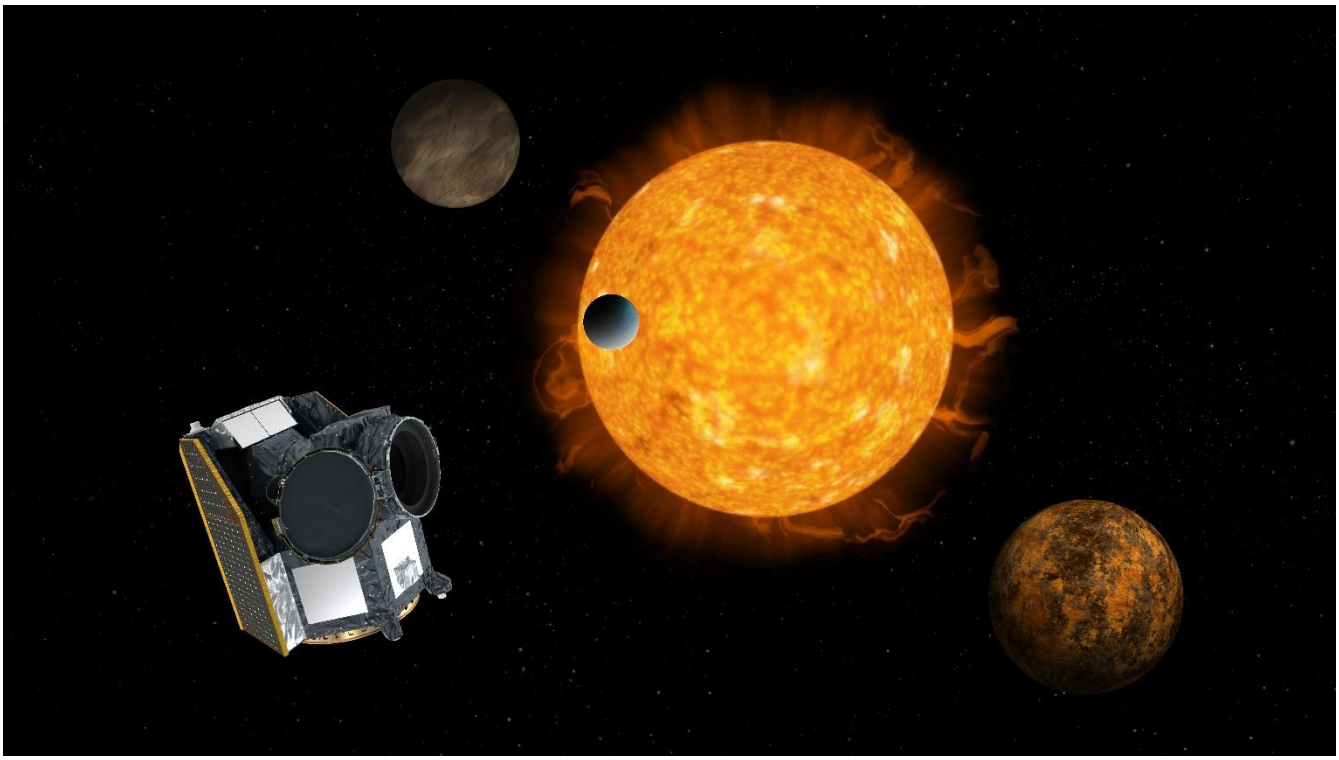
ANNUAL REPORT 2019



Cover picture: ESA's first Exoplanet Mission CHEOPS

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 2019, contributions from industrial members and research organizations about their space activities, and a current list of members with contact information.

Vienna, June 2020

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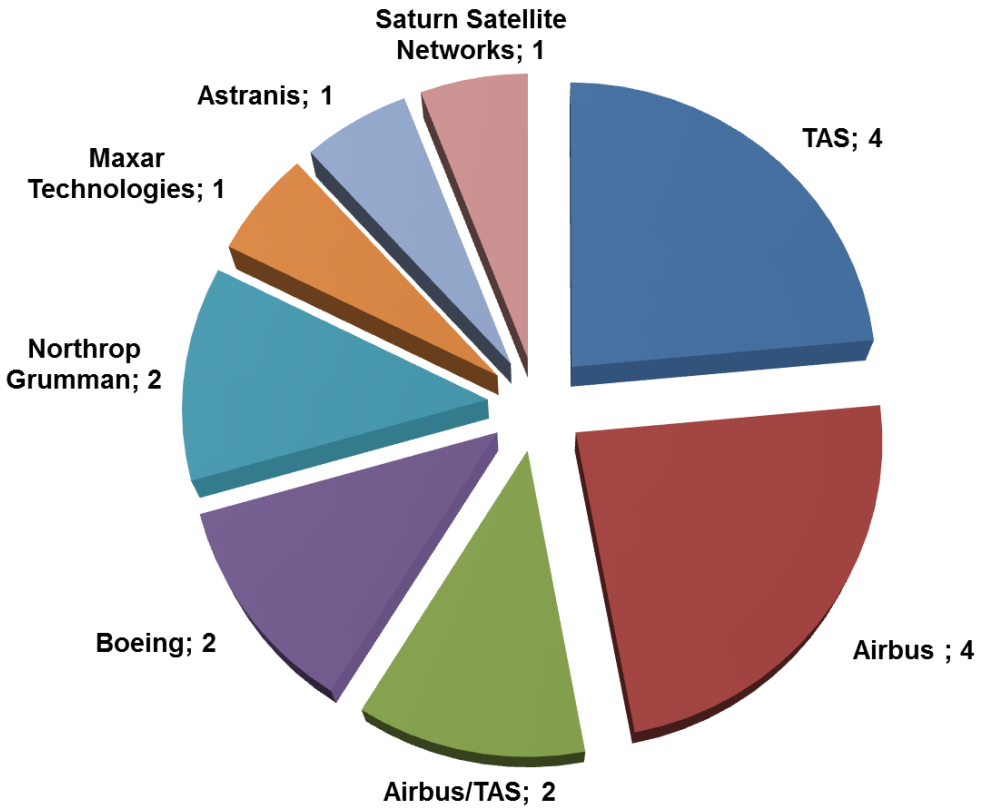
2 Year 2019 Review

In 2019 orders for seventeen geostationary (GEO) telecommunications satellites were placed worldwide, which means a significant increase compared to the previous year (5) and the first double-digit number since 2016. Ten contracts were awarded to European satellite manufacturers (Airbus: 4, Thales Alenia Space (TAS): 4, Airbus & TAS jointly: 2) and seven to their US competitors (Boeing: 2, Northrop Grumman: 2, Maxar Technologies: 1, Astranis: 1, Saturn Satellite Networks: 1). Satellites ordered ranged from the 350-kilogram Astranis small GEO to the heavyweight 6500-kilogram very high-throughput ViaSat-3 Asia-Pacific satellite booked by Boeing. For 2020 expert predictions vary between 10 and 20 GEOs. (Source: Space News, January 20, 2020).



Commercial geostationary telecommunications satellite orders 2019

(Source: Space News, January 20, 2020)

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 experienced further delays. The launch of the first six satellites, built by Airbus in Toulouse, at the end of February 2019 was a highly important milestone for the operator, at least. The next phase of the constellation deployment, however, had to be postponed to 2020. In the meantime, satellites are delivered from a new production

site in Florida jointly established by OneWeb Satellites and Airbus, where up to two satellites can be integrated daily.

OneWeb launch on Soyuz from Kourou

In May 2019 competitor SpaceX successfully launched the first 60 satellites for a much more complex network of 11.943 satellites (Starlink), which shall be deployed until 2025. Further 60 satellites were delivered in space in November. According to company information releases, currently seven satellites are produced daily, and, after further five launches of 60 satellites each, initial services shall be started in northern USA and Canada. Global operations shall commence after 22 launches.

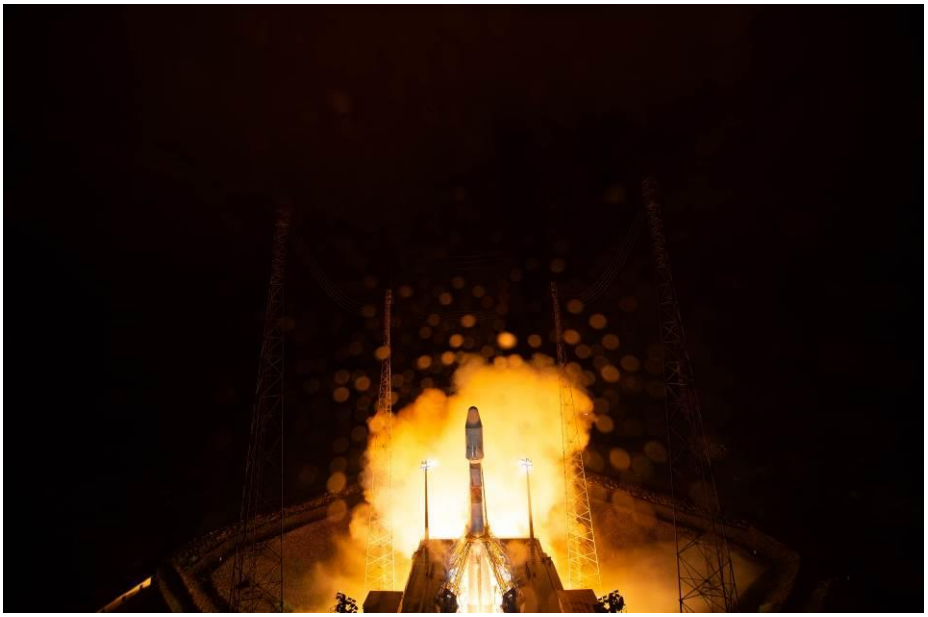
Starlink satellites in orbit

In January 2019 a SpaceX Falcon 9 launched the final ten Iridium NEXT satellites. This completed the deployment of the 75 satellites constellation.
With additional four satellites put into service in February 2019, the European satellite navigation system Galileo now is operational with 22 satellites. Unfortunately, the system suffered a week-long outage in July.

On December 18 the CHaracterising ExOPlanets Satellite (CHEOPS), developed under the direction of the University of Bern and ESA, was launched on a Soyuz-Fregat from Kourou.

The CHEOPS mission is dedicated to the characterization of exoplanet transits. The telescope will observe how planets pass in front of their mother star in other solar systems and support the search for potentially life-friendly planets. Austrian scientists and industry have contributed major elements to the challenging satellite payload.

CHEOPS at ESTEC (Source: ESA)



CHEOPS launch on Soyuz-Fregat from Kourou (Source: ESA)

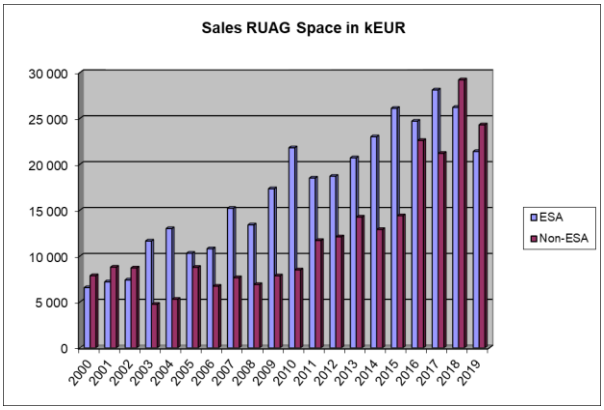
The ESA Ministerial Conference Space19+, which took place in Seville on November 27/28, concluded with a remarkable success for ESA and a very strong signal for the European institutional space market. New commitments confirmed by member states add up to 14.4 BEUR, which represents an increase of 40% compared to the previous conference in 2016.

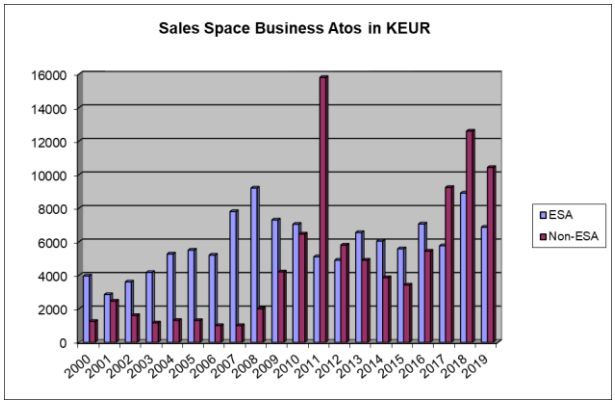
The budget for the science program and the basic activities of the agency was increased by almost 10%. The Earth Observation program, in particular the joint ESA/EU initiative Copernicus, received very high interest, but also the proposed activities in the areas of Human & Robotic Exploration and Space Transportation were strongly supported.

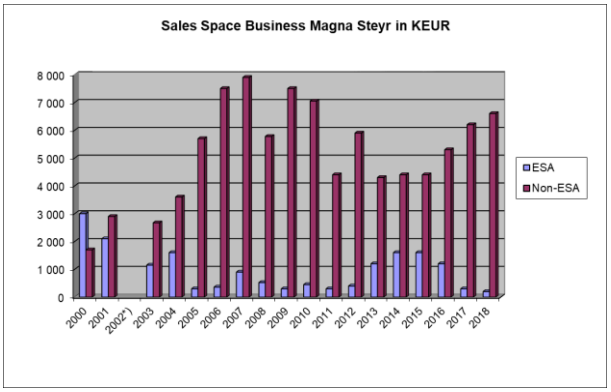
ESA Ministerial Conference Space19+ (Source: ESA)

Unfortunately, Austria could not fully adapt the subscription portfolio to this growth path, due to budgetary limitations. As a consequence, the relative level of total contributions declined from 1.9% in 2016 to 1.3%. The focus on Earth Observation and Telecom remained, but in some highly interesting new initiatives in Exploration as well as in Space Safety & Security there are currently no substantial opportunities for Austrian industry, despite attractive potential and product offerings identified by several companies. This unsatisfactory situation needs to be corrected by an adjustment of subscriptions, where possible. This is a matter of urgency, to avoid that Austrian suppliers lose ground in a dynamic market situation, where many new initiatives, both institutional and commercial, will shape the future of space industry for the next decade.

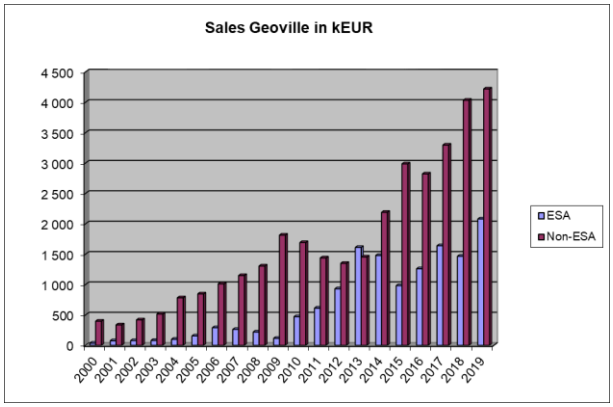
At the end of 2019 AUSTROSPACE had 20 members. The evolution of sales of the four biggest AUSTROSPACE companies is illustrated on the following page. The figures demonstrate a rather good leverage effect of ESA projects, i.e. a sustainable growth of commercial business.







*) no figures available due to organizational changes
no figures available for 2019



3 Reports of Industrial and Institutional Members

3.1 Austrian Academy of Sciences

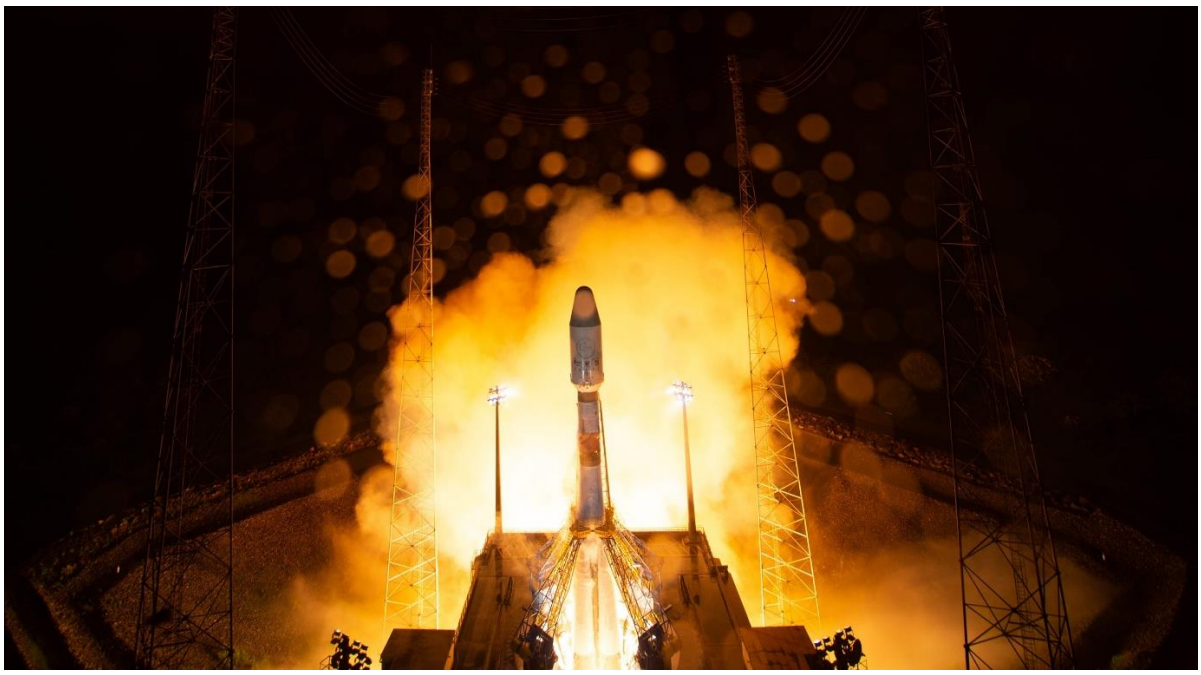
The Space Research Institute (Institut für Weltraumforschung, IWF) in Graz focuses on the physics of space plasmas and (exo-)planets. With about 100 staff members from 20 nations it is one of the largest institutes of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW).

