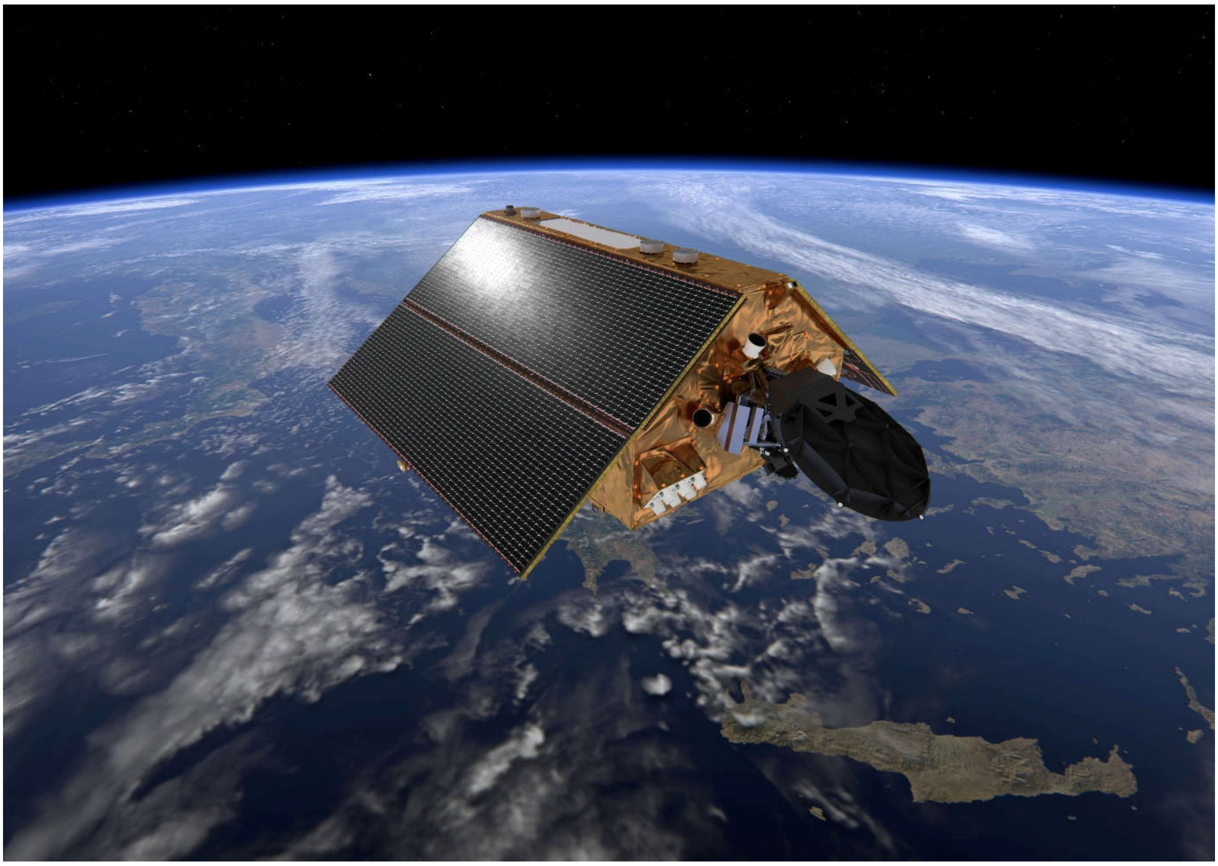
ANNUAL REPORT 2020



Cover picture: Sentinel 6 over Crete

Photo Credit: ESA

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1 Introduction

The present AUSTROSPACE Annual Report is composed of a brief review of major space events in 2020, contributions from industrial members and research organizations about their space activities, and a current list of members with contact information.

Vienna, June 2021

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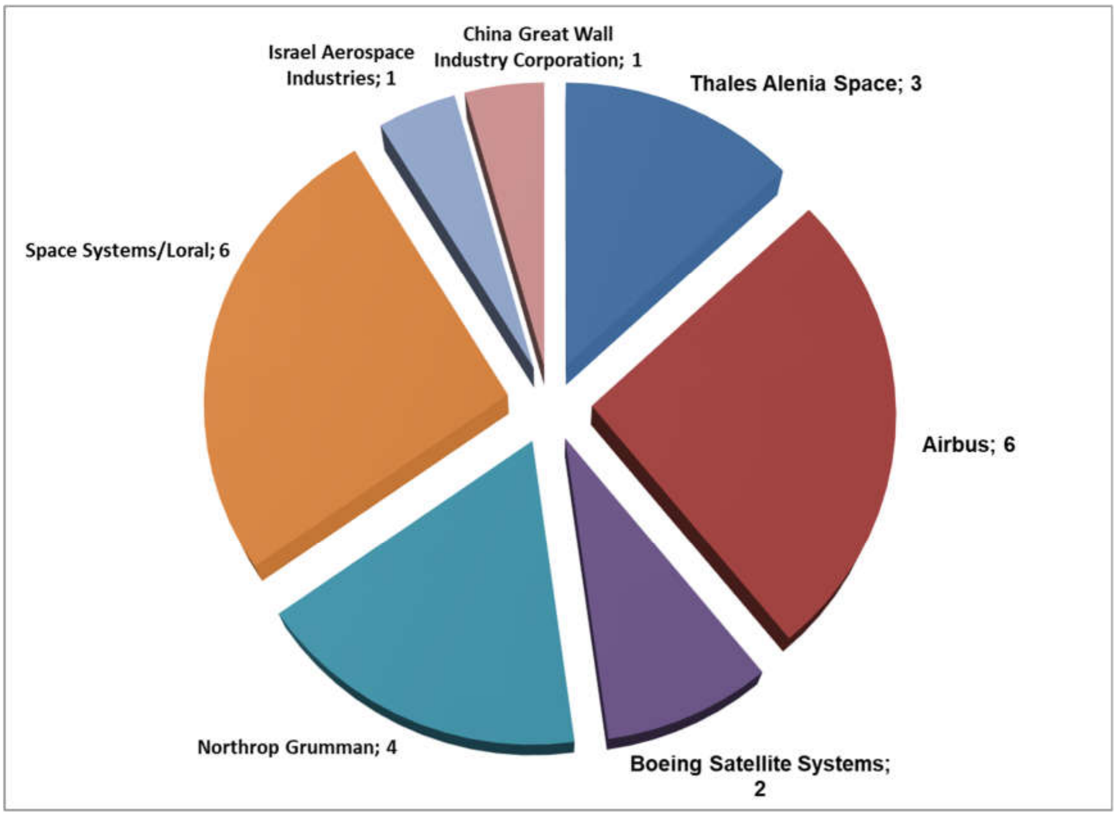
2 Year 2020 Review

In 2020 orders for 23 geostationary (GEO) telecommunications satellites were placed worldwide, again a double-digit number after the 17 GEOs in 2019. With 12 contracts in total, US satellite manufacturers Space Systems/Loral (6), Northrop Grumman (4) and Boeing Satellite Systems (2) outperformed their European competitors (Airbus: 6, Thales Alenia Space (TAS): 3). China Great Wall Industry Corporation (CGWIC) und Israel Aerospace Industries (IAI) booked one order each (Source: Gunter's Space Page).



Commercial geostationary telecommunications satellite orders 2020

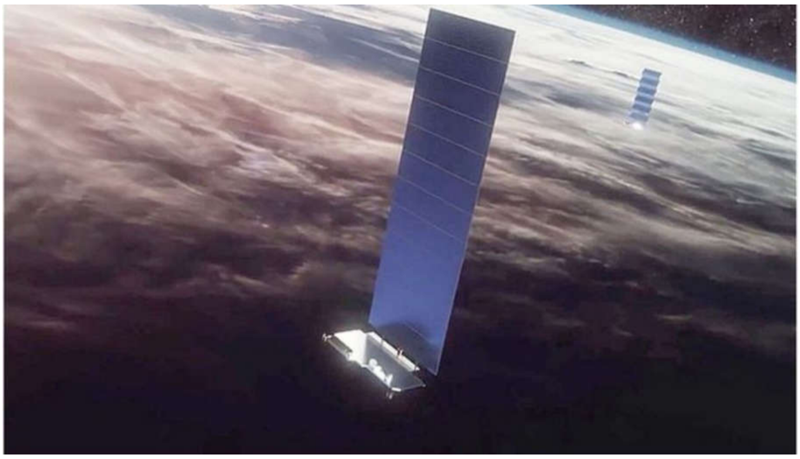
(Source: Gunter's Space Page)

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

The development of OneWeb, a constellation of 648 LEO satellites in the first phase with a planned follow-on extension, has been continued with two launches in February and March, each deploying 34 satellites. In March, however, the operator had to file for Chapter 11 bankruptcy in the US. Approval of a reorganization plan by a US bankruptcy court paved the way for sale of OneWeb to the British government and Indian telecommunications company Bharti Global in November. With the launch of further 36 satellites in December the total number in orbit reached 110. The satellites are delivered from a new production site in Florida jointly established by OneWeb and Airbus. Completion of the full constellation is planned for mid-2022. Test operations with initial services shall commence in fall 2021.

34 OneWeb satellites, mounted on their dispenser, as they are lowered onto a Russian Fregat upper stage (Source: Arianespace)

At the end of the year, Competitor SpaceX had some 900 satellites for a much more complex network of 11.943 satellites (Starlink) in orbit.



Artist's impression of Starlink satellites in orbit (Source: SpaceX)

The full network for global internet access shall be realized until 2027. Initial services in northern USA and southern Canada have commenced.

Launch of 60 Starlink satellites from Cape Canaveral (Source: Reuters)

In the middle of the year industry consortia for a new generation of Copernicus satellites were selected. Copernicus is a system of environmental monitoring satellites developed in the frame of the earth observation program of the European Space Agency (ESA) and operated by the European Union (EU). The six new satellites embark a variety of advanced instruments and are of high strategic interest for European space industry. In a tough competition between the three European system integrators, TAS has won the prime contract for three satellites, Airbus for two and OHB for one.

Following the decision of the European Commission to speed up the development of the next generation of the satellite navigation system Galileo, Airbus, OHB and TAS were invited to submit their binding bids for the first batch of advanced and flexible Galileo Second Generation (G2G) satellites. Award of two parallel contracts is foreseen, each encompassing delivery of six satellites, the first of which is scheduled for launch in late 2024.

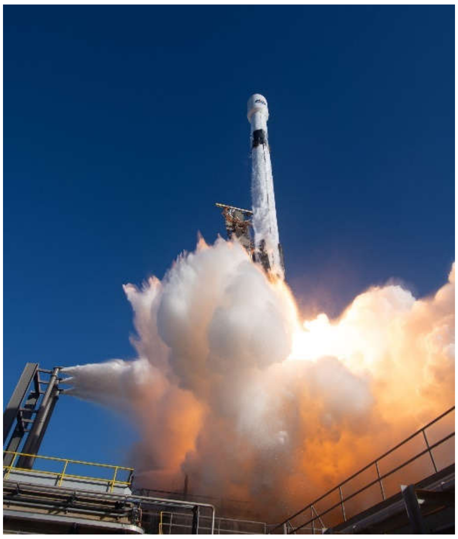
With major contracts for the Lunar Orbital Platform-Gateway (LOP-G) awarded, a new space station to be realized in an international cooperation of the space agencies NASA (USA), ESA (Europe), JAXA (Japan) and CSA (Canada), Europe has entered a new era of manned space exploration, providing European space industry enormous long-term business potential.

Artist’s impression of Lunar Orbital Platform – Gateway (Source: NASA)

On February 10 Solar Orbiter, the most complex scientific laboratory ever sent to the Sun, was launched aboard an Atlas V rocket from Cape Canaveral. The ESA-led mission with strong NASA participation will provide the first views of the Sun's unchartered polar regions from high-latitudes, giving unprecedented insight into how our parent star works. This important mission will also investigate the Sun-Earth connection, helping to better understand and predict periods of stormy space weather. Austrian industry and the Austrian Academy of Sciences have provided major contributions to the development and manufacturing of the spacecraft and its instruments.

Artist's impression of Solar Orbiter (Source: ESA)

On November 21 the Copernicus Sentinel-6 Michael Freilich satellite was launched on a SpaceX Falcon 9 from Vandenberg Air Force Base in California. This sea-level monitoring satellite will continue the long-term record of reference measurements, extending the record of sea-level height into a fourth decade. Since sea-level rise is a key indicator of climate change, accurately monitoring the changing height of the sea surface over decades is essential for climate science, for policy-making and, ultimately, for protecting the lives of those in vulnerable low-lying areas. Austrian technology on board as well as used during manufacturing and testing is key to mission success.

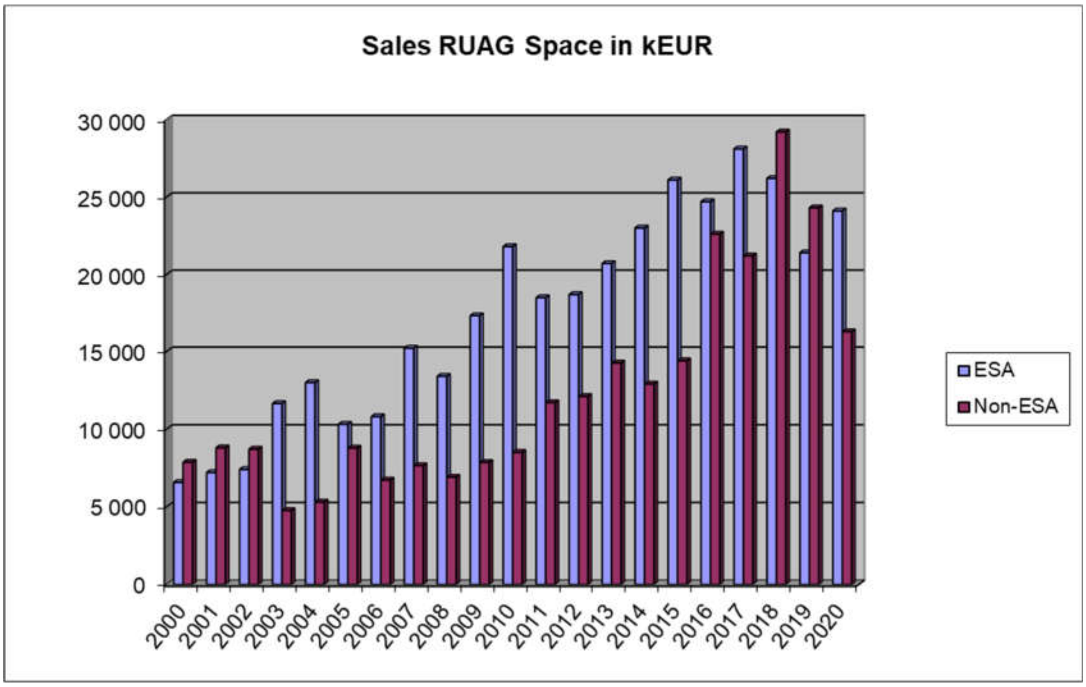


Sentinel-6 Michael Freilich lifts off from Vandenberg (Source: ESA)

The final highlight of the year was the nomination of Josef Aschbacher as new Director General of ESA. Born in Tyrol in 1962, Aschbacher has been working for ESA in a variety of positions for three decades. As Director of Earth Observation, he has been responsible for the biggest share of the ESA budget since 2016.

Josef Aschbacher meets Austrian Space Minister Leonore Gewessler (Source: APA/Robert Jaeger)

At the end of 2020 AUSTROSPACE had 21 members. The evolution of sales of the four biggest AUSTROSPACE companies is illustrated on the following pages. The figures demonstrate a rather good leverage effect of ESA projects, i.e. a sustainable growth of commercial business.


Sales RUAG Space in kEUR
30 000
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20 000
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10 000
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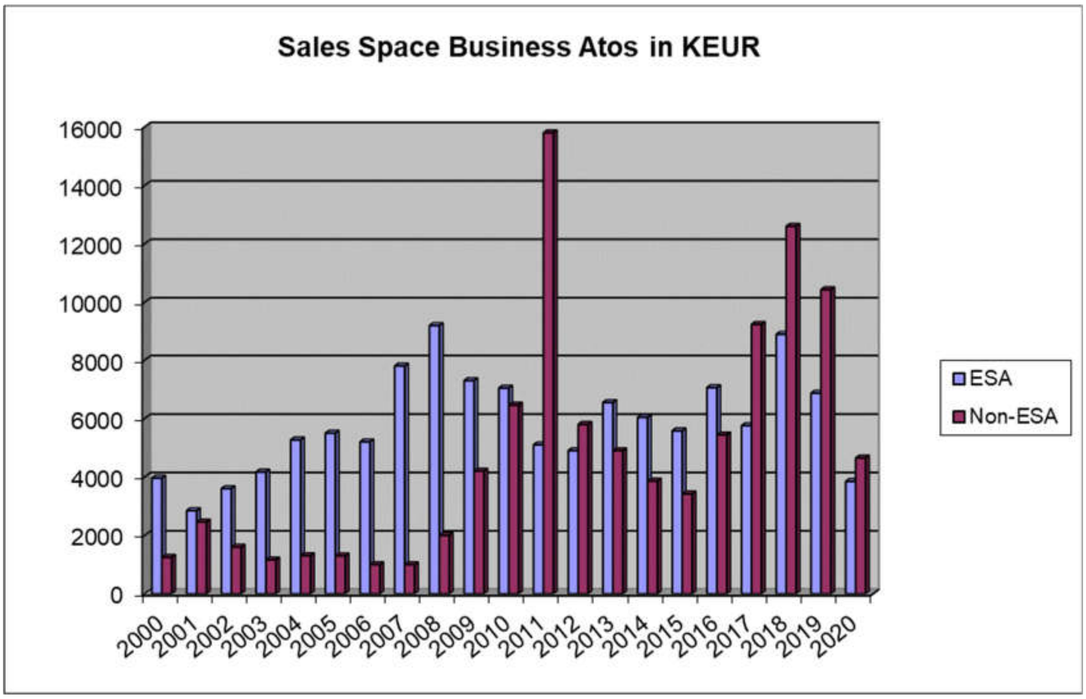
Non-ESA


Sales Space Business Atos in KEUR
16000
14000
12000
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8000
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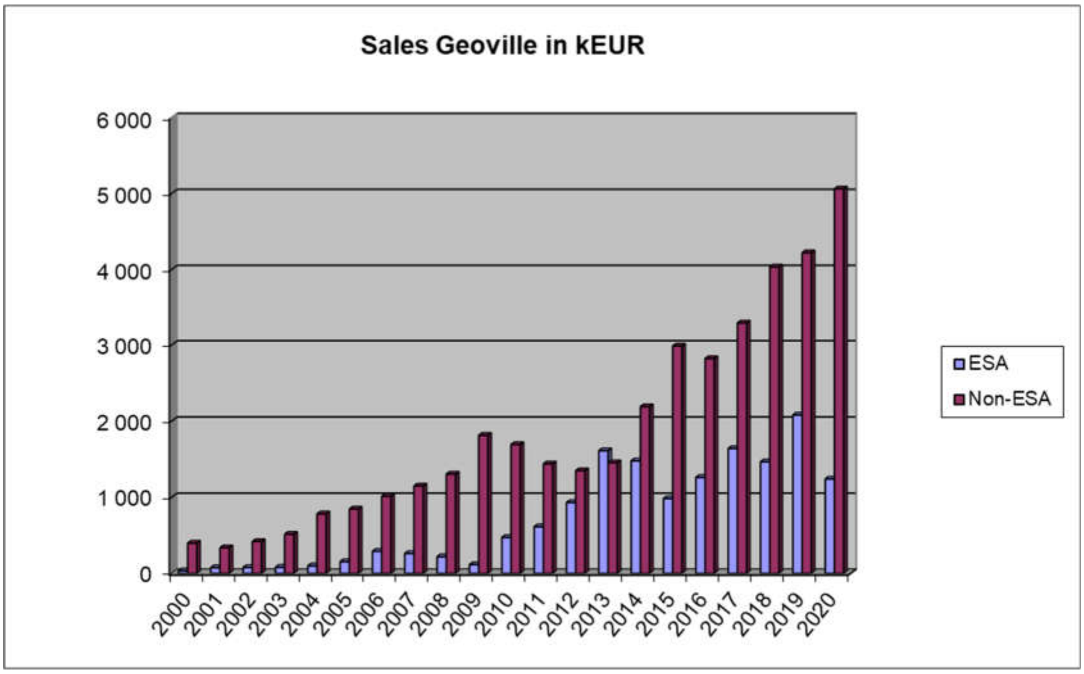
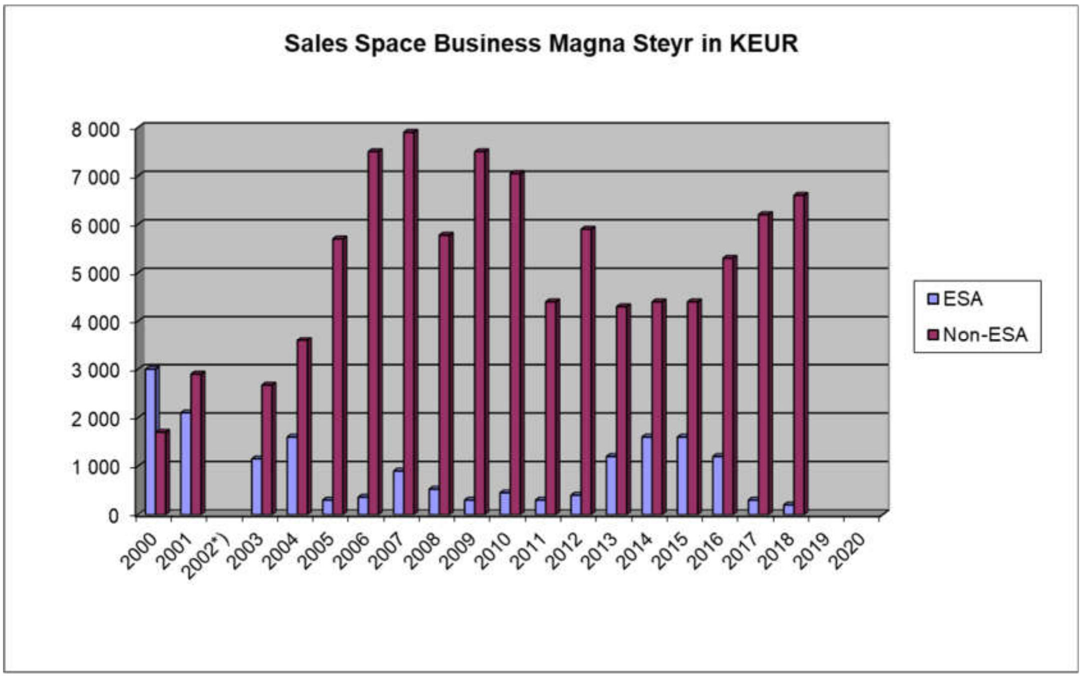




\) no figures available for 2019 and 2020

3 Reports of Industrial and Institutional Members

3.1 Austrian Academy of Sciences

The Space Research Institute (Institut für Weltraumforschung, IWF) in Graz focuses on the physics of our solar system and 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, ÖAW).

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

IWF cooperates closely with space agencies all over the world and with numerous other national and international research institutions. A particularly intense cooperation exists with the European Space Agency (ESA).

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

The *Cluster* mission celebrated its 20th anniversary in 2020 and still provides unique data to better understand space plasma.
For already five years, the four *MMS* spacecraft explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
The first *China Seismo-Electromagnetic Satellite (CSES-1)* has studied the Earth's ionosphere since 2018. CSES-2 will follow in 2022.
On its way to Mercury, *BepiColombo*, had gravity assist maneuvers at Earth (March) and Venus (October). It will investigate the planet, using two orbiters, one specialized in magnetospheric studies and one in remote sensing.
In its first operational year, *CHEOPS (CHaracterizing ExOPlanets Satellite)* has already provided significant results about the characteristics of exoplanets orbiting bright stars.
Along its innovative trajectory, ESA's *Solar Orbiter* flew by Venus in December to change its orbit around the Sun.

A United Launch Alliance (ULA) Atlas V rocket carrying *Solar Orbiter* lifts off on 9 February 2020 at 11:03 p.m. EST (© ULA).

ESA's *JUpiter ICy moons Explorer (JUICE*, launch: 2022) will investigate Jupiter and three of its largest moons, Ganymede, Callisto, and Europa.
FORESAIL-2 (launch: 2023) is one of three CubeSats to characterize the variability of ultra-low frequency waves in the inner magnetosphere.
SMILE (launch: 2023) is designed to study the interaction between the solar wind and Earth's magnetosphere.
*PLATO (*launch: 2026) is a space-based observatory to search for planets orbiting alien stars.
Comet Interceptor (launch: 2029) will characterize in detail, for the first time, a dynamically-new comet or interstellar object.

HIGHLIGHTS IN 2020

The successful launch of *Solar Orbiter* marked the highlight at the beginning of the year. The Chinese *Tianwen-1* mission followed in July.
Two studies in the "Journal of Geophysical Research" and "Geophysical Research Letters" explained the origin of bead-like structures in the aurora.
In "Astronomy & Astrophysics" the first measurement results from *CHEOPS* were presented, characterizing the exoplanet WASP-189b in detail.
In "Nature Communications" the first successful daylight space debris laser ranging was published.

***Tianwen-1* was launched aboard a Long March 5 rocket from the Wenchang Space Center (© CNSA).**

THE YEAR 2020 IN NUMBERS

Members of the institute published 168 papers in refereed international journals, of which 42 were first author publications. During the same period, articles with authors from the institute were cited 7089 times in the international literature. In addition, 26 talks (11 invited) and 33 posters were presented (virtually) at international conferences by IWF members. Last but not least, institute members were involved in the organization of four international meetings or workshops.

IWF STRUCTURE AND FUNDING

The institute is led by Director Wolfgang Baumjohann. Werner Magnes serves as Deputy Director. IWF is structured into six research groups: 1) Exoplanets (Lead: Luca Fossati), 2) Planetary Atmospheres (Lead: Helmut Lammer), 3) Space Plasma Physics (Lead: Rumi Nakamura), 4) On-Board Computers (Lead: Manfred Steller), 5) Magnetometers (Lead: Werner Magnes), and 6) Satellite Laser Ranging (Lead: Georg Kirchner).

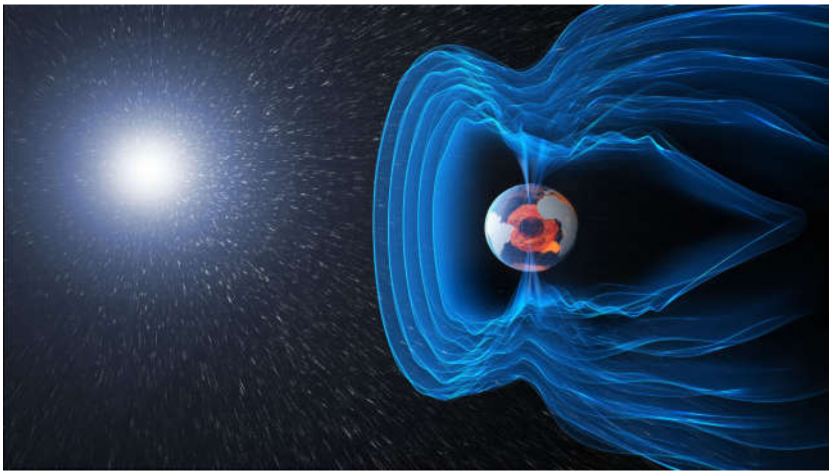
Most financial support is given by ÖAW. Significant support is also provided competitively by other national institutions, in particular the Austrian Research Promotion Agency (FFG) and the Austrian Science Fund (FWF). Furthermore, European institutions like ESA and the European Union contribute substantially.

I - NEAR-EARTH SPACE

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

New studies dealing with the interaction of the solar wind with the Earth's magnetosphere were completed using the data from the missions to which IWF contributes. Also theoretical and numerical studies helped to interpret the mission data. Among different results one of this year's highlights is the first 3D fully kinetic particle-in-cell simulation of a plasma instability called Kelvin-Helmholtz instability performed for a specific (i.e., southward) interplanetary magnetic field orientation. The simulation showed how the instability drives fast magnetic reconnection, which is the main scientific target of the *Magnetospheric Multi-Scale (MMS)* mission. The results will also significantly support the physical interpretation of *MMS* observations.

While *MMS* studies micro-scale processes, observations from the *Time History of Events and Macroscale Interactions during Substorms (THEMIS)* multi-spacecraft mission are suited for meso-scale magnetospheric boundary processes such as dipolarization fronts. This magnetic feature is considered to be produced in association with the interaction of plasma jets and the ambient magnetic field and is a major energy conversion region in the magnetotail. A detailed comparison between the *THEMIS* observations and a computer model of the plasma instability called interchange instability, unveiled detailed mechanisms how a localized magnetic field front structure is formed. The obtained knowledge from the near-Earth space observations contribute to enhancing our understanding of space plasma processes in other plasma environments within our solar system and beyond.



Artist's impression of the solar wind interaction with the Earth’s magnetosphere (© ESA/AOES Medialab).

CLUSTER

ESA's *Cluster* mission is designed to study different plasma processes created by the interaction between the solar wind and the Earth's magnetosphere. This first four-spacecraft mission has been successfully operating for twenty years starting from its launch in August 2000 and is currently planned to be extended until 2022. IWF is Principal and/or Co-Investigator (PI/Co-I) of five instruments and has contributed to data archiving activities at the *Cluster Science Archives (CSA)* in addition to the science data analysis.

THEMIS/ARTEMIS

NASA's five-spacecraft mission THEMIS (Time History of Events and Macroscale Interactions during Substorms), was launched in 2007. In 2010, the two outer spacecraft were renamed ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics mission) and put in orbit around the Moon. Both missions were extended until 2022. As Co-I of the magnetometer, IWF is participating in processing and analyzing data.

MMS

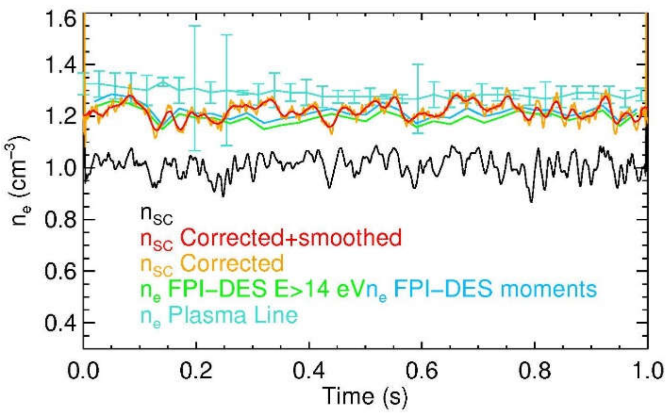
NASA's *Magnetospheric Multi-Scale (MMS)* mission, launched in 2015, explores the dynamics of the Earth's magnetosphere and the underlying energy transfer processes. Four identically equipped spacecraft carry out measurements in the Earth's magnetosphere with highest temporal and spatial measurements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

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

A spacecraft in a plasma becomes charged due to a number of different processes. The two most important are photoelectron emission from the sunlit surfaces of the spacecraft and the collection of thermal electrons by the spacecraft. For the regulation of the spacecraft potential on *MMS* an *ASPOC* instrument was included, which reduces the potential by emitting a current. If the photoelectron emission can be modelled, then the spacecraft potential can be used to obtain a measurement of the electron density. This has the advantage of an increased time resolution over direct measurements with plasma instruments. However, large external electric fields can accelerate lower energy photoelectrons that would not have energy to escape the spacecraft. This can cause the spacecraft potential to follow fluctuations in the electric field decreasing the quality of determination of the electron density from the spacecraft potential.

To correct for this effect, the following methodology was developed: The contribution of the electric field to the change in potential was determined empirically and then removed. An example from the *MMS* spacecraft of the corrected density estimation is shown in the figure below, where the measured potential is depicted in black and the corrected potential in red. The corrected potential determination matches well with other estimates of the electron density.

Roberts et al., J. Geophys. Res., 125, e2020JA027854, 2020.



Estimations of the electron density: the spacecraft potential not corrected for the electric field (black), the estimation where the electric field effect has been corrected and smoothed (red/orange). This agrees well with the estimates from the *Fast Plasma Investigation (FPI*, green) and the plasma frequency line (cyan).

CSES

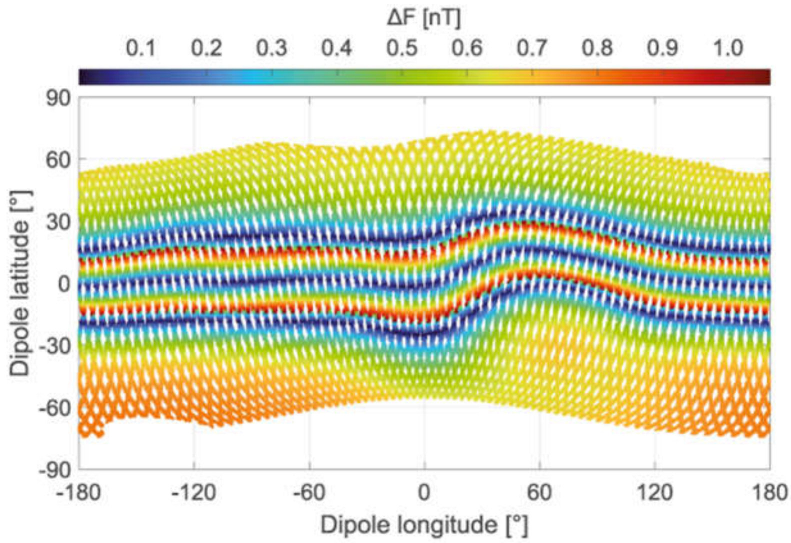
The *China Seismo-Electromagnetic Satellites (CSES)* are scientific missions dedicated to the investigation and monitoring of varying electromagnetic fields and waves as well as plasma parameters and particle fluxes in the near-Earth space, which are induced by natural sources on ground like seismic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

After the successful launch of the first satellite *CSES-1* in February 2018, the second satellite *CSES-2 i*s scheduled for launch in 2022. 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 National Space Science Center (NSSC), the Institute of Experimental Physics of Graz University of Technology (TUG), and IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while IWF and TUG participate with the newly developed absolute scalar magnetometer, called *Coupled Dark State Magnetometer (CDSM).*

Throughout 2020, the magnetometer sensors of *CSES-1* operated continuously in good health. The data from the scalar sensor were e.g. used to derive its absolute error. This was done by comparing the measurements to magnetic field models, measurements from other satellite missions, and through a comprehensive study of the integrity of its own data. The latter was based on the comparison of all available instrument parameters in flight with the verification measurements performed on ground before launch. This led to a maximum uncertainty in the measurement of 1.1 nT as shown in the figure below.

Pollinger et al., Geosci. Instrum. Method. Data Syst., 9, 275-291, 2020.



The worst case uncertainty of the magnetic field measurement by the scalar sensor aboard *CSES-1* as a function of geomagnetic coordinates.

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

During the second year of operation, flight data verification, in-flight calibration and operation support were continued. Furthermore, the *SOSMAG* ground processor software was finished. It has been integrated in the Space Weather Service Network of ESA's Space Safety program in the second half of 2020 for a real time release of the *SOSMAG* data to the space weather community.

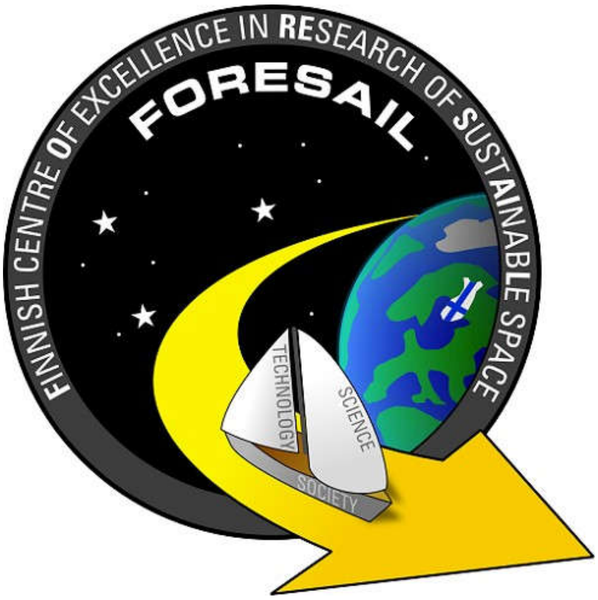
Magnes et al., Space Sci. Rev., 216, 119, 2020.

FORESAIL-2

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

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

In cooperation with the Institute of Electronics of Graz University of Technology, IWF contributes a miniaturized magnetometer, which will be based on a newly developed microchip for the readout of the triaxial magnetic field sensor. During the reporting year, the preliminary design of the magnetometer has been settled and the design and simulation of the prototype microchip has been nearly finalized.



CubSats will set sail to investigate the Earth's magnetosphere.

SMILE

The *Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)* is a joint mission between ESA and the Chinese Academy of Sciences (CAS), scheduled for launch in 2023. It aims to build a more complete understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere. IWF is Co-I for two instruments: the *Soft X-ray Imager (SXI)*, led by the University of Leicester, and the magnetometer *(MAG)*, led by CAS.

The institute, in close cooperation with international partners, contributes the instrument's control and power unit *EBOX* for *SXI*. IWF is coordinating the development and design of the Digital Processing Unit (DPU) and is responsible for the mechanical design and the tests at box level. In 2020, ESA changed its philosophy and requested to get rid of all electronic components, which need a US export license. Thus, IWF had to do a complete redesign of the DPU, using European semiconductors only. The component selection and the design process has been completed, but the printed circuit board layout activity is still ongoing. In parallel, the structural and thermal model of the *EBOX* has been designed and manufactured. All components are in house and the assembly has started.

Another activity was the design of the *SXI* simulator, which will be provided to Airbus instead of an Engineering Model. The simulator is based on a commercial Raspberry Pi enhanced by an in-house developed SpaceWire extension board. In addition to the hardware activities, IWF participates in the modeling and science working group activities.

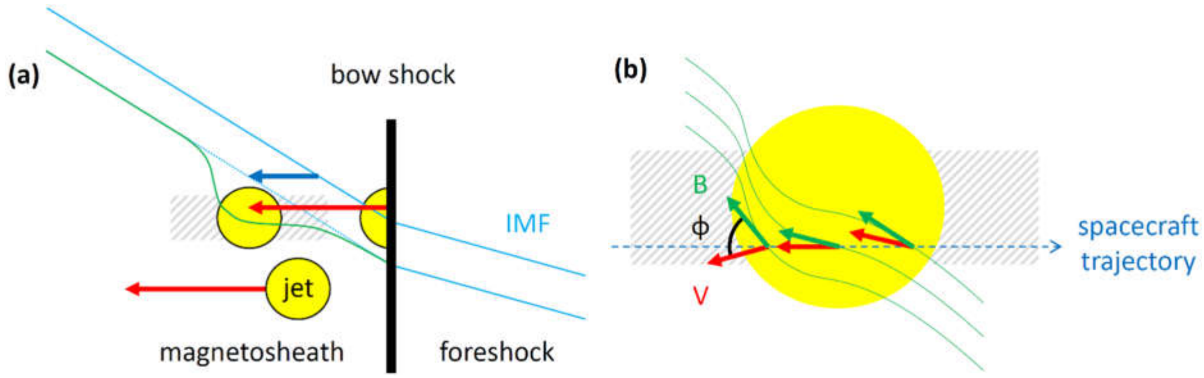
***SMILE SXI* simulator to be used at spacecraft level instead of an Engineering Model (© ÖAW/IWF/Steller).**

ALIGNMENT OF JET VELOCITY AND MAGNETIC FIELDS

Jets in the subsolar magnetosheath are localized enhancements in dynamic pressure that are able to propagate all the way from the bow shock to the magnetopause. Due to their excess velocity with respect to their environment, they push slower ambient plasma out of their way, creating a vortical plasma motion in and around them. Simulations and case study results suggest that jets also modify the magnetic field in the magnetosheath on their passage, aligning it more with their velocity. Based on *MMS* jet observations and corresponding superposed epoch analyses of the angles Φ between the velocity and magnetic fields, it was confirmed that this suggestion is correct.

