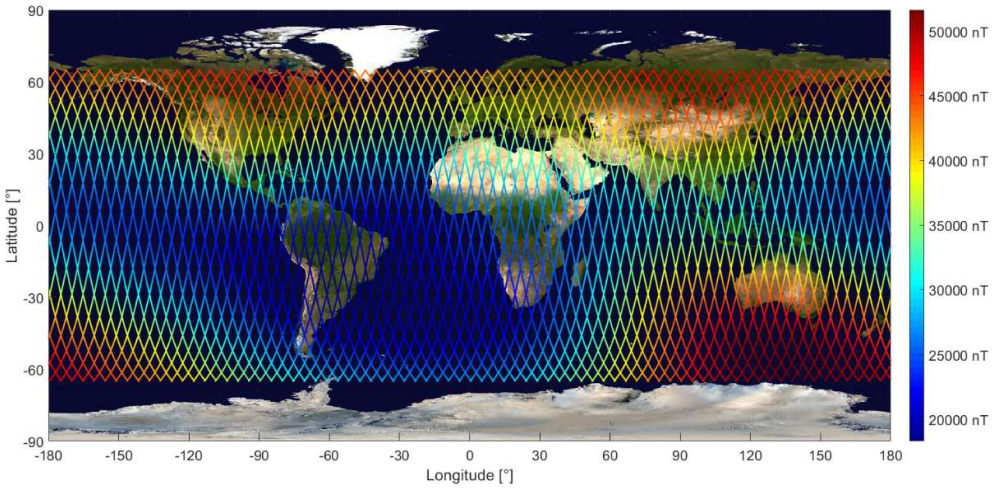
increase in the aerodynamic drag force and subsequently in the neutral density. As a result, satellites at very low altitudes may experience an orbit decay of several tens to a hundred of meters during an extreme ICME event. The figure below shows the graphical representation of the SODA service during a geomagnetic storm at the beginning of February 2022. This particular event led to the loss of up to 40 Starlink satellites due to an atmospheric drag increase of about 50% compared to quiet conditions. The service SODA is available at the website of the Heliospheric Physics Research Group (https://swe.uni-graz.at/index.php/services/esa-space-safety-services) and provides information for two different periods (a) last 72 hours and (b) last 50 days.



Visualization of the Service SODA which depicts the predicted orbit decay and the observed Bz component from the DSCOVR spacecraft located at the Lagrange point L1.

Institute of Experimental Physics (IEP)

The Institute of Experimental Physics (IEP) at Graz University of Technology is in joint collaboration with the Space Research Institute (IWF) of the Austrian Academy of Sciences. Both institutions are concerned with the development of a scalar Quantum Interference Magnetometer based on the Coherent Population Trapping (CPT) effect ready for space missions.



On board CDSM-Magnetometer Magnetic field data of several orbits. (A. Pollinger et. al. submitted to Earth Planets and Space)

For the first time this new (patented) approach allows the application of a CPT magnetometer as precise (absolute) reference magnetometer especially on space missions where a so called “in-flight” calibration of the commonly used fluxgate magnetometer is not possible (e.g. missions in the magnetosphere of a planet). Compared to other state-of-the-art reference magnetometers. The CPT magnetometer’s unique property of the omni-directionality (i.e. magnetic field measurement is independent of the sensor-orientation) is superior, as in each mission phase magnetic field data are available.
According to these potential space applications, the CPT magnetometer is prior prepared for an ESA large scale mission to the Jupiter Icy Moons (JUICE) and the Chinese Seismo Electromagnetic Satellite (CSES I) in low Earth’s orbit which has meanwhile passed the four-year continuous operation without any problems. The performance of the Instrument was externally evaluated by the SWARM-Team with top grades! The flight and the flight spare model of the CSES II mission are assembled and tested. The proper operation was evaluated at the Conrad Observatorium (ZAMG) by several test campaigns. The launch is planned in 2023.

Sensor of Coherent Population Trapping (CPT)-Magnetometer developed for ESA's JUICE-Mission. Here, mounted (2021) on the spacecraft at ESA. The sensor is visible on the left side at the bottom of the spacecraft.

Activities in 2021 regarding both missions (JUICE and CSES II):

- Evaluation of the data (operational and magnetic field data) obtained from CSES I scalar Magnetometer since Launch (see Figure)!
- Magnetic field data analysis and error-budget estimation of the CSES-Magnetometer! Publication of the Data Material obtained!
- Assembly of the flight and flight spare model (FM and FMS)-Sensor units for the JUICE-mission.
- Engineering and manufacturing of a new sensor concept calling dual-transition-sensor (DTS) for the coupled dark state magnetometer (CDSM) instrument of the JUICE-mission.
- Calibration and Test champagnes of the JUICE FM and FMS and the CSES II FM and FMS sensors.
- Assembly, Test (Thermo-, Thermo-Vacuum, Radiation-Test) and Qualification of the In- and Outbound optical fibres connecting the DTS to the electronics box.

Sales 2021 (TU Graz total): 0.633 M€
ESA Share : 0.203 M€

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