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 and on the upper atmospheres of planets and 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:

- ESA's *Cluster* mission, launched in 2000, still provides unique data to better understand space plasmas.
- *MMS*, launched in 2015, uses four identically equipped spacecraft to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
- The first *China Seismo-Electromagnetic Satellite (CSES-1)* was launched in 2018 to study the Earth's ionosphere. CSES-2 will follow in 2022.
- *BepiColombo*, launched in 2018, is on its way to Mercury. It will investigate the planet, using two orbiters, one specialized in magnetospheric studies and one in remote sensing.
- The Korean satellite *GEO-KOMPSAT-2A (GK-2A)* was launched in 2018 to conduct space weather investigations.
- ESA's first small (S-class) mission *CHEOPS (CHaracterizing ExOPlanets Satellite)* was successfully launched on 18 December 2019. The satellite flies at an altitude of about 700 km and observes roughly 500 bright stars, to characterize their planets.



CHEOPS lifts off from Europe's spaceport in Kourou, French Guiana (© ESA)

- Along an innovative trajectory, *Solar Orbiter* (launched in early 2020) is to study solar and heliospheric phenomena.
- ESA's *JUpiter ICy moons Explorer (JUICE)* will investigate Jupiter and three of its largest moons, Ganymede, Callisto, and Europa. It is planned for launch in 2022.
- *SMILE*, scheduled for launch in 2023, is designed to study the interaction between the solar wind and Earth's magnetosphere.
- ESA's third medium (M-class) science mission *PLATO* is a space-based observatory to search for planets orbiting alien stars. It is planned for launch by 2026.

HIGHLIGHTS IN 2019

- A "Nature Communications" study presented the first evidence of standing waves on the dayside magnetopause using the five *THEMIS* satellites.
- Three-dimensional numerical simulations provided new insights into energy conversion processes in space. How space plasmas can be heated was reported in "Physical Review Letters".
- Astronomers identified three new planetary systems for a total of six planets. This discovery may lead to the characterization of exoplanet geology. The three studies were published in "Nature Astronomy".
- The successful launch of *CHEOPS* marked the highlight in the last month of 2019.

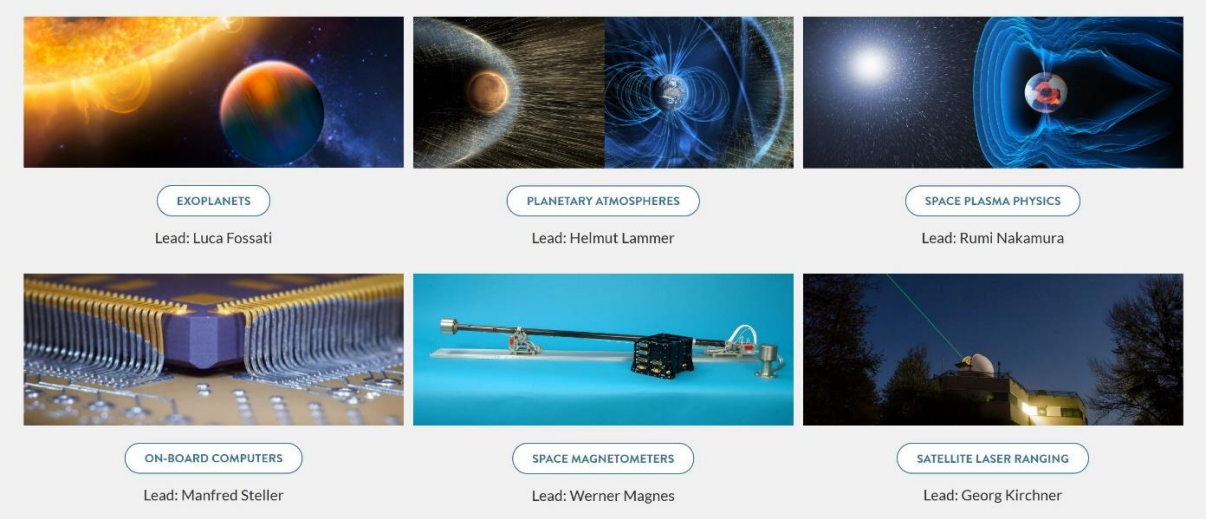
THE YEAR 2019 IN NUMBERS

Members of the institute published 142 papers in refereed international journals, of which 42 were first author publications. During the same period, articles with authors from the institute were cited 5705 times in the international literature. In addition, IWF members presented 70 talks and 55 posters at international conferences. Last but not least, institute members were involved in the organization of six international meetings or workshops.

IWF STRUCTURE AND FUNDING

IWF is structured into six research groups (see figure). Wolfgang Baumjohann serves as Director, Werner Magnes as Deputy Director. Most financial support is provided by ÖAW.

Significant support is also given by other national institutions, in particular the Austrian Research Promotion Agency (Österreichische Forschungsförderungsgesellschaft, FFG) and the Austrian Science Fund (Fonds zur Förderung der wissenschaftlichen Forschung, FWF). Furthermore, European institutions like ESA and the European Union contribute substantially.



IWF research fields and group leaders

NEAR-EARTH SPACE

Near-Earth space is a most suitable place to study fundamental space plasma processes through recent advancements in the in-situ measurements of charged particles together with electric and magnetic fields at high cadence. IWF has been participating in the hardware activities of numerous space missions in the Earth's magnetosphere, now under operation as well as in the planning phase. Data taken from these missions have been extensively analyzed at IWF by applying different analysis methods to the data and by theoretical modeling to compare with the observations. The obtained results contribute to enhancing the knowledge about space plasma processes applicable in other plasma environments within our solar system and beyond.

CLUSTER

The *Cluster* spacecraft have been providing data since 2001 for studying small-scale structures of the magnetosphere and its environment as the first four-satellite mission in space. The mission is currently planned to be extended to December 2020. IWF is PI/Co-Investigator on five instruments and has contributed to data archiving activities at the *Cluster Science Archives (CSA)* in addition to science data analysis.

MMS

NASA's *MMS (Magnetospheric Multi-Scale)* mission, launched in 2015, explores the dynamics of the Earth's magnetosphere and its underlying energy transfer processes. Four identically equipped spacecraft carry out measurements in the Earth's magnetosphere with high temporal and spatial resolution. *MMS* investigates the small-scale basic plasma processes, which transport, accelerate and energize plasmas in thin boundary and current layers. After successful completion of the science phase and the first extension phase, the second extension phase is being proposed for further five years where observations by a new constellation of the spacecraft is planned.

IWF has taken the lead for the spacecraft potential control *(ASPOC)* and is participating in the electron beam instrument *(EDI)* and the digital fluxgate magnetometer *(DFG)*. In addition to the operation of these instruments and scientific data analysis, IWF is contributing to inflight calibration activities.

THEMIS/ARTEMIS

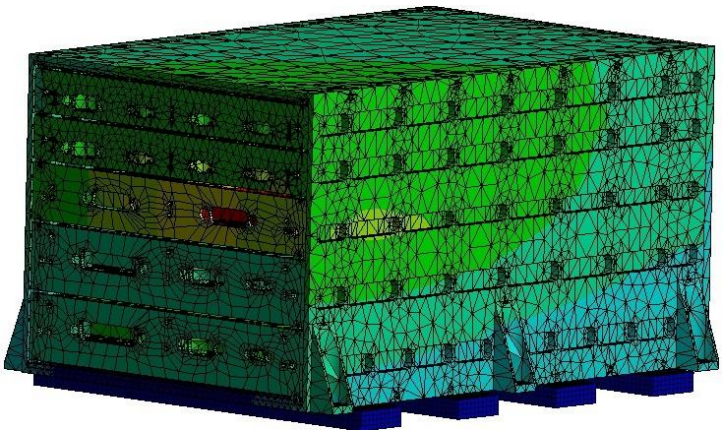
NASA's *THEMIS* mission *(Time History of Events and Macroscale Interactions during Substorms)*, launched in 2007, consists of five identical satellites flying through different regions of the magnetosphere. In autumn 2010 the two outer spacecraft became *ARTEMIS* and are orbiting the Moon, while the other three *THEMIS* spacecraft remained in their orbit. As Co-Investigator of the magnetometer, IWF is participating in processing and analyzing data.

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-Investigator for 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* (figure below) 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 2018, IWF established the concept for the DPU prototype and completed the preliminary design of the box mechanics.

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



Results from the thermal analysis for the SXI-EBOX when removing the radiation protection for the CCD

CSES

The China Seismo-Electromagnetic Satellites (CSES) are scientific missions dedicated to the investigation and monitoring of variations of 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* is 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).*

Up to now, the magnetometer sensors of *CSES-1* operate continuously in good health and validation activities indicate a good data quality. In 2019, the data from *CSES-1* were e.g. used to compute the only geomagnetic field model up to degree and order of 15 in a spherical harmonic representation, which is independent from magnetic field data measured by ESA's *SWARM* mission.

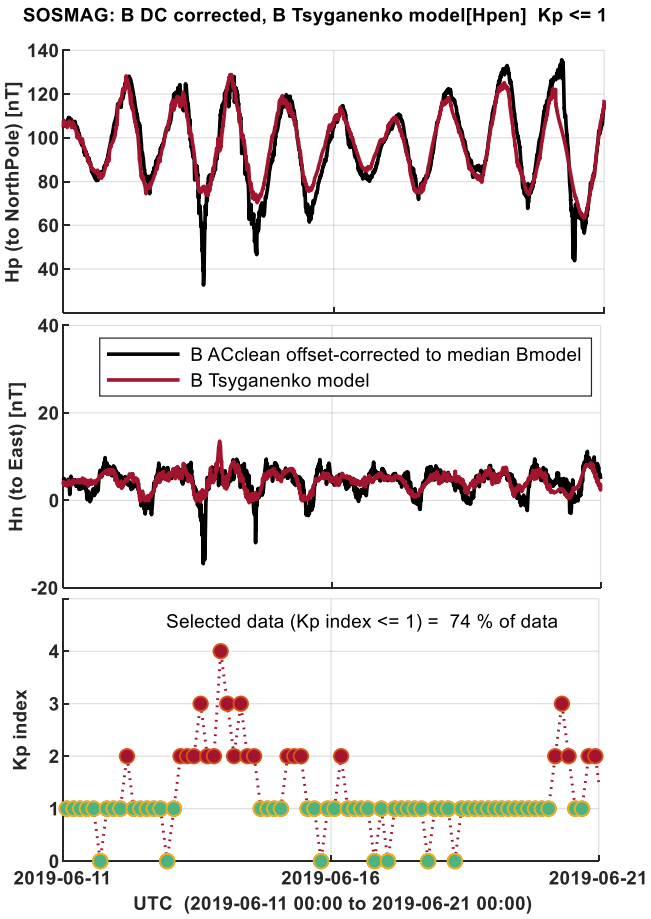
GEO-KOMPSAT-2A

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 implementation of the satellite, which was launched in 2018, and the necessary ground segment is managed by the Korean Meteorological Administration. 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.

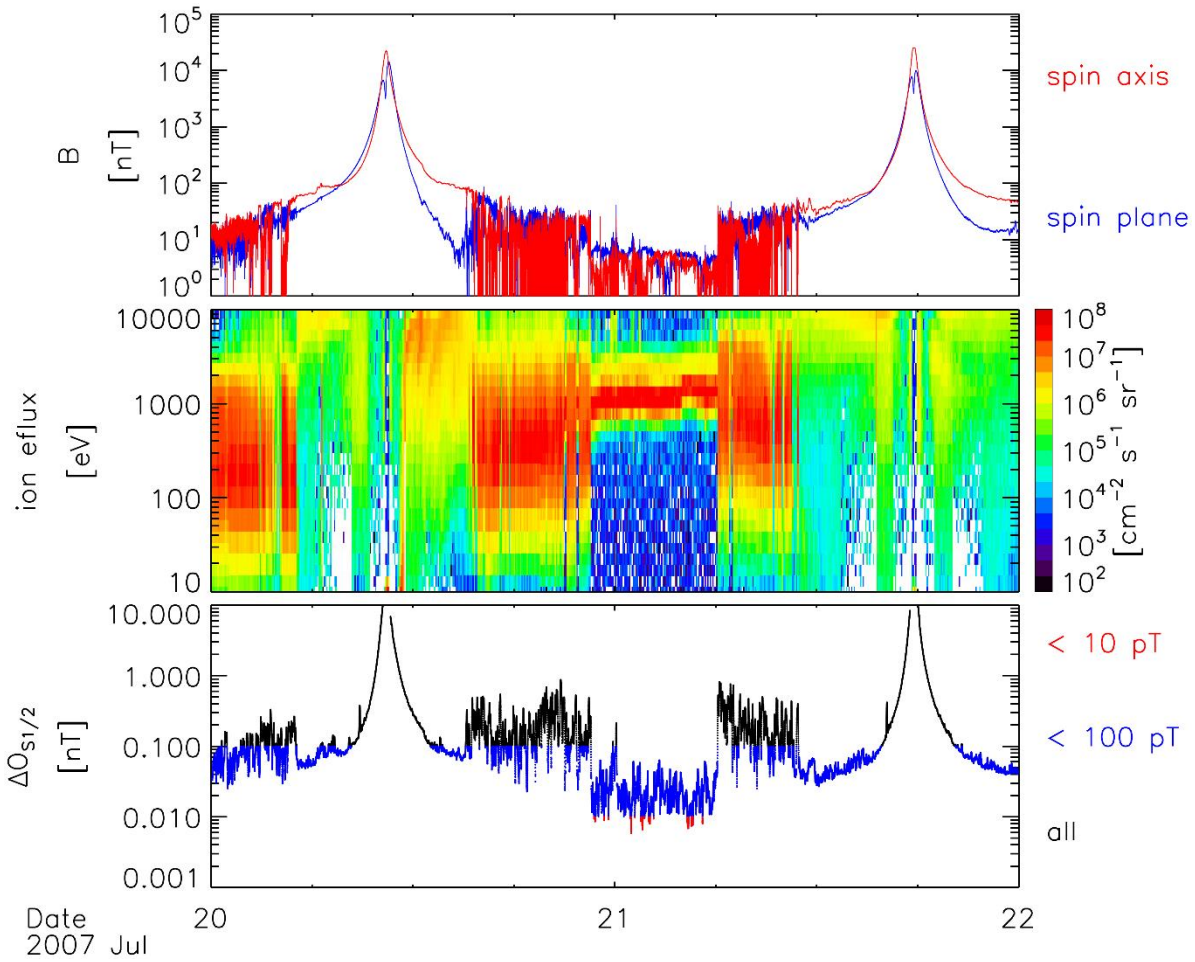
During the first year of operation it could be demonstrated that the four-sensor design enables a data quality, which is well within the mission requirements. The calibration, i.e. determination of the slowly-varying DC offsets of the spacecraft, is done at IWF through comparison of the AC- cleaned data with data calculated from the Tsyganenko model for actual solar wind parameters (obtained from the *WIND* spacecraft). The comparison is done in the physical reference frame of the geomagnetic field (Hp to North Pole, He to Earth center, Hn to East), such that the median values for each component of measured and model data coincide. The difference between the medians gives the DC offset for each component (figure below). In parallel to the flight data verification and calibration, the *SOSMAG* ground processor software has been under development in 2019. It shall be implemented in the data center of ESA's Space Safety program in 2020 for a nearly real time release of the *SOSMAG* data to the space weather community.



