AUSTROSPACE

VEREINIGUNG ZUR FÖRDERUNG
DER ÖSTERREICHISCHEN WELTRAUMINDUSTRIE

AUSTRIAN SPACE INDUSTRY ASSOCIATION

Annual Report 2022

CONTENTS

What we find is that if you have a goal that is very, very far out, and you approach it in little steps, you start to get there faster.

Your mind opens up to the possibilities.

– Mae Jemison, engineer, physician and former astronaut

The current AUSTROSPACE Annual Report comprises an up-to-date list of members, including their contact information, along with contributions from industrial members and research organizations detailing their space activities throughout the year 2022.

Holzhausen , October 2023

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Hans-Martin Steiner
Vice President and Managing Director

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In the Space and Avionics business, Atos sets tomorrow's standards developing customer-specific solutions. Atos is your trusted digital partner for your journey to next generation space solutions. Atos provides products, solutions and services, from upstream to downstream; for mega constellations & satellite manufacturers; for satellite operators and national space agency's, for satellite mission control ground segments and ground stations

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Leading supplier of advanced on-board digital signal processing solutions, including navigation receivers for precise orbit determination. Well-recognized partner for deployment/pointing subsystems (mechanisms and electronics) and high-performance mechanical ground support equipment (MGSE). European market leader for design, production and integration of space thermal insulation products.

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World leading manufacturer of electric propulsion systems for nano- and micro-satellites. The company is based in Wiener Neustadt, Austria and has a business development office in Silicon Valley, CA. In its own semi-automated production facility ENPULSION is manufacturing the IFM Thruster family, including the IFM Nano Thruster – the only compact, scalable, and modular electric propulsion system worldwide.

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Develops and operates advanced information platforms and services for access and combined analysis of data provided by satellite Earth Observation and other geospatial sources with information of socio-economic origins. EOX is technology partner of choice in major environment monitoring and space programs (e.g. Copernicus) and in applications domains like agricultural monitoring and digital cartography.

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Internationally renowned for its innovative Earth observation services, Austrian lead organisation and among the top-three in the European Commission Copernicus Land Monitoring Service Programme. GeoVille offers targeted, value-added geo-information products and related solutions for a broad international client base.

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With more than 20 years of experience as a supplier for piping, ducting and gas storage systems, Magna Steyr Aerospace has established a strong reputation as a reliable and experienced partner for the global space and aeronautics industry. Our competences encompass design, process development and manufacture according to the highest industry standards.

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OHB Digital Solutions GmbH is specialized in developing and combining navigation, telecommunications, and information technologies. The company is considered the leading provider of products and services for various applications in the context of satellite-based navigation systems. OHB Digital Solutions GmbH has more than two decades of research and development experience in the field of GNSS quality assurance and GNSS signal simulation.

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The company was founded in 2007 and is headquartered in Holzhausen, Upper Austria. By now Peak Technology GmbH is one of the major providers for cryogenic storage systems and high-pressure vessels as lightweight hybrid composite structures, which are installed in commercial launcher and satellite applications. By combining the whole value chain from product design to manufacturing in one place, integrated solutions for complete repulsion tank systems can be provided to our customers.

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The TTTech Group stands for reliability, robustness and safety. Its deterministic TTEthernet solutions are increasingly used in space applications with the NASA Orion MPCV being the most prominent use case.

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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 started in 1998 with the ESA-certified Space Materials Testhouse under ESTEC frame contract and is coordinator of European and national research cooperation projects in aeronautics and space.

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The Space Research Institute (Institut für Weltraumforschung, IWF) 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 not only one of the largest institutes of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW), but also the only institute in Austria that develops and builds space-qualified instruments on a large scale. The data returned by them are scientifically analyzed and physically interpreted at the institute. Currently, the IWF is involved in 23 international space missions, led by ESA, NASA or national space agencies in Japan, Russia, China, or South Korea. The missions cover fleets of satellites in near-Earth space, the observation of the Sun, and the exploration of planets such as Mercury, Jupiter, and extrasolar planets.

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Public-private partnership providing high performance computing, access to a multi-petabyte global archive of earth observation data. Through dedicated EODC services, our partners and customers are able to access.

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The University of Applied Science Wiener Neustadt provides a modern education in the field of Aerospace Engineering. Combining traditional education methods with the most cutting edge R&D in Space Propulsion Technology, Space Engineering and Additive Layer Manufacturing Methods, prepares their students for the most challenging jobs in the Aerospace Engineering industry.

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Internationally renowned partner in the areas of nanosatellite technology, satellite communications and navigation, satellite geodesy, remote sensing as well as development and test of Space-qualified hard- and software. Responsible for the first Austrian satellite TUGSAT-1/BRITE-Austria and follow-up missions OPS-SAT and PRETTY.

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Develops solutions and technologies for commerce and industry in a wide range of fields and carries out advanced research on an international scale. By focusing on applied research and technology development, the innovation company plays a key role in technology and knowledge transfer. The institute DIGITAL is your trustworthy partner in the field of digital innovation and transformation and develops applied high tech solutions for the following markets: Mobility, Space, Industry, Security & Defence, Energy & Environment, AAL & Digital Care, and Culture & Creative Industries.

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Institutional members

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The interest group for Austria's electrical and electronics industry makes an essential contribution to securing Austria's position as an attractive business location and positively influences and shapes the economic and legal framework – in ways that benefit the electrical and electronics industry. Together with 26 network partners, the FEEI plays a central role in strengthening the competitive position of the represented industry segments in the global marketplace.

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The products made by the approximately 145 members of this Association include all kinds of vehicles: from bicycles and motorbikes to on- and off-road cars, utility vehicles, trailers, surface mountings and small airplanes, as well as components such as motors, gear boxes and parts for the space industry. The products of the Austrian vehicle industry enjoy a very high reputation all over the world, which explains the high quota of international direct exports of presently 90%.

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Austria's strongest branch includes over 1,200 companies from mechanical engineering, plant construction, steel construction, metalware and foundry industries form the backbone of domestic industry. The export-oriented sector is medium-sized, consists of more than 85% of family businesses and accounts for a quarter of all Austrian exports. Many companies are world market leaders and "hidden champions".

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The Austria Research Promotion Agency (FFG) is the national funding agency for industrial research and development in Austria. All FFG activities aim to strengthen Austria as a research and innovation centre on the global market. The Aeronautics and Space Agency of the FFG is the docking station to the international aerospace world for Austrian business and science. The agency implements national aerospace policy and represents Austria on international aerospace committees.

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This Division represents the interests of more than 5,000 industrial companies in Austria. The domestic industry generates an annual production value of 169 billion euros and contributes around 44 billion euros to Austria's gross value added. Austria's industrial companies employ more than 450,000 people and have a strong international network with an export quota of 69%.

Member Reports

Meteosat-2 image of Earth © ESA

Aerospace & Advanced Composites GmbH

(AAC)

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.

AAC facilities at TFZ in Wiener Neustadt

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

New "XVC" in Clean room Class 7

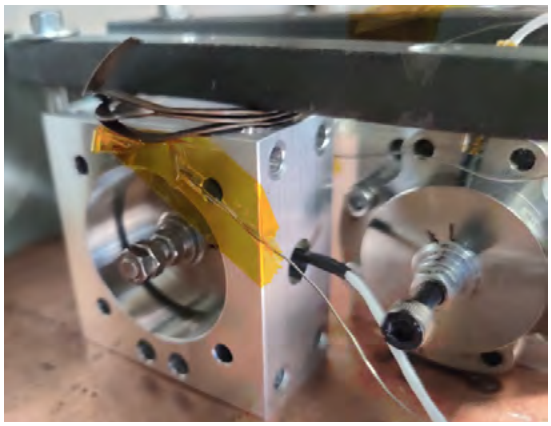
In 2012 AAC moved to its new premises in Wiener Neustadt, hich is based on strategic decision: in this area several new research entities and one University of Applied Sciences are located which provide for AAC a more prosperous growth. The infrastructure covers one building with labs and offices and 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.

Upgrade of XVC Thermal Vacuum Test Facility for MLI Bake-Out

On customer request, AAC has developed a special jig for thermal vacuum bake-out of larger MLI blankets, e.g. for METOP. The set-up had been successfully used for several activities. Apart from the METOP MLI Bakeout runs, AAC has performed a number of thermal vacuum cycling and bakeout activities for various ESA missions, like PLATO (manipulator rings). HERA (several components), JUICE (harness), CIRR (LDRS Hinge Breadboard, structural CFRP/Titanium struts), OPTISAT (TSTA MLI).

In collaboration with Space-Lock, several types of HDRMs were tested for functionality after exposure to thermal vacuum cycles.

Furthermore, thermal vacuum qualification projects of various components on breadboard and EM level had been successfully performed for several European customers.



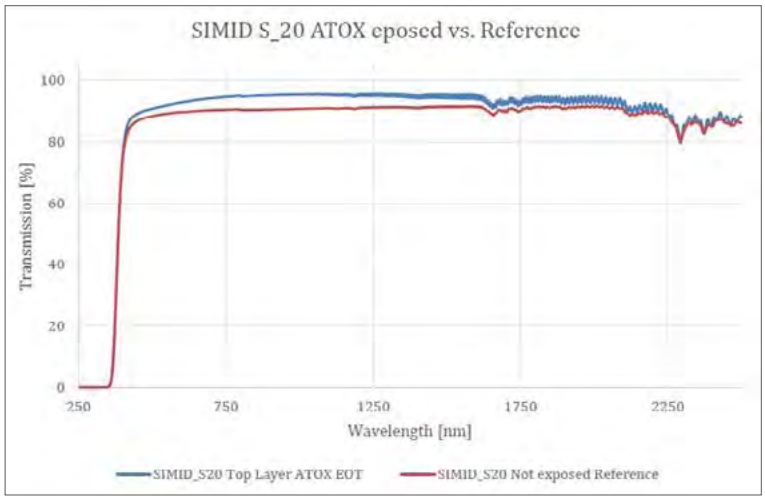
New AAC transparent foils selected for flight to ISS for application towards OSR or MLI

The low Earth orbit (LEO) environment includes altitudes up to several hundred kilometres above the Earth's surface. Under the microgravity environments of the low earth orbit (LEO), highly reactive atomic oxygen (ATOX) is the most of the abundant elements in space environment. In addition, there are UV radiation, micrometeoroid particulates and temperature cycling on orbit. The effects of all these constituents make the LEO environment extremely harsh and results in significant degradation of polymeric materials. Although polyimides (PIs) belongs to the group of the most applicable organic materials in space, they still suffer from long term ATOX induced erosion.

The problems connected with the degradation of polymers known from flight missions resulted in the need for the development of new space-durable light-weight polymeric materials. In the previous activities (NanoHTM, TPFfTOA projects) also AAC has started with the development of new PI based materials with improved not only ATOX resistance, however also thermo-optical properties. Recently, AAC has developed a new type of PI material,

which was selected for the testing in real space environment within the activity announced by ESA "Euro Material Ageing" on-board the International Space Station ISS. A pre-flight ATOX screening test of the AAC flight candidate (polyimide based foil "SIMID S20") was performed in the ESTEC TEC-QEE Laboratory LEOX facility. The test samples received on average the total fluence of 8.2 x 10^{20} atoms/cm^2 and the results indicate that SIMID_20 remains transparent and additionally has significant lower erosion yield (7.81 x 10^{-26} cm^3/atom) compared to commonly used Kapton H (3.00 x 10^{-24} cm^3/atom).

SIMID S20 a new type of polyimide based foils prepared for the testing within the "Euro Material Ageing" activity on-board the International Space Station



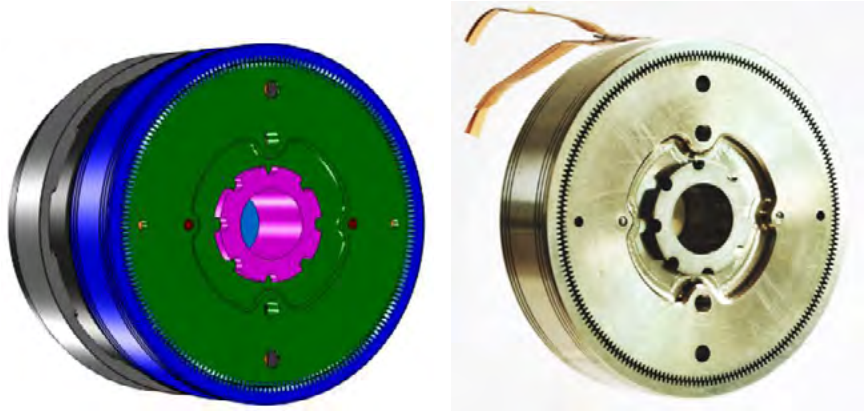
SIMID S20 Transmission in UV VIS NIR of ATOX exposed layer vs. a non-exposed reference.

Magnetic Brake for Driving Units for Applications in Space Environments

Within the ESA-project "Magnetic Brake" an Austrian consortium designed, built and tested a braking system which can be attached to a motor and increase it's holding torque. This device – the magnetic brake – helps to reduce the power consumption on satellites.

AAC's part was to test the magnetic brake under space conditions (high vacuum hot and cold) and verify it's predicted performance. The test campaign was finished successful in 2022 and the device outperformed ESA's specifications.

Magnetic brake: FE-Model (left) and BB after intense TVAC testing at AAC (right)



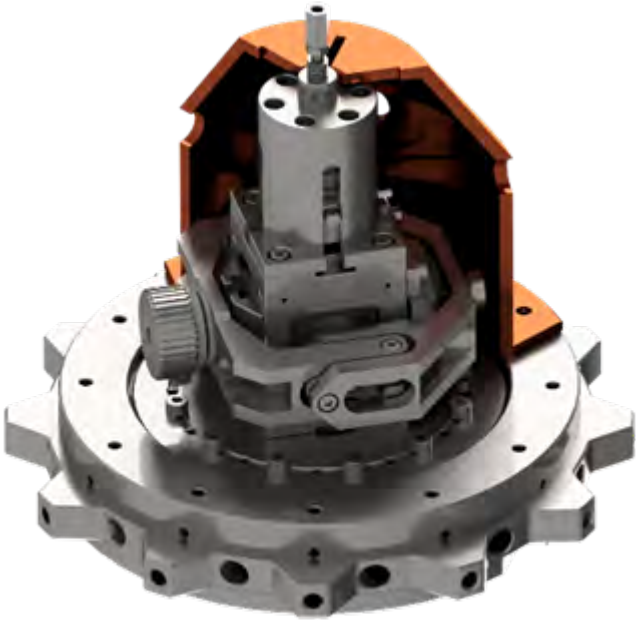
Advanced Bearing Testing under TVAC

Currently AAC is upgrading its test device for (ball) bearing tests. Following a trigger by deployment applications, where the pre-load of bearings is changing during deployment, the HADES test device is currently getting upgrade by a new setup, that allows two new features:

- **Dynamic loading (DynAx):** the HADES offers two in-line-shafts for testing of Harmonic Drive® gears, and offers to day ball bearings test with pre-load in TVAC from -170°C up to +200°C. One shaft will also in future be used to drive the ball bearings and measure the operating torques. The second can soon be used to change the axial pre-load of a tested bearing pair in-situ.
- **Radial or Bi-Axial loading (BiAx):** the new setup will also enable to apply a radial pre-load. This can be done in combination to the axial pre-load and again in same TVAC conditions.

These new setups will enable to investigate bearing performance under TVAC much more efficient, as time consuming thermal vacuum steps may be reduced.

HADES test device with two motion shafts: top and bottom



New setup for DynAx and BiAx pre-loading of ball bearings

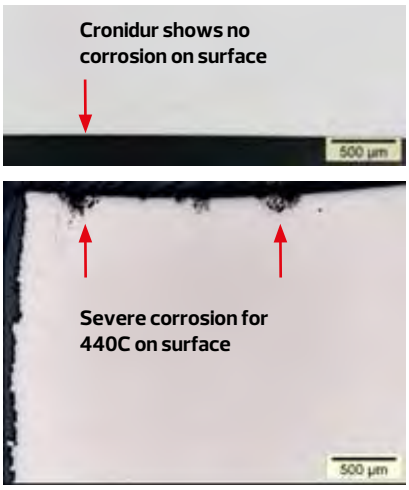
CronHard — It is feasible ... for a bearing steel to become SCC-resistant!

For ball bearings, steels were developed with a high hardness to obtain good wear resistance and to survive high contact stresses. As long as "classical bearing designs" with nominally only compressive stresses had been used, stress corrosion cracking (SCC) was no issue. However, the trend to higher efficiency and mass reduction leads to "integrated solutions", like combining bearing with housing for which tensile stresses appear in the rings and the problem with SCC compatibility arises.

Bearing steels are usual not SCC-resistant (Class 3 acc. to ECSS-standards). Former detailed studies performed at AAC under ESA contract revealed that a bearing steel might be "upgraded" to "high resistance against SCC", if

Wave Generator Bearing

AAC test device "HADES" with test box for Harmonic Drive ® Gears



Cross section of specimens after SCC-test showing partly severe corrosion pits underlining performance of Cronidur

only optimised manufacturing processes would be used. Therefore, a dedicated project was initiated to investigate the options to increase the resistance to SCC.

An initial screening revealed Cronidur 30 as most promising candidate. The performed work enabled to identify a heat treatment providing a material variant which withstands SCC test at a stress level of 50% of Rp02 without any signs of corrosion and stress-corrosion cracking phenomena. This variant shows high strength and hardness (UTS ~ 2100MPa, Rp02 ~ 1600MPa, 650-670 HV1 / 58 HRC).

As a final bread board test, a Harmonic Drive ® Gear was selected. Inside, the Wave Generator Bearing consists of two thin rings, which are deflected during operation causing tensile stresses. They were machined from Cronidur and thermally treated via AAC. Finally, a life test in thermal vacuum was run for almost 6 months (from +90°C to -40°C). Post-inspection showed the bearing rings to be in good conditions, no signs of wear in the races nor degradation of its microstructures were identified. **It is concluded that a bearings steel being SCC-resistant can be obtained.** Moreover, this benefit may be applied to other stress loaded components like gear wheels.

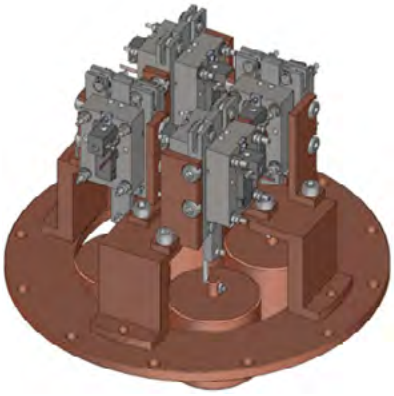
AAC releases a new test device to validate material pairs for friction-based actuators

The usage of linear piezo motors offers attractive advantages (such as outstanding torque vs mass ratio, irreversibility and stable positioning when unpowered) which may be of interest for space applications like for positioning, where long holding times are combined with low share of motion. Friction based actuators would not need any energy during holding times.

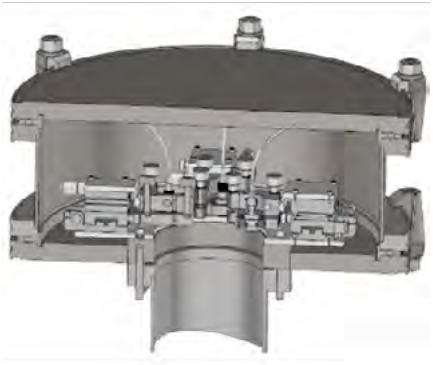
However, the usage of piezo motors for space applications is still very limited: The main disadvantage of this type of motors lies in the intrinsic use of friction for the achievement of motion, some of the moreover relying on the tribological of stick-slip - phenomenon. This is especially of concern in terms of repeatability, reliability and sensitiveness to varying environmental conditions causing change in friction and wear. The major objective of an ongoing ESA activity is to assess and improve the lifetime and reliability of piezo motors technology.

AAC is responsible to validate proper material pairs that offer stable friction coefficient under different environments (as required for the reliable motion) and low wear rate. As classical pin-on-disc tribometers are not ideally represent the motion profile of such piezo actuators, AAC developed a dedicated test setup, based 4 piezoelectric motor. After manufacturing, implantation and functional testing it passed recently successfully TRR. It will not be

AAC's vacuum test device "SALOTTE" offers testing of actuators and gears



Setup to validate the friction pairs aimed for piezo-motors



Add-on for "SALOTTE" containing the laser sensor system to monitor the motion

able to validate friction pairs in different working conditions in terms of environment (e.g., high/low temperature, vacuum, etc.) and contact loads and speeds.

The developed setup is regarded as much more representative compared to standard tribometers, as the latter are based on "forced" motion (which may cause different behaviour in terms of friction and wear than the actual actuator later on), whereas the new setup is fully representing the motion created by kind of piezo actuators. Monitoring of the motion is done via laser sensor system.

Low temperature Mechanical Testing for Cryogenic Tanks

Since several years, AAC develops and performs mechanical tests under ultra-low temperature conditions, especially important for the development of new materials such as lightweight Ti and Al alloys partly manufactured using 3d printing, composites or honeycomb structures used in cryogenic tanks or brackets for e.g. space propulsion.

Tensile failure of UD composite

Compression Test

ILSS Test

Beside standard tests for metals, plastics, composites, honeycomb panels and joints, special fixtures such as metal shear, pin type bearing or fracture toughness, composite bearing or honeycomb shear were designed, manufactured and are in use for tests in liquid helium at 4.2 K, liquid nitrogen at 77K or between –160°C till 600°C.

Materials testhouse @ AAC

AACs frame contract to ESTEC on Metallic Material Characterisation ("ESA testhouse") aims to validate new materials and processes for use in space. The contract shall provide data necessary for space engineers to apply those new materials in their missions (which often do neither have time nor budget for extended validation of new materials).

Recent studies continued validating the SCC-resistance of new materials made by AM (Additive Manufacturing, 3D-Printing). As those alloys are intended for use in structural applications being subjected to tensile stresses, they need to offer at least medium, but preferable high resistances against Stress-Corrosion-Cracking (SCC, according to the ECSS-Q-ST-70-36).

With upcoming of his new manufacturing method concerns were raised that due to "composing" those materials from powders high risk of failure due to SCC might follow. Recent studies were focusing on new Al- and Ti-based alloys. Results are published via ESA.

AAC as test service provider offers to initiate further such validation campaigns under this ESA-funding. Industry and space players are welcome to contact AAC.

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FACTS

Sales:	1,5 M€
ESA Share:	0,4 M€
SpaceIND:	1,1 M€

Solar Orbiter © ESA/ATG medialab

Atos IT Solutions and Services GmbH

Atos is a global leader in digital transformation with 111,000 employees and annual revenue in 2022 of € 11"3 billion. European number one in cybersecurity, cloud and high-performance computing, the Group provides tailored end-to-end solutions for all industries in 69 countries. A pioneer in decarbonization services and products, Atos is committed to a secure and decarbonized digital for its clients. Atos is an SE (Societas Europaea), listed on Euronext Paris.

The purpose of Atos is to help design the future of the information space. Its expertise and services support the development of knowledge, education and research in a multicultural approach and contribute to the development of scientific and technological excellence. Across the world, the Group enables its customers and employees, and members of societies at large to live, work and develop sustainably, in a safe and secure information space.

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 Controllers
  - Ground Segment Solutions and Integration
  - Mission Control System Maintenance and Evolution
- For Satellite Operators
  - Carrier Monitoring and Interference Localisation 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 2022 Atos Space & Avionics' revenue reached almost € 25 million, based on commercial space markets, ESA, and Galileo activities. The share of Austrian ESA sales therein accounted for € 5.4 million.

In September 2022, Atos SE and Terma A/S signed an agreement, whereby Terma will take over all the Atos Satellite Testing activities, including all rights and obligations, projects, outstanding offers, employees and assets.

The new company in Austria taking over the Satellite Testing business is called "Terma Technologies GmbH" and shall be in operation as of March 1, 2023.

The 2022 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 Galileo 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 origi-

nate from the test equipment. A specific effort has therefore been concluded 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.

The first cyber-secured implementation was presented to ESA at the end of 2022 with ProUST UniverSAS® 2.1 and is currently being delivered.

Radio Frequency, Telemetry/Telecommand and RF Suitcase Test Systems

In 2022, 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 continued two funding projects in this field. One is to develop an SDR modem (SDR – Software Defined Radio), consisting of a frontend (USRP – Universal Software Radio Peripheral) + backend (PC), which offers several benefits since it can be easily reprogrammed, supports frequencies up to 6 GHz and supports different modulation schemes without the need of extra external equipment. Moreover, new features can be implemented through software keeping the same hardware.

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.

Atos' mission related work in 2022 was for: OneWeb, SpaceRider, Copernicus CO2M, Copernicus CRISTAL, Copernicus LSTM, Copernicus ROSE-L, Galileo G2G, Hera, H2Sat, Mars Sample Return, Euclid, Juice, 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.

The Atos RF PTS and TTC SCOE will be enhanced with additional features to serve project needs, like Cortex Integration, Multichannel I/O, Digitizer support features, Next Gen timing signal distribution, Next Gen COTS measurement equipment integration and Next Gen master test controller. The Atos RF PTS and TTC SCOE will be realize following features:

- Deployment of GSE3 to GSE4 for the TTC SCOE
- Cortex Integration
- Multichannel I/O
- Digitizer support features
- Next Gen timing signal distribution
- Next Gen COTS measurement equipment integration
- Next Gen master test controller

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 2022. SpaceRider, Hera and Copernicus CO2M are based on our product UniverSAS® as well.

The Instrument EGSE projects that were started in previous years, were finished, among those were Instrument EGSEs for Hera and Euclid. We have started the work on the ROSE-L Instrument Frontend and the Instrument Backend EGSEs.

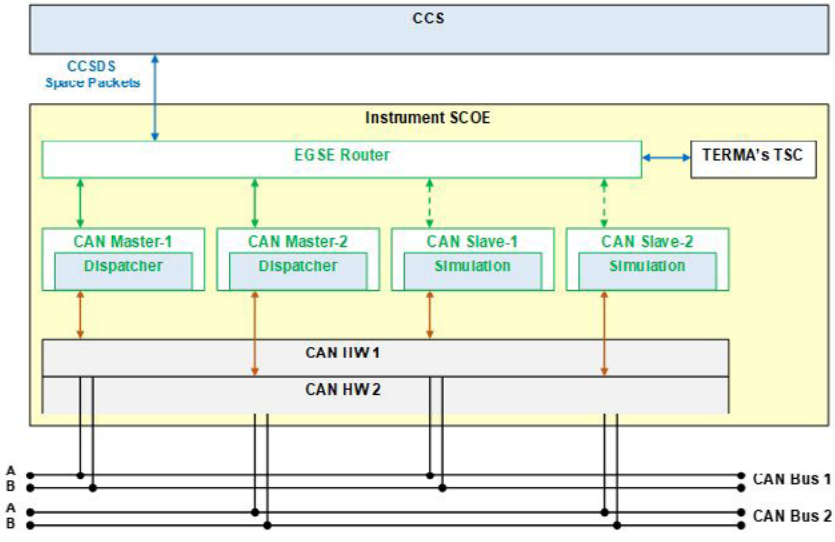
VEGA-C Navigation Equipment GSE and Neosat UMB

Atos Instrument SCOE challenges is to keep the existing and well established functions available and stable and to improve Instrument SCOE with the new features:

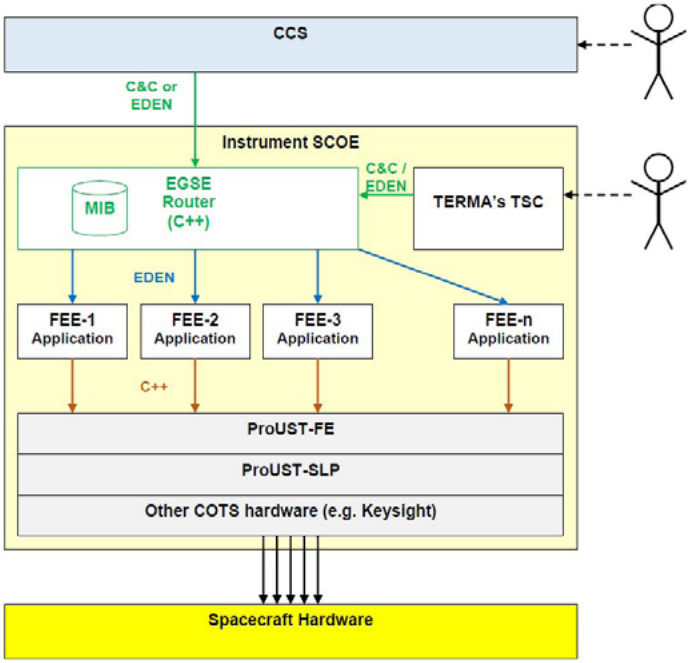
CAN Bus support: The CAN bus is included as a new FEE solution for the ATOS SCOE product. The CAN bus integration is shown in the picture below with its external interfaces, on one side to the CCS and the connection to the HW bus on the other side.

ProUST-FE driver update: The existing low layer GNU/LINUX driver for the ProUST-FE shall be updated to support the current versions of the Linux kernels of up to date UBUNTU/DEBIAN Versions and is prepared for easy adaptation for further updates by modularization of the different ProUST-FE driver modules.

Simulation Software: Instrument EGSEs are used during the spacecraft AIT (Assembling, Integration, Testing). These systems replace parts of the hardware on the spacecraft that is attached to the platform. The EGSE shall simulated functionality when the original parts are not available on a detailed functional level in quasi real time.



INSTRUMENT SCOE: CAN bus interface architecture



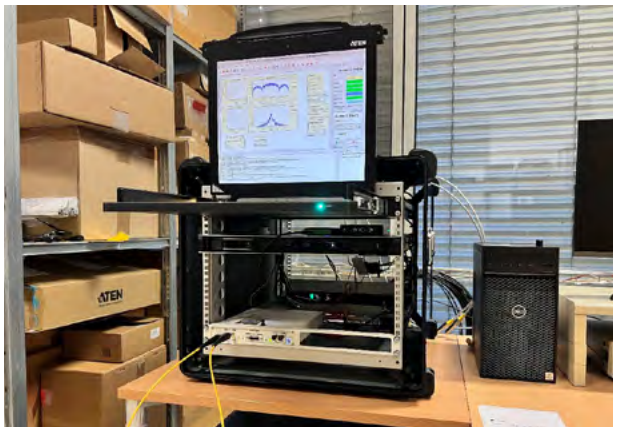
Enhanced Instrument SCOE architecture

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 started.

In 2022, after an analysis phase, with the aim of improving the modem's performance and reducing its size, the modem hardware was updated.

The backend (PC) was replaced by a new 1U PC with better CPU, GPU, faster storage, new serial (RS422) and SFP+ NIC (so that the FE and BE can be connected through optical fiber and use DPDK to improve latency). Moreover, some of the signal processing blocks developed during the initial phase were moved from the CPU to the GPU using Nvidia parallelization technology. The frontend (USRP) was updated to make use of the remaining space in its FPGA, moving some of the signal processing done by the PC to the USRP. ESA-Code ranging will be implemented in the SDR modem as well.



2022 Prototype of SDR Modem

New product: ProUST UniverSAS® 2.1

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

The 0 series of the ProUST UniverSAS® 2.1 has been produced with 50 machines and some have already been delivered to customers.

For the expansion of the ProUST product family, a multi-channel PYRO/relay module in ProUST UniverSAS® 2.1 made it possible to provide simple PYRO solutions in large numbers. In order to maintain the well-known ProUST specific display, an additional external display was developed.

In order to keep pace with advancing battery technology in terms of performance and service life, an extension of the ProUST UniverSAS® 2.1 for extensive battery testing was started in 2022. Here, the prognosis of the reliability of the battery in production should already be predicted by means of high-precision battery parameter measurements under realistic working cycles.

For this purpose, both the performance in terms of current capability and the necessary measurement accuracy are increased. Since the lifetime of batteries is heavily dependent on their chemical processes, chemical activation must also be implemented and tested in a controlled manner using modulated load profiles.

Several ESA study contracts have been concluded, among those the

Telco EGSE TMTC SCOE:

The overall function of the Atos Baseband TM/TC SCOE and TM/TC Crossbar is to provide validated interface hardware and software functions to interface baseband TM and TC hardware with the remaining EGSE infrastructure. This includes high-speed baseband data interfaces to On-Board Computers, COMMS elements such as Transponders and Modulators, Security Units, etc. Further applications of the envisaged functions are EGSE systems on subsystem level, which require baseband TM/TC interfaces and functions based on these, as well as Umbilical Test Systems used at the launch location, prior to connecting the actual spacecraft.

Telco EGSE Power SCOE:

The Power Special Check-Out Equipment (SCOE) is part of the electrical ground Support Equipment that provides via the current Atos UniverSAS® product the required electrical power, simulates the real spacecraft battery and the solar array behavior and provides monitoring of some onboard electrical parameters. It is used during all phases of the spacecraft integration and test, i.e. from Avionics Test Bench (ATB) and Service Module (SVM) integration up to the launch campaign. The main objective was to extend the capabilities of the Atos UniverSAS® product to cover also different Telecom satellite requirements through generic firmware and software solutions. Among the achievements were S3R, Higher power efficiency, less ripple and less spikes in the Solar Array Simulator, Battery Simulator and Battery Conditioner.

These new innovative EGSE features are requested for the Manufacturing, Assembly, Integration and Test (MAIT) of almost all types of missions and satellites, therefore the product/technology will address:

Satellite Control: Ground Segment Systems and Mission Control Software

Also, in the year 2022, the main focus of Atos Space activities in the Ground Segment Systems and Mission Control Software domain was in the following areas:

- Evolution of generic Mission Control and EGSE SW architectures and building blocks
- Performance Evaluation and Improvements of the ESA Common Core developments

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

Virtualization

SkyMon was recently selected by Eutelsat as base system for the development of a next generation payload monitoring tool to meet the growing challenges of a new space era which include new satellite communications technologies, the need to integrate 5G and the potential increase of signal interferences caused by the growing number of satellite mega constellations.

The solution consists of a cloud-based state-of-the-art microservice architecture on top of a high-performance generic core, allowing flexible adaptation on changing requirements with minimal risks. By incorporating artificial intelligence, big data and cloud features, Atos makes the system more intelligent, with automated monitoring features. Seamlessly interacting with customer business applications, SkyMon can process data no matter, where they are stored and enables to visualize and analyze metrics through a smart dashboard.

The new microservice architecture enables realizing virtualized monitoring to reduce CAPEX on the ground. Each monitoring functionality is cut into microservice, integrated into a docker container with a standardized REST-API and can be accesses from anywhere. Satellite signals captured and digitized on the ground can be streamed to a virtualized environment (e.g. cloud), where the relevant microservices perform centralized signal analysis tasks.

Passive Ephemeris Determination (PED)

Any service provider that relies on satellite communications, such as broadcasters, governments, defense groups, disaster response teams, banking or enterprise groups, usually picks satellite for its always-on and far-reaching capabilities. Should a paid-for TV broadcast go down, for example, the broadcast company stands to lose a great deal in both public opinion and financial penalties. In the defense sector, on the other hand, should vital information not be communicated to the required person in a timely fashion, lives can be lost.

New technologies are a major reason why interference has become an increasingly significant problem in recent years. Small, mobile VSAT terminals, high throughput satellites (HTS), and the growing popularity of high-frequency bands have all played a role. To combat the rising interference challenge before it becomes completely out of control, new solutions are being developed, while working groups and associations like the satellite innovation group SIG and the Global VSAT Forum (GVF) educate a growing number of members on both proactive and reactive responses. The best cure for satellite interference has been and will continue to be vigilant monitoring by advanced sophisticated interference detection systems, with algorithms that determine the identity of interfering carriers.

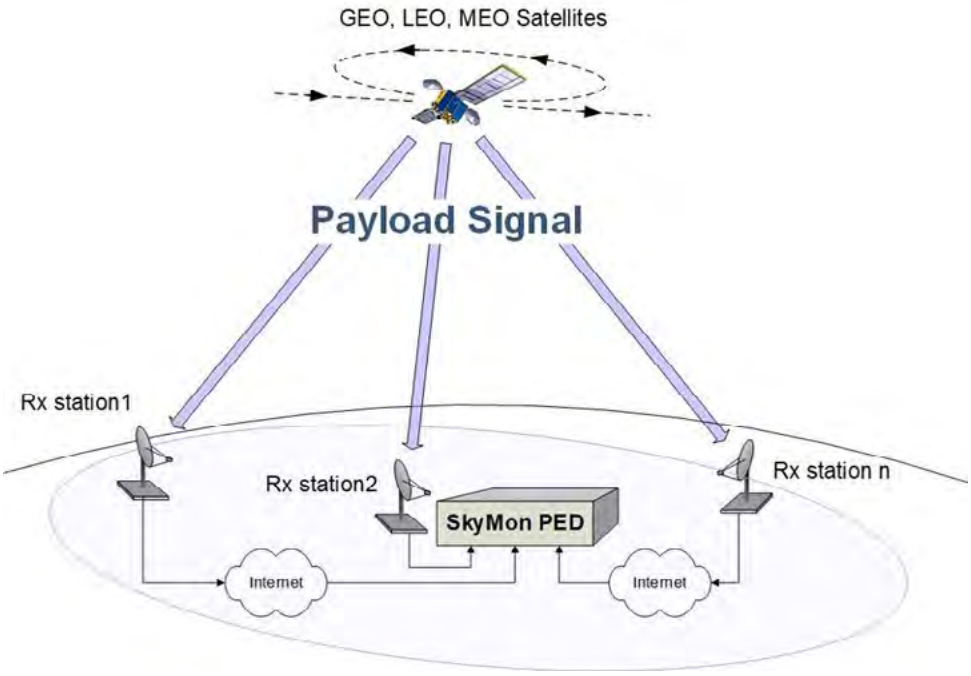
Atos is successfully marketing its SkyMon product, which is one of the most comprehensive satellite monitoring and geolocation systems in the world. It is used by major satellite operators to monitor the quality of their satellite communication channels and to detect, classify and geolocate interferences. Its fully integrated Interference Localization System ILS is one of the most precise geolocation systems. Nevertheless, some preconditions have to be met for performing successful and accurate geolocation measurements. One of these preconditions is the precise knowledge of satellite orbital parameters at the time of the geolocation measurement.