However, while the alignment is more significant for faster than for slower jets, and for jets observed close to the bow shock, the overall effect is small: typically, reductions in Φ of around 10° are observed at jet core regions, where the jets' velocities are largest. Furthermore, time series of Φ pertaining to individual jets significantly deviate from the superposed epoch analysis results. They usually exhibit large variations over the entire range of Φ: 0 to 90°. This variability is commonly somewhat larger within jets than outside, masking the systematic decrease in Φ at core regions of individual jets.

Plaschke et al., Ann. Geophys., 38, 287-296, 2020.



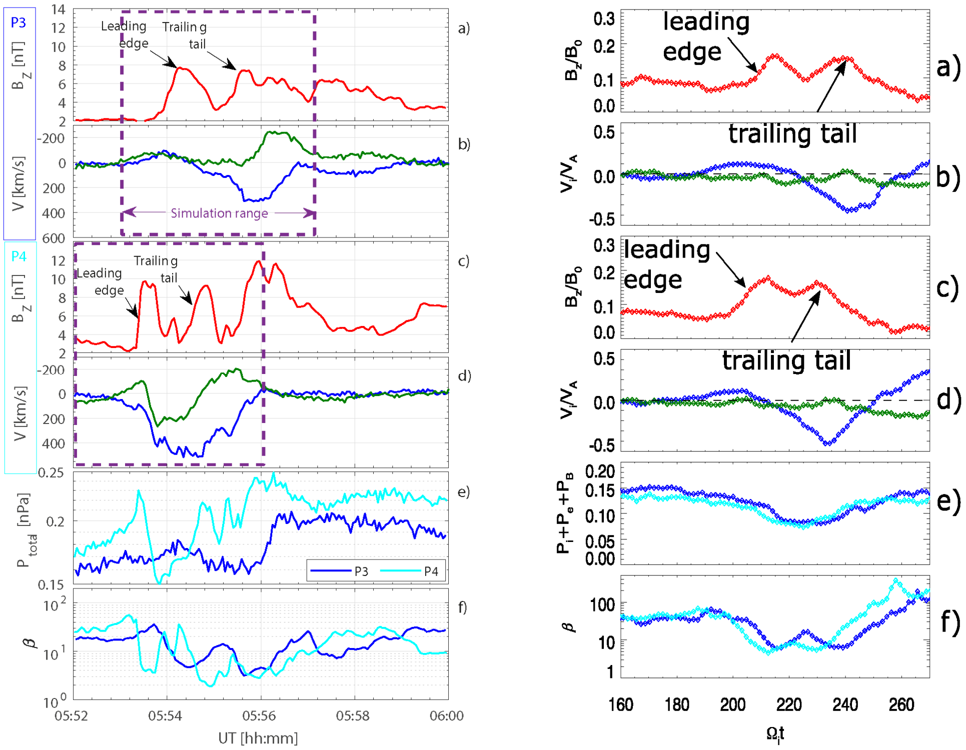
(a) Sketch of how magnetic fields in the magnetosheath may be modified by the motion of fast plasma jets. Velocities of jets and ambient plasmas are illustrated by red and blue arrows, respectively. (b) Close-up on a jet. Green and red arrows show local directions of the magnetic field B and velocity V measured by a spacecraft on its trajectory through the jet. The angle between B and V is φ.

S/C TRAJECTORIES THROUGH INTERCHANGE HEADS

The terrestrial magnetic field lines on the anti-sunwardside of the Earth form an elongated structure (the magnetotail), which is periodically disrupted by magnetic reconnection. An instability was recently found to produce azimuthally narrow heads that intrude into the dipole region from the near-Earth magnetotail. At the developed stages of the instability, it was predicted that localized plasma structures, which have narrow heads and contain enhanced northward magnetic fields (dipolarization front), grow toward the Earth that may cause a full-scale disruption of the magnetotail.

By combining high-performance computing plasma simulations with multi-point in-situ observations by *THEMIS*, it is shown that under the right magnetotail conditions the dipolarization fronts can also be generated by this instability at about ten Earth's radii downtail in the transition region between the geomagnetic dipole and tail fields.

Panov et al., J. Geophys. Res., 125, e2020JA027930, 2020.



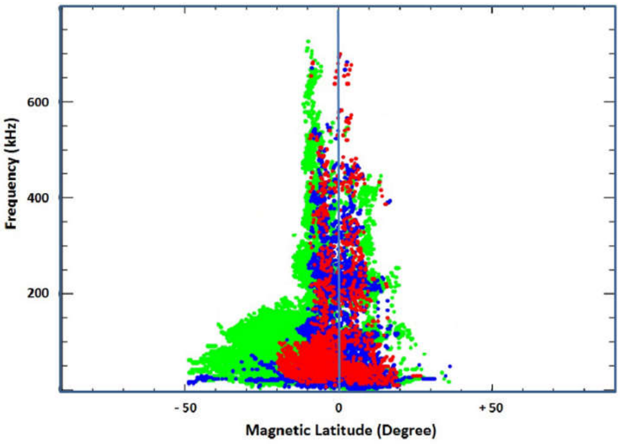
Left: THEMIS P3 (a, b, e, and f) and P4 (c–f) observations during dipolarization

VLF/LF RADIO PROPAGATION

Frequency-banded wave emission has been recorded near the Earth's equatorial region by the *DEMETER* satellite. This emission occurs on the night side in the frequency range from few kHz up to 800 kHz when the satellite's magnetic latitude mainly varies between -30° and +20°. This emission exhibits different spectral behavior before and after the crossing of the magnetic equator. Two spectral components have been investigated, one appears as frequency bands continuous in time between a few kilohertz and up to 50 kHz, and the other one is from 50 to 800 kHz.

The first component exhibits positive and negative frequency drift rates in the Southern and Northern Hemisphere, at latitudes between -40° and 20°. The second one displays multiple spaced frequency bands as shown in the figure below. Such bands mainly occur near the magnetic equatorial plane with a particular enhancement of the power level when the satellite latitude is close to the magnetic equatorial plane. It is important to note that the number of parallel narrow bands is found to be different from one event to another. In addition, the enhanced banded frequencies above 200 kHz, may be considered harmonic components of a fundamental frequency appearing around 140 kHz. The power distribution of such emissions shows restrained and extended deployment around the equatorial magnetic plane. Hence, the latitudinal beam is found to be about 40° when the frequency is, on average, less than 100 kHz. Above this limit and up to about 800 kHz, the latitudinal beam is decreasing and found to be about 20°.

Boudjada et al., Ann. Geophys., 38, 765-774, 2020.



Variation of the power levels versus the frequency and the magnetic latitude for all events. The red, blue and green colors indicate the intense, moderate and weak frequency-banded emissions.

II - SOLAR SYSTEM

IWF is engaged in many missions, experiments and corresponding data analysis addressing solar system phenomena. The physics of the Sun and the solar wind, its interaction with solar system bodies, and various kinds of planetary atmosphere/surface interactions are under investigation.

SUN & SOLAR WIND

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

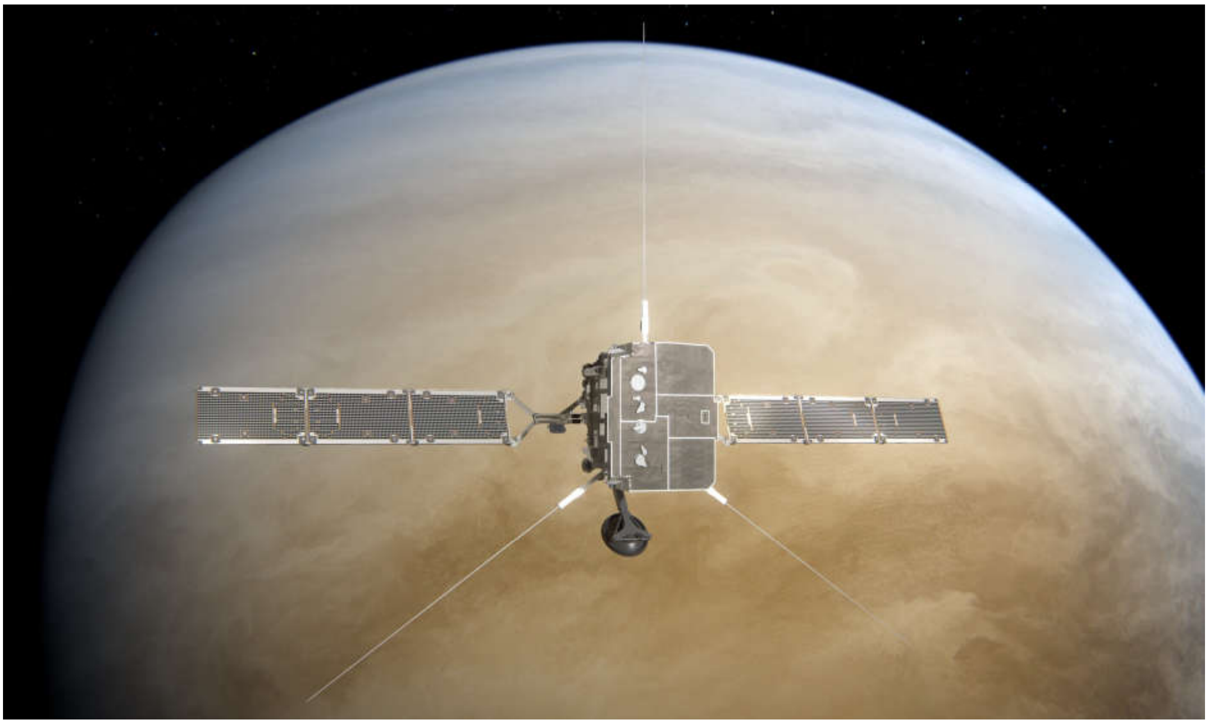
2020 marks the beginning of a new era of investigating the Sun and solar wind with the launch of *Solar Orbiter* in February. The remote sensing instruments got a first chance to make measurements in June, when the spacecraft surrounded the Sun for the first time at a distance of about 0.5 AU. Further scientific observations were made by the *Solar Orbiter* payload during the first Venus flyby in December 2020.

SOLAR ORBITER

Solar Orbiter is an ESA space mission 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 high elliptical orbit with perihelion at 0.28 AU.

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

RPW will measure the magnetic and electric fields at high time resolution and will 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.

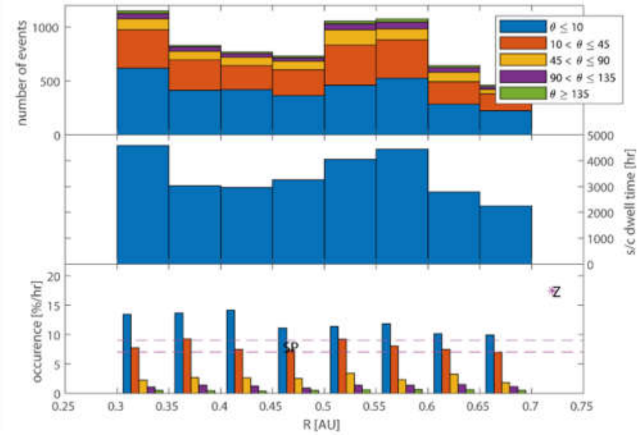


Artist's impression of Solar Orbiter making a flyby at Venus (© ESA/ATG medialab).

MAGNETIC HOLES IN THE SOLAR WIND BETWEEN MERCURY AND VENUS

The Interplanetary Magnetic Field (IMF) shows various kinds of structures and discontinuities on different scales, one of which is the Magnetic Hole (MH). This structure is characterized by a decrease in magnetic field strength and an increase in plasma density and/or temperature. Two special cases of MHs are discussed, the Linear MH (LMH) and Pseudo MH (PMH) where the magnetic field rotates less than 10° over the structure and between 10° and 45°, respectively.

The *MESSENGER* magnetometer data during the cruise phase from Venus to Mercury were used and the occurrence rate of MHs was determined as a function of radial distance from the Sun and categorized by the magnetic field rotation over the MH.



Histogram of the MHs occurrence rate as a function of radial distance and color coded after the rotational bins as given in the legend. The two dashed lines in the bottom panel show the average occurrence rates from Helios data.

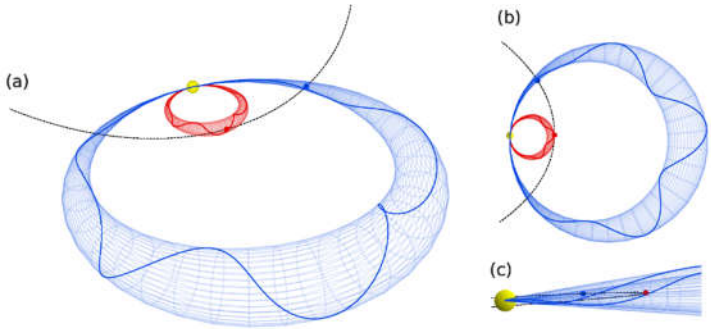
The occurrence rate of LMHs (blue) and PMHs (dark orange) does not change much between Mercury and Venus. The small difference between the occurrence rates over the observation interval rules out the "dilution" or "parametric decay" of the structures. The narrow range of widths between ~4 and ~30 s, assuming Bohm-like diffusion of the structures happen, which would make them larger, would argue for a constant creation and diffusion and (stochastic) decay of these structures between Mercury and Venus.

Volwerk et al., Ann. Geophys., 38, 51-60, 2020.

INTERPLANETARY CME RATE IN SOLAR CYCLE 25 & PSP DOUBLE CROSSINGS

The *Solar Orbiter* and *Parker Solar Probe (PSP)* missions are destined to make groundbreaking observations of the Sun and interplanetary space in this decade. Through simulations with the semi-empirical flux rope model (3DCORE), a particularly interesting case of a possible coronal mass ejection (CME) observation by *PSP* was found, which may happen when a CME erupts during times when *PSP* is near its aphelion (<0.1 AU). The same magnetic flux rope inside a CME was observed in-situ by *PSP* twice, by impacting its nose or front part and its leg or side part. In order to look at the odds of this unprecedented observing situation to happen, the in-situ CME rate valid for Earth as well as at *PSP* and *Solar Orbiter* was calculated, based on two predictions for the sunspot number (SSN, peak at 115 and 232). On the order of 1 to 10 possible *PSP* flux rope double crossings were found, which holds considerable promise to determine the structure of CMEs in the solar corona. A double crossing is essentially a multi-point in-situ CME observation very close to the Sun. Ideally, *Solar Orbiter* would image the event from a vantage viewing point or detect the same CME in-situ, further constraining the 3DCORE simulations. For the higher sunspot number prediction, during the next solar maximum around 2025, about five CMEs would impact Earth per month on average, which would form the strongest space weather impacts since the early 1990s.

Möstl et al., Astrophys. J., 903, 92, 2020.



Simulation of a PSP CME double crossing from different viewing angles (a-c). 3DCORE model flux rope at simulation time of +4 hours (red) and +26 hours (blue). Dashed line: PSP trajectory. Further imaging and in situ observations may be provided by Solar Orbiter, STEREO-A, SOHO, Wind, and BepiColombo.

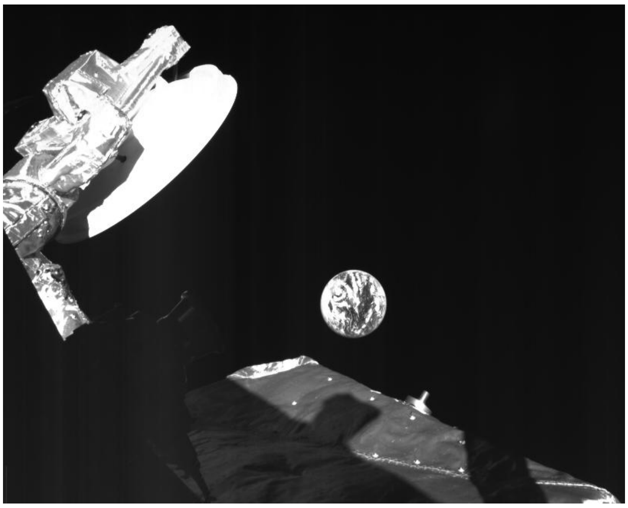
MERCURY

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

In 2020, *BepiColombo* experienced its first two planetary flybys: Earth in April and Venus in October.

BEPICOLOMBO

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



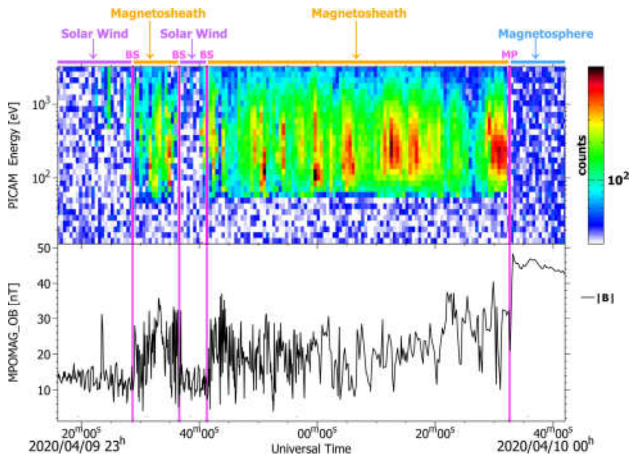
Selfies taken by the camera of BepiColombo's Mercury Transfer Module (MTM) as the spacecraft neared Earth (left) and passed Venus (right) during its gravity-assist manoeuvers in April and October
(© ESA/BepiColombo/MTM, CC BY-SA 3.0 IGO).

The first and only Earth flyby took place in April, with the closest approach at a distance of 12,677 km from the Earth's surface on 10 April, 04:45 UTC. Half a year later *BepiColombo* visited Venus for the first of two times around 15 October. Many sensors use the flybys for further calibration activities and for the first science measurements, including the three sensors with an IWF hardware contribution on both the European *Mercury Planetary Orbiter (MPO)* and the Japanese *Mercury Magnetospheric Orbiter (MMO)*.

The *MMO-MGF* (IWF PI-ship) magnetometer with its two sensors on the still stowed boom was switched on during the flybys and a number of other constellation and instrument check-out campaigns. The Earth flyby has been used for an evaluation of the scale factors and the exact orientation of the stowed sensors.

MPO-MAG (IWF technical management) has been monitoring the magnetic field almost continuously. Apart from the instrument calibration during the Earth flyby, *MPO-MAG* data have already been widely used for scientific evaluation of magnetospheric features during the two planetary flybys and interesting structures of the solar wind like a specific Coronal Mass Ejection, which could be measured in concert with the Solar Orbiter spacecraft.

PICAM (IWF sensor PI-ship), the ion mass spectrometer with imaging capability as part of the *SERENA* instrument suite on *MPO*, was operated in different science modes for about 20 hours near Earth and for 27 hours at Venus. The campaigns brought the first real science measurements, which significantly aid in the calibration and flight software update activities.



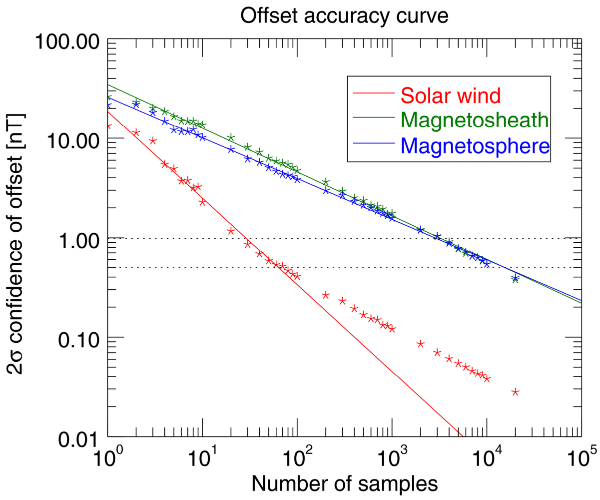
An example of *BepiColombo* observations during its Earth flyby. The top panel shows the ion spectrogram from *PICAM* and the bottom panel the total magnetic field from *MPO-MAG*. *BepiColombo* successfully captured the dynamics of plasma at the moment of entry from the interplanetary space to the Earth's magnetosphere.

DETERMINING MAGNETOMETER OFFSETS IN HERMEAN ENVIRONMENT

The offsets of a magnetometer are usually evaluated from observations of Alfvénic fluctuations in the pristine solar wind, if available. While *BepiColombo's MMO* orbit will indeed partially reside in the solar wind, *MPO* will remain within the magnetosphere at most times during the main mission phase. An alternative offset determination method, based on the observation of highly compressional fluctuations, the so-called mirror mode technique, becomes important in such orbit conditions.

To evaluate the method performance in the Hermean environment four years of *MESSENGER* magnetometer data were analyzed. They were calibrated by the Alfvénic fluctuation method and compared with the accuracy and error of the offsets determined by the mirror mode method in different plasma environments around Mercury. It is shown that the mirror mode method yields the same offset estimates and thereby confirms its applicability. Furthermore, the spacecraft observation time within different regions necessary to obtain reliable offset estimates is evaluated. Although the lowest percentage of strong compressional fluctuations were observed in the solar wind, this region is most suitable for an accurate offset determination with the mirror mode method. 132 hours of solar wind data are sufficient to determine the offset to within 0.5 nT, while thousands of hours are necessary to reach this accuracy in the magnetosheath or within the magnetosphere.

Schmid et al., Ann. Geophys., 38, 823-832-, 2020.



Relationship between the best-estimate offset and the number of samples to obtain this value with 95% confidence. The time interval to take one sample is 30 s. The solid lines represent the linear least squares fits of the offsets above 0.5 nT.

It is concluded that in the solar wind the mirror mode method might be a good complementary approach to the Alfvénic fluctuation method to determine the (spin-axis) offset of the *MMO* magnetometer. However, although the mirror mode method requires considerably more data within the magnetosphere, it might also be the most valuable scheme for *MPO* to determine the offsets accurately.

VENUS AND MARS

Venus and Mars are the Earth's nearest inner and outer planetary neighbors, respectively. Venus orbits the Sun at 0.7 AU in 224 days, has a radius slightly smaller than the Earth, and has a very dense atmosphere. Mars orbits the Sun at 1.5 AU in 687 days, has about half the radius of the Earth, and has a very tenuous atmosphere. Both planets do not have an internal magnetic field, although Mars does show remnant surface magnetization, which might indicate that the planet used to have a functioning dynamo. Through their interaction with the solar wind, however, a so-called induced magnetosphere is created.

2020 was a busy year for exploring the Red Planet. Three missions lined up for launch: NASA's *Perseverance*, the Emirate's *al-Amal (Hope)*, and China's *Tianwen-1*.

TIANWEN-1

China's Mars orbiter, lander, and rover mission will conduct a comprehensive remote sensing of the Red Planet, as well as surface investigation. IWF contributed to a magnetometer aboard the orbiter.

The Tianwen-1 team with the spacecraft (© CNSA).

INSIGHT

NASA's *InSight (INterior exploration using Seismic Investigations, Geodesy and Heat Transport)* landed on Mars in 2018. The *Heat flow and Physical Properties Probe (HP^3)* was designed to measure the internal heat flux of the planet as well as the thermal and mechanical properties of the regolith. The hammering of the "Mole" into Martian ground got stuck, caused by lacking friction of the regolith.

With the numerical model developed at IWF it could be demonstrated that the first half meter is the most difficult part of the insertion process. Throughout 2020 the "Mole" penetration attempts were further supported with the Instrument Deployment Arm and finally the hole that was formed around the "Mole" was filled in. At the same time due to seasonal effects and an increased dust load on the solar panels the energy situation of *InSight* became critical. Therefore, in February 2021 it was decided to discontinue the HP^3 deployment attempts.

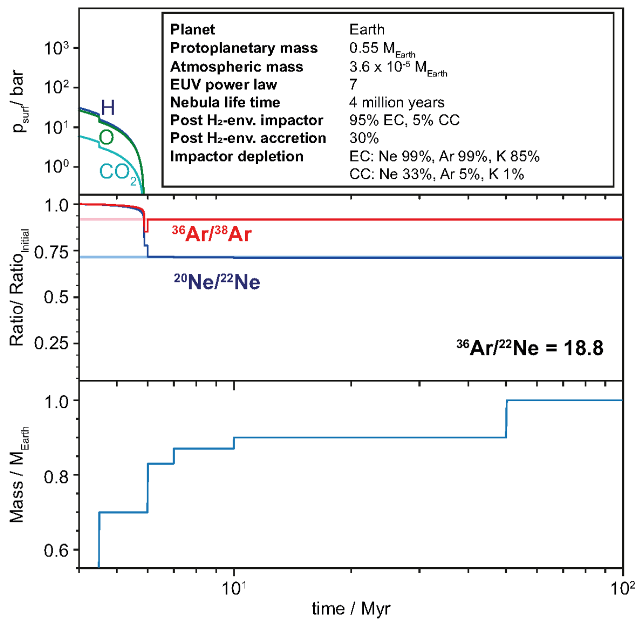
EARLY EVOLUTION OF EARTH AND VENUS

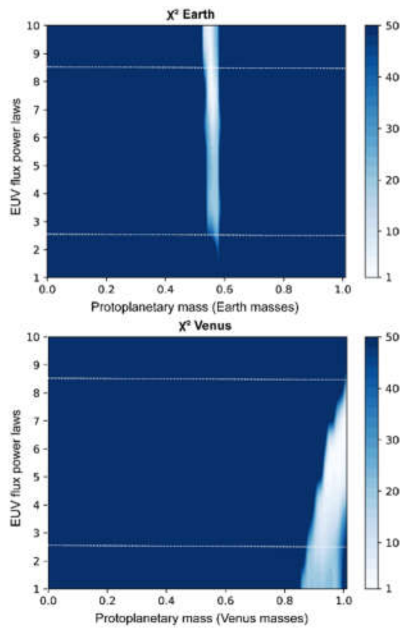
The atmospheric ^{36}Ar/^{38}Ar, ^{20}Ne/^{22}Ne, ^{36}Ar/^{22}Ne, noble gas isotope and elemental bulk ratios on Venus and Earth provide important information on their origin and evolution. For reproducing Earth's and Venus's present atmospheric isotope ratios, hydrodynamic upper atmosphere escape and smooth particle hydrodynamics impact models were applied to study losses of captured H_2-dominated primordial atmospheres for different proto-planetary masses. Additionally, a wide range of possible solar EUV evolution tracks and initial atmospheric compositions based on mixtures of captured nebula gas, outgassed and delivered material from planetary building blocks was added to the modeling of growing proto-planets. It was found that for outgassed noble gases and rock-forming elements from planetary building blocks with masses that are less than that of Earth's Moon the gravity is too weak so that all outgassed elements will escape immediately to space. For these bodies the loss rates of noble gases Ar and Ne are so high that there will be no fractionation of their isotopes. The studied planetary embryos, even though not isotopically fractionated, are strongly depleted in noble gases and moderately volatile elements.

Depending on the disk lifetime and the composition of accreted building blocks after disk dispersal, it was found from the reproduction of today's atmospheric Ar, Ne, and some bulk elemental ratios (see left figure), that early Earth's evolution can be explained if it had accreted masses of up to 0.58 M_{Earth} by the time the gas disk dissipated (top panel, right figure). If proto-Earth would have accreted a higher mass during this early period the Earth's present atmospheric Ar and Ne isotope ratios cannot be reproduced and for masses >0.75 M_{Earth}, Earth would have ended as an H_2/He-dominated sub-Neptune. It was also discovered that if proto-Venus captured a primordial atmosphere from the gas disk it should have grown to masses between 0.85 - 1.0 M_{Venus} until the disk dissipated (bottom panel, right figure). However, in the case of Venus, a future spacecraft to our inner neighbor should carry out new precise re-measurements of atmospheric noble gases that will better constrain the material that was involved in the planet's accretion history and possibly also the EUV activity evolution of the young Sun.

Lammer et al., Space Sci. Rev., 216, 74, 2020.

Lammer et al., Icarus, 339, 113551, 2020.





Left: Reproduction of Earth's present atmospheric Ar and Ne isotope ratios by assuming a composition based on the analysis of isotopic data from lithophile-siderophile elements. Right: Statistical χ^2 parameter study of the isotope evolution for proto-Earth and -Venus. Today's ratios of both planets can be reproduced within the white areas if the young Sun was between a slow (EUV power laws: 1-5) and a moderate rotating young G star (EUV power laws (>5-10). The EUV fluxes within the two horizontal lines can reproduce both planets simultaneously.

JUPITER AND SATURN

Jupiter and Saturn, the two largest planets in our solar system, both have several dozens of moons. For Jupiter, the most prominent moons are the four Galilean satellites, and three of them will be visited frequently by the future *JUICE* spacecraft. For Saturn, Titan is clearly the most prominent satellite with its dense atmosphere consisting of nitrogen and methane.

Although *Cassini* had 126 close Titan flybys, no lightning has been detected. On the hardware side, the *MAGSCA* sensor for *J-MAG* was delivered to Imperial College London for integration.

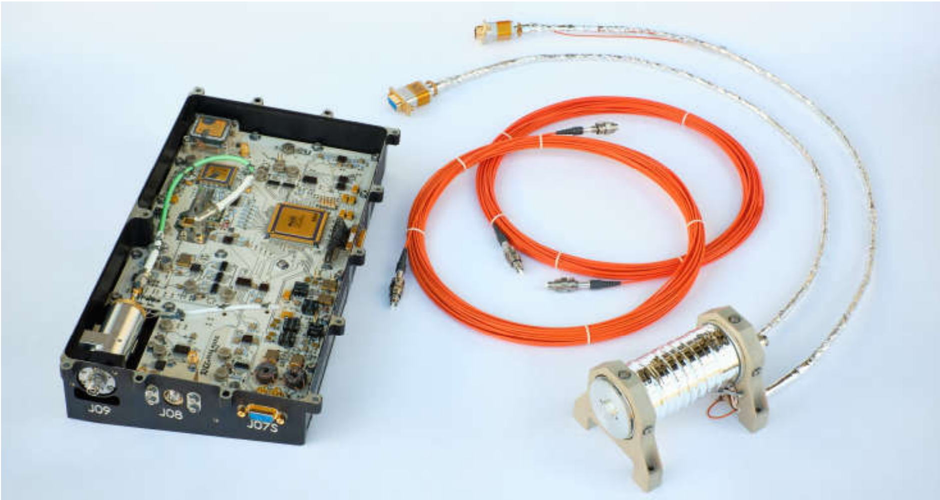
JUICE

ESA's first large (L-class) mission *JUpiter ICy moons Explorer (JUICE)* is planned to be launched in June 2022 and to arrive at Jupiter in late 2029, starting a 3.5 years discovery mission. It will make detailed observations of the gas giant and three of its largest moons, Ganymede, Callisto, and Europa. These three moons are thought to have water oceans below their icy surfaces. Towards the end of the mission *JUICE* will orbit Jupiter's largest moon Ganymede. In 2020, ESA and the prime contractor Airbus have begun with the assembly of the flight spacecraft in Friedrichshafen, Germany.

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

In 2020, the qualification sensor needed to be reworked due to a problem with the optics at the very low qualification temperature of -160 °C and the flight model was assembled, tested and delivered to ICL for integration into the *J-MAG* instrument. The *Particle Environment Package (PEP)* is a plasma package with sensors to characterize the plasma environment of the Jovian system and the composition of the exospheres of Callisto, Ganymede, and Europa. IWF participates in the *PEP* consortium on Co-Investigator basis in the scientific studies related to the plasma interaction and exosphere formation of the Jovian satellites.

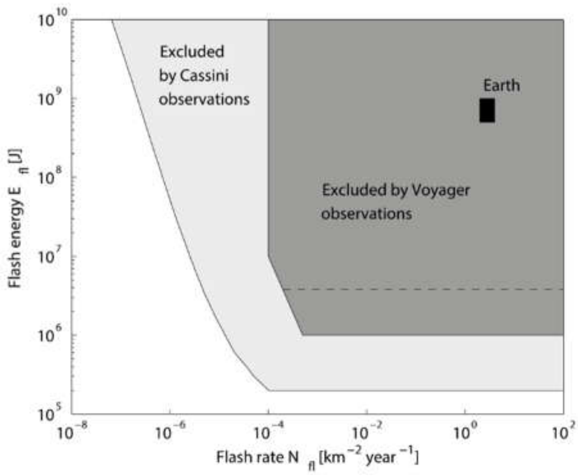
IWF was also responsible for the calibration of the radio antennas of the *Radio and Plasma Wave Investigation (RPWI).* In August 2020, the *RPWI* instrument was completed and shipped to Airbus in Friedrichshafen for implementation on the spacecraft.



Flight model of the atomic scalar sensor together with the related front-end electronics and the optical fibers (with orange jacket), which connect sensor and electronics (© Andreas Pollinger/IWF/ÖAW, CC-BY 4.0).

NO LIGHTNING ON TITAN

The Saturn-orbiting *Cassini* spacecraft completed 126 close Titan flybys from 2004 until the end of the mission in September 2017. During almost all of them the *Radio and Plasma Wave Science (RPWS)* instrument was turned on to search for radio emissions from Titan lightning. However, a careful inspection has revealed no corresponding emissions. This puts new and strong constraints on the permissible flash energy and flash rate of potential Titan lightning, as detailed in the figure below.



Flash energy of potential Titan lightning versus its rate; various regions excluded by *Voyager 1* and *Cassini* observations are shown as gray areas.

In this figure, the black square shows the flash energy and rate of typical Earth lightning. The dark gray region was excluded by the single *Voyager 1* observation in 1980. The light gray region is the additional region to be excluded after the non-detection of Titan lightning by *Cassini*. The white region marks the flash energy and rate combinations, which are left for potential Titan lightning. This means that any lightning on Titan must be either very weak (5000 times weaker than typical Earth lightning), very rare (just ~80 flashes per year all over Titan), or does not exist at all. The latter could be due to cloud electric fields being too low to initiate a discharge. This finding has important implications for the prebiotic chemistry of Titan's atmosphere.

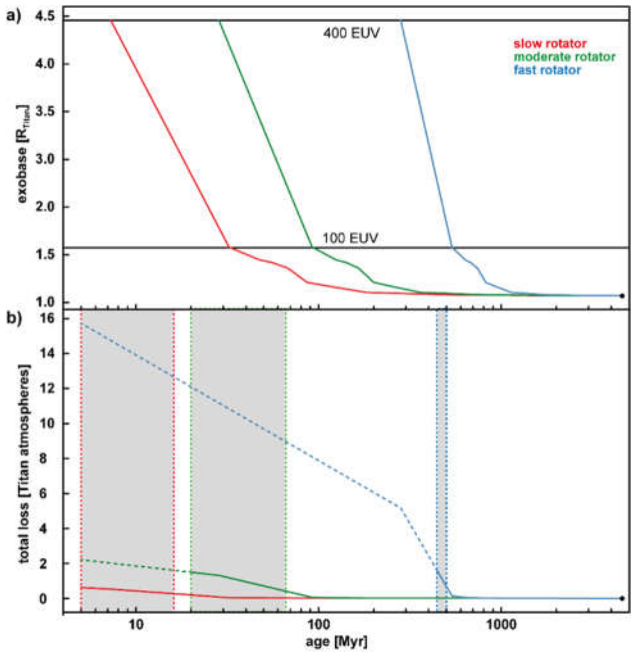
Fischer G. et al. J. Geophys. Res., 125, e2020JE006496, 2020.

NITROGEN ATMOSPHERES OF THE ICY BODIES IN THE SOLAR SYSTEM

Titan is the only body in the solar system, besides Earth, that holds a substantial N_2-dominated atmosphere, but its origin and evolution is still debated. A 1D upper atmosphere model and simple scaling laws were used to study thermal and non-thermal escape of nitrogen over Titan's history. It was found that, depending on whether the Sun was a slow, moderate, or fast rotator, Titan could have lost between 0.5 and 16 times the present-day atmospheric N_2-reservoir. This indicates that if the Sun were no slow rotator, Titan's atmosphere must have outgassed later-on in its history, otherwise it could not have been maintained until the present day.

These simulations also show that Titan's present-day atmospheric ratio of $^{14}N/^{15}N$ ~167 could not have been changed significantly by atmospheric escape over time with the most likely initial value being ~166-172. This also indicates that Titan's original building blocks must have been different from those of the Earth's N_2. While the latter originated from primitive meteorites, Titan's N_2 likely resulted from NH_3 and complex organics within cometary ices having $^{14}N/^{15}N$ ratios comparable to Titan's initial value. The N-bearing molecules were decomposed in Titan's interior and subsequently outgassed to form its present atmosphere.

Scherf et al., Space Sci. Rev., 216, 123, 2020.



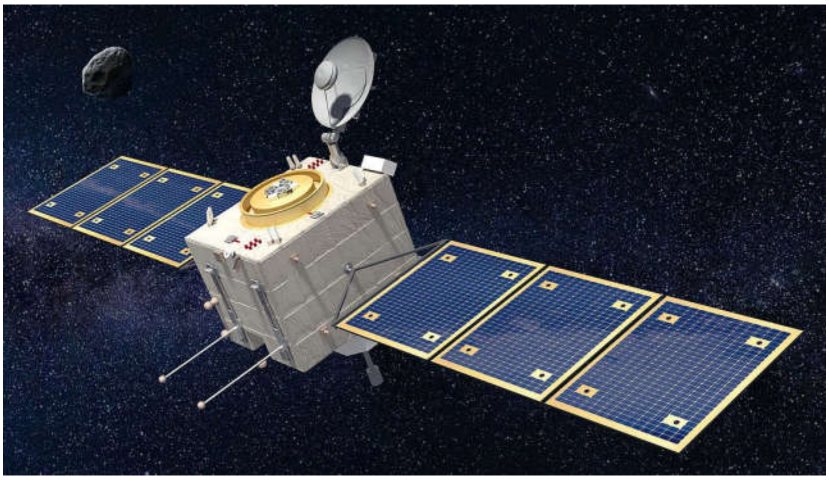
Panel a: Titan's exobase level over time for a slow, moderate and fast rotator. Panel b: The loss of nitrogen over time. The gray areas indicate the earliest possible origin of Titan's atmosphere for the different solar rotators.