Example of the DC calibration for 10 days in June 2019. The correction with the DC offsets yields good results for times with Kp <= 1: the deviation between model data and DC corrected data is minimal. Stronger deviations are seen for times with disturbed magnetosphere (Kp > 1)

CALIBRATION OF MAGNETOMETERS ON SPIN-STABILIZED SPACECRAFT

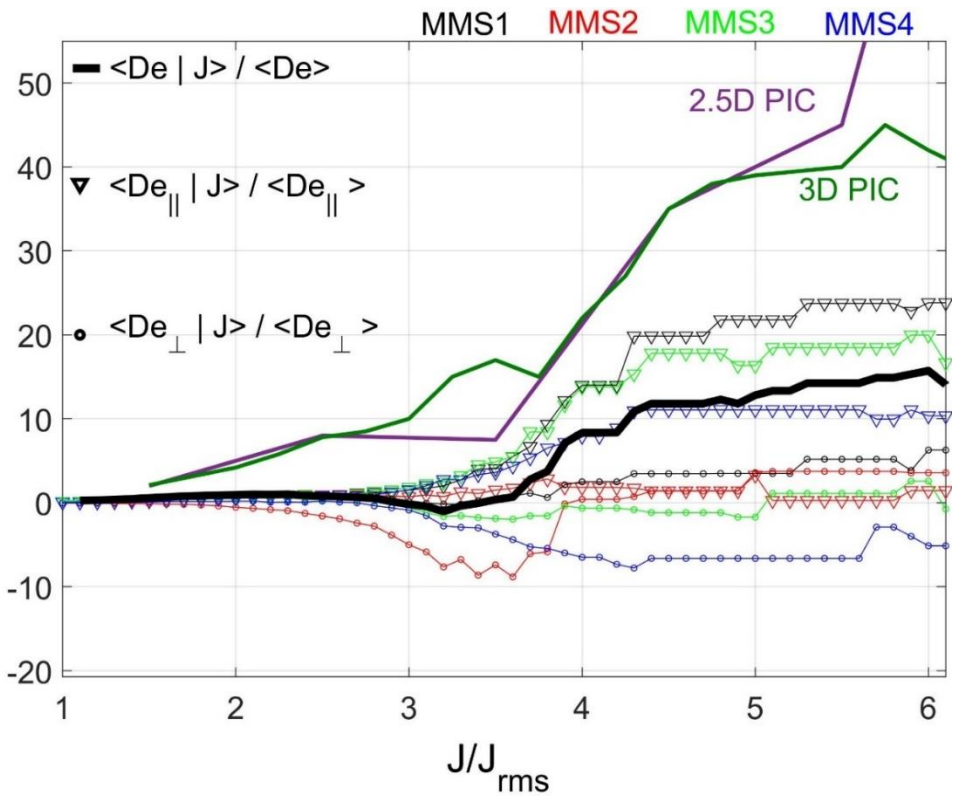
Magnetometers are key instruments on board spacecraft that probe the plasma environments of planets and other solar system bodies. The linear conversion of raw magnetometer outputs to fully calibrated magnetic field measurements requires the accurate knowledge of 12 calibration parameters: six angles, three gain factors, and three offset values. The in-flight determination of 8 of those 12 parameters is enormously supported if the spacecraft is spin-stabilized, as an incorrect choice of those parameters will lead to systematic spin harmonic disturbances in the calibrated data. Unfortunately, previously published equations and algorithms for the determination of the eight spin-related parameters are far from optimal, as they do not take into account the physical behavior of science-grade magnetometers and the influence of a varying spacecraft attitude on the in-flight calibration. Thus, advanced calibration equations, parameters, and algorithms are introduced. A version of these algorithms is routinely applied to calibrate magnetometer data from *MMS*. With their help, it is possible to decouple different effects on the calibration parameters, originating from the spacecraft or the magnetometer itself. A key point of the algorithms is the bulk determination of parameters and associated uncertainties. Lowest uncertainties are expected under parameter-specific conditions, i.e., in specific regions. It is shown where these conditions are fulfilled in the near-Earth plasma environment.



From top to bottom: magnitude of the spin axis and spin plane magnetic fields in red and blue, omnidirectional ion spectral energy flux density indicating different regions in near-Earth space, and uncertainties of the estimates of the spin plane offsets representing a group of calibration parameters

ENERGY CONVERSION AT KINETIC SCALES IN THE MAGNETOSHEATH

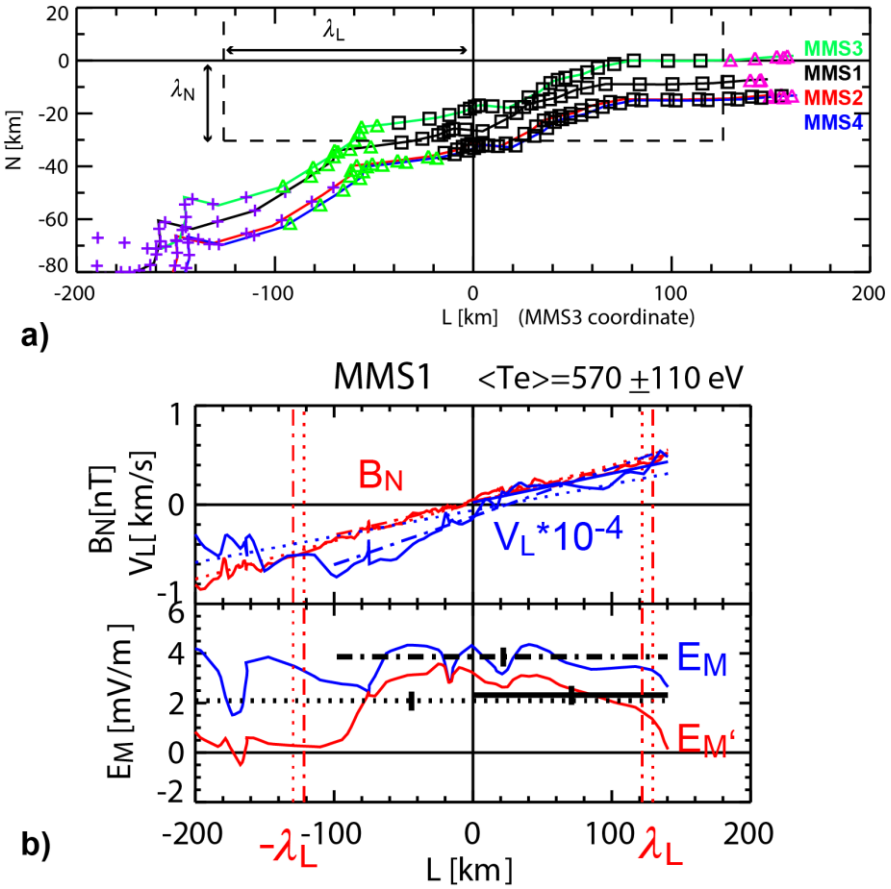
The processes of converting or dissipating energy in nearly collisionless turbulent space plasmas are yet to be fully understood. Besides wave-particle interactions and non-resonant stochastic heating, (reconnecting) current sheets can contribute to irreversible energy dissipation in a turbulent space plasma environment. The terrestrial magnetosheath, downstream of a quasi-parallel bow shock, represents a turbulent region where the energy conversion associated with ion/electron scale current sheets can be studied. A statistical analysis based on high-resolution *MMS* measurements in the quasi-parallel magnetosheath revealed that properly defined and normalized energy exchange/dissipation measures, in average, increase with the current density (thick black line in the figure below). A similar trend was found in 2.5- and 3-dimensional turbulence Particle-In-Cell (PIC) simulations (green and magenta lines). The measure De in the figure corresponds to the work done by the electric field on particles without the transport term for the net charge. De was estimated in parallel (triangles) and perpendicular (circles) directions to the magnetic field. The results show that dissipation occurs preferentially in parallel directions, presumably because of the significant guide fields at current sheets in the quasi-parallel magnetosheath.



Normalized current density J/J_{rms} (rms = root mean square) versus conditional temporal averages of normalized energy conversion measure De, calculated by conditioning on the values of current density J. The color code corresponds to the spacecraft *MMS1-4*. The thick black line represents temporal and spatial averages of the normalized measure De between *MMS1-4* spacecraft. The green and magenta lines illustrate the results of the 2.5- and 3-dimensional turbulence PIC simulations

CURRENT SHEET NEAR THE CENTER OF MAGNETIC RECONNECTION REGIONS

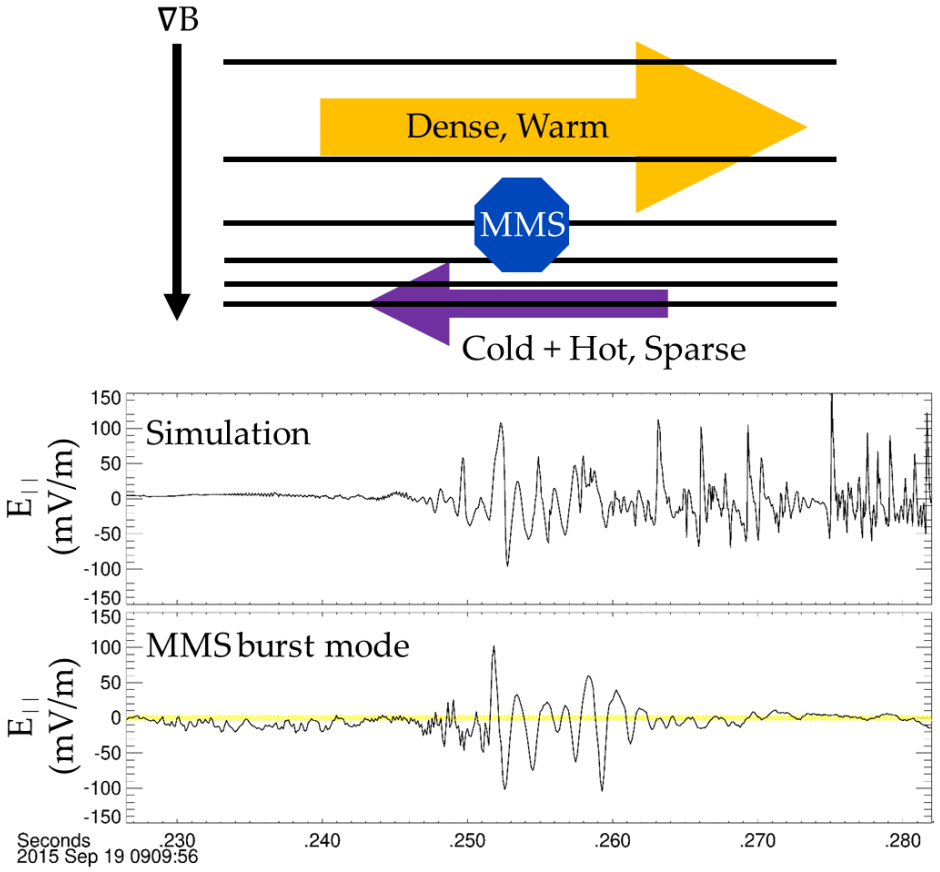
Magnetic reconnection is the process by which magnetic field lines coming from one region are broken and reconnected with magnetic field lines coming from another region. The simplest descriptions of magnetic reconnection are two-dimensional, and a number of theoretical predictions have been made using the two-dimensional assumption. Using multi-point data analysis techniques applied to an observation by the *MMS*, structures and evolution of a thin current sheet near the center region of magnetic reconnection are obtained and compared with these theoretical models. An agreement between the observations and the predictions of a two-dimensional theoretical model is found including the scale size of the reconnection region, details of the particle orbits, and the rate of reconnection. This agreement suggests that the scale size of the central region of reconnection, called "inner electron diffusion region", where the magnetic field is too small to make electrons gyrate around it, is determined by the thermal motion of the ambient electrons. It is shown that this non-gyrating feature of electrons is directly related to the rate of magnetic reconnection underpinning how reconnection works in a thin current sheet with quasi 2D geometry.



a) Location of the four spacecraft between 22:34:01.7-22:34:03.1 UT relative to the X-line. The colored symbols show the different types of electron velocity distribution function. b) Magnetic field, B_N (red) and electron flow velocity, V_L (blue) (upper panel) and electric field in spacecraft frame, E_M (blue) and electric field in electron frame $E_{M'}$ (red) (lower panel). Scale size of the center region is indicated by λ_L. The horizontal bars b) indicate the theoretical estimation of $E_{M'}$

ELECTRON-SCALE PLASMA MIXING ON RECONNECTION SEPARATRICES

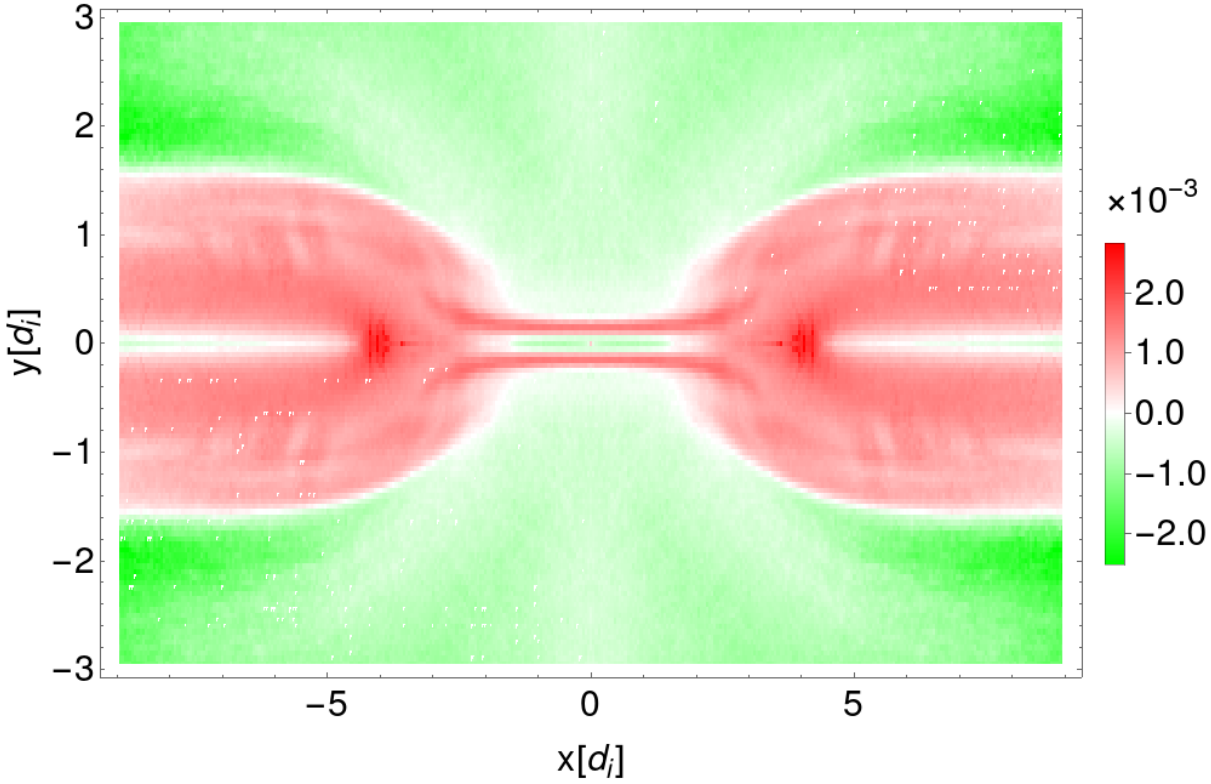
One of the natural consequences of reconnection is the mixing of plasma across a magnetic boundary. Mixing is often violent, and may have a significant impact on the reconnection process itself. For instance, narrow bands of high velocity electrons are frequently observed flowing toward the reconnection X-line along the separatrix dividing the larger scale inflow and outflow. It is suspected that the electric field required for acceleration is related to kinetic structures frequently observed in this region. One way to grow electric fields is by inflow and outflow electrons gyrating around the magnetic field such that they overlap at the separatrix, leading to thin, distinct layers of wave activity sandwiched between the magnetosphere and magnetosheath. Kinetic structures such as plasma double layers, however, are expected to form from a disturbance parallel to the magnetic field. For example, a head-on collision between the inflow and outflow may be set up by larger scale ripples frequently observed in the separatrix surface. To model this interaction, a numerical simulation was performed where two electron populations were allowed to mix and evolve. *MMS*-measured parallel electric fields from the separatrix region and corresponding data from the simulation are shown in the figure below. Despite their highly nonlinear nature, the largest amplitude features in $E_{||}$ were reproduced remarkably well, lending support for the parallel mixing model.



Schematic of *MMS* location relative to mixing electron populations. Central spike signatures of measured parallel electric fields are reproduced well by the simulation

STABILITY & CHAOS OF ENSEMBLES IN MAGNETIC RECONNECTION REGIONS

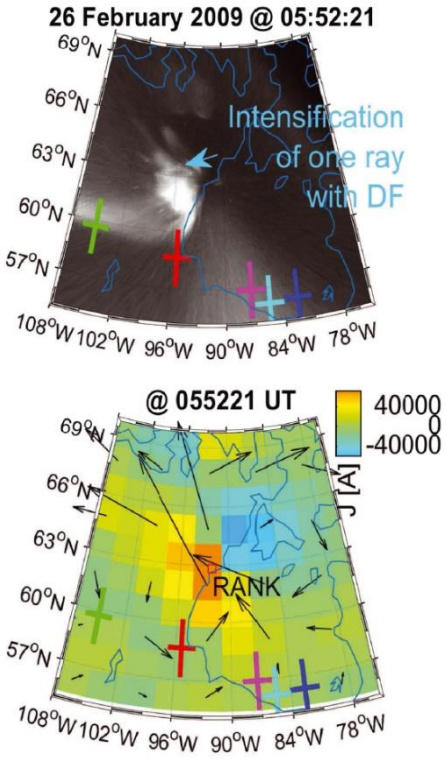
Energetic outbursts on the Sun, like solar flares, and auroral substorms on Earth are two of several phenomena in space science that are driven by magnetic reconnection. This process of local recombination of magnetic field lines builds up stress in space plasma that accelerates particles, together with the field, and forms a shock front. The study of such non-collisional plasmas is impossible in laboratory experiments on Earth, and can only be done in space. Theoretical studies are necessary for the accurate interpretation of space-based measurements. Numerical simulations were used to better understand the topology of regions of regular and chaotic motions of plasma particles close to the reconnection site in the Earth's magnetotail. The theory of Lyapunov exponents, originally invented for single particle dynamics, was generalized to ensembles of plasma particles and successfully implemented in computer code to amend particle in cell simulations. Regions of strong and weak excitation of local perturbations in different plasma regions are found, and strong acceleration centers have been identified (see figure). The further analysis of chaos in space plasma may lead to a better understanding of the mixing behavior of plasma particles, i.e. the transformation of velocity distribution functions in different regions of Earth's magnetotail.