Unfortunately, frequently, this information is not available or not available with the required accuracy due to several reasons:

- The accuracy of this data typically focuses on routine operations such as pointing/tracking of antennas and is adequate for that purpose but does not have highest accuracy as required for geolocation.
- Satellite operators do not want to share accurate owner operator ephemeris in general or do not share it on a regular basis.
- Adjacent satellite operators do not want to share this data with the operator of the affected (primary) satellite who is frequently a commercial competitor.
- Sometimes satellite operators do not even have precise ephemeris data with the required accuracy.
- Publicly available, third-party data (e.g. NORAD) typically suffers from a lack of accuracy too (especially for the velocity vector).
- Ephemeris of electric propulsion satellites frequently suffers from higher error because more frequent observational data would be needed for gaining highest accuracy.

PED determines satellite ephemeris data (orbital parameters describing the trajectory of a satellite) for the purpose of improving the accuracy of geolocation systems and tracking of satellite orbits. It offers to

- continuously determine satellite ephemeris data for the purpose of tracking GEO, MEO and LEO satellites
- calculate accurate satellite ephemeris data as input for geolocation systems for the purpose of improving their accuracy
- predict the trajectory of a satellite based on historical ephemeris data.



Passive Ephemeris Determination Architecture

In addition, this data can be used for

- Traditional satellite ranging activity (supporting flight dynamics operators to prepare satellite maneuvers and calculate the state vector before/after the maneuver)
- Collision and interference avoidance (e.g. coordination of co-located satellites)
- Space situational awareness activities
- Remote sensing applications.

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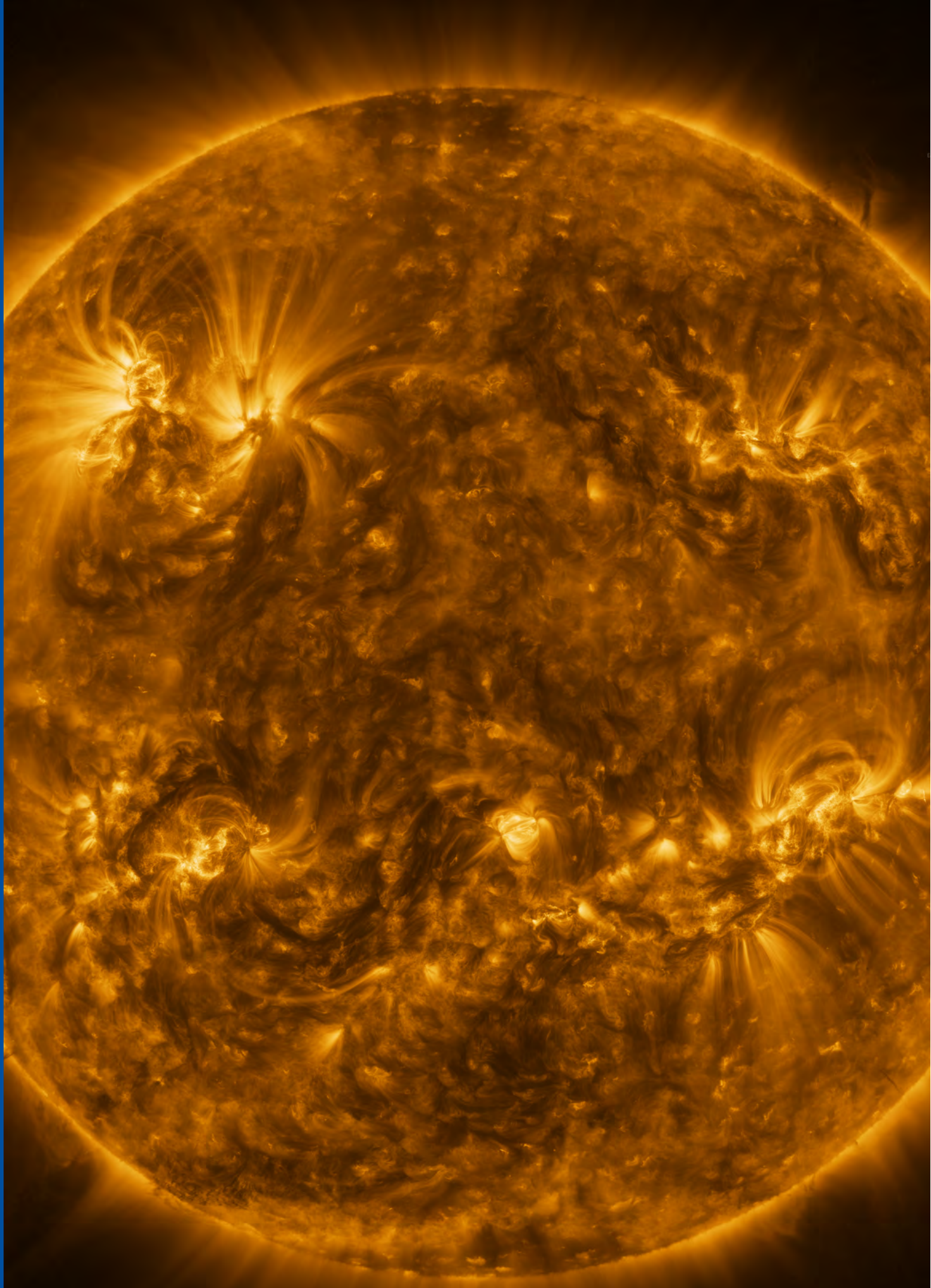
FACTS

Sales: 24,9 M€
ESA Share: 5,4 M€



The Sun in high resolution © ESA & NASA/Solar Orbiter/EUI team; Data processing: E. Kraaikamp (ROB)

Austrian Academy of Sciences

Space Research Institute

The Space Research Institute (Institut für Weltraumforschung, IWF) 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).

The IWF develops and builds space-qualified instruments and analyzes and interprets the data returned by the space missions. 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 the 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.

The 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). In 2022, the IWF was involved in 23 active and future international space missions; among these:

- The Cluster mission continues to provide unique data to better understand plasma processes in near- Earth space.
- The four Magnetospheric MulitScale (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 2023.
- On the halfway point of the journey to its destination, BepiColombo had its second Mercury flyby in June.
- CHEOPS (CHaracterizing ExOPlanets Satellite) continued nominal science operations, characterizing exoplanets around bright stars.
- ESA's Solar Orbiter saw a giant solar eruption in February, was hit by a CME before its third Venus flyby in September and approached the Sun in October at a distance of about 0.29 AU.
- The NASA CubeSat CUTE (Colorado Ultraviolet Transit Experiment) delivered its first science data.
- ESA's JUpiter ICy moons Explorer (JUICE, launch: April 2023) will investigate Jupiter and three of its largest moons, Ganymede, Callisto, and Europa.
- SMILE (launch: 2025) is designed to study the interaction between the solar wind and Earth's magnetosphere.
- The FORESAIL-2 (launch: 2025) CubeSat will characterize the variability of ultra-low frequency waves in

the inner magnetosphere.
- PLATO (launch: 2026) is a space-based observatory to search for planets orbiting alien stars.
- HelioSwarm (launch: 2028) was selected as NASA's new Medium-Class Explorers (MIDEX) mission in February 2022. The multi-satellite mission will help to better understand the interaction between the solar wind and Earth.
- Comet Interceptor (launch: 2029) will characterize in detail, for the first time, a dynamically-new comet or interstellar object.

HIGHLIGHTS IN 2022

- In "Physics of Plasmas" K. Blasl et al. presented the first kinetic scale observations of the Kelvin-Helmholtz instability under southward interplanetary magnetic field conditions using high-resolution MMS data. These observations were complemented by fully kinetic Particle-In-Cell simulations and have led to the detection of space plasma processes such as magnetic reconnection and wave instabilities at different temporal and spatial scales.
- In the "Journal of Geophysical Research: Planets" D. Schmid et al. shared findings about the tenuous exosphere surrounding Mercury. Through on- site detection of plasma waves by magnetic field measurements it was possible to obtain the hydrogen density profile at various altitudes around the planet. This new information has provided valuable insights into the complex dynamics of Mercury's exosphere and contributed to our understanding of the physical processes in the inner solar system.
- In "Nature Astronomy" F. Borsa et al. reported the results of observations carried out with the CARMENES high-resolution spectrograph that have led to the detection of neutral oxygen in the atmosphere of the ultra-hot Jupiter KELT-9b. This detection has been guided by new models produced by members of the institute and opened a new way to detect oxygen in exoplanetary atmospheres.
- In "Astronomy & Astrophysics" D. Kubyshkina and L. Fossati presented the results of atmospheric evolution modeling for planets in the 1-108 $M_\oplus$ mass range and its further comparison with the mass-radius distribution of the currently known exoplanets. The predictions reproduced the observed mass-radius distribution well. The simulations led to the conclusion that the observed characteristics of low-mass planets ($\leq$10-15 $M_\oplus$) strongly depend on the impact of atmospheric mass loss, while the parameters at formation play the dominant role for more massive planets.
- In "Astronomy & Astrophysics" P. Woitke et al. presented a model for vertical turbulent mixing in thermo-chemical models for planet-forming disks. It was shown that vertical mixing enriches the mixture of ions, atoms, molecules and ice species which creates a more active chemistry and opens new chemical pathways. Icy grains were shown to reach the visible disc surface where they cause mid-IR ice emission features that will be observable with the James Webb Space Telescope.

THE YEAR 2022 IN NUMBERS

Members of the institute published 158 papers in refereed international journals, of which 32 were first author publications. During the same period, articles with authors from the institute were cited 8163 times in the international literature. In addition, 89 talks (18 invited) and 37 posters were presented by IWF members at international conferences. Institute members were involved in the organization of 15 international meetings, e.g. EGU General Assembly, EPSC, the 22nd International Workshop on Laser Ranging (ILRS), European Astrobiology Institute (EAI) Academy, and the CHAMELEON Network Retreat.

IWF STRUCTURE AND FUNDING

The institute is led by Christiane Helling, who simultaneously holds a university professorship in space science at the Graz University of Technology. In April, Luca Fossati followed Werner Magnes as Deputy Director.

The IWF 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: Michael Steindorfer)

The 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.

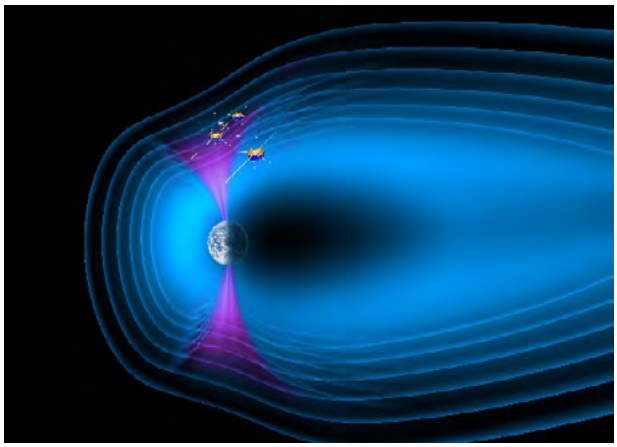
NEAR-EARTH SPACE

Near-Earth space is a natural plasma laboratory with different types of boundaries and regions that are created as a consequence of the interaction between the solar wind and the Earth's intrinsic magnetic field and plasmas. It allows us to study fundamental plasma physical processes such as acceleration or heating as well as geo/planetary sciences, i.e., how the Sun and solar wind affect the Earth/planetary plasma environment, called, in a more general term, space weather phenomena. The 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 the IWF by applying different methods and by theoretical modeling to compare with the observations.

Among the different space plasma missions, the Magnetospheric MultiScale (MMS) mission is designed to study the Earth's magnetosphere on the electron scales with high-cadence multi-point measurements. This year new studies on the Kelvin-Helmholtz instability (KHI), which is an important instability to explain the solar wind plasma entry process at the flank of the magnetosphere, have been reported. By combining the detailed particle and electric and magnetic field observations from MMS and an advanced computer simulation, these studies succeeded to show the structures and the evolution of secondary instabilities within the K-H waves that lead to deformations of the vortices and mixing of the plasma across the boundary layer. These studies highlighted the importance of multi-scale and multi-processes that take place within the KHI and the complex nature of the interaction processes between the solar wind and the Earth/planetary magnetosphere.

CLUSTER

ESA's Cluster mission is designed to study different plasma processes due to the interaction between the solar wind and the Earth's magnetosphere. Cluster, launched in July and August 2000, is the first four-spacecraft mission that can differentiate between temporal and spatial changes of the different plasma processes. Request from the scientific community for the Cluster mission extension during the time interval 2023-2025 has been submitted. The IWF is Principal and/ or Co-Investigator (PI/Co-I) on five instruments and has contributed to data archiving activities at the Cluster Science Archives (CSA) in addition to the science data analysis.



Artist's impression of the four Cluster spacecraft crossing the northern cusp of Earth's magnetosphere © ESA/AOES Medialab

Celebrating the successful 22 years in space, the Cluster 22nd Anniversary Symposium was held at

the European Space Operations Centre (ESOC) in early November. The talks covered not only the newest scientific results, but also comprehensive reviews on the missions, instruments and science relevant to Cluster. Several IWF members gave invited talks at the symposium.

MMS

NASA's Magnetospheric Multi-Scale (MMS) mission, launched in 2015, explores the dynamics of the Earth's magnetosphere and its underlying energy transfer processes. Four identically equipped spacecraft carry out highest temporal and spatial measurements in the Earth's magnetosphere. MMS investigates the small-scale basic plasma processes, which transport, accelerate and energize plasmas in thin boundary and current layers. Extension of MMS until 2025 is under discussion.

The 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, the IWF is contributing to inflight calibration activities and also deriving a new data product such as the density determined from the controlled spacecraft potential.

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 orbits.

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 until 2025 is under discussion. As Co-I of the magnetometer, the IWF is participating in processing and analyzing data.

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 a 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.

Flight data verification, in-flight calibration and operation support were continued also during the fourth year of operation. In addition, a concept for a further improved data cleaning was elaborated and proposed to ESA. It includes the correction of temperature induced offset drifts of the fluxgate sensors which face a temperature change of more than 100°C every 24 hours.

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

CSES

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

CDSM flight model sensor for CSES-2 © OeAW/IWF

After the successful launch of the first satellite CSES-1 in February 2018, the second satellite CSES-2 is scheduled for launch in the second half 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 the IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while the IWF and TUG participate with the newly developed absolute scalar magnetometer, called Coupled Dark State Magnetometer (CDSM).

In 2022, the testing of the flight instrument for CSES-2 was completed in Austria and it was subsequently delivered to China. Remote support for a successful integration and testing of the CDSM with the Chinese magnetometer hardware took place throughout the year.

Like in the years before, the magnetometer sensors of CSES-1 operated continuously in good health. Based on a cross comparison analysis between the CDSM of CSES-1 and the Absolute Scalar Magnetometer (ASM) of the Swarm Alpha and Bravo satellites it has been possible to demonstrate that the CDSM has maintained long-term stability and accuracy.

FORESAIL-2

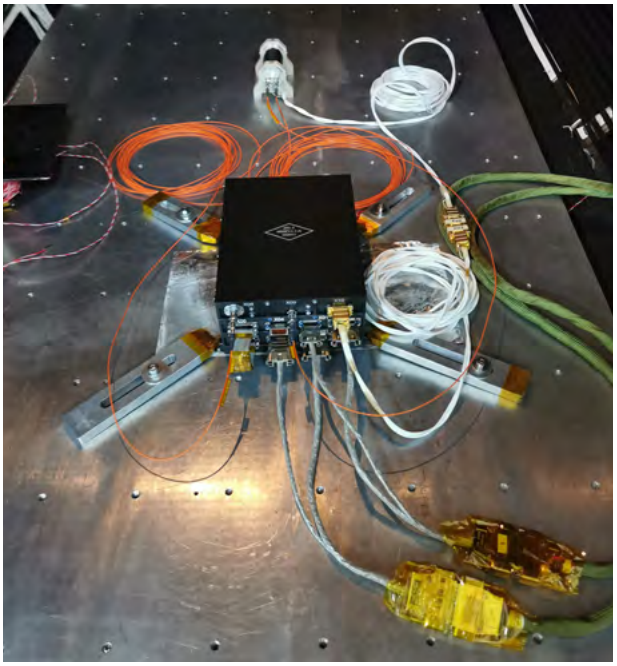
FORESAIL is a CubeSat program conducted by Aalto University in the frame of the Finnish Centre of Excellence in Research of Sustainable Space. FORESAIL-1, was launched in May 2022, but contact was lost after a short time of in-orbit operation. A replacement satellite, FORESAIL-1-PRIME is therefore planned to be launched in 2023. The construction and launch of this additional CubeSat delayed the plans for FORESAIL-2, which contains an IWF-provided magnetometer. This CubeSat is now planned for launch into geostationary transfer orbit (GTO) in 2025, although finding a CubeSat launch provider for this orbit turned out to be a challenge that is currently not resolved. The technology demonstration goal of this mission is to survive the harsh radiation of the Van Allen belts 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 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, the IWF contributes a miniaturized magnetometer, which will be based on a newly developed microchip for the readout of the triaxial magnetic field sensor.

In 2022, the first prototype microchip was received from XFAB Silicon Foundries and extensively tested. The knowledge gained was incorporated into the design of the second prototype microchip, which was delivered to XFAB for production in October 2022. Furthermore, the development of an Engineering as well as an Interface-Verification Model of the FORESAIL-2 magnetometer was continued.

MACAO SCIENCE SATELLITE



Flight model of the scalar magnetometer mounted in the thermal vacuum chamber of the National Space Science Center (NSSC) of the Chinese Academy of Sciences © NSSC

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 mid 2023.

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. Currently, this magnetic anomaly is increasing its spatial extension and the field strength is further decreasing. Together with ESA's Swarm mission, launched in 2013, it 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 the 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 2022, the flight model of the scalar magnetometer was integrated with the Chinese magnetometer hardware followed by a set of environmental and calibration tests. In November 2002, the magnetometer was installed on the spacecraft.

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 2025. It aims to complete our understanding of the Sun-Earth connection by measuring the solar wind

Qualification model of the SMILE SXI EBox © O eAW/IWF/Steller

and its dynamic interaction with the magnetosphere. The 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. The 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.

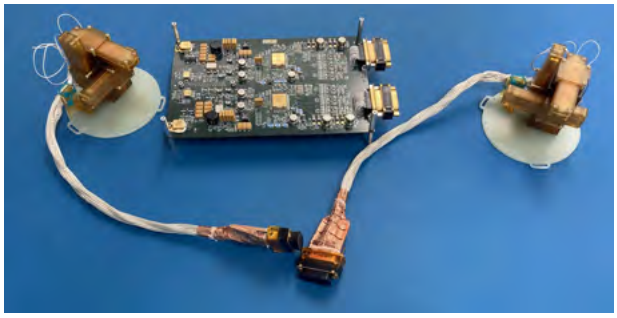
In addition to hardware activities, the IWF is participating in the preparation of the science working group activities such as modeling and in-situ measurements.

In 2022, the team concentrated on the qualification model of the DPU and the EBox. Extensive board level tests of the DPU were followed by the electrical integration of the power supply with the DPU and the radiation shutter electronics. In parallel the mechanical structure of the EBox was prepared for the installation of the electronics. The environmental tests have been completed with only minor issues, thus the model was delivered to University of Leicester in Q3 2022. In addition to the hardware activities, the thermal and structural analysis has been updated in accordance with results from the environmental tests. Finally, the manufacturing of the components for the flight model has been initiated. The delivery of the flight model is planned for Q3 2023.

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 L1. 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.



Flight model of SWFO-MAG with the two fluxgate sensors and the sensor control board © OeAW/IWF/Valavanoglou

The Southwest Research Institute together with two sub-contractors at the University of New Hampshire, Durham, and the 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. The 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 the IWF in 2022 included the completion of the parts engineering, the finalization of the layout for the sensor controller board, and the start-up, testing and pre-calibration of the flight model.

HELIOSWARM

HelioSwarm is NASA's new Medium-Class Explorers (MIDEX) mission to be launched in 2028. The IWF is a member of the science team contributing to the multi-point analysis. HelioSwarm consists of nine spacecraft (1 hub and 8 nodes). The HelioSwarm constellation makes multipoint measurements of magnetic fields, density and velocity as well as single point measurements of the velocity distribution function. The instruments on board consist of fluxgate and search coil magnetometers, Faraday Cups and an ion electrostatic analyzer.

SOLAR SYSTEM

The IWF is involved in several international space missions and experiments that address solar system phenomena, planetary environments and related data analysis. Solar physics and the solar wind, its interaction with the magnetospheres, upper atmospheres or surfaces of solar system planets and bodies are studied. Moreover, theoretical studies related to comparative planetology, habitability and space plasma physics between solar system planets and exoplanets are also carried out for understanding the early and later evolution of Venus, Earth and Mars. A highlight occurred on 23 June 2022, when the ESA/JAXA BepiColombo spacecraft had its second successful flyby at the Sun's innermost planet, Mercury.

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 plans to investigate in-situ plasma properties of the inner solar heliosphere and to observe the Sun's magnetized atmosphere and polar regions. Gravity assist from Venus and Earth will be used to reach the operational orbit, a highly elliptical orbit with perihelion at 0.28 au.

The 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.

On 26 March, Solar Orbiter encircled the Sun within a distance of approximately 48 million kilometers. This corresponds to less than one third of the distance between Earth and Sun and marks a preliminary highlight of the mission. All instruments have been operating during flyby. The in-situ imaging instruments observed several bursts of energetic particles and solar flares. The flare registered on 31 March 2022 was classified as one of the highest categories. Later in the year, on 4 September, Solar Orbiter did its third Venus flyby, at a distance of about 12,500 km. Just shortly before, on 30 August, the probe has been hit by a CME directly. Fortunately, there was no damage to the spacecraft. It is designed to withstand and measure violent outbursts from our Sun.

MERCURY

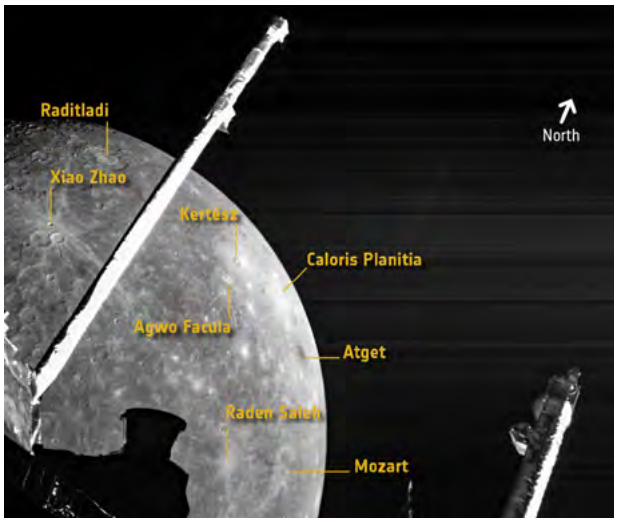
Mercury is in the center of attention because of the ESA/JAXA BepiColombo mission. The planet has a weak intrinsic magnetic field that results in a small magnetosphere, which strongly interacts with the solar wind plasma so that elements can be released from the surface minerals which produces a silicate-rich exosphere.

On 23 June 2022, BepiColombo made its second close flyby at Mercury. This was three and a half years after the launch, and it's still three and a half years to go before the spacecraft will finally reach Mercury. Half time! All instruments worked well and produced data that were analyzed. It was also possible to identify various geological features that will be studied in more detail once the spacecraft will be in Mercury's orbit.

BEPICOLOMBO

The European-Japanese spacecraft, launched in 2018, is on its way to Mercury. During its seven-year cruise to the innermost planet of the solar system, BepiColombo performed its second gravity assist maneuver at Mercury

on 23 June 2022. This flyby was the fifth of nine flybys. The spacecraft flew by Mercury at a distance of just 200 km from the planet's surface. The closest approach, which took place at 09:44 UTC, was on the planet's nightside. As BepiColombo flew from the nightside to dayside, the Sun seemingly rose over the cratered surface of the planet, casting shadows along the terminator – the boundary between night and day – and highlighting the topography of the terrain. The three monitoring cameras of the spacecraft shot a number of photos of this dramatic scenery.



BepiColombo captured this view of Mercury during its second of six gravity assist maneuvers. The image was taken at 09:55:32 UTC by the Mercury Transfer Module's Monitoring Camera 2, when the spacecraft was 2862 km from the planet's surface, shortly before closest approach © ESA/BepiColombo/MTM, CC BY-SA 3.0 IGO

Similar to the first Mercury flyby in 2021, most scientific instruments were switched on to investigate Mercury's planetary environment, including the three payloads with IWF hardware contribution on both the European Mercury Planetary Orbiter (MPO) and the Japanese Mercury Magnetospheric Orbiter (Mio).

As part of the SERENA (Search for Exospheric Refilling and Emitted Natural Abundances) suite, PICAM (Planetary Ion CAMera, IWF PI-ship) was operational from one day before, until two days after the closest approach. During this period of time PICAM observed the solar wind as well as Mercury's magnetosphere. However, this was the first time that PICAM was in high cadence mode, sampling the ion distribution at 250 ms. These high time resolution data are currently being analyzed, providing more details on bow shock and magnetopause crossings, as well as inner-magnetosphere ion dynamics. The observations were mostly aimed at BepiColombo's cruise science campaign, but also for the investigation of spacecraft outgassing. Furthermore, PICAM was switched on for more than 30 days of 2022 in the interplanetary medium.

In addition, the BepiColombo magnetometers MPO-MAG (IWF technical management) and Mio-MGF (IWF PI-ship) were active during the flyby and (Mio-MGF only partially) during the cruise phase, returning valuable scientific measurements of the inner heliosphere. The data from both magnetometers are affected by the spacecraft's magnetic disturbances, as the spacecraft is still in cruise configuration, which is not optimal for magnetic measurements. A dedicated cleaning of the data using measurements of both magnetometers (MPO-MAG and Mio-MGF) has been initiated to make high quality data available, in order to enable reliable scientific analysis of the highly dynamic magnetosphere of Mercury.

VENUS & MARS

Venus and Mars are Earth's neighbors at a distance of approximately 0.7 astronomical units (au) and 1.5 au from the Sun, respectively. They have orbital periods around the Sun of 224 and 687 days, respectively. While Venus is approximately the same size as the Earth, Mars only has about half the size of the Earth. Where Venus has a very dense and hot atmosphere, Mars's is tenuous and cold. Both planets do not have an internal magnetic field, however, their interaction with the solar wind creates a so-called induced magnetosphere.

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. The IWF contributed to a magnetometer aboard the orbiter.

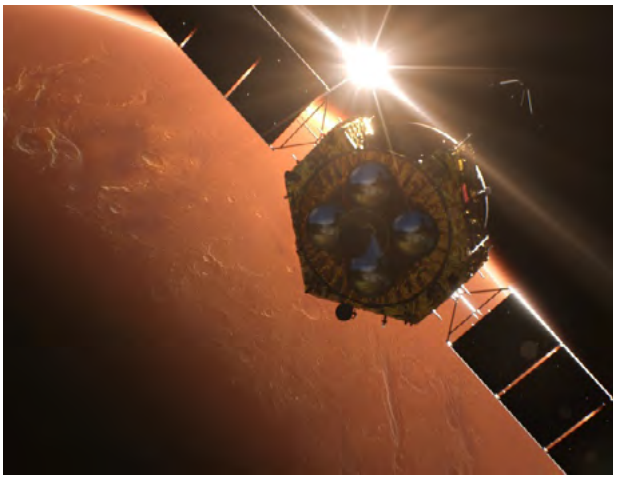


Illustration of Tianwen-1 in orbit around Mars © CASC

Since the switch-on of the Mars Orbiter MAGnetometer (MOMAG) on 13 November 2021, it has been in continuous operation with two operational modes: 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 all 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 from the outboard, is used to remove the spacecraft magnetic effects successfully in year 2022, and the cleaned scientific data are expected to be issued to public soon in the future.

JUPITER AND SATURN

Jupiter and Saturn, the two largest planets in our solar system, together with their numerous moons remain fascinating targets for in-situ investigations: Saturn was orbited by the Cassini spacecraft from 2004 until 2017. Since 2016 the Juno spacecraft has been around Jupiter, and it is planned to stay there until 2025. ESA will launch the JUICE mission to Jupiter and its icy moons in 2023, and NASA will follow in 2024 with the Europa Clipper mission. In 2022, JUICE and its ten scientific instruments were brought into flight configuration and the mission critical electromagnetic compatibility, vibration, acoustic, magnetic stray field and end-to-end operation test campaigns were accomplished successfully.

JUICE

JUpiter ICy moons Explorer (JUICE) was selected as ESA's first "Large-class" mission of the Cosmic Vision program. With its powerful instrument package, it will provide the most detailed analysis yet of Jupiter as an archetype for gas giants across the Universe.

The launch of JUICE is planned for April 2023. A several months long test phase of all instruments, which includes the deployment of e.g. the magnetometer boom, the Langmuir probe booms and the radio antennas, will start right after launch.

After three gravity assist maneuvers at Earth and one at Venus, JUICE is scheduled to arrive at Jupiter in mid-2031 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 be the first spacecraft ever to orbit a moon other than our own - Jupiter's largest moon Ganymede.

The IWF participates on Co-Investigator basis in three of the ten scientific instruments aboard JUICE: J-MAG, PEP and RPWI.

The Jupiter MAGnetometer (J-MAG) is led by Imperial College London 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 quantum-interference 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 behaviour of rapidly rotating magnetic bodies. The IWF supplied the atomic scalar sensor (MAGSCA) for J-MAG, which was developed in close collaboration with TU Graz.

The highlights for the MAGSCA activities in 2022 were the completion of the spare model, the end-to-end performance test with the flight model mounted on the spacecraft and the preparation of the test phase of the instrument after launch, which will last for several days.

The Particle Environment Package (PEP) is a suite of different kind of sensors to characterize the plasma environment of the Jovian system and the composition of the exospheres of Callisto, Ganymede, and Europa. PEP is led by the Swedish Institute of Space Physics and the IWF participates in the PEP consortium with scientific studies related to the plasma interaction and exosphere formation of the Jovian satellites.

The IWF has also been responsible for the calibration of the radio antennas of the Radio and Plasma Wave Investigation (RPWI). Besides the three dipole radio antennas, RPWI also harbors a search-coil magnetometer and four Langmuir probes. RPWI will cover the Jovian radio spectrum in the frequency range from DC to 45 MHz, and the magnetic field measurements will go from DC to 20 kHz. The Langmuir probes on the tips of four 3 m long booms will perform plasma and 3D electric field measurements.

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 Waves instrument, which uses a dipole antenna to measure electromagnetic field components of incident waves. In 2022 it was used to determine the fine and coarse spectral structures of Jovian broad-banded and narrow-banded kilometric radiation.

COMETS

Comets are the remainders of the building blocks of the solar system after the planetary formation had finished. They are located in two distant regions around the solar system: between 30 and 50 astronomical units (au) from the Sun in the Kuiper belt, and further than 2000 au in the Oort cloud. Through close encounters (comet-comet, or possibly a nearby passing star) some of these can be pushed out of their orbit and will start to move towards the Sun. When such an object passes Jupiter's orbit, the solar irradiance is strong enough to start heating up the surface of the comet and to start the sublimation of (sub) surface volatiles. This leads to the escape of gas and dust, which create the characteristic coma and tails of a comet.

The Comet Interceptor mission was adopted by ESA on 8 June 2022 and the prime contractor to build the spacecraft was selected in November.

COMET INTERCEPTOR

Comet Interceptor is ESA's first F(ast)-class mission, now formally adopted on 8 June 2022. A prime contractor (OHB, Italy) has been selected to build the spacecraft. The goal of this mission is to investigate a dynamically new comet, i.e. a comet which has just been kicked-out of the Kuiper belt or the Oort cloud, and has not yet had a close encounter with the Sun. This will ensure a look at a pristine object, which will provide detailed information about the structure and composition of the early building blocks of the solar system.

Comet Interceptor is the first multi-spacecraft mission to visit a comet, consisting of three parts, which will fly by the target at different distances. The mother spacecraft (A - ESA), which will also serve as a relay station, will stay furthest from the comet, two smaller subcraft (B1 - JAXA, B2 - ESA) will approach the target closer. The mission is planned to be launched in 2029.

The IWF is building parts of two instruments on Comet Interceptor: for spacecraft A the Data Processing Unit (DPU) for the Mass Analyser for Neutrals and ions at Comets (MANiaC) and for B2 the front-end electronics of the FluxGate magnetometer (BFG), part of the Dust Field and Plasma package (DFP), led by the Space Research

BFG Engineering Model © OeAW/IWF/Valavanoglou)

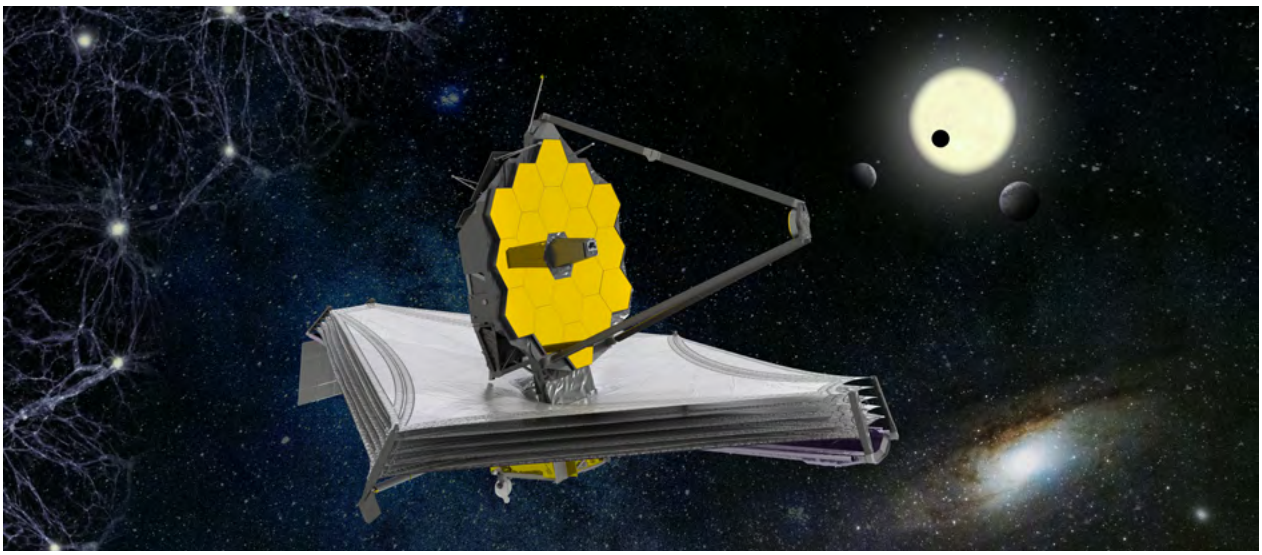
Centre of the Polish Academy of Sciences (Centrum Badań Kosmicznych, CBK).

In 2022, the MANiaC DPU design was focused on the consolidation of all external interfaces. Due to changes within the instrument consortium, new partners joined the team and therefore new interface specifications had to be incorporated. With Q4 2022, the design was frozen, the electronical schematic completed and the PCB layout activity has been started.

A major step forward was the finalization of the EEE components list and the initiation of the parts procurement process. The design of the boot software was finalized, the code generation completed and the test phase has been initiated. In terms of the application software, the requirement engineering is still ongoing.

In 2022 the focus for BFG was on consolidating the design of the magnetometer with its thermal, mechanical and electrical interfaces to the DFP common electronics units as well as the B2 daughter spacecraft. There was a successful completion of the Preliminary Design Review in the middle of the year and the selection of the flight components, materials and processes was started. In November the first instrument model (i.e. Engineering Model) was delivered to CBK and successfully integrated into the electronics.

EXOPLANETARY SYSTEMS



Artist's impression of JWST © ESA/ATG medialab

The investigation of planets orbiting stars other than the Sun – also known as exoplanets – has developed strongly in the past decades. The first exoplanet was detected in 1995. More than 5300 exoplanets 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 observed. This is particularly thanks to the advent of the James Webb Space Telescope (JWST) that was launched on Christmas day of 2021 and started science operations in July 2022. JWST's large collecting area and broad suite of instruments is driving a revolution in our view of exoplanetary atmospheres and of the cosmos at large. Members of the IWF are involved in

a number of JWST observing programs aiming at characterizing exoplanetary atmospheres. For some of them, JWST has already collected data in 2022, but more will come in the upcoming years.

The main exoplanet missions in which the IWF is involved with hardware and/or science are CHEOPS, CUTE, PLATO, ARIEL, and ATHENA. The 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 weather and climate, atmospheric clouds and chemistry as well as atmospheric mass loss. The research is based on the collection and analysis of ground- and space-based observations to constrain the models, as well as on the modeling of planet and cloud formation from first principles.

With the aim of detecting the metastable Helium infrared triplet probing planetary upper atmospheres, transits of the hot Jupiter WASP-80b have been observed with the GIANO-B high-resolution spectrograph attached to the Telescopio Nazionale Galileo (La Palma, Spain). Surprisingly, the observations led to no detection, providing the first demonstration that planetary atmospheres can have a significantly subsolar Helium content.

Planetary atmospheric evolution models have been employed to reproduce the width of the observed exoplanet mass-radius relation. This is one of the first attempts to constrain planetary atmospheric evolution through the observed mass-radius relation. The results led us to identify the planetary mass ranges within which atmospheric accretion or atmospheric escape control atmospheric evolution and the observed mass-radius relation.

The CUTE data reduction pipeline has been completed and published. The pipeline is now routinely employed to reduce data collected by the CUTE CubeSat mission.

CHEOPS

CHEOPS (CHaracterising ExOPlanet Satellite), successfully launched in December 2019, 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 precisely measure the radii of Neptune- to Earth-sized planets to constrain the internal composition and atmospheric evolution, study the atmospheric properties of transiting giant planets, and look for new planets particularly in already known systems. In 2022, the CHEOPS consortium started to work on the development of the science case for the first mission extension that is foreseen to begin in 2023.