COMETS AND DUST

Comets and dust are the remains of the proto-planetary cloud surrounding the new-born Sun, from which the planets were created. Although, dust can also be created at a later stage through collisions of e.g. asteroids. After the groundbreaking *Rosetta* mission ESA's first fast (F-class) mission *Comet Interceptor* has kicked off.

COMET INTERCEPTOR

Comet Interceptor's primary science goal is to characterize, for the first time, a dynamically-new comet or interstellar object, including its surface composition, shape, structure, and the composition of its coma. It will consist of three spacecraft, which will give a unique, multi-point "snapshot" measurement of the comet solar wind interaction region, complementing single spacecraft observations made at other comets.



Artist's impression of *Comet Interceptor* (© OHB Italia).

A new comet, fresh from the Kuiper belt or the Oort cloud, is to be spotted by Earthbound telescopes, its ephemeris determined and then selected as a target if it crosses the ecliptic at an appropriate distance from the Earth. If available, an interstellar object like 1I/'Oumuamua or 2I/Borisov, can also be defined as a target.

Comet Interceptor will be launched with ESA's *ARIEL* spacecraft in 2029. It will be a multi-element spacecraft comprising a primary platform (*A*), which also acts as the communications hub, and two sub-spacecraft (*B1* built by JAXA and *B2* built by ESA), allowing multi-point observations around the target.

IWF will build the DPU for the *MANIaC* package on the primary platform and is involved in the *Dust-Field-Plasma (DFP)* package, for which it will contribute the front-end electronics for the magnetometer on the *B2* spacecraft. In 2020, the work for both instruments was focused on establishing the instrument, performance and interface requirements, which has led to successful completions of the Preliminary Requirements Reviews by the end of the year.

III - EXOPLANETARY SYSTEMS

The field of exoplanet research (i.e. investigation of planets orbiting stars other than the Sun) has developed strongly in the past decades. Since the discovery of 51 Peg b in 1995, the first detected exoplanet orbiting a Sun-like star, about 4500 exoplanets, most in planetary systems, are now known. Improved instrumentation and analysis techniques have led to the detection of smaller and lighter planets, down to Earth-size, Earth-mass planets, some orbiting in the habitable zone of the cooler stars. However, hot Neptunes and (ultra-)hot Jupiters are still prime targets for atmospheric characterization, mostly because of their larger radii, which indicate the presence of a volatile-rich atmosphere that facilitates observations and analyses.

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

CHEOPS data collected during the first stages of science operations have been used to constrain the reflective properties, the day-side temperature, and the planetary orbital obliquity of the hot Jupiter WASP-189b. The data have further demonstrated the excellent quality of *CHEOPS'* photometry.

A tool enabling the use of the cloudy non-local thermodynamic equilibrium radiative transfer code for computing exoplanetary transmission spectra has been developed. It has been demonstrated that the code has a wide applicability range, spanning from Earth-like planets to ultra-hot Jupiters, and that it will be a key tool for interpreting both ground- and space-based transmission spectroscopy observations.

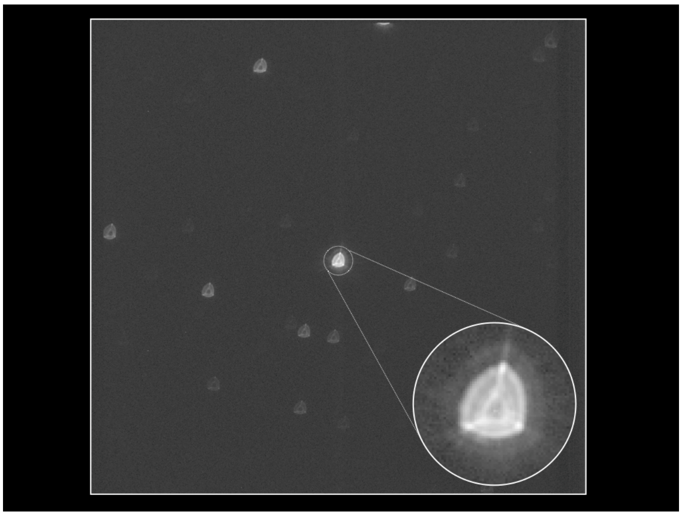
KELT-9b is one of the hottest known exoplanets (Illustration: Harald Ritsch, © ÖAW).

CHEOPS

CHEOPS (CHaracterisingExOPlanetSatellite), successfully launched on 18 December 2019, has started regular science operations on 18 April 2020. The mission aims at studying exoplanets by means of ultra-high precision photometry. The main science goals are to find transits of small planets, known to exist from radial-velocity surveys, measure precise radii for a large sample of planets to study the nature of Neptune- to Earth-sized planets, obtain precise observations of transiting giant planets to study their atmospheric properties, and look for new planets particularly in already known systems. IWF provided the *Back-End-Electronics (BEE)*, one of the two on-board computers, which controls the data flow and the thermal stability of the telescope structure. The institute also developed the mission's signal-to-noise calculator. Within the guaranteed time observations of the *CHEOPS* consortium, IWF is also responsible for two observing programs aiming at improving our understanding of the mass-radius relation of planets and of processes affecting planetary atmospheric evolution.

Between January and April 2020, *CHEOPS* went through its commissioning phase that has culminated in the demonstration of the achievement of the mission requirements. In particular, *CHEOPS* shall be able to detect Earth-size planets transiting G5 dwarf stars (i.e. 0.9 solar radii) in the V = 6-9 magnitude range by achieving a photometric precision of 20 ppm in 6 hours of integration time. In the case of K-type stars (i.e. 0.7 solar radii) in the V = 9-12 magnitude range, *CHEOPS* shall be able to detect transiting Neptune-size planets achieving a photometric precision of 85 ppm in three hours of integration time. To demonstrate the achievement of the science requirements, during commissioning *CHEOPS* observed HD88111, which is a magnitude V = 9.2 G-type star for which *GAIA* provides a radius of 0.9 solar radii. The photometric precision and stability were estimated by finding the transit depth that can be detected with a signal-to-noise ratio of one. For a six hours period of observations, the achieved photometric precision was 15.5 ppm that is well within the requirements. Furthermore, *CHEOPS* observed TYC 5502-1037-1 that is a magnitude V = 11.9 K-type star with a radius of 0.7 solar radii, achieving a 75 ppm precision, compliant with the science requirements. These precisions have been achieved without any detrending, therefore reflecting the intrinsic stability of *CHEOPS*.

A few stars known to host planets were also targeted during commissioning as part of the end-to-end validation of the operational process. The giant planet KELT-11b was among these targets. The planet orbits an evolved sub-giant star of magnitude V = 8 in a period of about five days. The data were analyzed employing “pycheops” that is a python code developed by the *CHEOPS* science team specifically for the analysis of *CHEOPS* data. Considering the stellar radius given in the literature, the results of the data analysis led to a planetary radius measurement in agreement with that provided in the literature, but with an about five times smaller uncertainty.



***CHEOPS* image of its first target star (© ESA/Airbus/*CHEOPS* Mission Consortium).**

CUTE

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

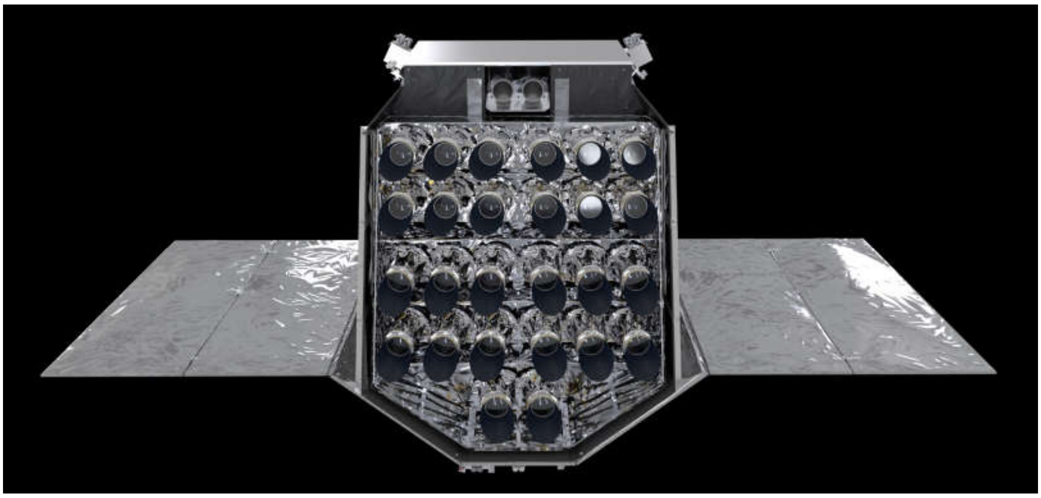
IWF is the only technological contributor to the mission outside of the University of Colorado (Boulder), where *CUTE* is being developed. IWF is responsible for the development of the data simulator, of the data signal-to-noise calculator, of the ground data reduction software, and of the algorithms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

In 2020, IWF has finalized the development of the *CUTE* data signal-to-noise calculator and has focused on the development of the data reduction software that will reach completion following laboratory tests on the flight instrument to be performed in 2021 and following the collection of commissioning data right after launch.

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. IWF takes part in two 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 I*nstrument Controller Unit (ICU)* with the development of the *Router and Data Compression Unit (RDCU)*. Launch is expected in 2026.

PLATO consists of 24 telescopes for nominal and two telescopes for fast observations. Each telescope has its dedicated front-end-electronics, reading and digitizing the CCD content. Twelve nominal and two fast DPUs collect the data from the front-end-electronics and extract the areas of interest. The *RDCU* is a key element in the data processing chain, providing the communication between the DPUs and the *ICU*. The second task of the *RDCU* is the lossless compression of the science data. For performance reasons, the compression algorithm is implemented in an FPGA.



Artist's impression of ESA's *PLATO* spacecraft. This top view highlights the unique payload that comprises 26 cameras. Two smaller cameras, seen at top in this image, are not part of the payload, but rather startrackers used for navigation (© ESA/ATG medialab).

Main tasks in 2020 were the finalization and manufacturing of the *RDCU* engineering models, the continuation of the design of the VHDL code and the finalization of the test environment. The design of the compressor, in particular the communication with the *ICU*, has been completely redesigned to comply with the increased number of imagettes. The latest design of the *RDCU* is compliant with all requirements and can handle 20% more scientific data than actually requested.

ARIEL

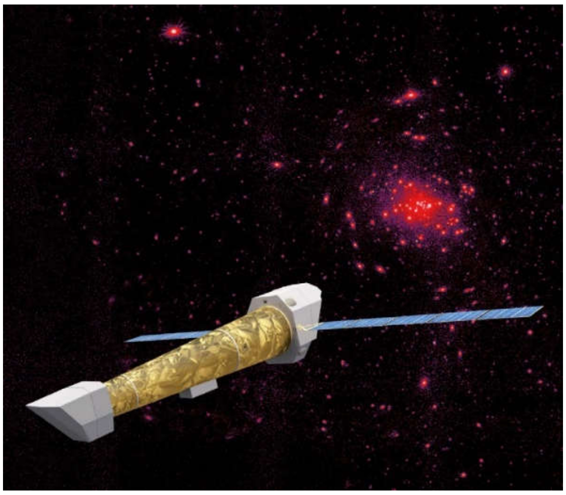
ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) is ESA's fourth medium (M-class) mission, led by University College London, to be launched in 2028. It will investigate the atmospheres of several hundred exoplanets to address the fundamental questions on how planetary systems form and 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.

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

ATHENA

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

The institute will contribute to the *Wide Field Imager (WFI)* with the development of the *Central Processing Module (CPM)*. At present, the team is executing a study to classify the performance increase when using the latest processor technology. Key topics are the performance of the processor cores, efficiency of the internal data bus system, the multi-core configuration, but also the communication between the four processor cores.



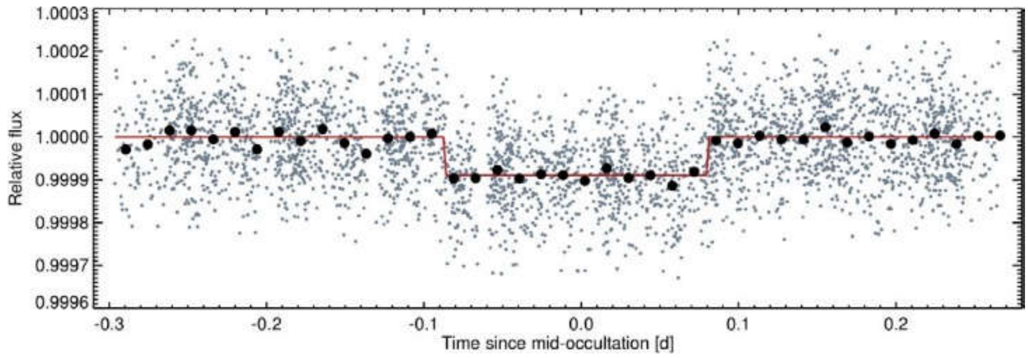
Artistic view of *ATHENA* (© IRAP, CNES & ESA, ACO) looking at the Andromeda Galaxy (© N. Vulic).

HOT DAYSIDE & ASYMMETRIC TRANSIT OF WASP-189B SEEN BY CHEOPS

As *CHEOPS* carries out its observations in a broad optical passband, it can provide insights into the reflected light from exoplanets. It can constrain the short-wavelength thermal emission for the hottest planets by observing occultations and phase curves. Observations of the hot Jupiter WASP-189b, a two Jupiter-masses planet orbiting an A-type star, have been collected with *CHEOPS* during the first stage of science operations. Four occultations of WASP-189b have been detected at high significance in individual measurements resulting to an occultation depth of 87.9±4.3 ppm. Comparisons with model predictions indicate that the occultation measurement is consistent with an unreflective atmosphere heated to a temperature of 3435±27 K, when assuming inefficient heat redistribution. Furthermore, two additional *CHEOPS* transits of WASP-189b reveal an asymmetric shape that is attributed to gravity darkening of the host star caused by its high rotation rate. These measurements have been also used to refine the planetary parameters, finding an about 25% deeper transit compared to literature. Also, the data enabled one to measure a projected orbital obliquity of 86.4+2.9-

4.4 deg, in good agreement with a previous spectroscopic measurement, and to derive a true obliquity of 85.4±4.3 deg. The data reveal that for a 6.6 mag star, and using a one-hour binning, *CHEOPS* delivers data with a residual root mean square error between 10 and 17 ppm on the individual light curves, and 5.7 ppm when combining the four transits.

Lendl et al., Astron. Astrophys., 643, A94, 2020.

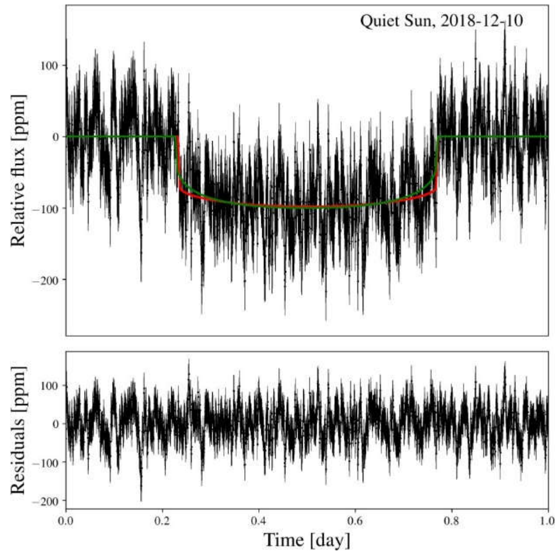


Corrected and phase-folded *CHEOPS* occultation light curve of WASP-189b. Black points show the light curve binned into 20-minute intervals, the red line shows the final occultation model.

MITIGATING FLICKER NOISE IN HIGH-PRECISION PHOTOMETRY

The short-timescale stellar photometric variability ("flicker") can reach amplitudes comparable to the transit depth of Earth-sized planets. Characterizing the statistical properties of flicker noise and quantifying its impact are therefore critical. Solar observations have been used to identify flicker noise and simulate realistic transits across the solar disk to estimate the errors made on the transit parameters due to the presence of real solar noise. *Kepler* observations have been further used to extend the study to a wider parameter range. It was shown that stellar granulation is a stochastic colored noise. Both the flicker correlation timescales and amplitudes increase with the stellar mass and radius. Biases can occur if these correlations are not taken into account, when fitting for the parameters of transiting exoplanets. In particular, errors of up to 10% on the planet-to-star radius ratio have been found for an Earth-sized planet orbiting a Sun-like star. Therefore, flicker will significantly affect the inferred parameters of transits observed at high precision with *CHEOPS* and *PLATO* for F- and G-type stars.

Sulis et al., Astron. Astrophys., 636, A70, 2020.

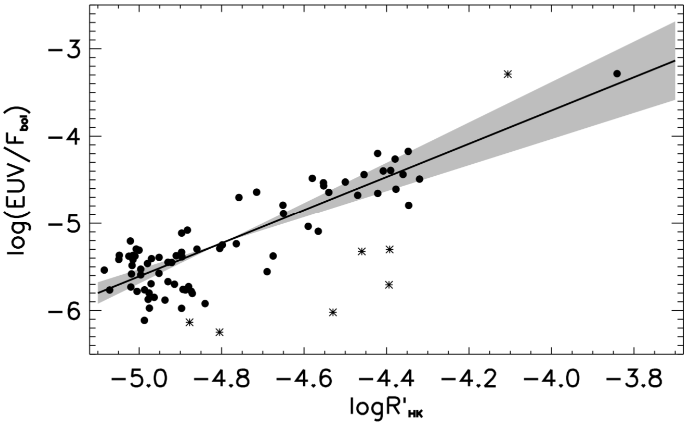


Top: Artificial transit of an Earth-sized planet crossing the disk center of the Sun (black). The transit model with the true input parameters is shown in green and the model computed using the inferred parameters in red. The error on the planet-to-star radius ratio is around 2% in this example. Bottom: Residuals based on the inferred transit model.

CaII H&K STELLAR ACTIVITY PARAMETER AS A PROXY FOR STELLAR EUV FLUXES

Atmospheric escape is an important factor shaping the exoplanet population and hence drives our understanding of planet formation. Atmospheric escape from giant planets is driven primarily by the stellar X-ray and extreme-ultraviolet (EUV) radiation. Furthermore, EUV and UV radiation power disequilibrium chemistry. Our understanding of atmospheric escape and chemistry, therefore, depends on our knowledge of the stellar UV fluxes. While the far-ultraviolet fluxes can be observed for some stars, most of the EUV range is unobservable due to the lack of a space telescope with EUV capabilities and, for the more distant stars, due to interstellar medium absorption. Thus, it becomes essential to have indirect means for inferring EUV fluxes from features observable at other wavelengths. Analytic functions have been developed for predicting the EUV emission of F-, G-, K-, and M-type stars from the $\log R'_{HK}$ activity parameter that is commonly obtained from ground-based optical observations of the CaII H&K lines. The scaling relations are based on a collection of about 100 nearby stars with published $\log R'_{HK}$ and EUV flux values, where the latter are either direct measurements or inferences from high-quality far-ultraviolet (FUV) spectra. The scaling relations return EUV flux values with an accuracy of about three, which is slightly lower than that of other similar methods based on FUV or X-ray measurements.

Sreejith et al., Astron. Astrophys., 644, A67, 2020.

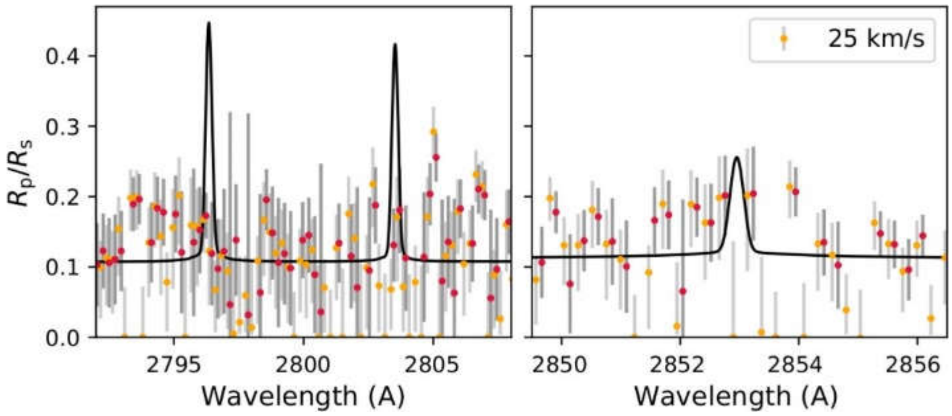


Correlation between the stellar activity index (logR'$_{HK}$) and EUV flux for F-, G-, and K-type stars. The RMS on log(EUV/F_{bol}) after the fit is 0.40. Stars removed as a result of a sigma clipping algorithm applied to remove outliers are indicated by the asterisks. The gray areas indicate the uncertainties on the fit.

NEAR-ULTRAVIOLET TRANSMISSION SPECTROSCOPY OF HD209458b

The inflated transiting hot Jupiter HD209458b is one of the best studied objects since the beginning of exoplanet characterization. A re-analysis of near-ultraviolet (NUV) transmission observations of HD209458b enabled us to detect ionized iron (FeII) absorption in a 100 Å-wide range around 2370 Å, lying beyond the planetary Roche lobe. However, absorption of equally strong FeII lines expected to be around 2600 Å has not been detected. Neutral magnesium (MgI), ionized magnesium (MgII), and neutral iron (FeI) have also not been detected. These results avoid the conflict with theoretical models present on the basis of previous analyses, which detected MgI but did not detect MgII from this same dataset. The data reveal evidence for the presence of strong hydrodynamic escape that carries atoms as heavy as iron beyond the planetary Roche lobe, even for planets less irradiated than extreme ultra-hot Jupiters such as WASP-12b and KELT-9b. The detection of iron and non-detection of magnesium in the upper atmosphere of HD209458b can be explained by a model in which the lower atmosphere forms (hence, sequesters) primarily magnesium-bearing condensates, rather than iron condensates, as suggested by current microphysical models. The inextricable synergy between upper- and lower-atmosphere properties highlights the value of combining observations that probe both regions.

Cubillos et al., Astrophys. J., 159, 111, 2020.

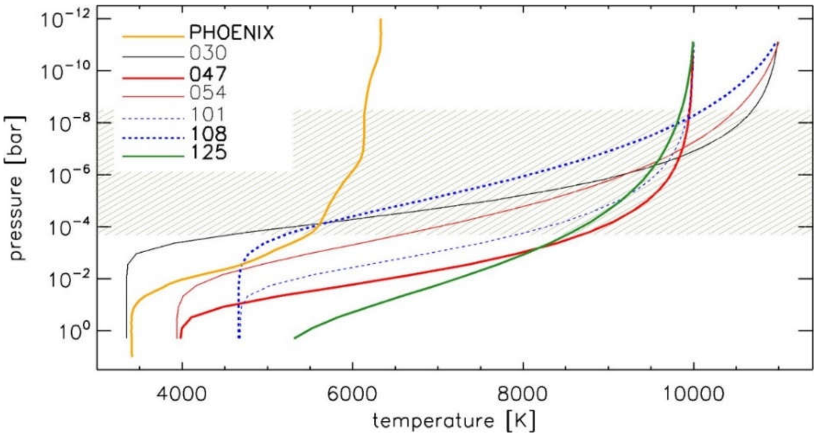


HD209458b transmission spectrum around the MgII h&k (left) and MgI (right) resonance lines at 25 km/s spectral resolution. The yellow and red dots denote the transit depths obtained from two different data analysis methods, the gray lines show the error bar (see legend). A horizontal shift has been implemented for visibility. The black solid lines show the magnesium absorption profiles based on the densities obtained from a recent upper atmosphere model uncapped at the Roche lobe boundary. No significant absorption feature has been detected at the wavelengths of the magnesium lines.

CONSTRAINING THE ATMOSPHERIC TEMPERATURE STRUCTURE OF KELT-9b

Observationally constraining the atmospheric temperature-pressure (TP) profile of exoplanets is an important step forward for improving planetary atmosphere models. The observed transmission spectra of the Hα and Hβ lines have been employed to constrain the TP profile of the ultra-hot Jupiter KELT-9b. Almost 150 one-dimensional TP profiles have been constructed varying the lower and upper atmospheric temperatures, as well as the location and gradient of the temperature rise. For each TP profile, transmission spectra of the Hα and Hβ lines have been computed employing the Cloudy radiative transfer code, thus accounting for non-local thermodynamic equilibrium (NLTE) effects. The TP profiles leading to the best fit of the observations are characterized by an upper atmospheric temperature of about 10000 K and by an inverted temperature profile at pressures higher than 10^{-4} bar. The assumption of local thermodynamic equilibrium leads to overestimate the level population of excited hydrogen by several orders of magnitude, and hence to significantly overestimate the strength of the Balmer lines. Modeling the atmospheres of ultra-hot Jupiters requires one to account for metal photo-ionization and NLTE effects.

Fossati et al., Astron. Astrophys., 643, A131, 2020.



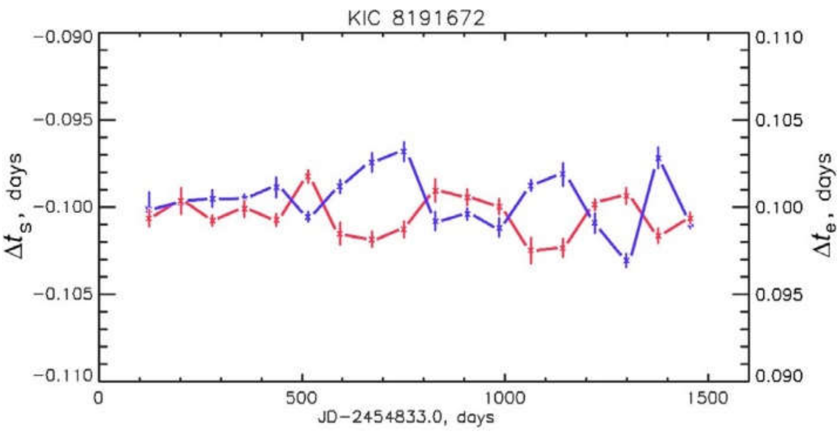
TP profiles (for different runs) best fitting the observed Hα and Hβ lines. The thicker lines indicate the three TP profiles fulfilling stricter conditions set for the line fit. The hatched area shows the main formation region of the Hα and Hβ lines according to the three best fitting models.

VARIABILITY OF TRANSIT LIGHT CURVES OF KEPLER OBJECTS

Hitherto, the study of exoplanetary transit timing and duration variability supposed the transit light curves (TLCs) to be symmetric, suggesting a priori a spherical shape for the transiter. As a result, the independent positions of transit borders are unknown. Using a-quadratic approximation for the independently considered start-, end-, and minimum-parts of the long-cadence phase-folded TLCs of different types of exoplanets, provided by the *Kepler* space telescope, their variability is checked for the first time. Temporal and cross-correlation analysis of the TLCs timing parameters over the whole observation period of *Kepler* (> 3 years) enable detection and diagnostics of the varying transit borders and TLCs' asymmetry. Among the considered TLCs of 98 *Kepler* Objects of Interest (KOIs), 15 confirmed giant exoplanets and five objects with still debatable status (probably non-planets) show variations in their transit timing parameters at timescales from ≈400 to > 1500 days. These variations are especially well manifested as an anti-correlation between the transit start- and end-time, indicating variability in the dimensions of transiting shadows.

Also the objects with well pronounced oscillations of transit border timing and asymmetry were found. The discovered variability of transit timing is an important indicator of the large-scale non-stationary processes in the atmospheres of KOIs, as well as dust and aerosol generation in their upper layers and in their close vicinity. A catalog of the most peculiar objects, which deserve further investigation and detailed modeling was elaborated.

Arkhypov et al., Astron. Astrophys., 638, A143, 2020.



Anti-correlated variations of the start- (Δt_S, red) and end- (Δt_e, blue) time for the KOI 18.01 revealed in the TLC of KIC 8191672.

IV - SATELLITE LASER RANGING

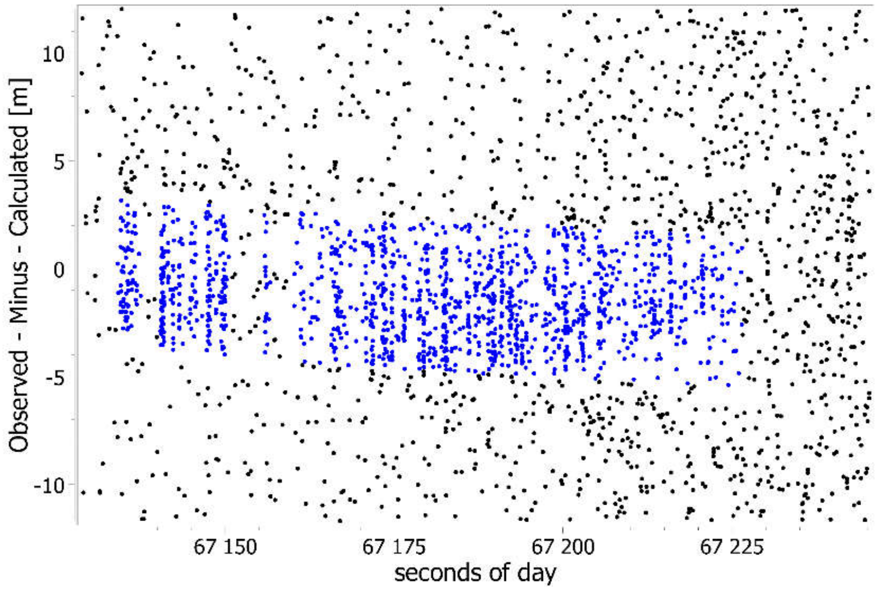
In addition to routinely tracking more than 150 targets, which are equipped with laser retro-reflectors, the Satellite Laser Ranging (SLR) station of IWF is working on various international projects.

Recent highlights include a publication in "Nature Communications" presenting first successful daylight space debris laser ranging, MHz laser ranging with millimeter accuracy both during day and night, and a new technique called quanta photogrammetry to measure unique light curve fingerprints of tumbling satellites and space debris.

DAYLIGHT SPACE DEBRIS LASER RANGING

The daylight space debris laser ranging observation routine consists of the following steps: the tracking of a target is usually started at elevations above 15°. The target is visualized against the blue sky background using a 20 cm piggyback telescope. As soon as the target is detected using a self-developed real-time detection software and the determined offsets are used to correct the inaccurate orbit predictions and to center the target within the field of view of the SLR telescope. Additional across-track offsets are corrected by applying pointing offsets to the receiving telescope. Varying biases are continuously corrected during tracking, primarily by correcting the time bias. Range biases of the target due to two line element (TLE) errors cannot be estimated via image analysis and the only chance to apply corrections to the predictions is by shifting the activation time of the detector. The closer the activation of the detector is to the arrival time of a reflected photon the higher the chances of detection are.

The space debris laser ranging search routine is an iteration process consisting of applying time biases, optically centering the target and experimentally shifting the detector activation times. Four successful space debris passes were measured between March and October 2019. Space debris laser ranging measurements were regarded as daylight passes if the elevation of the Sun was above the horizon. Three different types of SL (Sea Launch) rocket bodies originating from Zenit, Tsyklon or Vostok launches between 1971 and 1995 were observed. The maximum Sun elevation during the measurement was 39° at 10:31 local time on 22 March 2019. The observed-minus-calculated residuals of an SL-16 rocket body relative to the predicted pass (corrected by the real-time time bias applied to center the target) are displayed in the figure.



Daylight space debris laser ranging results to an SL-16 upper stage rocket body (NORAD ID: 22803). The figure shows the orbit corrected Observed-Minus-Calculated Residuals [m] vs. the seconds of day on 2019/10/01 at a Sun elevation of 11.5°. Identified photons from the rocket body are highlighted in blue.

The measurement lasted for approximately 100 s. A slope within the reflected photons indicates that the time bias used to center the target was slightly underestimated, which is related to imperfect alignment of the optical axis of the piggyback telescope. Due to the remaining time bias, the object moves to regions further away from the initial detector activation time and the trace of the debris within the noise would soon disappear. Once recognizing the returns from the object, the observer hence shifts the triggering time towards the returning photons, increasing the detection probability. A correct time bias results in returns appearing as a straight line within the residuals. Applying the time and range biases to the predicted orbit, it is possible to match the measured values to predicted ones resulting in residuals close to zero. Returns coming from the front and back of the body are statistically detected corresponding to range differences of up to 8 m giving an indication of the rocket body's size.

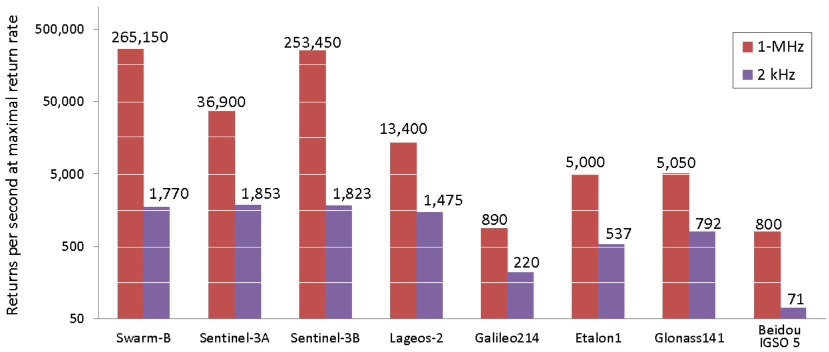
These daylight space debris laser ranging results guide the way to significantly increasing potential observation times. Depending on the season, for the Graz SLR station twilight conditions occur for a maximum of 6 h per day while daylight lasts for 8-16 h, increasing potential observation times in Graz up to 22 h. The increased coverage will encourage an observation network of space debris stations to be formed (similar to the International Laser Ranging Service), which could immediately react in case of conjunction warnings targeting a certain object rapidly improving the predictions. Improved predictions are central in decision-making with respect to avoidance maneuvers. In addition to that, highly accurate orbits are crucial for future active removal or laser nudging missions.

Steindorfer et al., Nat. Comm., 11, 3735, 2020.

MHZ LASER RANGING DEMONSTRATION

In the past 20 years, the kHz SLR technology was practiced widely in the International Laser Ranging Service (ILRS) network. Ultra-high repetition rate laser ranging (up to MHz) is the next promising strategy for future SLR. Increased repetition rates, ultra-short pulse width and low pulse energy can significantly improve the performance of SLR in terms of data density, accuracy, precision and stability to further enhance its unique contributions to the International Terrestrial Reference Frame.

In July 2020, the SLR station in Graz demonstrated 1 MHz SLR using a laser with a very low pulse energy of ~7.8 µJ. Targets from low Earth orbits up to inclined geosynchronous orbits were successfully tracked during nighttime up to a maximum slant range of 38,000 km. Among those, a maximum return rate of up to 53% was achieved, equivalent to 265,000 returns per second for the satellite *Swarm-B*. Compared to the conventional 2 kHz SLR system in Graz, the 1 MHz SLR system leads to significantly higher return rates in all orbital regimes. According to the ILRS normal point (NP) algorithm, this will significantly improve the precision of the final NP results in view of statistical errors. Consequently, it will also lead to an increased temporal resolution for distinguishing individual retro-reflector cubes, analyzing the spin rate, spin axis motion, signature and attitude of satellites and space debris objects.



A comparison of returns per second between Graz 2 kHz system (in the year 2020) and the 1 MHz demonstration in different orbits from Low Earth Orbit (LEO) up to Inclined Geosynchronous Orbit (IGSO). It shows that a 1 MHz system improve by up to two magnitudes for some LEO satellites (*Swarm*, *Sentinel*), and up to one magnitude more data for high orbiters (e.g. *Beidou*).

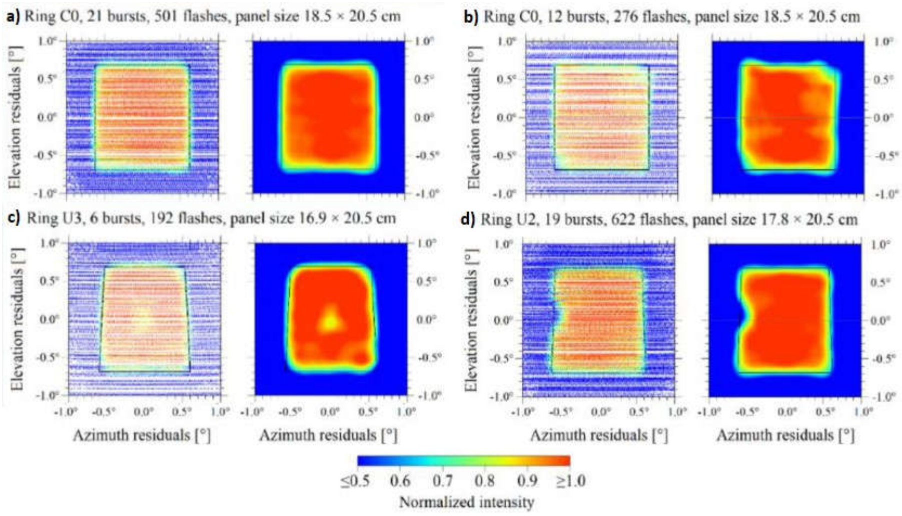
Currently, SLR Graz tracks uncooperative space debris with a 16 Watt, 200 Hz laser ranging. Although the lower pulse energy will decrease the detection probability, this can be compensated by increasing the laser repetition rate. A new MHz laser with increased power will be installed as a next step to further test this potential application.

QUANTA PHOTOGRAMMETRY

The conventional detection of Micro-Meteoroid and Orbital Debris (MMOD) impacts on satellites is based on in-situ sensing or direct, visual inspection of the retrieved surface elements exposed to the particle flux and thus requires active in-orbit operations. Quanta Photogrammetry (QPM) is an optical method for remote detection of surface structural anomalies of passive satellites by measuring solar photon flux reflected off the satellite surface towards the ground detection system.

The light curves of the experimental geodetic satellite *Ajisai* (NORAD 16908, altitude of 1490 km) are collected with a single photon avalanche diode (SPAD) counting system. QPM utilizes the inertial attitude model of the satellite to project the high-rate photometric samples onto the spacecraft body fixed frame. Single-photon light curves collected from October 2015 until January 2018 are used to map the reflectivity of 149 mirror panels on-board of *Ajisai* (approx. sized 20 × 20 cm each).

The superposition of the photometric samples collected over multiple passes reveals the structural details of the reflective surfaces and locates the persistent anomalies. Exemplarily four mirrors are presented in the figure below where plateau-normalized observations are fitted by a low-degree polynomial mesh in order to generate the photogram. Relatively small, irregularly shaped (panel b) and spot-like (panels c, d) anomalies are revealed that can indicate surface degradation due to long-term environmental interactions and MMOD hypervelocity impacts.



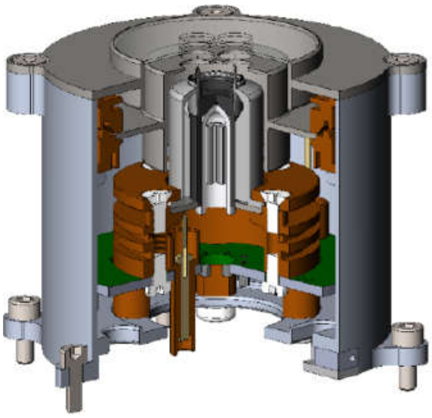
Measured flux and average photogram of 4 different mirrors of *Ajisai* with different panel sizes. The flux is displayed relative to the angular coordinate system with respect to the central normal N of each mirror. a) an expected reflection pattern of a good quality panel, b) panel with reflectivity irregularities at the edges, c) panel with a central spot-like reflectivity defect, d) panel with a spot-like reflectivity defect at the edge of the mirror.