Mean Lyapunov Ensemble Number close to the reconnection center of Earth's magnetotail (color code: green - damping, red - excitation of local perturbations; normalized units of length, d_i, in configuration space x-y). Strong acceleration centers are shown in dark red

IONOSPHERIC FOOTPRINTS OF DETACHED INTERCHANGE HEADS

The Earth's magnetotail periodically accumulates energy in the form of the magnetic flux in the tail lobes and dumps the energy as fast earthward and tailward plasma flows, which are produced by magnetic reconnection. Yet there is no consensus on what magnetotail processes may lead to reconnection. Examples of multiprobe space observations were used to reveal the possible process that might be important for azimuthally localized reconnection in the tail that leads to pseudo-breakups in aurora and local ionospheric current systems. The examples show the appearance of earthward-propagating reconnection (dipolarization) fronts amidst azimuthally propagating clumps of more dipolar field lines that were produced by an instability, which was predicted to lead to localized reconnection by earlier plasma computer simulations. The conjugate ground auroral and magnetic field observations support the fronts' origin hypothesis. In particular, using *THEMIS* observations in the plasma sheet and conjugate ground-based All-Sky-Imagers and ground magnetometer network observations, examples of prominent dipolarization fronts (DFs) were shown with moderate earthward flows that were observed amidst azimuthally drifting interchange heads at XGSM ≈ -11 R_E. The conjugate ground observations revealed ionospheric current intensifications and growth of auroral bright spots out of dimmer azimuthal beads/rays near *THEMIS* footprints. The DFs can be interpreted as separate Ballooning/InterChange Instability heads that detached from the region with reversed radial gradient of B_Z and propagated earthward-driving ionospheric pseudo-breakups.



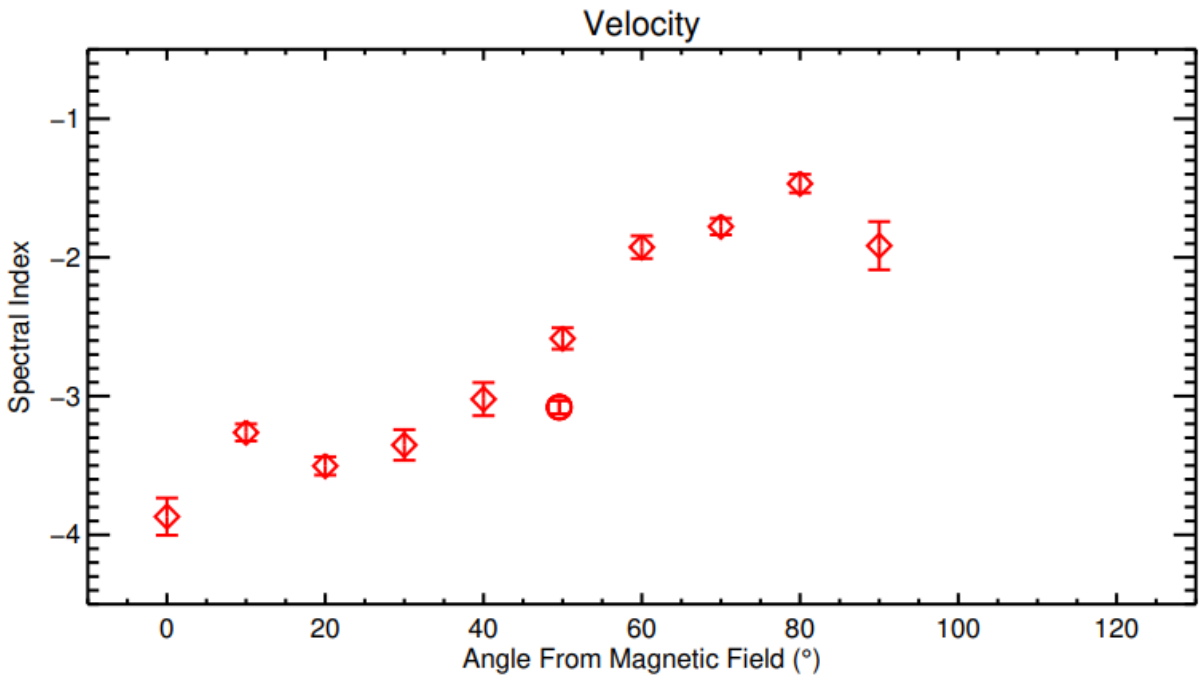
Snapshots from *THEMIS* Ground-Based All-Sky-Imager at Rankin Inlet, NU, Canada, and equivalent ionospheric current/Spherical Elementary Current System observations on 26 February 2009 during dipolarization front encounter by *THEMIS* at 5:52:21 UT

3D STRUCTURE OF PLASMA FLUCTUATIONS AT ION KINETIC SCALES

Using *MMS,* the structure of plasma fluctuations in three dimensions was obtained for the first time. On 7 September 2015, the *MMS* spacecraft were located in the Earth's magnetosheath. During this interval the *MMS* spacecraft had separations of around 100 km before beginning their nominal mission with much smaller separations. The unique configuration of inter-spacecraft separations close to proton gyration scales and the exceptionally high time resolution of plasma data allow a much more detailed investigation of turbulence than was previously possible with the *Cluster* mission, where only magnetic and density data could be studied.

The results revealed that the temperature fluctuations as well as the velocity fluctuations have anisotropies with respect to the mean magnetic field direction similar to those in the magnetic field. The energy of the fluctuations for all parameters were found to decay faster in the direction of the mean magnetic field direction with respect to the perpendicular direction with the velocity fluctuations having the strongest anisotropy.

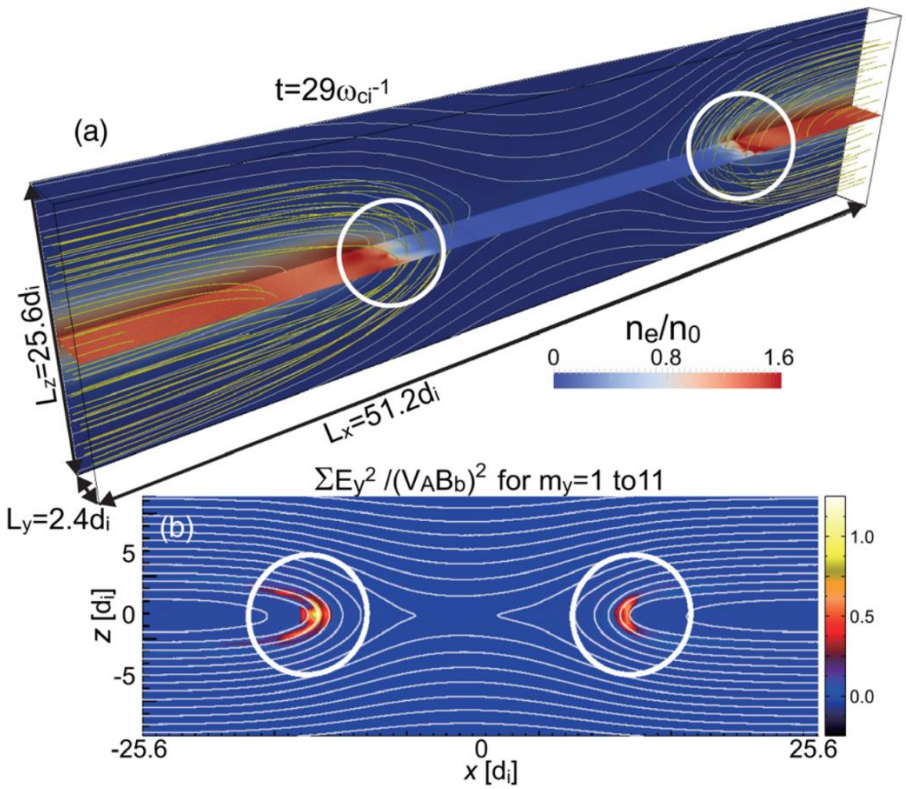
The figure shows the anisotropy of the spectral index for velocity fluctuations in the magnetosheath. The relation for the magnetic field has been explained theoretically and observed, however this is the first observation at ion kinetic scales of the other parameters. The fluctuation power was also found to decay faster in the ion velocity fluctuations when compared to magnetic fluctuations suggesting that the fluctuations in the magnetosheath are not related to slow mode like oscillations but rather to kinetic Alfvén wave oscillations. The observations presented here will allow theoretical predictions to be tested in future, to better understand the mechanisms of turbulent heating in the magnetosheath.



Variation of the spectral index of velocity fluctuations as a function of the angle from the mean magnetic field direction

DISTURBANCE OF THE FRONT REGION OF RECONNECTION OUTFLOW JETS

Magnetic reconnection is a key process in collisionless plasmas that converts magnetic to plasma kinetic energy. The energy conversion in the reconnection process occurs in various locations in the reconnection layer. A new three-dimensional fully kinetic simulation of reconnection, whose system size is large enough to treat many of the important energy conversion locations, demonstrated that the energy conversion rate measured by $J \cdot E' = J \cdot [E + (V_e \times B)]$ in the front region of the reconnection outflow jets is comparable to that in the central reconnection region where the stored magnetic energy is first released (figure below). By applying a recently developed fully kinetic dispersion solver to parameters obtained from the simulation, it is confirmed that the strong energy conversion in the jet front region is led by the Lower-Hybrid Drift Instability (LHDI) induced by the sharp density gradient at the jet fronts. These results indicate that the LHDI fluctuations in the jet front region have a substantial effect on the energetics of reconnection. Interestingly, similar jet front fluctuations as seen in the simulation were observed by *MMS* on 18 July 2017. By applying the linear dispersion solver to this *MMS* event, it is confirmed that the jet front fluctuations in this *MMS* event are also driven by the LHDI, indicating the importance of the LHDI fluctuations in the Earth's magnetotail. Furthermore, by applying the linear dispersion solver to some other realistic parameter sets that cannot be handled by simulations and specific observation events, it is predicted that the LHDI fluctuations in the reconnection jet front region could occur over a wide parameter range in space plasma including the Earth's magnetotail and even solar flares.



3D simulation results of (a) selected magnetic field lines near the jet fronts with density contours in the x-y plane at z=0 and x-z plane at y=0, and (b) integrated amplitudes of electric field (E_y) fluctuations in the y direction, highlighting the location of the LHDI fluctuations

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.

SOLAR ORBITER

Solar Orbiter, launched in early 2020, 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.

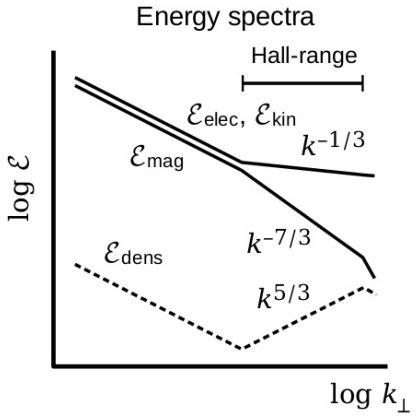
IWF has built the Digital Processing Unit (DPU) for the *Radio and Plasma Waves (RPW)* instrument aboard *Solar Orbiter* and has calibrated the *RPW* antennas, using numerical analysis and anechoic chamber measurements. Furthermore, the institute has contributed to the magnetometer.

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, developed by IWF.

Solar Orbiter removed from its shipping container at the Astrotech Space Operations Facility in Florida, US, on 18 November 2019

HALL EFFECT IN SOLAR WIND TURBULENCE

Plasma and magnetic fields in space often develop into turbulence, for example in the freely-streaming solar wind and in the magnetopause region (boundary between the solar wind and the planetary magnetosphere). On smaller spatial scales, typically at length scale of 100 km, ions become inert and decouple from the electron motion, causing a Hall electric field in the plasma and leading to a Hall inertial range in plasma turbulence. A theoretical model of the Hall turbulence spectrum is proposed in a two-dimensional geometry perpendicular to the large-scale magnetic field. The Hall turbulence model gives a possible explanation for the steepening of the magnetic energy spectra in the solar wind, and can be tested against spacecraft measurements in the solar wind and planetary magnetopause region.



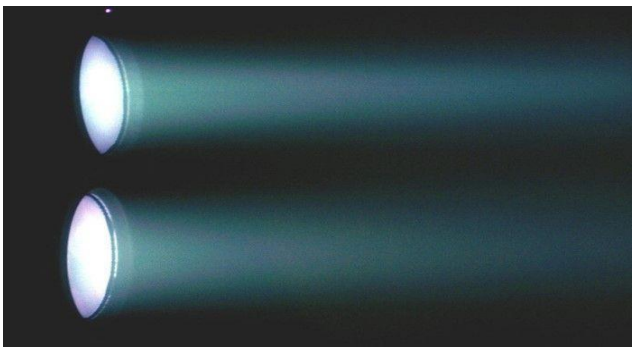
Spectra of the kinetic, electric, and magnetic energy, and density fluctuations in plasma turbulence in transition from magnetohydrodynamic behavior on smaller wavenumbers into Hall inertial range with steepening of magnetic energy and flattening of electric energy

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.

BEPICOLOMBO

BepiColombo was launched from the European Spaceport in Kourou, French Guiana, aboard an Ariane-5 rocket in 2018. By the end of 2019 it has already traveled over one billion kilometers but still only covered about 12% of its voyage before arriving at Mercury at the end of 2025. Related, BepiColombo saw its first electric propulsion arc. Solar electric propulsion is one of the key flight challenges. 22 arcs will be necessary to let BepiColombo spiral closer to the inner solar system and finally reach the orbit around Mercury.



Two gridded ion thrusters as used on *BepiColombo* undergoing a joint test firing inside a vacuum chamber. In space the plumes seen here would not be visible; however, the glow from the thrusters would be visible (Credits: QineitQ)

PICAM (IWF sensor PI-ship), the ion mass spectrometer with imaging capability as part of the *SERENA* instrument suite on *MPO*, underwent its high voltage commissioning in July 2019. The sensor is now technically verified. The first in-flight calibration will follow during the Earth flyby in 2020 by referring to the average plasma distribution and flux in the Earth's magnetosphere. A detailed planning was already required in 2019 to ensure both good measurements and the instrument's safety related to radiation.

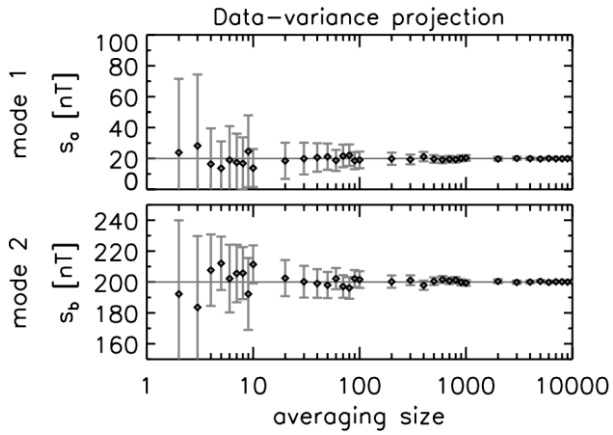
MERCURY'S INTERNAL AND EXTERNAL MAGNETIC FIELDS

Mercury's magnetic field is considered to be complex. The planetary magnetosphere is so small and comparable to the size of the planet itself, so the external field from the currents flowing in the planetary magnetosphere has a significant influence even when measuring the field in the near-surface region. Identification of the internal and external magnetic fields in Mercury's magnetosphere is one of *BepiColombo*'s scientific goals. A novel data analysis method is being developed for the *BepiColombo* magnetometers. The method is based on an algorithm of nonlinear minimum variance projection developed for wave studies in space plasma, and can identify various sources from the spatially sampled magnetic field data in Mercury's magnetosphere. The analysis method was successfully tested against a synthetic two-spacecraft data set assuming an internal dipolar magnetic field and an external field from a planar magnetopause current on the dayside. In contrast to the conventional spherical harmonic analysis, the novel method can decompose the magnetic fields into various origins even if the currents are flowing or external fields are significant in the measurement. This innovative method opens the door to diagnose both the planetary internal structure and the current pattern in the planetary magnetosphere using *BepiColombo's* magnetic field data.

An extensive series of in-orbit commissioning activities showed that the mission requirements as to overall capabilities and performance are met. In particular, the magnetic field sensors with IWF contribution are in very good health on both spacecraft, JAXA's *Magnetospheric (MMO)* and ESA's *Planetary Orbiter (MPO)*.

MMO-MGF (IWF PI-ship) with the two sensors on the still stowed boom was switched on only for a few hours during two health checks in May and December as well as during the very important release of the boom launch locks in August. The latter was postponed from November 2018 to mid-2019 because of the fact that the *MMO* spacecraft within the Sun shield is colder than originally expected.

MPO-MAG (IWF technical management) with the two sensors on the already deployed boom has been monitoring the magnetic field continuously except for the solar electric propulsion phase. Extensive calibration and data processing activities have since enabled to greatly decrease spacecraft-generated disturbances in the magnetic field observations; these activities constitute a key step towards making the data suitable for scientific analysis.



External magnetic field (mode 1) and internal dipolar magnetic field at the planetary surface (mode 2) plotted as a function of averaging size for the statistics. The mode amplitudes are obtained from the synthetic data modeled for the *BepiColombo* magnetometer on the dayside of Mercury using the nonlinear data-variance projection

VENUS AND MARS

Venus and Mars are the Earth's nearest inner and outer 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 around each planet.