The IWF is responsible for the Back-End-Electronics that is one of the two onboard computers and it is responsible 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 of the CHEOPS consortium, the 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 2022, CHEOPS continued nominal science operations, demonstrating that the satellite performs and ages as expected. The European consortium in charge of the majority of observing time made use of CHEOPS data to publish more than a dozen refereed articles.

CUTE

CUTE (Colorado Ultraviolet Transit Experiment) is a NASA-funded 6U-form CubeSat led by the University of Colorado that was launched in 2021. CUTE performs low-resolution transmission spectroscopy of transiting extrasolar planets at near-ultraviolet wavelengths. It studies 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 allows one to detect transit asymmetries, which are possibly connected with the presence of planetary magnetic fields. Following a rather long commissioning phase, CUTE started to deliver scientific data in 2022. The IWF is the only technological contributor to the mission outside of the University of Colorado (Boulder), where CUTE was built. The institute devel-

oped the data simulator, the data signal-to-noise calculator, the ground data reduction software, and the algorithms defining the onboard data reduction software.

With the arrival of the first science data in 2022, the IWF has finalized the development of the ground data reduction pipeline.

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.

The IWF co-leads the work package aiming at studying planetary habitability and takes part in two further work packages (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 Instrument 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 2022, the team concentrated on the assembly and test of the qualification model. In parallel, the solder qualification for the PLATO RDCU board, in particular the soldering of passive electronic components with the vapor phase equipment, has been successful completed. This achievement reduces the workload for the PCB assembly significantly. The logic design for the data compressor has been updated, to implement changes in accordance with the results from testing and post place and route simulations. The test of the qualification model is ongoing, the delivery has been shifted to 2023. As a first step towards the flight model production, the PCB layout was updated. In particular, the impedance control for all SpaceWire signals was optimized to improve the signal integrity of the links.

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. The IWF co-leads the upper atmosphere working group and is involved in testing the mission's performances, advancing the atmospheric retrieval tools and improving the inference of fundamental parameters (e.g. mass, age) of the host stars.

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). The study concerning processor performance has been completed in 2022. The instrument design was continued and further optimizations envisaged to reduce mass and space, but also optimize costs. Due to the unclear situation with the ATHENA mission, the consortium decided to build a so-called demonstrator. The goal is to have prototypes for all instrument sub-units, to establish a working instrument, demonstrating its capabilities and performance. The team submitted a proposal within the ASAP#19 call to fund the necessary EEE components for the demonstrator.

SATELLITE LASER RANGING

Exterior view of the ESA SLR Station during night time satellite laser ranging operation at Teide Observatory © ESA

The IWF's Satellite Laser Ranging (SLR) station at the Lustbühel Observatory in Graz works in the areas space ecology and safety by tracking more than 150 targets which are equipped with laser retro-reflectors. In 2022, the new Izaña-1 SLR station was handed over to ESA with the main laser ranging and detection components fabricated in Graz.

Within the RADS project, a tool was developed to simulate SLR residuals of satellites in arbitrary rotation conditions to efficiently design backup retroreflectors on future satellite missions. The spin period and attitude of the defunct Jason-2 satellite was studied throughout ESA's tumbling motion project.

TENERIFE SLR STATION ACCEPTANCE

An increasing demand of facilities capable of doing satellite laser ranging, space debris laser ranging or optical communication pushes the demand to create accurate, cost-efficient, reliable and yet simple components to be integrated into SLR stations.

In 2022, the new Izaña-1 SLR station on Teide passed the final acceptance test and was handed over to ESA. The SLR group of the IWF was developing the core components of the SLR station - the laser and detection package. For these packages a modular approach is used primarily based on Commercial-Off-The-Shelf components. The whole fabrication process ranging from optical raytracing simulation, computer aided design, integration of the components to the testing and validation of the equipment tracking and ranging to satellites is performed at the IWF.

Laser packages consist of the laser with two separate beam expansion telescopes with a collimated part in between, which can be used for imaging of e.g. the backscattered laser beam or the visualization of stars for alignment purposes. A combination of wave plates and polarizing beam splitters allow for power adjustment and measurement. One of the lenses is mounted on an electronically movable lens holder which gives the possibility of flexible variation of the beam divergence and a tip-tilt mirror enables remote direction control of the laser beam. Furthermore, start pulse detection is integrated.

Detection packages are mounted in one of the Nasmyth foci of an astronomical telescope. In the beam path direction, the field of view iris is followed by optics to collimate the entering photons to approx. 1 cm with some flexibility to tune the telescope's field of view. Dichroic mirrors separate the incoming light w.r.t. wavelength and distribute it to various sensor modules (e.g. single photon avalanche detectors for green and infrared, single photon light curve detection, optical guiding cameras and beam adjustment cameras). Both sensor and detection package operate a temperature control system and the necessary interfaces to connect to e.g. event timers, power supply or control pc.

The IWF is also involved in the future upgrade of the Izaña station allowing it to perform space debris laser ranging. Within the activity which started 2022, the IWF is currently developing a new type of large aperture beam expansion telescope facilitating a compact design with reduced beam divergence to be embedded in a split configuration transmit and receive system.

RETROREFLECTOR-BASED ATTITUDE DETECTION

Defunct satellites or space debris can begin to rotate due to numerous forces acting on the body. A prerequisite for future removal missions is a profound knowledge of the orbit and attitude of such objects. Rotational parameters can be measured utilizing different techniques such as satellite laser ranging (SLR), space debris laser ranging, radar or light curves. Within the ESA study Retroreflector-based Attitude Detection System (RADS) the design and placement of additional corner cube retroreflectors (CCRs) on side faces of satellites was studied. Within the International Laser Ranging Service (ILRS) approximately 40 SLR stations are cooperating generating precise ranging data of a large number of satellites. The placement of CCRs on future satellite missions would allow accurate monitoring of the tumbling behavior.

A modular simulation tool is introduced allowing to simulate SLR residuals (the difference between the predicted and measured ranges to the CCRs). Rotating satellites produce a distinct periodical residual pattern connected to the movement of the CCRs with respect to the center of mass of the satellite. Different parameters (satellite, orbit, CCRs, rotation period, rotation axis, reference coordinate frame) can be arbitrarily adjusted, allowing to design CCRs according to specific needs of the satellite operator. Within the simulations a box-type satellite body is rotated with a rotation period of 150 seconds with CCRs arranged approx. 1 meter from each other. Due to the rotation a repeated transition from reflections of surfaces with a different number of CCRs gets visible. Based on the placement of the CCRs, from the residual pattern it is possible to identify visible surfaces, determine the rotation direction or period and to draw conclusions on the laser beam incident angle.

JASON 2 TUMBLING ANALYSIS

Within the ESA project "Tumbling Motion Assessment for Space Debris Objects" attitude dynamic characterization is studied with state-of-the-art high-rate Satellite Laser Ranging (SLR) and photon counting systems operating at the single photon sensitivity level. Space debris observations support physical research in Space Situational Awareness to better understand the behavioral characteristics for the development and validation of accurate environmental interaction models. Especially long-term orbit determination, conjunction analysis, reentry and impact predictions are of interest. Emerging technologies that can benefit from space debris observation and characterization are:

1. Rendezvous and Proximity Operations for satellite servicing, refueling and mission extension
2. Active Debris Removal services for safety and sustainability of space operations, including human flight.

Graz performs observations in the visible and near-IR bands at high temporal resolution that reveals short duration signal features not detectable by other systems including millisecond glints of sunlight reflected off tumbling satellites. High-rate data is analyzed applying a set of post-processing methods that determine frequency and periodicity spectra to characterize in-orbit behavior of the observed space debris population. The methods include Savitzky-Golay filters, fast Fourier transformation, phase dispersion minimization or autocorrelation. Tiny shifts in the observed signal lines throughout the pass are known as an apparent rotation effect and can be used to determine the inertial orientation of the satellite's spin axis. The case of the tumbling and decommissioned satellite Jason-2 (orbital altitude of 1,300 km) demonstrates fusion of SLR and photometric data. The combination of

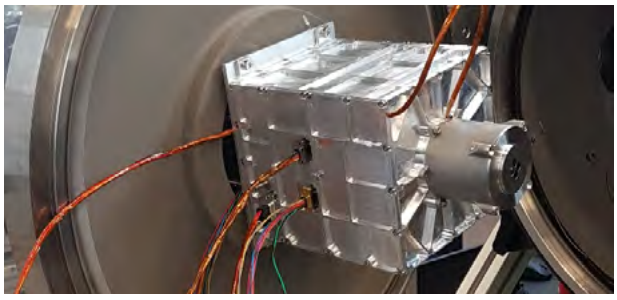
different observational techniques improves accuracy of the fitted trend, documenting a spin-up from 75 s to 40 s within 1.5 years. Such spin energy increase over time can e.g. result from solar radiation pressure continuously exerting force and torque on the solar panels.

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. The 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, eight years after launch, are still operating flawlessly.



The ASPOC-NG mounted on in the FOTEC test chamber
© OeAW/IWF/Jeszenszky

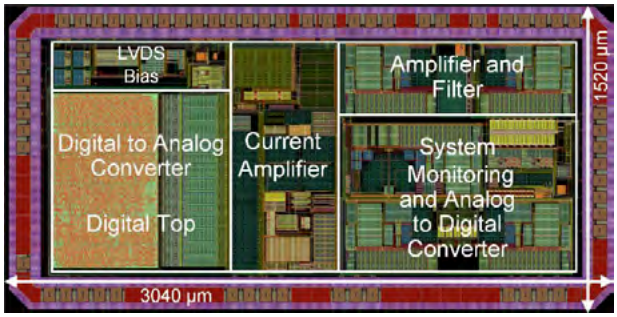
In a final review held by ESA, the presented roadmap to reach TRL-7 (Technical Readiness Level 7) emphasized that all goals of the study have been met:

- Modular design allows an optional operation with an ion or electron emission module
- Tungsten multi-needle emitters replace capillary emitters (increased mass efficiency)
- The used Indium-Gallium alloy reduces the heater power consumption by 68 % compared to MMS
- Improved wetting properties, enabling the feeding system to achieve increased reliability
- Revised electronics design results in reduced mass and less power consumption

These values qualify the next-generation ASPOC (ASPOC-NG) as a candidate for the DEBYE mission to study.

MAGNETOMETER FRONT-END ASIC

The 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 includes 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 feature an improved dynamic range and increased radiation hardness. It will be space qualified in the frame of the FORSESAIL mission.



Layout of the MFA 4.4 microchip. It contains one feedback (digital-to-analog converter and current source) and one forward path (low noise input amplifier, filter with synchronous demodulator and a low-bit analog-to-digital converter).

In 2022, a triple-axis feedback chip (MFA-4.3), with each feedback channel containing a high perfor-

mance digital-to-analog converter (DAC) and a fully differential current source, was manufactured and extensively tested. XFAB Silicon Foundries was selected as chip manufacturer because of the excellent noise performance of the transistor elements which come with a well-defined radiation characterization. The measured signal-to-noise ratio (98.3 dB) and total harmonic distortion (80 dB) of the MFA-4.3 are unfortunately lower than expected from the simulation results (104.2 dB and 100.2 dB, respectively). The cause of the performance limitations was evaluated and design modifications were implemented in the next prototype microchip (MFA-4.4). It was released for production in November 2022. Simulation results indicate a signal-to-noise ratio of 116 dB and a total harmonic distortion of nearly 100 dB which would fulfill the initially defined requirements. Only one feedback channel is implemented on the MFA-4.4 in order to avoid inter-channel interference and to reduce the complexity of the digital interface. Instead, it includes a single-channel forward path with a low noise input amplifier, an N-path filter stage for the extraction of the amplitude modulated signal from the fluxgate sensor and a low-bit analog-to-digital converter. The MFA-4.4 front-end chip occupies a total area of about 4.6 mm^2.

MACHINE LEARNING ACTIVITIES

Left: Mars Reconnaissance Orbiter/HiRISE image of mounds on Mars. Middle: Ground truth mask. Right: Predicted mask.

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 work package "Machine Learning (ML) Solutions for Data Analysis and Exploitation in Planetary Science", led by the 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 or surface features on Mars - see figure) to different classification problems (e.g., surface composition on Mercury, plasma wave emissions, or mineral identification).

Machine learning software technology was also explored within the Marie Curie Innovative Training Network for European Joint Doctorates (MC ITN EJD) CHAMELEON. A tool for fitting spectral energy distributions for planet-forming disks is developed in order to utilise large sets of ProDiMo (PROtoplanetary DIsk MOdel) thermo-chemical disk models.

IMPACT BEYOND SCIENCE

IWF GRAZ. LEADING AUSTRIA INTO SPACE. SINCE 1971.

As a dependable partner for international space agencies, the IWF has been successfully leading Austria into space for more than 50 years. With scientific know-how and high-precision instruments, the IWF is on board of numerous spacecraft exploring our solar system and our home galaxy, the Milky Way.

The achievements of the institute have contributed significantly to Austria's development over the past five decades into an internationally recognized and important space center. This success was celebrated on 28 June 2022. Around 150 people gathered at the IWF in Graz. Congratulations were extended by OeAW President Anton Zeilinger, BMK Section Head Henriette Spyra, BMBWF Minister Martin Polaschek, Mayor Elke Kahr, Head of Science and Research of the Styrian Government Wolfgang Stangl, and ESA Science Director Günther Hasinger.

Among the guests were numerous representatives from science and industry, including TU Graz Rector Harald Kainz and University of Graz Rector Peter Riedler. Students of the Graz Model School were invited to the opening of the exhibition "Young Art Meets Space Research @ IWF". This special kind of ancestral gallery, composed by the young artists, showed portraits of all IWF directors and their fields of research.

Christiane Helling cuts the birthday cake in the presence of Anton Zeilinger, Henriette Spyra, Harald Kainz, Peter Riedler, and Wolfgang Baumjohann © IWF/Harry Schiffer

Former Director Wolfgang Baumjohann gave a review of 50 years of the IWF. Director Christiane Helling took the guests on a journey into the future, from the solar system to the galaxy, to distant, alien worlds and presented the young talent program for interdisciplinary space and planetary sciences YRP@Graz. She thanked Children's Museum Director Jörg Ehtreiber and his team for their successful collaboration on the anniversary exhibition MISSION POSSIBLE!, which was shown in the CoSA – Center of Science Activities between 18 December 2021 and 11 September 2022 and attracted 15,514 visitors, of which over 4,000 were schoolchildren.

YRP@GRAZ: IWF'S NEW YOUNG RESEARCHER PROGRAM

In 2022, the Young Researcher Program in interdisciplinary space science and planetary research YRP@Graz was inaugurated during IWF's 50th anniversary ceremony. The close collaboration between the IWF and the two local universities, Graz University of Technology (TU Graz) and University of Graz, helps future researchers to gain first experiences in science.

The program has two main pillars: "Pupils and Undergraduates" and "PhD Students". For the first pillar the IWF offers, e.g., lectures at schools or internships at the institute. During summer time 2022, five high-school students performed an internship at the IWF. They worked on the exploration of the Earth's magnetosphere using satellite data, calibrated magnetic field sensors for current missions and tested new magnetometer developments, studied small cometary dust particles with Rosetta/ MIDAS data, conducted functional and performance tests of the PLATO/RDCU electronics board, and analyzed and simulated light curves of satellites at Lustbühel Observatory. One university student worked on expanding 3D General Circulation Model results into the low-pressure regime of exoplanet atmospheres.

The second pillar was designed to offer students a full PhD study in Graz. In the first year of YRP@Graz three PhD positions were opened which were funded by each of the three participating institutions. 23 interviewees of 14 nationalities were selected from 118 candidates who submitted their application through an anonymized application form.

The first cohort of YRP@Graz funded PhD students span a wide range of research topics:

- Substructures of Coronal Mass Ejections and their Solar Source Region
  - PhD Student: Greta Cappello, Supervisors: Manuela Temmer, Astrid Veronig (University of Graz)
- Quantum Vector Magnetometer based on the Nonlinear Hanle Effect
  - PhD Student: Sunny Laddha, Supervisors: Roland Lammegger (TU Graz), Werner Magnes (OeAW)
- The Gas and Dust in edge-on TTauri Disks
  - PhD Student: Elena Suslina, Supervisors: Peter Woitke, Christiane Helling (OeAW)

Additionally, Wolfgang Baumjohann served as Vice Director and chair of the Program Committee of the Summer School Alpbach, which took place from 12 to 21 July and was dedicated to "Comparative Plasma Physics in the Universe". Every year, 60 students and about 25 lecturers and tutors from ESA's member states are invited to this meeting.

PUBLIC OUTREACH

Werner Magnes, Christiane Helling, Martin Polaschek und Gunter Laky in the IWF cleanroom © OeAW/Harry Schiffer

The IWF is engaging actively in science education and public outreach. Highlight of 2022 was the Austrian "Lange Nacht der Forschung" (LNF) on 20 May, which attracted almost 1000 people, visiting 13 stations in Schmiedlstraße and at the Lustbühel Observatory. Paper rockets were built and launched, labs and the planetary garden could be visited, "Martian faces" were soldered, and lectures on various themes were held non-stop. Through the telescopes of the Styrian Astronomers' Association (StAV), the visitors could observe solar activity by day and take a fascinating look at the starry sky by night. A huge THANK YOU goes to Johannes Kügerl and his students from BG/BRG Kirchengasse, students from the Graz University of Technology and last but not least the tireless students from Akademisches Gymnasium, Gymnasium Sacré Coeur Graz and BG/BRG Seebacher, who supported the IWF team so tirelessly.

In summer, Martin Polaschek, Federal Minister for Education, Science and Research, and OeAW President Heinz Faßmann visited the IWF. On 30 September, Martin Volwerk and Daniel Schmid presented the mystery of Northern lights to the visitors of the European Researchers' Night in Vienna.

In the new IWF colloquium and seminar series, international guest speakers (colloquium) and local speakers (seminar) inform about current research topics and scientific results every Thursday at 2 pm. In 2022, 16 colloquia and 17 seminars were given, most of them are available on IWF's YouTube channel. The topics ranged from "The path to habitable worlds" to "In situ mass spectrometry with ESA's comet missions".

Throughout the year, several public lectures were given. Christiane Helling talked about the uniqueness of the Earth and the great variety of exoplanets at the Halle für Kunst, the Forum Joanneum Research, as part of the lecture series "Facetten der Physik" at the University of Graz and "alumniTalks" at TU Graz.

In the frame of the TUG/KFU Physics Colloquium Summer 2022 Peter Woitke talked about the physico-chemical processes in planet-forming disks. At URANIA Steiermark in Graz Wolfgang Voller talked about the autumn and winter sky. Bruno Besser opened the 23rd Annual Meeting of the Wiener Arbeitsgemeinschaft für Astronomie (WAA), presenting 50 years of IWF. Ruth-Sophie Taubner held a lecture on icy moons for the Burgenländische Arbeitskreis Astronomie (BAA) and gave an insight into the amazing world of being an astrobiologist in the European Astrobiology Institute (EAI) seminar series.

Following the OeAW young science initiative "Akademie im Klassenzimmer" Martin Volwerk visited the BG/BRG Leibnitz and introduced the phenomenon of the Northern light to the scholars. For the Science Academy Niederösterreich he held a workshop on planet Venus.

Topics discussed in the space blog of the Austrian newspaper "Der Standard" were life on Mars, JWST's "teething troubles", and Giuseppe (Bepi)Colombo. In the Servus TV show "P.M. Wissen" Michael Steindorfer explained how space debris can be better localized.

RECOGNITION

Christiane Helling was appointed as member of the Scientific Advisory Committee of the Leibniz-Institut für Sonnenphysik in Freiburg, Germany. The long-time IWF Director Wolfgang Baumjohann was elected to the new OeAW Presidium Committee as President of the Division of Mathematics and Natural Sciences.

Christian Möstl received a Consolidator Grant from the European Research Council (ERC) to further expand his research on the practicable prediction of solar storms. The ERC Grant enabled him to form the new Austrian Space Weather Office of GeoSphere Austria in Graz.

Patricio Cubillos was awarded an associate position in the CHEOPS science team.

Kevin-Alexander Blasl received the Outstanding Student Presentation Award (OSPA) of the American Geophysical Union and Patrick Barth the Outstanding Student and PhD Candidate Presentation (OSPP) Award of the European Geosciences Union.

The newspaper Kleine Zeitung nominated Martin Reiß as "Head of the Year from Southern and Western Styria" in the category "Economy and Research". He is now working as a staff scientist at NASA's Goddard Space Flight Center.

Since 1 July 2023, the OeAW has got a new Presiding Committee: Christiane Wendehorst, Heinz Faßmann, Ulrike Diebold, Wolfgang Baumjohann (f.l.t.r.) © OeAW/Peter Rigaud

LECTURING

In summer 2022 and in winter term 2022/2023 IWF members gave (online) lectures at the University of Graz, Graz University of Technology, University of Vienna, TU Braunschweig, and FH Wiener Neustadt.

THESES

Besides lecturing, IWF members are supervising Bachelor, Diploma, Master and Doctoral Theses. In 2022, the following supervised theses have been completed:

- Cappello, G.: Non-local thermodynamic equilibrium modelling of hot and ultra-hot Jupiter atmospheres, Master Thesis, Università degli Studi di Torino, 120 p., 2022.
- Herbort, O.: Atmospheres of Rocky Exoplanets, Doctoral Thesis, University of St. Andrews, 171 p., 2022.
- Kutnohorsky, V.: CCD Datenreduktion – Entwicklung der Datenreduktionspipeline für differentielle Photometrie am Lustbühel Observatorium, Bachelor Thesis, Universität Graz, 72 p., 2022.
- Samra, D.: Mineral Snowflakes on Exoplanets and Brown Dwarfs, Doctoral Thesis, University of St. Andrews, 167 p., 2022.

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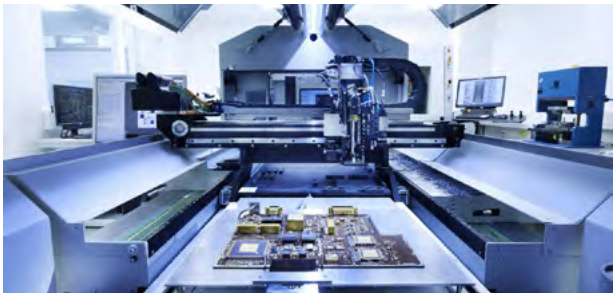
MORE INFO

More information about IWF's research activities and publications during the year 2022 is found in the IWF Annual Report: https://www.oeaw.ac.at/en/iwf/publications/annual-reports
Twitter: @IWF_oeaw

Beyond Gravity Austria GmbH





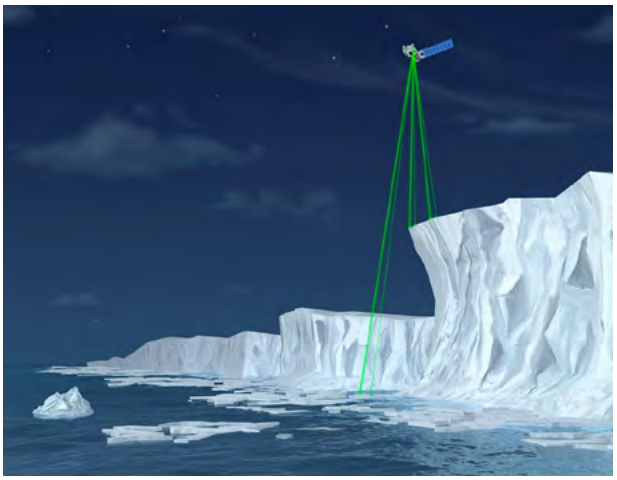
Beyond Gravity Austria product portfolio examples

Among a manifold of highlights, 2022 has brought the rebranding from RUAG Space GmbH to Beyond Gravity Austria GmbH (BGA) – a company name reflecting an ambitious vision in response to the exciting evolution of the space business –, witnessing the launch of the 500th satellite protected by BGA thermal insulation and celebrating accumulated 100 years of flawless BGA satellite-navigation-receiver operation in orbit.

Since 2008 Beyond Gravity Austria GmbH has been part of Beyond Gravity (formerly RUAG Space) with its headquarters in Switzerland. Beyond Gravity is Europe's largest independent space product supplier and employs around 1600 people in Switzerland, Sweden, Austria, Finland, Germany and the USA. Beyond Gravity Austria with around 240 employees is the largest space company in Austria and started its operations in 1983. The product portfolio comprises on-board electronics, mechanisms and thermal hardware as well as mechanical ground support equipment.

Electronic products of high strategic importance for Beyond Gravity Austria are spaceborne Global Navigation Satellite System (GNSS) Receivers. While providing outstanding navigation accuracy en-route, BGA's PODRIX receivers also deliver high-quality multi-frequency carrier and code phase measurements to ground, allowing for Precise Orbit Determination (POD) with centimeter-level accuracy. LEORIX is a slim PODRIX derivative for premium real-time navigation while GEORIX is optimized for satellites at higher altitudes ranging from Medium Earth Orbits (MEO) beyond GEO to cis-lunar trajectories.

As of December 2022, Beyond Gravity has received orders for more than 110 GNSS receivers.



NASA's ICESat-2 mission with a BGA navigation receiver aboard

Many of the satellites using the GNSS receiver products from Beyond Gravity are monitoring earth's climate and its changes. Examples of our first receiver generation, launched prior to GALILEO becoming operational, thus fully relying on GPS, are flying on board all Sentinel A&B satellites of the European Union's Copernicus program as well as on NASA's ICESat-2 mission. The current generation of multi-constellation receivers is enabling technology for the succeeding Sentinel 1, 2, 3 C&D missions and for the most recent Copernicus flagships CO2M, LSTM and CRISTAL.

CO2M will be the first mission to measure how much carbon dioxide is released into the atmosphere specifically through human activity. LSTM (Land Surface Temperature Monitoring) will provide observations of land-surface temperature and 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.

CRISTAL (Copernicus Polar Ice and Snow Topography Altimeter) will measure and monitor sea-ice thickness, overlying snow depth, and ice-sheet elevations which are known to drive climate processes. In addition to facilitating such climatological satellite infrastructure, BGA's spaceborne GNSS-receivers are key for earth science as performed by ESA's Earth Explorer missions. After having delivered essential data on-board the three SWARM satellites, BGA GNSS receivers were selected also for EarthCARE (Earth Cloud Aerosol and Radiation Explorer), BIOMASS monitoring the state of our forests and how they are changing to understand their role in the carbon cycle, and for the FLuorescence EXplorer (FLEX) mission, which will provide global maps of vegetation fluorescence, which is directly related to plant health and stress.

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

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

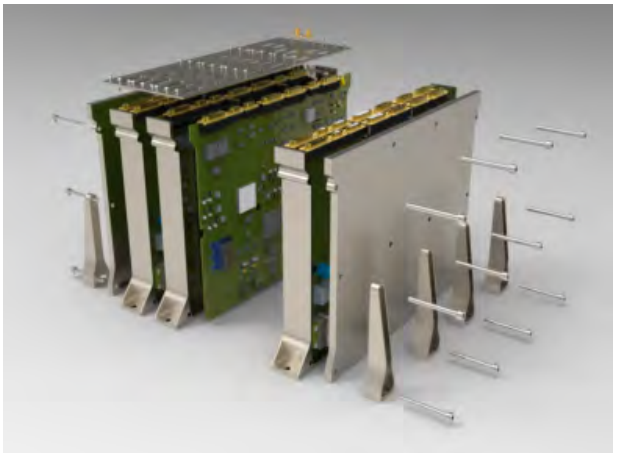
In Europe, Beyond Gravity Austria's market share for multi-frequency receivers exceeds 90%. Several contracts from South Korea and the first order from Canada demonstrate the strong market position also outside of Europe.

A remarkable success in the US institutional market was the selection of the BGA receiver for NASA's Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE) mission to be launched in 2024. The decision of NASA's Goddard Space Flight Center (GSFC) in favor of BGA against domestic competitors was a real breakthrough and a strong indicator of the excellent position in the global space market with this product. This has been confirmed with the recent receiver order from Ball Aerospace for the Weather System Follow-On – Microwave (WSF-M) mission which represents the next-generation operational environmental satellite system for the US Department of Defense.

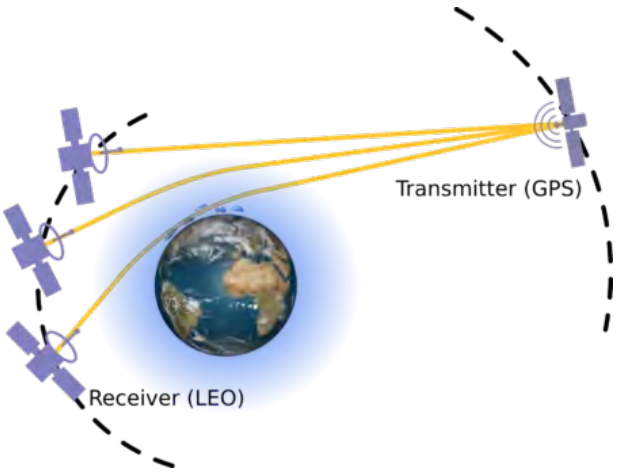
Weather System Follow-On – Microwave (WSF-M) environmental satellite (source: Ball Aerospace)

While the legacy GNSS-receiver products are gradually reaching their orbital destinations - the first PODRIX made its successful in-orbit premiere aboard the sea-level monitoring satellite Sentinel-6 Michael Freilich launched in November 2020 and the GEORIX maiden flight is scheduled for April 2023 with the NASA climate mission TEMPO aboard an Intelsat telecom satellite – the development of BGA NewSpace receivers targeting satellite constellations is already well advanced. In 2022 the first NewSpace GNSS receivers, which are integrated in the Constellation On Board Computer (cOBC) of BGA's sister company Beyond Gravity Sweden, were sold to various international customers together with the cOBC.

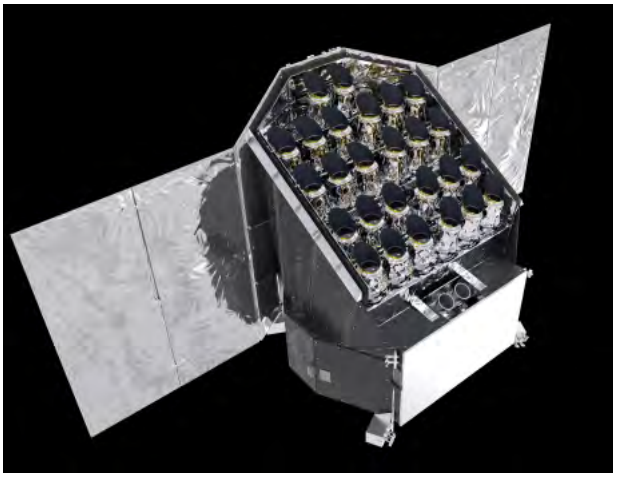
BGA GNSS Receiver modules also form the basis of the advanced radio occultation (RO) instrument of the Metop Second Generation satellites. RO exploits GNSS signals to provide vertical profiles of temperature, pressure, and humidity at high resolution and makes a noticeable difference to the quality of the daily weather forecasts. In total 26 flight units have been delivered in the frame of this contract.



BGA GNSS Receiver product family
top left: GEORIX
top right: NewSpace NavRIX integrated in Constellation Onboard Computer
right: PODRIX/LEORIX



Radio occultation for atmospheric sounding (source: EODC)



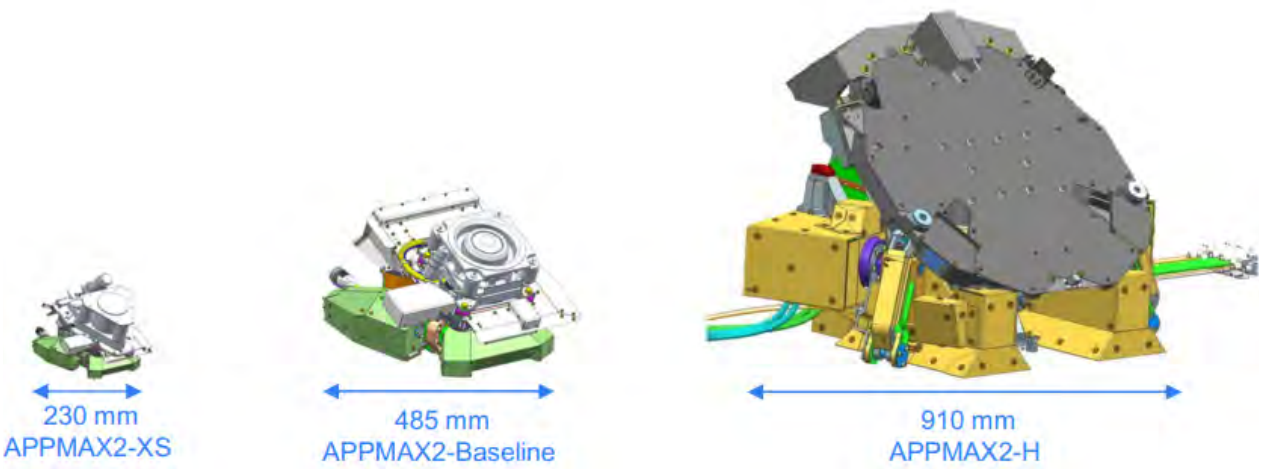
Artist's impression of PLATO (source: ESA)

To the EUMETSAT Metop Second Generation meteorological satellite infrastructure BGA also contributes with Antenna Pointing Drive Electronics enabling data transmission to ground and with so called Remote Interface Units (RIUs) facilitating control of assets hidden in the most remote spacecraft corners.

Important ongoing contracts concern PLATO, the PLAnetary Transits and Oscillations of stars mission of ESA which will be launched in 2026 to find and study extrasolar planetary systems with special emphasis on rocky planets within habitable zones around sun-like stars. Besides electronics modules for a Remote Interface Unit, BGA will supply the Payload Accurate Thermal Control Unit which is a prerequisite for achieving utmost telescope sensitivity and the Antenna Deployment and Pointing Mechanism Electronics facilitating the transfer of science data to ground.

Another ESA mission relying on proven BGA 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. BGA will supply the Solar Array Drive Electronics (SADE) for the spacecraft.

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



APPMAX2 – member of the new electric propulsion pointing mechanism family

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

APPMAX2 mounted on a shaker (source: Anna Rauchenberger)

are Northrop Grumman, leading the development of the Habitation and Logistics Module (HALO) and Maxar Technologies, responsible for the Power and Propulsion Element (PPE).

For the latter, BGA will also provide APPMAX2-H (heavy), the world's largest electric propulsion pointing mechanism tailor-made for PPE's main high-power thrusters. This component provides the capability to steer or move the electric propulsion thrusters for maneuvering, orbit adjustments, and performing cislunar transfers during the life of the space station.

APPMAX2-H represents the upper end of BGA's brand new family of Electric Propulsion Pointing Mechanisms, referred to as APPMAX2 and APPMAX3 (Advance Propulsion Pointing Mechanism 2-axis and 3-axis) and optimized for volume production and scalability, which in 2022 has matured to the point where several customer contracts and flight model productions have started. These innovative mechanisms in their various sizes and configurations form a considerable part of BGA's annual order intake and will be the backbone of the Mechanism product line for the next years to come.

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

Apart from having delivered the first 15 flight models of the Gimbal Joint for the Vinci engine of Ariane-6, work has continued on the design of a very similar device for the thrust vector control of the VEGA-E upper stage. The Gimbal Joint is essential for steering the stage along its flight path.

BGA Satellite Transport Container for PLATO (source: Florian Neumüller)

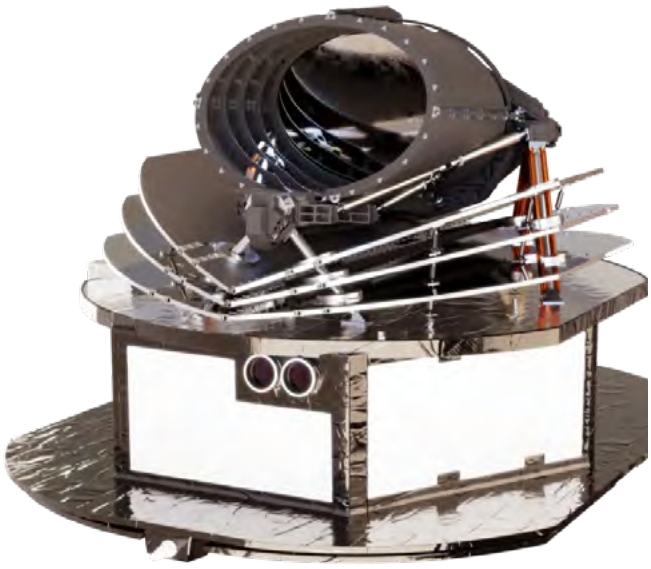
A significant contribution to the mechanical products revenue in 2022 originated from several major orders for Mechanical Ground Support Equipment (MGSE) from European and US satellite builders for integration and transport of satellites such as the ESA Plato spacecraft, for three NASA missions (Europa, Psyche) and for other US-missions. These contracts underline BGA's strong position with MGSE products on the world's biggest space market, the USA.

Starting the development of the Multi-Layer Insulation (MLI) for the ESA ARIEL mission and the OptSat Satellite as well as the development of deep-space MLI with aerobreaking capabilities represent significant steps for the thermal hardware product line in 2022. In 2022 further OneWeb internet satellites were launched with our thermal insulation protecting the low-earth orbit satellites.

To the new generation of European weather satellites Meteosat Third Generation (MTG) Beyond Gravity Austria provided several mechanisms, high-tech covers for the sun visor of MTG and refocusing mechanisms, as well as thermal insulation and electronics. In addition, a contract to develop High Temperature Thermal Insulation for the upper stage of Small Launchers was signed. The technology applied for this application has been derived from ongoing developments for the Ariane 6 thermal insulation.

Clearly, sales in the area of cryogenic insulation for terrestrial applications – a spin-off of the company's space business – has remained a strong and commercially successful element in our thermal hardware offerings throughout 2022.