V - NEW DEVELOPMENTS

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

NEXT GENERATION ASPOC

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



Emitter module (left) and electronics box design (right) of the *ASPOC-NG* (© ÖAW/IWF/Wallner).

The developed next generation *ASPOC* (*ASPOC-NG)* consists of the following major components: 1) ion or electron emitter module (by FOTEC), 2) power and control electronics box (by IWF), and 3) on-board software (by IWF).

High voltages are fed through the top plate of the electronics box directly into the base of the emitter module via spring contacts. The reservoir for the ion source is heated by driving a current over a Pt100 temperature sensor.

IWF completed the *ASPOC-NG* vacuum chamber setup and conducted performance and beam divergence tests with an emitter test module from FOTEC. The typical operating voltage for a beam current of 10 µA was 7.70 kV. Successive stability tests at different beam currents ranging from 5 to 80 µA showed an overall good performance. By using a Gallium-Indium alloy as propellant, it was possible to reduce the heating power from 800 mW *(MMS)* to 200 mW *(ASPOC-NG)*.

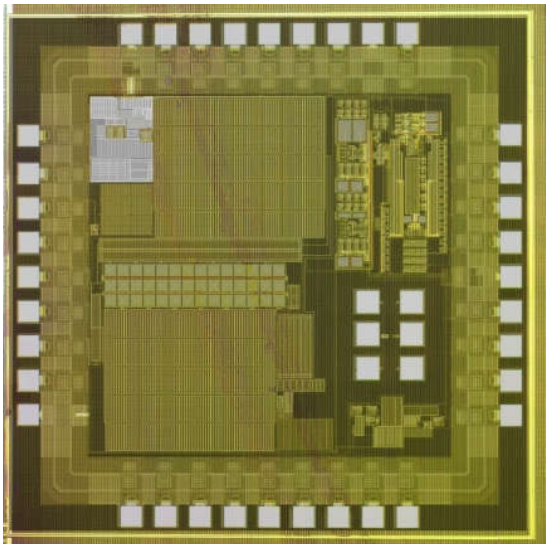
Concerning the control electronics developed by IWF, the layout of all boards (DPU extension board, filament converter, HV control and HV cascade) was finished. IWF also finalized the grounding scheme, which applies to the *ASPOC* electronics box and the emitter module. Finally, the mechanical design of the electronics box has been completed. In December 2020, IWF also successfully passed the Detailed Design Review with ESA, which allows IWF to continue with assembly, integration and test.

MAGNETOMETER FRONT-END ASIC

IWF and the Institute of Electronics of the Graz University of Technology (TUG) are collaborating on the next generation of the space proven Magnetometer Front-end ASIC (MFA). It features the readout electronics for magnetic field sensors, which is optimized in terms of size and power consumption. The next generation Application Specific Integrated

Circuit (ASIC) shall overcome dynamic range limitations. It will be space qualified in the frame of the *FORSESAIL* mission.

In 2020, two earlier developed test chips have been further evaluated. The first chip was fabricated in a 180 nm technology by United Microelectronics Corporation (UMC), the second chip by XFAB Silicon Foundries. The first chip contains a single axis of the required feedback path including a single-bit digital-to-analog converter, which combines delta-sigma modulation with the benefits of pulse width modulation. Measurement results have shown that all developed building blocks have a signal-to-noise ratio of over 100 dB. The digital-to-analog converter on the second test chip consists of 64 current steering cells, dynamic element matching and a digital delta-sigma modulator. In order to meet the requirements regarding low power consumption and high linearity a two-stage cascaded delta-sigma modulator with current output was implemented. Each noise shaper was realized as a third-order modulator with a current-steering cell. Evaluation results indicated an effective number of 17 bits for a given bandwidth of 512 Hz.



Microchip fabricated in a 180 nm technology by UMC for early performance demonstration. The implemented feedback path including a digital-to-analog converter features a signal-to-noise ratio of over 100 dB (© TUG/IHF).

OPTICAL FIBERS

The *J-MAG* instrument on board ESA's *JUICE* mission to the icy moons of Jupiter is going to perform magnetic field measurements with the help of two vector (fluxgate) sensors and one optical scalar sensor *(MAGSCA)*, which provides very accurate reference measurements for the in-flight-calibration of the fluxgate sensors. *MAGSCA* uses light fields produced by a modulated laser to excite electrons in Rubidium atoms for measuring the magnitude of the surrounding magnetic field. The optical sensor is located at the tip of a 10.5 m long boom, whereas the light source and the photodetector are part of the *J-MAG* instrument electronics located within the *JUICE* satellite. Two optical fibers, with a routed length of nearly 20 m each, are needed to transmit the laser light from the instrument electronics to the sensor and back. A 50 µm graded-index multi-mode fiber was selected for the outbound optical transmission whereas the return path was realized with a 400 µm step index multi-mode fiber.

A 400 µm step index multi-mode fiber with non-magnetic connectors and a polymer jacket, which protects the fiber over a wide temperature range from -190 °C to +120 °C (© ÖAW/IWF/Pollinger).

Due to the *JUICE* mission's harsh environmental conditions in terms of particle radiation (several Mrad of total ionizing dose) and low temperature (-190 °C) as well as the need for a fully non-magnetic design, a set of customized fiber assemblies had to be designed and qualified. This challenging development could be finished in 2020 based on an excellent teamwork between industry (Airbus Defense & Space, Schaefter + Kirchhoff GmbH, and Linden Photonics, Inc.), ESA, Fraunhofer INT, the Institute of Experimental Physics of TUG, and IWF.

ON-BOARD COMPUTER

The institute is involved in several missions with the development of digital processing units. IWF started to work with the latest generation of the LEON-type processors, the quad core GR740. This new processor type is based on the fourth generation, the LEON4 core. The primary goal is to find the optimal configuration in terms of system clock, memory configuration, wait states and usage of the processor-inbuilt cache memory. Another topic is to run tasks simultaneously on all four cores to study their interaction when accessing same memory areas, the impact of the cache pre-fetch strategy, bus load, etc.

The typical tasks for Digital Processing Units are the interpretation and execution of tele-commands, packing of telemetry data and execution of pre-programmed timelines. A growing aspect is data compression to maximize the amount of science data for a limited telemetry channel, thus improving instrument performance but also science output. The compression algorithms are designed and optimized for the actual application or instrument. Starting points are either physical parameters, e.g. the calculation of plasma parameters instead of transmitting the measured distribution function, or classical compression algorithm, like classical lossless compression algorithms as used for imaging detectors.

In the frame of the development of *PLATO's Router and Data Compression Unit (RDCU)*, IWF designed an IP core to implement a SpaceWire interface in FPGA logic. This core was used to build a SpaceWire to USB/Ethernet interface unit, based on a commercial single board computer. The first application, an instrument simulator for the *SMILE Soft-X-ray Imager*, is based on a Raspberry Pi board. An in-house developed HAT (Hardware Attached to the Top) provides an FPGA containing the SpaceWire IP core and the LVDS driver components. This design is rather cheap in comparison to commercially available SpaceWire-USB, very compact and versatile due to the software running at the Raspberry Pi. However, the data rate is limited, since the Raspberry Pi does not provide direct access to the data bus. A future design may be based on a more powerful industrial version of a single board computer.

Engineering Model of *PLATO's Router and Data Compression Unit* (© ÖAW/IWF/Steller).

VI - PUBLIC OUTREACH

IWF is actively engaged in science education and public outreach.

During the *Solar Orbiter* Launch Event in the early morning hours of 10 February, about 50 space enthusiasts listened to the talks of Christian Möstl and Philippe Bourdin and followed a flawless lift-off of ESA's new Sun-exploring spacecraft aboard a US Atlas V rocket from NASA's Kennedy Space Center in Cape Canaveral, Florida.

***Solar Orbiter* Launch Event at IWF Graz (© ÖAW/IWF).**

After March 2020, no visitors could be guided through the labs and most events (Fifteen Seconds Festival, the space exhibition during the Graz Fair, etc.) had to be canceled due to Covid-19. However, IWF found new ways to bring science to the public.

In the frame of ÖAW's Science Bites series, Tanja Amerstorfer gave an interview about solar storms, which was recorded and presented at YouTube. On the ÖAW website, Günter Kargl discussed the possibility and risks of going on vacation in outer space. Last but not least, Manfred Steller answered the "ÖAW Forschungsfrage" in a video about the development of space-borne instruments.

Most seminars were given virtually. In the "Magnetosphere Online Seminar Series" organized by different US hosts, international speakers, including two IWF scientists, gave insights into the magnetosphere's mysteries. On 15 May, Ferdinand Plaschke talked about the magnetosheath and on 22 June, Takuma Nakamura explained the low latitude boundary layer.

The "Game Changers" series of the International Space Science Institute (ISSI) explain how missions change(d) our view of the solar system. On 15 October, Rumi Nakamura talked about the results of NASA's *MMS* mission and showed how magnetic field lines around Earth break and reconnect.

On 9 October, the Austrian "Lange Nacht der Forschung" (LNF) was held online for the first time. The whole program was available until the end of the year. IWF participated with videos about different topics for both younger and adult audience.

In the same month, Manuel Scherf reported about news from Mars and Wolfgang Voller told about the autumn sky at URANIA Steiermark in Graz. In November, Ute Amerstorfer gave a lecture about space weather at Planetarium Wien.

The European Researchers Night took place on 27 November and also presented its program online. Tanja Amerstorfer talked about how to predict the arrival of solar storms and junior scientist Andreas Weiss interacted in a "Science Flash" with young people, who were interested in his educational and professional background.

Future scientists during the shooting of the LNF video about how to make magnetic putty (© ÖAW/IWF).

During summer time, eight high-school students performed an internship at IWF under the "Talente-Praktika" program of FFG. They worked on magnetometer microchips, measurement of analog signals, boot-software and load simulator for *SMILE*, historic Sun spots observations, magnetic field data of *BepiColombo* and *CSES* as well as aurora phenomena.

Topics discussed in the space blog of the Austrian newspaper "Der Standard" were the launch of *Solar Orbiter* and machine learning as basis for efficient data analysis.

The Servus TV show "P.M. Wissen" interviewed Luca Fossati about the exoplanet mission *CHEOPS* and Manuel Scherf about life on Mars.

Luca Fossati next to a bright star, explaining the transit method for discovering exoplanets during the video shooting of P.M. Wissen (© ÖAW/IWF).

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

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

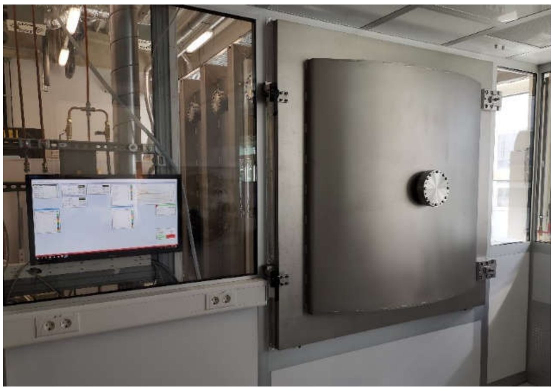
AAC integrates the staff and the facilities of AIT's former Aerospace Department and continues its aerospace research started in 1998 with the ESA-certified **Space Materials Testhouse** under ESTEC frame contract. AAC is coordinator of European and national research cooperation projects in aeronautics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

With its 24 employees, comprise an interdisciplinary AAC background in physics, chemistry, materials science, polymer engineering and mechanical and electrical engineering. More than one hundred research projects have been successfully concluded in the past 25 years. Based on the successful development in aerospace, AAC has extended its business to other industrial applications and will focus on three major areas:

- Polymer Composites
- Inorganic Composites
- Materials & Component Testhouse

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

AAC facilities at TFZ in Wiener Neustadt



New "XVC" in Clean room Class 7

XVC – Upgrade of our largest TVAC in New Clean Room at AAC

AAC again upgraded its TVAC-test capabilities inside the new clean room (ISO class 7). Our XVC test facility was recently fitted with additional equipment for flight hardware bakeout. The bakeout of large parts up to ~1,400x1,400x1,900 mm^3 is now feasible, at temperatures up to 165 °C. The progress of the bakeout can be monitored by means of TQCM (Temperature Controlled Quartz Microbalance) and RGA (Residual Gas Analysis), using mass spectroscopy and FTIR gas analysis.

Additionally, a specially designed bakeout jig with 13 trays, each measuring approx. 1,750x1,380 mm, had been manufactured. It had already been successfully employed for MLI bakeout for a local customer. As the number and height of the trays is flexible, the jig can be adopted to any hardware dimension. For ease of installation, the jig can be installed and instrumented outside the TVAC, as shown in the lower right photograph.

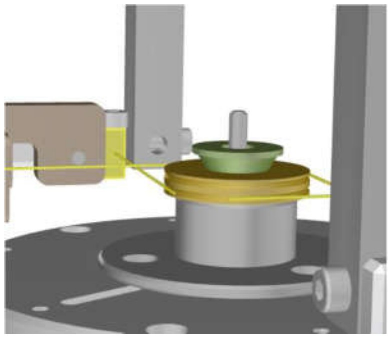
AAC developed materials selected for LEO-exposure on-board ISS

AAC in cooperation with RUAG Space (A) and TOSEDA (CZ) are partner in the ESA GSTP project TPF-for-TOA. This follow-up project of the earlier ESA NANO-HTM project is developing transparent polyimide foils for MLI and OSR applications. The consortium has been selected for testing their transparent fluorinated Polyimide foils, developed within the ESA NANO-HTM project, at the European Materials Ageing Platform (EMA platform).

The SESAME project is a collaboration between ESA and CNES allowing the testing of materials at the BARTOLOMEO platform on-board the International Space Station (ISS).

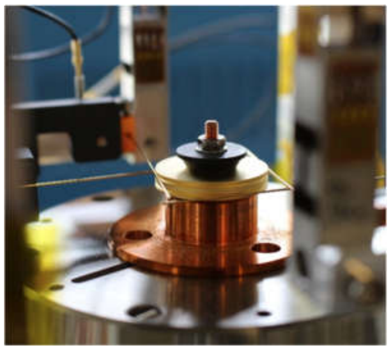
The aim is to study the materials ageing in real LEO environment to obtain relevant data of the radiation and ATOX stability of the selected foils. The flight to the ISS is expected end of 2022. The materials will be expected back to earth after 6 month in LEO environment on board the ISS.

“ECM” - New electrical contact materials selection and assessment for sliding electrical transfer applications



In 2021 the ESA EXPRO Project “ECM” was finally finished. Based on the background, that most electrical contact materials have been developed in the 60s and 70s and are procured in the USA, newer materials and designs might allow more robust slip-rings. It is believed that this specific material already exists in Europe.

AAC adapted its “Salotte 2” – facility to measure sliprings in thermal vacuum under space conditions and did more than 110 tests on different materials to find new European materials that could replace the actual used standard material.

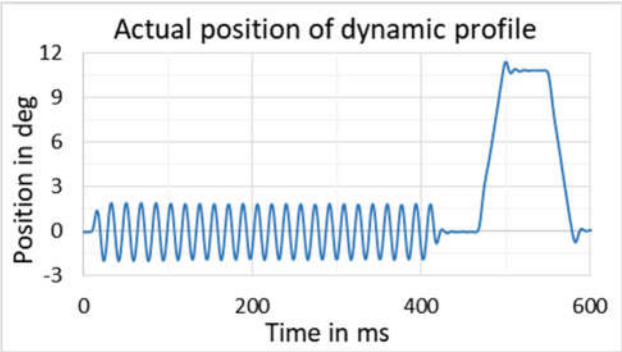


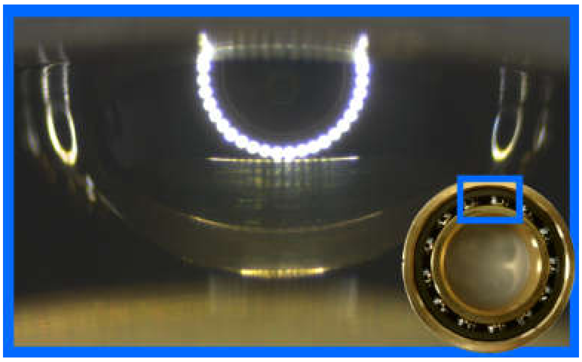
After 5 years of testing we found that there are new European materials for sliprings available, which outperform the actual commonly used materials. The materials were tested under rougher conditions than the supplier specified and nevertheless AAC found good performance.

AAC is looking forward to see European material used in sliprings for space – tested and approved in Austria.

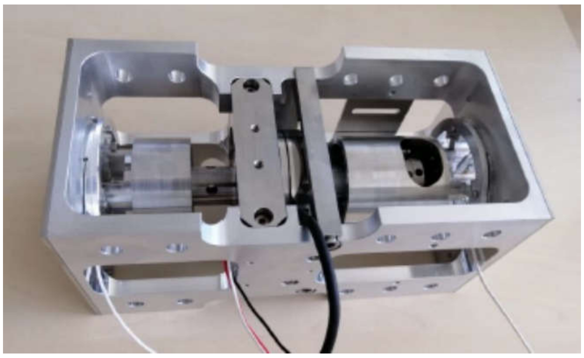
BBT ² – Advanced Ball Bearing Testing

In 2020 AAC designed and built a new device for ball bearing testing which is suitable for testing at ambient conditions and thermal high vacuum in a range of -50 to 100 °C. In comparison to usual ball bearing testing devices – which perform mostly uni-directional movements – BBT² is also capable of implementing more complex move patterns adjustable to special customer and/or mission parameters. The friction torque is measured with high resolution directly at the bearings, without the need to take any residual torque into account.



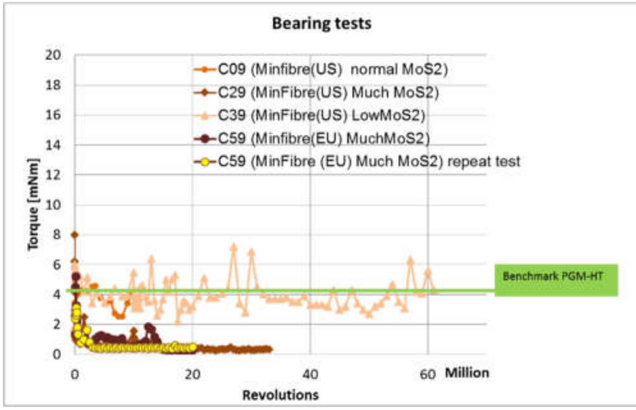


The bearings can be mounted either in single or paired setup, and BBT² can also be adapted to custom hard/soft preloads and ball bearing sizes. Two torque sensors enable to measure torque for each single or pair. The plot shows a custom dynamic movement profile with a sinus vibration of 60 Hz with a duration of 0.4 seconds and an excitation of +/- 2 deg, following a fast movement to 11 deg and back to the starting position.

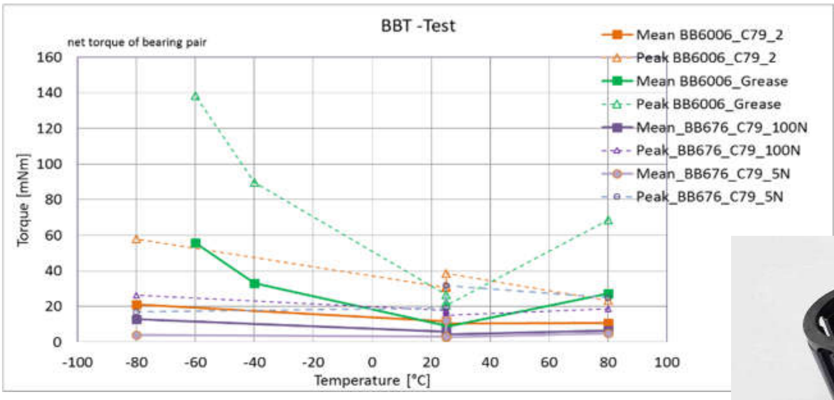


Solid lubrication for Large Scale Antennas (LDA)

To get non-dependent from non-EU-suppliers, a new material based on PTFE was developed by ENSINGER SINTIMID (AT) under assistance of AAC (Project "SLPMC2", ARTES). It's targeted use as cages in ball bearings offers the lubricant to be transferred by the balls from the cage onto the races. Bearings can be equipped only with a cage made of the new PTFE-based material. The GSPT-project "SLPMC2" could be finalised successfully in 2020. Long term ball bearing tests show promisingly low torque of less than 1mNm, which is even lower than for competitive materials The new PTFE-material is meanwhile available as TECASINT TSE 8591.



Following these results, the material was seen as promising solution for an LDA: It might enable to deploy a large reflector without the need of heating. Currently, grease is foreseen, and the requirement of deployment down to -80°C needs heating. To check the feasibility, a De-Risk activity "A3Lub" was initiated together with the companies that develop such an LDA (HPS and RUAG space Germany). The LDA needs 5 different types bearings, 3 of them were selected for BB-testing: "medium" size ball bearing 6006, a precision ball bearing with OD of only 12mm and a linear bearing (Cages made of a variant of TSE 8591 are shown in the image below). For the latter no metric European product was identified but only a "standard" linear bearing made of stainless steel. This was refurbished: a new cage was designed by AAC. The cages for the linear bearing and the precision bearing were machined in Austria (RAUCH). Finally, the ball bearings were tested at AAC in under appropriate pre-loads. Torque was measured first in ambient and then in vacuum from +80°C down to -80°C. The plot shows that under solid lubrication torque is steady and low over all temperature range. Whereas, the greased bearing exhibited increasing torque towards lower temperatures and was limited to -40°C. Following this success, phase 2 of this DeRisk project is being started early 2021.



Sales 2020: 1.3 MEUR

ESA Share: 0.8 MEUR

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3.3 Atos IT Solutions and Services GmbH

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

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

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

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

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

A specific effort has been initiated to incorporate in all our EGSE offerings cyber security protections. This project started in 2020 and will continue in 2021 in collaboration with the European Satellite manufacturers.

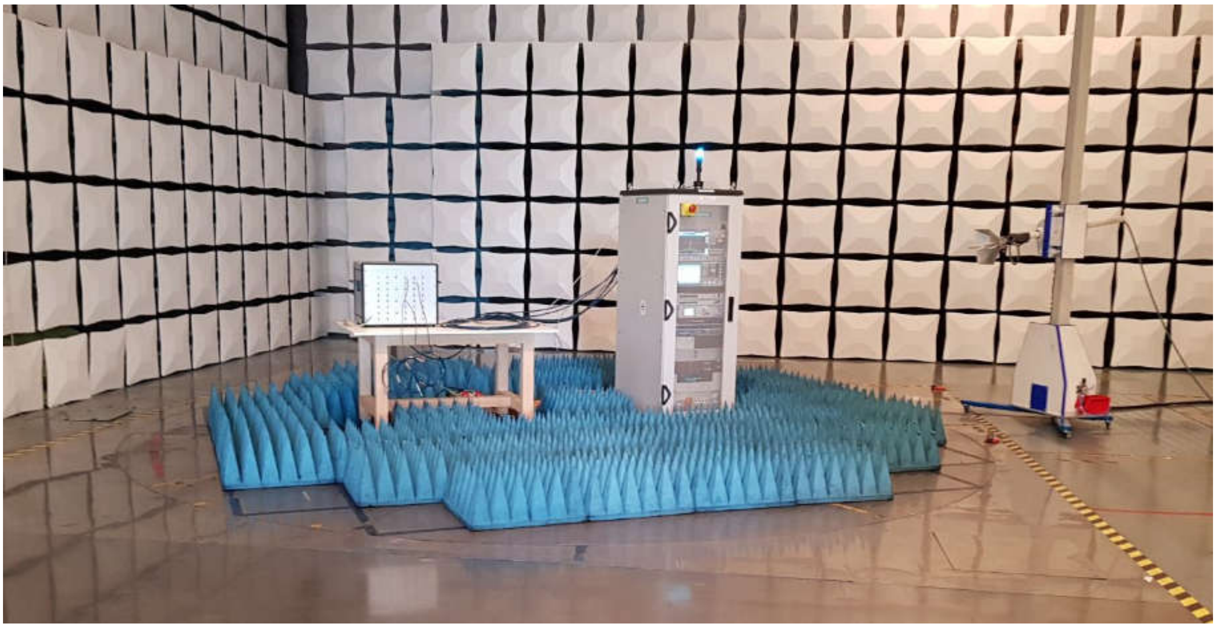
ProUST Equipment in a rack of the JUICE COMS EGSE
(Photo: Atos IT Solutions and Services)

Radio Frequency, Telemetry/Telecommand and RF Suitcase Test Systems

In 2020, the Atos RF department started it's 'go digital' strategy. The aim is to replace expensive COTS equipment with software. In close cooperation with FFG and ESA, Atos was able to win two funding projects in this field. One is to develop an SDR modem (SDR – Software Defined Radio), the other is to develop a fully digital RF SCOE. Both together are expected to be game changers in terms of compactness and costs, and they will form the building blocks of our Ground Segment virtualization strategy. In 2020 we finished the feasibility phases of both projects.

Atos' mission related work in 2020 was for: OneWeb (despite chapter 11 proceedings), Space Rider, Sentinel 4, SolarOrbiter, Proba-3, Galileo, Hera, SARah, OptSat, H2Sat, C03D, MetOp-Second Generation, Juice, Biomass and Plato.

The GSE4 software, whose development started in 2018, is in its rollout phase. After the successful usage of GSE4 in OneWeb, the second mission operated with GSE 4 is Biomass.



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

Power SCOE, Instrument and Payload EGSE Test Systems

In the Power SCOE domain Atos worked on missions such as OneWeb (despite chapter 11 proceedings) – mainly for the launches, Sentinel-6, Juice and Copernicus. 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 2020.

The Instrument EGSE projects that were started in previous years, were continued, among those were Instrument EGSEs for Sentinel 4, where we implemented a customer change request, Sentinel 5, Euclid, Metop Second Generation, where we delivered Set 4 of the MWS Instrument EGSE.

OneWeb Launch Preparation in Vostochny
(Photo: OneWeb)

Innovation: Software defined Radio Modem

In the frame of a GSTP 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.

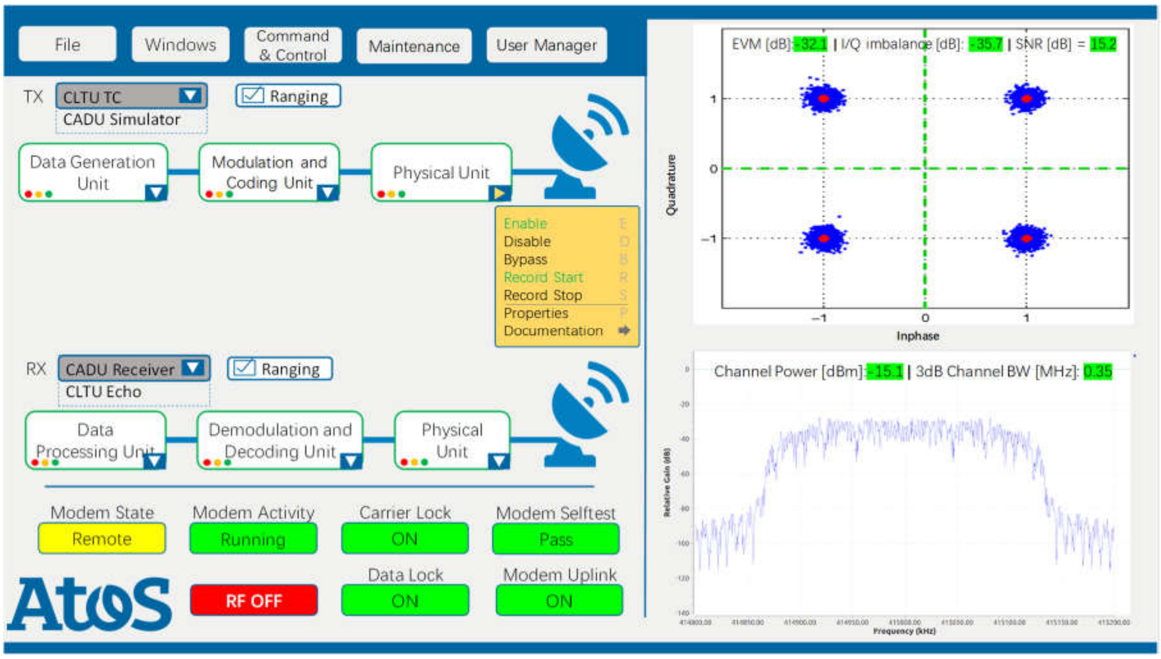
This development was started at the end of 2019.

Work performed in 2020:

- Definition of functional, performance, operational and environmental requirements

- Evaluation and selection of RF-frontend platform
- Development of mandatory and optional signal processing modules (modulation types)
- Development of CADU / CLTU Loopback
- Frequency and data synchronization, carrier and clock recovery
- Development of Command and graphical user interface

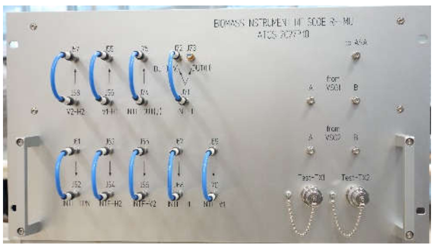
The figure below shows the current prototype of the graphical user interface.



Prototype of Graphical User Interface
(Photo: Atos IT Solutions and Services)

Innovation: Biomass Instrument Radio Frequency SCOE - First highly phase stable test system for P-band radar payloads.

The Atos RF Matching and Switching Unit (RF-MU, see below front & rear panel) as part of Atos' RF-SCOEs, serves 4 different Devices Under Test (DUT I, DUT II, DUT III, DUT IV) during their Integration Phases up to System Testing.



Atos RF-MU
(Photo: Atos IT Solutions and Services)

With symmetric phase-invariant cable assemblies as special innovations, phase symmetry on the outputs were achieved.

Synchronization: The state of the art already offers vector signal generators with 2 outputs each. So far, however, the synchronization of the 4 output signals with a maximum phase offset of 0.5 degrees was not possible (e.g. to operate all four outputs synchronously with a maximum phase offset of 0.5 degrees). Two vector signal generators with 2 output signals each are optimized so that the amplitude and phase can be set as desired and the signals are still always synchronous. This provides a high level of test flexibility between tests, where amplitude and phase can be changed with a high dynamic range via software settings (not through hardware set-up changes). Ultimately, this synchronization increases the number of simulation options with the same hardware setup. A complex calibration matrix had to be developed, which achieved phase synchronicity and amplitude accuracy for the entire dynamic range.

Echo Pulses: It turned out that the trigger delay of the arbitrary waveform generators was too long, which made it impossible to send the echo pulse within the desired time window. A new function had to be found that sends out the echo pulses periodically and synchronously with the PRI and fades them out during unwanted time-periods using a gate signal.

A new software for pulse evaluation is available. The user receives the IQ samples directly for evaluation in an offline tool (e.g. Matlab).

BIOMASS Instrument RF-SCOE
(Photo: Atos IT Solutions and Services)

Gate signals in the data stream: An FPGA trigger implementation is available in the data stream. With these triggers it can be detected whether signals (IQDS) come from H (horizontal) or V (vertical).

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

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

New product: ProUST UniverSAS® 2.0

The new product resulting from learnings of the ProUST CSAS study and going towards the development of an operational product is **ProUST UniverSAS®**. In 2020, UniverSAS® version 2.0 development was continued.

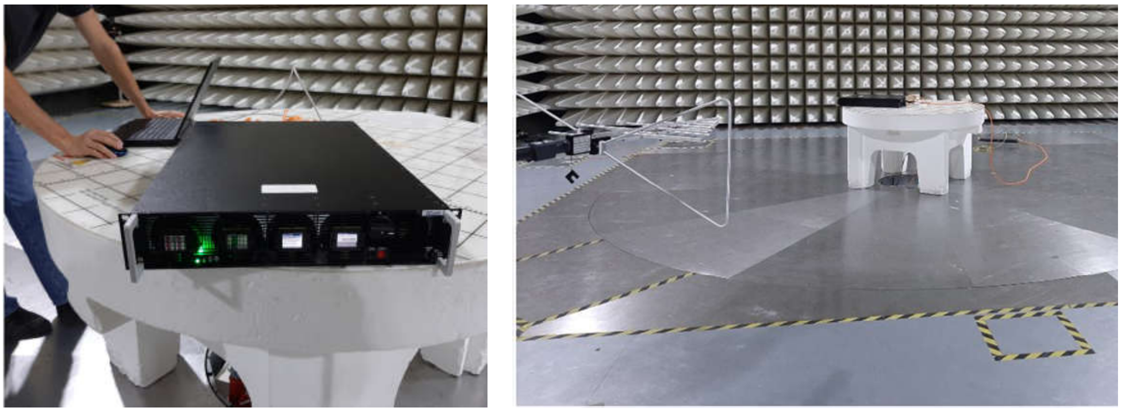
Performed work in 2020:

- Starting from the design of CSAS and univerSAS 1.2 and the lessons learned, the design for univerSAS 2.0 has been performed to cover a higher power envelope, higher voltage output, additional features and the non-functional requirements (e.g. thermal, EMC, isolation, etc.)
- DAB (Dual Active Bridge) 2 kW full power achieved
- VRB (Vienna Rectifier Bridge) 20 kW full power achieved
- Series production of all UniverSAS® 2.0 boards

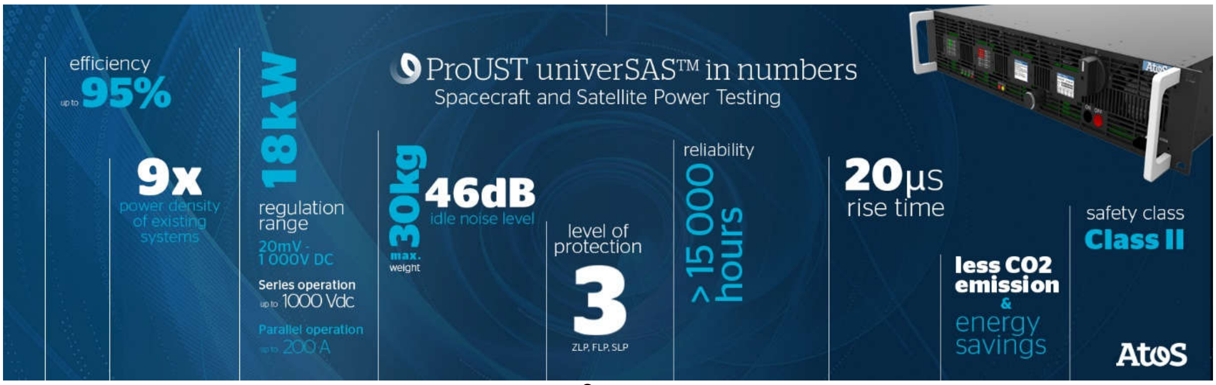
CE and UL certification as a standalone product were achieved in 2020.
UniverSAS® is a true game-changing technology. It is complementing the product portfolio of ProUST SLP and ProUST FE in the EGSE/SCOE area, and it paves the way for a new generation of AIT solutions.

DAB ProUST UniverSAS® 2.0 (Photo: Atos IT Solutions and Services)

ProUST UniverSAS® 2.0 (Photo: Atos IT Solutions and Services)



UL CE Certification - ProUST UniverSAS® 2.0 (Photos: Atos IT Solutions and Services)



Main achievements - ProUST UniverSAS® 2.0 (Photo: Atos IT Solutions and Services)

Satellite Control: Ground Segment Systems and Mission Control Software

In the year 2020, the main focus of Atos Space activities in the Ground Segment Systems and Mission Control Software domain was in the following area:

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

ESA Main Control Room (Photo: ESA)

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

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

Satellite Communication: Carrier Monitoring and Geolocation Systems

Artificial Intelligence (AI) is set to take up position at the heart of contemporary business technology. It becomes central to digital transformation. It is set to become a clear driver of business differentiation.

The introduction of artificial intelligence and cognitive computing is fostering a new generation of applications capable to understand like a human, to develop more and more expertise with a non-stop self-learning capability. These new applications can understand the underlying contexts and provide hypothesis, recommendations and automatically launch operations.

AI has the potential to be a game changer in the satellite industry as well, where it could be used to improve processes and increase efficiency. AI could establish a digital assistant, capable of processing information about everyday satellite procedures, resolving and predicting issues before they become errors. On top of this, it could be taught a whole spectrum of things relating to the day-to-day tasks of satellite operations engineers.

Interference remains a major problem within the satellite sector today, and it's not going away any time soon. Most interference is unintentional, which can make it extremely difficult to overcome. However, interference costs the industry in terms of both money and reputation, rendering it a vital area of focus.

Any service provider that relies on satellite communications, such as broadcasters, governments, defense groups, disaster response teams, banking or enterprise groups, usually picks satellites 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 assets due to 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.

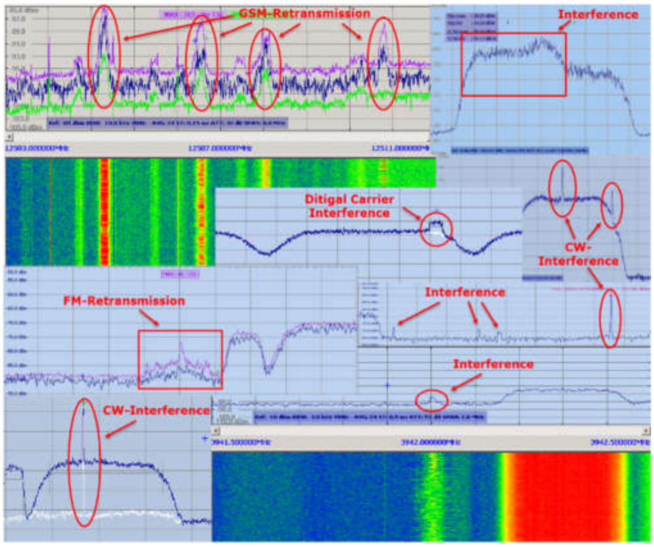
New technologies are a major reason why interference has become an increasingly significant problem in recent years. Small, mobile VSAT terminals, high throughput satellites (HTS), and the growing popularity of high-frequency bands have all played a role. To combat the rising interference challenge before it becomes completely out of control, new solutions are being developed, while working groups and associations like the interference reduction group iRG (now 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.

Satellite interference is not going to be a problem of the past any time soon. One of the most talked-about potential challenges is the number of very large satellite constellations coming online. In the next few years, OneWeb, SpaceX, Telesat etc. plan to launch tens of thousands of small satellites into LEO, on top of the already significant number of satellites in orbit from Iridium and O3b Networks. What will 700 satellites do to our systems? What will 4000 satellites do to it? The truth is, nobody knows for sure. There isn't a model of our current system onto which we can mathematically add these new satellites to work out what's getting to affect who, and when. No investigations have been conducted so far to determine the threat when these satellites are interfering with other satellites, or even terrestrial communication networks.