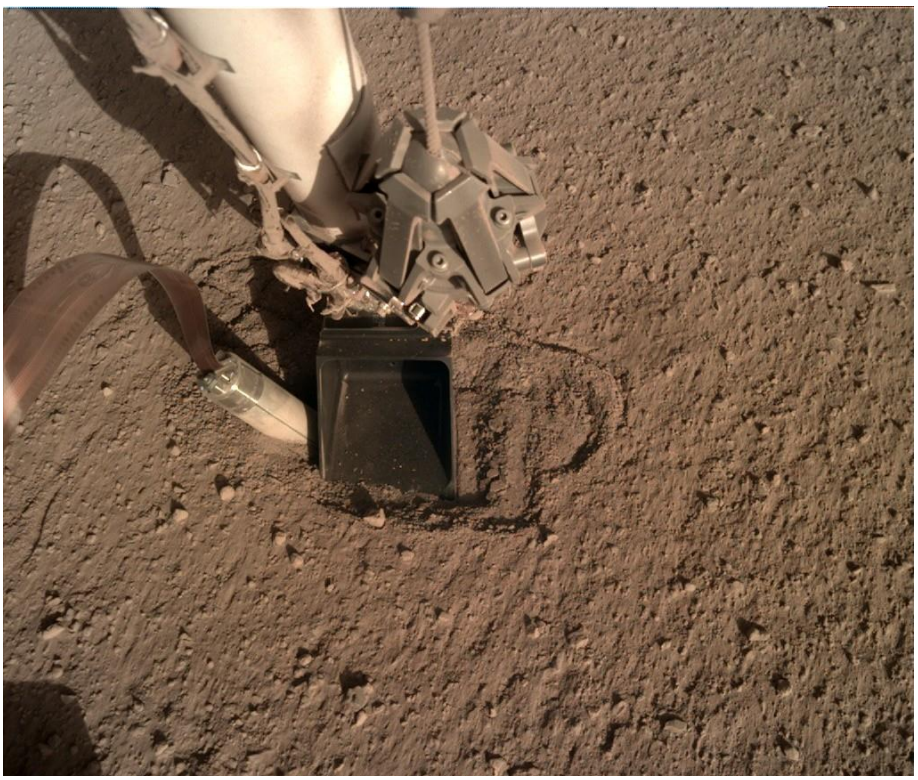
CHINA MARS EXPLORATION MISSION

China's Mars orbiter, lander, and rover mission is ready for launch in 2020. The main mission will conduct a comprehensive remote sensing of the Red Planet, as well as surface investigation. IWF contributed to a magnetometer aboard the orbiter.

China Mars Exploration Mission in launch configuration, with the orbiter and lander/rover inside the heat shield (top), undergoing thermal vacuum testing (© CAS)

INSIGHT

NASA's Mars mission *InSight (INterior exploration using Seismic Investigations, Geodesy and Heat Transport)* successfully landed in Elysium Planitia in 2018. The *Heat flow and Physical Properties Probe (HP³)* was designed to measure the internal heat flux of Mars as well as the thermal and mechanical properties of the Martian regolith. In order to describe the penetration progress and to derive soil mechanical parameters for the first couple of meters of the regolith, two numerical models have been developed at IWF. In February 2019, the "Mole" started hammering itself into Martian ground but got stuck only after about 30 cm, caused by lacking friction of the Martian sand. Even though assistance by *InSight's* scoop was successful, it is not certain whether the "Mole" will go deeper by itself. However, even in the numerical model it could be demonstrated that the first half meter is the most difficult part of the insertion process.



***InSight's* robotic arm used its scoop to pin the "Mole" against the wall of its hole (© NASA/JPL-Caltech)**

TESTING OF EXOMARS ROVER SAMPLING SYSTEM

ESA's *ExoMars* rover, due for launch in 2022, is part of a mission addressing the question of whether life has ever existed on Mars. Therefore, the rover is equipped with a drill, to create boreholes to a maximum depth of 2 m and to take core samples within the drill's range. In order to facilitate the chemical analysis of the Martian ground, the retrieved drill cores must first be milled. This task is performed by a crushing station (CS), which delivers the milled sample material to a dosing device (PSDDS). From there the material is distributed further to the analysis instruments. To demonstrate the proper functionality of the CS and the PSDDS laboratory tests under simulated Mars conditions were performed in the Surface Laboratory at IWF. The focus was on the investigation of the effects of cementation in Martian regolith on the performance of the system.

JUPITER AND SATURN

Jupiter and Saturn are the two gas giants in our solar system at a distance of 5.2 and 9.5 AU, respectively. Both planets have strong inner magnetic fields and rotate rapidly with a day lasting around 10 hours. Consequently, they have rotationally dominated magnetospheres and are strong radio sources in the sky. Jupiter has four large moons (but 79 in total), Io, Europa, Ganymede and Callisto. Of these four, Ganymede is the target moon for the upcoming *JUICE* mission. Saturn has 82 moons of which two have been studied in great detail: Titan was the target for the *Huygens* probe and Enceladus has shown to eject water and is expected to have an ocean under its icy surface.

JUICE

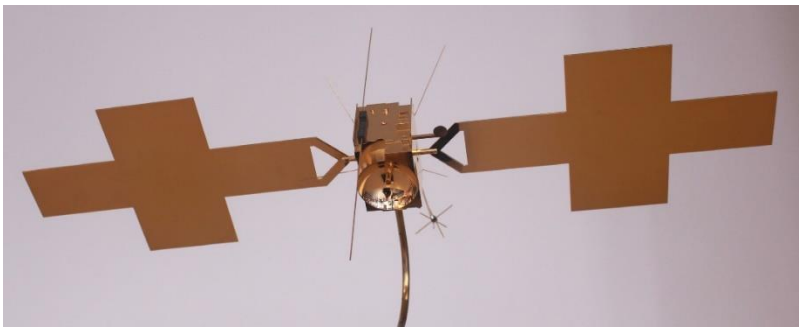
ESA's first large (L-class) mission *JUpiter ICy moons Explorer (JUICE)* is planned to be launched in June 2022 and to arrive at Jupiter in late 2029, starting a 3.5 years discovery

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 it will orbit Jupiter's largest moon Ganymede. Currently, ESA and the prime contractor Airbus are testing the engineering models, and the assembly of the flight model has also begun.

The *Jupiter MAGnetometer (J-MAG)* is led by Imperial College London 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 supplies the atomic scalar sensor for *J-MAG*, which is developed in collaboration with TU Graz. In 2019, the qualification model was finished and delivered to IC London for environmental testing. The acceptance tested optical fibers have already been integrated on the 10.5 m long flight boom and the manufacturing of the flight instrument has been started.

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 is also responsible for the calibration of the radio antennas of the *Radio and Plasma Wave Investigation (RPWI).* In 2019, additional numerical antenna simulations were performed to estimate the influence of the radar antenna on the *RPWI* sensors. It was found that the strong radar pulses with a radiated power of 10 W will saturate the radio antenna receiver, not allowing scientific measurements at the same time.

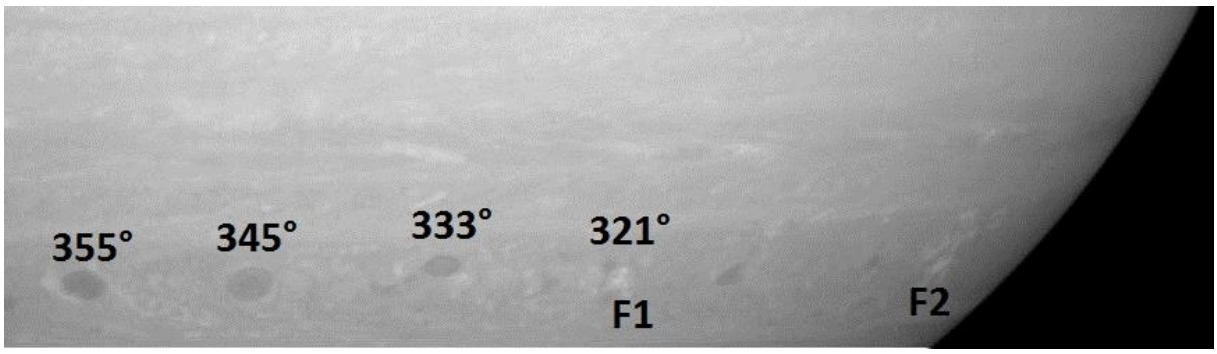


The miniature gold-plated metallic model of *JUICE*, used to test the spacecraft's antennas, was ESA's Space Science Image of the Week in November 2019

DYNAMICS OF SATURN LIGHTNING STORMS

NASA's *Cassini* mission orbited the gas giant Saturn for more than 13 years (2004-2017). It has provided a wealth of scientific data that will keep scientists busy for several more years.

A combined analysis of data from *Cassini's RPWS (Radio and Plasma Wave Science)* instrument together with images from the *Cassini* cameras and from ground-based amateurs has revealed new clues about the dynamics of Saturn's lightning storms. It suggests that decreases in the flash rate are caused by the splitting of the thunderstorm into a bright cloud and a dark oval. These dark ovals drift westward as can be seen in the image below.



Saturn's storm alley around 35° South latitude imaged by the *Cassini* camera on 23 April 2008. The two bright features F1 and F2 are thunderstorm cells, which have spawned several dark ovals, indicated by their western longitudes

Cassini RPWS detected about 277 000 lightning strokes in 439 episodes during this storm that lasted for 7.5 months from November 2007 until July 2008. Another comparison with images showed that lightning radio emissions can already be detected when the storm is still beyond the visible horizon. This so-called over-the-horizon effect was found to mainly occur when the storm is on the night side and the observer *Cassini* on the day side. It is thought to be due to a temporary trapping of the radio waves below Saturn's ionosphere.

COMETS AND DUST

Comets and dust are the remains of the 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. ESA's *Rosetta* mission to comet 67P/Churyumov-Gerasimenko restarted the interest in in-situ cometary physics and will be followed up by ESA's first fast (F-class) mission *Comet Interceptor.*

COMET INTERCEPTOR

The mission'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 gas 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.

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.

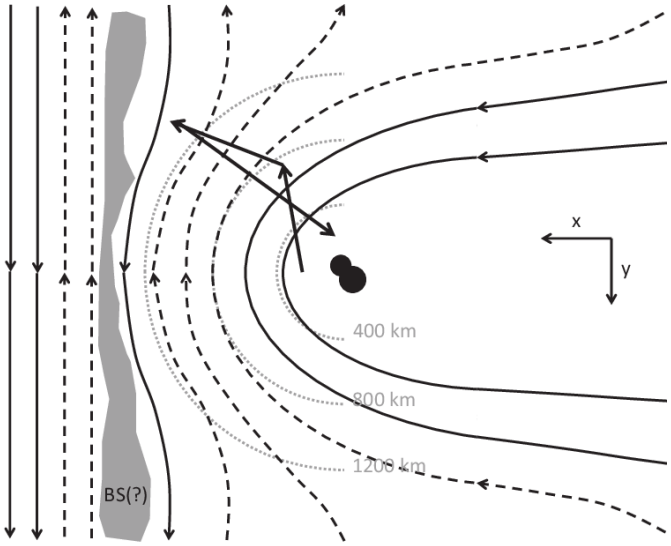
Comet Interceptor will be launched with ESA's *ARIEL* spacecraft in 2028.

DYNAMIC FIELD LINE DRAPING AT COMET 67P/CG

The *Rosetta* dayside excursion took place in September-October 2015 when comet 67P/Churyumov-Gerasimenko (67P/CG) was located at ~1.36 AU from the Sun after it had passed perihelion on 13 August 2015 at ~1.25 AU. At this time, the comet was near its most active period, and its interaction with the solar wind was expected to be at its most intense, with ion pickup and magnetic field line draping.

The data from the *Rosetta Plasma Consortium (RPC)* were used to investigate the interaction of solar wind and comet. Calculating the cone, clock angle, and draping pattern of the magnetic field around the comet's nucleus was determined.

The cone angle changed several times, which means that the magnetic field direction changes from pointing sunward to anti-sunward as shown in the figure below. This is caused by the changing directions of the interplanetary magnetic field that is transported toward the comet. The cone-angle direction shows that mass-loading of the interplanetary magnetic field of the solar wind leads to dynamic draping. The ion velocity and the magnetic field strength are correlated because the unmagnetized ions are accelerated more (less) strongly by the increasing (decreasing) magnetic field strength. *Rosetta RPC* has shown that (dynamic) draping also occurs at mildly active comets, as was found at highly active comets such as 1P/Halley and 21P/Giacobini-Zinner, but also that determining both dynamic and nested draping will require a combination of fast flybys and slow excursions for future missions.

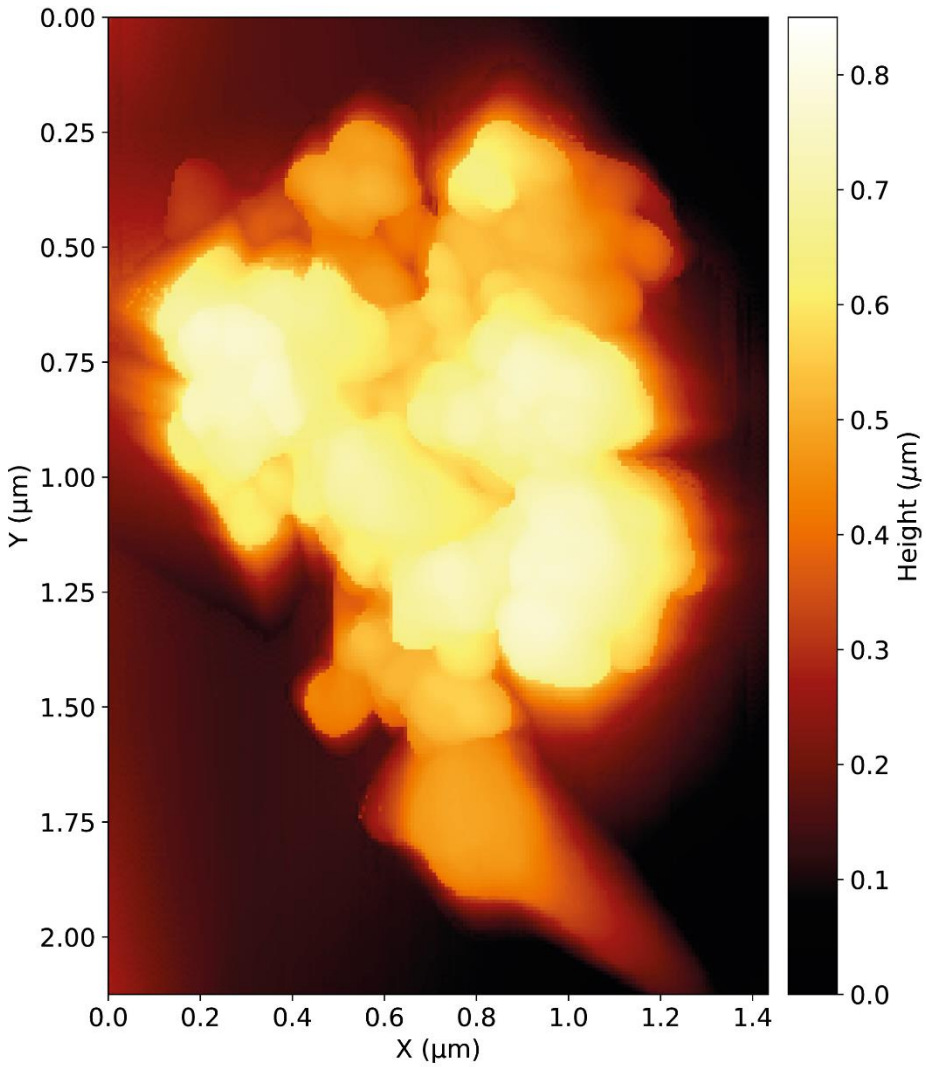


The draped magnetic field around 67P/CG. The three arrows in the figure illustrate the path of *Rosetta* during the dayside excursion

COMETARY DUST AT THE NANOMETER SCALE

The *MIDAS* atomic force microscope on board the *Rosetta* orbiter collected and imaged µm-sized dust particles of comet 67P/Churyumov-Gerasimenko. *MIDAS*' dataset contains 3D images of structurally minimally altered, µm-sized cometary dust particles. Its investigation contributes to the understanding of our early solar system.

MIDAS data analysis at the µm scale already revealed cometary dust as hierarchical. The figure below shows a cometary particle of 1 µm size scanned with a resolution of 8 nm. Its structure continues the typical hierarchical agglomerate structure where the smallest identifiable features are of 100 nm size shape and of about 400 nm sized for clusters. The smallest features are of bulbous shape, their sizes follow a log-normal size distribution with a mean of about 100 nm and a standard deviation between 20 and 35 nm.