Finally, the consortium of BGA, TU Graz and Seibersdorf Laboratories reports that the development of the Austrian nanosatellite mission PRETTY (Passive Reflectometry and Dosime-

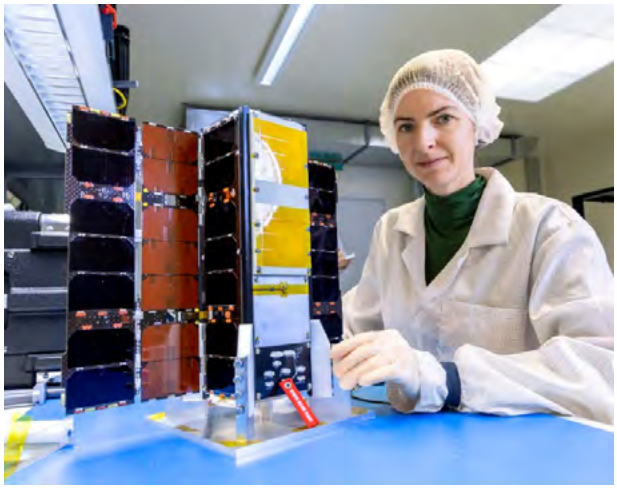


Artist impression of ESA's Ariel exoplanet satellite (source: Airbus)

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

try), funded through an ESA contract, has well advanced. BGA acts as prime contractor of the satellite (launch scheduled for Q3 2023) and as designer of the passive reflectometer, TU Graz is responsible for design and integration of the satellite and Seibersdorf Laboratories provides the dosimeter payload. The BGA payload processes direct and indirect GNSS signals reflected by ice or water and will soon deliver essential data to the international climate change research community.

In 2022 BGA total sales reached around 42 million Euros with the institutional contribution having fallen below 50% in favor of commercial contracts and with an almost equal split between Electronics on the one side and Mechanisms/Thermal Hardware/MGSE on the other.



Beyond Gravity is the prime contractor for the Austrian climate cubesat PRETTY (source: TU Graz, Lunghammer)

Beyond Gravity Austria GmbH

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FACTS

Sales:	41.8 M€
ESA Share:	19.7 M€

The Moon © ESA/NASA—T. Pesquet

Enpulsion GmbH

With close to 200 thrusters in space, more than 300 thrusters shipped worldwide and more than 160 years of accumulated on-orbit operation, ENPULSION is the world's leading manufacturer of electric satellite propulsion systems.

Founded in 2016, the company has fast grown to be a leading provider of highest quality propulsion solutions for small to mid-sized and even large satellites of up to 2.000kg launch mass. In 2022 the company turnover has increased by 100% to more than 10 Mio Euro.

Successes 2022

In 2022 fast-growing ENPULSION has reached several notable milestones. More than 80 employees in 3 different locations in Europe and the USA are working with more than 40 international customers, including well-known companies like Blue Canyon Technologies, OHB Italia and OHB Sweden as well as scientific institutions and space agencies, including ESA and NASA.

OHB Sweden — EIS Mission

In December 2022 OHB Sweden and ENPULSION have joined forces on a Horizon2020 IOV/IOD Mission called EIS making it the next important milestone in a long and very successful cooperation between the two companies.

After having delivered ENPULSION's propulsion products to previous OHB Sweden's InnoSat microsatellite platform missions, OHB Sweden now decided to order a next series of ENPULSION thrusters for its EIS mission. OHB Sweden and ENPULSION have very successfully worked together on previous mis-

sions, including the Arctic Weather Satellite (AWS) programme, using the ENPULSION NANO R3 thrusters, as well as the GMS-T satellite, launched in 2021, in which the ENPULSION MICRO R3 thrusters are being used. The AWS is part of ESA's Earth Watch programme, and the AWS satellite will be the proto-flight model for a possible constellation of satellites. The launch of the AWS is planned for 2024.

OHB Italy – IRIDE Constellation

OHB Italia selected ENPULSION as their propulsion partner for the IRIDE constellation. In December 2022 OHB Italia and ENPULSION signed a contract for the delivery of 12 NANO thrusters, using ENPULSION's unique Field Emission Electric Propulsion (FEEP) technology.

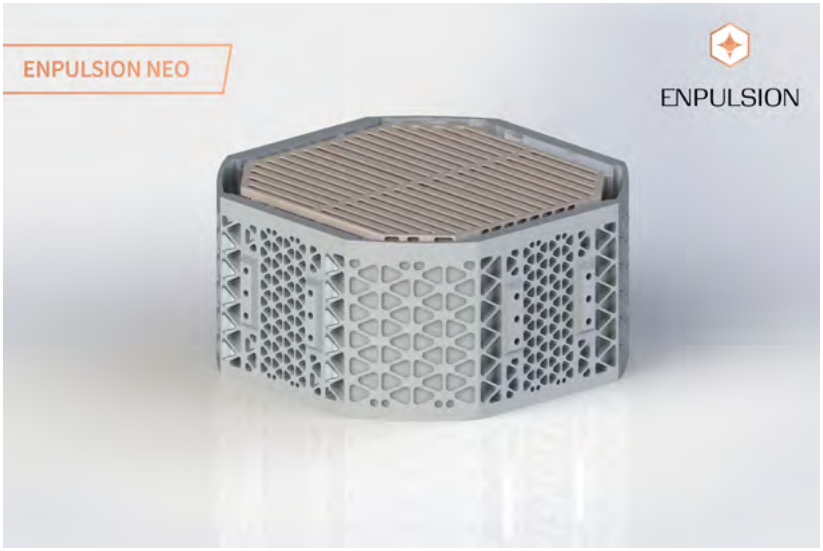
Under the supervision of ESA and ASI (Agenzia Spaziale Italiana) and in the frame of PNRR (Piano Nazionale Ripresa e Resilienza) the IRIDE constellation will be implemented in Italy and completed by 2026. ESA (European Space Agency) and OHB Italia have signed the contract for the development of an initial batch of 12 satellites to be delivered by November 2024, with a negotiated option for a further batch of 12 satellites to be delivered by November 2025. The industrial consortium led by OHB Italia also includes Telespazio, Optec, and Aresys as partners.

Development of the ENPULSION NEO thruster

As the next step in the development of FEEP-thruster products, ENPULSION has reached another important milestone. In December 2022 the ENPULSION NEO thruster successfully passed the Preliminary Design Review (PDR) with ESA.

ENPULSION NEO propulsion system is designed to provide more than 500 kN.s of total impulse and 20mN of thrust in a low volume package. It is especially well suited for commissioning ESPA and ESPA Grande class spacecraft and is dimensioned to meet operator requirements for orbit raising, station-keeping and de-orbiting mission phases.

ENPULSION NEO is designed for easy satellite integration. With their non-toxic, non-pressurized indium propellant all of ENPULSION's propulsion systems are shipped to customers through normal parcel carriers. They include the propulsion subsystem as well as propellant. They do not necessitate any special procedure for integration on the spacecraft and are virtually plug and play solutions. The NEO thruster development and qualification is supported by the European Space Agency as part of the ESA ARTES programme.



3D render of the ENPULSION NEO propulsion system

The Future of Space Sustainability

ENPULSION is investigating how far the FEEP thruster technology can be a good base to enter the business of automated deorbiting at the end of spacecraft lifetime. Adjacent and complementary technologies are evaluated for expanding the capabilities beyond thruster system level. This might lead to the development of an innovative In-Space Mobility Suite comprising several subsystems to enable automated de-orbiting in accordance with the five-year timeframe set by the new deorbiting requirements of the FCC. In this way, sustainability is not just a buzzword, but is built in by design.

About ENPULSION

ENPULSION was founded in 2016 in Wiener Neustadt, Austria, to produce and commercialize electric propulsion systems for small to midsized satellites using Field-Emission Electric Propulsion (FEEP) technology for the global market. This technology is based on more than 30 years of research and development work by FOTEC and in cooperation with the European Space Agency (ESA).

ENPULSION GmbH

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FACTS

Sales: 10.5 M€
ESA Share: 624 K€

ESA/NASA–T. Pesquet© contains modified Copernicus Sentinel data (2021), processed by ESA, CC BY-SA 3.0 IGO

EODC

Earth Observation Data Centre for Water Resources Monitoring GmbH

The EODC is a public-private partnership (PPP) between the Vienna University of Technology, GeoSphere Austria (Bundesanstalt für Geologie, Geophysik, Klimatologie und Meteorologie), 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
- Long-term data repository
- Automated processing workflow solutions

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

Project highlights in 2022

The Austrian Space Applications Programme

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.

GHG-KIT – Prototyping a tool-kit system for GHG verification in Austria

The project goal is the finalisation of a reliable and scientifically proven concept for the development of an EO-supported GHG reporting system. This system will support the stakeholder with the overall GHG reporting process, including data collection, integration, processing, modelling, and visualisation.

In addition to the overall system, we propose to develop and demonstrate two specific prototypes, enabling

- an improvement in the LULUCF reporting (GHG-KIT LULUCF Inventory Reporter, bottom-up approach)
- the verification of the currently reported emissions (GHG-KIT Verification Element, top-down approach)

both to showcase the value of EO information for the improvement and verification of GHG reporting in Austria as well as to demonstrate the sustainability of the KIT approach.

INTERFACE – INformaTion accEss seRvice For Austrian CopErnicus & contributing missions data

The "INformaTion accEss seRvice For Austrian CopErnicus and contribution missions data" (INTERFACE) aims to simplify the data access for the public sector. The focus will be on user-centric interfaces and data standards with special attention to integrating different data sets and setting up a prototype system that allows the systematic generation of higher level information products. During a consultation phase while preparing for INTERFACE, we have identified the following initial specific products:

1. Indicating and monitoring sealed surfaces based on Sentinel-2 and on-demand VHR Pleiades access for verification
2. Wetland monitoring service using Sentinel-1
3. Snow characteristics service using Copernicus Sentinel data and information
4. Semantic content based image retrieval system for automated provision of cloud-free Sentinel-2 data before and after an event based on a user-defined date
5. Ground motion and mass movement detection service based on Sentinel 1 InSAR data

Service for deriving on-demand high resolution 3D products (DSM and DTM) from Pleiades (Tri) - stereo data
We aim to set up a flexible system that allows us to expand the INTERFACE service prototype with additional information and data layers, e.g. from other existing or future ASAP or Horizon projects. This would provide the public sector one interface at their disposal towards several EO-based developments within Austria. These developments will significantly contribute to lowering the entrance barrier to accessing data and products from Copernicus and contributing missions as well as ASAP results in general.

ROSSIHNI – Remote Sensing and Social Interest for Humanitarian Insights

ROSSIHNI is the first research-driven attempt to link a new drought monitoring data product based on radar backscatter observations from Sentinel-1 and ASCAT to a suite of algorithms that measure social interest and

awareness at a global scale. The resulting prototype dashboard will use the radar-based drought product as visual evidence for emergency impacts and related humanitarian financing requirements . Our study region is Eastern Africa, a humanitarian hot spot region frequently hit by droughtsother natural extremes. The radar-based drought product will be developed by merging a new full-resolution ASCAT soil moisture data set with Sentinel-1 data, and by calculating anomaly percentages suited to compare drought conditions across different climatic regions.

ESA

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.

DHR Framework Austria

The Collaborative Data Hub Relay Framework – Austria Service (DHR Framework AT) is supporting the ground segment operations on national level, with the intention of new data integration access services.

EU – Copernicus

C3S2 - 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

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.

c-scale.eu

interTwin – Co-designing and prototyping an interdisciplinary Digital Twin Engine.

interTwin is an EU-funded project with the goal to co-design and implement the prototype of an interdisciplinary Digital Twin Engine – an open source platform based on open standards that offers the capability to integrate with application-specific Digital Twins. Its functional specifications and implementation are based on a co-designed interoperability framework and conceptual model of a DT for research – the DTE blueprint architecture.

www.intertwin.eu

GREAT – GREEN DEAL DATA SPACE

The GREAT project, funded by the Digital Europe program, aims to establish the Green Deal Data Space Foundation and its Community of Practice which builds on both the European Green Deal and the EU's Strategy for Data. The project will deliver a roadmap for implementing and deploying the Green Deal Data Space, an infrastructure that will allow data providers and initiatives to openly share their data to tackle climate change in a multidisciplinary manner.

www.greatproject.eu

EODC Earth Observation Data Centre for Water Resources Monitoring GmbH

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FACTS
Sales: 3.3 M€
ESA Share: 393 K€

EOX IT Services GmbH

EOX IT Services GmbH (EOX) is a geospatial engineering and service company based in Austria, a non-start-up, 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 organisations.

EOX is among the main ESA contractors in Austria and has successfully carried out more than 70 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 organisations and research institutes interested in engineering, consultancy and in the new data product services provided by EOX. The Sentinel commodity product series "EOx-Cloudless", which currently includes Sentinel-1 and -2 global product offerings has opened the doors for EOX to a wide consumer market.

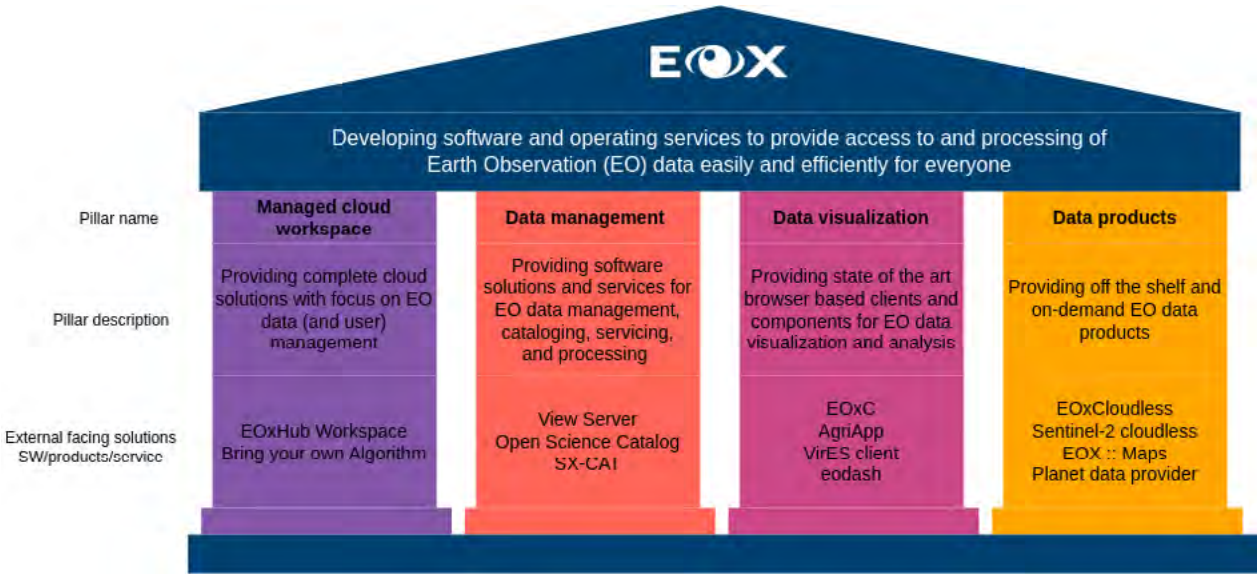
EOX has a fifteen-years long record of space software projects building components of Earth Observation satellite payload ground segments most of them including (sophisticated) geospatial Web GUI implementations together with adequate server infrastructure functions including data cubes, as can be checked 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 utilising and contributing to Open Source Software for example via the EOX GitHub organisation. In this respect, EOX is an active member of FOSSGIS and OSGEO, the most important associations promoting free and open source software in the geospatial sector. EOX is further committed to comply with and improve Open Standards particularly those of the Open Geospatial Consortium (OGC). EOX is an active promoter of such standards and offers related consultancy and implementation services.

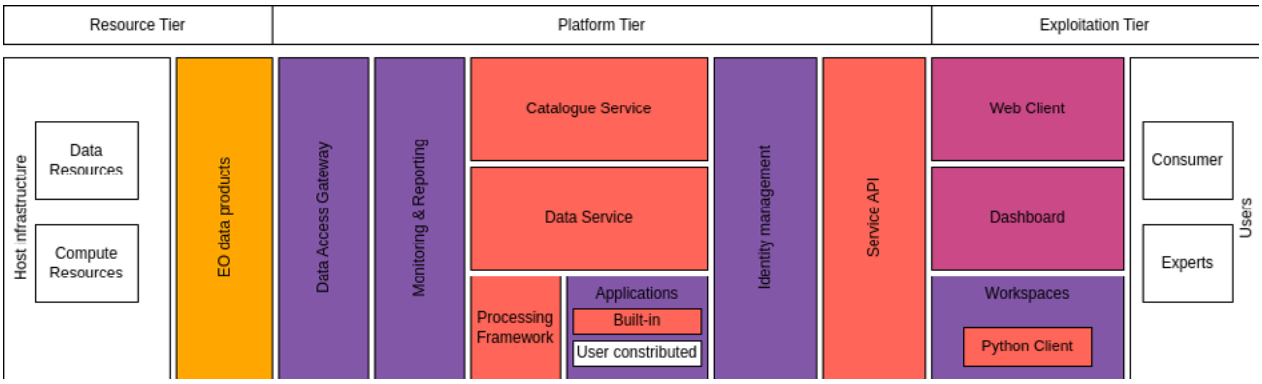
At present, EOX employs 25 full-time, permanent staff and, in addition, temporary co-workers including master students and stagiaires. Administrative processes are to a good deal outsourced to external professionals.
Under the following headlines the 2022 highlights are reported.

Technology

EOX is a full-stack technology provider for the handling of big data from Earth observation (EO) satellite missions. The following figure shows the 4 main technology pillars of EOX.

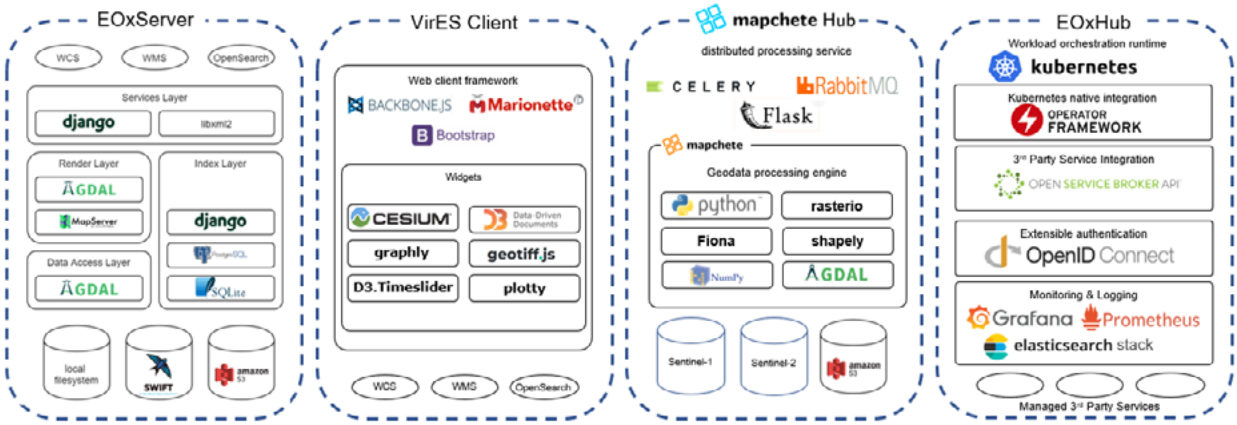


The technologies built within these pillars are modular and re-combinable. This allows re-use and synergistic developments where implementations done for one project benefit all other projects using the same modules.
The following figure shows what aspects of a complete system architecture can be covered by software modules developed and delivered by EOX. 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.



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].

[1] https://github.com/ESA-VirES
[2] https://github.com/eox-a

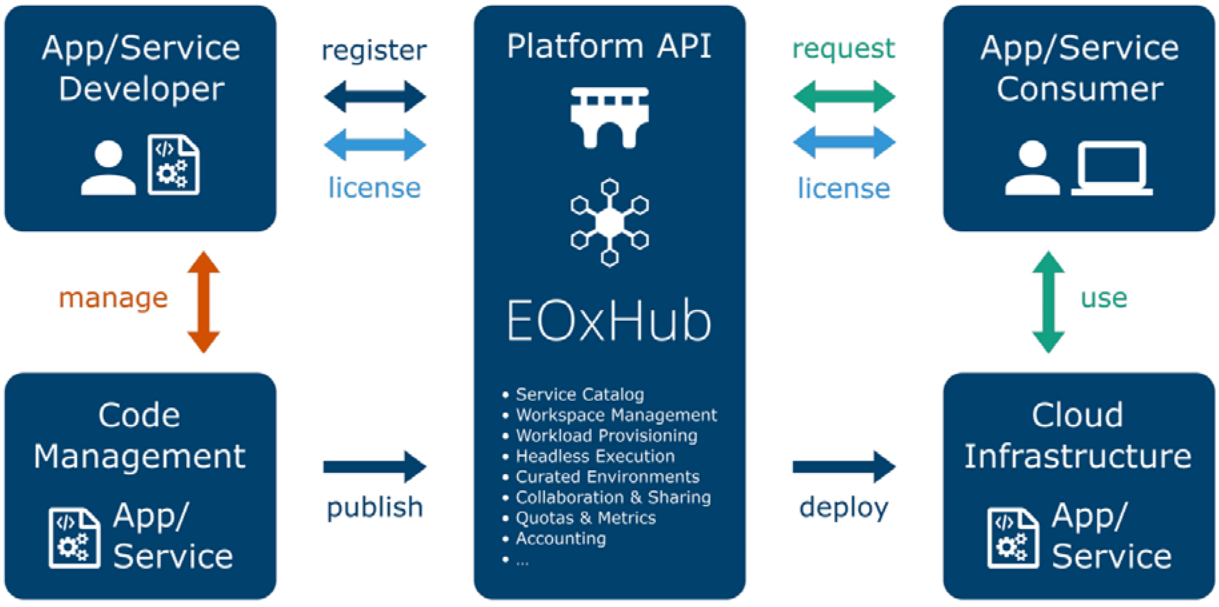


Following are highlights from within these technology pillars.

Managed cloud workspace

EOxHub – Business-enabling, scalable cloud deployment and operations

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.



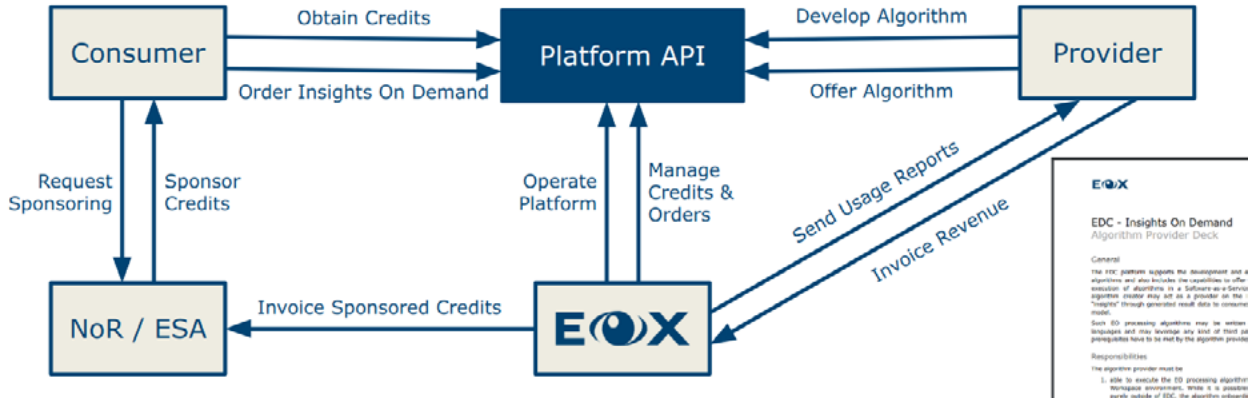
Through EOxHub [3] also optimal data access strategies (e.g. those implemented in Euro Data Cube [4]) are offered in a pluggable and unified way.

[3] https://hub.eox.at
[4] https://eurodatacube.com

Bring your own Algorithm (BYOA)

When working with Big Data it has become necessary to bring algorithm development to the data, as it is no longer possible to hold the data in user managed spaces. EOX provides a new service, as part of EOxHub for programmatic on demand process execution via the so-called Bring Your Own Algorithm (BYOA) functionality. Users can exploit this functionality using a straightforward checkout wizard helping to guide them to parameter selection like area of interest on a map. Algorithm providers can offer and even sell their algorithms via this mechanism to users.

The figure below shows the steps involved. The algorithm consumer can, after obtaining credits, directly order Insights On Demand. The algorithm provider develops and offers an algorithm on the platform including signing a provider agreement with the platform operator and sending invoices to the platform operator as agreed. The platform operator is responsible to operate the platform, manage credits and orders, and to send usage reports to operators.



[5] https://medium.com/euro-data-cube/sharing-your-algorithms-with-data-on-demand-on-edc-c159084ded00

Data management

View Server

View Server is truly cloud native supporting deployments over Docker Swarm and Kubernetes, disseminated as Docker images, natively using Object Storage (S3, Swift), Logging, Helm charts, Flux GitOps, Elastic Search, fluentd, Kibana, etc. It is scalable to a virtual unlimited size of an EO repository. It is flexible concerning different rendering scenarios (On-the-fly, Masking, CQL, layers, projections, etc.), various pre-processing registration needs (S3/Swift/local access; direct product registration, or pre-process to COGs), and individual caching strategies (on-demand, pre-seeding, no delay between ingestion and WM(T)S cache access)). It supports the full-fledged EOxC web client (fully standard compliant see section 2.2) but also interoperable clients from different vendors. View Server is running on/building upon Python 3, Ubuntu 18.04 base images, and Redis queues.

The following services, extensions, and best practices are currently provided by EOxServer (integral component of View Server) and thus readily available:

- WCS (1.0, 1.1, 2.0
  - CRS, scaling, interpolation, and range subsetting extensions
  - GeoTIFF encoding parameters
  - Earth Observation Application profile (EO-WCS)
- WMS (1.0, 1.1, 1.3)
- Earth Observation Application profile (EO-WMS)
- OpenSearch
  - Geo and Time extension
  - Extension for Earth Observation
  - CEOS best practices for Earth Observation
- WPS 1.0, WPS 2.0
- Direct HTTP proxy access
-

View Server allows dynamic processing to generate portrayals of multi-spectral data (band-maths, range stretch, grey-scale mapping to colour scales, pansharpening, percentage histogram based rendering etc.).
The Cache component of the View Server is realised via MapCache, which provides the following interfaces:

- Tiled Map Service (TMS)
- Keyhole Markup Language (KML)
- OGC WMTS
- OGC WMS
- GoogleMaps XYZ
- Virtual Earth tile service

Further functionality is also supported: Log handling including searching and alerting; Shibboleth authorization interface (collection level); vs-starter to help Operator setup new collections for docker compose deployments from default Kubernetes Helm charts; Search service (OpenSearch); Download service (WCS, DS-EO), View Service (WMS, WMTS).

View Server Open Source Software [6], Operator Guide [7]
[6] https://gitlab.eox.at/vs
[7] https://vs.pages.eox.at/documentation/user/main

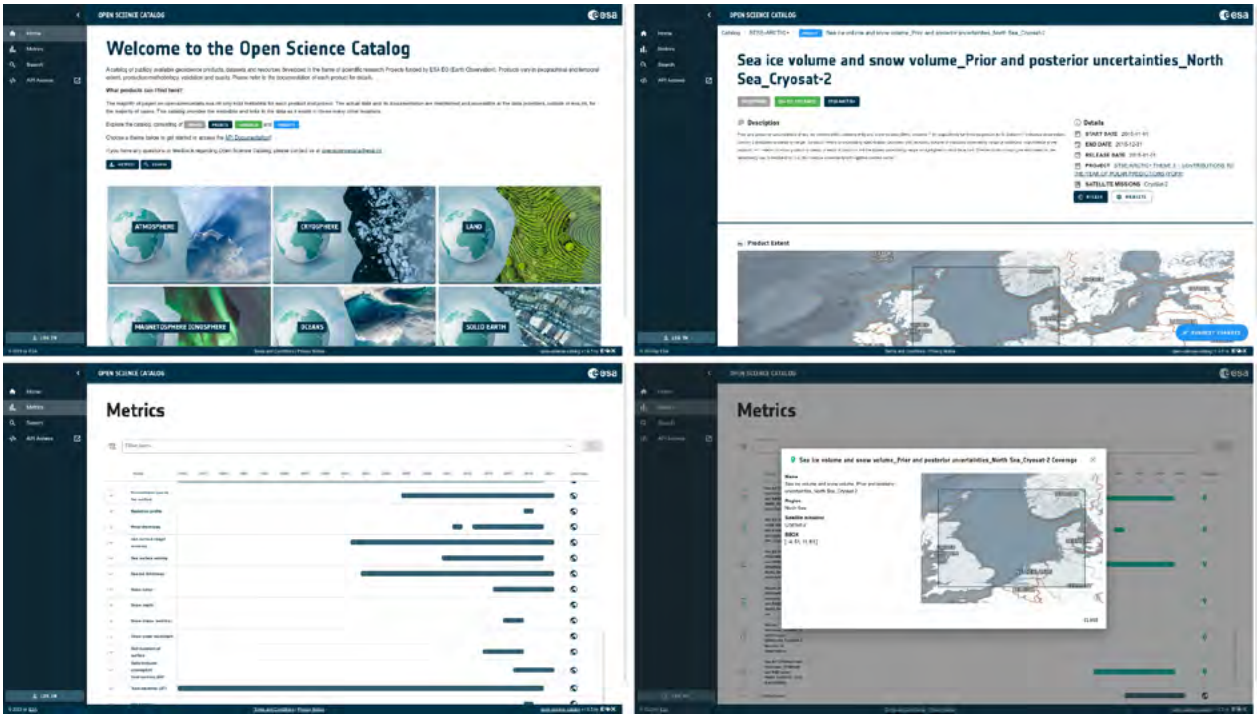
Open Science Catalog

EOX is developing the Open Science Catalog (OSC) [8] a SpatioTemporal Asset Catalog (STAC) based catalog relying on the components provided by EOEPCA.

The Open Science Catalogue is one of the elements contributing to an Open Science framework and infrastructure, with the scope to enhance the discoverability and use of products, data, and knowledge resulting from Scientific Earth Observation exploitation studies.

Adhering by design to the "FAIR" (findable, accessible, interoperable, reproducible/reusable) principles, the Open Science Catalogue aims to support better knowledge discovery and innovation, and facilitate data and knowledge integration and reuse by the scientific community.

The Open Science Catalog is centred around STAC (SpatioTemporal Asset Catalog) and the OSC web client (see screenshots in the figure below) is proposed to be used as the catalogue client for the **DESP Data Catalogue & Discovery Services**.



[8] https://opensciencedata.esa.int

SX-CAT

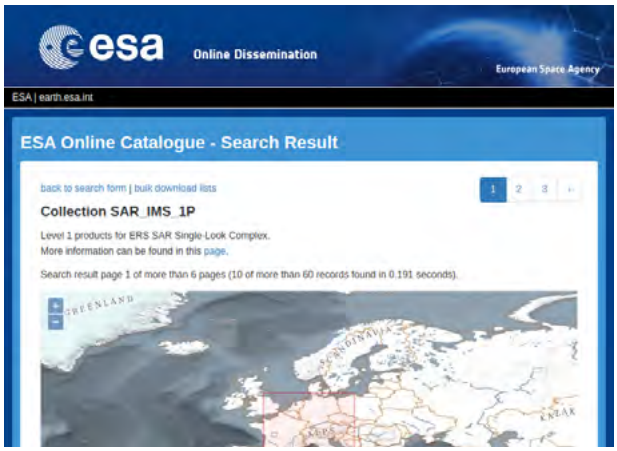
The ESA Sx-Cat catalogue, developed by EOX, is a lightweight and flexible catalogue allowing searching, metadata inspection and download (through the stored direct download URLs) of collections of EO products or auxiliary data files.

The Sx-Cat catalogue consists of two functional modules:

1. Simple Online Catalogue (SO-Cat) module allowing dynamical search and metadata inspection of the available data items.
2. Static Map Catalogue (SM-Cat) module allows search of EO products based on their spatial location by simple browsing of pre-rendered maps.

The Sx-Cat is designed to allow simple deployment and operations while providing good performance. The Sx-Cat catalogue is highly configurable for specific needs and a broad range of EO missions and sensors. The employed HTML templating allows bespoke look & feel customization of the WebUI and easy integration into existing portals.

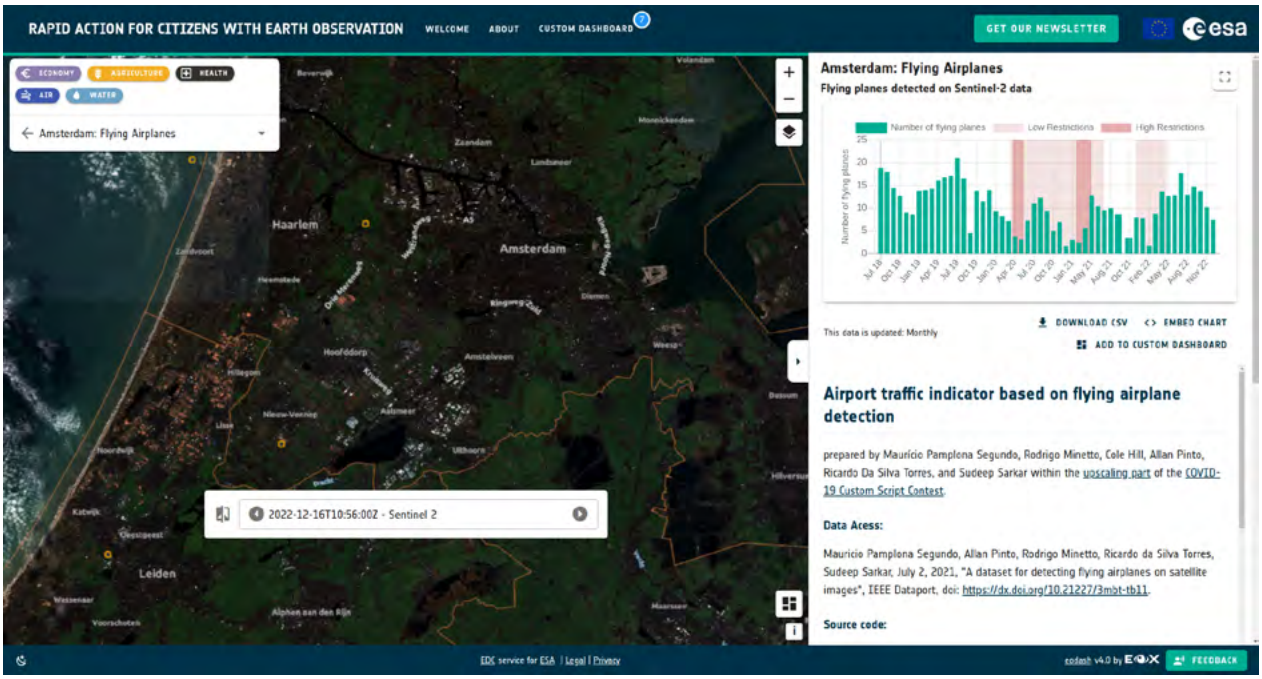
[9] https://ec-pdgs-discovery.eo.esa.int/sxcat



Data visualisation

eodash

The eodash client is a state of the art highly configurable web browser dashboard client. The software initially developed for the Rapid Action for citizens with Earth observation presents the results of the Joint cooperation between ESA and the European Commission to inform on societal global challenges using Earth Observations. The activity, initially called "Rapid Action for coronavirus EO" started in 2020, triggered by Covid-19 crisis and was expanded in scope in 2022.



The Earth Observing Dashboard combines the resources, technical knowledge and expertise of three partner agencies ESA, JAXA, and NASA to strengthen our global understanding of global environmental changes and other societal challenges impacting our planet.

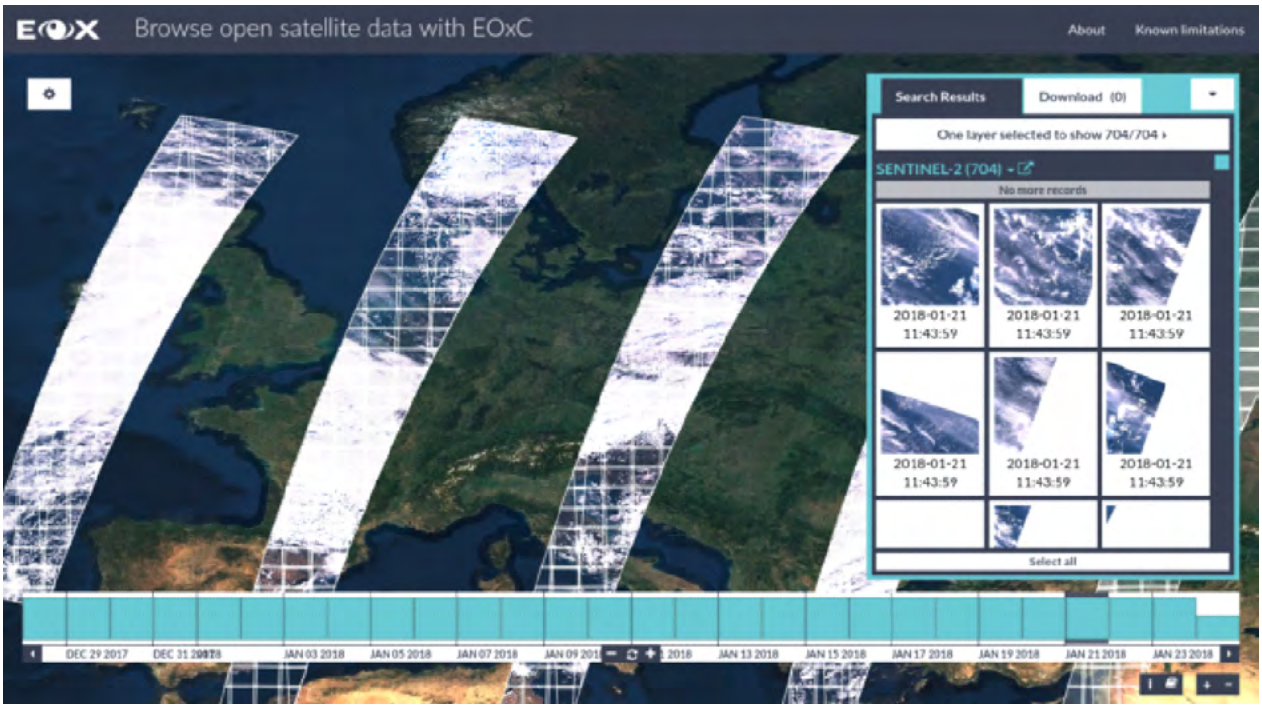
The platform demonstrates how the use of Earth observation data can help shed new light on societal and eco-

nomic changes currently taking place owing to the coronavirus pandemic. The information contained on this website are mainly provided by third parties based on experimental methods and without any warranty as to their veracity. The European Commission cannot be held responsible for any use which may be made of the information contained therein.