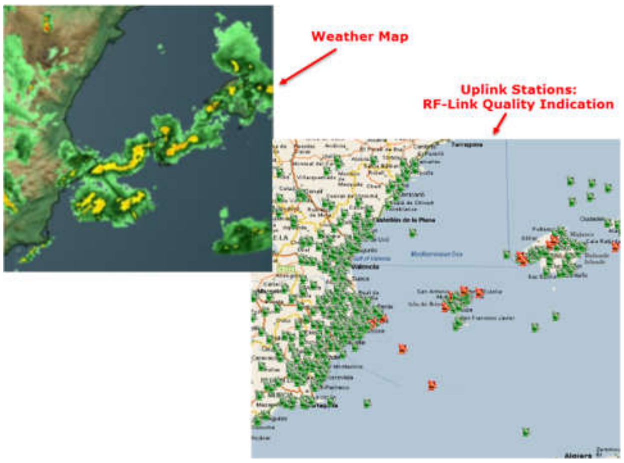
Our main research and development activities in 2020 in the frame of our carrier monitoring and geolocation systems were exactly addressing the above-mentioned issues. AI can help to automatically determine the identity of interfering carriers. It can help to classify the interference source, for example from terrestrial communication networks (GSM, LTE, WiFi) or other satellites (GEO-ASI, LEO, MEO). The current view of available data shows the possibility of predicting, where and when interference might occur in the future.

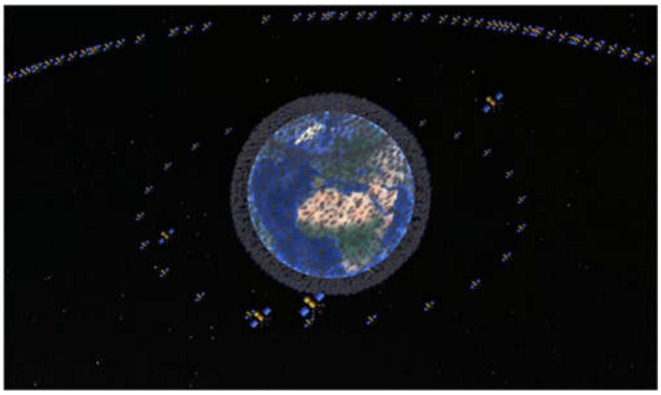
The following main objectives were addresed:

- **Automatic identification of interference situations via spectrum analysis**.
  Interferences are usually detected via manual investigations by the operator, a problem reported by the customer (quality degradation or service outage) or via alarms generated by carrier monitoring systems (by comparing pre-configured nominal carrier data with real measured values). The objective is to support the operator in detecting problems faster and more efficiently by applying AI to automatically identify interferences cases.



- **Prediction of satellite link quality degradation caused by bad weather scenarios**.
  When operators are faced with massive carrier degradations, its often very hard to correlate them and find the cause of the problem. Very often such massive quality degradations are caused by bad weather situations in specific areas. In such situations, operators are therefore manually verifying weather situations. AI shall help to turn this reactive approach into a proactive one to avoid massive signal degradations by adapting signal power levels at the right time.



- **Interference Detection in Complex Satellite Environment**
  
  To address the increasing scale and complexity of the satellite environment (mega constellations) interference detection will be assisted by AI mechanism considering measurements from multiple sources (different satellites; different polarizations, different beams) taken at similar times. The idea is to enhance the methods with automated mechanism to “search for” possible relationship(s) within spectrum measurements of signals of different satellites, polarizations and beams taken at the same or similar time frame (correlate information between different sources). This approach supports identifying and finding the source of interference in an efficient way especially when considering the potentially increasing number of short-term interferences caused by highly complex and fast changing satellite environment (e.g. coexistence of geostationary (GEO) and non-geostationary (NGEO) satellite networks)

Sales 2020: 8.5 MEUR
ESA Share: 3.85 MEUR

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3.4 ENPULSION GMBH

The year 2020 had been affected by the worldwide pandemic situation from COVID-19. Although the unemployment rate in Austria reached the highest level since end of World War II ENPUSLION had been able to countersteer this trend and increase his number of employees by 14 new scientists and top qualified engineers in 2020.

With this team we delivered more than 200 thrusters to our international customers. With the market launch of ENPULSION MICRO R³ Thruster we introduced the second product out of ENPULSIONs electric propulsion product portfolio. This scaled version of the successful established ENPULSION NANO R³ and IR³ thrusters targets small and medium sized spacecrafts.

ENPULSION MICRO R³

ENPUSLION signed another R&D contract with ESA for the development of an electric propulsion system used in spacecraft with weights more than 1000 kg and usage as main propulsion system - financed with 1.7 MEUR from ESA.

ENPULSION customer development and in-orbit demonstration:

By end of the year ENPULSION got 62 NANO thrusters and 1 MICRO thruster operating in space and therefore emphasized its position as worldwide market leader in electric propulsion systems for Nano- and Micro satellites.

Sales 2020: 3.88 MEUR

ESA Share: 1.49 MEUR

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

What we do

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

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

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

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

Project highlights in 2020

The Austrian Space Applications Programme

SuLaMoSA - Subsidence and Landslide Monitoring Service in Austria

The use of advanced differential SAR interferometry (D-InSAR) techniques is nowadays well-established in the field of subsidence and landslide monitoring and many initiatives are currently trying to install national D-InSAR based ground motion services. However, in Austria, characterized by rough terrain, no such was established yet despite highly feasible and necessary. The core ambition of the proposed project is therefore to establish an Austrian subsidence and landslide monitoring service with a strong engagement of potential users who define the requirements and interfaces. The set-up of the project will ensure a maximum quality of the service. A prototype service will be installed in the EODC collaborative IT infrastructure and tested and validated in specific test areas using alternative software solutions and methods as well as independent reference data.

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

DWC Radar
The goal of the DWC-Radar project is to exploit the first-time availability of five contemporary C-band radar instruments in space (three Metop ASCAT instruments, two Sentinel-1 Synthetic Aperture Radar (SAR) sensors) to retrieve soil moisture (SM) and rainfall (RF) estimates at 1km resolution to support Phase 0 activities for G-Class, demonstrating scientific algorithms and data products, and highlighting known strengths and weaknesses of this ground-breaking technology. Furthermore, the project will demonstrate the high practical utility of this technology by using the developed sub-daily SM and improved RF data as input for three applications targeted by G-Class, namely irrigation water use mapping, flood forecasting and landslide risk assessment. The data records and three use cases will be tested and validated over the larger Mediterranean region, which is particularly vulnerable to climate change, and the main target area of G-Class. The data records of sub-daily backscatter, SM, and RF will be made publicly available through a visualization tool at the Earth Observation Data Centre for Water Resources Monitoring. The results of DWC-Radar will directly feed into the ESA EE10 Phase 0 activities closely interacting with the G-Class Science Team, addressing science requirements for G-Class and providing algorithms for sub-daily SM and RF documented in two separate Algorithm Theoretical Baseline Documents.

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

ESA

DryPan - Novel EO data for improved agricultural drought impact forecasting in the Pannonian basin
In DryPan we propose to integrate several European EO datasets to characterize drought and to forecast drought impacts on agriculture in the Pannonian basin. Here we understand drought as a compound event that is usually driven by a lack of precipitation and a high atmospheric water demand (i.e. meteorological drought), often accompanied by a heatwave and that impacts land surface states such as soil moisture

and vegetation and might affect agricultural yields (i.e. agricultural drought). The resulted drought system will be hosted at the EODC IT infrastructure.

DHR - Operations of a Data Hub Relay – Austria
The purpose of the Data Hub Relay (DHR) is, under overall ESA coordination and responsibility, to facilitate the bulk delivery of Sentinel data products from the ESA operated collaborative data hub towards the ESA member state collaborative GS mirror archives. The Data Hub Relays establish a distributed dissemination network in order to avoid bottlenecks / saturation in the dissemination and potentially to establish an overall load balancing scheme towards the collaborative ground segments.

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.

EU – Copernicus

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

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

EU – H2020

EOSC-Hub - Integrating and managing services for the European Open Science Cloud

The EOSC-hub project creates the integration and management system of the future European Open Science Cloud that delivers a catalogue of services, software and data from the EGI Federation, EUDAT CDI, INDIGO-DataCloud and major research e-infrastructures. This integration and management system (the Hub) builds on mature processes, policies and tools from the leading European federated e-Infrastructures to cover the whole life-cycle of services, from planning to delivery. The Hub aggregates services from local, regional and national e-Infrastructures in Europe, Africa, Asia, Canada and South America.

OpenEO - a common, open source interface between Earth Observation data infrastructures and front-end applications

The openEO project will design such an interface, implement it as an open source community project, bind it to generic analytics front-ends and evaluate it against a set of relevant Earth observation cloud back offices. The openEO interface will consist of three layers of Application Programming Interfaces, namely a core API for finding, accessing, and processing large datasets, a driver APIs to connect to back offices operated by European and worldwide industry, and client APIs for analysing these datasets using R, Python and JavaScript. To demonstrate the capability of the openEO interface, four use cases based chiefly on Sentinel-1 and Sentinel-2 time series will be implemented. openEO will simplify the use of cloud-based processing engines, allow switching between cloud-based back office providers and comparing them, and enable reproducible, open Earth observation science. Thereby, openEO reduces the entry barriers for the adaptation of cloud computing technologies by a broad user community and paves the way for the federation of infrastructure capabilities.

Sales 2020: 3.5 MEUR
ESA Share: 393 kEUR

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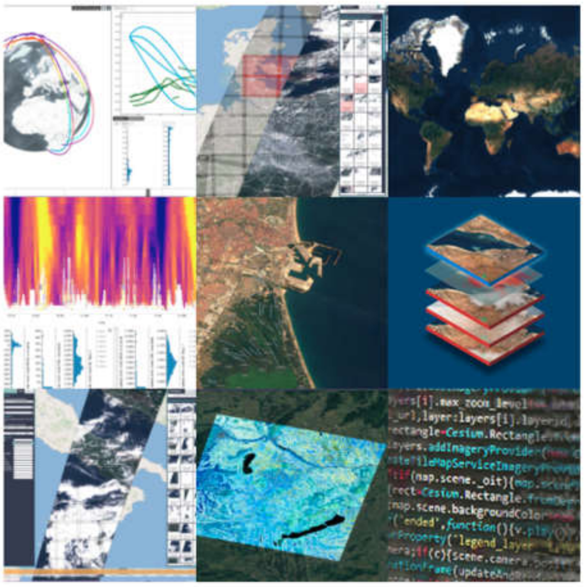
3.6 EOX IT Services GmbH



EOX

VIEW THE WORLD THROUGH OUR EYES

Overview

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

EOX is among the main ESA contractors in Austria and has successfully carried out more than 50 engineering and operations projects for ESA. In recent years, the client base has been expanding to customers stemming from private industry sectors, non-space public organizations and research institutes interested in engineering, consultancy and in the new data product services provided by EOX. The Sentinel commodity product series “EOxCloudless”, which currently includes Sentinel-1 and -2 global product offerings has opened the doors for EOX to a wide consumer market.

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

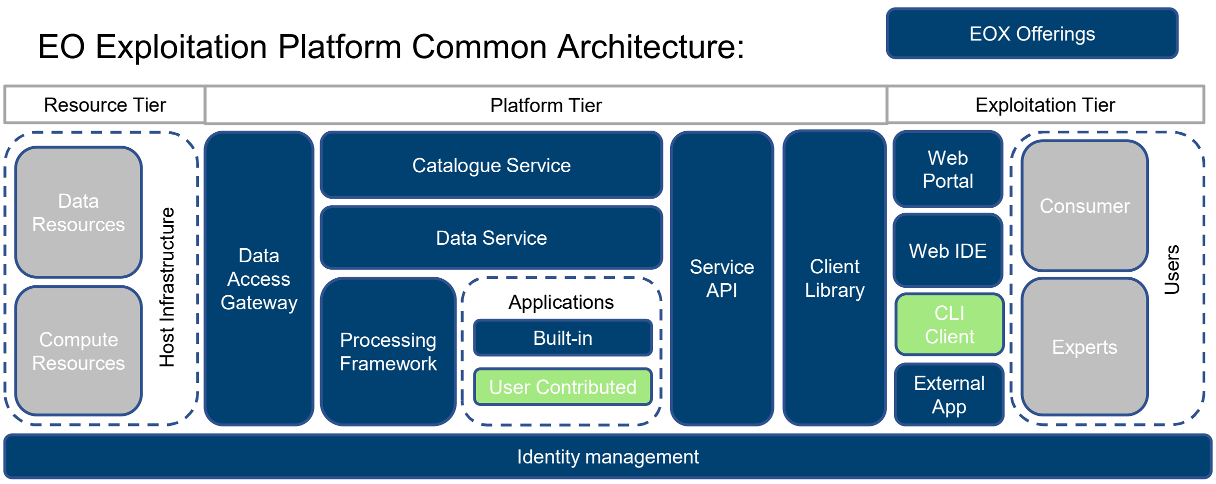
EOX is strongly committed towards utilizing and contributing to Open Source Software for example via the EOX GitHub organization. EOX is further committed to comply to and improve Open Standards particularly those of the Open Geospatial Consortium (OGC). EOX is an active promotor of such standards and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

At present, EOX employs 17 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 2020 highlights are reported.

Technology

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



The following illustrates some of these components.

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

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

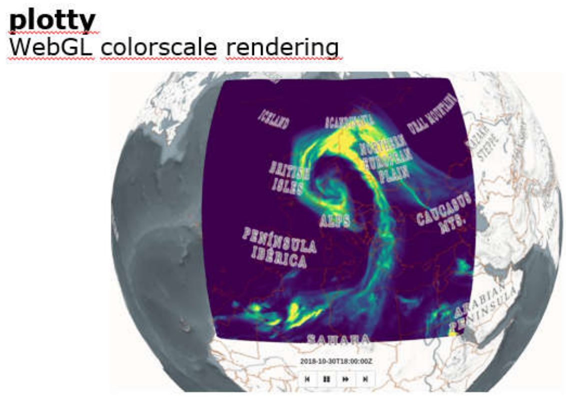
Example instances of EOxC are running as part of Mundi Copernicus Data and Information Access Service (DIAS) [1] and PRISM Data Access Service (PASS) [2]. The software is provided by EOX as Free and Open Source Software (FOSS) [3].

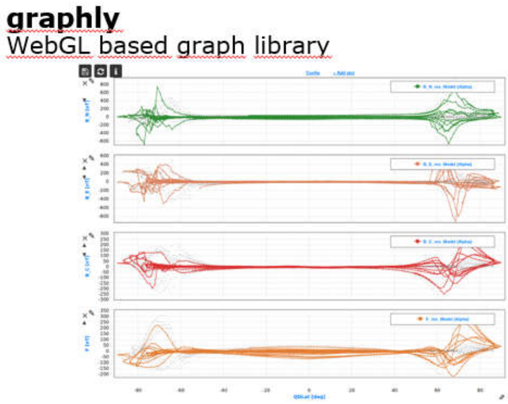
[1] https://mundiwebservices.com/geodata/S2_MSI_L2A

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

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

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





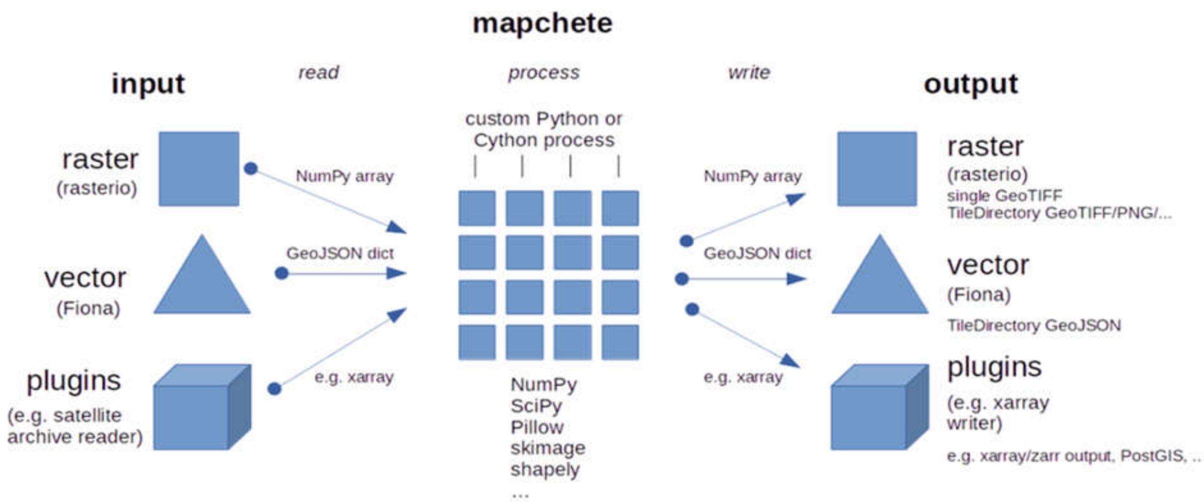
Example instances of graphly and plotty are being used in VirES for Swarm [6], VirES for Aeolus [7] and TOP [8] services.

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

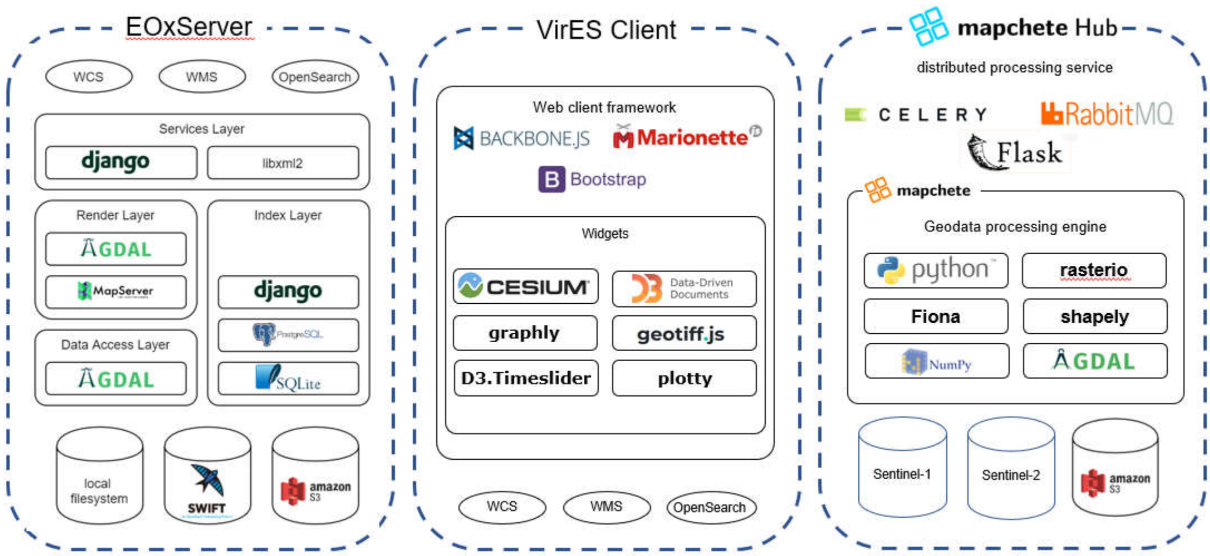
[6] https://vires.services/ [7] https://aeolus.services/ [8] http://top-platform.eu/

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

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



Software zoo - EOX excels in know-how about EO-relevant FOSS and its integrability. Three examples of the many software elements integrated in EOX-provided packages are shown in the following figure: EOxServer [9], the nucleus of EOX data access technology; VirES Web client framework [10] as it is used in [6] and [7]; and the above-described mapchete package. The “home” of EOX FOSS is at [11].



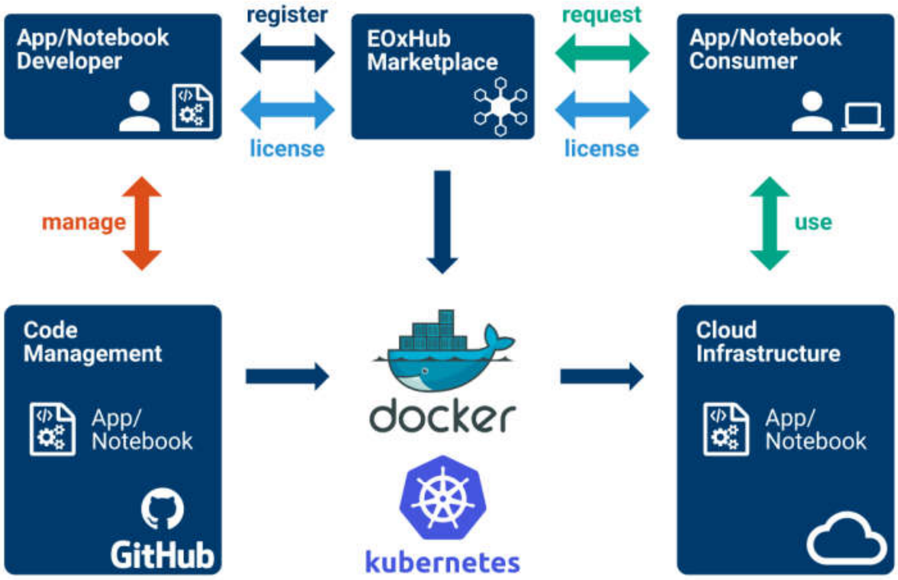
[9] https://ows.eox.at [10] https://github.com/ESA-VirES [11] https://github.com/eox-a

Services

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

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

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

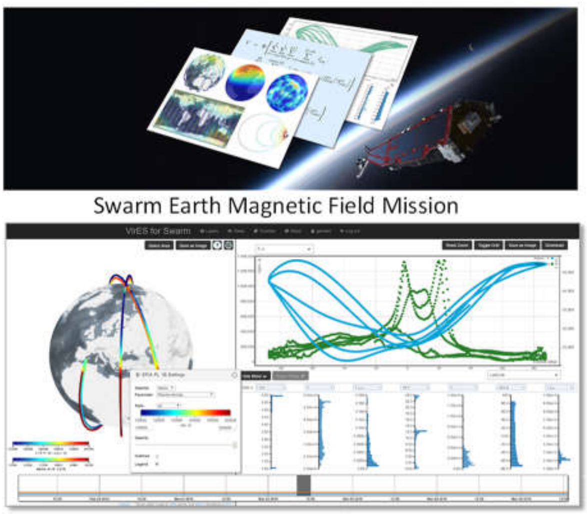


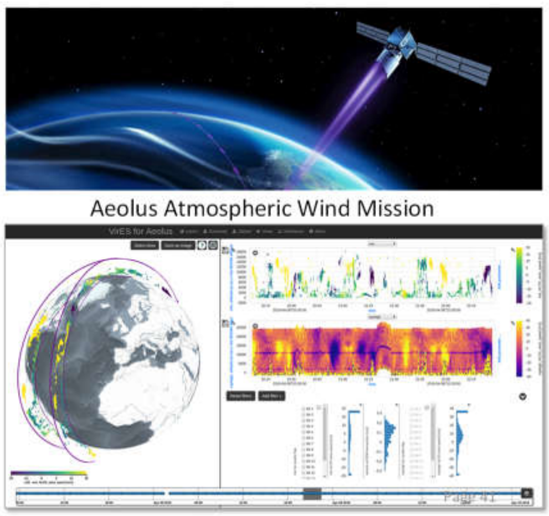
Through EOxHub [12] also optimal data access strategies (e.g. those implemented in Euro Data Cube [13]) are offered in a pluggable and unified way.

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

Virtual Research Environments

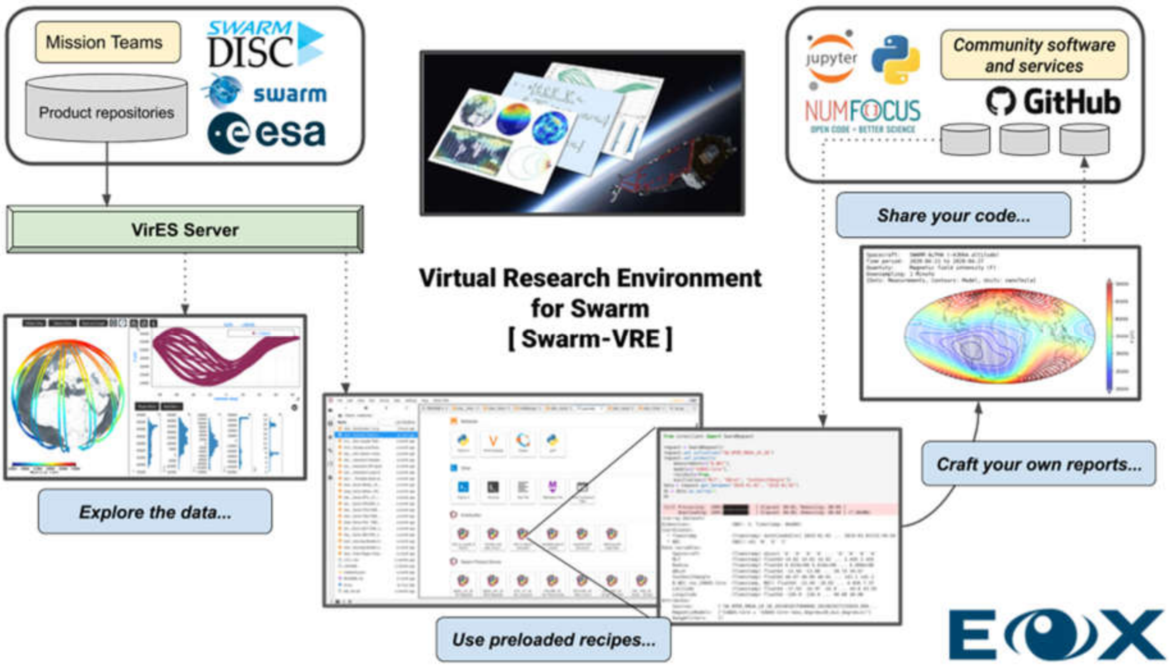
The VirES family of services [14], [15] operated by EOX for ESA are providing operational interactive user services for the Earth Explorer missions Swarm, launched into space on 22 November 2013, and Aeolus, launched into space on 22 August 2018.





EOX is continuously synchronizing the entire Swarm and Aeolus mission data archives and provides data access to them via VirES Server. Besides the direct access via the dedicated

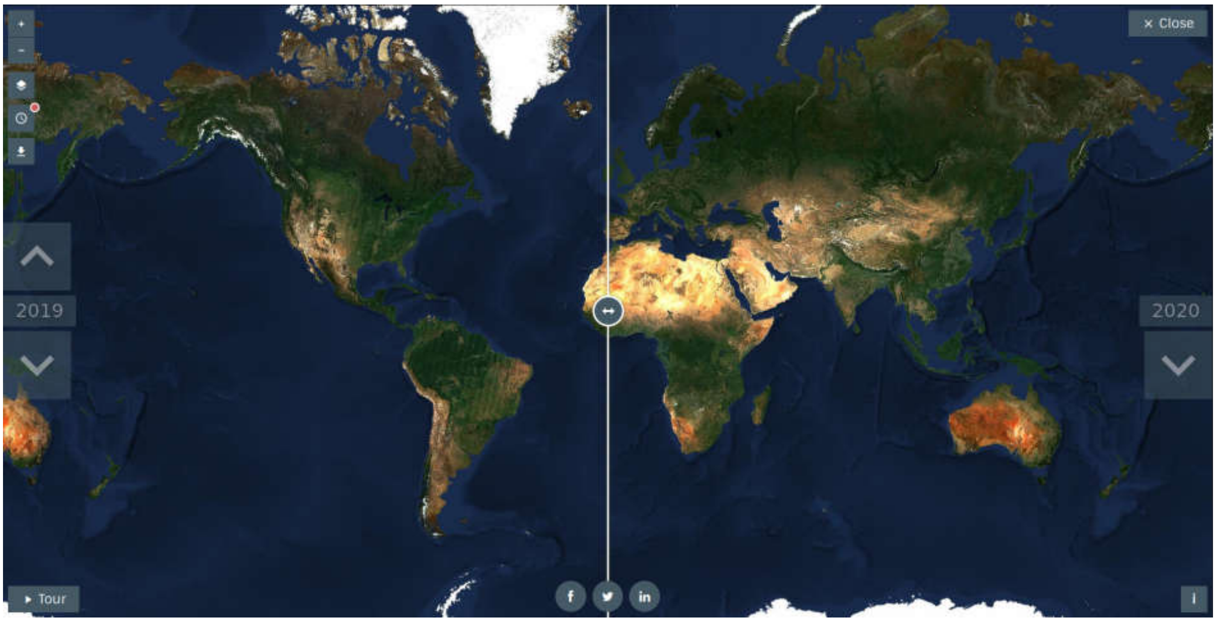
Web GUI for data exploration, a workflow which supports flexible scientific data analysis and collaboration by code sharing using Jupyter Notebooks has been implemented, as shown in the following figure [16].



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

Open Geospatial Data

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



Sentinel-2 cloudless – https://s2maps.eu by EOX IT Services GmbH (Contains modified Copernicus Sentinel data 2019 & 2020)

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

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

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

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

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

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

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

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

Sales 2020: 1.7 MEUR

ESA Share: 1.4 MEUR

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

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

<u>Electric Propulsion</u>

FOTEC has developed the porous tungsten crown emitters based on FEEP technology. Starting in 2015 the integrated FEEP propulsion module "IFM Nano Thruster" has been developed which includes apart from the core element, the crown emitter, a reservoir capable of storing up to 250 g Indium as propellant, a heater, contact-less temperature measurement, two redundant electron sources (thermionic neutralizers) and a power processing unit (PPU). The PPU is able to control the operation of the propulsion system and the reservoir temperature. The integrated high voltage sections are used to generate the desired thrust and specific impulse.

In 2017, the FOTEC spin-out ENPULSION was founded to commercialize the IFM Nano Thruster and to qualify the prototype into a product for the commercial market.

The IFM Nano Thruster
(Source: FOTEC, Credits: Daniel Hinterramskogler)

In 2018 the first IFM Nano Thruster, manufactured by FOTEC, was successfully operated onboard of a 3U CubeSat of a US constellation operator. Two burn maneuvers have been performed and the thruster telemetry was used to compute the expected orbit raise which was later confirmed by GPS.

In 2019 the success story ranging from first crown emitter development up to funding of a spin-out and the in-orbit demonstration of the technology was awarded second place in the Houska Prize in the category University Research.

Houska Prize ceremony 2019
(Credits: B&C Privatstiftung)

In order to broaden the application range of the FEEP thruster technology, efforts were started to increase the thrust level and total impulse. In close cooperation with ENPULSION, the IFM Micro Thruster has been developed featuring four porous tungsten crown emitters. FOTEC scaled up their IFM Nano Thruster PPU based on commercial off-the-shelf (COTS) components to meet the increased power and reliability requirements. In parallel the IFM Nano Thruster PPU has been tested and optimized in terms of performance, efficiency, reliability and resilience to radiation.

In 2019, FOTEC started a 3-year activity supported by the ESA science directorate to improve the FEEP technology which is intended to be used for future science missions, such as the Next Generation Gravity Mission (NGGM) or Laser Interferometry Space Antenna (LISA).

Another application area for the FEEP technology is spacecraft potential control. Based on the heritage technology flying on the NASA MMS mission, FOTEC, in cooperation with the Institute for Space Research in Graz, started development of an improved generation of potential control instruments. These not only allow the emission of ions but also of electrons on demand which allows two-quadrant potential control.

Chemical Propulsion

Two internally financed projects were initiated in late 2018 to make the chemical propulsion group fit for the future. The first project focused on the design and build of a new test facility. The first commissioning tests were carried out in the course of 2020. They showed that mass flow rates can be accurately measured for pulses as short as 7 ms. The typical error at these pulses is less than 5%. It was furthermore successfully demonstrated that the vacuum chamber can hold its vacuum level when firing a 1 N HTP thruster. Further characterization of the new facility is ongoing, but it is already clear that a unique facility in Europe was created.

In the second project it was aimed for to manufacture high-temperature resistant ceramic powders as base material for catalysts. In the second half of 2020 FOTEC succeeded in synthesizing lanthanum hexaaluminate. Not only is this material high-temperature resistant, it has also excellent mechanical properties. Further work is ongoing to scale-up the production to levels more suitable for further industrialization.

The outcome of both projects enabled the successful initiation of an ESA GSTP de-risk project that will be carried out in 2021. This project will aim at verifying the suitability of the technology for space propulsion applications and pave the way for further development.

Energy Systems

Within a research project started in 2018, FOTEC developed processes for the controlled fabrication of porous aluminum structures with additive layer manufacturing (ALM). This enabled the manufacturing of first prototypes of a 3D-printed heat pipe for thermal management of a high-power-density thruster PPU. The ALM heat pipes could be useful for specialized applications where conventional heat pipes are less appropriate. The project was concluded in 2020 with test campaigns for the ALM heat pipe and the upgraded PPU.

FOTEC is also participating in an ESA project started in 2019 that is concerned developing a miniaturized in-plane radiator technology for CubeSat applications. In 2020, the developed design options were evaluated and breadboarded. One design was selected for manufacturing. FOTEC is responsible for environmental tests of the radiator prototype.

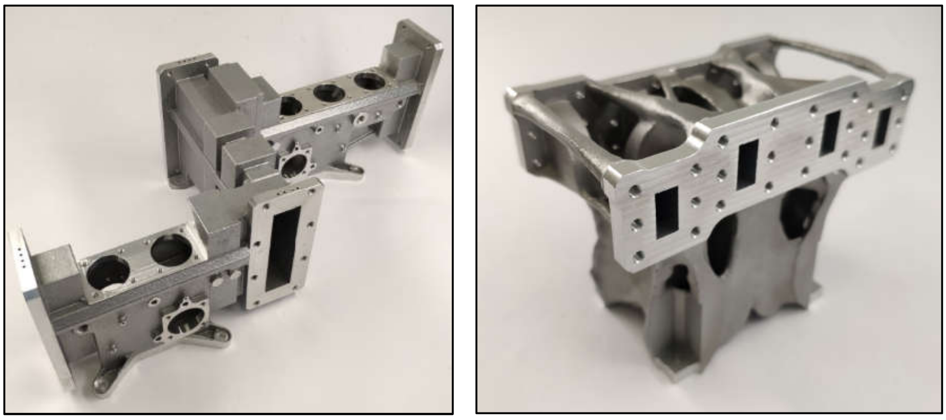
Additive Layer Manufacturing (ALM)

The complete optical bench of the ATHENA project (https://sci.esa.int/web/athena) has a diameter of approx. 3 m and alternatives to conventional machining are required due to the issues regarding purchasing the raw material and as mentioned above the difficulty in terms of machining. The project SME4ALM was aiming on finding alternatives by investigating the manufacturing strategies for large metallic structures via a near-net-shape approach. In cooperation with ESA and the prime contractor RHP Technology GmbH a promising manufacturing opportunity for difficult to machine materials, such as the Ti6Al4V alloy, was developed and the project was closed successfully. The illustration of the partly machined optical bench was ESA technology image of the week (06/05/2020).

Optical bench demonstrator partly machined (Source: RHP/Robert Syrovatka)

Furthermore, the near-net-shape approach used in this project increases the resource efficiency.

After the second development phase in 2019, the work on the RF antenna demonstrators in cooperation with TESAT Spacecom (Germany) was continued. Two design concepts were chosen, a C-band diplexer and a Ku-band butler matrix, to apply another design iteration and increase the majority of the products. Furthermore, to increase stiffness and reduce mass a topology optimization on the Ku-band butler matrix was performed leading to a bionic shape of the channel section between the ports. The cooperation between TESAT Spacecom and FOTEC is very fruitful, meaning that a request for additional budget was forwarded to the ESA responsibilities. This requested was granted by ESA in 2020 and by the end of the year both partners started with the first design iterations and discussions about the manufacturing strategy. The objective is to increase the majority of the design and manufacturing routine towards market readiness.



C-band diplexer (left) and Ku-band butler matrix (right) after interface machining (Source: FOTEC)

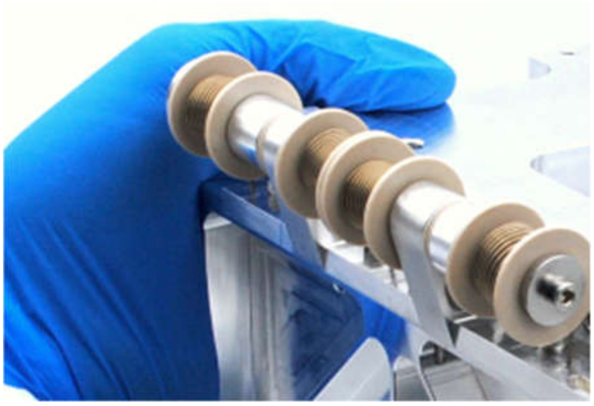
Efforts in the FFG funded project SpaceNDT have shown reproduceable procedures to place realistic defects in Titanium and Aluminium ALM parts, which can be detected by x-ray computer tomography (X-CT) at University of Applied Sciences Upper Austria (Wels, project lead). The artificial defects include pores and inclusions of particles, which both can be formed during the ALM process. Since then, fatigue samples with intentional defects have been manufactured, CT-scanned and tested by Aerospace & Advanced Composites GmbH (AAC). In 2020, the results were incorporated in simulation models for mechanical analysis of ALM components.

In 2020, the project SEfAM (Surface engineering for parts made by additive manufacturing) funded by ESA was successfully closed. Within 5 years this activity investigated surface finishing methods for metal components produced by additive manufacturing and its impact on the mechanical properties on sample level. The main objective was the development of finishing scenarios for 3 alloys (AlSi10Mg, SS316L and Ti6Al4V) that combine minimized surface roughness with acceptable or improved mechanical properties and coating adhesion. As an example, the fatigue life of all metal alloys was increase by an average of 46.5% compared to the as-built condition after manufacturing.

Furthermore, in November 2020 the project 4D Printing (Assessment of reliability of 4D printing materials due to ground/space environmental effects) was started. This ESA activity aims on the evaluation of shape memory alloys (SMA) to be used for space missions. To reduce the number of moving parts and decrease the failure risk during operation in space environment the idea is to replace springs, bearings and other mechanisms by SMAs triggered by heat. Different one- or multiple-way movements such as the opening of solar panels or the release of a covering plate are quite common during space missions and SMAs could add value in terms of efficiency, repeatability and minimization of operation failures. Both polymer and metal shape memory materials are investigated and processed using additive manufacturing technologies.

Miniaturized Hold Down and Release Actuator (Mini-HDRA)

The ESA project started in 2020, initiated by the startup “Space Lock” together with AAC (Aerospace & Advanced Composites) and RHP (Rapid Hot Pressing). The aerospace engineering department of the FHWN presents a potential end user of the hold down and release actuator and contributes a market survey and integration study. Thereby especially, the design of the interface and definition of requirements are arranged to the input of FHWN. The objective of the project is the finalization of a new product, including the hardware components. This Mini-HDRA will be suited for nano satellites as well as for large ones. During the project an innovative SMA (Shaped Memory Alloy) technology is investigated in order to facilitate a simple reset mechanism.