A 1 µm sized particle scanned with *MIDAS* showing the typical hierarchical structure of cometary dust. It consists of about 100 nm sized subunits clustering into about 400 nm sized structures

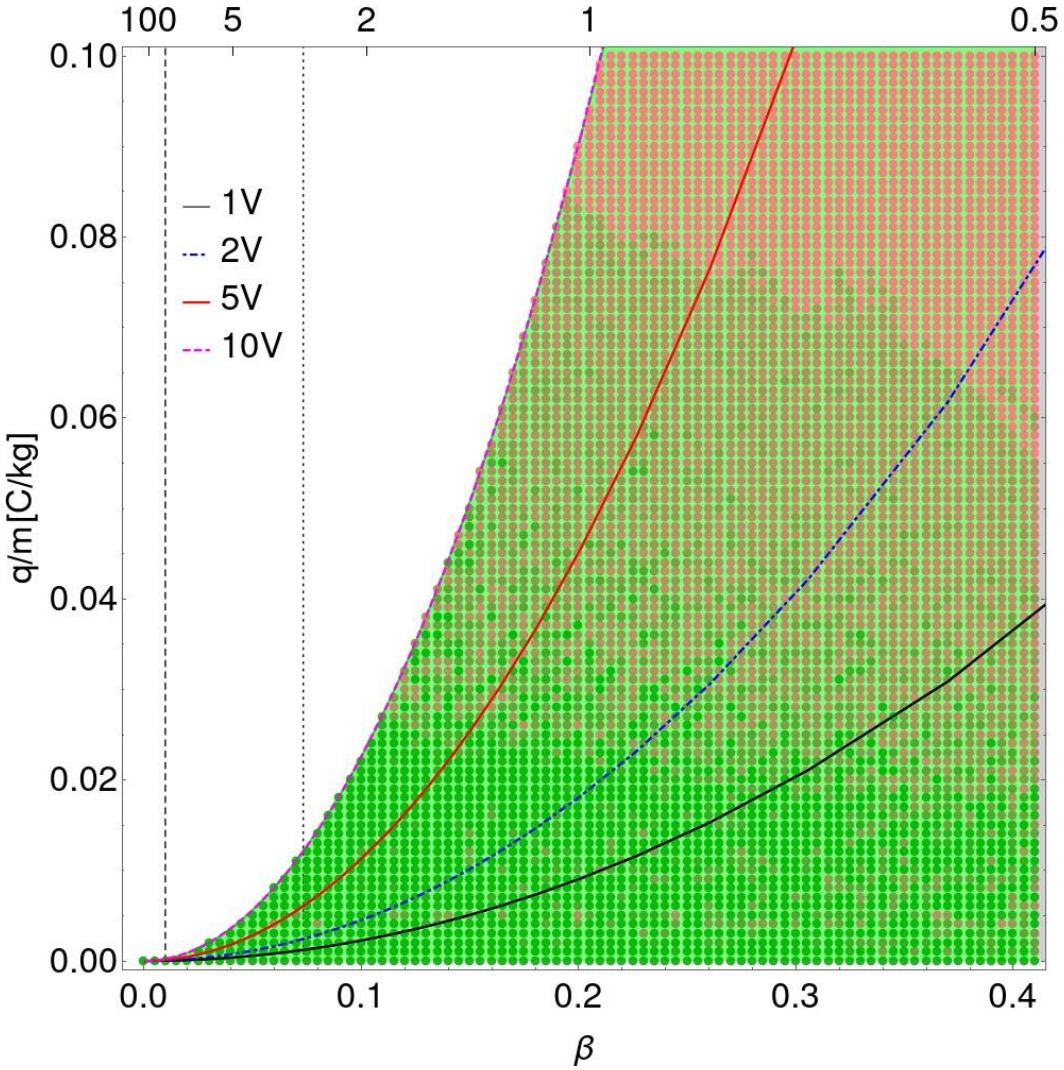
Cometary material suitable for comparison are Chondritic Porous Interplanetary Dust Particles (CP IDPs). Their fundamental building blocks show subunit size distributions, shapes, and arrangements similar to that of *MIDAS* particles. This strengthens the link between CP IDPs and comets, and indicates that the smallest subunits identified by *MIDAS* could be the fundamental building blocks of comet 67P/CG.

TEMPORARY CAPTURE OF CHARGED DUST IN THE OUTER HELIOSPHERE

It is well known that cometary activity is one of the major sources for the production of micron-sized dust in the heliosphere (besides collisions of minor planets and dust streams from the interstellar medium). Several space missions to comets, like *Rosetta*, have revealed a deeper understanding of cometary dust in the inner part of the heliosphere. The origin, life-time and composition of dust grains in the outer parts of the solar system is currently less known and the scientific progress in this research field strongly relies on pure theoretical studies. A better understanding of dust grain dynamics will not only affect the interpretation of recent

measurements in the outer heliosphere (e.g. *New Horizons*), but also help to design the next generation instruments aboard future space missions to the outer planets (i.e. *MUSE*).

In a recent study it has been found that dust grains with specific charge-to-mass ratios (see figure) can be trapped at specific distances from the Sun for long times due to their interaction with planet Jupiter. Their orbital life time is increased despite the perturbations from non-gravitational effects, due to radiation, the interplanetary magnetic field, and interactions with the solar wind. To conclude, dust density enhancements in the solar wind are more likely to exist in the outer solar system than it was previously thought.



Probability of temporary capture (green: high, red: low) of dust with specific charge-to-mass ratios q/m versus solar radiation efficiency factor β, being inverse proportional to dust grain radius in micrometers (provided at the top of the figure)

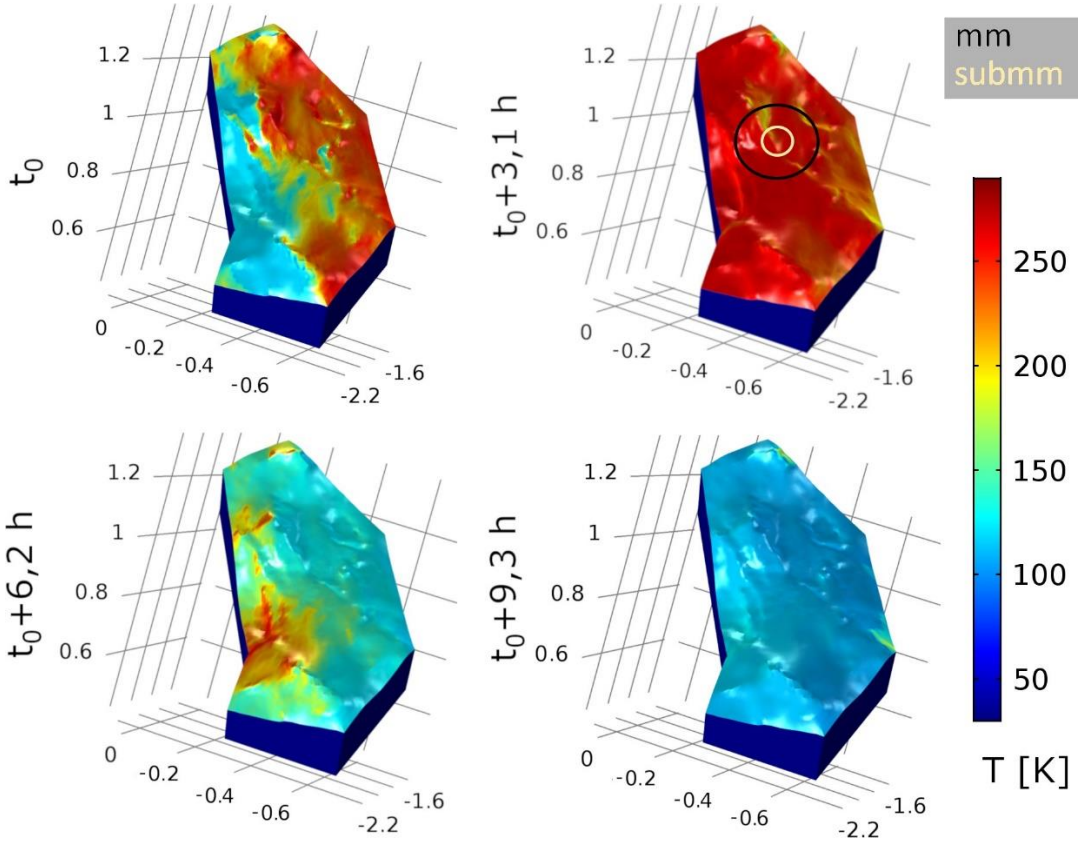
HEAT BALANCE ON COMETARY SURFACES

The heat flow on cometary surfaces due to solar illumination is a dominant factor of influence on all physical processes on the surface of comets. In this context, it is usually assumed that only the flow normal to the surface is of importance and that lateral flows (tangential to the surface) are negligible. This conjecture was investigated by numerical simulations for two spots on comet 67P/Churyumov-Gerasimenko, which were observed by the *MIRO* instrument

aboard the *Rosetta* orbiter. For this purpose, the temperature evolution due to insolation and heat flow in the upper subsurface regions was calculated and the results compared with the *MIRO* observations. The figure below shows the temperature distribution on the region surrounding spot 1 for the observation time, and for quarters of the comet rotation later. The black and yellow circle indicate the spot sizes for the two channels (mm- and submm-wavelength) of the *MIRO* instrument.

It was found that lateral heat flow is, on average, very weak. However, at shadow margins it can be responsible for considerable temperature offsets of 10 K or more from the purely normal heat flow regime. Since the surface is very rough with asperities ranging from micrometer to meter size, shadow margins are distributed densely over the sunlit part of the surface. Therefore, it cannot be ruled out that lateral heat flow plays a significant role in other physical processes going on in the uppermost surface layers.

An integration of the radiated thermal emissions throughout the respective spots enables a comparison with the actual *MIRO* measurements. Very good agreement was found for the mm, but a significant deviation for the submm wavelength. Since the two different wavelengths have different penetration depths (4 and 1 cm, respectively), these results are an indication of the heterogeneity of the uppermost subsurface region of a few centimeters depth. Potential origins have been identified for the submm discrepancy, in particular surface roughness, thermal conductivity discontinuity and sublimation of water ice with consequential gas flow.



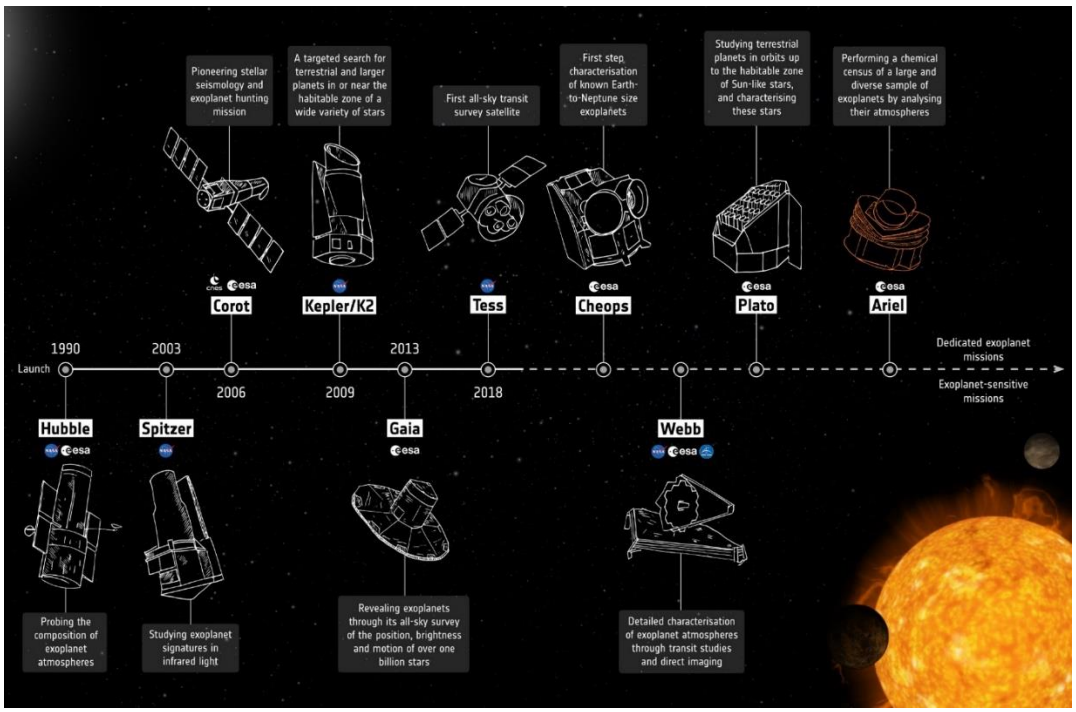
Temperature evolution around a spot on comet 67P/CG, observed by *Rosetta/MIRO*

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 now prime targets for atmospheric characterization, mostly because of their larger radii, which indicate the presence of a volatile-rich atmosphere and facilitate observations and analyses.

The main exoplanet missions with IWF contributions are *CHEOPS*, *CUTE*, *PLATO*, and *ARIEL*. *CHEOPS* will precisely measure the radii of already known planets to greatly improve their inferred density and hence provide a first characterization. *CUTE* will obtain low-resolution near-ultraviolet transmission spectra of transiting giant planets to study upper atmospheres and mass loss processes. *PLATO* will look for planets in large portions of the sky, with the primary aim to find Earth-like planets in the habitable zone of Sun-like stars. *ARIEL* will collect low-resolution infrared transmission spectra of transiting planets to characterize planetary atmospheres, with the final goal of measuring C and O abundances, which constrain planet formation theories.

IWF concentrates on the study and characterization of planetary atmospheres using both theory and observations, focusing particularly on the analysis of exoplanet atmospheric escape and mass-loss processes. Further research is conducted to study star-planet interaction and carry out atmospheric characterization through the collection and analysis of ground- and space-based observations.



Exoplanet mission timeline (© ESA)

CHEOPS

CHEOPS (CHaracterising ExOPlanet Satellite), successfully launched on 18 December 2019, will study extrasolar planets and observe planetary systems at an unprecedented photometric precision. The main science goals are to detect transits of small planets, known to exist from radial- velocity surveys, precisely measure planetary radii to study the nature of Neptune- to Earth-sized planets, and obtain precise observations of transiting giant planets to study their atmospheric properties. 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 was also responsible for the planning of two observing programs within the Guaranteed Time Observations of the *CHEOPS* consortium.

Academy President Anton Zeilinger (second from right) welcomes Federal Ministers Andreas Reichhardt, Iris Rauskala, IWF Director Wolfgang Baumjohann, and head of FFG/ALR Andreas Geisler (from left to right) to the *CHEOPS* Launch Event at ÖAW in Vienna

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 hundreds 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. Thermal and scattering properties of the atmosphere will also be studied.

ARIEL consists of a one meter telescope feeding two infrared low-resolution spectrographs and the fine guiding sensor (FGS), working in the optical. To improve the satellite's pointing stability, the FGS provides optical photometry of the target in three broad bands that are used to control instrumental systematics, measure intrinsic stellar variability, and constrain the

presence of high-altitude aerosols in planetary atmospheres. Within the *ARIEL* mission, IWF co-leads the upper atmosphere working group and is heavily involved in testing the mission's performances and advancing the atmospheric retrieval tools.

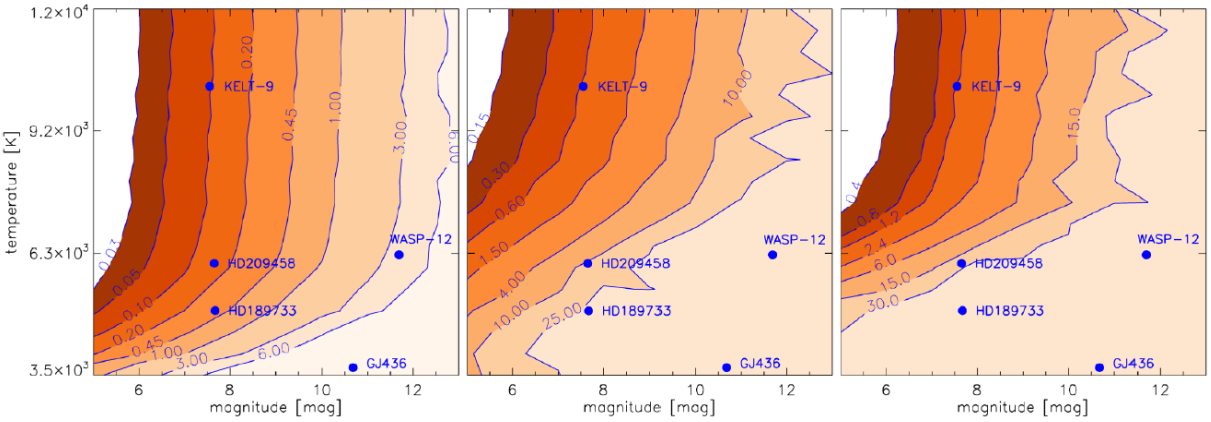
CUTE

CUTE (Colorado Ultraviolet Transit Experiment) is a NASA-funded 6U-form CubeSat led by the University of Colorado and scheduled for launch in December 2020. It will perform low-resolution transmission spectroscopy of transiting extrasolar planets at near-ultraviolet wavelengths. *CUTE* will study the upper atmosphere of short period extrasolar planets with the aim of observationally constraining atmospheric escape processes, which are key to understand planetary evolution, and detect heavy metals, which constrain the presence and composition of aerosols in the lower atmosphere. Furthermore, *CUTE*'s continuous temporal coverage of planetary transits will allow to detect transit asymmetries, which are possibly connected with the presence of planetary magnetic fields.

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

In 2019, IWF has finalized the development of the *CUTE* data simulator, which is a set of IDL routines generating images that reproduce spectral time series of stars taking into account the wavelength-dependent planetary absorption during transit and instrumental effects. The simulator recreates the effects that CCDs (e.g., size, pixel scale, and cosmetics), readout electronics, optical elements (telescope and spectrograph), planetary absorption during transit, spacecraft orientation and jitter, and systematic noise sources have on the data. This allows the user to best foresee the data quality and the magnitude of different sources of noise (both white and red).