[10] https://race.esa.int
[11] https://eodashboard.org
[12] https://gtif.esa.int

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) [13] and PRISM Data Access Service (PASS) [14]. The software is provided by EOX as Free and Open Source Software (FOSS) [15].

[13] https://mundiwebservices.com/geodata/S2_MSI_L2A
[14] https://vhr18.pass.copernicus.eu/
[15] https://github.com/eoxc/eoxc

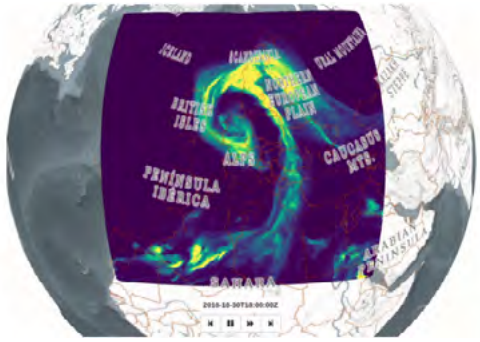
plotty & graphly

Interactive graphics and high-end plotting in Web browser

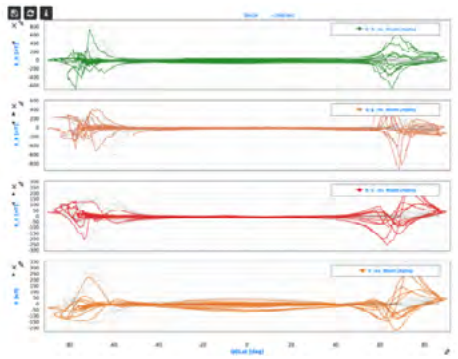
These are two examples of JavaScript libraries developed and maintained by EOX allowing developers to build complex Web portals for interactive visual analytics of EO and auxiliary data. Both libraries are FOSS [16], [17].

Example instances of graphly and plotty are being used in VirES for Swarm [19], VirES for Aeolus [18].

[16] http://santilland.github.io/plotty/
[17] https://eox-a.github.io/graphly/
[18] https://vires.services/
[19] https://aeolus.services/



plotty – WebGL colorscale rendering

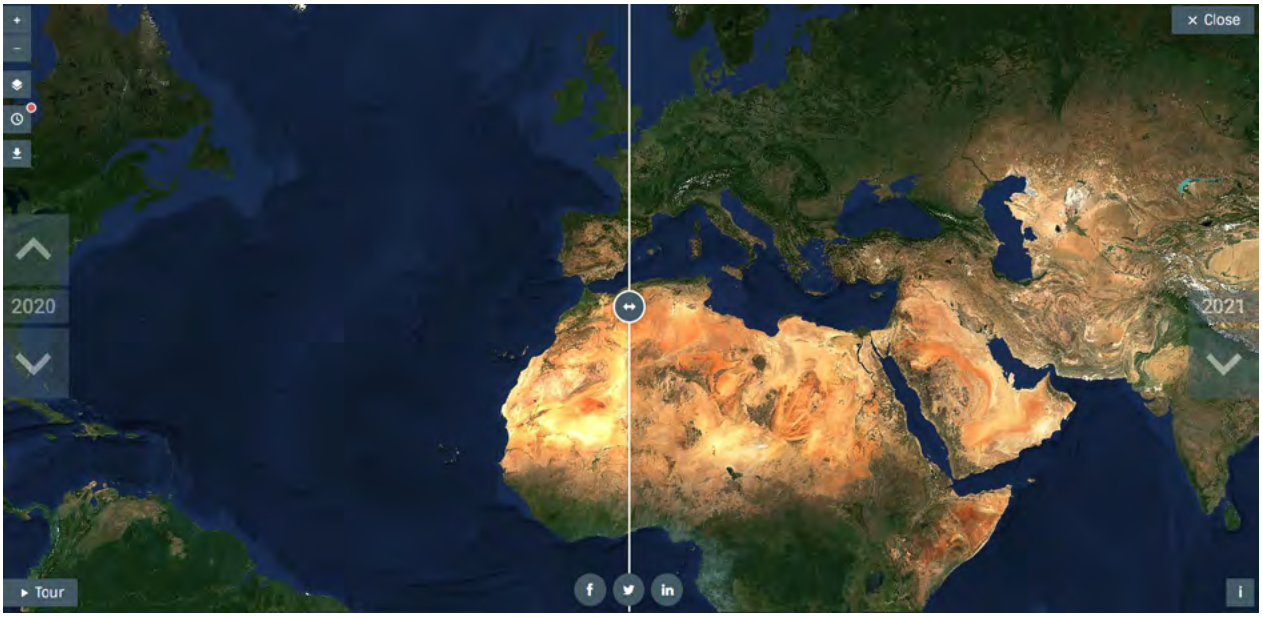


graphly – WebGL based graph library

EO data products

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, 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

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.

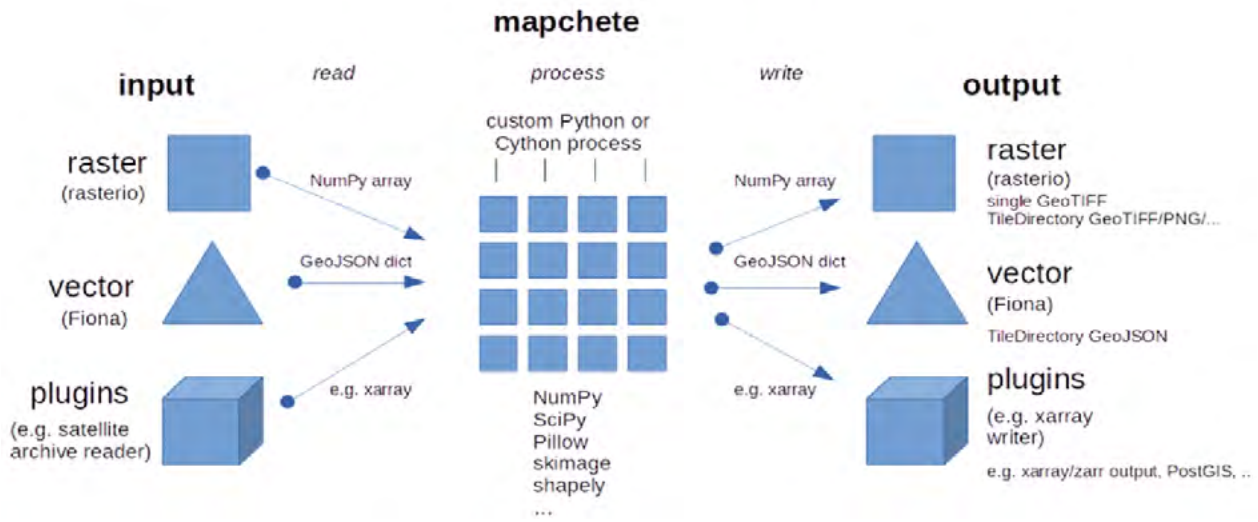
All maps are provided free-of-charge as Web Map Tile Service (WMTS) and Web Map Service (WMS) layers in simple lat lon projection also known as WGS84 or EPSG:4326 or pseudo-mercator projection also known as Google projection, EPSG:3857, or EPSG:900913. Special customers, such as ESA, are served by EOX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

[20] https://s2maps.eu
[21] https://maps.eox.at

The URLs to include the open maps in tools like QGIS, Leaflet or OpenLayers are:
[22] WMTS https://tiles.maps.eox.at/wmts/1.0.0/WMTSCapabilities.xml
[23] WMS https://tiles.maps.eox.at/wms?service=wms&request=getcapabilities

mapchete

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).



Complete solutions & services

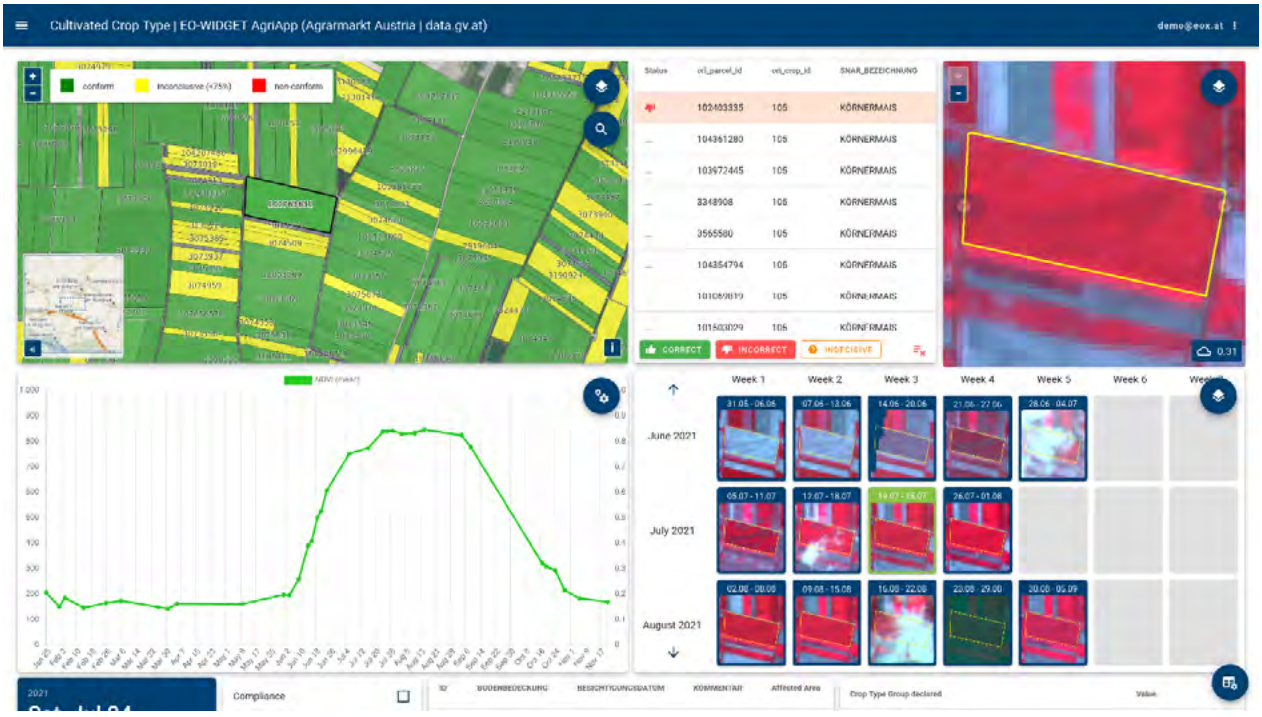
As described the technology pillars are composed of interchangeable modules which can be combined and configured based on needs of specific projects.

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.

In this section we want to highlight some of the complete solutions that are provided by EOX and that make use of a larger set of the technology pool.

EO-WIDGET

EOX offers **Agricultural Area Monitoring** solutions based on satellite EO data to support expert judgement and decision making compliant with the EU Common Agricultural Policy (CAP). The following diagram 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.

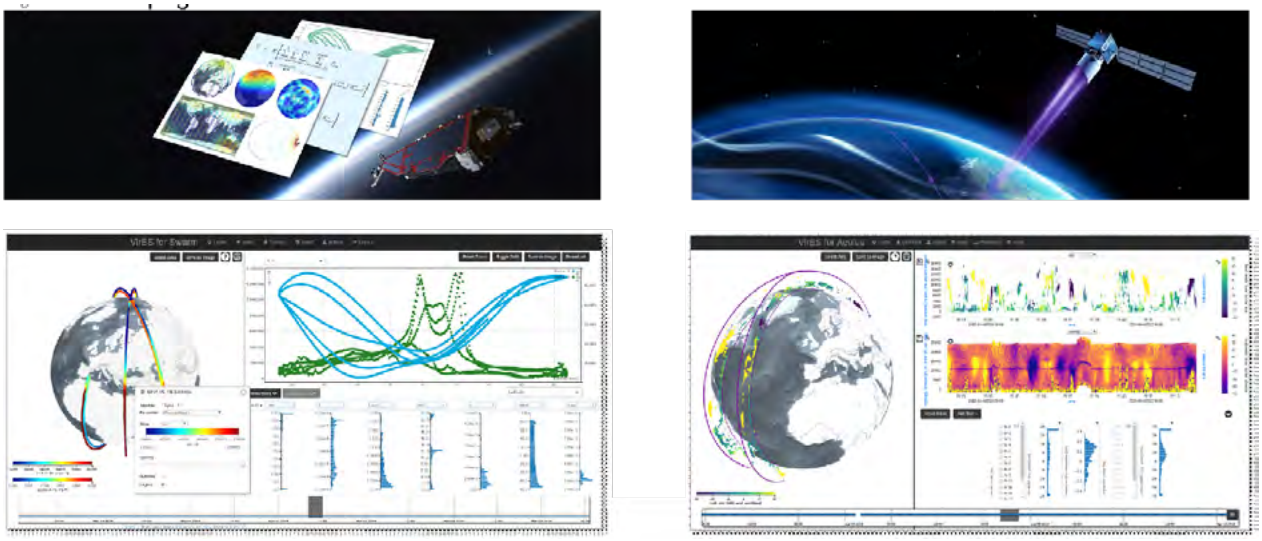


In 2022 first long-term contracts have been awarded to EOX for providing operational CAP Area Monitoring Services by the Paying Agencies of Austria and Ireland. EOX' footprint in this market is expected to grow in the years to come thus establishing an increasingly important business sector for EOX.

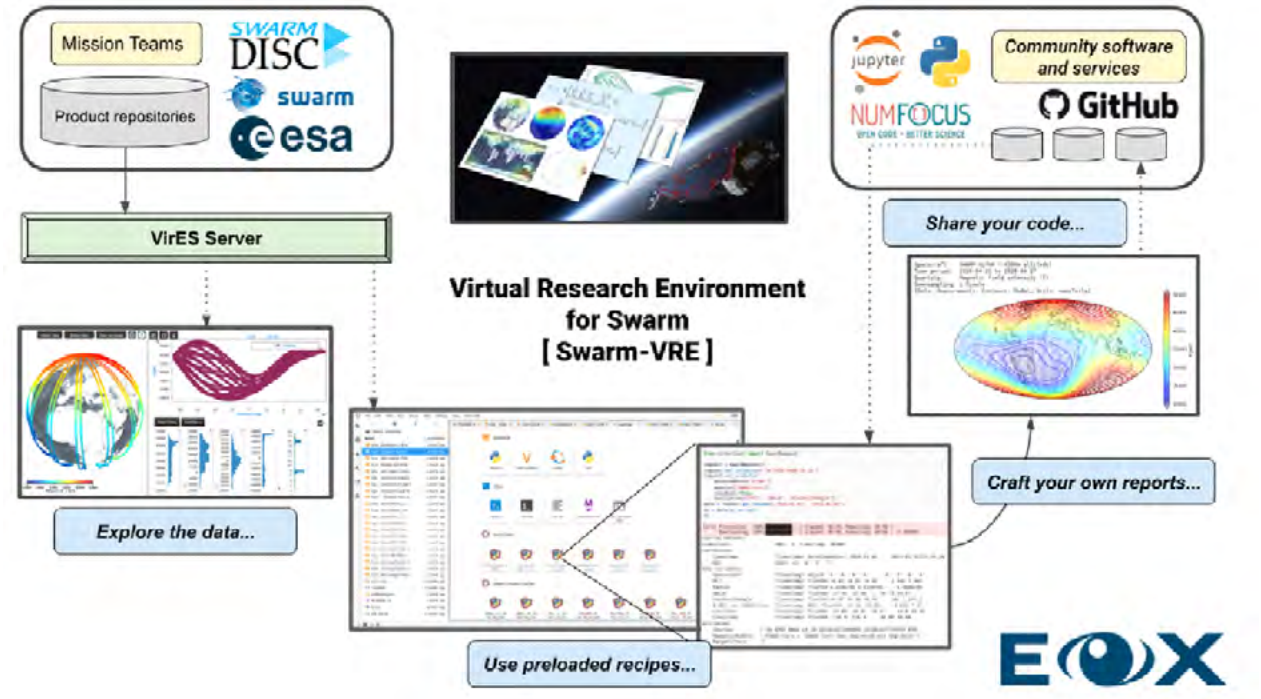
[24] https://eowidget.services

Virtual Research Environments

The VirES family of services [24], [25] 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.



EOX is continuously synchronising 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 [27].



[25] https://vires.services
[26] https://aeolus.services
[27] https://eox.at/2019/01/using-python-interface-of-vires-in-eox-jupyter-platform/

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FACTS

Sales: 2,8 M€
ESA Share: 1,7 M€

BepiColombo hugs Mercury © ESA/BepiColombo/MTM, CC BY-SA 3.0 IGO

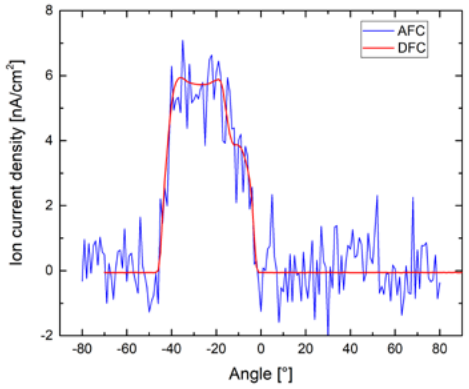
Fachhochschule Wiener Neustadt GmbH

with its Forschungsgesellschaft FOTEC

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 capability specifically for small satellite systems and CubeSats. Particular attention is paid to the plasma plume of an electric thruster and its interaction with the environment as well as to the thermal interaction of the thruster with the satellite. Obtained knowledge will be used to develop a new syllabus to be implemented in the cur-riculum of Aerospace Engineering at the FHWN.

FOTEC developed a plasma diagnostic system dedicated to measure the characteristics of an ion plume expelled from a FEEP thruster or other electric propulsion system. In FOTEC's large vacuum facility (3.5 m length, 2 m di-ameter, 14 m^3 volume) 23 Faraday cups are being mounted on a moveable boom to allow scanning through the entire plume. Within project DEEP, the Faraday cups were strongly improved to increase the dynamic range and to reduce the noise floor. Signal conditioning and analogue-to-digital conversion of the measured current is now performed within the Faraday cup. It could be shown that the signal-to-noise ratio could significantly be improved as shown below.



Digital Faraday Cup with integrated conditioning and measurement electronics (left) and achieved reduction in the measurement noise compared to an analog Faraday cup (right)

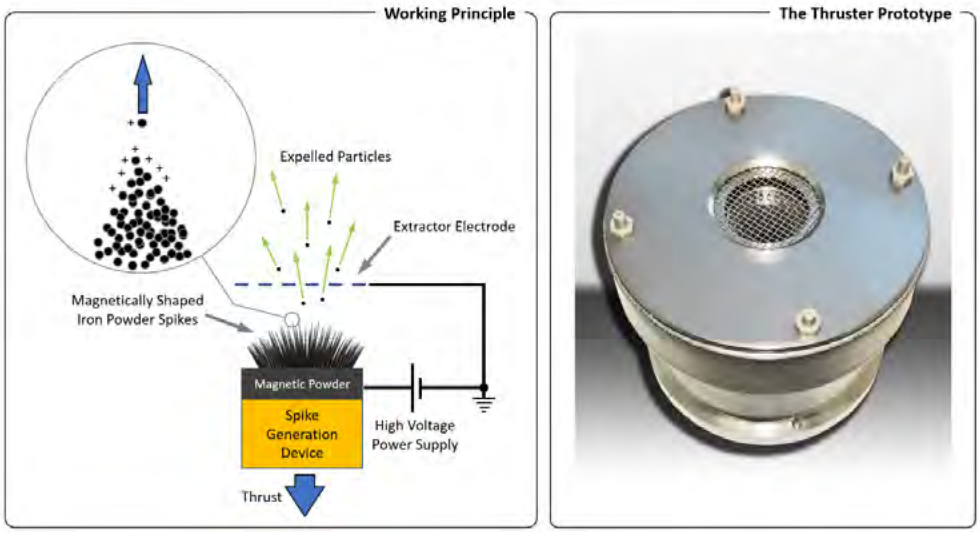
Thrust vector balance consisting of a rotational stage allowing a two-axis movement which is being measured by two interferometric displacement sensors and compensated by precision magnetic force actuators.

FOTEC has a long-term experience in the development, characterization and qualification of direct thrust measurement systems in the low thrust range (few µN up to several mN). Apart from the measurement of the total thrust generated by a propulsion module, which is actually derived from the measured torque acting on the horizontal torsion balance, the off-axis angle of the thrust vector is crucial for the dimensioning of the AOCS since this needs to compensate for the off-axis components of the propulsion system. There is nothing like a "thrust vector balance" available which would allow to measure the total thrust and the off-axis angles in pitch (vertical) and yaw (horizontal) direction. Therefore, FOTEC develop their own test stand to characterize the off-axis thrust vector components in addition to the in-axis component. The prototype is shown in the figure below.

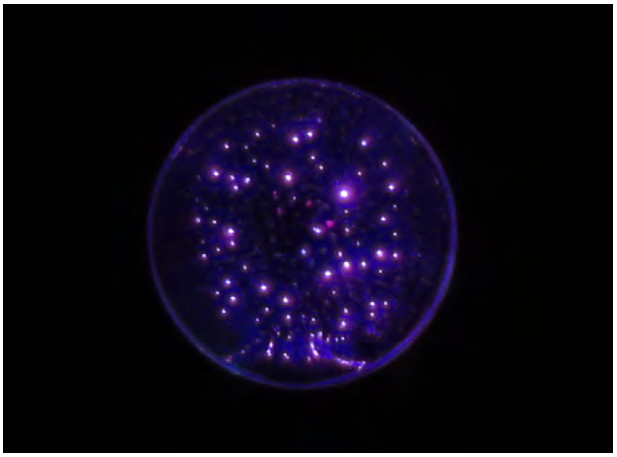
This thrust vector balance will not only allow significantly faster measurement of the thrust vector misalignment for different thrusters and operation points, but is also suitable for propulsion systems that expel a quasi-neutral plasma instead of an ion plume. In that case, the plasma diagnostic system consisting of Digital Faraday Cups is not suitable to be used as an indirect thrust measurement method.

Advanced Electric Propulsion Technologies

Within the advanced electric propulsion technology developments, FOTEC concluded the project MPEP in February 2022. The main objectives of this project were to develop a thruster prototype based on magnetic powder electrostatic propulsion and to test it in vacuum with direct thrust measurements. The aim was to check the robustness of the concept and to measure and calculate important performance parameters such as thrust and specific impulse, to allow a comparison with other thruster technologies. The main advantages of such a propulsion concept would be, for example, high density propellant storage and the possibility to use propellant materials available in space, e. g. asteroid regolith (In Situ Resource Utilisation). While previously proposed acceleration methods involved the use of sharp needles at high voltage to charge the particles, the concept presented in this project introduced a novel approach, where the propellant itself is shaped in the form of sharp spikes by magnetic fields, and the particles are emitted directly from the tips of these spikes when high voltage is provided.



Working principle (left) and thruster prototype developed during the MPEP project (right)



Operational emitter with more than 100 firing needles during performance testing (left) and thruster module with the emitter visible in the centre (right) from the MAGNIFIED project.

After the conclusion of the MPEP project, FOTEC started another advanced propulsion development project in April 2022, where an innovative method to produce dense arrays of needle-like structures to manufacture the emitter element of the FEEP thruster is investigated. The most promising emitters manufactured with this method are then tested in the vacuum chamber to determine their performances with respect to the existing crown emitter, used on the IFM Nano and IFM Micro thrusters. So far, successful results have been achieved, where more than 100 needles were ignited during testing on different emitters.

Thanks to the successful results so far, the project is planned to continue with a follow-up activity starting from the beginning of 2024, where the thruster module is planned to be further optimized and tested.

Environmental Testing Service for Aerospace Applications

FOTEC offers its customers extensive testing capabilities and supports them with many years of experience in the planning and execution of environmental tests related to space applications and other technical sectors. We provide acceptance and qualification tests of components, systems, instruments, and small spacecraft – such as CubeSats. This helps our customers to expose weaknesses during development, to evaluate products for ruggedness and to increase operational reliability. Results are gathered, verified, and interpreted in accordance with the applicable ESA ECSS standard. This guarantees standardised and reproducible test campaigns. All environmental test activities are accompanied by dedicated quality assurance measures. We are experienced on an international level and have proven our expertise in the frame of numerous national and international research projects.

FOTEC´s test facilities allow the application of sinusoidal sweeps, random noise, and quasi-static loads along all three axes. For that purpose, the LDS V730-185T electromagnetic shaker system combined with the m+p VibControl data acquisition system. The armature table has a diameter of 185 mm whereas a mass-optimised head expander is available to enable larger DUTs to be tested (see figure below). To allow tests in lateral direction, a slip table is used providing an area of 330 by 330 mm.

Electric propulsion system mounted on an in-house 3D printed test adapter for a qualification campaign

FOTEC's shock table consisting of ringing plate and an adjustable hammer (in- and out-of-plane configuration) to apply shocks according to customized PSD profiles.

FOTEC's shock table comprises of a ringing plate and a hammer that can be deflected and released (see figure below). A variety of factors affects the achievable PSD waveform. The following adjustments are possible to configure the application of the impact energy:

1. in-plane and out-of-plane setup,
2. variable hammer mass,
3. adjustable drop height,
4. different hammer materials and
5. different target materials.

Additive Layer Manufacturing (ALM)

In January 2023 , FOTEC started the ESA project RAMMEC (Recycling enhanced addi-tive manufacturing processes under Martian environmental conditions) in cooperation with the University of Innsbruck (AT) with the objective to further develop the existing knowhow in the field of in-situ resource utilization. The processing of Lunar or Martian regolith for the manu-facturing of, e.g., protecting habitats is essential for future missions to Moon or Mars. Two important aspects will be investigated:

1. Recycling of polymeric packaging waste as potential binding agent
2. Paste extrusion process in representative Martian environment (CO_2 rich atmosphere and reduced pressure, approx. 6 mbar)

Several technology demonstrators (JSC-Mars 1A regolith simulant with phosphoric acid as binding agent) additively manufactured by paste extrusion process from the previous ESA project ISRU (successfully closed in 2017, Source: FOTEC)

Within the project duration of 18 months also the impact of the simulated Martian environment on the mechanical properties (e.g., bending strength) shall be addressed.

FOTEC continued the work on the 4D-printing topic within the ESA project "Assessment of reliability of 4D printing materials due to ground/space environmental effects". Several mate-rial samples made of NiTi alloy were tested to assess the transition temperatures (using differential scanning calorimetry – DSC method) and 3D-printed bending bars were trained by heating and bending and showed acceptable shape memory effects.

In the upcoming project phase, three demonstrators (self-deployment mechanism, gripper and rotary stage) will be designed and manufactured. The big advantage of using shape-memory alloys (SMA) is the significantly reduced number of moving parts and therefore increased operation stability. This project is planned to be finished in June 2023 and beside FOTEC the companies RHP Technology (AT) and AAC GmbH (AT) are part of the consortium.

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FACTS

Sales:	3,5 M€
ESA Share:	0,6 M€


Leaflet | © Bing Satellite © CartoDB, Landcover Dynamics 2016-2018 © by GeoVille

GeoVille Information Systems and Data Processing GmbH

GeoVille provides a wide range of value-added services derived from Earth observation data to enable GIS applications. Our mission is to provide turnkey geospatial intelligence solutions for 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.


Agriculture & Rural


Energy & Infrastructure


Environment & Natural Resources


Transport & ICT


Population & Urban

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

European Environment Agency, European Space Agency, European Union, IFAD, United Nations Programmes

Financial Institutions

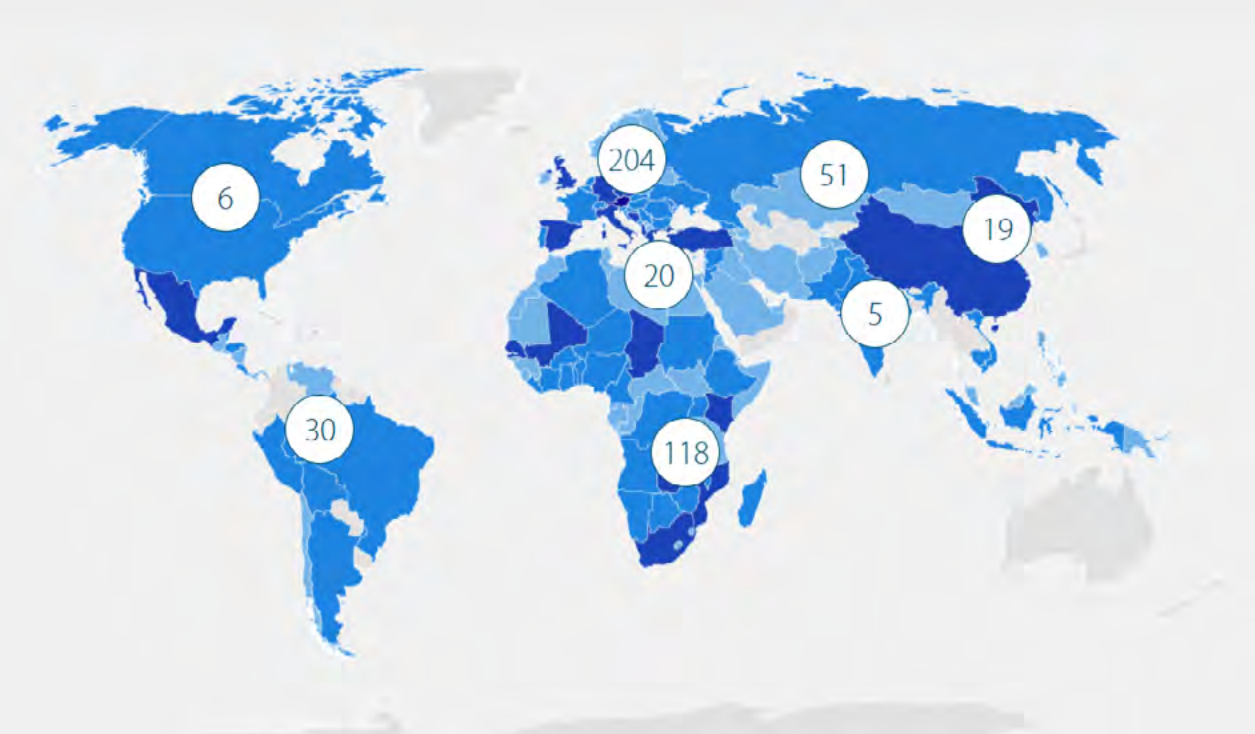
Asian Development Bank, European Investment Bank, EuropeAid, World Bank

Public Authorities

Various ministries and agencies for environment, agriculture, forestry, research, water and energy commissions

Private companies

Agriculture, Financial Sector, Consulting, Construction, Oil & Gas, Telecommunication, etc.



Realised projects worldwide (excl. global projects)

New Project Highlights

Austrian Space Application Programme

GHG-KIT Keep it traceable – Prototyping a satellite enabled, independent tool-kit system for GHG verification in Austria

One of the major environmental challenges is to understand how global changes are affecting the Earth system and how human societies must adopt to mitigate and adapt to them. The carbon cycle is an essential part of the Earth system, where carbon is exchanged between the atmosphere, land, and ocean. The quantification of this cycle is fundamental to understand the status, dynamics, and evolution of the terrestrial biosphere.

GHG-KIT: Keep it traceable'' is set up as a ASAP flagship project for EO and climate protection. GHG-KIT will deal with one of the most important environmental challenges of our generation, namely climate change, its effects and impacts on the Earth system and human society. Under the consortium lead of GeoVille Information Systems and Data Processing GmbH, a large team of Austrian (and international) experts from different sectors (EO, GHG, climate, atmosphere, environment, and IT) has been united along with the most relevant stakeholders.

GHG-KIT will design, consolidate, and validate an overall system design to provide an independent GHG verification system to Austria. GHG-KIT will use highly flexible toolkit elements to fit the current and future needs. The overall system approach will be proven along two vertical prototypes (verification element / inventory reporter). The entire GHG-KIT concept design and all technical developments aim towards a system solution with a long-term potential for growth.

From an economic perspective, the foreseen developments and innovations within GHG-KIT will not only enhance the competitiveness of Austrian EO companies, but also strengthen Austria as an economic site as well as generate more national and international visibility for Austrian technology developments. From a scientific perspective, GHG-KIT will strengthen the visibility of the Austrian science community, related to climate and atmospheric research, meteorology, and EO.

More information: https://ghg-kit.at
Contract Value: 2,39M €

EUROPEAN SPACE AGENCY

SENTINELS AnyTIME

Persistent cloud cover affects the quality of derived information products and still impedes full adoption of EO derived information in the decision-making processes of end users. This is particularly an issue in higher latitude and tropical regions.

SENTINELS AnyTIME aims to overcome this hurdle by implementing a revolutionary real-time Sentinel-1/2 fusion-based timeseries reconstruction API service through AI based Deep Bayesian Neural Networks Reconstruction. The end goal is to provide continuous (gap free) time series needed for many high demand sectors, as well as offering a real-time S-2 cloud free tile service with B2B focus through the ESA Network of Resources as well as commercial EO Federated platforms, supporting a wide range of innovative added value services, thereby benefiting the entire EO VAS community.

Example for a reconstructed, cloudfree Sentinel-2 Tile (32TPT) above Innsbruck. Shown are harmonically reconstructed images between winter and summer 2020 (Processed by GeoVille, 2021)

Very recent advances in AI-based techniques for high performance & high accuracy image analytics have demonstrated the power of Deep Bayesian Neural Networks to allow for memory-based predictions away from single pixel analysis to include spatial context. Translated to the application of Sentinel (1&2) data, this means that individual pixels "disturbed" by unusual patterns, other than concrete changes, can be identified with a known confidence interval, and be substituted with last valid observations.

With SENTINELSAnyTIME we make these technologies available for a broad consumer basis and build the foundation of an easily accessible, radar corrected and highly optimized source for cloud-free Sentinel-2 data that can be retrieved without the need for in-house expert knowledge or customized pre-processing developments.

Contract Value: 350K €

GDA Blue Economy

The Global Development Assistance – Agile EO Information Development (GDA-AID) on Marine Environment and Blue Economy is part of ESA´s 'Space in support of International Development Assistance' (Space for IDA) program, set up in close cooperation with the World Bank (WB) and the Asian Development Bank (ADB) to facilitate the natural integration and acceptance of EO technology into IFIs investments in Blue Economy.

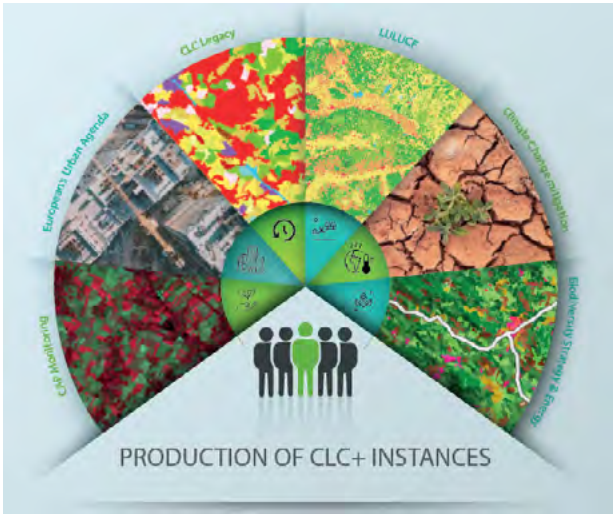
This GDA project seeks to support WB and ADB in their projects related to Marine Environments and Blue Economy by providing dedicated Earth Observation (EO) services which are adapted to address the specific user demands. EO offers the opportunity to fill existing gaps in a cost-effective manner through the provision of data and information needed by local users on a large scale and comprehensive area. Moreover, the services produce a continuous stream of data with constant high quality to allow monitoring and evaluation of the situation. The focus is set on coastal zones and the sea in several locations across the world to promote and facilitate efficient and sustainable economic use of their natural resources, while protecting the environment and fostering social responsibility for the communities living in and depending on these ecosystems.

GeoVille is leading the use cases on "Ecosystem Extent and Status, Ecosystems Protection and Management Services" as well as "Assessing and tracking environmental damages from maritime disasters". GeoVille provides support by offering and adapting services for land cover mapping and monitoring of coastal ecosystem and the detection of oil spills using Sentinel-1 SAR imagery. Further, contributions are delivered on topics of water pollution and water quality as well as the provision of a strategic & integrated Marine Spatial Planning roadmap.

Contract Value: 250K €

COPERNICUS

CLC + Instances



The CLC+ suite of products is set to become the European standard in Land Cover/Land Use (LC/LU) monitoring,establishing the "2nd generation CORINE Land Cover (CLC)". The now requested implementation of a series of CLC+ Instances is – after the production of the CLC+ Backbone and the now operational CLC+ Core System ("the Core") – the next big step towards realizing the full vision of CLC+ serving many current and future needs in European LC/LU monitoring and policy reporting for the coming 10-15 years (Arnold et al., 2013 & 2016, Kleeschulte et al., 2016).

The CLC+ Instances are tailor-made series of datasets derived by combining information from datasets ingested into the CLC+ Core database on a 100 m grid level, building upon an intensified monitoring of LC/LU at a level of detail with a Minimum Mapping Unit (MMU) of 1 to 0.5 ha. Instances therefore are geospatial products derived from CLC+ Core via extraction rules. The Instances are never one product, but a series of iteratively improved products. Rather than a pure geospatial data production task, the goal is to apply an iterative process with all involved stakeholders (EEA, ETC support tasks, country representatives) through discussion, consultation, testing and improvement resulting in "final", operational Instances.