Symbolic illustration of an actuator mechanism

Sales 2020: 30 MEUR
ESA Share: 0.74 MEUR

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3.8 GeoVille Information Systems and Data Processing GmbH

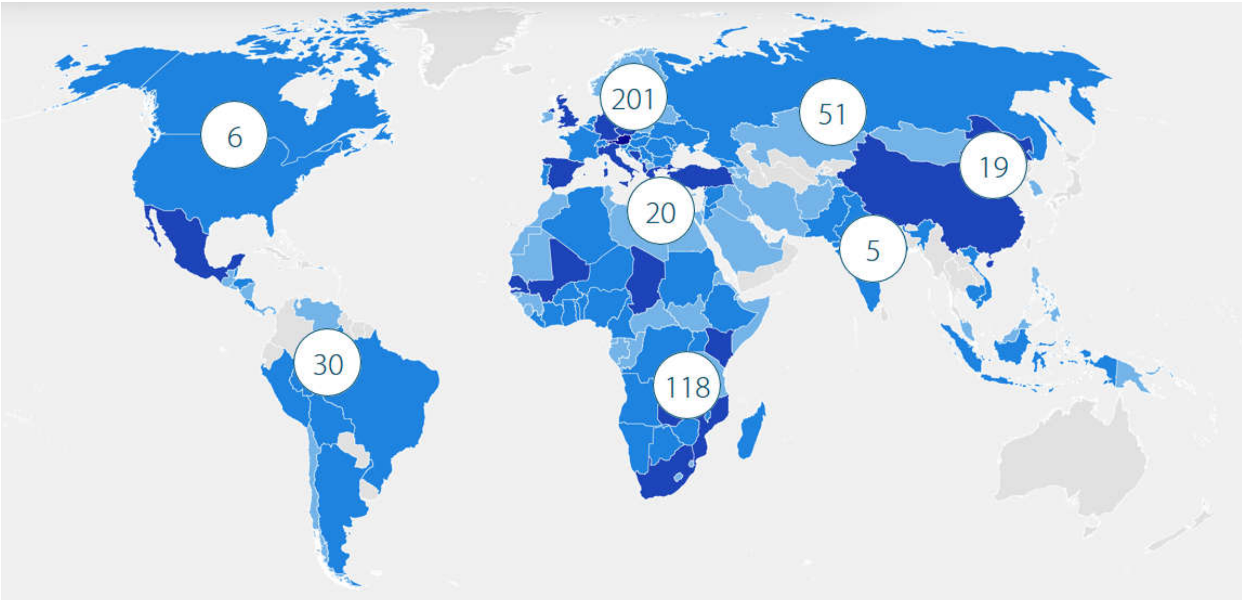
WHAT WE DO

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

OUR CLIENTS

We have a global clients' base in more than 135 countries world-wide. Our clients are institutions, NGOs, public authorities and commercial customers.

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



Realised projects worldwide (excl. global projects)

PROJECTS

ESA EO APPLICATIONS

EO WIDGET – Changing the online EO Service Concept

The ESA funded project "EO WIDGET" develops easy to integrate and downloadable mini-applications, providing customers with independent and fast access to EO-based information services. To date, EO industry players are providing isolated, closed service offerings and are slow to adapt to open-value-chains. In contrast, ICT providers specializing on online based information content services have started to provide their offerings through Widgets, or Apps. Widgets are considered one of the big online business enablers and could be the icebreaker for end-user onboarding, especially for public authorities to integrate EO data into their digital reporting processes. For example, the EU identified necessary digital tools, such as Widgets, as essential enablers to be able to ensure that current policies are enforced and effectively implemented (e.g. Green Deal Agenda). This is the baseline for EO-WIDGETs - providing EO based monitoring solutions easy-to-onboard mini-applications with fast access to information. Each EO-WIDGET delivers content corresponding to monitoring, assessment and reporting tasks of the various sectors. These EO-WIDGETs deliver a shortcut to high-quality monitoring streams hosted on our EO-WIDGET system.

Contract Value: 1200K €

EO CLINIC - Rapid-Response Solutions for Development Aid Project Requests

International Financing Institutions and Multilateral Development Banks provide financial support and professional advice to public sector entities for development activities. These activities generally take place in developing countries and are organised in dedicated projects financed by long-term loans or grants for infrastructure development in a wide range of fields leading to socioeconomic benefits. Previous collaborations with ESA on the use of EO information for development activities raised significant interest in the Banks to enter into further collaboration with ESA to explore the use of EO information on a strategic, longer-term and larger-scale basis.

The ultimate aim of the ESA funded project "EO CLINIC" is to address many, short-term, more speculative and more innovative information enquiries and requests that are being regularly received from a wider range of Bank staff beyond the current projects supported. Services for various thematic areas of collaboration are provided, such as agriculture, climate change, coastal zone management, disaster risk management and many more.

Contract Value: Framework Contract

EU – COPERNICUS OPERATIONS

Copernicus Land Monitoring Service CLC+ Core production

After nearly 30 years and five successful reference year implementations of Corine Land Cover (CLC; 1990, 2000, 2006, 2012, 2018), the new CLC+ product suite constitutes the next evolution step of this well-established European reference product, setting a new standard from the reference year 2018 onwards for the EEA-39 countries. The key elements and technologies were developed within the ASAP 6 project “Land Information System Austria - LISA” and assisted GeoVille to position itself as part of the core team for the CLC+ production.

With the CLC+ Core, a consistent multi-use grid-based, Land Cover / Land Use (LC/LU) hybrid database repository will be developed and implemented. The CLC+ Core will essentially host all existing and future European CLMS data as well as provide the technological solution to enable the standardized integration of national land use and ancillary data via the EAGLE data model. CLC+ Core will be the centrepiece for European environmental land monitoring information, populated with a broad range of land cover and land use information, forming the engine derive tailored thematic information products. From the CLC+ Core, it will be possible to derive tailored products, the so called CLC+ “Instances”, in support of key EU policy needs, as well as to support specific needs as expressed by stakeholders in the Member States.

Contract Value: 2764K €

Automated, Global, Satellite-based Flood Monitoring Product for the Copernicus Emergency Management Service

The aim of the Global Flood Monitoring Service (GFM) for the Joint Research Centre (JRC) is the provisioning of an automated, global, satellite-based flood monitoring product enabling a continuous global, systematic monitoring of flood events complementing the existing Copernicus Emergency Management Service components for flood early warning and on-demand mapping. The solution is based on all-weather, day-and-night SAR data provided by the Copernicus Sentinel-1 satellites. It will provide a continuous, Near-Real-Time global monitoring of all major flood events by the systematic, automated delineation of flooded areas and waterbodies and will therefore

- enable a continuous global, systematic monitoring of flood events,
- enhance the timeliness of flood maps for emergency response due to its fully automated process, and
- improve the effectiveness of Rapid Mapping activation requests through a better identification of the area of interest.

GFM will deliver useful information to address the challenges of climate change response management.

Contract Value: 4997K€

Subsidiary

MapOrbit GmbH

In the beginning of 2020 GeoVille has founded MapOrbit, with its headquarters in Vienna. MapOrbit GmbH develops and operates information technology services combining satellite Earth Observation and other geospatial data with expert domain knowledge and artificial intelligence technology. MapOrbit's vision is to contribute to more efficient geospatial Monitoring and Evaluation of policies, programmes, or projects. Its mission therefore is to provide actionable and validated geo-information layers, maps and indicators with known levels of accuracy about where an intervention is relative to its targets and insights into why targets are or are not being achieved.

Sales 2020: 6.3 MEUR
ESA Share: 1.24 MEUR

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3.9 Joanneum Research Forschungsgesellschaft mbH

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

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

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

A) Communications & Navigation Technologies

a. Be Aware Development and Verification of an Earth-space Statistical Clutter Loss Model

The activities of the World Radiocommunication Conference (WRC) of the International Telecommunication Union, Radiocommunication sector (ITU-R, an agency of the United Nations) include the allocation of radio-frequency spectrum to a number of services, such as the Earth Exploration-Satellite Service (EESS), the Space Research Service (SRS) and the Mobile Service (MS). A range of frequencies has been made available to be used by the fifth generation (5G) of cellular mobile communications, also known as IMT-2020. These frequencies overlap or are adjacent to frequency bands used by space applications, which need to be duly protected from the risk of harmful interference caused by other radio services.

Two main cases of interference can be identified (see Figure):

a) Interference from a ground station for terrestrial (e.g. a 5G base station) or space radio services to a station in space (e.g. a passive remote sensing satellite).

b) Interference from a ground station for terrestrial radio services (e.g. a 5G base station) to a ground station for space radio services (with particular regard to EESS and SRS).

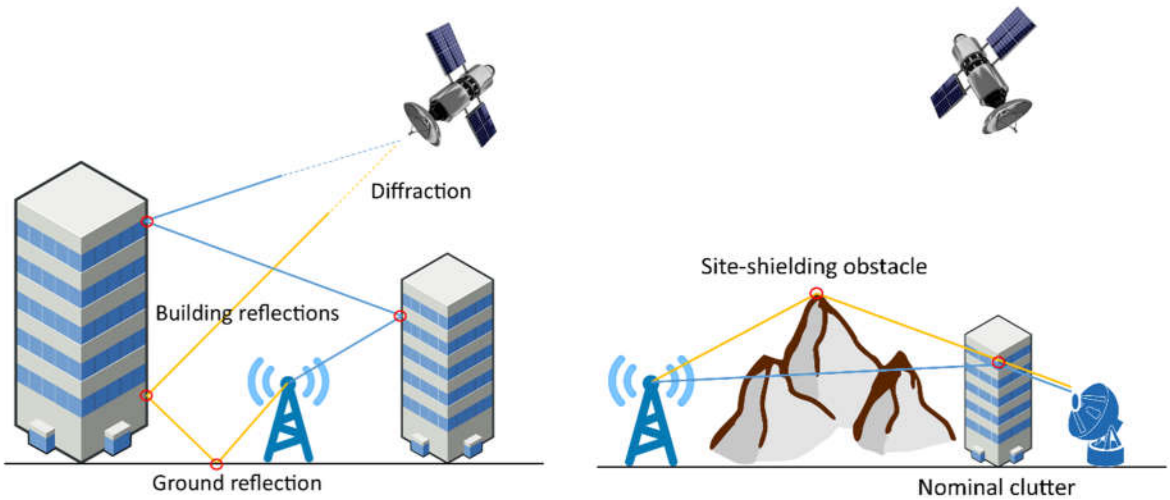


Figure: Geometry of main cases of interference. Left: Interference between stations on Earth and in space (case *a*). Right: Interference between stations on Earth (case *b*).

The analysis of the interference between the two stations requires the estimate of the overall path loss resulting from the combination of all the effects that can occur along the possible propagation paths. These include atmospheric attenuation, line-of-sight (focusing and multipath), terrain diffraction, tropospheric scatter (for long paths), surface ducting (over flat areas and sea), reflection and refraction from atmospheric elevated layers, hydrometeor scatter and diffraction losses from local ground clutter. All these effects can occur at different percentages of time and depend on the frequency, the radioclimatological conditions and the characteristics of the local environment. The accuracy of the propagation models provided in the Recommendations issued by ITU-R Study Group 3 (SG3) is critical for the frequency management and the coordination process.

The project starts with a thorough documentation of the state-of-the art. In the case of interference between stations on Earth and stations in space (case *a*), ITU-R SG3 recommends the method in ITU-R P.619. When the calculation is not possible, either because there are too many emitters or their position is not known (as it will be the case for the deployment of 5G base stations), this recommendation indicates the use of the statistical clutter model provided in ITU-R P.2108. The method was developed through simulations of urban and suburban environments using parameters derived from central parts of London, UK and Melbourne, Australia. The model provides, for Earth-space and aeronautical paths, the statistical distribution of clutter loss for frequencies ranging from 10 to 100 GHz, all elevation angles (0 to 90 degrees) and all percentages of locations ($0 < p < 100$). Figure shows the cumulative distributions of clutter loss not exceeded for percentage of locations at various elevation angles for 30 GHz.

Some observations can be made to the method in ITU-R P.2108: The clutter loss could be presumably lower in different areas (due to their configuration and materials) and environments (e.g. rural or forest). Additionally, the method does not take into account the reflection to space of the signal transmitted by the base station, which can be quite relevant in the case of water surfaces or large metallic objects on ground (e.g. solar panels or vehicles). Therefore, the method may overestimate the clutter loss and hence underestimate the interference levels on the space station. This is particularly relevant for the case of EESS passive missions, especially in the 23.6-24 GHz band. This topic is being reviewed by SG3 during the current study cycle and is related to Agenda Item 1.2 of the next WRC-23 to consider possible additional allocations to the mobile service on a primary basis.

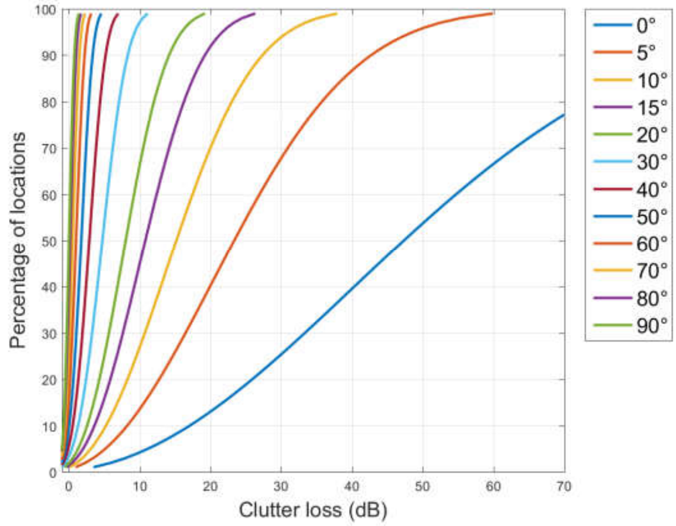


Figure: Cumulative distribution of clutter loss not exceeded for 30 GHz (ITU-R P.2108)

In the case of interference between stations on Earth (case *b*), ITU-R SG3 recommends the method in ITU-R P.452 to determine the distribution of propagation losses and the required system coordination between the ground stations. In this method, diffraction losses from local ground clutter are assumed to be fixed. The method does not take into account the variations with frequency and some characteristics of the site-shielding obstacle such as its width. Therefore, there could be room to improve the model to provide a better protection from interference in coordination activities. In addition, it could be useful to develop a statistical clutter model to assess statistical distances for coordination between ground stations.

Starting from this situation, the two main objectives of the present activity are:

1) To develop, test and validate an Earth-space statistical clutter loss model using data from recent propagation campaigns for Land mobile-satellite communication links, taking into account the needs of interference analysis in space systems. The results will be used to propose updates to ITU-R Rec. P.2108 in order to include:

- Environments not considered in the studies that led to the current recommendation (e.g. urban and suburban areas different from London and Melbourne, rural, etc.).
- The effects of reflection from ground, which could reduce the actual clutter loss in the interference from a base station to a space station, with particular regard to frequency bands allocated to EESS passive sensors.

2) To review and update the clutter loss model in ITU-R Rec. P.452 to support ESA activities for the evaluation of interference between stations on Earth, with a particular focus on the coordination distance between IMT-2020, SRS and EESS ground stations, in order to:

- Account for the variability with frequency and with the characteristics of the site-shielding object.
- Include the reflection effects to improve the accuracy of analysis for coordination activities.
- Develop of a statistical model of ground clutter loss to be used by the Agency for the analyses of general scenarios to derive statistical coordination distances using ITU-R Rec. P.620 for coordination between earth stations.

The results of this study shall be submitted to ITU-R Study Group 3 for radio-regulatory activities and to support European Space industry, satellite operators and national spectrum management organisations.

JOANNEUM RESEARCH leads this project as the prime contractor, coordinating a team including the University of Vigo, Spain and the Czech Technical University in Prague, Czech Republic.

B) Space Robotics Vision / Space Science & Exploration

a. ExoMars PanCam 3D Vision

The joint ESA/Roscosmos ExoMars Rover Mission is scheduled for launch in summer 2022 and landing on the Red Planet in spring 2023 to search for signs of past and present life on Mars. One important scientific sensor is a panoramic imaging system (PanCam), mounted on the Rover Mast. It consists of a wide-angle multispectral stereo pair and a high-resolution monoscopic camera. 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.

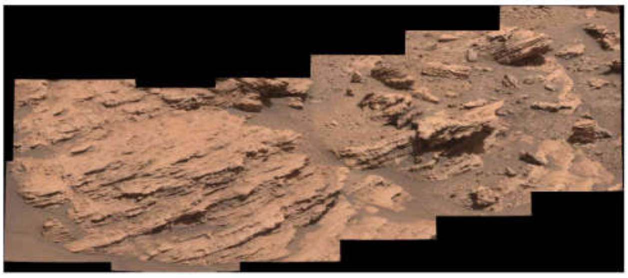
The three-dimensional (3D) PanCam vision processing toolchain “PRoViP” is an essential component of mission planning and scientific data analysis. Standard ground vision processing products will be digital terrain maps, panoramas, and virtual views of the environment. In 2020, further processing components were delivered by the PanCam 3D Vision Team under JOANNEUM RESEARCH coordination (PRODEX Contract) to be ready for processing at the Rover Operations Control Center (ROCC) at ALTEC in Turin / I. The processing tools were tested on entire quarterly deliveries of images from the Mastcam instrument of the Mars Science Laboratory (MSL) mission, see Figure (1).

Particular emphasis is given to visualization tools for geological interpretation (PRo3D), where JOANNEUM RESEARCH is supported by the Austrian research entity VRVis. Prof. Christian Koeberl from the Museum of Natural History in Vienna supported the Austrian team in terms of scientific exploitation, with emphasis on impact structures (e.g. meteorites, shatter cones).

Job 2586_013585

- SOL 2586, Instrument MAST_LEFT, Sequence ID mcam13585
- Observation request: Stereo documentation of layered material at Central Butte around target Bonny_Braes
- Number of stereo pairs: 12
- Status: done

Product: mosaic



Product: stereomosaic

- Horizontal/vertical range: 32.48/14.45 degree
- Camera distance range (raw): [4.37,10.72] m, 10-90% percentile: [4.72,7.43] m
- Stereo accuracy: [0.009,0.020] m

Figure: Excerpt of MSL Mastcam 3D Vision processing protocol. Credits: NASA/JPL/CalTech/ASU/MSSS

b. Mars 2020 Mastcam-Z 3D Vision

The NASA Mars 2020 *Perseverance* Rover mission was launched on 30th July 2020 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. In the frame of an ESA PRODEX Contract, JOANNEUM RESEARCH and VRVis in 2020 prepared the 3D vision building blocks (3D vision processing PRoViP and visualization – PRo3D – pipeline, and geometric calibration) to be able to assemble 3D models from Mastcam-Z stereo pairs for further geologic interpretation during the mission in the operational time frame from landing on 18th Feb 2021 until Dec 2022. In 2020, the components were further shaped in terms of functional processing components and visualization capability, see Figure (2). Later in 2020, they were made mission-ready in final tests.

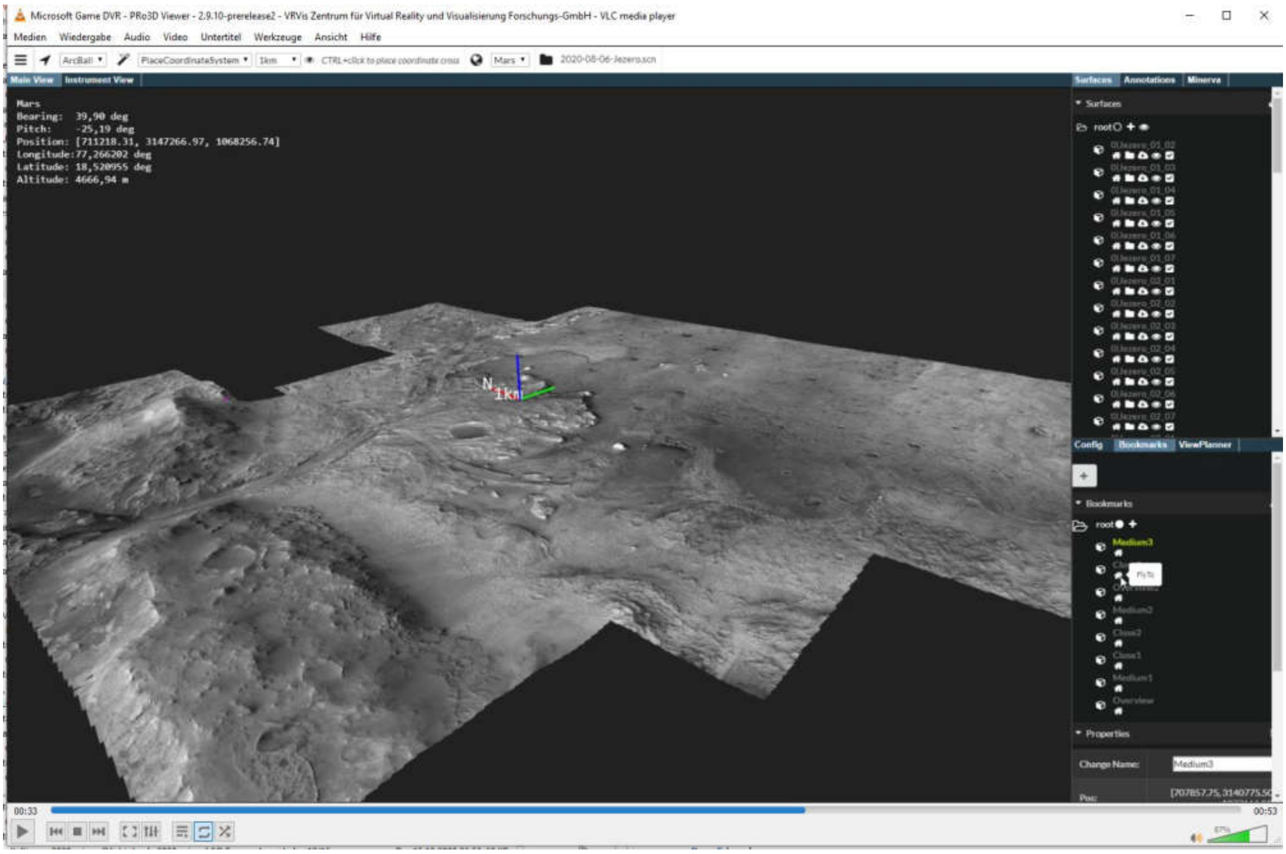


Figure: Screenshot of real-time demonstration of multi-scale viewing of Perseverance's landing target area Jezero Crater. Credits: USGS.

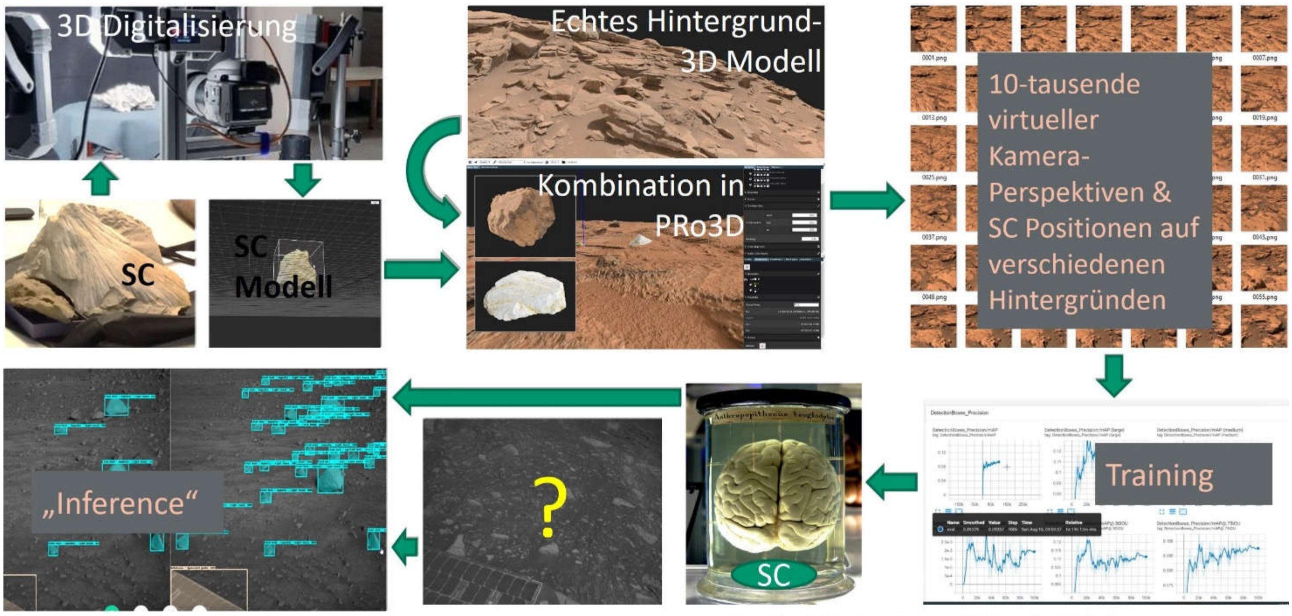
c. ExoMars NavCam/LocCam 3D vision processing

The ExoMars-2022 Rover *Rosalind Franklin* will be controlled from Turin in Italy, where the Rover Operations Control Centre (ROCC, provided by ALTEC/Thales Alenia Space Italy) is located. To plan the Rover's daily operations, in particular to avoid dangerous morphological formations (cliffs, rocks, dunes etc.) during its ride on our outer neighbour planet's desert surface and to select the next scientifically interesting targets, a precise 3D model of its surrounding is needed. JOANNEUM RESEARCH is providing the software to generate such 3D models based on daily images from the Rover's navigation and localization cameras (NavCam & LocCam) for the so-called "tactical" planning. The processing components are developed in high synergy with PanCam 3D vision processing, with emphasis on fast and robust 3D vision products' delivery and embedding in the mission environment to allow scientific and engineering tactical decisions being taken within minutes after data downlink receipt.

d. Mars-DL

Mars-DL (Planetary Scientific Target Detection via Deep Learning) targeted in the adaptation and test of simulation & deep learning mechanisms for autonomous detection of scientific targets of interest during robotic planetary surface missions. To obtain large sets of training data (otherwise only feasible with known / manually annotated objects, regions or semantic content), the project assessed the feasibility of machine-learning based support during and after missions by automatic search on planetary surface imagery.

Mars-DL objective was to raise science gain, meet serendipitous opportunities and speed up the tactical and strategic decision-making during mission planning. Trained by 3D simulations gained from real (digitized) objects embedded in real (digitized) Martian environment (such as "shatter cones", see Figure (3)), an automatic "Science Target Consultant" (STC) was realized in prototype form which, as a test version, can be plugged in to ExoMars operations once the mission has landed. During mission operations of forthcoming missions (Mars 2020, and ExoMars & SFR in particular) the STC can help avoid the missing of opportunities that may occur due to tactical time constraints preventing in-depth check of image material. The project final presentation is available in YouTube under https://www.youtube.com/watch?v=_-I5ZyOgrDg.



Credits: Wikipedia. https://en.wikipedia.org/wiki/Brain#/media/File:Chimp_Brain_in_a_jar.jpg

Figure (3): Mars-DL end-to-end workflow from digitization of interesting objects (SC….Shatter Cone)

e. HERA 3D Vision

In 2019, JR and Austrian Partner VRVis had started their developments for vision-based tactical 3D reconstruction of the double Asteroid system Didymos for the HERA Asteroid mission to support the spacecraft's rendezvous with Didymain and its moon Dimorphos. In 2020, the main technologic background for 3D vision processing was settled, and simulation and tools for scientific visualization (Figure (4)) were developed. Virtual views based on the spacecraft trajectories as planned for the approach to the asteroids were used to verify a photogrammetric chain that allows the seamless three-dimensional modelling of the asteroid bodies in all phases of the proximity operations.

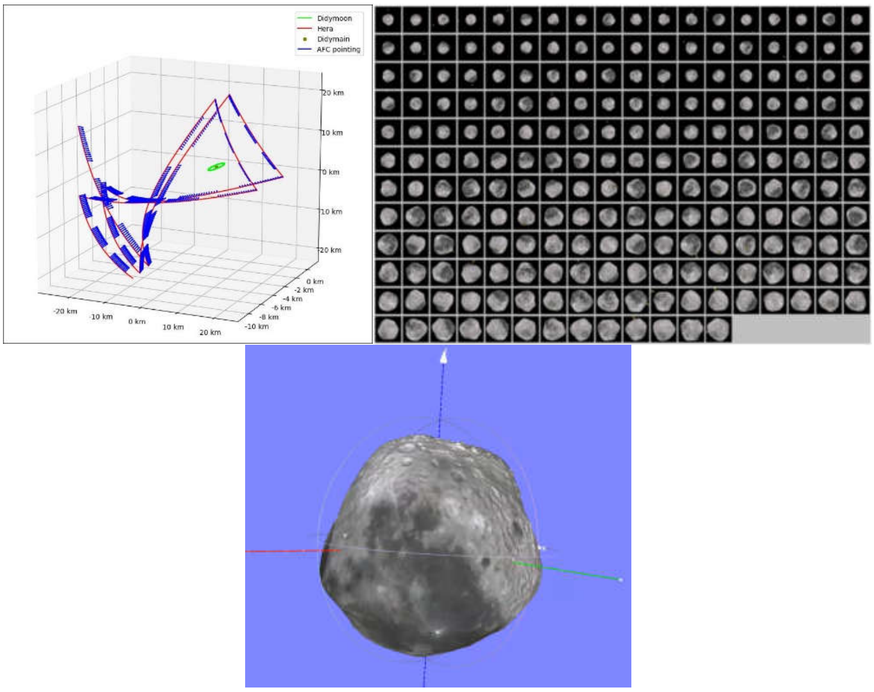


Figure: Simulation and 3D reconstruction building blocks for HERA 3D vision. Left: Approach scenario trajectories. Middle: Examples of simulated images captured during approach used for testing (thumbnails, using texture from the Moon, as Didymos itself is too distant to Earth for a previous mapping campaign). Right: Dense reconstruction using the simulated images & trajectory data.

f. ADE: Autonomous Decision Making in Very Long Traverses

The Horizon 2020 SPACE Project “ADE” (Autonomous Decision Making) deals with Rover autonomy in terms of navigation, planning and science decisions. JOANNEUM RESEARCH settled the “ground truth” infrastructure for the validation of specific ADE navigation components by building a high-fidelity 3D simulation framework that allows realistic renderings of images from real environments measured in various scales that are combined to a multi-scale 3D model (Figure (5)).

For the visualization component, the VRVis Planetary Robotics 3D Viewer (PRo3D) was used. Further JOANNEUM RESEARCH activities in ADE were the support and annotation of science training data, and the definition of the test scenario.

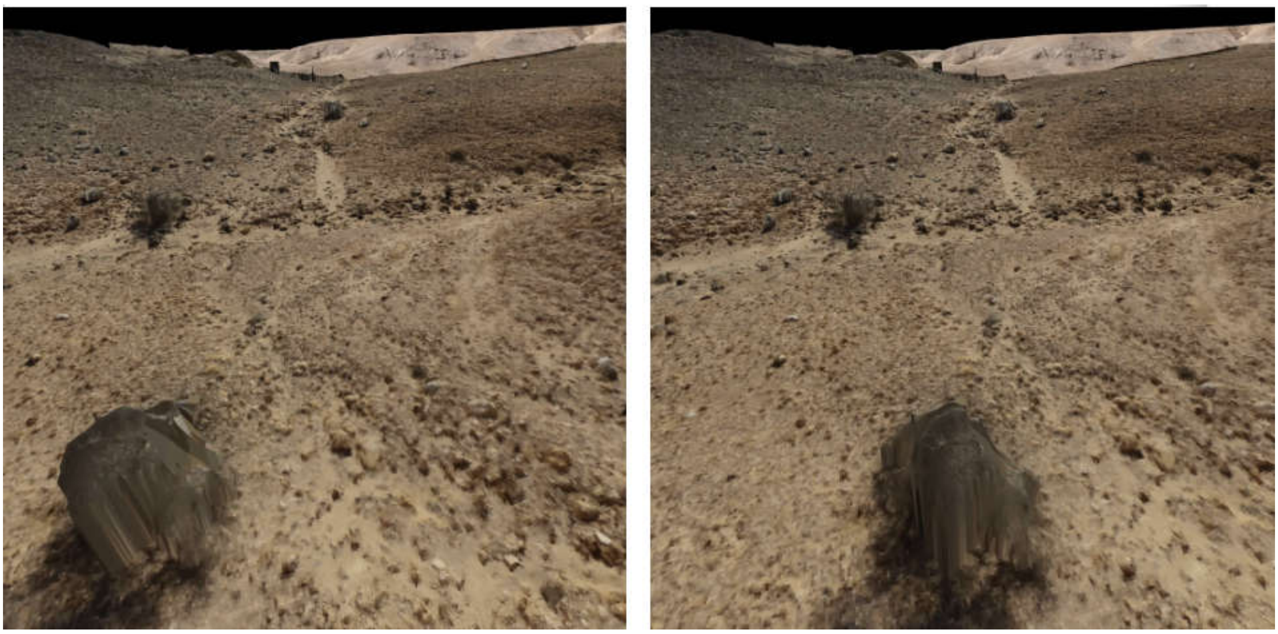


Figure: Simulated images as used for verification of vision-based navigation capabilities as embedded in the ADE framework. The 3D simulation environment was captured in a field campaign in October 2019 at the island of Fuerteventura (data credits for background terrain captured by UAV: ESA)

Outlook for 2021

The participation in the Mars 2020 mission with 3D vision data processing and visualization for the Mastcam-Z instrument will go on with JR and VRVis until the end of 2022, with scientific support from Prof. Christian Koeberl from the Austrian Academy of Sciences / ÖAW. In 2021, further testing of processing and visualization assets will be elaborated by JOANNEUM RESEARCH and VRVis for ExoMars PanCam, and for the ExoMars ROCC (Rover Operations Control Centre) in 2020 the 3D vision data processing for the NavCam and LocCam engineering rover camera systems for tactical mission planning will be finalized, tested and deployed. This also includes maintenance and calibration of the “Mars Terrain Simulator (MTS)” 3D vision system. The Horizon 2020 SPACE Project ADE will be finalized with a field trials’ campaign close to Bremen, Germany. The HERA 3D vision framework will undergo further improvements in processing and imaging strategy. A novel approach for data provenance (following up the history and story of mission science data) will be started to investigate in a separate ESA activity. The DIARY (fielD trIal dAta pRocessing sYstem) study will establish a framework to provide the required tools for the archiving of data sets generated as a result of field trials and simulations.

Sales 2020: 3.2 MEUR
ESA Share: 1.4 MEUR

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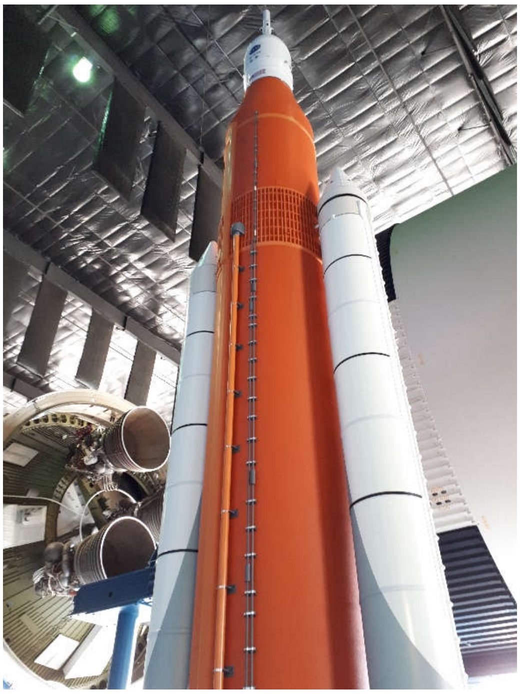
3.10 Magna Steyr Fahrzeugtechnik AG & Co KG Aerospace

SLS (Space Launch System) – Pressurization Lines, Flexible Joints

The cooperation with The Boeing Company for the manufacturing of propulsion system Components for NASA's Space Launch System (SLS) was successfully continued in 2020. An important milestone was the completion of the installation of all Magna flight hardware for the SLS inaugural flight and the successful completion of important test of the hardware in the so-called green run test campaign.

Manufacturing of several flexible components for the SLS propulsion system was completed and new parts have been added to Magna's portfolio.

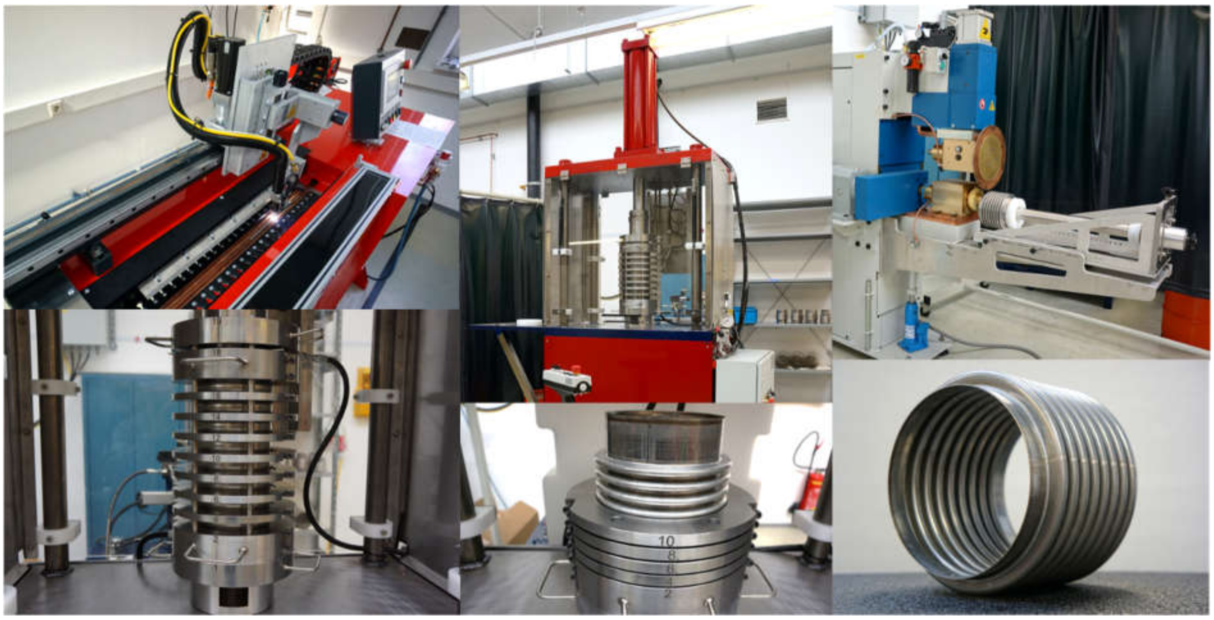
The development of components for SLS Exploration Upper Stage (EUS) was continued which contribute to use the full potential of this powerful launch system.



Bellows Manufacturing Capability

The development, manufacturing and testing capabilities for metallic bellows made of stainless steel and Nickel-alloys have been significantly enhanced and was successfully proven in several customer projects.