The simulator is fed by a wide range of input parameters providing high flexibility. It follows that the simulator, which is originally designed for *CUTE*, can be easily adapted to work for any other mission carrying on-board a long-slit spectrograph and a charge transfer device as detector. The simulator has been used to estimate the precision on the transit depth, in %, that will be obtained with *CUTE* by integrating over four different wavelength regions as a function of magnitude and effective temperature of the host star (see figure).



Left: Uncertainty on the transit depth, in %, for a five minutes *CUTE* observation integrating in wavelength above 3000 Å. Middle: Same as left panel, but integrating in wavelength around the MgII h&k resonance lines (2790-2810 Å). Right: Same as left panel, but integrating in wavelength around the MgI resonance line (2850-2854 Å). Each panel marks also the position of some of the systems for which signatures of atmospheric escape have been observed in the past. The results account for the effects of spacecraft jitter

Two of the four selected wavelength ranges are broad and cover the region with the highest stellar flux in the *CUTE* band (i.e., above 3000 Å) and the region below 2700 Å, which has been shown to be also sensitive to exoplanet atmospheric escape. The other two regions are centered on the MgII h&k resonance lines and the MgI resonance line at 2852 Å. It has been found that the uncertainty on the transit depth decreases with increasing stellar temperature and decreasing magnitude. Considering an average transit duration of 2.5 hours, without gaps over one transit the precision on the transit depth improves by a factor of about five. At the wavelengths of lines probing atmospheric escape, transit depths are typically larger than 2-3%. Therefore, within a few transits *CUTE* will be capable of detecting escape for planets orbiting stars brighter than the 13th magnitude and hotter than about 6500 K. For cooler stars, the detection of atmospheric escape will be limited to the brighter ones, such as the hot Jupiter HD189733, for which reaching the necessary precision will require the observation of about 10 transits. The case of the ultra-hot Jupiter KELT-9 is particularly remarkable as within a single transit *CUTE* will be able to reach a precision on the transit depth at the position of the MgI and MgII lines of about 0.1%. This translates to a precision on the planetary radius of about 2.2%, which corresponds to about two pressure scale heights.

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 extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. *PLATO* has also been designed to investigate seismic activity of stars, enabling the precise characterization of the host star, including its age. IWF 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. Six 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.

Main tasks in 2019 were the design of the *RDCU* engineering model, the continuation with the design of the VHDL code and the development of the test environment. The design of the compressor has been further optimized to comply with the increased number of imagettes, from ~18000 to ~28000. An improved concept for the data transfer is under development to gain another 20% in performance. The *RDCU* design is compliant with all requirements and ready for manufacturing the engineering models.

Artist's impression of *PLATO* on its way to Lagrange Point 2 (L2). Here, the spacecraft is shielded from the Sun and has a clear view of the whole sky (© OHB System AG)

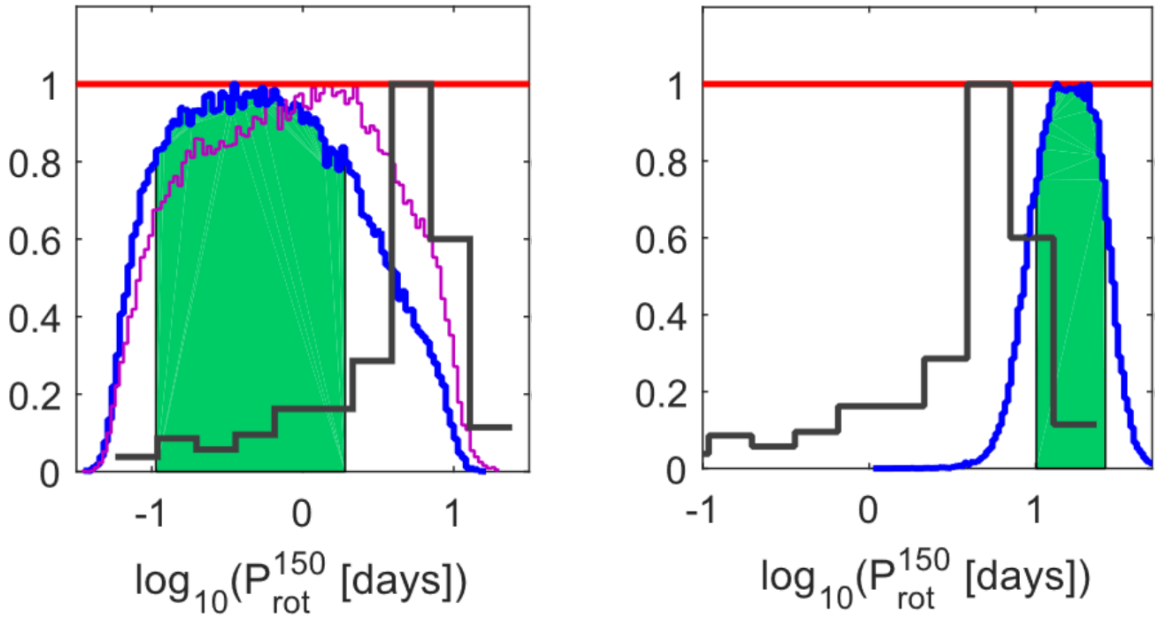
OTHER TELESCOPES

Members of the institute obtained 10 nights of observing time with the *ESPRESSO* instrument at the *Very Large Telescope (VLT)* at the Paranal site of the European Southern Observatory (ESO), in Chile. These spectroscopic observations will be used in conjunction with *CHEOPS* observations to study the effect of stellar activity on radial velocity measurements and in turn identify possible ways of correcting radial velocity/photometric measurements using photometric/radial velocity observations.

CLOSE-IN SUB-NEPTUNES REVEAL ROTATION HISTORY OF HOST STARS

Planet atmospheric escape induced by high-energy stellar irradiation shapes the structure and evolution of planetary atmospheres. Therefore, the present-day properties of a planetary atmosphere are intimately connected with the amount of stellar flux received by a planet during its lifetime, thus with the evolutionary path of its host star. A Bayesian framework has been developed and employed to track the evolution of planets as a function of stellar flux evolution history, constrained by the measured planetary radius. The tool has been tested on a large number of synthetic systems identifying the framework's validity range and that the ideal

objects for this type of study are close-in sub-Neptune-like planets. Such planets are highly affected by atmospheric escape, and yet retain a significant fraction of their primordial H-dominated atmospheres. The algorithm has been applied to the HD3167 and K2-32 planetary systems. For HD3167, the most probable irradiation level at 150 Myr has been found to lie between 40 and 130 times solar, corresponding to a rotation period of $1.78^{+2.69}_{-1.23}$ days. K2-32 had a surprisingly low irradiation level ranging between half and four times solar at 150 Myr. For multi-planet systems, the analysis framework enables one to constrain poorly known properties of individual planets, such as planetary masses.

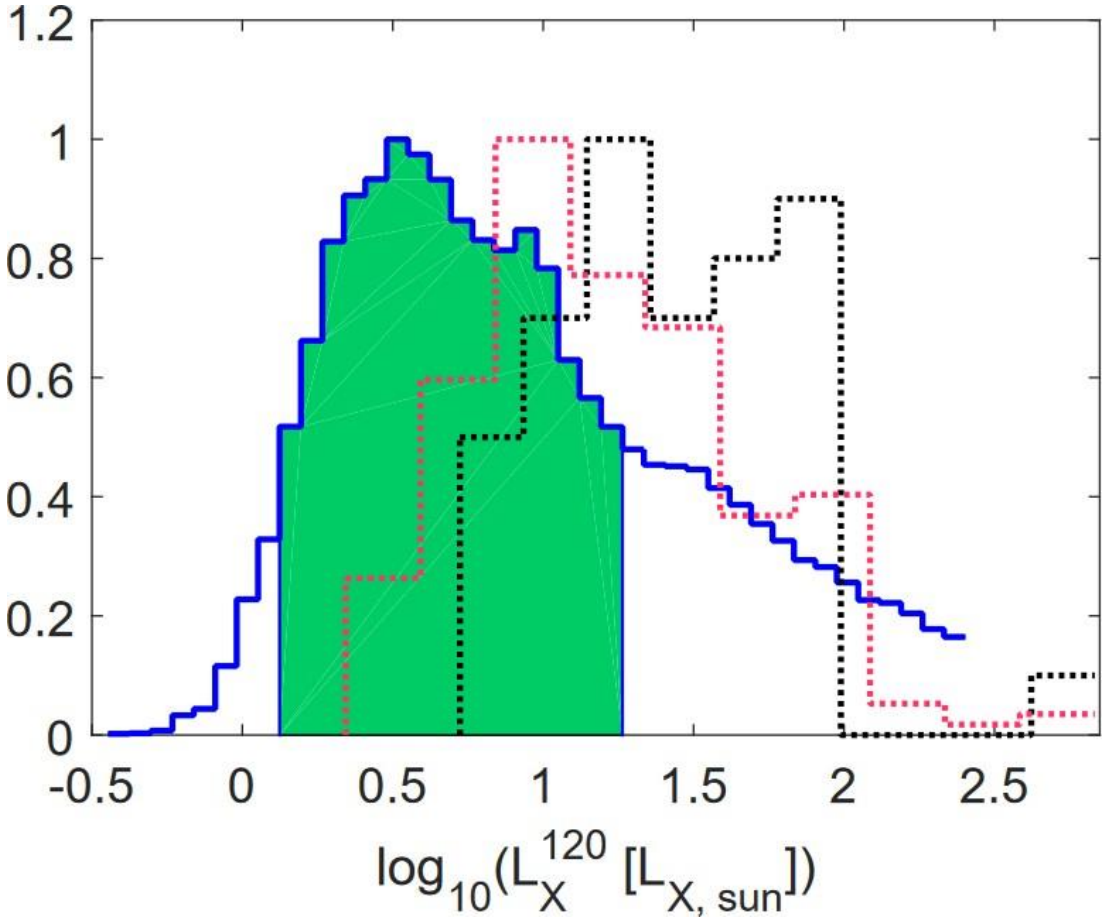


Markov-chain Monte Carlo (MCMC) posterior distributions for the stellar rotation period at an age of 150 Myr obtained from the modeling of HD3167c (left) and K2-32b (right). The shaded areas correspond to the 68% highest posterior density (HPD) credible interval. In the left panel, the blue and violet distributions are for two different sets of system parameters. The red line shows the assumed prior. The black line histogram shows the distribution of rotation periods for young open cluster stars with masses between 0.8 and 0.9 solar masses

KEPLER-11: HIGH-ENERGY EMISSION AND ATMOSPHERIC MASS FRACTIONS

The atmospheres of close-in planets are strongly influenced by mass loss. It has been shown that the framework enabling the recovery of the past evolution of the stellar high-energy emission from the present-day properties of its planets can also provide constraints on planetary initial atmospheric mass fractions. The constraints on the output parameters improve when more planets can be simultaneously analyzed, making the Kepler-11 system, which hosts six mini-Neptunes, an ideal target. The results indicate that the star has likely evolved as a slow rotator (slower than 85% of the stars with similar masses), corresponding to a high-energy emission at 120 Myr of between 1-10 times that of the current Sun (see figure).

The derived planetary initial atmospheric mass fractions are <4.1% for planet c, 3.7-5.3% for planet d, 11.1-14% for planet e, 1-15.6% for planet f, and 4.7-8.7% for planet g assuming a disc dispersal time of 1 Myr. For planet b, the range remains poorly constrained. The analysis also implies slightly higher masses for planets b, c, and f compared to suggestions by transit timing variation measurements. The work shows that the framework is capable of constraining important properties of planet formation models.

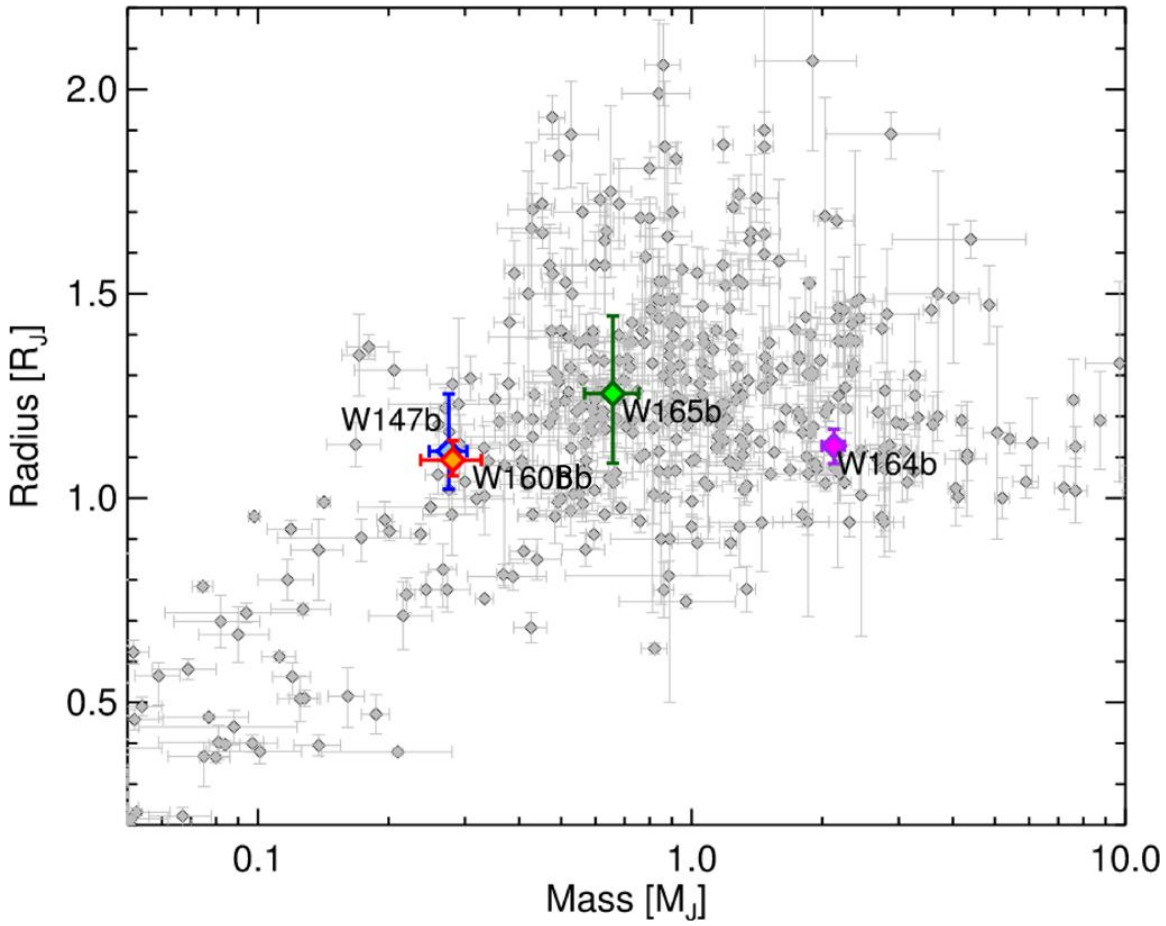


Posterior probability distribution for the X-ray luminosity of Kepler-11 at an age of 120 Myr (solid blue line; 68% confidence interval in green) in comparison to the distributions obtained for stars of similar spectral type in NGC 2516 (black dotted line; 48 stars) and for all detected stars in the same cluster (red dotted line; 239 stars)

TWO HOT SATURNS AND TWO JUPITERS, TWO OF THEM WITH METAL-RICH HOSTS

The SuperWASP exoplanet detection facility has led to the discovery of four transiting hot Saturns or Jupiters, WASP-147b, WASP-160Bb, WASP-164b, and WASP-165b.

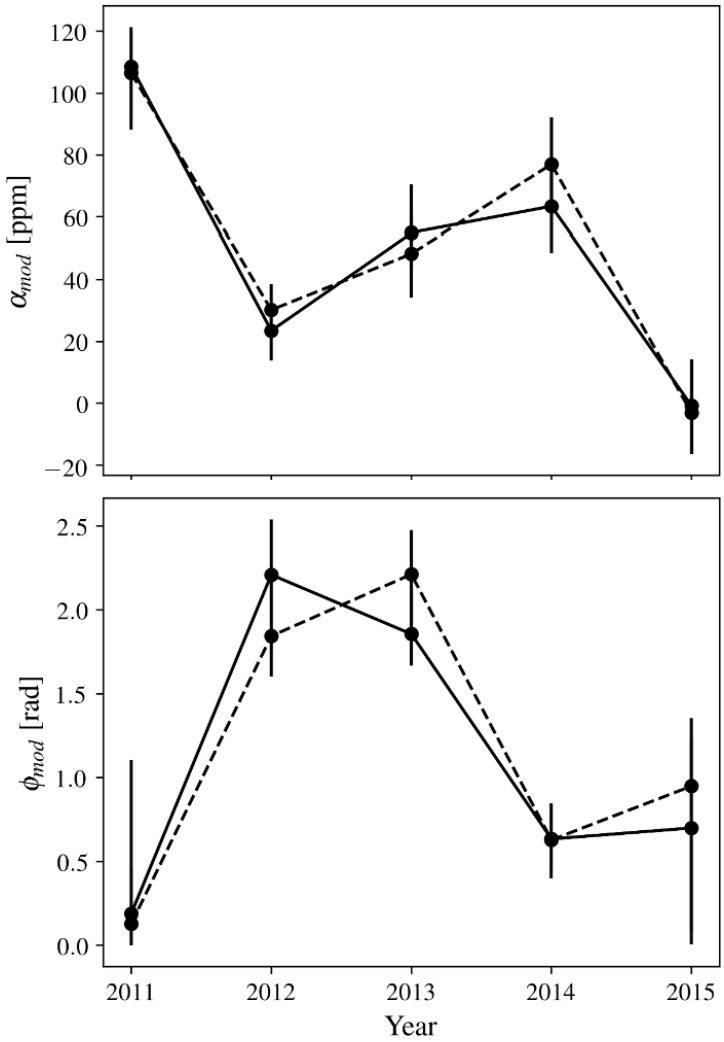
WASP-147b is a near Saturn-mass (M_p = 0.28 M_J) object with a radius of 1.11 R_J (see figure) orbiting a G4 star with a period of 4.6 d. WASP-160Bb has a mass and radius (M_p = 0.28 M_J, R_p = 1.09 R_J) nearly identical to WASP-147b, but is less irradiated, orbiting a metal-rich ([Fe/H] = 0.27) K0 star with a period of 3.8 d. WASP-160Bb is part of a near equal-mass visual binary with an on-sky separation of 28.5 arcsec. WASP-164b is a more massive (M_p = 2.13 R_J, R_p = 1.13 R_J) hot Jupiter, orbiting a G2 star on a close-in (P = 1.8 d), but tidally stable orbit. WASP-165b is a classical (M_p = 0.66 M_J, R_p = 1.26 R_J) hot Jupiter in a 3.5 d period orbit around a metal-rich ([Fe/H] = 0.33) star. The masses and radii of the newly detected planets are shown in the figure below. WASP-147b and WASP-160Bb are promising targets for atmospheric characterization through transmission spectroscopy, while WASP-164b represents a good target for emission spectroscopy.