Contract Value: 2.250 K €

AgrarMarkt Austria (AMA)

Operational Area Monitoring System Service Contract

Agricultural monitoring has gained ever-increasing attention recently in the face of a major global food crisis and growing concerns over food security. Within Europe, the EU's Common Agricultural Policy is a fundamental pillar of the continent's food supply, and the CAP now requires national governments to carry out much more comprehensive checks and controls of agricultural production and payment claims from farmers.

Anticipating the vital role that Earth observation would play in enhancing and simplifying subsidy-compliance monitoring, in 2017 ESA initiated the Sen4CAP (Sentinels for CAP) activity in coordination with the EU. This research and development project was aimed at providing European institutions with validated algorithms, based on data from the Copernicus Sentinel missions, that address the monitoring needs of the CAP.

From data to dashboard

While Sen4CAP produces invaluable information on crops and grassland, it is not provided in a form that is immediately transferable into the operational contexts of the Paying Agencies in the EU Member States. GeoVille, recognised the need for a commercially and truly operational production line for monitoring products that builds on the outputs from Sen4CAP to give government Paying Agencies exactly the monitoring information they need for meeting their CAP obligations. EOX, a specialist in Earth observation service platforms and ESA contractor for dashboards and Web interfaces has identified the associated cloud-based workflow and graphical user-interface solutions.

Resulting from EO-WIDGET, a solution developed by GeoVille and EOX is offered to the market that enables compliance monitoring through machine-to-machine APIs and through an interactive Web interface, giving Paying Agency users a range of insights on the crop status of each 'parcel' of land. There is also a quality assessment tool that reports on CAP compliance performance over an entire territory.

Frontend of Area Monitoring System (GeoVille, EOX)

The GeoVille / EOX consortium has signed a long-term contract with AgrarMarkt Austria (AMA), the national agency for administering CAP payments. The agreement involves supplying tailored and managed services for monthly monitoring of compliance with the new CAP regulations beyond 2027 and includes extra-high-resolution imagery for evaluating small parcels of land.

Frontend of Area Monitoring System (GeoVille, EOX)
Contract Value: > 5.000 k€

GeoVille Information Systems and Data Processing GmbH

Sparkassenplatz 2, 6020 Innsbruck
www.geoville.com

CONTACT

Dr. Christian Hoffmann
+43(0)512 562021-0
info@geoville.com

FACTS

Sales:	6,7 M€
ESA Share:	1,1 M€

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Graz University of Technology

Technische Universität Graz

Institute of Geodesy

The Working Group of Navigation

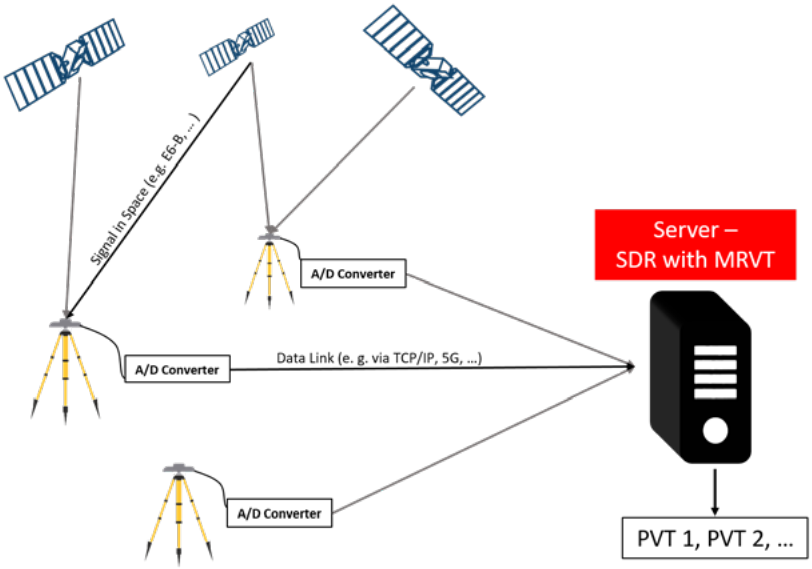
The Working Group of Navigation at the Institute of Geodesy (ifG) at Graz University of Technology puts its focus on satellite-based positioning and navigation systems. In the field of satellite-based positioning the team focuses on robust and precise positioning algorithms and methods for Global Navigation 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.

GARFIELD – New GNSS services and innovative processing procedures for target group-specific applications

The project GARFIELD – New GNSS services and innovative processing procedures for target group-specific applications – deals with concepts from the Galileo High Accuracy Service (HAS) with the background of the requirements of the Austrian stakeholders and users. This includes the analysis of the two different service levels (SL1 or SL2) and if they are suitable for the users' requirements. Further it is investigated if multi-frequency multi-system evaluations (beyond Galileo and GPS) are possible whether it is possible to use the HAS data or signals for integrity determination.

Due to the fact, that GNSS networks have become more and more important in the last 10 years, a new concept of processing multiple GNSS receivers is also investigated. Current GNSS networks consist of wide and expensive ground stations. For operators and users of GNSS networks, hardware replacement to use new signals or features is usually the limiting factor. A new approach to improve scalability and configurability and reduce costs while

maintaining compatibility with traditional GNSS stations is the use of Remote Radio Head (RRH) sensors. With RRH, the signals are analog-to-digital converted already at the antenna and then transmitted to a server. The actual signal processing then takes place there by means of a software-based receiver (SDR) within a multi-receiver vector tracking algorithm (MRVT). Due to the SDR, this is an extremely flexible and highly configurable solution. It reduces the necessary hardware to a minimum, enables rapid upgrades through software and allows new cooperative processing strategies to be implemented. The RRH concept thus represents an innovative and future-proof solution and follows the trend "monitoring network-as-a-service".



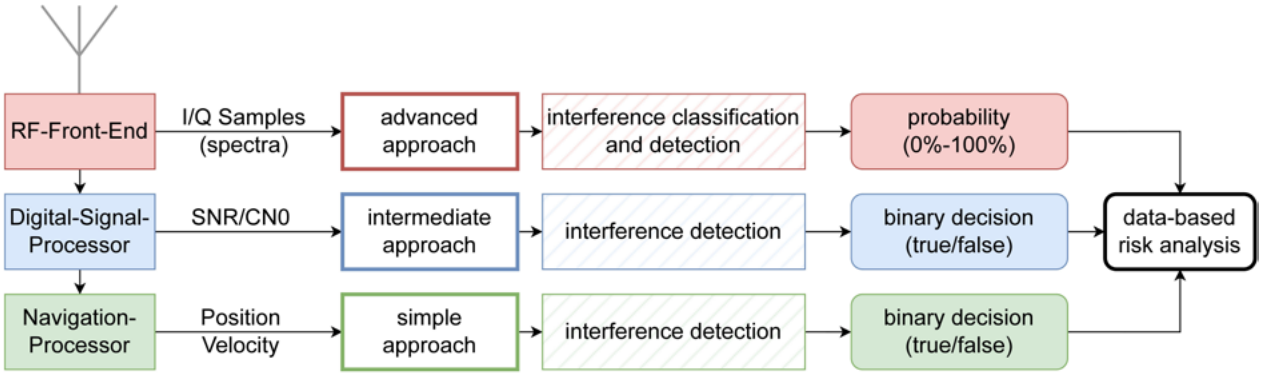
GARFIELD Remote Radio Head Concept

Assessing the impact of GNSS signal loss

In recent years, intentional interference incidents like jamming and spoofing have significantly increased worldwide. These incidents are a growing concern and have garnered attention due to notable examples such as the mass spoofing attack on ships in the Black Sea in 2017 or mysterious GPS malfunctions near the Kremlin since at least 2016. Consequently, it is expected that Austria will also face GNSS interference attacks in the future. The widespread application of GNSS services, such as location-based services, asset tracking, and timing and synchronization, makes them crucial for various industrial stakeholders.

The primary objective of the project is to examine the methods for assessing the impact of GNSS signal loss on Austria's critical national infrastructure, applications, and organizations. Consequently, the project aims to develop a GNSS risk management tool that assists users of GNSS services, regardless of their level of expertise, and enhance awareness regarding potential risks associated with GNSS interference.

Within the field of GNSS risk management, effective monitoring of GNSS risks plays a crucial role. To achieve this, a novel and innovative risk monitoring tool is being developed, which combines theoretical and data-based risk analysis. The Institute of Geodesy, specifically the Working Group of Navigation, is primarily responsible for designing the data-based risk analysis component. Machine learning-based techniques are being employed to analyze the GNSS-related user data, aiming to establish a universal approach for detecting and categorizing GNSS interference, including jamming and spoofing. Therefore, to ensure the integration of a wide variety of user data, the data-based risk management tool is designed to have a modular structure. Depending on the available GNSS-data sources (NMEA files, KML files, RINEX observation files, raw I/Q GNSS data), different detection or classification algorithms are applied accordingly. Figure 2 shows the associated system design with the total of three different approaches (advanced, intermediate, and simple) for classification and/or detection of interference.



Modular design of data-based risk management tool

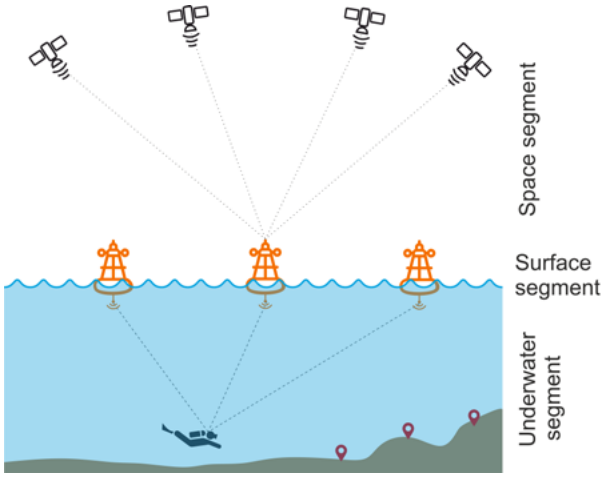
The different machine learning methodologies applied to accomplish this task include transfer learning, where pre-trained models are reused and extended by jamming and spoofing spectrograms, representing the advanced approach. Another methodology employed is variational autoencoders based on recurrent models, which are used for detecting anomalies in signal-to-noise ratio (SNR) observations, representing the intermediate approach.

ScubaNAV – Underwater navigation

Underwater navigation is a particular challenge for divers and often a risk factor that should not be underestimated. A reliable positioning system could increase safety and support the practice of special forces in emergency organisations (firefighters, military divers, water rescue, etc.). This is precisely what the ScubaNAV exploratory project aims to achieve by laying the foundations for the development of such a GNSS-based underwater navigation system.

The ScubaNAV project proposes a solution based on a terrestrial GNSS pseudolite system that allows underwater positioning on a terminal in a similar way to conventional GNSS-based positioning systems. Floating transceivers (e.g., buoys or beacons) receive the GNSS signals and independently determine their position. The transceivers generate GNSS-like long-wave signals based on the GNSS clock or time stamp, which are transmitted synchronously by the underwater transceivers. Like a GNSS receiver, the underwater receiver processes the signals and uses them to determine its position. Through the participatory involvement of different user groups (recreational divers, firefighters, military divers, professional divers), the technology will be designed to meet the needs of the users.

The project is carried out in cooperation with Pentamap GmbH, Disaster Competence Network Austria (DCNA) and 1st-Relief GmbH. The role of the TU Graz is primarily the technical investigation and design of an underwater positioning system. In a first step, investigations were performed on a simulation level. By simulating all important underwater parameters, a link budget calculation could be carried out. Both acoustic and electromagnetic signal were considered and compared. The signal propagation underwater depends on various factors. Main contributions such as temperature, salinity and depth were considered as well as reverberation effects and background noise. Based on this simulation, the signal strength and SNR (signal-to-noise ratio) for different distances and frequencies could be evaluated.



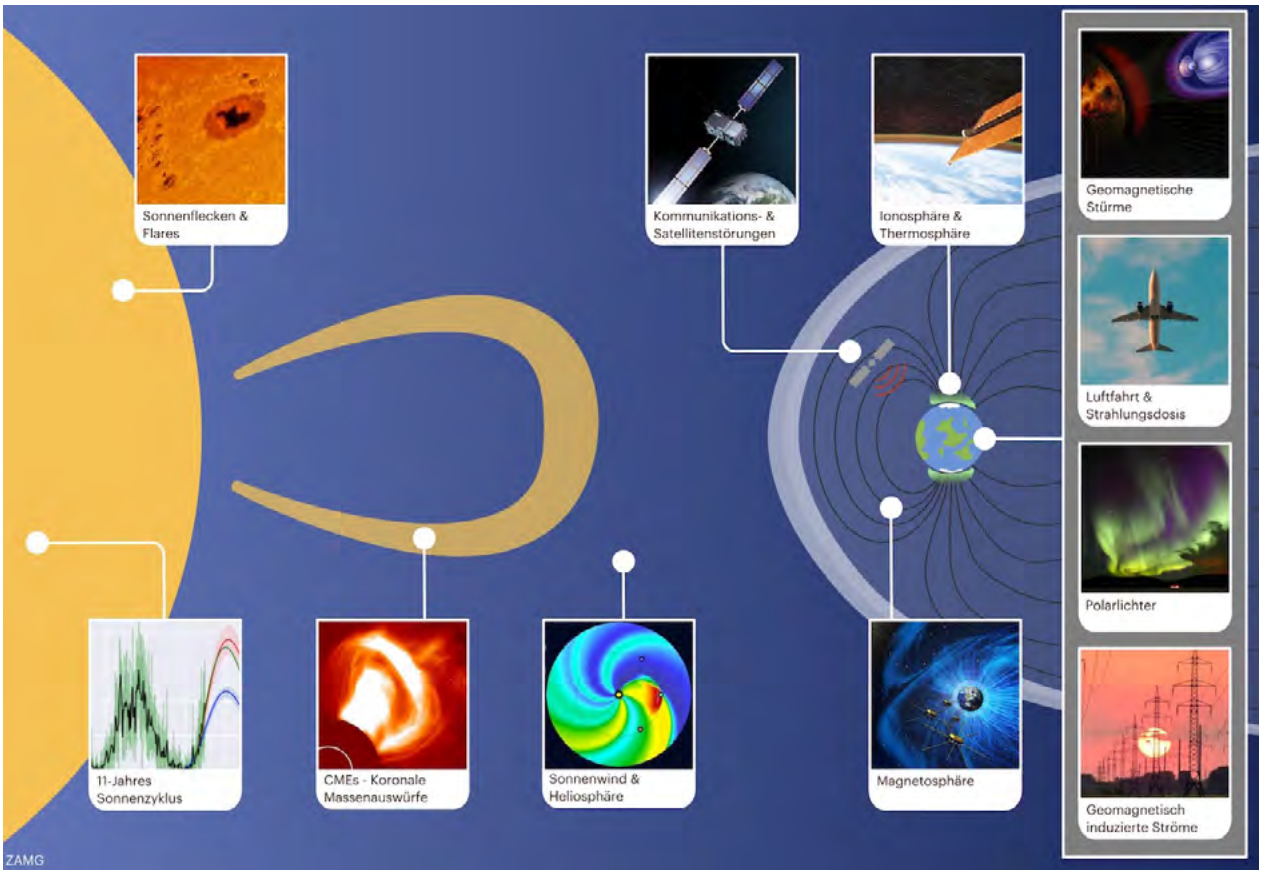
Concept of underwater navigation using GNSS-like signals

ScubaNAV test measurement set-up

In a next step, a suitable signal for underwater positioning was designed. Based on the link budget simulation suitable centre frequencies were picked and modulated to enable distance estimation. Variations in the design were performed and tested with real equipment over cable to find a promising solution. Due to the slower speed of the signal underwater, data rates, bandwidth and interferences must be respected. Also, a possible simplified data message was developed for transferring information of the buoys to the receiver. Expertise in GNSS is used to select the appropriate positioning method for the buoys floating on the water.

The final phase, a proof of concept (PoC) was designed. Using COTS Hardware for signal generation and a self-made antenna, designed signals could be transmitted underwater and recorded with a second identical device. Various tests were performed to investigate the signal and antenna behaviour. Besides calculation of SNR and channel power, an GNSS software-based receiver was adapted to achieve signal tracking over different distances. These first promising results will be used for follow-up activities.

Working Group Theoretical Geodesy and Satellite Geodesy



The SWAP competence atlas – overview of different scientific research and application areas within Austria which are covered by native research institutions.

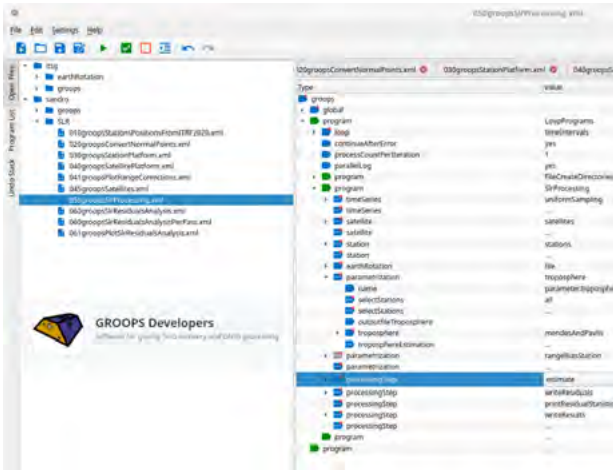
SWAP – the Austrian Space weather platform

The term space weather is generally used to describe the condition of near-Earth space and the Earth's upper atmosphere. Space weather is mainly determined by the sun, and phenomena that occur are often referred to as solar storms. Due to the rapidly increasing technological progress in the last decades, the issue of space weather and its influences on our everyday life gains more and more importance. Today satellite-based navigation plays a key role in aviation, logistics and transportation systems. Hence, a deterioration of the familiar services becomes immediately apparent to anybody. Within the project SWAP (Space Weather: the Austrian Platform) the aim is a well-funded presentation of scientific contents and the development of sustainable cooperation's. This comprises the networking of researchers, end users and Austrian stakeholders in the area of critical infrastructure. This will enable the promotion of synergies between the interdisciplinary research fields as well as the development of scientific content, based on the research of the participating institutes. The project is managed by the Geosphere Austria and is supported by the University of Graz, Seibersdorf Laboratories, Austrian Academy of Sciences, Joanneum Research, and the Graz University of Technology. This allows a wide range of scientific topics (from the Sun to the Earth's surface) to be covered. The Figure on the left page illustrates various focus area's which the consortium deals with.

The scientific contributions from the Institute Geodesy cover in general the subjects Ionosphere and Thermosphere and specifically the effects of solar storms on near-Earth satellites. This includes the determination of the conditions of the Earth's upper atmosphere and the prediction of potential satellite orbit decays due to the impact of coronal mass ejections. For the latter, in cooperation with the Institute of Physics, the forecasting tool SODA (satellite orbit decay) has also been developed which accepted as official ESA Service and will be part of the ESA Ionospheric Weather SSP program/Ionospheric Weather Expert Service Centre (I-ESC). SWAP is funded by the Austrian research and promotion agency (FFG), and offers potential end users more detailed content on the preliminary website https://cobs.zamg.ac.at/swap/.

Building new partnership for climate and geophysical research

Within the framework of the project COVER one of the objectives is to enable the evaluation of satellite laser ranging (SLR) observations within the software package GROOPS, from the Institute of Geodesy at the Graz University of Technology. The development of the software began 20 years ago and through continuous further development it represents today a highly sophisticated and well accepted tool in the scientific community. As key features GROOPS include gravity field recovery from satellite and terrestrial data, the processing of Global Navigation Satellite System (GNSS) constellations and ground station networks and the determination of satellite orbits from GNSS measurements. Through the project COVER, GROOPS is now also capable to process SLR observations (see Figure) and to provide orbit predictions for SLR stations.

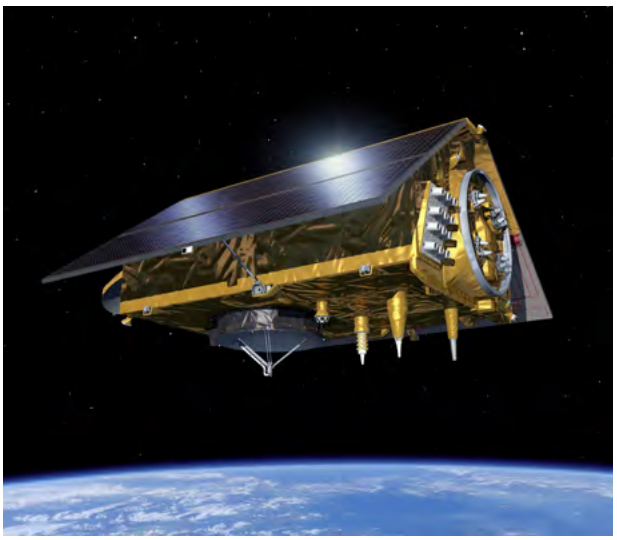


GUI view of the software package GROOPS

https://github.com/groops-devs/groops

Based on a close collaboration with the local SLR station Graz Lustbühel, from the Austrian Academy of Sciences, the aim is also to improve the possibility of tracking uncooperative space debris objects. Following ESA, in over 60 years of space activities, more than 6050 launches have resulted in some 56450 tracked objects in orbit. Thus, space debris and especially the avoidance of collisions with satellites is one of the principal threats nowadays. In the further course of the project a consistent combination of SLR and GRACE/GRACE-FO for improved mass change estimates is proposed. Thus, improved mass change estimates which directly benefit Earth-, climate and geophysical sciences is envisaged.

Quality Working Group (QWG) of the Copernicus POD Service



Sentinel-6a satellite in orbit since November 2020

Since November 2022, Graz University of Technology has been a member of the Quality Working Group (QWG) of the Copernicus precise orbit determination (POD) Service. The current CPOD QWG is composed by many leading centers on GNSS and POD, including ESA, EUMETSAT, CNES, AIUB, DLR, GFZ, TU Delft, TU Munich, JPL, GSFC and CLS/GRG. The task of this group is to monitor the quality of the POD and make recommendations for the further operation of the satellites. Currently monitored satellites are Sentinel-1a, Sentinel-2a, Sentinel-2b, Sentinel-3a, Sentinel-3b and Sentinel-6a.

Besides, most of these centers participate in periodic reviews, on which each center provides independent orbital solutions, and we generate a combined solution to assess the quality of the operational products. The results show that orbit determination is possible with a precision of a few millimeters.

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FACTS

Sales:	0,1 M€
ESA Share:	0 M€

Joanneum Research Forschungsgesellschaft mbH

DIGITAL – Institute for Digital Technologies

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

- Satellite communications and navigation
- Microwave propagation and radar technology
- 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 technology development partner in projects funded by the European Space Agency ESA, the European Union, space industry, research establishments as well as foreign space agencies such as NASA, ASI and DLR. The capability of cooperative technology development covers prototype development as well as commercial products. Successful examples are a monitoring service for forest damage, a satellite channel emulator and satellite signal monitor, as well as vision-based navigation and 3D reconstruction operations for space probes operating on planetary surfaces. Successfully developed systems are validated and further optimised in field trials and have a clear scientific or commercial perspective.

Communications & Navigation Technologies

IOT terminal for Q/V band operated over Alphasat

In this project we implemented a satellite network consisting of small and cost effective terminals as remote sensors that integrate beacon power measurements and backhauling of the measured data, as well as the Q/V band earth station on the Hilmwarte tower in Graz, which acts as hub station of the network. The Q/V-band payload of Alphasat is used as source of the beacon, and as transponder for the sensor data communication service.

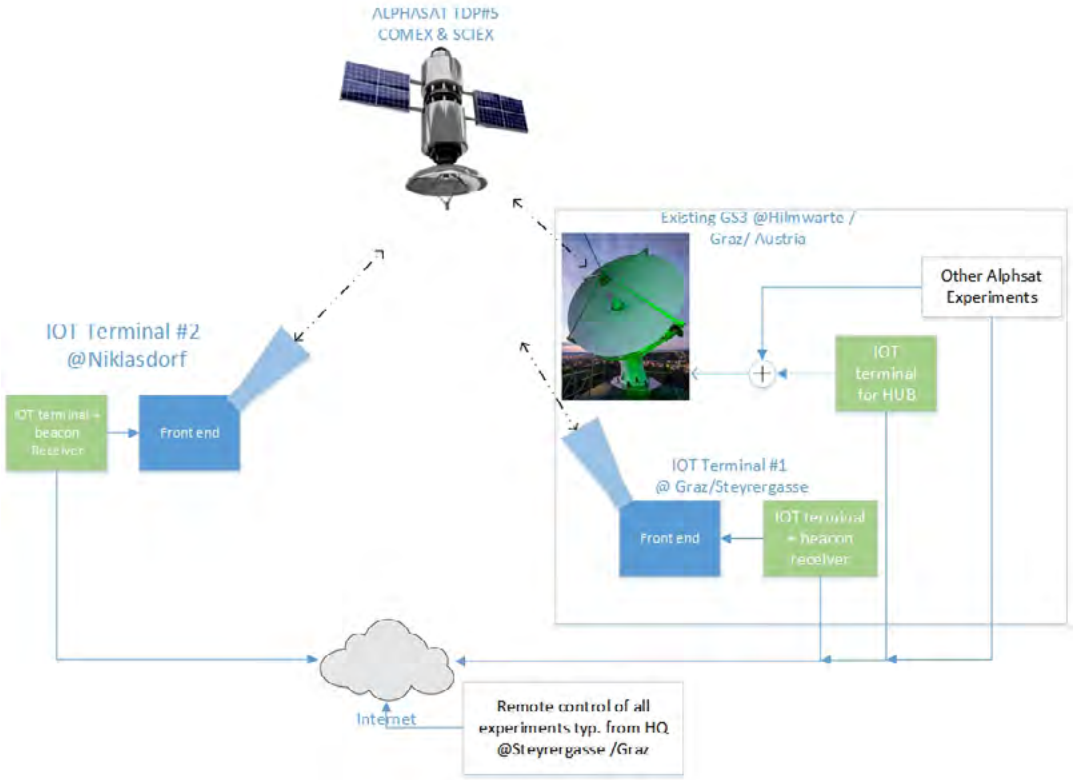
We are aware that a sensor data communication service would normally not be implemented on Q/V-band, since

this band is more dedicated to feeder links. Nevertheless, this approach is also feasible on Ka-Band, where it would lead to a cost effective and scalable solution for an IoT-type of network.

The basic approach for the IoT service is to use an antenna with low gain at the sensor terminal. The advantage of a low gain antenna is that the terminal is small, cheap and there is no or at least not an accurate pointing and tracking necessary. On the other hand, we have to consider an accordingly weak link budget as well as harsh off-axis emission limits.

For the current activity we use a horn antenna with 25 dB gain for several reasons:

- The Alphasat Q/V-band transponder is designed for large earth stations in the 60 dB-gain class. Therefore, the achievable SNR is significantly lower than with Ka-band transponders. The 25 dB horn compensates the difference.
- In order to enable sufficient dynamic range and measurement accuracy for the beacon measurements 25 dB antenna gain was necessary.



Overall architecture of the IOT terminals, IOT Hub and Alphasat

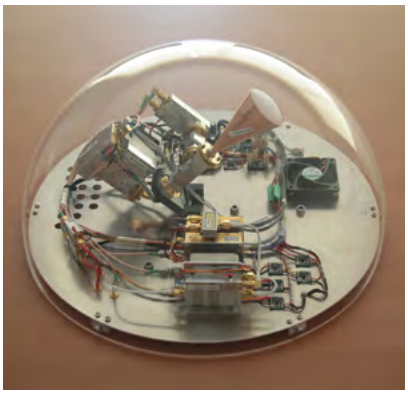
The project consists of two IOT terminals and one hub for the IOT network. The hub has the same baseband hardware as the terminals but uses the existing 3 m antenna and front end from the Hilmwarte station in Graz.

One IOT terminal is located directly at our office building at Steyrergasse / Graz which helped with the debugging of the system. The second station was placed at the facilities of JOANNEUM RESEARCH in Niklasdorf about 50 km north of the Hilmwarte station.

All stations have remote internet access for control and monitoring and will typically be operated from our offices at Steyrergasse 17 in Graz.

Outdoor unit with white radom

Indoor unit under table



Outdoor unit with transparent radom, for testing only.

The IOT network has a forward performance of 112 bit/s from the hub station to the IOT terminal and each IOT terminal can send on the return channel 112 bit/s back to the hub station. In both directions, the BPSK signal is spread with a factor of 512. This data rate allows 4 beacon values per second to be transmitted with a resolution of 14 bits. The system is under long-term stability test and showed already a very robust behavior to recover from heavy rain fading events. The collected beacon data will be used for our Q/V band channel modeling to improve fade mitigation techniques like site diversity and adaptive coding and modulation.

Research Project ESRIUM

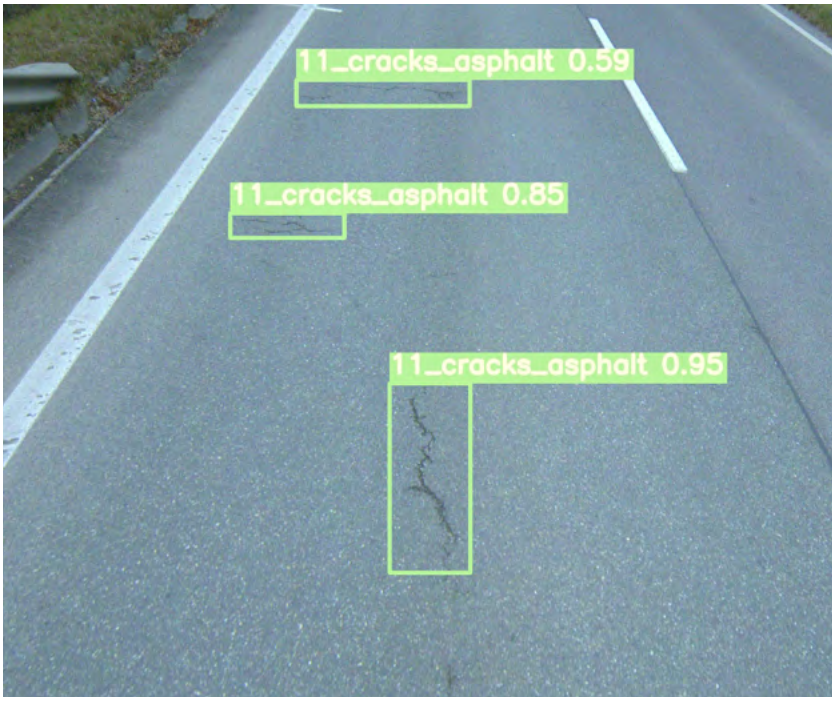
Road wear is ubiquitous and a major cost factor in infrastructure maintenance. Detailed, early detection and mapping of road wear can make these costs more manageable and at the same time extend the service life of road surfaces by advising drivers and autonomous vehicles about driving courses optimized for the current state of the road.

The key innovation of ESRIUM (EGNSS-enabled Smart Road Infrastructure Usage and Maintenance for increased energy efficiency and safety on European road networks) is formed by a homogeneous, accurate, and recent digital map of road surface damage and road wear. This "road wear map", contains unique information, which is important for lowering the road maintenance effort through optimal planning.

For the primary use case (artificial intelligence-based road damage prediction for road maintenance), a time series of road wear information is acquired and used to create a prediction of severity for each identified damage. This information is aggregated and forwarded to the road maintenance departments optimally managing repair efforts. In order to have this up-to-date information on the road condition, a cost-efficient sensor setup was designed and developed so that it can be mounted on numerous maintenance vehicles of road operators. The sensor setup consists of a cost-efficient GNSS/IMU system with Galileo, and two cameras.

The collected data of the sensor system is further post-processed to achieve highly accurate position and attitude information using the benefits of Galileo E1 and E5 signals. A boresight-calibration was performed to achieve the relative orientation of the stereo camera setup with respect to the IMU. Applying the calibration parameters, detected road wear in the image data can be georeferenced. Finally, the detected road wear is visualized in a geospatial information system with underlying map data categorized into predefined damage classes.

Road wear sensor vehicle including sensor setup



Detected cracks in the asphalt with confidence values.

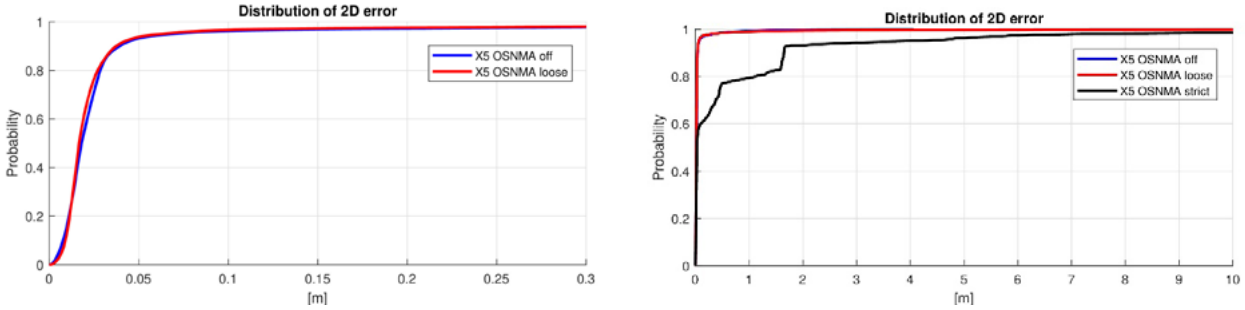
Further, road operators can use this information to lower road wear and increase traffic safety, especially for heavy vehicles. Therefore, accurate routing recommendations are exchanged with vehicles utilizing existing C-ITS (cooperative intelligent transportation system) infrastructure, which can be visualized in navigation systems to bypass road damages. A prerequisite is the availability of accurate localization information in the vehicles. Therefore, the achievable GNSS accuracy using latest mass-market GNSS chips (Septentrio Mosaic X5 and uBlox F9P) were investigated under diverse reception conditions (urban, suburban, rural, highway) with the partners Virtual Vehicle Research GmbH, Finnish Geospatial Research Institute and JOANNEUM RESEARCH, who analyzed the positioning performance using RTK (Real-Time Kinematic) data from the Austrian GNSS correction service provider EPOSA. ASFINAG provided the C-ITS infrastructure along the A2 highway providing RTK correction data from EPOSA as well as providing the routing recommendations.

The performance of the Galileo OSNMA (Open Service Navigation Message Authentication) feature was also investigated. The idea behind Galileo OSNMA is to enable a protection against spoofing. This service will very likely be an important security feature for satellite-based localization systems for safety critical applications in the near future. For performance analysis of the overall system including the Galileo OSNMA service, three Septentrio Mosaic X5 receivers with different configurations were connected to the same antenna mounted on the test vehicle. The first receiver was configured to use all GPS + Galileo L1/E1/L5/E5 satellite signals (called OSNMA off), the second receiver used all GPS signals but only Galileo signals from Galileo satellites with authenticated navigation messages (called OSNMA loose), and the third receiver was configured to use only Galileo satellites with the authenticated navigation messages (called OSNMA strict).

The presented results are from a test drive covering urban, suburban, rural and highway conditions with a total driving duration of 1.8 hours. The figures show the cumulative distribution function of the 2D localization errors of the three RTK solutions calculated from the Septentrio Mosaic X5 receivers receiving EPOSA data via 4G mobile internet. One can clearly see that the OSNMA strict solution suffered from a reduced satellite count since the service is currently only supported by a limited number of Galileo satellites and hence the performance was limited as expected. On the other hand, the performance of the other two solutions was very good for a mass-market receiver. According to the data analysis 97.66% of the localization solutions are found to be below 20 cm accuracy for this particular test run.

This project has received funding from the European Union Agency for the Space Programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004181. Details of the project can be found under esrium.eu.

This project was supported by the Austrian RTK service provider EPOSA (www.eposa.at) providing their service free of charge.



Cumulative Distribution Function of 2D errors

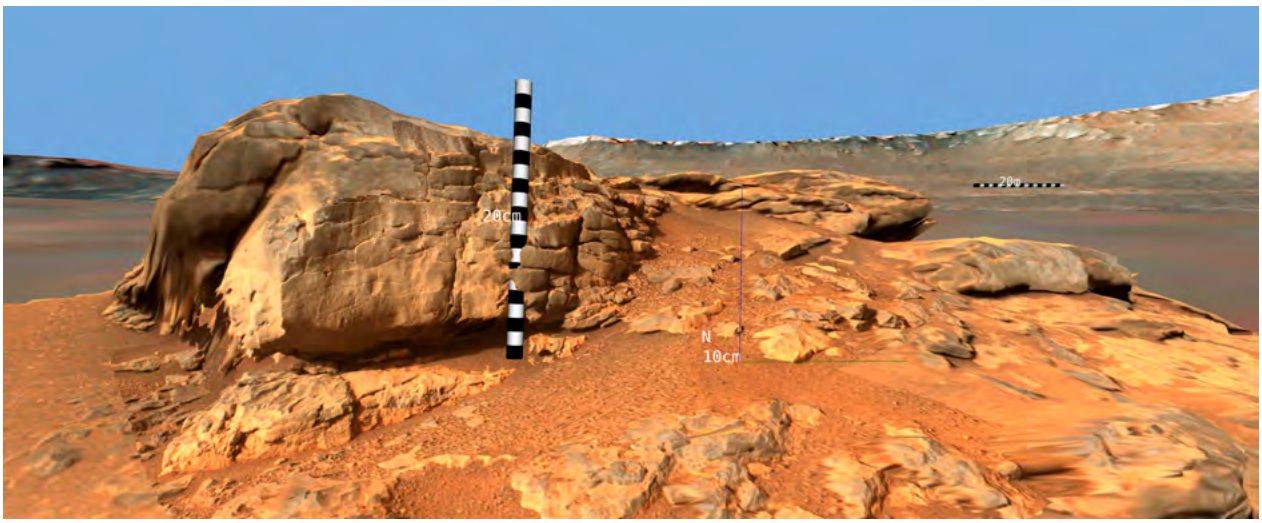
Space Robotics Vision / Space Science & Exploration

Mars 2020 Mastcam-Z 3D Vision

The NASA Mars 2020 Perseverance Rover mission landed on Mars on 18th February 2021 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), with Austrian collaborators from VRVis (Dr. Christoph Traxler and Team), the Austrian Academy of Sciences (Prof. Christian Koeberl and Team), and two collaborators from Imperial College London (Prof. Sanjeev Gupta).