Existing capabilities were extended by laser beam welding of thin wall sheet metal and will be further enhanced in 2021 by the investment in hydroforming machinery for the manufacturing of large diameter bellows up to 12".



Metallic Bellows will augment Magna's future portfolio for piping systems for launchers, spacecraft and the aeronautic industry.

AVIO Vega Evolution

After an intensive development phase and passing of the required milestone reviews, the manufacturing of propellant piping for the upper stage engine of AVIOs future Vega "E" launch vehicle was started.
The engine piping for the first prototype engine is scheduled to be completed in 2021and will eventually be tested in a ground test campaign by Avio.

Source: ESA

Contact:

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3.11 OHB Digital Solutions GmbH

Field of Work

OHB Digital Solutions GmbH has expert know-how in the field of GNSS signal processing, precise positioning, and reliable navigation, and covers particularly the areas of development and combination of navigation, telecommunication, and information technologies, and services for applications in the context of transport and mobility. OHB Digital Solutions GmbH works intensely and has already introduced specific products and solutions to cover the increasing needs of the defence sector. OHB Digital Solutions is active in the value streams:

- Location Based Services
- GNSS Signal Processing
- Consulting
- Internet of Things
- Defense

Field of Expertise

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

International Partners

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

Our Customers

- Governmental Agencies
- Public Service Providers
- Industry and SME
- Defense Sector
- Strategic Industry

Our offices

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8044 Graz
Austria

Branch Office Address Vienna:
OHB Digital Solutions GmbH
Lothringerstraße 14/3
1030 Vienna
Austria

Project Highlights in 2020

GIPSIE-RTX – GNSS Signal Generator with Real Time Extension

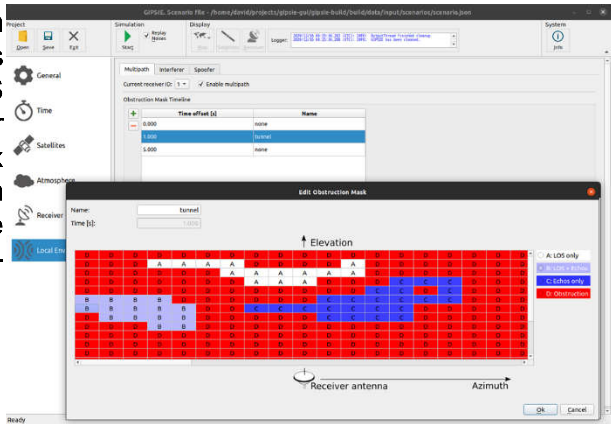
OHB Digital Solutions GmbH develops systems for simulating various GNSS constellations and signals including several degradation effects and disturbances.

GNSS signal generator + GNSS simulation environment

GIPSIE-RTX is a fully featured GNSS signal generator with real-time streaming functionality including real-time control of the simulation environment. It consists of a high-quality signal simulator as hardware platform and the flexible and powerful GNSS simulation environment GIPSIE.
The multi-system and multi-frequency capable **GIPSIE-RTX** simulates arbitrary satellite orbits using a sophisticated orbit integrator and can model all error sources, delays, and propagation effects. These include various models for satellite clock offsets, ionosphere, and troposphere, multipath, signal power, antenna patterns and noise.

In addition, multiple types of signal interference, like jamming and spoofing, can be defined. Customized navigation message formats and contents can be used to simulate future GNSS signal features.

The software GIPSIE (GNSS multisystem performance simulation environment) provides the possibility to generate simulated GNSS constellations and signals for various user defined scenarios including complex trajectories and environments. All settings can be made within the user-friendly and intuitive graphical user interface or within an easy-to-read configuration file.



Software GIPSIE

GIPSIE provides the following features:

- Simulation of complete GNSS constellations including all satellites based on default almanac or accurate ephemeris information and clock parameters
- Orbit integration module based on earth gravitational models including gravitational effects of sun and moon
- Simulation of accurate models for ionospheric and tropospheric delays
- Simulation of user-defined receiver antenna characteristics including reception gain patterns and multipath effects
- Navigation message simulation based on GNSS ICDs or customized user-defined message formats
- 100% reproducible noise and signal degradation simulations
- Graphical user interface
- Comprehensive data logging of all intermediate results for detailed analyses and debugging support

Besides generating RF signals, **GIPSIE-RTX** is also capable of directly simulating digital signals considering user-defined modelling of a radio-frequency front-end.
In combination with a high-quality signal simulator a real-time and streaming mode is offered, while keeping the flexibility, performance, and distinguished features of GIPSIE.
GIPSIE-RTX provides a real-time input interface and thus supports hardware-in-the-loop (HIL) testing, e.g., for automotive applications.
GIPSIE-RTX is a new compact multi-channel high performance platform for complex and versatile GNSS testing:

- Highly reproducible scenarios
- Modelling of all error sources, delays, and propagation effects
- Interference (jamming and spoofing) simulation
- HIL (Hardware in the Loop) simulation
- Synchronization of multiple simulators for advanced testing (e.g., array antenna)
- 2 separate RF outputs per device

GIPSIE-RTX front view

Supported GNSS signals GPS: L1 C/A, L2C, L5
Galileo: E1 B/C, E5a-I/Q, E5b-I/Q

	GLONASS: G1 C/A, G2 C/A BeiDou: B1, B2 NavIC: L5 SPS, S-Band SPS QZSS: L1 C/A, L2C, L5 SBAS: L1 C/A
Constellation update rate	up to 250 Hz
Number of channels	up to 128

GIPSIE-RTX rear view

esa Acknowledgement: GIPSIE-RTX has been developed within the project **GSGSE**, which was carried out under a program of and funded by the European Space Agency. The view expressed herein can in no way be taken to reflect the official opinion of the European Space Agency.

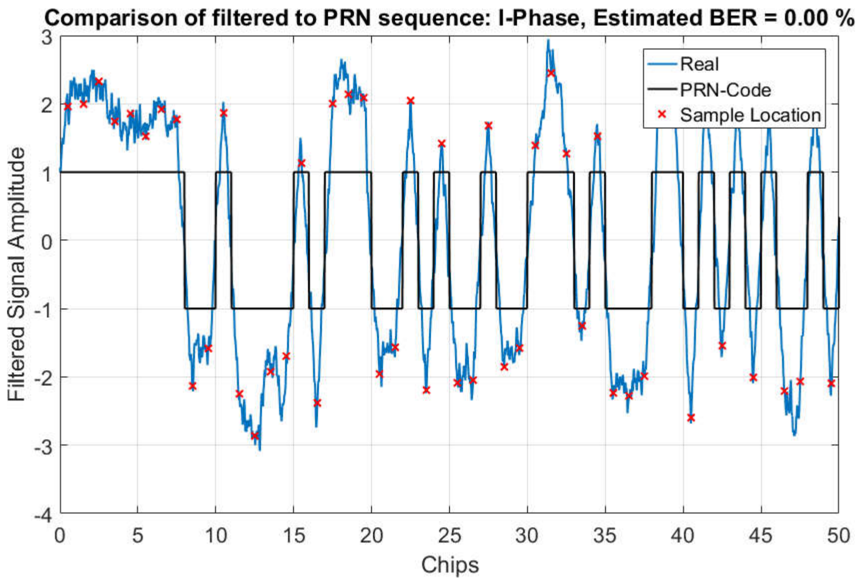
BGSRT - Blind GNSS software receiver tool for field test assessment in harsh environments

The Blind GNSS software receiver tool for field test assessment in harsh environments (BGSRT) activity, which is funded by the European Space Agency (ESA), seeks to exploit Signals of opportunity (SoO), i.e., RF signals in airspace, with unknown code sequences that can be used for positioning. Exploiting signals with unknown code chip sequences (or symbol sequences) is of interest for improving the positioning performance especially in harsh propagation conditions.

Global navigation satellite systems (GNSS) use code-division multiple access (CDMA) to transmit signals from different satellites in the same, overlapping spectrum. Since the GNSS signal received on earth is below the thermal noise floor, a GNSS receiver needs to know the CDMA sequence and the signal properties (e.g., center-frequency, code-rate, and modulation) in advance, to use the GNSS signals for positioning, navigation, and timing (PNT). The CDMA sequences are generally pseudo-random noise (PRN) codes and are published in an interface control document (ICD) for each GNSS. In general, a navigation message or a secondary code is modulated onto the CDMA sequence.

To use so called blind code sequences within a software-defined GNSS radio, it is necessary to estimate the transmitted sequence from the satellite. This can be achieved by isolating the satellite signal with a high gain parabolic dish antenna. The antenna limits the cross-interference from other signals (satellites) and ensures sufficient gain. Any signal transmitted by the satellite can be perceived as a SoO and exploited for PNT. One limitation of this direct estimation is that the actual spreading code cannot be separated from the data message. However, this limitation can also be regarded as an excellent advantage for a receiver: a sequence that incorporates the navigation message provides the receiver with a pilot signal. Therefore, the receiver can employ arbitrary long coherent integration during processing, allowing weak signals and receptions in challenging environments to be used. Such a system can be used to carry out experiments with signals even without a corresponding ICD. Also signals employing spreading code encryption can be tracked and evaluated, and their position, velocity, and time (PVT) performance determined, without security restrictions.

The possibility to exploit navigation SoOs with unknown code chip sequences (or symbol sequences) in a GNSS software-defined receiver (SDR) is of interest for the early assessment of new techniques (e.g., acquisition, tracking and positioning techniques) specifically designed for those signals without the need to have full access to the underlying code chip sequences (or symbol sequences). In general, these navigation signals might have specific signal properties (e.g., in terms of autocorrelation) that represent a challenge to the receiver when used in harsh propagation conditions, such that advanced techniques need to be applied. One particular case of interest are high-order BOC signals, whose acquisition and tracking (and later positioning) in the presence of fading/multipath conditions or when using low-end RF front-ends can be challenging. Another application is to use SoOs with an ICD that is not yet publicly available due to the signal being in the deployment and testing phase. The last application is that the targeted satellite it is not a GNSS but rather another satellite based SoO, which is exploited for navigation. If the sequence can be determined without an ICD, then a receiver developer may independently develop and test the receiver functionality.



Comparison of blind demodulated chip sequence with known reference PRN sequence

High gain parabolic antennas for satellite tracking and recording of unknown SoOs

The objectives of BGSRT are:

- Design and development of a software tool to automatically recover unknown code chip sequences (or symbol sequences) from multiple SoOs and satellites based on low-noise signal recordings from high-gain antennas to enable the de-spreading and exploitation of those SoOs when received with commercial GNSS antennas.

- Design and development of a blind GNSS SDR concept demonstrator automatically exploiting the recovered code chip sequences (or symbol sequences).
- Design and implementation of advanced techniques for robust acquisition, tracking and positioning of the SoOs in the concept demonstrator.
- Design and implementation of hybrid PVT solutions exploiting both the GPS/Galileo L1/E1 open signals (OS) and the SoOs from multiple GNSS satellites in the concept demonstrator.
- Assessment of the performance of the concept demonstrator with real field signals recorded in urban propagation conditions.

The project started in 2019 and is carried out by the following partners:

- OHB Digital Solutions GmbH, Austria (Project Lead)
- Cillian O'Driscoll Consulting, Ireland
- Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung e.V., Institut für integrierte Schaltungen, Germany

Acknowledgement:
BGSRT was carried out under a programme of and funded by the European Space Agency.

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OHB DIGITAL

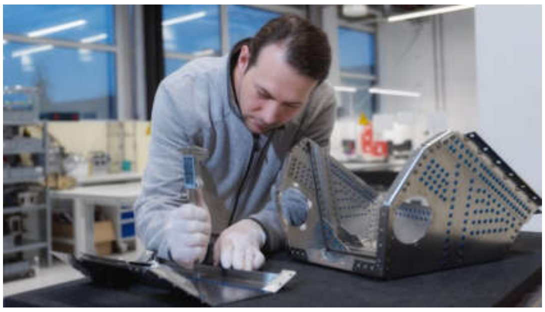
Sales 2020: 1.0 MEUR
ESA Share: 0.7 MEUR

3.12 Peak Technology GmbH

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

Vega / Vega-C

In 2020 Peak Technology produced their first flight model for the aerothermal cover of the Vega and Vega C upper stage. Furthermore, Peak Technology has also accomplished the qualification of the igniter cases for the Zefiro9 and Zefiro40 Stage of the new Vega C launcher in close collaborative with AVIO.



Aero Thermal Cover

Igniter Case

Vega-E

Based on the successfully developed parts in the Vega and Vega C programs, Peak Technology started in 2020 with the development of helium tanks for the upcoming Vega E launcher. This lightweight high-pressure tank is going to be responsible for the pressurization in the fuel lines of the newly developed upper stage.

Composite Overwrapped High-Pressure Tank

Sales 2020: 13 MEUR
ESA Share: 2.5 MEUR
Commercial Space: 1.5 MEUR

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3.13 Ruag Space GmbH

RUAG Space GmbH (RSA) belongs to Swiss RUAG International since 2008. The company is part of the RUAG Space Segment, which employs around 1.300 people in Switzerland, Sweden, Austria, Finland, Germany and USA, thus forming the largest independent space product supplier in Europe. RSA, with some 240 employees the largest space company in Austria, has started its operations in 1983. The product portfolio comprises on-board electronics, mechanisms and thermal hardware as well as mechanical ground support equipment.



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

Automated assembly of Navigation Signal Processor

As of December 2020, 22 flight models of the first product generation have been delivered, of which 20 are operating in orbit. This includes all Sentinel A&B satellites of the joint ESA/EU Copernicus program and the NASA mission ICESat-2.

Building upon this dual-frequency GPS expertise and heritage, a next generation multi-constellation GNSS Receiver, incorporating Galileo signal processing capability, has been qualified in 2016. Orders for 44 flight models could be booked until end of 2020, and 36 units have been delivered already. The new receiver will fly on the Sentinels 1, 2, 3 C&D as well as on the German reconnaissance satellites SARah and OptSat developed by OHB. The latest order concerns the Copernicus Carbon Dioxide Monitoring (CO2M) mission. The new generation receiver already made its successful in-orbit premiere aboard the sea-level monitoring satellite Sentinel-6 Michael Freilich launched in November 2020.

SARah radar reconnaissance system (source: OHB)

In Europe, the RSA market share for dual-frequency receivers exceeds 90%. Several contracts from South Korea demonstrate the strong market position also outside Europe.

With the development of lower cost GPS & Galileo single-frequency receivers for low earth orbit (LEO) as well as geo-stationary (GEO) satellites the product portfolio has been extended. LEO receivers were delivered to customers in Europe, the US, South Korea and the United Arab Emirates already. A remarkable success in the US institutional market is the selection of the RSA receiver for NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission to be launched in the 2022-2023 timeframe. The decision of the Goddard Space Flight Center (GSFC) in favor of RSA against domestic competitors is a real breakthrough and a strong indicator of the excellent position with this product in the global space market.

Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission (source: NASA)

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

RSA GNSS Receiver product family

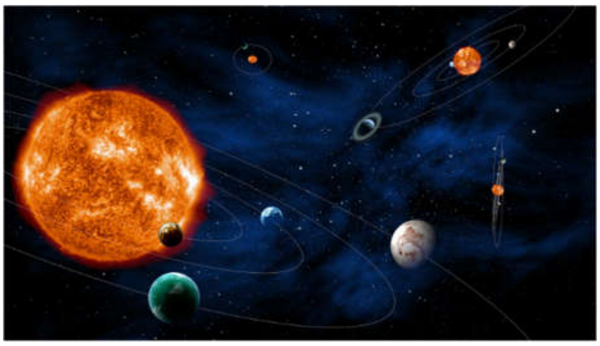
RSA GNSS Receiver Modules also form the basis of the advanced radio occultation (RO) instrument of the Metop Second Generation satellites. RO uses GNSS signals to provide profile information of temperature and humidity at high vertical resolution. A total number of 26 flight units will be delivered in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

GNSS receiver products contributed roughly one third to the RSA total sales in 2020.

In the frame of the Meteosat Third Generation (MTG) program, carried out by ESA on behalf of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Flight Model (FM) activities have been completed with the delivery of all remaining flight units. RSA contracts include the Solar Array Drive Electronics, the Antenna Deployment and Pointing Mechanism Electronics, electronics modules of the Satellite Management Unit, the Refocusing Mechanism and the Solar Baffle Cover for the main meteorological instrument as well as the motorized Aperture Cover for the Sentinel-4 instrument.

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

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



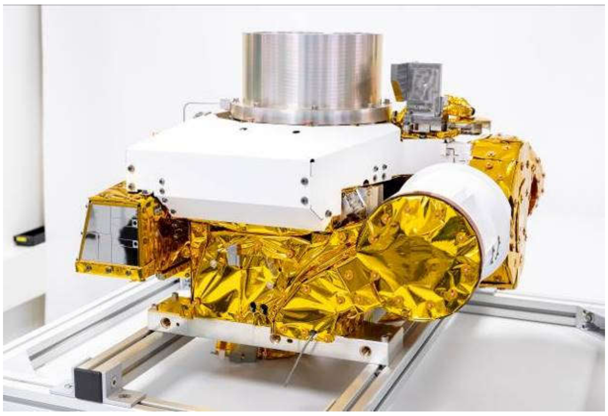
Searching for exoplanetary systems with PLATO (source: ESA)

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

The strategic cooperation with TTTech concerning the very promising development of high-performance data network space electronics based on the Time-Triggered Technology has entered the next phase. The NASA development of the Lunar Orbital Platform – Gateway (LOP-G) presents a highly attractive business opportunity for the jointly offered products, and major contracts from two US customers are expected shortly.

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

In the product segment Mechanisms, the third flight set (4 units) of an Electric Propulsion (EP) Pointing Mechanism (EPPM) for the all-electric Spacebus-Neo platform of Thales Alenia Space (TAS) was delivered. The first set, delivered end of 2018, has been integrated in the propulsion system of EUTELSAT KONNECT launched in January 2020. The satellite provides broadband services to Europe and Africa.



EPPM for Spacebus-Neo and integration on EUTELSAT KONNECT (source: ESA)

In a further contract the development of a Thruster Orientation Mechanism for the Electra platform of OHB has been continued. The development of a simplified mechanism concept optimized for volume production and targeting the multi-satellite constellation market has advanced.

A real breakthrough in the US is an order from Maxar for the supply of the worldwide largest Electric Propulsion Pointing Mechanism for the high-power thrusters of the Power and Propulsion Element (PPE) of the NASA Gateway. Maxar's PPE is the first element of the Gateway, providing power, maneuvering, attitude control and communications systems for the lunar orbiting outpost. Gateway is a foundational part of NASA's Artemis program, which aims to land the first woman and next man on the Moon by 2024 and enable future crewed missions to Mars.

Concept art of Maxar's Power and Propulsion Element (source: NASA)

A significant contribution to the 2020 sales in the mechanical area still came from the completion of the Mechanical Ground Support Equipment (MGSE) for integration and transport of the OneWeb satellites. This activity has been the biggest MGSE contract in the history of RSA so far. New orders for several satellite transport containers from two US customers underline the company's strong position with these products in the biggest space market.

Transport Containers for OneWeb satellites

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

Production of thermal insulation blankets for OneWeb satellites

Of big strategic relevance is the entry of the launcher thermal insulation market in the frame of the Ariane 6 development. In late 2020 production of the first flight models of high-temperature thermal protection has been confirmed.

Sales in the area of cryogenic insulation for terrestrial applications, a spin-off of the company's space business, declined in 2020 and contributed 10% to the total company sales.

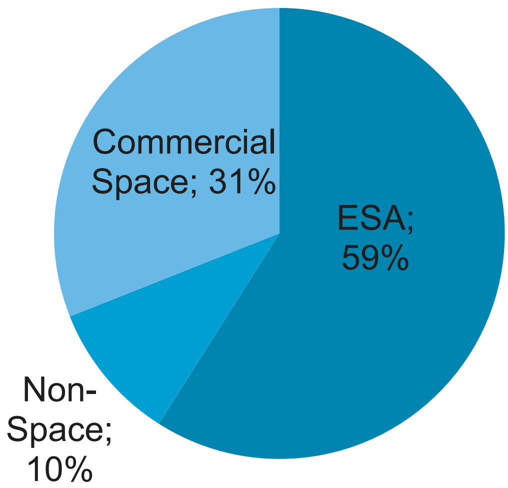
The year 2020 brought a number of satellite launches with key RSA contributions on board. On 10 February Solar Orbiter was launched aboard an US Atlas V rocket from NASA's Kennedy Space Center in Cape Canaveral, Florida. RSA has supplied the multi-layer thermal insulation for this new Sun exploring spacecraft of ESA, and, for the first time in its history, the company had been responsible for the development of a complete thermal subsystem.

Solar Orbiter lifts off atop an Atlas V rocket from Cape Canaveral (source: ESA)

On 21 November Copernicus Sentinel-6 Michael Freilich satellite, a joint development of ESA, NASA, EUMETSAT and the US National Oceanic and Atmospheric Administration (NOAA), started its mission aboard a SpaceX Falcon 9 from Vandenberg Air Force Base in California. Sentinel-6 is the first satellite flying the RSA's new generation multi-constellation GNSS POD Receiver. According to ESA, the addition of Galileo measurements brings a significant improvement in orbit determination quality, which adds to the overall performance of this sea-level monitoring mission. Multi-layer insulation supplied by RSA protects the satellite against the harsh thermal environment in space.

Sentinel-6 Michael Freilich at Vandenberg launch site (source: ESA)

Total RSA sales declined by 12% compared to 2019, due to the COVID-19 pandemic and the related delayed start of new programs. The non-ESA share reached 41%.



Sales 2020: 40.4 MEUR
ESA Share: 24.1 MEUR

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3.14 Seibersdorf Labor GmbH

SEIBERSDORF LABORATORIES

SPACE ACTIVITIES 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 153 staff and trainees in 2020. Seibersdorf Labor GmbH has been founded in 2009 as a subsidiary and spin-off of AIT - Austrian Institute of Technology GmbH, to act as a commercial service provider for industry, medicine, national and international organisations. Seibersdorf Laboratories focus their space activities to space radiation and its effects to humans, electronic components, systems and materials. The activities cover the following topics:

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

In the following, we present our space related public projects and studies carried out during 2020:

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

In their own **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 2020 the **5th RADHARD Symposium** with topics on:

- SmallSats and COTS Components Testing
- Practical Aspects of Radiation Hardness Assurance
- Radiation Hardness Testing with Laser Systems

The 5th RADHARD Symposium was organised the first time online with great success!

In addition we conducted projects and offered services for the European Space Industry.

AVIDOS - AVIATION DOSIMETRY SERVICE IN SPACE WEATHER CONTEXT

Introduction

Space weather deals with various, constantly changing space conditions near Earth caused by solar phenomena. Distorted states of Earth's magnetosphere, ionosphere, and thermosphere may influence human-made systems located not only in space but also on ground or even endanger human health. One aspect of space weather are radiation doses. Mainly Galactic Cosmic Radiation (GCR) shapes those levels. Some of occasional solar phenomena as solar flares or coronal mass ejections may temporary enhance radiation doses even on ground posing a risk on technological infrastructure and human health. It is therefore of interest to establish systems that constantly monitor radiation environment and even predict the expected enhancements of radiation doses especially in case of strong solar events. Various organisations already took an effort to establish such systems. An example from Europe is the Space Situational Awareness (SSA) Programme of European Space Agency (ESA) that started already in 2009. Part of this programme is Space Weather Segment, which provides owners and operators of critical space-borne and ground-based infrastructure timely and accurate information that supports mitigation of the adverse impacts of space weather. An example from worldwide level is the joint initiative of World Meteorological Organization (WMO) and International Civil Aviation Organization (ICAO) which focuses on providing space weather information services to aviation sector.

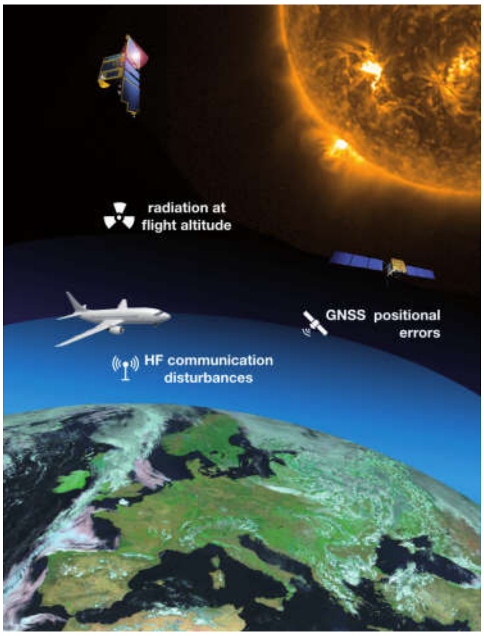


Figure: Space weather services are essential for functioning air traffic. A disturbed Earth's magnetosphere, ionosphere and thermosphere, lead to GNSS position errors, RF communication interference and increased radiation levels, can create health risks for pilots, flight attendants and passengers at flight altitudes.

Methods and Results

Seibersdorf Laboratories supports ESA's Space Situational Awareness (SSA) Programme in the segment of Space Weather (SWE). Seibersdorf Laboratories is a long-time member of Radiation Expert Service Centres (R-ESC) and focuses on services to aviation. Seibersdorf Laboratories provides the public with the real-time aviation dosimetry service AVIDOS. The service is federated with ESA's Space Weather portal (http://swe.ssa.esa.int) and accessible in its Aviation domain (http://swe.ssa.esa.int/web/guest/avidos-federated). AVIDOS is an informational and educational online software to increase public awareness of space weather and its effects at aviation altitudes available in the Internet since 2005. Following advancements in web technologies and the evolution of the ESA SWE portal, we took an effort to improve AVIDOS significantly. In 2020, we finished programming works and started testing phase. Our goal is to have a completely new version of AVIDOS, version 3.0, available on the ESA SSA SWE portal in 2021.

Figure: A snapshot of the AVIDOS 3.0 graphical user interface.

Seibersdorf Laboratories is part of the PECASUS consortium (Partnership of Excellence for Civil Aviation Space Weather User Services), which was founded with the aim of establishing a global space weather information service for ICAO (International Civil Aviation Organization). After preparatory works in 2019, Seibersdorf Laboratories started together with the PECASUS consortium a pilot phase of 24/7 provision of aviation dosimetry services tailored to ICAO's requirements. In 2020, we improved our service adapting to consortium's needs and continued the pilot phase.

Publication

Peter Beck, Marcin Latocha, *AVIDOS 3.0 New Aviation Radiation Assessment Services,* ESA SWE Service Network Workshop, October 2020.

Peter Beck, Marcin Latocha, Michael Wind, Christoph Tscherne, *Space Weather Research and Services of Seibersdorf Laboratories*, Space Weather Activities in Austria, UN COPUOS Expert Group on Space Weather: International Space Weather Initiative, February 2020.

Acknowledgements

Seibersdorf Laboratories' space weather activities are supported by ESA (ESA Contract No.: 4000113187/15/D/MRP), the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), the Austrian Aeronautics and Space Agency (ALR) as part of the Austrian Research Promotion Agency (FFG). Authors acknowledge all PECASUS partners, the SSCC team, neutron monitor station in Oulu, Finland, http://cosmicrays.oulu.fi, NMDB – Neutron Monitor Database http://www.nmdb.eu, and ANEMOS service http://swe.ssa.esa.int/web/guest/anemos-federated.

PRETTY - PASSIVE REFLECTOMETRY AND DOSIMETRY

Introduction

PRETTY is an ESA CubeSat space mission on Passive Reflectometry and Dosimetry (PRETTY), which is coordinated by RUAG Space and carried out in collaboration with Seibersdorf Laboratories and Graz University of Technology. The PRETTY CubeSat platform hosts two scientific payloads: A passive reflectometer, exploiting signals of opportunity for passive bistatic radar measurements and a reference dosimeter system, for continuously assessing the ionizing dose on-board the PRETTY spacecraft. Seibersdorf Laboratories is responsible for the reference dosimeter system. After completion of Phase B, PRETTY Phase C/D for design finalization, system assembly, and integration was successfully initiated. In September 2020, the consortium held the critical design review (CDR) with ESA, freezing the satellites design and initiating manufacturing, assembly, integration and testing. The launch of the PRETTY 3U CubeSat into a low-Earth sun-synchronous orbit is scheduled for Q2 2022.

Objectives

The objectives for the proposed radiation dosimeter payload are:

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

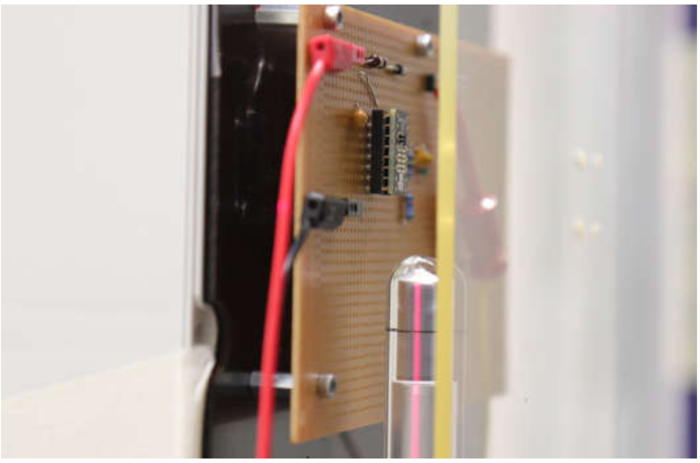
The assessment of the radiation mission dose and dose rate during the whole satellite's space mission is a main objective for the radiation sensor payload. The radiation sensor will provide information regarding total ionizing dose deposited in electronic components. For non-laboratory conditions like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

Total Ionizing Dose Detection

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

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

The PRETTY mission is a CubeSat space mission dedicated to the use of commercial components that are not primarily designed for the use in space. Although the project budgets forces the project team to use commercial off-the-shelf components (COTS) for the PRETTY payload, Seibersdorf Laboratories is undertaking a significant effort on radiation hardness testing of all used electronic key components of their payload. Radiation hardness testing at Seibersdorf Laboratories shows, that some COTS components show already significant performance degradation and even loss of functionality at about 5 krad (50 Gy), which is only 1/3 of the typical annual mission dose for PRETTY. Using such a component in the PRETTY mission would lead to permanent failure of the satellite electronics. However, through radiation testing at Seibersdorf Laboratories, the sensitive parts were identified and replaced. The figure below shows radiation exposure experiments using the Cobalt-60 source of the TEC-Laboratory of Seibersdorf Laboratories.



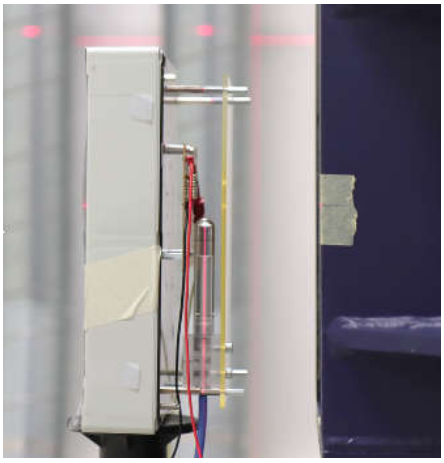


Figure: Radiation measurements of electronic components at the TEC-Laboratory of Seibersdorf Laboratories.

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

Single Event Effect Assessment

In addition to the above described highly recommended risk mitigation, Seibersdorf Laboratories has further investigated available measurement circuitry and identified a solution to further increase the scientific value of the dosimeter payload, by supplementing observation data from accumulated total-dose with the in-orbit detection of single event effects (SEE). SEE are caused by single, energetic particles that lead to a broad variety of soft to fatal errors in electronic devices. These effects pose a high risk to every space mission, as an impact by an energetic proton or heavy ion in the sensitive area of any electronic device can happen from day one of a space mission, eventually ending the mission due to a fatal impact on the system. In order to quantify the threat of single event effects, the TID dosimeter payload shall be extended by a single event upset (SEU) assessment system. The SEU assessment system will be based on SRAM memories and is carried out as collaboration with CERN. The integration of two SRAMs with well-different energy response allows to discriminate SEU contribution of low and high linear energy transfer (LET) particles. Further, the measurements allow to compare and finally validate widely used space radiation environment and SEU rate prediction models using the characterization data of the memories and calculated flux and fluence data of the space radiation environment. The measurements are representative for other silicon-based electronic systems e.g. during reliability testing of electronic components, in particular commercial off-the-shelf (COTS) components on-board CubeSat.

Summary and Conclusion

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

Publications

M. Moritsch, C. Tscherne, A. Dielacher, H. Fragner, M. Wind, P. Beck, A. Hörmer, O. Koudelka, *Approval of the detailed PRETTY Design*, RADHARD 2020, Symposium, 10. November 2020, Online

Koudelka, O. F. S., Wenger, M., Hörmer, A. J., Zeif, R., Fragner, H., Dielacher, A., Moritsch, M., Beck, P., Tscherne, C., Wind, M., Walker, R. & Martin-Neira, M., *A Passive Reflectometry and Dosimetry Mission Using a 3U Cubesat,* Mai 2020, Proceedings 12th IAA Symposium on Small Satellites for Earth Observation, 2020.

Fragner, H., Dielacher, A., Moritsch, M., Zangerl, F., Beck, P., Koudelka, O., Høeg, P., Wickert, J., Cardellach, E., Wenger, M., Hörmer, A., Zeif, R., Teschl, F., Martín-Neira, M., Semmling, M. & Walker, R., *Recycling GPS signals and radiation monitoring: The two payloads onboard PRETTY*, Jan 2019, CubeSats and SmallSats for Remote Sensing III. Pagano, T. S., Norton, C. D. & Babu, S. R. (Hrsg.). SPIE, 111310J. (Proceedings of SPIE - The International Society for Optical Engineering; Band 11131).

Dielacher, A., Fragner, H., Koudelka, O., Beck, P., Wickert, J., Cardellach, E. & Hoeg, P., *The ESA Passive Reflectometry and Dosimetry (Pretty) Mission*, 1 Jul 2019, 2019 IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2019 - Proceedings. Institute of Electrical and Electronics Engineers, S. 5173-5176 4 S. 8898720. (International Geoscience and Remote Sensing Symposium (IGARSS)).

Acknowledgements

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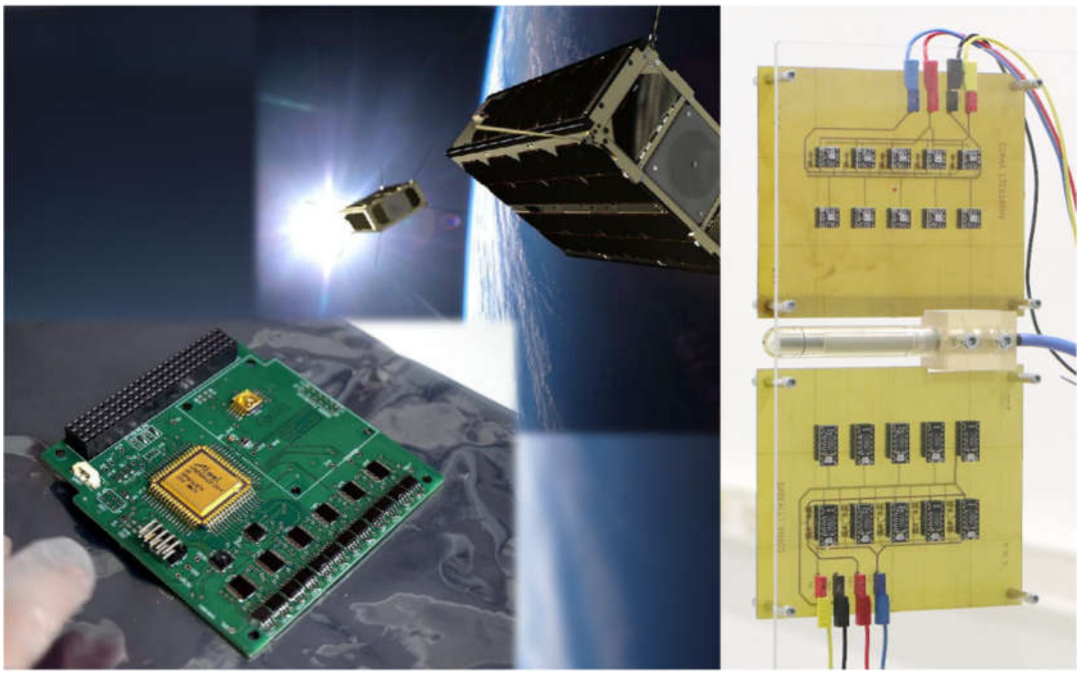
CORHA - RADIATION SCREENING OF COTS COMPONENTS AND VERIFICATION OF COTS RHA APPROACH

Introduction

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

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



Objectives

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

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

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

Method and Results

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

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

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

Table: List of parts scheduled for testing.

Component Type	Part	DESCRIPTION	Manufacturer
Memory	MT28EW256ABA	128Mb Embedded NOR Flash Memory, single bit per cell	Micron
Memory	CY14V101PS	1-Mbit (128k x 8) Quad SPI nvSRAM with Real Time Clock (NVM is SONOS)	Cypress
Memory	MB85RS256TY	256K (32 K x 8) Bit SPI FRAM	Fujitsu
Memory	CY15B102QN	ExcelonTM- 2-Mbit (256K x 8) Serial (SPI) F-RAM	Cypress
Microcontroller	STM32F103	Microcontroller, standard version	ST Microelectronics
Microcontroller	STM32L152	Microcontroller, low power version	ST Microelectronics
Operational Amplifier	LT1499HS	10MHz, 6V/µs, Dual/Quad Rail-to-Rail Input and Output Precision C-Load Operational Amplifier	Linear Technology
Operational Amplifier	LTC6240	CMOS Operational Amplifier	Linear Technology
Multiplexer	CD74HC4051	Hi-Speed CMOS 8-Ch MUX	Texas Instruments
Multiplexer	ADG5408TCPZ-EP	HV Latch-up proof 8 Channel MUX	Analog Devices
DC/DC Converter	LTC3895	Synchronous Step-Down DC/DC Controller	Linear Technology
ADC	ADC128S102	500 ksps to 1Msps, 12-Bit A/D Converter	Texas Instruments

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

Status of the Test-Progress

The table below presents an overview on all the test activities planned within the CORHA project. Also, the test status is shown that is either (1) test performed – indicated in green, (2) test scheduled – indicated in blue or (3) test not to be performed – indicated in black. It is noted, that scheduling of the proton SEE tests depends on the results of the respective heavy ion tests, as proton tests are only performed for parts that are susceptible to heavy ions with an LET of less than 15 MeV·cm²·mg⁻¹. This is, since protons may induce secondary short range heavy ions that have a LET of maximum 15 MeV·cm²·mg⁻¹.

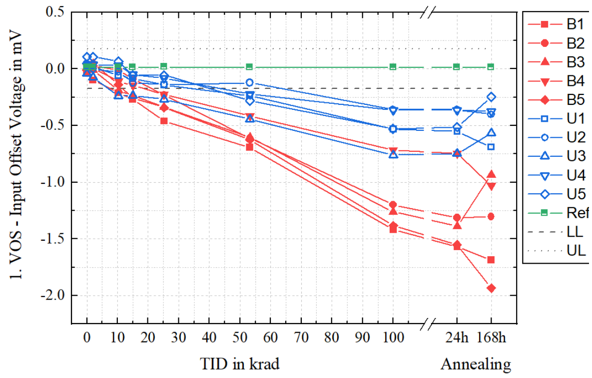
Due to the COVID-19 situation, significant amount of the heavy ion and proton tests, had to be shifted to 2021 as travelling was only possible to a very limited extend. In fact, only one heavy ion campaign could be realized in September 2020. This led to a significant delay of the project schedule.