Mastcam-Z 3D Vision, in the frame of an ESA PRODEX contract in 2022 continued to cover 3D vision building blocks (3D vision processing PRoViP and visualization – PRo3D), assembling 3D models, data fusion products and visualizations from Mastcam-Z stereo pairs in various scales (Figure) for further interpretation of the Martian geology, climate, impact structures and soil during the mission in the operational time frame.

The Austrian team is embedded in daily operations and contributes to the regular publication waves of the mission with a few dozens of publication contributions so far, emphasizing on impact science, aeolian and geologic analysis, as well as provision of outreach data products.



3D reconstruction from Mastcam-Z camera stereo images of the Boston Knob Formation taken on Mars Days ("Sol") 458 and 459 of the Perseverance Mars Rover Mission. The incorporated scaling information is important for interpreting grain sizes and layer thicknesses, for example, to identify rocks with traces of possible former life on Mars. In the background, the remains of a former river delta. The 3D model of the rock is surrounded by a 3D model of the Martian surface created from satellite imagery to replicate the situation on Mars as closely as possible. Credits: NASA/JPL/CalTech/MSSS/ASU/USGS/JR/VRVis/ÖAW/ICL

ExoMars PanCam 3D Vision

The joint ESA/Roscosmos ExoMars Rover Mission is scheduled for launch in 2028 and landing on the Red Planet in 2030 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.

JOANNEUM RESEARCH Geometric PanCam Emulator (GEPE) placed on its tripod in the environment of the ARCHES 2022 field trials at Mount Etna (Sicily). Credits: ESA/DLR/JR

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 2022, the main processing components as provided by the PanCam 3D Vision Team under JOANNEUM RESEARCH coordination (ASAP-15 Contract) were finalized and embedded in the Rover Operations Control Center (ROCC) at ALTEC in Turin / I. The processing tools were used in ExoMars design simulations taking place at Turin, and thorough testing of interfaces and science operations took place in the frame of the ARCHES Field trials organized by the German Aerospace Center (DLR) in June 2022 at Mount Etna (Figure). Particular emphasis is given to visualization for geological interpretation (PRo3D tool), which is under further development by the Austrian research entity VRVis.

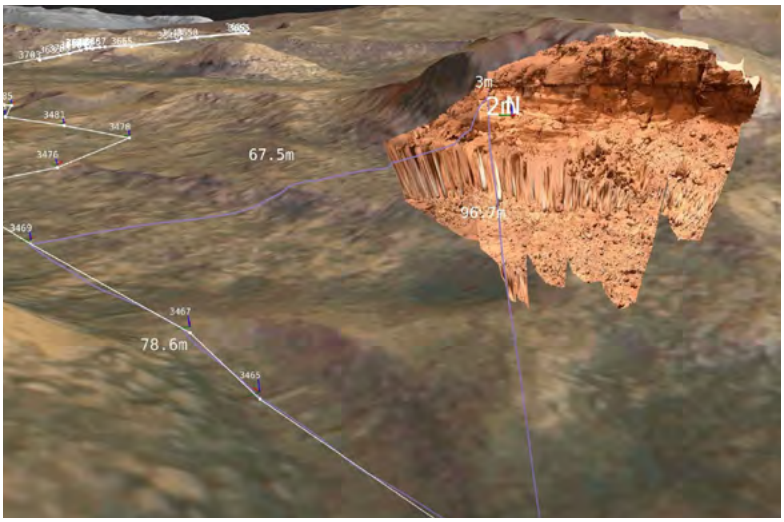
ExoMars NavCam/LocCam 3D vision processing

The ExoMars-2028 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 under ALTEC contract provided 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 compatible 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. Throughout 2022, the vision sensors on the ExoMars Ground Test Model (GTM) were started to be geometrically calibrated by JOANNEUM RESEARCH, in preparation for following end-to-end testing in the environment of the Mars Terrain Simulator in the ROCC in Turin.

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 "long baseline stereo" (LBS) 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, in cooperation between JOANNEUM RESEARCH, VRVis, SLR Engineering and ALTEC (Turin), dealt 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. Long Baseline stereo processing and visualization functions were implemented and tested and applied to specific cases within the Mars 2020 and MSL missions (Figure). Long baseline stereo processing for ExoMars 2028 was successfully implemented and tested.

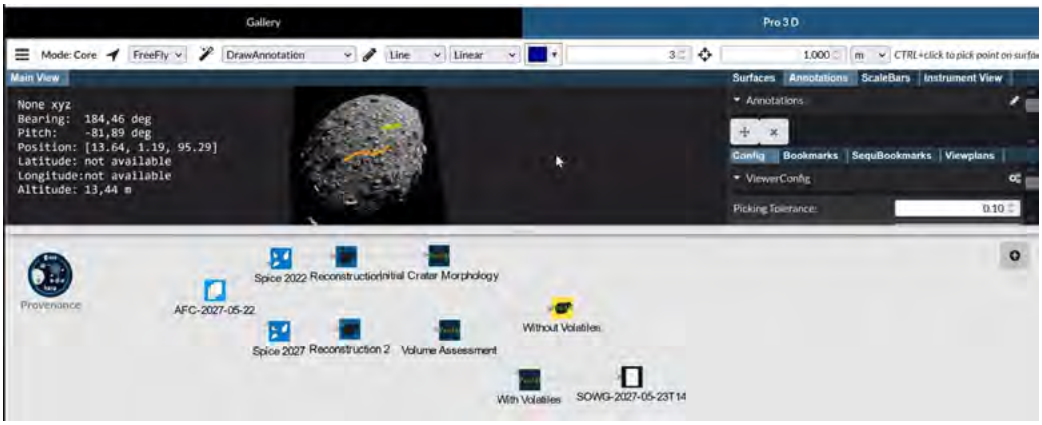


Long baseline stereo and 3D reconstruction along the route of the MSL Rover Curiosity (overlaid on the satellite elevation model). Credits: NASA/JPL/CalTech/ASU/MSSS/JR/VRVis

PROVEX: Provenance

In space and planetary science, collaboration between different instrument teams is essential but insufficiently supported by most analysis tools used. Heterogeneous data from various sources are usually exchanged in different formats and very frequently, information about data provenance is lost or not documented at all. This concerns the origin of raw data and its uncertainty at the beginning of the workflow. Further, it also includes all products derived from it such as interpretations and analyses, i.e., who carried them out, how, and for what purpose. The PROVEX project (Full Provenance Planetary Science Exploration Workflows) aims to extend the PRo3D visualization tool (https://github.com/pro3d-space/PRo3D) to support automatic provenance tracking of its provided features as well as means to manually extend provenance information.

An extension of PRo3D envisioned in PROVEX visualizes the lineage of products, how they were created or derived and by whom, in an intuitive way. The resulting provenance graph (Figure) is an interactive visualization that allows users to efficiently access products, open them with the appropriate viewer, investigate how and why they were accomplished and contact their authors. Furthermore, the provenance graph is a representation of the workflow leading to a product, which users can query, visualize, and manipulate via Graphical User Interfaces (GUI) or notebook-style interfaces integrated with PRo3D. In 2022, the main building blocks for PROVEX in terms of data preparation, provenance tracking and embedding into PRo3D were designed, emphasizing the vision instruments on board of ESA's Hera Asteroid mission.



PROVEX screenshot of combined 3D visualization (top, using the PRo3D Planetary Robotics 3D Viewer) and provenance graph (bottom). The data workflow is reflected in the graph showing dependencies and forks of different versions. Annotations made in the PRo3D tool can be followed in higher granularity, allowing to track different analysis paths and therewith support scientific hypotheses in a traceable and repeatable manner.

Outlook for 2023–2025

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 2024 in the frame of a joint ASAP contract. In that activity, also the bridging and testing phase for ExoMars PanCam as well as regular processing for the Mastcam instrument on board the MSL Rover Curiosity will be lightly supported. Scientific processing and visualization / 3D GIS contributions for the Hera 3D vision framework will be defined and implemented as prototype versions. PROVEX will be finalized with use cases representative for the Hera scientific requirements. Within the temporarily suspended DIARY field trials archiving activity, the implementation and testing phase will use trials data from final activities of Sample Fetching Rover (SFR) development.

The TNS research group pursues consistent further development both in technological excellence as well as in application relevance and the commercialisation of the results. The focus is in the field of developments in satellite communications technology, such as the use of transmission frequencies in the Q/ V and W bands and the integration of 5G and 6G technology. In the field of satellite navigation, applications in the automotive sector and the security of GNSS reception are worth mentioning.

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FACTS

Sales:	2,8 M€
ESA Share:	0,9 M€

Magna Steyr Fahrzeugtechnik GmbH & Co KG

Division Aerospace

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

As was for 2021, our cooperation with The Boeing Company for the manufacturing of propulsion components for NASA's Space Launch System (SLS) remained on the same trajectory set last year, with – again – additional contracts for new flight hardware awarded to Magna Aerospace during Q3.

NASA wrote history again, when on November 16, 2022, the world's most powerful heavy-lift rocket finally lifted off from the Kennedy Space Center. The third launch attempt in 2 months marked the beginning of the Artemis 1 SLS mission. The splash down of the Orion spacecraft in the Pacific Ocean on December 11, 2022, was not only the successful conclusion of this first episode but represented the preamble of the return of human presence on the Moon and certainly a moral booster to NASA, participating primes, and the entire supplier community.

NASA's Space Launch System rocket carrying the Orion spacecraft launches on the Artemis I flight test at NASA's Kennedy Space Center

We at Magna are extremely proud to be part of this exciting journey initiated as early as in 2015. We have been entrusted by our client with build-to-spec and build-to-print work packages for the Core Stage (pressurization lines including compensators) and Exploration Upper Stage (semi-rigid lines and other welded assemblies for fluid conveyance).

During 2022, we manufactured and delivered assemblies for the core stage only. We currently produce flight hardware for mission # 5 and 6.

AVIO Vega Evolution – Engine and LPM lines & compensators

Magna is responsible for the M10 engine lines and upper stage propellant lines, also referred to as the Liquid Propellant Module (LPM). The scope of responsibility also encompasses all compensator designs as well.

Progress during 2022 for the M10 engine lines was aligned to AVIO's agenda. This mostly build-to-print package (Magna still contributes to this program with design activities) saw the delivery of the second shipset of engine line prototypes (DM2) towards the end of the year, the successful M10 engine fire testing with the first line prototype shipset installed (DM1; delivered last year), and the early-stage activities re. the third shipset of prototype engine lines (DM3) initiated during Q4.

M10 DM1 Engine Test at Avio in Sardegna

On the LPM line side, a full build-to-spec package, highlights during 2022 included the review of the exhaustive material trade-off analysis submitted to AVIO (aluminum vs. conventional steel solutions) and our initial proposal for the pipework routing. Ultimately, AVIO favored a conventional steel pipework design for the LPM lines and compensators instead of the one proposed by Magna that was based on a disruptive and newly patented low-weight aluminum/steel hybrid solution.

Shortly afterwards, the preliminary design phase for the LPM lines was initiated. The focus was on the development of breadboard models (so-called universal joint). These proceedings were completed after a successful breadboard model design review in October. The next step will see these prototypes being manufactured and tested during 2023, with a Preliminary Design Review set to occur in Q4.2023.

All in all, design activities for the Vega E LPM propellant lines and compensators were in line with the development timeline set by AVIO for the year.

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OHB Digital Solutions GmbH

Field of Work

The major activities of OHB Digital Solutions GmbH comprise the field of GNSS quality assurance and GNSS signal simulation, in particular precise positioning, reliable navigation, and applications in the satellite downstream market. We are specialists in 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 our team members, we develop solutions, services, and applications according to customer and market needs.

OHB Digital Solutions GmbH Headquarters located at Kärntner Straße 7b/1, 8020 Graz

Field of Expertise

Topics of work include technical consultancy, system design, and analysis, 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 and is active in all relevant fields of technology. Universities, research centers, industry, and small and medium-sized enterprises work tightly with OHB Digital Solutions. The company is a reliable and experienced partner of EU organizations related to the space industry such as ESA, EUSPA, and Horizon Europe.

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 timeservers
- Defense sector

Project Highlights in 2022

GIDAS: Jamming and Spoofing Detection

OHB Digital Solutions researches and develops in the field of GNSS for more than two decades. In all of our activities since, a deep understanding of the GNSS signal design, its strengths but also weaknesses has been an integral part of what we do. One of the main focuses is and has always been the monitoring of the quality of the GNSS signals and services. Early on, we conducted field measurement campaigns to observe and analyze the received GNSS signals and evaluate their quality and possible disturbance by surrounding factors. Analyzing the recorded data revealed that aside from natural interference, such as e.g., multipath, also intentional interference, such as signals from jammers appears on a frequent basis.

GNSS signal interference is not only a theoretical or military threat

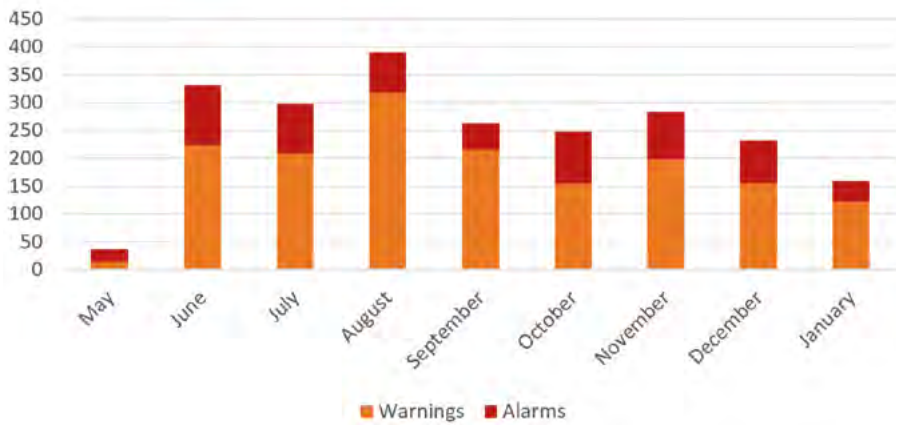
A measurement campaign alongside the A9 motorway in Styria, Austria back in 2014 showed a first correlation of interference signals in the GNSS frequency band with bypassing trucks. These worrisome results lead to the development of permanent monitoring solutions – especially for safety-critical infrastructure - which are the basis of today's GNSS quality assurance solutions of OHB: GIDAS. Its technology performs robust, real-time interference detection and alerting.

GIDAS: monitoring center and monitoring sensors

GNSS interference occurs on a daily basis – especially along motorways

Since May 2022 we operate a permanent GIDAS installation at a European airport, together with the local air navigation service provider. The goal of the commonly operated GNSS quality assurance system is to gather data-based evidence for future decision-making and strategy definition on how to handle GNSS interference, inflicting air traffic surrounding the airport premises. The GIDAS installation recording the presented data is composed of three distinct monitoring sensors, placed at strategic positions on the airport premises. The monitoring sensors cover both approach directions on the north and south end of the runway and host one additional monitoring sensor at the airport tower.

The first eight months of operation show, that especially along motorways and construction sites, the quantity of interference signals in the restricted GNSS bands is even higher than expected. Between the 17th of May 2022 and the 18th of January 2023 (246 days of operation), the system detected 630 interference events with a severity clas-



Number of warnings/alarms per month (N=2244, May 2022 and January 2023 are not full months)

sified as an alarm (which means that there was an actual degradation of the GNSS measurement quality). During this period an additional number of 1614 interference events with a severity classified as a warning has been captured. More than 80% of the recorded interference events, both warning, and alarm have a duration of 30 seconds or less, which is expected for bypassing vehicles. On the other hand, more than 450 events had a duration of more than 30 seconds. And at least two recorded events, classified as alarm, have continuously lasted for more than 30 minutes. Analyzing the interference event data with respect to weekdays and time of day shows, that a significant number of interference events correlate with work-related traffic. This supports the thesis of company trucks operating jamming devices inside their truck cabin to shield their position against a fleet management system, with the side effect of jamming GNSS signals in a wider area and even affecting airport systems.

So it is clearly demonstrated, that GNSS signal interference is more than a theoretical threat on a daily basis. Especially for safety-critical applications and infrastructure, close monitoring of the GNSS signals' health and quality is crucial! In the case of an airport being monitored, the air traffic management (ATM) can directly be interfaced with custom alert interfaces (software-based or hardware-based). With GIDAS, air traffic controllers have a live view at the on-site health and quality of GNSS, before navigation systems are negatively affected by GNSS interference.

Our recommendation is: The first vital step for GNSS-dependent applications is to be aware in real-time as soon as the GNSS performance is not nominal. By learning from recorded interference event data over time, a solid mitigation strategy can be designed to improve the robustness of safety-critical applications and systems!

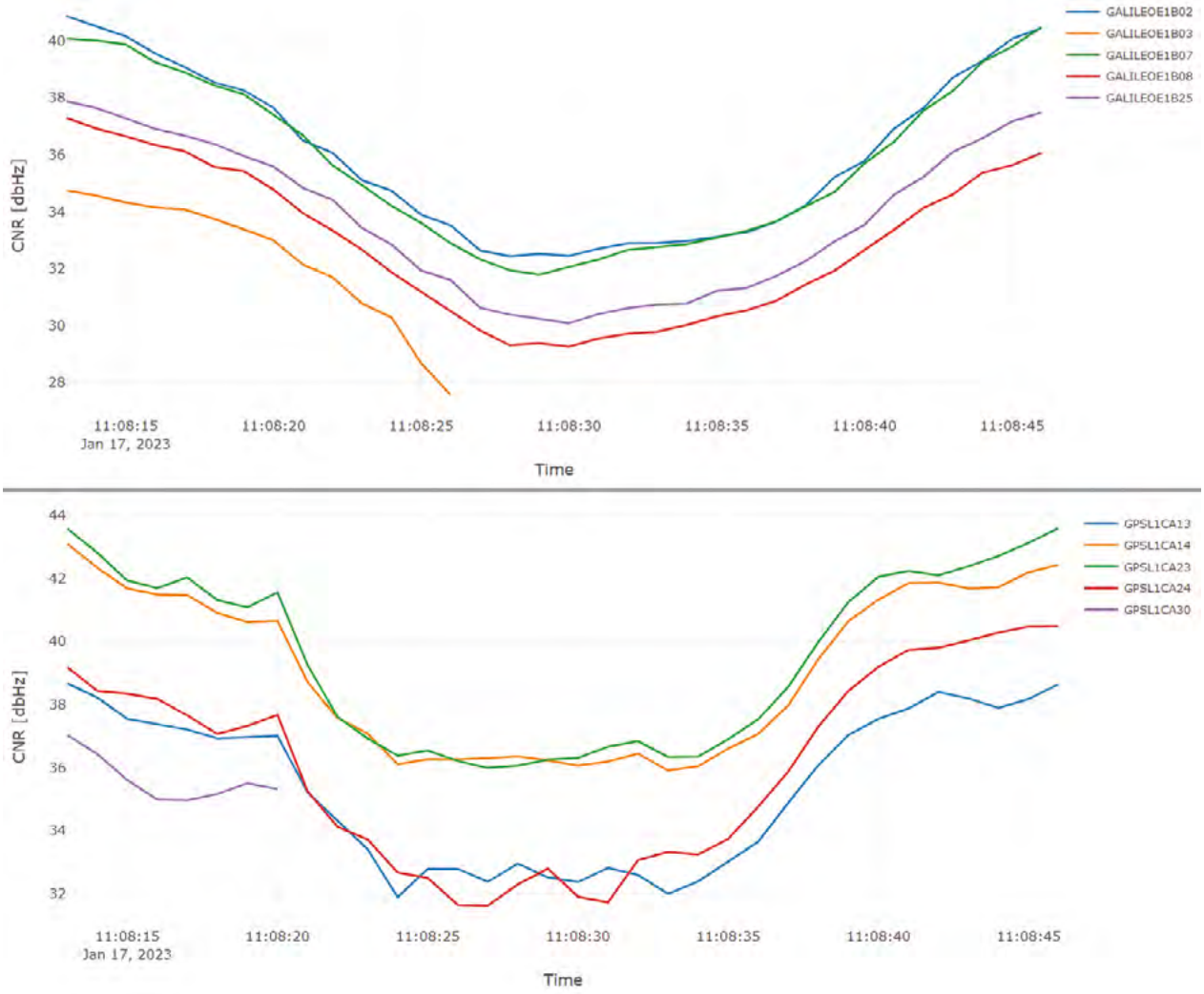
Tackle the issues by post processing analyses

Since GIDAS automatically captures and stores raw baseband signal snapshots for every interference event, it is even possible to gather more detailed insights on the jamming signals by post processing analyses.

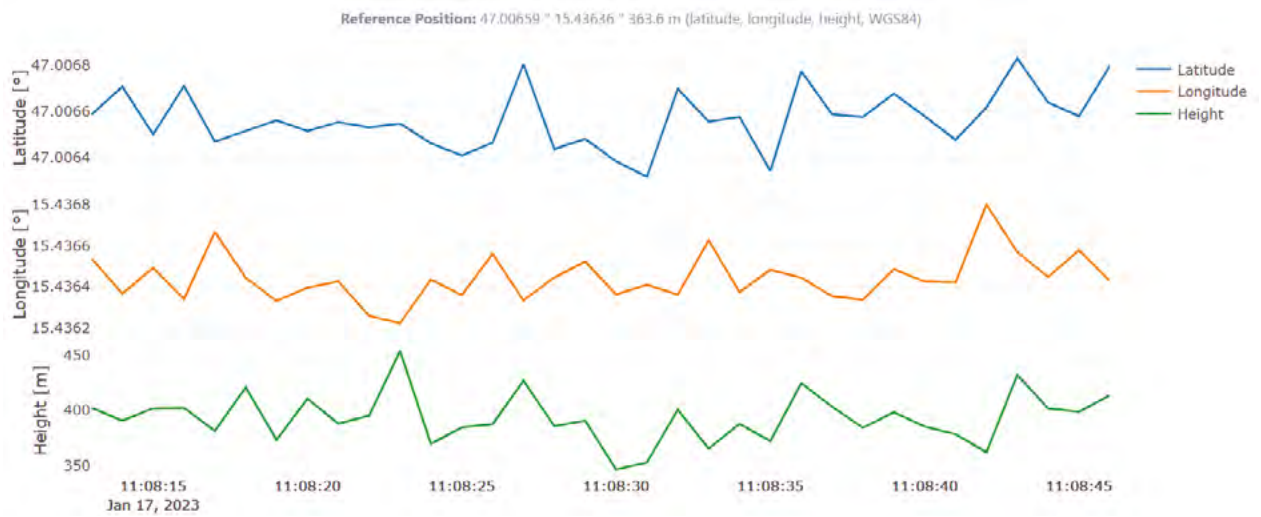
As an example of a typically recorded interference, a swept continuous wave (SCW) jammer is displayed. The recorded SCW jammer leads to a significant drop in the measured carrier-to-noise ratio (CNR) of the tracked GPS and Galileo satellite signals.

Even though the GNSS measurement quality is degraded significantly during the presence of a jamming signal, a typical GNSS receiver is still outputting a position solution, without any warning. This can lead to misleading PNT information without recognition of the jamming.

Commercial off-the-shelf (COTS) GNSS receivers are typically designed to output a PNT solution to the extent possible, even during the presence of interference signals. Thus, it is very important to monitor the quality of GNSS with an independent system, designed to have quality monitoring as its first priority.



CNR of the tracked satellite signals



PNT solution as an output of a COTS GNSS receiver

GIDAS development, outlook, and go-to approach

The go-to approach of GIDAS is to continuously monitor the GNSS signals and services. GIDAS supports all civilian GNSS constellations (GPS, Galileo, GLONASS, Beidou, QZSS) and all civilian GNSS signals. Based on 24/7 monitoring, GIDAS processes the digitized GNSS signals and performs a multitude of combined detection techniques to robustly and reliably detect interference signals. vThe jamming detection model combines detection techniques with individual strengths in different scenarios and different jammer types. Depending on specific combinations of the detection techniques indicating the presence of interference, the system either raises a warning or an alarm. This approach covers a wide range of different jammer types and minimizes the probability of false alarms.

For spoofing detection, the GIDAS system uses another set of carefully selected techniques. For the combined approach, the same mechanism applies as for the jamming detection model. Depending on specific combinations of the detection techniques indicating the presence of interference, the system either raises a warning or an alarm. After the detection, GIDAS performs additional steps and classifies the interference signal type as well as localizes the signal source.

The classification of jamming signals distinguishes between amplitude modulated (AM), frequency modulated (FM), continuous wave (CW), swept continuous wave (SCW) and pulsed jammer types. A GIDAS installation typically includes three or more monitoring sensors (MS), depending on the size of the area that needs to be monitored. Each monitoring sensor is built up by a distinct dual-module GNSS antenna combined with a local signal processing unit. Multiple monitoring sensors distributed over the to-be-monitored area can localize the interference signal source by triangulation.

The next step after detection, classification, and localization is the automatic alerting to an operator or higher-level system which is available within GIDAS via a customizable, automatic alerting interface. The typical time-to-alert (TTA) of the GIDAS system is well below six seconds. For troubleshooting, evaluation of countermeasures, and long-term mitigation measures, the GIDAS system automatically records snapshots of the raw baseband signal as well as all intermediate detector results and jamming or spoofing alarm levels.

OHB's GNSS interference detection and analysis system is a turn-key solution for safety-critical infrastructure, to automatically monitor the GNSS signals and services in real-time.

GIDAS Portable

Since 2022 GIDAS is also available as a portable version. All features of GIDAS are integrated into a ruggedized form factor, designed for fully autonomous use. In addition to the autonomous operation mode, GIDAS portable can also be connected to a stationary GIDAS installation as an easily relocatable monitoring sensor.

XPLORA: GNSS Signal Simulation

Simulators are playing an increasingly important role in research and product development. Of course, this also applies in the GNSS simulation area. GNSS equipment development requires testing under controlled conditions. Engineers, scientists, manufacturers, and system integrators involved in GNSS development must be able to control test conditions, repeat tests precisely, simulate new satellite constellations and signals in advance (before the systems and signals are even available), and perform realistic tests in GNSS denied environments (without a line of sight to the satellites).

With XPLORA from OHB Digital Solutions, resources and time can be optimized in the development, qualification, and certification of GNSS equipment and GNSS applications.

XPLORA One – the cost-optimized solution for all GNSS developments

In addition to our allrounder for professional use, we have developed a new generation of XPLORA that offers most of the proven XPLORA features in a cost-optimized variant:

- Simulation of signal disturbances (delays, multipath, etc.)
- Jamming and spoofing simulation
- Numerous software options for flexible adaptation to customer and project requirements
- Highly flexible user-defined scenarios
- Accurate repetition of tests
- All civil GNSS frequency bands (GPS, Galileo, GLONASS, BeiDou, QZSS, SBAS)
- Graphical user interface for flexible interaction

GNSS signal simulation with XPLORA

XPLORA One is even functional for critical infrastructure for internal testing of devices relying on GNSS receivers. Since there is no need for an additional GPU or a specific processor, XPLORA One can be connected to any PC or Laptop. This GNSS simulator is small, lightweight, comfortable, and easy to use and fits anyone who wants to use GNSS an optimized way.

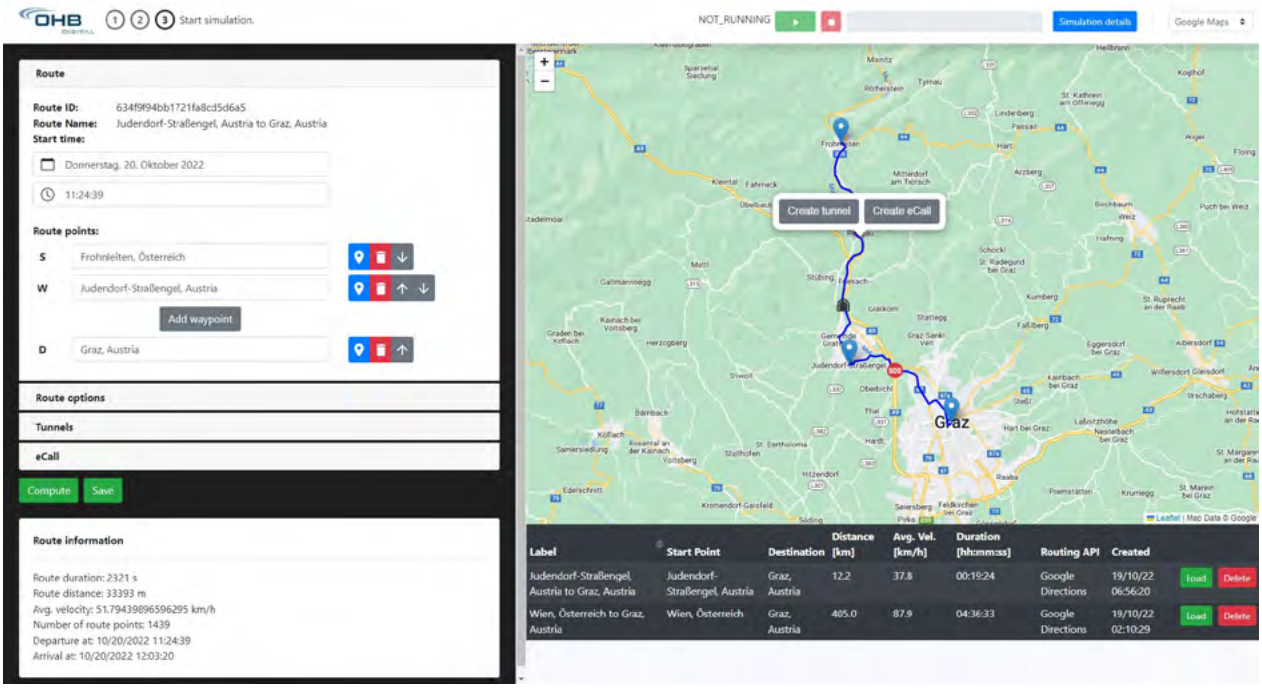
XPLORA Core for developments in the automotive industry

In addition to integrating new hardware into the XPLORA product family, OHB Digital Solutions has expanded XPLORA's software for the automotive sector. The purpose is to test infotainment systems of vehicles regarding navigation and eCall functionality (automatic emergency call module after traffic accidents).

For the navigational purpose, a new route planner functionality creates routes for cars by specifying a start/end point and waypoints in between. The user has the possibility to define simulation routes within a map beforehand and export them to an XPLORA scenario. XPLORA Core generates the radio replication of the GNSS satellite constellation along the simulated route at the time of the simulation.

XPLORA Core is controlled via a web-based route planner software running on external computer where the GNSS simulation is directly altered by the device and steers the simulated receiver in real-time (HIL: hardware in the loop).

With XPLORA system integrators, GNSS equipment manufacturers and users, governmental authorities, and armed forces in a navigation warfare scenario can harden their GNSS-based infrastructure or equipment against interference.



Route planner functionality of XPLORA

Acknowledgment: XPLORA has been developed within the project GSGSE. Both GSGSE and GIDAS were 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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FACTS

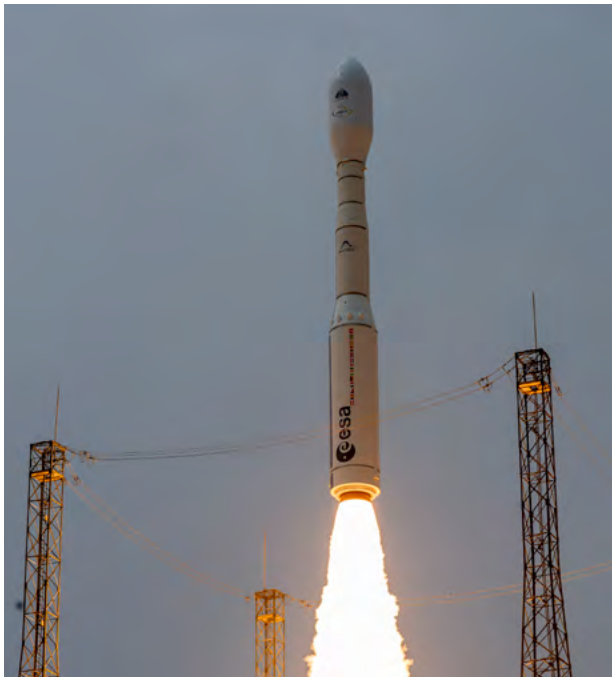
Sales: 1,0 M€
ESA Share: 0,5 M€

Vega-C fully stacked for flight VV21 © ESA–Manuel Pedoussaut

PEAK Technology GmbH

PEAK Technology GmbH has developed its core competence towards the design and manufacturing and serial production of composite overwrapped high-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-C Maiden Flight (©ESA)

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.

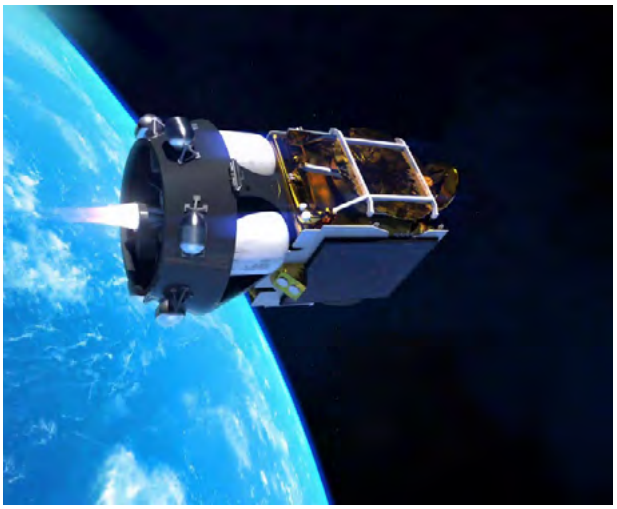
In 2022 finally we saw a successful maiden flight of Vega-C with our aerothermal covers, the igniter cases for the Zefiro9 and Zefiro40 on board.

Igniter Case for Zefiro9

Composite Overwrapped High-Pressure Tank

Vega-E

In 2021 with reached PDR in the development of the helium tanks for the upcoming Vega E launcher. These lightweight high-pressure tanks are going to be responsible for the pressurization in the fuel lines of the newly developed upper stage.



Ariane 6 Astris Kick Stage (©AGG)

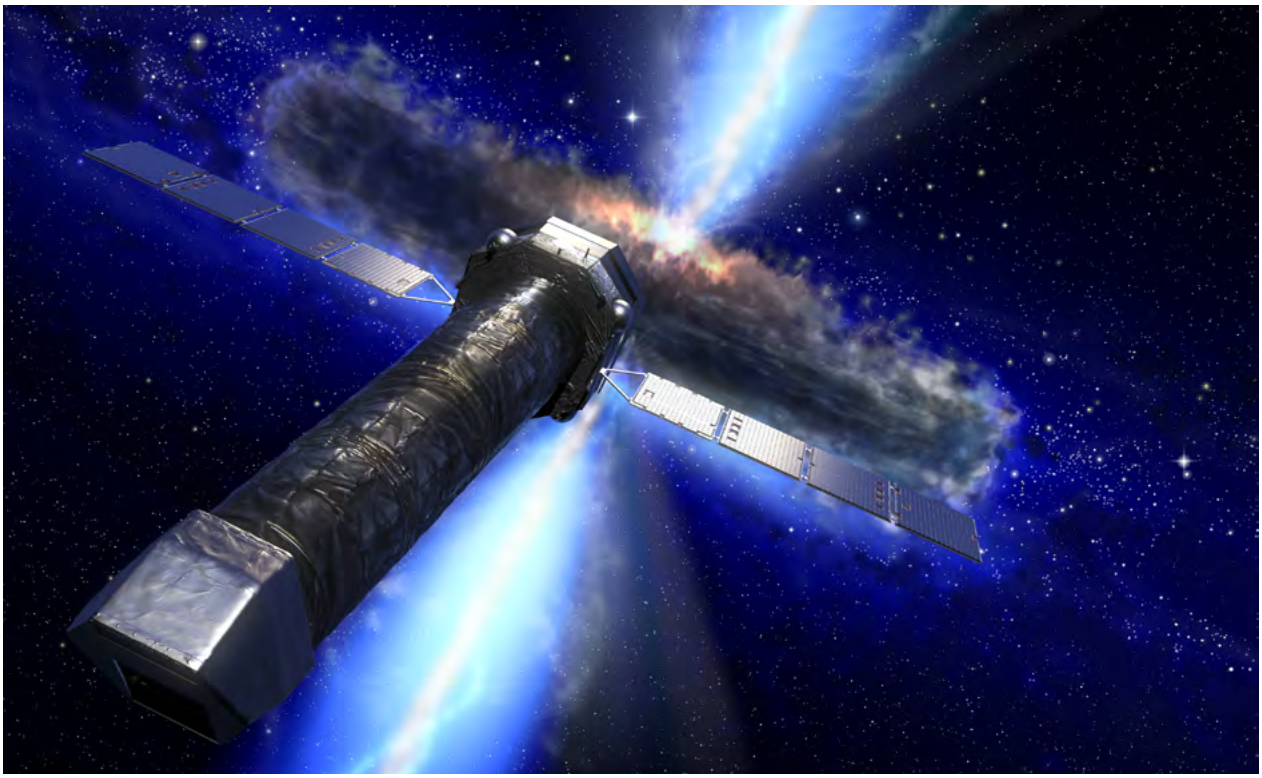
Astris Kick Stage for Ariane6

In 2022 we reached PDR of the Helium high pressure tanks for the new Astris Kick stage from Ariane Group for the development for Ariane6

SWISSto12 HummingSat (©ESA)

HummingSat

In 2022 we signed a contract with OHB Sweden for the development of a Xenon high pressure gas tank for the electric propulsion system of HummingSat for SWISSto12. Next step is reaching PDR in 2023.



Athena X-ray Telescope (©ESA)

Athena X-ray Telescope

In 2022 we signed a contract with ESA for the development and manufacture for a composite structure demonstrator for the planned Athena X-ray telescope. Next step is reaching PDR in 2023.

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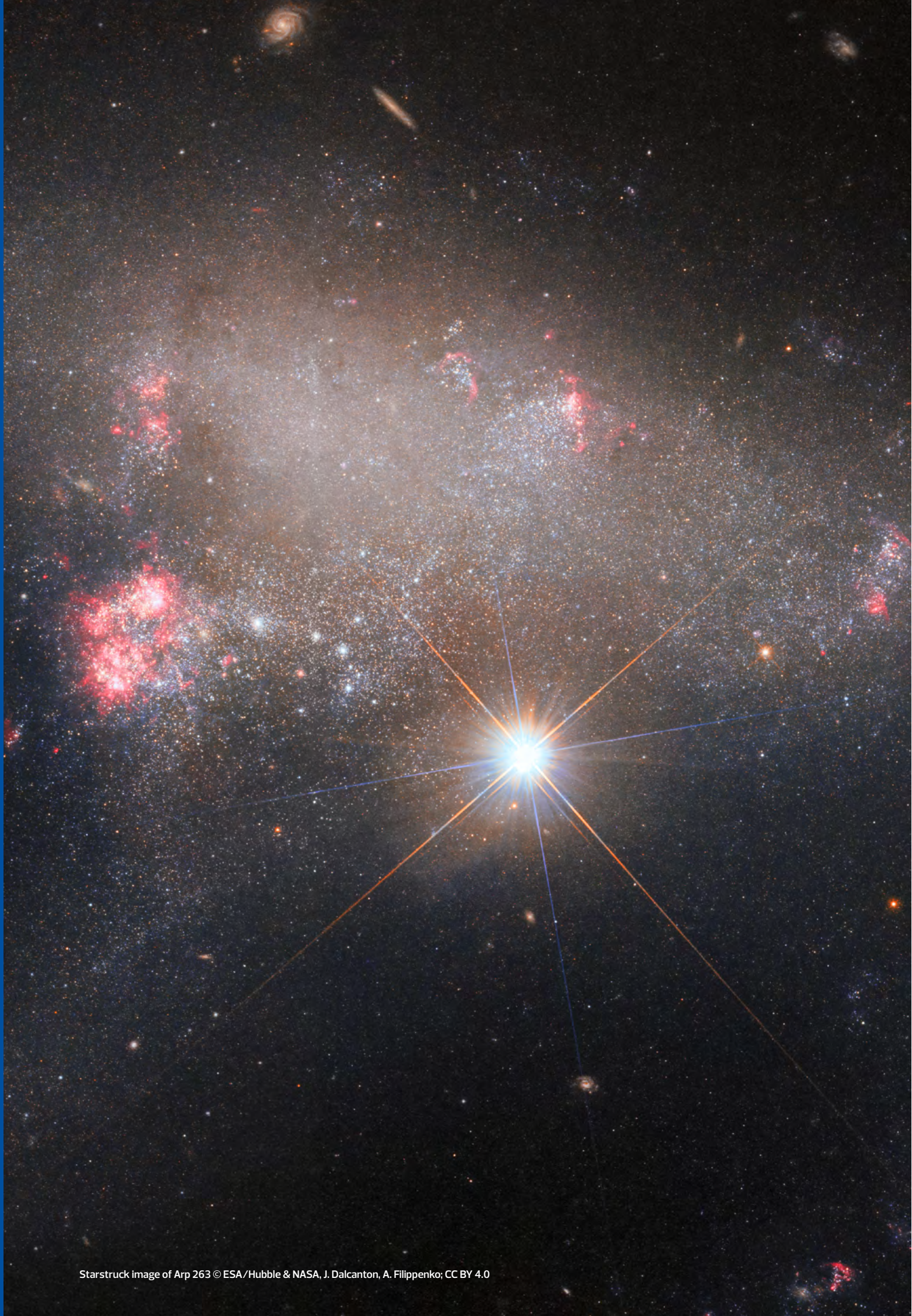
FACTS

Sales:	17 M€
ESA Share:	1.5 M€
Commercial Space:	7.5 M€



Starstruck image of Arp 263 © ESA/Hubble & NASA, J. Dalcanton, A. Filippenko; CC BY 4.0

Seibersdorf Labor GmbH

Seibersdorf Laboratories

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 2022. 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 dosimetry services for aerospace
- 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 2022:

- **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
- **SEELAS** Exploration of Single Event Effect Radiation Testing of COTS Components with Laser and Heavy Ions

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 2022 its 7th edition of the annual RADHARD Symposium. The 2022 edition of the RADHARD Symposium focused on:

- Radiation Testing Facilities
- Current Inventive SmallSat Projects
- Radiation Testing and COTS Components

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 refers to the environmental conditions in space as influenced by solar activity. Extreme events (so-called solar storms) have a variety of adverse effects in aviation, e.g., on navigation and communication signals, on electronic systems, and pose an increased radiation hazard for aircraft crew and passengers. For the latter, the main concern are so-called Ground Level Enhancements – a temporarily enhanced radiation levels measured on the ground.

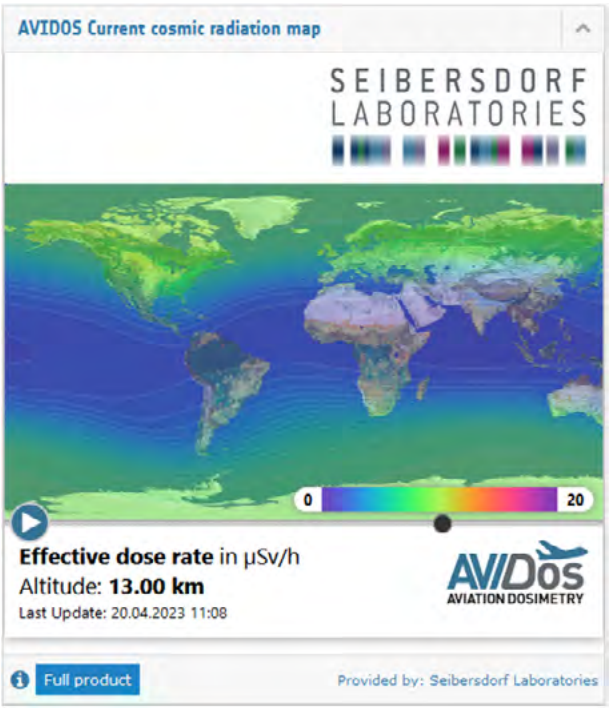
The European Space Agency (ESA) in their Space Safety Programme continues a provision of their Space Weather Service Network of high-quality scientific observations, results and models in the space weather domain that aims at mitigating and preventing the impact of hazards from space. Space weather is in focus also in other international organisations. For aviation sector, the International Civil Aviation Organization (ICAO) formulated their specifications on space weather advisory information.

Methods and Results

Seibersdorf Laboratories has contributed to the ESA's Space Weather Service Network (https://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 2022, we continued provision of AVIDOS 3.0 (https://swe.ssa.esa.int/web/guest/avidos-federated). Next to the AVIDOS 3.0 application, we also continued provision of a world map that present current values of effective dose rate – see Figure below. Every user that is logged-in to the ESA Space Weather Portal can navigate to the aviation dashboard (https://swe.ssa.esa.int/nso_air_dashboard) that provides a quick overview on current impact of space weather on aviation in a graphical form, and see the actual map of radiation doses at aviation altitudes.

Seibersdorf Laboratories contributes to the PECASUS consortium (Partnership of Excellence for Civil Aviation Space Weather User Services). PECASUS (https://pecasus.eu) is a global space weather information service centre for ICAO. PECASUS delivers advisory information on space weather that has the potential to affect communications, navigation and the health of passengers and crew. The advisories are publicly available on a consortium's leader (https://www.ilmailusaa.fi/warnings.html#top=0#id=swx#select-area=4#FMILang=en) website. With AVIDOS, Seibersdorf Laboratories plays a major role in the PECASUS by delivering information on assessed radiation exposure at aviation altitudes in a real-time manner.

Seibersdorf Laboratories contributed also to an FFG-supported project SWAP (Space Weather: An Austrian Platform). The aim of the project is to establish a web platform on which Austrian key-players, stakeholders, and group of interest can find information on space weather tailored to Austrian users. Till the end of 2022, Seibersdorf Laboratories contributed to the state-of-the art review and to the definition phase of the platform.



World map of effective dose rate, E, for conditions on 20. April 2023 from the Aviation Dashboard of the ESA's Space Weather Service Network portal.

Publications

M. Latocha, Flugdosimetrie – Dosimetrie für Flugpersonal, Presentation at 7. Österreichische Strahlenschutzplattform, held in Vienna on 06.12.2022 at the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)

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 Beyond Gravity Austria (former: RUAG) and carried out in collaboration with Seibersdorf Laboratories and Graz University of Technology. The PRETTY CubeSat hosts two scientific payloads: A passive reflectometer, exploiting signals of opportunity for passive bistatic radar measurements and SATDOS-1, Seibersdorf Laboratories' miniaturized reference dosimeter system for nanosatellites. SATDOS-1 will continuously assess the total ionizing dose and single event upsets on-board PRETTY. The launch of the PRETTY 3U CubeSat into a low-Earth sun-synchronous orbit is scheduled for mid-2023.

Objectives

The objectives for SATDOS-1 within PRETTY 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.

SATDOS-1: Seibersdorf Laboratories' nanosatellite dosimeter payload for assessing the radiation environment in space is smaller than 10 cm x 10 cm

Total Ionizing Dose Detection

In regard to total ionizing dose assessment, SATDOS-1 operates two different types of radiation integrating sensors:

1. MOSFET optimized for radiation sensitivity (RADFET) and
2. floating gate dosimeters (FGDOS).

Seibersdorf Laboratories characterized 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 compares shielded and un-shielded conditions to discriminate dose contribution from different radiation particles.

Single Event Effect Assessment

Single event effects (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, SATDOS-1 features a single event upset (SEU) assessment system. The SEU assessment system is 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 provides SATDOS-1, a TID reference dosimeter and SEU assessment system for technology demonstration under non-laboratory conditions, on-board the planned CubeSat mission PRETTY (Passive Reflectometry and Dosimetry). SATDOS-1 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, SATDOS-1 features a SEU assessment system, based on two commercial, but radiation characterized SRAM, realized in collaboration with CERN. SATDOS-1 was successfully approved by ESA. The dosimeter payload was successfully tested against its requirements and integrated into the PRETTY satellite. The launch of the PRETTY satellite is scheduled for mid-2023. After a commissioning phase the dosimeter payload will start collecting scientific data on the space radiation environment.

Publications

C. Tscherne, M. Wind, L. Huber, M. Latocha, A. Coronetti, I. Slipukhin, S. Uznanski, R. Garcia Alia, A. Hörmer, R. Zeif, O. Koudelka, H. Fragner, A. Dielacher, C. Pirat, F. Perez-Lissi, G. Santin, P. Beck, Development of a Miniaturized Reference Dosimeter Payload for SmallSat Applications, Oral Presentation, Radiation Effects on Components and Systems Conference, RADECS 2021, Vienna, Austria, 14. September 2021.

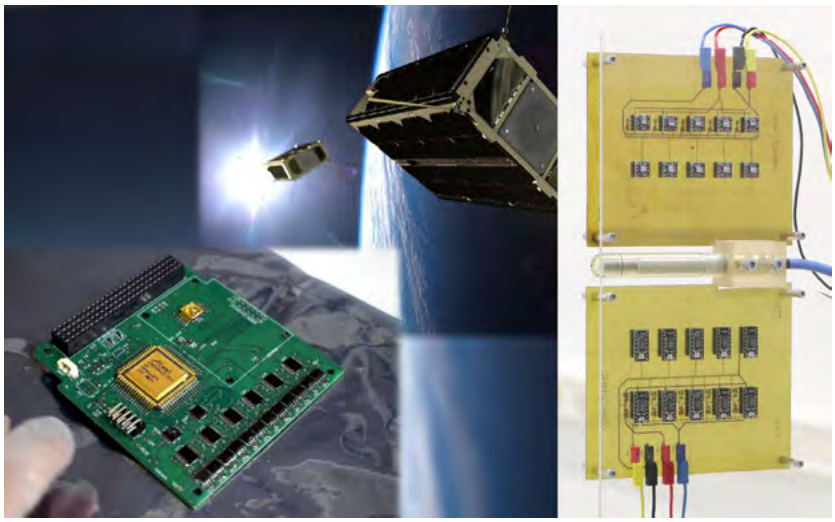
Acknowledgements

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 offer great benefits especially when considering aspects such as high performance, low cost, and rapid availability. However, the use of COTS components requires expert knowledge and comprehensive risk management, especially when considering Radiation Hardness Assurance (RHA) issues. For COTS it is important, that RHA 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. The objectives in detail are:

- To use a comprehensive set of relevant COTs components for the experimental work.
- The gathered data shall serve as a base for the formulation of an ad-hoc RHA approach together with recent scientific and literature data.
- Within the scope of the experimental work exposures are performed in both Co-60 as well as in high energy proton and/or heavy ion radiation fields as defined in ESCC Basic Specifications No. 22900 and ESCC 25100.

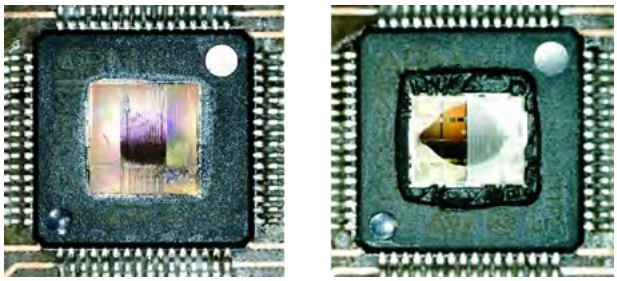
Methods and Results

The strategy for the 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

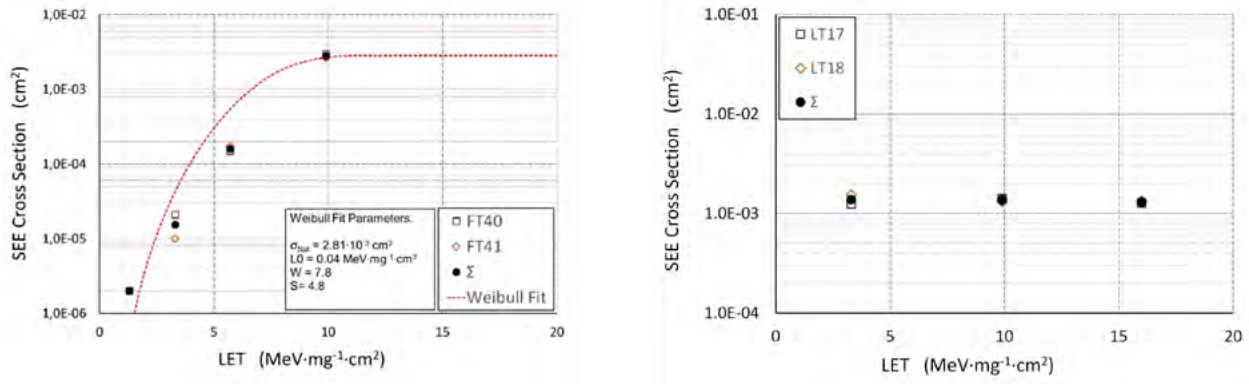
Exemplarily Result: SEE Testing of COTS Microcontroller

Two microcontrollers, namely the STM32F103RGT6 and the STM32L152RET6, are investigated with respect to their SEE susceptibility with heavy ions. The tested devices are supplied in plastic packages. Therefore, it is necessary to open the package before exposure to allow the ions to penetrate the silicon die. Exemplarily pictures of the decapped devices are presented in in the figures below.



Exposed dies of the STM32F103RGT6 (left) and the STM32L152RET6 (right) microcontroller.

For the exposures four heavy ion species are used that span the LET range from 3.3 to 62.5 MeV·mg-1·cm2. The sample size for the exposure of each ion is two. During exposure the device is monitored for the occurrence of Single Event Transient (SET), Single Even Latch-Up (SEL) and Single Event Functional Interrupt (SEFI). No SETs have been observed during the conducted measurement campaigns for both microcontroller on the examined GPIOs. The STM32F103RGT6 proved to be immune to SELs while the STM32L152RET6 showed very intense latching even for the smallest LETs. Both microcontrollers exhibited a significant number of SEFIs. The SEFI cross section of the STM32F103RGT6 and the STM32L152RET6 as determined during the measurement campaign is presented in the Figures below.



SEFI cross section as determined during the measurement campaign for the for the STM32F103RGT6 (left; samples FT40 and FT41) and the STM32L152RET6 (right; samples LT17 and LT18).

Summary and Conclusion

The experimental activities undertaken within the scope of the present project 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, Lukas Huber, Marta Bagatin, Simone Gerardin, Marcin Latocha, Alessandro Paccagnella, Marc Poizat, Peter Beck, SEE Testing of COTS Microcontroller and Operational Amplifier in the Framework of the ESA CORHA Study, Conference RADECS 2022, Venice, October 2022

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).

SEELAS – EXPLORATION OF SINGLE EVENT EFFECT RADIATION TESTING OF COTS COMPONENTS WITH LASER AND HEAVY IONS

Introduction

Single event effects are a major threat to space missions since individual charged particles of the space radiation environment, such as protons or heavy ions, can irretrievably damage electronic devices. The increasing use of modern and commercial technologies in space and the deployment of extensive satellite constellations have been driving the demand for irradiation tests for the past years. For 2022, the European Space Agency (ESA) determined that the demand for beam time for heavy ion tests exceeds the available beam time by 30 – 50%, up to more than 1,500 hours, and predicts that the situation will continue to worsen over the next few years. The need for alternative test facilities for manufacturers and suppliers is therefore enormous. Although some US and European laboratories and industry look towards laser testing as an economic alternative, the current standards only accept heavy ion testing. The comparisons of laser induced SEE with heavy ion induced SEE is currently under investigation. There will be the need for rules and procedures in the future to correlate both kinds of testing.

Laser test systems, like tests with heavy ions, allow a characterisation of electronics with regard to single event effects and have shown a rapid technological development in recent years up to series production readiness. Laser tests offer numerous advantages compared to tests with heavy ions: Laser test systems have a high availability and reliability at lower costs than heavy ion tests. Laser tests allow the localisation and identification of sensitive areas in complex components, such as application-specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs). Furthermore, laser tests allow to determine failure probabilities of individual functional blocks, to validate models, to operate fault injection and to economically check and select components (screening), especially in the case of commercial electronics.

Objectives

Seibersdorf Laboratories, Beyond Space Austria (formerly RUAG Space) and the Technical University of Vienna proposed the project SEELAS on the exploration of single event effect (SEE) radiation testing of commercial off-the-shelf (COTS) components by comparing effects due to laser and heavy ion irradiation. The objective of the SEELAS project was to investigate the applicability of laser testing as a modern approach to radiation hardness assurance by carrying out both, laser testing and traditional heavy ion testing for the same components. A thorough analysis of the results using statistical methods and Monte Carlo and TCAD simulations allowed for an objective evaluation of the applicability of laser testing to qualitatively and quantitatively reproduce the results of the more expensive and resourceful heavy ion testing.

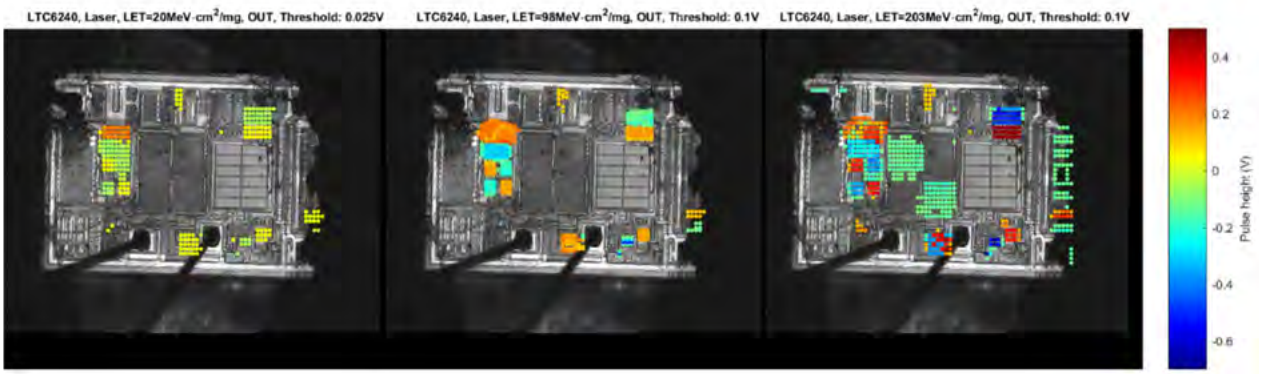
Method and Results

A survey of the scientific literature on SEE laser testing had been carried out. The evaluation of the literature had been performed with regard to understanding of essential parameters, which are:

1. wavelength, pulse length, penetration depth,
2. comparability with HI test results,
3. laser transparency of materials, and
4. laser testing systems.

Components selection was driven by industrial interest and – in case of the PIN photodiodes – because they are ideal modelling devices, finally allowing to practically and theoretically compare the effects of heavy ion testing against that of laser testing. Heavy ion testing for the SEELAS project was carried out at GSI (i.e. Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany) in March 2021 and May 2022. Laser testing for the SEELAS project was carried out PULSCAN, France, in December 2021 and March 2022. The facility uses a PULSYS-Rad system with PULSBOX PICO laser source.

Further work packages involved the investigation of using laser testing for FPGA testing and modelling to investigate to what degree current laser testing methods allow to quantitatively replicate radiation hardness assurance (RHA) data from heavy ion testing.



Results of laser testing of the LTC6240 OpAmp. Laser testing can provide spatial information of the single event transients.

Summary and Conclusion

The SEELAS project investigated the applicability of laser testing as a modern approach to radiation hardness assurance by carrying out both, laser testing and traditional heavy ion testing for the same commercial components. The consortium studied current literature and currently available laser testing systems and carried out experiments as well as simulations. It was clearly shown that laser testing is a highly capable and powerful tool to investigate the performance of components in regard to single event effects. High agreement was found qualitatively between the heavy ion and laser test results for the tested components.

Expert feedback from the industry, the agencies and feedback from the participants gathered during the project revealed that public opinion is that laser testing is not seen as a general replacement for heavy ion testing. The advantages of laser testing in regard to heavy ion testing are appreciated by the community, such as the spatial information, tuneable LET, higher accessibility and lower testing costs. Further, laser testing can make heavy ion testing obsolete, e.g. when laser testing results indicate high susceptibility. Another practical example that was given from the industry is that laser testing is used to qualify new lots. The new lot undergoes laser testing with the same parameters as the old lot. When the results are similar, the new lot does not need to undergo qualification with heavy ion testing. When the results deviate, heavy ion testing of the new lot is carried out. Based on the promising results of the project, Seibersdorf Laboratories will extend its radiation testing portfolio and will provide laser testing. The service is planned to become available starting from the second half of 2023.

Publications

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, 5th RADHARD Symposium, November 10, 2020, online, abstract available online https://www.seibersdorf-laboratories.at/fileadmin/uploads/intranet/events/radhard/2020/radhard-book-of-abstracts-2020.pdf
Expert Workshop on Laser Testing, May 18, 2021, https://www.seibersdorf-laboratories.at/en/radhard/archive/2021-radhard

Acknowledgements

The project is carried out within the scope of the Exploration of Single Event Effect Radiation Testing of COTS Components with Laser and Heavy Ions (SEELAS) project under FFG project No. 873705. The consortium acknowledges the support by the Austrian Research Promotion Agency.

RADHARD SYMPOSIUM 2022

Introduction

On April 26, 2022, Seibersdorf Laboratories organized its 7th 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 to the upcoming RADECS Conference.

The 7th RADHARD-Symposium in 2022 was a online event streamed live from the premises of Seibersdorf Laboratories ensuring the necessary safety for all participants during the Covid pandemic. The 2022 edition focused on:

- Radiation Testing Facilities
- Current Inventive SmallSat Projects
- Radiation Testing and COTS Components

The session on radiation testing facilities was opened by a keynote given by international expert Gerd Datzmann, founder and CEO of Datzmann interact & innovate on "RADNEXT – Responding to the Emerging Needs of Radiation Testing", continued with insights into "The Challenges of Testing at European Irradiation Facilities" by ESA expert Anastasia Pesce. The second session on "Current Inventive SmallSat Projects" featured international space operators presenting their space projects and sharing their individual experience, knowledge and lessons learnt. The presentations showed the numerous different applications of SmallSats. The third session on "Radiation Testing and COTS Components" perfectly complemented the session on SmallSat projects, as it dealt with practical aspects of radiation testing of commercial components, that are regularly used for low-cost space missions. The Symposium concluded with an expert panel discussion on SmallSats – An attractive business case? The question was discussed considering the vast increasing number of commercial nanosatellites and constellations, current and future launch and operation costs, business concepts, the increasing competitive pressure, but also reflecting on the increasing criticism regarding the high number of space objects and questions regarding the safety and sustainability in space for future generations.

The 7th RADHARD Symposium 2022 overview

- More than 150 participants from 21 Countries
- Keynote: RADNEXT – Responding to the Emerging Needs of Radiation Testing
- Invited Talk: The Challenges of Testing at European Irradiation Facilities
- Three Sessions
- Discussion Panel

Further information is provided at: www.radhard.eu

Book of Abstracts

The book of abstracts is available for download online at https://www.seibersdorf-laboratories.at/fileadmin/uploads/intranet/events/radhard/2022/RADHARD-Book-of-Abstracts-2022-web.pdf
Reference: ISBN (Print) 978-3-902780-23-2 ISBN (Ebook) 978-3-902780-22-5

Book of Abstracts 7th RADHARD Symposium 2022

Organizers and Supporters

The 7th RADHARD Symposium 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, ecoplus Aerospace Platform and in cooperation with the Graz University of Technology (TUG), the University of Applied Sciences Wiener Neustadt (FHWN) and the RADECS Association.

Our special thanks go to our supporters, AUSTROSPACE, ecoplus Aerospace Platform and the Austrian Research Promotion Agency (FFG), who once again enabled us to provide the RADHARD Symposium without participation fee.

Acknowledgements

Seibersdorf Laboratories would like to thank all participants, organizers, and supporters for their outstanding contribution to a successful RADHARD Symposium 2022.

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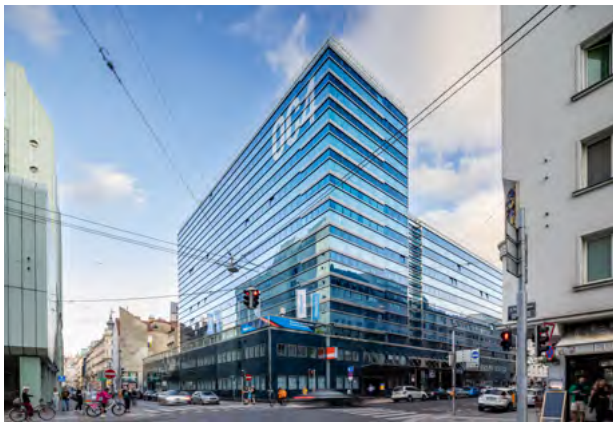
TTTech Computertechnik AG

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 2,300 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 offers software and hardware solutions for aviation and space applications. TTTech Aerospace products for the space sector are used in the largest international space programs, including NASA Artemis and ESA Ariane 6.

TTTech Aerospace delivers high-performance, dependable safety-critical networked computing platforms (the 'brains' and the 'nervous system') that ensure the reliable and safe operation of spacecrafts and launchers. TTTech Aerospace's computing platforms guarantee highly reliable operation and allow the integration of different systems such as guidance navigation and control, tele-communication and tele-command, life support, environmental control, or other systems.



TTTECH AEROSPACE

Part of ..... TTTech Group
Headquater ..... Vienna, Austria
Market ..... Aviation and Space
Global Presence .. Austria, USA, Germany, Japan

Number of Employees (as by Oct. 2022)
2022 ..... 100 (Business Unit)
2021 ..... 87 (Business Unit)

Operating Performance
2021 ..... 39 M€
2020 ..... 34 M€

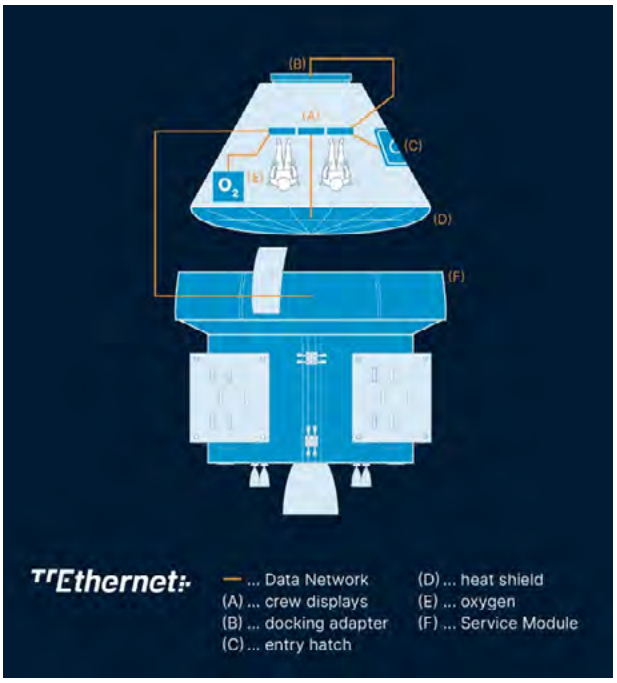


Illustration showing a simplified picture of how the TTEthernet® data network connects Orion and the European Service Module, reliably transferring all data needed for communication within the spacecraft as well as between the spacecraft and space stations, launch vehicles and ground stations.
Credit: TTTech Computertechnik AG

Artemis I – first mission successfully completed

November 2022 marked the launch of the Artemis I mission. This is the next step in NASA's return to the Moon under Artemis and preparing the way for human missions to Mars. Artemis I is an uncrewed test flight of NASA's Orion spacecraft and ESA's European Service Module (ESM) around the Moon. After completion of this first uncrewed test flight, a crewed flight test (Artemis II) will take place, with more missions to follow in the coming years.

TTTech is on board the avionics system (the 'central nervous system' of the spacecraft) of NASA Orion and the European Service Module with its TTEthernet® products. TTTech has been working with US companies Honeywell (provider of the avionics systems – Orion's 'brain'), Lockheed Martin (NASA's prime contractor for Orion) and NASA since 2006. The first successful NASA Orion Exploration Test Flight (EFT-1) was completed in 2014 and NASA Orion has since undergone a series of tests and adaptations in preparation for the launch of Artemis I.

Artemis – Gateway

The Artemis program consists of multiple key building block which together will bring humanity back to the moon with a sustainable permanent presence as well as the prove all technologies for a later mission which will bring humans to safely mars and back.

A corner stone of this program is the Gateway which is a human rated station in the moon orbit which is able to host astronauts on its way to the moon and back. This station is currently in development with TTTech providing network and compute equipment to the different modules. As lessons learned from the international space stations, where hundreds of low performance communication busses have been used which were cascaded to be able to deliver the quality of service needed to control and operate the stations, the Gateway uses a solution which allows to integrated multiple modules in a modular way by not losing these services. The integration of this modules is quite complex and needs technologies and products to master it and keep the possibility to add and upgrade the overall station.

European Space Activities 2022

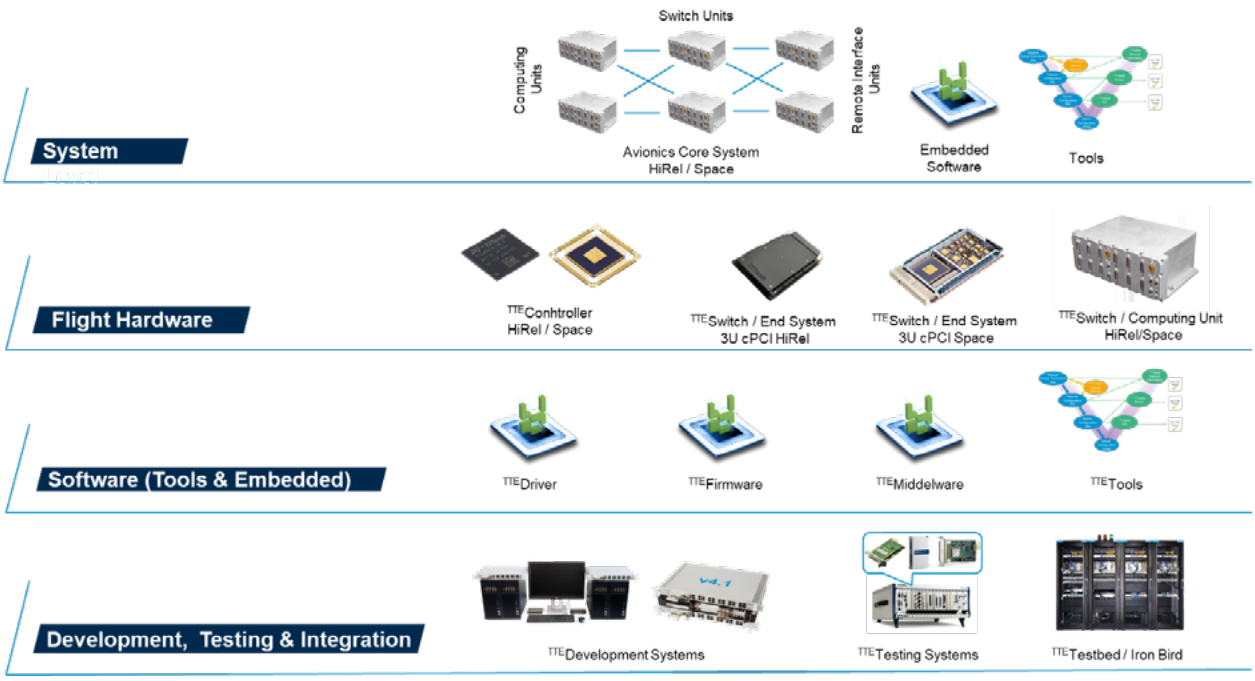
Europe's new flagship launcher Ariane 6 will ensure independent access to space for the European space sector. TTTech contributed substantially to the creation of the avionics backbone system in Ariane 6. Its "chips" and the related software are integrated into more than 50 avionic units handling functions such as guidance navigation and control, telemetry and telecommand, power management, video streaming or thrust-vector

actuation, which all connect to a single, redundant TTEthernet network, the launcher's "nervous system". TTTech also contributed to Ariane 6 with firmware development and qualification as well as integration support. In March 2022, the launcher's fully integrated avionics network was qualified at ArianeGroup's development center near Les Mureaux and signed the exploitation agreement including series production and maintenance, France. This was a key milestone ahead of the first launch, which is expected to take place in late 2023. In addition, European Space Agency (ESA) and its partners have, with support from TTTech, established the open ECSS Time-Triggered Ethernet standard for space applications (ECSS-E-ST-50-16C) which ensures compatibility and interoperability between different Time-Triggered Ethernet hardware components that are used.

ESA early partnered with NASA, the Canadian Space Agency and the Japanese Space Agency on the international Artemis program. To ensure the availability according to the needed technology readiness level (TRL) in Europe, ESA and the Austrian Space Agency ALR as part of FFG) have together with TTTech and Beyond Gravity decided to start a development and qualification activity to de-risk ESAs Gateway modules and ensure compliance to ESAs ECSS standards. This ESA GSTP activity for the qualification of key TTEthernet® avionics elements – space-grade TTEthernet switches and network interface cards was executed reaching the critical design review. These elements are developed in close cooperation between TTTech and Beyond Gravity which is also responsible for the production and qualification of these deep space equipment. The support from FFG and the Austrian government allowed to multiple programs outside of ESA and shows the impact of Austrian technology.

In 2022 TTTech has made major progress on the contracts for ESA's Gateway modules "International Habitat" and "ESPRIT Refueling Module". 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.

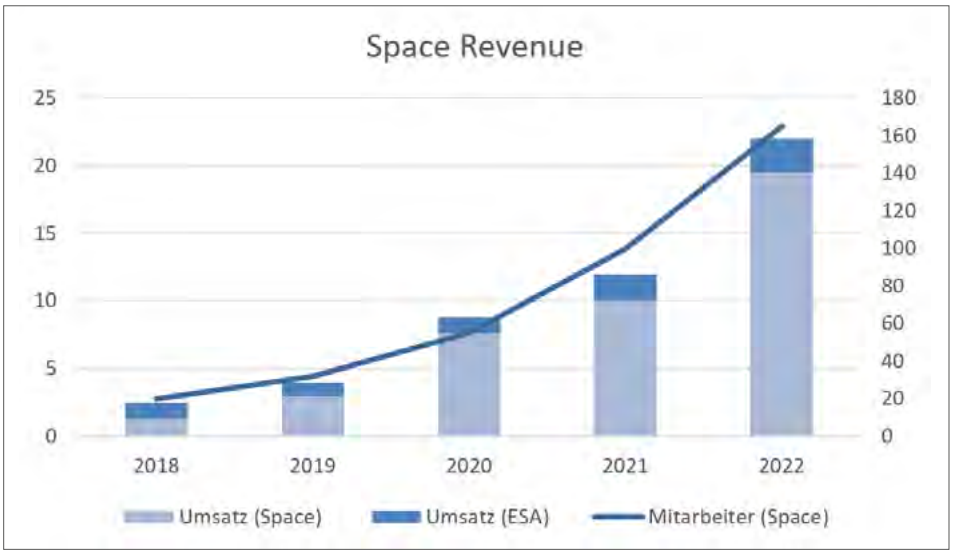
Product Portfolio



TTTech Aerospace provides network and avionics core systems for the use in safety critical applications. These products are comprising development and testing, embedded software, configuration and verification tools, fight hardware and integrates system solutions. The products are certified to the highest quality and safety requirements and have passed safety reviews for multiple application such as human space flight, launchers and satellites and have therefore been certified to the related standards and with multiple authorities.

Revenue

Total European space revenue of 2022 grew to Euro 3,1 million with an ESA share of 2,6 million. Clearly outnumbered by sales in the other regions (mainly North America) which more than doubled in comparison to 2021. Further growth in 2023+ is planned based on TTTech's Artemis contracts as well as additional business from the launcher and satellite market.



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FACTS
Sales: 3,1 M€
ESA Share: 2,6 M€

Photo: ESA/Hubble & NASA, J. Bally, M. Robberto; CC BY 4.0