Component	Status - TID Test	Status - HI SEE Test	Status - p^+ SEE Test
MT28EW128ABA	performed 2020	scheduled 2021	scheduled 2021*
CY14V101PS	performed 2020	scheduled 2021	scheduled 2021*
MB85RS256TY	performed 2020	scheduled 2021	scheduled 2021*
CY15B102QN	performed 2020	scheduled 2021	scheduled 2021*
STM32F103RGT6	performed 2020	scheduled 2021	scheduled 2021*
STM32L152RET6	performed 2020	scheduled 2021	scheduled 2021*
LT1499HS	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm·mg^{-1}
LTC6240	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm·mg^{-1}
CD74HC4051	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm·mg^{-1}
ADG5408TCPZ-EP	performed 2020	performed 2020	LET_{HI} > 15 MeV·cm·mg^{-1}
LTC3895	scheduled 2021	scheduled 2021	scheduled 2021*
ADC128S102	performed 2020	scheduled 2021	scheduled 2021*

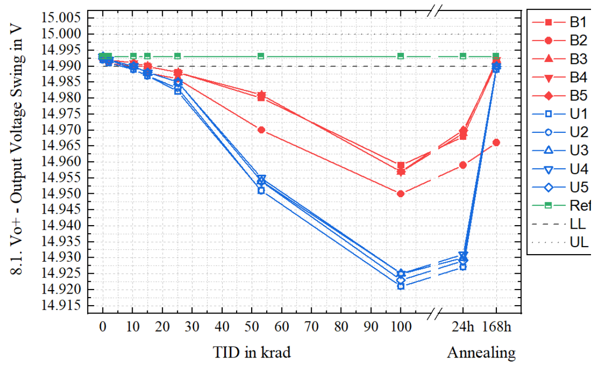
Exemplarily Result: TID response of two COTS Operational Amplifiers

Within the CORHA study, all TID exposure tests are performed in the TEC-Laboratory, an ISO/IEC 17025 accredited Co-60 irradiation facility operated by the Seibersdorf Laboratories. Exemplarily presented are the TID testing results of two COTS operational amplifiers (LT1499HS, LTC6240HVCS8). The exposures have been performed according the ESCC 22900. For each device type, a total of eleven components were randomly selected from one single lot of 100 components, resulting in five samples for biased configuration, five for unbiased configuration and one as non-irradiated reference. The DUTs are exposed in six dose steps at a constant dose rate of 0.6 krad$_{(Si)}$/h to a target TID dose of 100 krad$_{(Si)}$. Subsequent to the TID exposure two annealing steps are performed that are (1) a 24 hours room temperature annealing step and (2) a 168 hours elevated temperature aging step.

A total of 17 device parameters are characterised and exemplified for two COTS operational amplifiers (LT1499HS, LTC6240HVCS8). The following diagrams show the degradation of the Input Offset Voltage V_{OS} (LTC6240HVCS8) and Positive Output Voltage Swing V_{O+} (LT1499HS).



Degradation of the Input Offset Voltage V_{OS} of the LTC6240HVCS8 COTS operational amplifier as a function of dose.



Degradation of the Positive Output Voltage Swing V_{O+} of the LT1499HS COTS operational amplifier as a function of dose.

The table below presents for both biased and unbiased devices, an overview on the TID testing performance of two COTS operational amplifiers (LTC6240HVCS8, LT1499HS). A green cell colour indicates that all biased (B) or unbiased (U) devices are within the specification limits, otherwise the cell is marked red.

	LTC6240HVCS8															
	Applied Dose in krad$_{(Si)}$												Annealing			
Symbol	2		10		15		25		53		100		24h R.T.		168h 65°C[1]	
V_{OS}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_S^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_S^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{OS}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
A_{VO}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
CMRR	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_O^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_O^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{SC}^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{SC}^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
SR+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
SR-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
PSRR+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
PSRR-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U

	LT1499HS															
	Applied Dose in krad$_{(Si)}$												Annealing			
Symbol	2		10		15		25		53		100		24h R.T.		168h 100°C	
V_{OS}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_S^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_S^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_B	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{OS}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
A_{VO}	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
CMRR	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_O^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
V_O^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{SC}^+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
I_{SC}^-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
SR+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
SR-	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
PSRR+	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U
PSRR-																

The table indicates that a significant number of parameters exceed the specification limits already at very low dose levels. For the investigated dose levels and device parameters, both devices can withstand 2 krad(Si) without showing any parameter degradation that exceeds the defined specification limit. After application of the final dose of 100 krad$_{(Si)}$, we performed 24h annealing at room temperature and 168h annealing/accelerated aging at an elevated temperature. After annealing, parameter degradation for both investigated op-amps did not recover completely for all parameters. In addition, for the LT1499HS, the unbiased exposure condition is observed to be the worst case, while for the LTC6240HVCS8, the worst case is the biased exposure condition.

Summary and Conclusion

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

Publication

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

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

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

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

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

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

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

Acknowledgements

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

RADHARD SYMPOSIUM 2020

Introduction

On November 10, 2020, Seibersdorf Laboratories organized their **5th RADHARD-Symposium**, on radiation hardness assurance issues related to CubeSat space missions. The mission of the RADHARD Symposium is to provide a forum for the exchange of practical experience in the field of space radiation hardening, which is important for industrial applications as well as for science and research. The vision for the RADHARD Symposium is to provide a stimulating atmosphere for technical discussions and the initiation of new space projects to improve the radiation hardness of space electronics.

The **5th RADHARD-Symposium** in 2020 was organised online for the first time with great success, with topics on:

- SmallSats and COTS Components Testing
- Practical Aspects of Radiation Hardness Assurance
- Radiation Hardness Testing with Laser Systems

The RADHARD Symposium is addressed to space systems integrators, EEE manufacturers, industrial stakeholders, research and science as well as students interested in radiation. International experts present new results and highlighting reviews. We strongly encourage students to present their early research on radiation hardness effects.

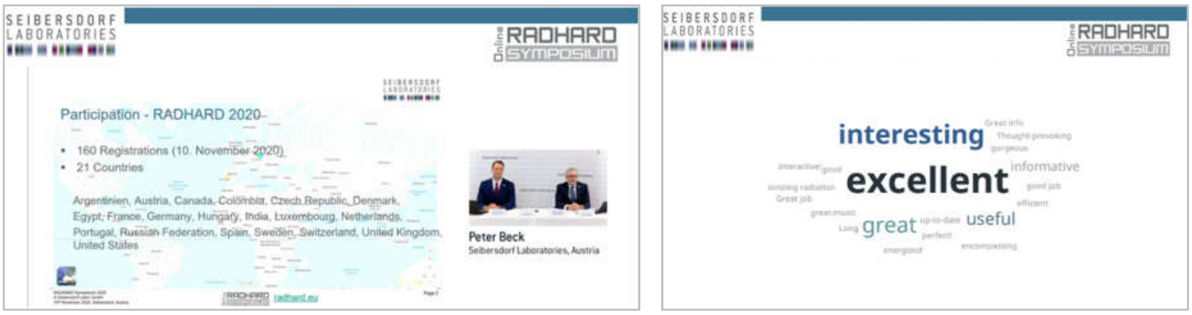


Figure: Presentation Screen of the 5th RADHARD 2020 Online Symposium und the summary word-cloud created by the participants at the end of the symposium.

The 5th RADHARD Symposium 2020 overview

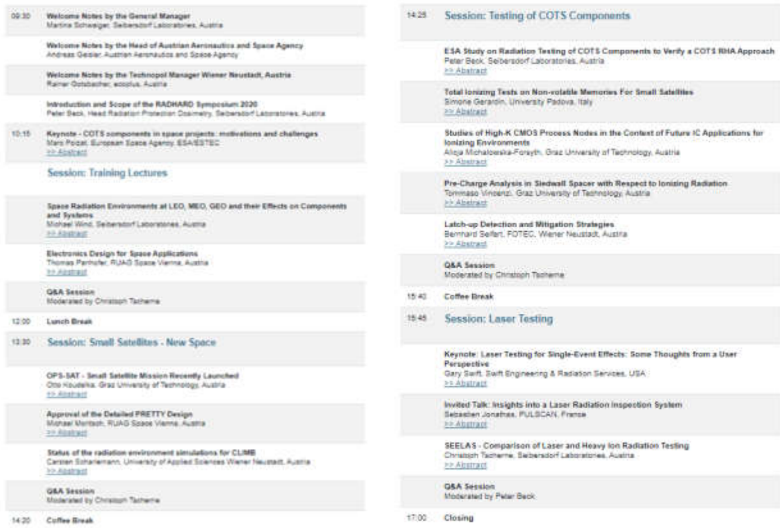
- 160 participants, 21 Countries
- One Keynote Presentation by ESA
- Training lectures on space radiation environment and Electronic Design for Space Applications
- Seven international lectures on practical aspects of COTS in space and radiation hardness assurance testing
- Four Q&A Sessions with Questions and Answers about the Lectures

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

Book of Abstracts

The book of abstracts is available for download online at https://www.seibersdorf-laboratories.at/fileadmin/uploads/intranet/events/radhard/2020/radhard-book-of-abstracts-2020.pdf

Reference: ISBN for print: 978-3-902780-18-8, ISBN for e-book: 978-3-902780-19-5.



09:30 **Welcome Notes by the General Manager**
Martina Schweiger, Seibersdorf Laboratories, Austria

Welcome Notes by the Head of Austrian Aeronautics and Space Agency
Andreas Geisler, Austrian Aeronautics and Space Agency

Welcome Notes by the Technopol Manager Wiener Neustadt, Austria
Rainer Gotsbacher, ecoplus, Austria

Introduction and Scope of the RADHARD Symposium 2020
Peter Beck, Head Radiation Protection Dosimetry, Seibersdorf Laboratories, Austria

10:15 **Keynote - COTS components in space projects: motivations and challenges**
Marc Poizat, European Space Agency, ESA/ESTEC
>> Abstract

Session: Training Lectures

Space Radiation Environments at LEO, MEO, GEO and their Effects on Components and Systems
Michael Wind, Seibersdorf Laboratories, Austria
>> Abstract

Electronics Design for Space Applications
Thomas Parnhofer, RUAG Space Vienna, Austria
>> Abstract

Q&A Session
Moderated by Christoph Tscherne

12:00 **Lunch Break**

13:30 Session: Small Satellites - New Space

OPS-SAT - Small Satellite Mission Recently Launched
Otto Koudelka, Graz University of Technology, Austria
>> Abstract

Approval of the Detailed PRETTY Design
Michael Moritsch, RUAG Space Vienna, Austria
>> Abstract

Status of the radiation environment simulations for CLIMB
Carsten Scharlemann, University of Applied Sciences Wiener Neustadt, Austria
>> Abstract

Q&A Session
Moderated by Christoph Tscherne

14:20 **Coffee Break**

14:25 Session: Testing of COTS Components

ESA Study on Radiation Testing of COTS Components to Verify a COTS RHA Approach
Peter Beck, Seibersdorf Laboratories, Austria
>> Abstract

Total Ionizing Tests on Non-volatile Memories For Small Satellites
Simone Gerardin, University Padova, Italy
>> Abstract

Studies of High-K CMOS Process Nodes in the Context of Future IC Applications for Ionizing Environments
Alicja Michalowska-Forsyth, Graz University of Technology, Austria
>> Abstract

Pre-Charge Analysis in Siedwall Spacer with Respect to Ionizing Radiation
Tommaso Vincenzi, Graz University of Technology, Austria
>> Abstract

Latch-up Detection and Mitigation Strategies
Bernhard Seifert, FOTEC, Wiener Neustadt, Austria
>> Abstract

Q&A Session
Moderated by Christoph Tscherne

15:40 **Coffee Break**

15:45 Session: Laser Testing

Keynote: Laser Testing for Single-Event Effects: Some Thoughts from a User Perspective
Gary Swift, Swift Engineering & Radiation Services, USA
>> Abstract

Invited Talk: Insights into a Laser Radiation Inspection System
Sebastien Jonathas, PULSCAN, France
>> Abstract

SEELAS - Comparison of Laser and Heavy Ion Radiation Testing
Christoph Tscherne, Seibersdorf Laboratories, Austria
>> Abstract

Q&A Session
Moderated by Peter Beck

17:00 **Closing**

Figure: Book of abstracts and Schedule of the 5th RADHARD Symposium on 10. November 2020

Organizers and Supporters

The RADHARD Symposium was organized by Seibersdorf Laboratories in close collaboration and supported by Austrian Research Promotion Agency (FFG), AUSTROSPACE, Graz University of Technology, University of Applied Sciences Wiener Neustadt (FHWN), and in Liaison with RADECS.

Acknowledgements

Seibersdorf Laboratories thanks all participants, organizers and supporters for a successful RADHARD Symposium 2020.

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3.15 Graz University of Technology (TU Graz)

Graz University of Technology has been very active in space technology and space experiments since 1969, where the first ionospheric experiment was launched on a Norwegian sounding rocket. 2021 marks the 30th anniversary of AUSTROMIR, the mission to the MIR Space Station, the largest single Austrian space project so far. TU Graz in cooperation with Joanneum Research, the Space Research Institute and Seibersdorf Research Centre (as it was called in 1991) developed several highly successful instruments which continued to be used by German and ESA missions in 1992, 1994 and 1995. Another milestone was the successful launch of the first Austrian satellite TUGSAT-1/BRITE-Austria in 2013.

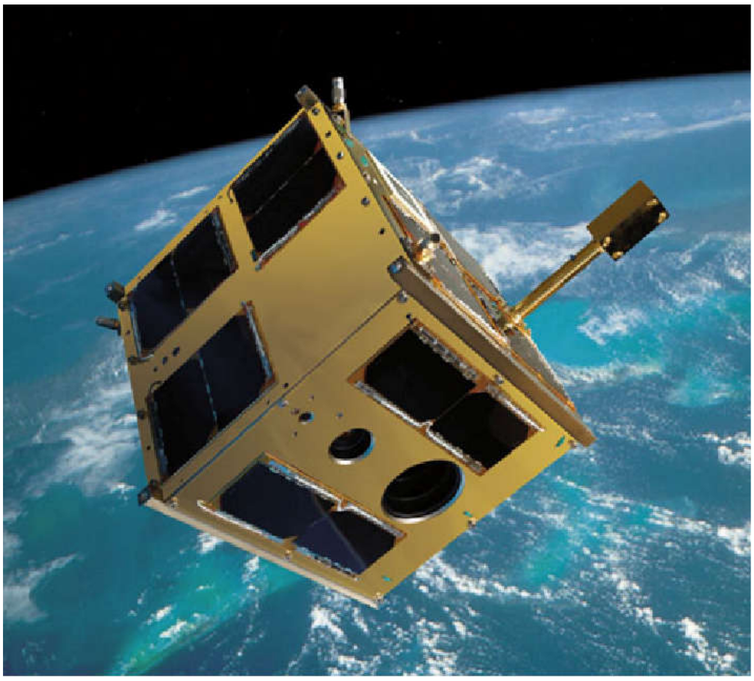
The current activities by the Institute of Communication Networks and Satellite Communications, the Institute of Geodesy, the Institute of Experimental Physics and the Institute of Electronics focus on satellite communications, satellite navigation, satellite geodesy, remote sensing, the development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

TUGSAT-1/BRITE-Austria

On 25 February 2013 the first Austrian satellite TUGSAT-1/BRITE-Austria was launched and has been successfully operated by the own ground station ever since. Designed for a mission duration of 2 years, we could celebrate in February 2021 eight years of operations, four times the design lifetime. This is a remarkable achievement for a low-cost mission using COTS electronics components. This project has been a highly productive cooperation with the University of Vienna, the Spaceflight Lab of the University of Toronto and the University of Innsbruck exploiting synergies between space systems engineering and astronomy.

BRITE stands for "Bright Target Explorer" and is the world's first nanosatellite constellation dedicated to asteroseismology, measuring the brightness variation of massive luminous stars. Five nearly identical satellites, two from Austria, two from Poland and one from Canada contribute to the international mission which is supported by 60 scientists, constituting the BRITE Executive Science Team. This team defines the stars and star fields to be observed. An observation campaign typically lasts for 6 months.

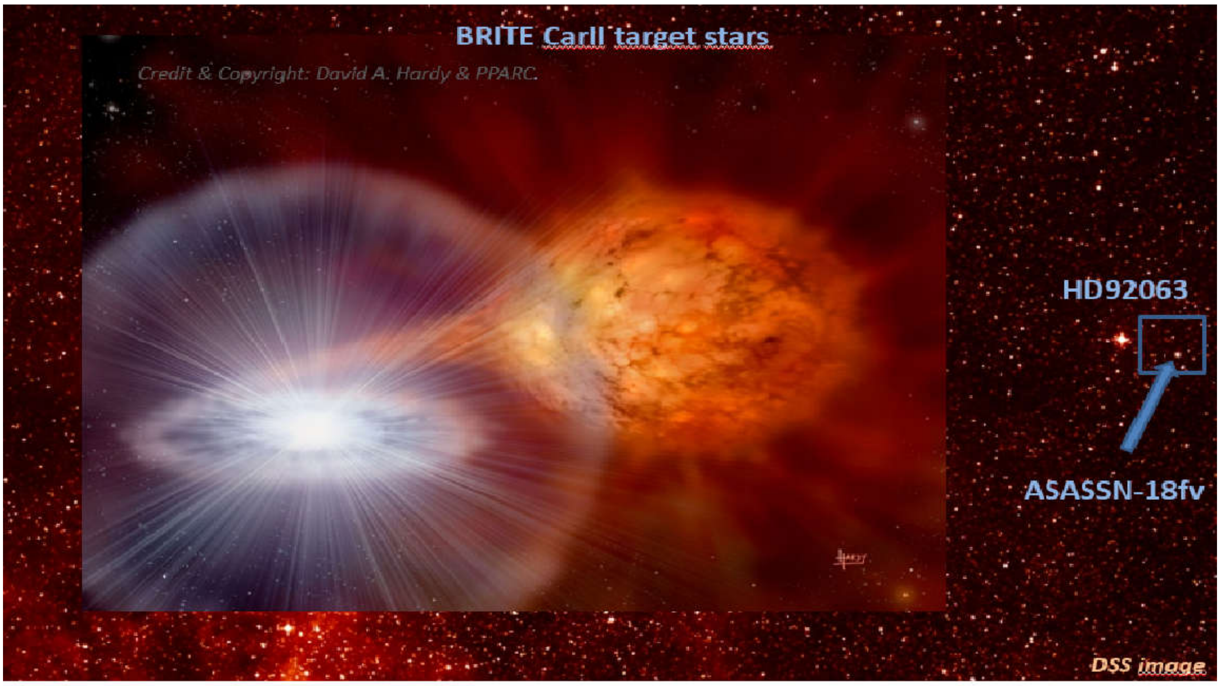
By now 735 stars in 63 campaigns have been observed resulting in a significant scientific output: 45 peer-reviewed papers in high-class science journals have been published. Including contributions to conference proceedings the number of publications has risen to 216, roughly one publication every 6 weeks since the beginning of science data analysis.



BRITE Satellite

BRITE Constellation

- allowed the detailed investigation of pulsations driven by gravity modes in one of the brightest Slowly Pulsating B stars,
- enabled the modeling of spots-induced rotational variations in the presence of pulsations,
- led to a unique study of the ‚heart beat' phenomenon of close interacting binary systems,
- provided unprecedented details of the interaction between stellar pulsations, circumstellar disks and shells.



Nova Carinae near the BRITE Target Star HD92063 (Artist's View)

A highlight has been the discovery of a Nova close to an observed star (Carina) by BRITE Constellation in 2018. BRITE Constellation was the only mission (ground or space-based) which could collect data on the whole cycle from beginning to the end. The team is proud that it led to a highly cited publication in "Nature Astronomy".

With respect to small satellite engineering the knowledge gain was very high which led to award of contracts for ESA's nanosatellite missions OPS-SAT and PRETTY.

BRITE Constellation also demonstrates that demanding scientific requirements can be fulfilled with small, inexpensive satellites which have matured from the original educational and demonstration projects to scientific and technological missions including large commercial constellations like Planet and Spire.

Nanosatellite Mission OPS-SAT

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

The launch took place on 18 December 2019 on board of a Soyuz-Fregat from Kourou. OPS-SAT is operated from a dedicated S- and X-Band ground station at the European Space Operations Centre ESOC in Darmstadt with support by a specially established UHF ground station at TU Graz.

The first phase covered the commissioning of the spacecraft and the payloads:

- on-board computer with GPS receiver and UHF telemetry
- coarse ADCS system
- electrical power system
- 2 Mbit/s S-band transceiver
- 50 Mbit/s X-band transmitter
- CCSDS protocol engine
- Satellite Experimental Payload Processor (SEPP)
- HD Camera (ground resolution: ~ 90 m)
- Software-defined Radio (SDR) receiver
- Optical data receiver
- Fine ADCS system for experimentation

OPS-SAT behaves as any other ESA spacecraft and is fully compatible with ESA's ground infrastructure since it implements the full CCSDS protocol stack.

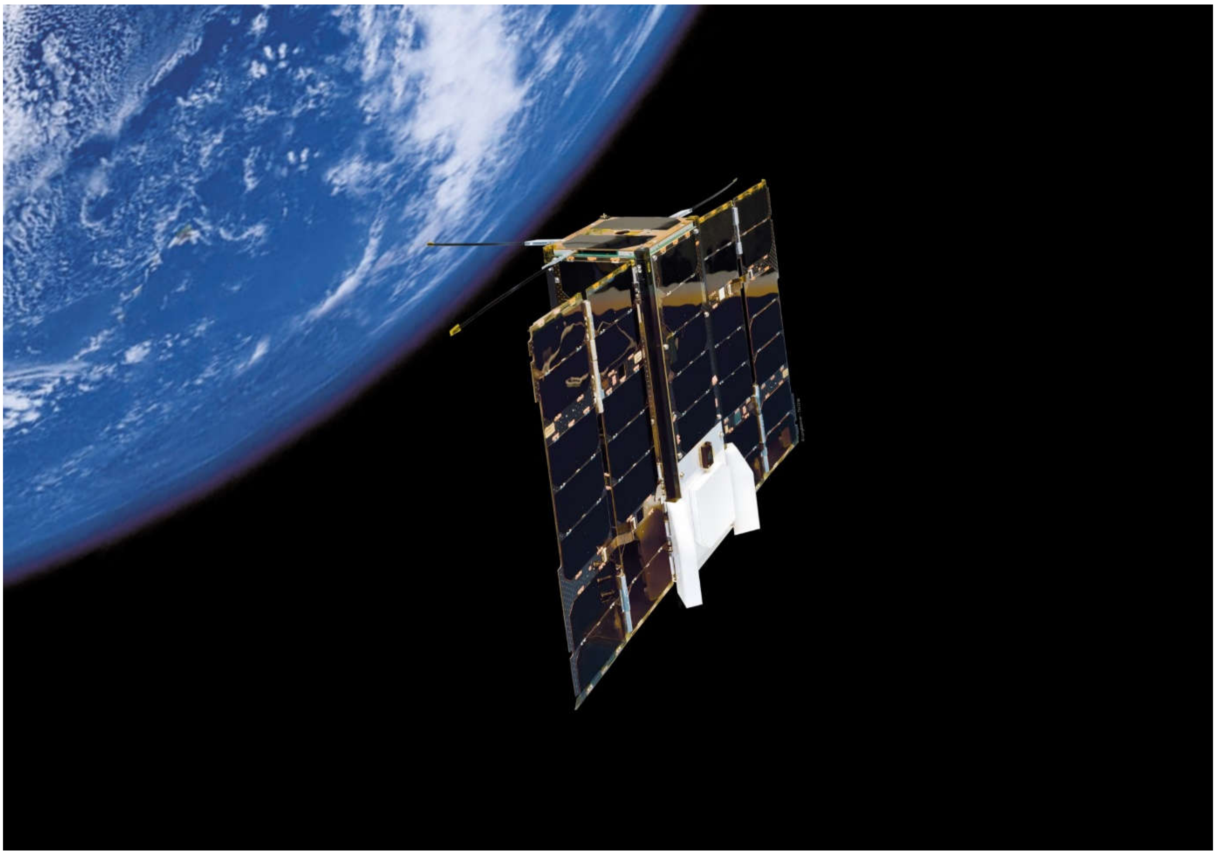
After completion of commissioning numerous experiments including on-board autonomy, artificial intelligence, remote sensing and radio signal monitoring have been carried out.

The SEPP processor which is a dual-core ARM-9 with a large Field Programmable Array (FPGA) is the core of experimentation. It is many times more powerful than traditional satellite processors and runs under Linux and Java. The new CCSDS Mission Operation (MO) services have been tried out for the first time. This will facilitate future space missions.

Images captured by the HD camera have been processed on board using data compression algorithms before downloading. AI software on the SEPP allowed to skip images taken over the high seas or under cloud cover. Novel compression techniques to optimise the download of data have been implemented and tested.

A very successful experiment was conducted recently using the SDR payload and the SEPP: radio signals were picked up by OPS-SAT, stored on board and downloaded when the spacecraft was in contact with the ESOC-1 ground station. Interference signals, especially radar signatures, in the UHF and L-band could be identified and located.

OPS-SAT-1 has been a very successful mission and will continue to be used by international experimenters. In July 2021 an optical data transmission experiment from the Laser station in Graz will be demonstrating the transfer of cryptographic keys to a low-orbiting spacecraft.



OPS-SAT Spacecraft

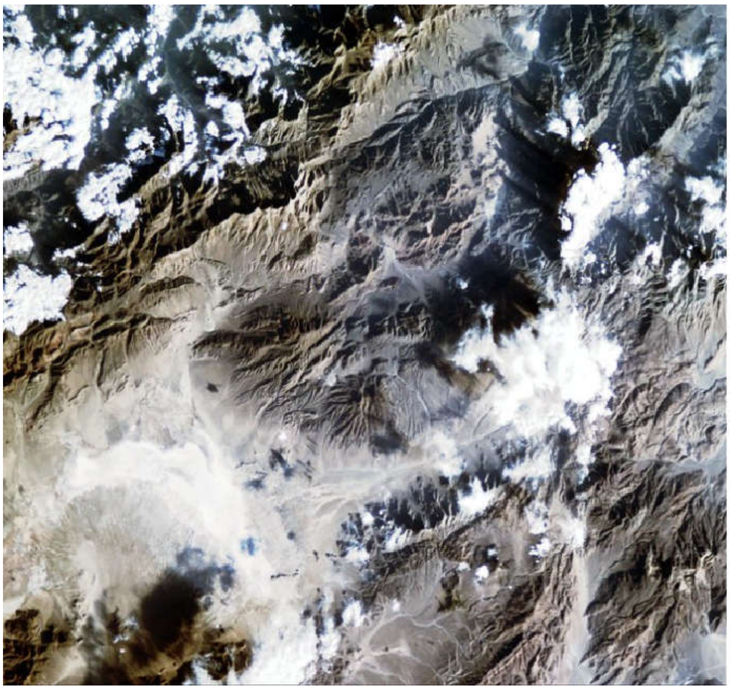
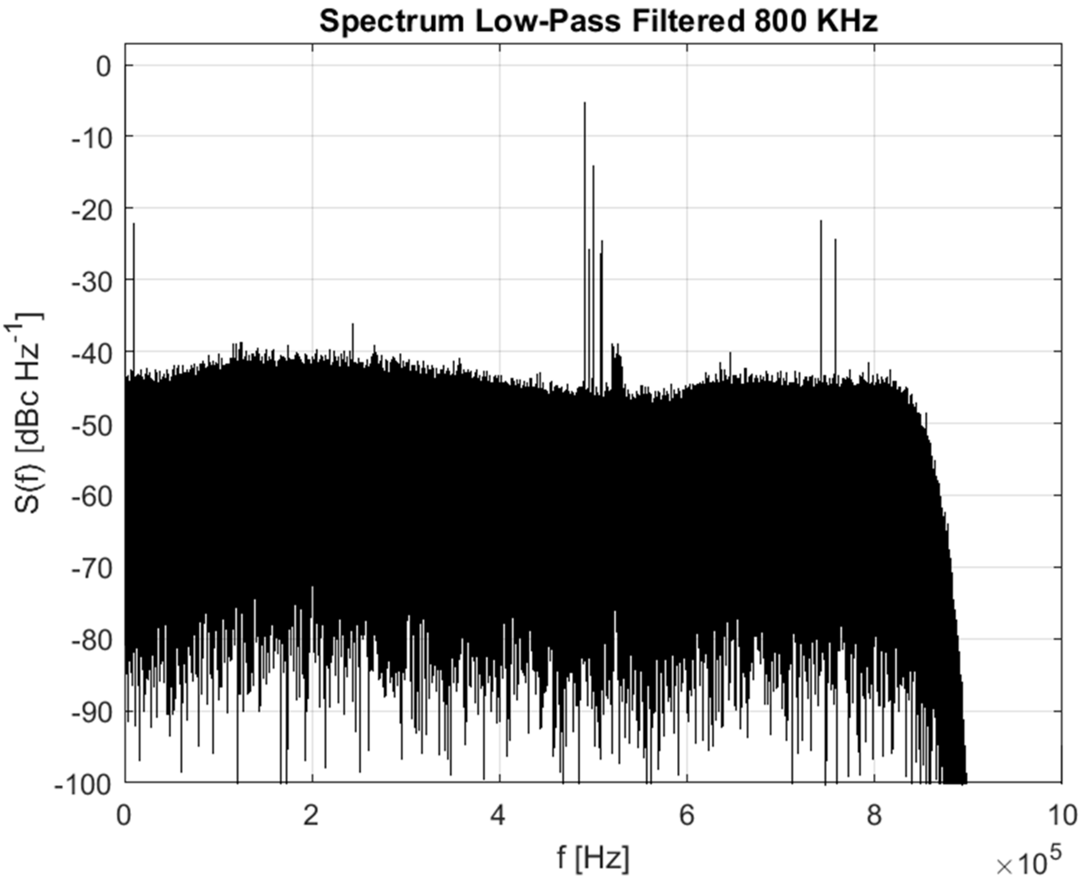


Image captured over the Andes by OPS-SAT



Interference Signals captured by the Software-defined Radio Payload in the 430 MHz band

Nanosatellite Mission PRETTY (Passive Reflectometry and Dosimetry)

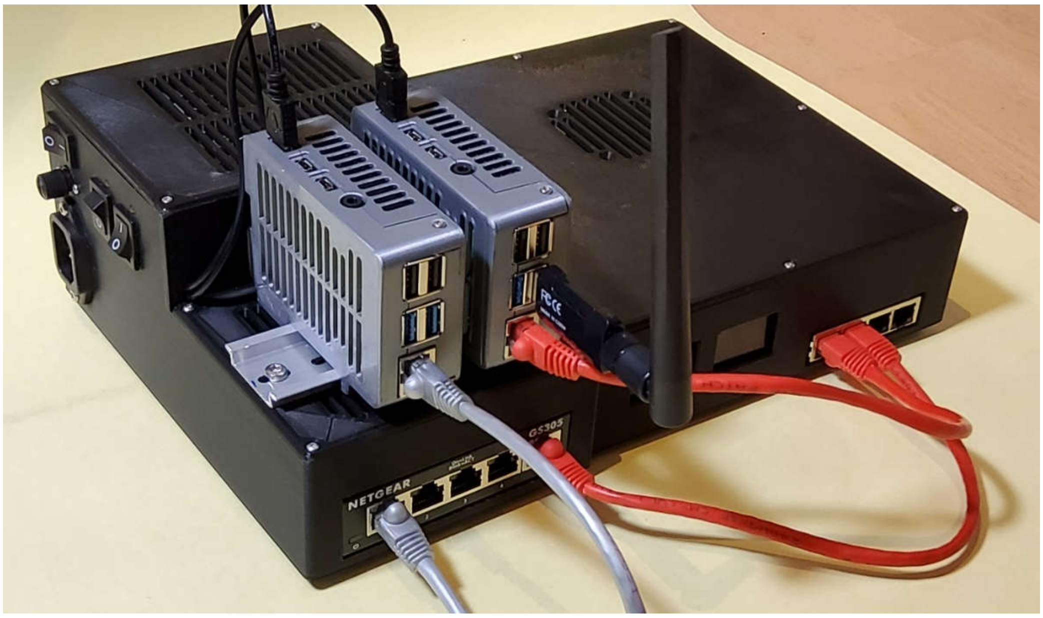
PRETTY is a nanosatellite mission with the objective to demonstrate and validate passive reflectometry in space. The method was verified by a joint ASAP project by RUAG and TU Graz earlier. PRETTY includes a payload similar to the software-defined radio with SEPP processor developed for OPS-SAT. Direct and ground-reflected GNSS signals are received by the spacecraft. By correlation the time difference is measured and this constitutes a precise altimeter. Sea waves or glaciers can be surveyed by a low-power and small payload. Thus, PRETTY can provide valuable contributions to climate research. In addition, the radiation environment is measured by a novel dosimeter developed by Seibersdorf Laboratories.

PRETTY is realised under an ESA GSTP contract with RUAG Space Austria as prime contractor. The project is in Phase D and will be launched in Q3/4 of 2021. At TU Graz currently the S- and VHF-band ground station is being established.

PRETTY is a 3U CubeSat, very similar to OPS-SAT. The Institute designed the special GNSS antenna and the hardware for the reflectometer payload and is responsible for system design, integration and testing.

Satellite Communications

In the EU-project EO-ALERT the Institute is designing the communications system for the next generation of Earth observation satellites. The consortium is led by DEIMOS (Spain) with OHB Italia, DLR (Germany), Politecnico di Torino (Italy) and TU Graz as partners. Powerful on-board processing of visual and SAR images is taking place on board using very powerful FPGAs. By image processing alerts are generated and delivered globally with a maximum latency of 5 minutes. TU Graz developed the communications emulator being part of the OHB Test Bench. This unit is planned to be commercialised as a flexible general-purpose simulator for sitcom systems in cooperation with Unitel IT Innovationen in Graz.



Communications Systems Emulator

Sales 2020 (TU Graz total): 268 kEUR
ESA: 155 kEUR

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3.16 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.

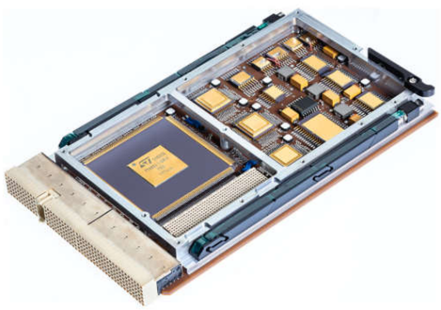
TTTech was established in 1998. The TTTech Group employs more than 2000 employees worldwide of which the majority works in engineering and development departments (with a focus on software development). The Group is headquartered in Vienna, Austria. TTTech Auto AG is its largest subsidiary and works mainly on software platforms for advanced driver assistance systems enabling also future autonomously driving cars.

TTTech Aerospace is a business unit within TTTech Computertechnik AG which is dedicated to the global aerospace markets. 2020 was the first year in which the revenue from space programs exceeded the sales related to aeronautics (not a surprise probably given the downturn in commercial aviation due to the COVID-19 pandemic).

European Space Activities 2020

In this year the finalization of the qualification activities for the Ariane 6 program was an important achievement and the company now looks forward to the maiden flight of the first launch vehicle which uses TTEthernet as sole data network, a technology developed in Austria to the largest extent.

The standardization of Time-Triggered Ethernet for use in space applications continued (ECSS working group) and at the end of the year a large new ESA project was started. It targets the qualification of key TTEthernet elements – space-grade TTEthernet switches and network interface cards (see picture to the right) as well as a modular avionics hosting unit. These elements are needed for various international human and robotic exploration programs, most notably Artemis and Gateway. They are developed in close cooperation with RUAG Space GmbH which will be responsible for all manufacturing aspects.



The largest bids ever for European programs were submitted in November 2020 for the switches and network interface cards needed for the modules which ESA contributes to the Gateway. These are the International Habitat and the ESPRIT Refueling Module with Thales Alenia Space being the prime contractor for both.

Being absorbed with these exploration programs, the progress with launcher projects other than Ariane 6 was somewhat limited.

Outside Europe

Both North American TTTech offices were highly active with the Gateway program driven by large contracts with Maxar and Northrop Grumman Innovation Systems (former Orbital ATK) for key elements of the PPE and HALO avionics. The collaboration with NASA JSC continued to focus on software building blocks which will simplify the development and operation of complex spacecraft.

The successful work with iSpace in Japan continued and contacts with Mitsubishi Heavy Industries and NEC intensified at the end of the year.

Revenue

Total European space revenue amounted to Euro 0.75 million with an ESA share of 0.4 million. Exports to North American space customers (i.e. sales of the US subsidiary) however exceeded Euro 5 million.

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3.17 Fachverband Elektro- und Elektronikindustrie

Der Fachverband der Elektro- und Elektronikindustrie vertritt in Österreich die Interessen des zweitgrößten Industriezweigs mit rund 300 Unternehmen, rund 69.000 Beschäftigten und einem Produktionswert von 18,56 Milliarden Euro (Stand 2019). Gemeinsam mit seinen Netzwerkpartnern – dazu gehören u. a. die Fachhochschule Technikum Wien, UFH, die Plattform Industrie 4.0, Forum Mobilkommunikation (FMK), der Verband Alternativer Telekom-Netzbetreiber (VAT) und der Verband der Bahnindustrie – ist es das oberste Ziel des FEEI, die Position der österreichischen Elektro- und Elektronikindustrie im weltweit geführten Standortwettbewerb zu stärken. www.feei.at

2019 ist die Anzahl der Beschäftigten der österreichischen Elektro- und Elektronikindustrie gewachsen und verzeichnete gegenüber dem Vorjahreszeitraum ein Plus von 2,6 Prozent. Mit Jahresende waren 68.721 Personen in der Elektro- und Elektronikindustrie beschäftigt, davon 42.522 Angestellte und 26.199 Arbeiter. 2019 haben die Unternehmen der Elektro- und Elektronikindustrie Produkte im Wert von 16,98 Mrd. Euro exportiert – die Exportquote erhöhte sich so auf 84,1 Prozent. Dabei sind aber die Exporte in den EU-Raum, der mit 64,6 Prozent Anteil an den Gesamtausfuhren der wichtigste Exportmarkt für österreichische Elektrotechnik- und Elektronikprodukte ist, aufgrund des allgemeinen Konjunkturabschwungs, um -2,4 Prozent gesunken. Im asiatischen Raum konnten die Exporte hingegen um 2,6 Prozent gesteigert werden. Der Anteil der Elektro- und Elektronikindustrie an den Gesamtausfuhren Österreichs belief sich 2019 mit 11,3 Prozent auf mehr als ein Zehntel.

Fachverband der
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