Planetary mass against planetary radius for known exoplanets. Only planets with well-measured masses and radii (relative uncertainties smaller than 50%) are shown. The newly-discovered objects are shown in color and labeled

OPTICAL MODULATION PHASED WITH THE ORBIT OF SUPER-EARTH 55 Cnc e

55 Cnc e is a transiting super-Earth orbiting a solar-like star with an orbital period of just 17.7 hours. In 2011, the *MOST* satellite detected a quasi-sinusoidal flux modulation having the same period as the planetary orbit. The amplitude of this modulation was too large to be explained by a change in light reflected or emitted by the planet. The *MOST* telescope continued to observe 55 Cnc e for a few weeks per year over five years (from 2011 to 2015), covering 143 transits. Phase modulations similar to those seen in 2011 have been found in most of the subsequent years; however, the amplitude and phase of maximum light are seen to vary, from year to year, from 113 to 28 ppm and from 0.1 to 3.8 rad.



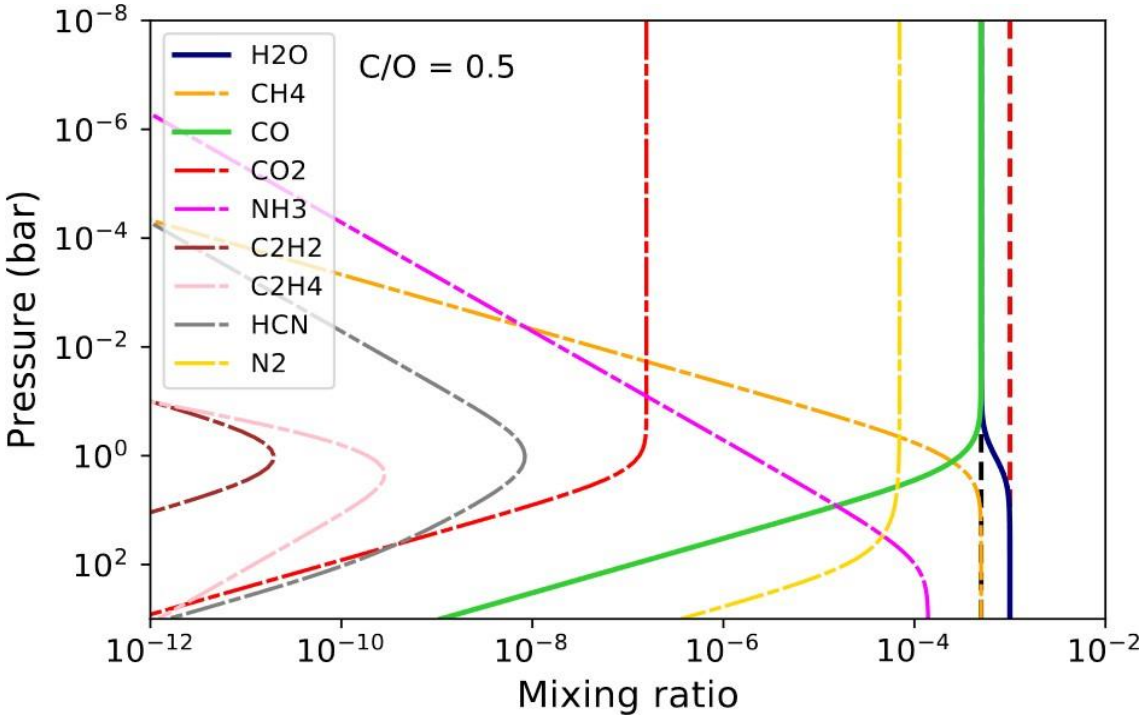
Evolution of the amplitudes (top) and orbital phases (bottom) parameters of the modulation in flux observed at the planet orbital period. The solid and dashed lines indicate the light curves detrended using two different methods

The secondary eclipse is not detected, but the geometric albedo could nevertheless be constrained to <0.47 (2σ). While a single origin of the observed optical modulation could not be identified, the data are consistent with a few possible explanations. Those include star-planet interaction, such as coronal rains and spots rotating with the motion of the planet along its orbit, or the presence of a transiting circumstellar torus of dust. However, a detailed

interpretation of these observations is limited by their photometric precision. Additional observations at optical wavelengths, e.g. with *CHEOPS*, could measure the variations at higher precision, contribute to uncovering the underlying physical processes, and measure or improve the upper limit on the albedo of the planet.

ANALYTIC THERMOCHEMICAL-EQUILIBRIUM ABUNDANCES

An analytic framework to obtain thermochemical- equilibrium abundances for H_2O, CO, CO_2, CH_4, C_2H_2, C_2H_4, HCN, NH_3, and N_2 for a system with known temperature, pressure, and elemental abundances has been previously developed. However, the implementation of that approach becomes numerically unstable under certain circumstances (e.g., C/O ≥ 1 atmospheres at low pressures). Building up on the already existing approach, the conditions that prompt inaccurate solutions have been identified, and a new framework to avoid them has been developed, providing a reliable implementation for arbitrary values of temperature (200 to 2000 K), pressure (10^{-8} to 10^{3} bar), and CNO abundances (10^{-3} to 10^{2} times solar elemental abundances), for hydrogen-dominated atmospheres.

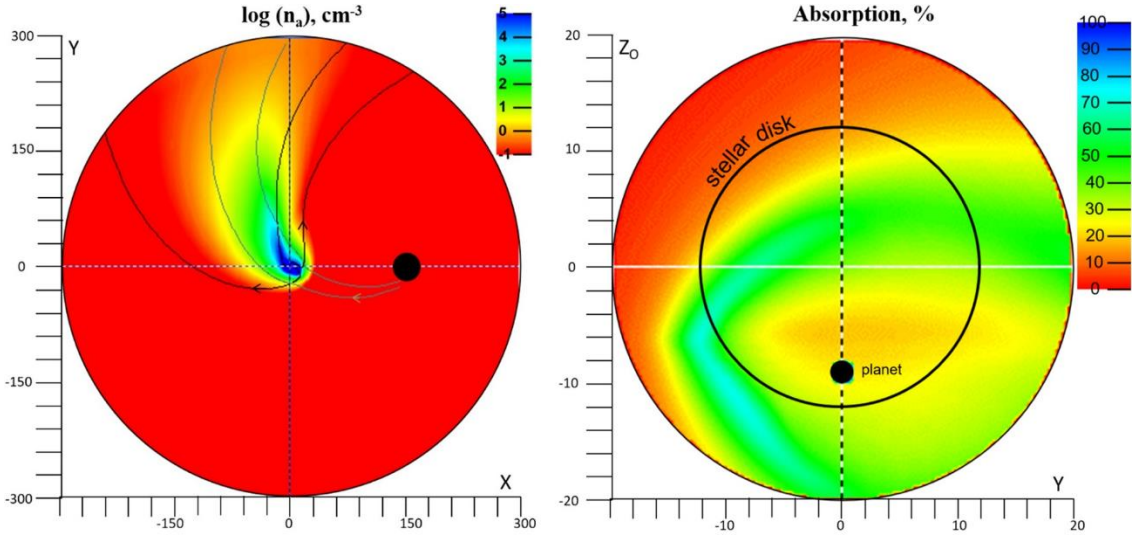


Thermochemical-equilibrium abundances for atmospheres with N_c/N_o <1. The atmosphere has a fixed temperature of 1200 K, $N_o = 5\times10^{-4}$, and $N = 7\times10^{-5}$. The black and red dashed vertical lines denote 2N and $2N_O$, which are related to the maximum values that carbon- and oxygen-bearing species can take, respectively

The accuracy of the newly developed analytic framework is better than 10% for the more abundant species that have mixing fractions larger than 10^{-10}, whereas the accuracy is better than 50% for the less abundant species. Additionally, the equilibrium-abundance calculations of atomic and molecular hydrogen into the system have been added, and the physical limitations of this approach have been explored. Efficient and reliable tools, such as this one, are highly valuable for atmospheric Bayesian studies, which need to evaluate a large number of models. The new analytic framework has been implemented into the RATE Python open-source package.

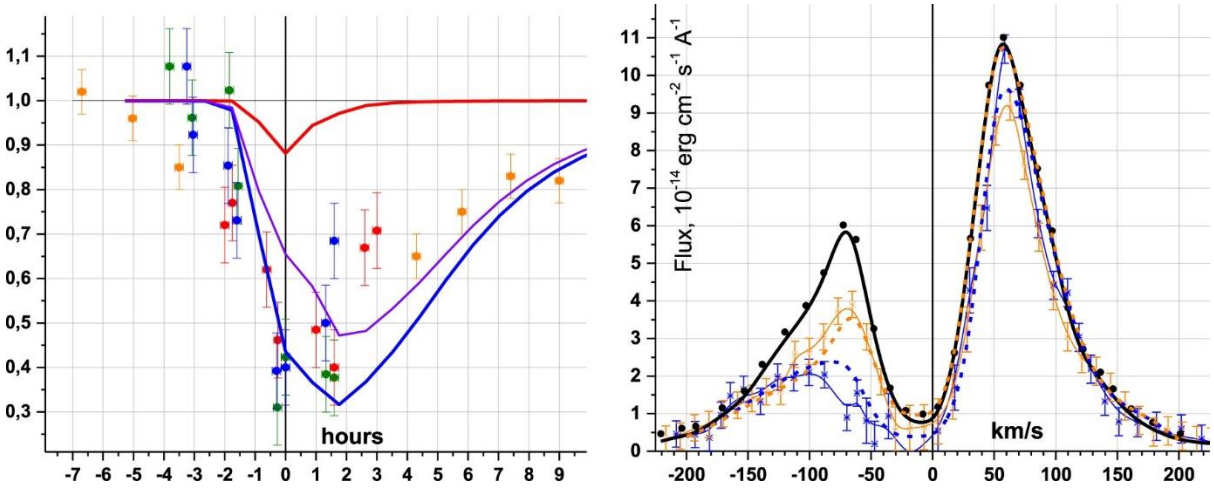
HYDRODYNAMIC MODELLING OF IN-TRANSIT Lyα ABSORPTION OF GJ436b

The fully self-consistent 3D multi-fluid hydrodynamic model simulates the escaping upper atmosphere of warm Neptune GJ436b. It is driven by the stellar XUV radiation, gravitational forces, and interaction with the stellar wind, which is also simulated by the model. Calculations of in-transit absorption in Lyα in the simulated dynamical environment of GJ436b confirm that it is produced mostly by energetic neutral atoms outside the planetary Roche lobe, due to resonant thermal line broadening.



Distribution of atomic hydrogen density in the equatorial plane around GJ436b (left panel) and the line-of-sight absorption, averaged over the blue wing of the Lyα line, as seen by remote observer (right panel) calculated with typical SW parameters of GJ436

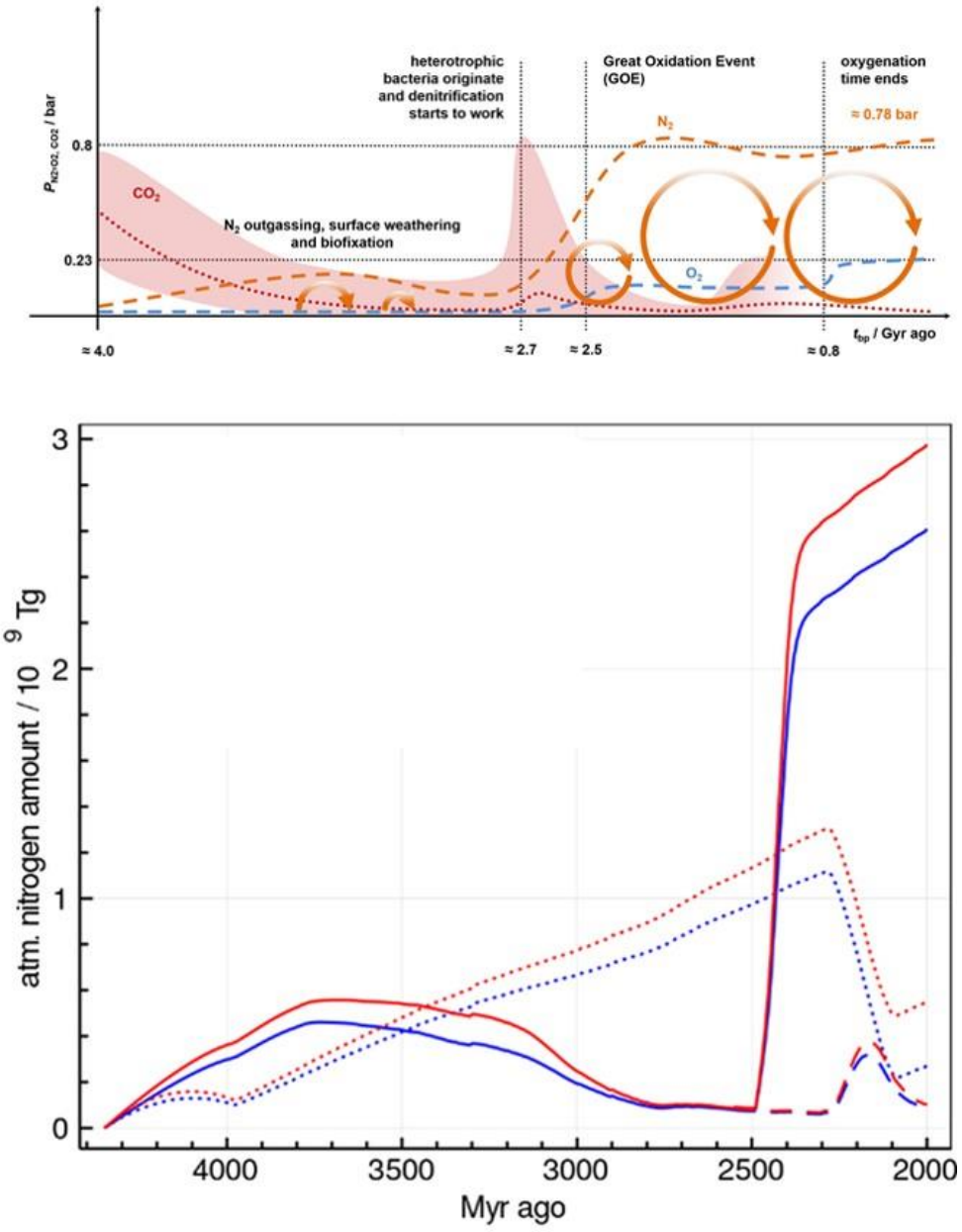
The influence of radiation pressure was shown to be insignificant. By varying the model parameters it was possible to achieve reasonable agreement between the model predictions and observations (see figure below), e.g., in asymmetry of the absorbed Lyα line profile, transit depth (>70%) and early ingress. Some difference between the simulated and measured features can be explained by different stellar wind conditions during the measurement campaigns.



The simulated transit light curves of GJ436b in the blue ([-120; -40] km/s; blue line) and red ([30; 110] km/s; red line) wings of Lyα line (left panel) and the modeled Lyα line profiles at the mid-transit (t=0h; blue dashed) and post-transit (t=5h; orange dashed) phases (right panel) Observed data are shown by symbols with error bars. Black line depicts the out-of-transit case

N_2/O_2-DOMINATED ATMOSPHERES ARE BIOMARKERS

Nitrogen is an essential element in the building blocks of life; hence, the geobiological nitrogen cycle is a fundamental factor in the long-term evolution of both Earth and Earth-like exoplanets. Since life-forms are the most efficient means for recycling deposited nitrogen back into the atmosphere at present, they sustain its surface partial pressure at high levels. Also, the simultaneous presence of significant N_2 and O_2 is chemically incompatible in an atmosphere over geological timescales. Thus, it is argued that an N_2-dominated atmosphere in combination with O_2 on Earth-like planets within circumstellar habitable zones can be considered as a geo-biosignature. Terrestrial planets with such atmospheres will have an operating tectonic regime connected with an aerobic biosphere, whereas other scenarios in most cases end up with a CO_2-dominated atmosphere.

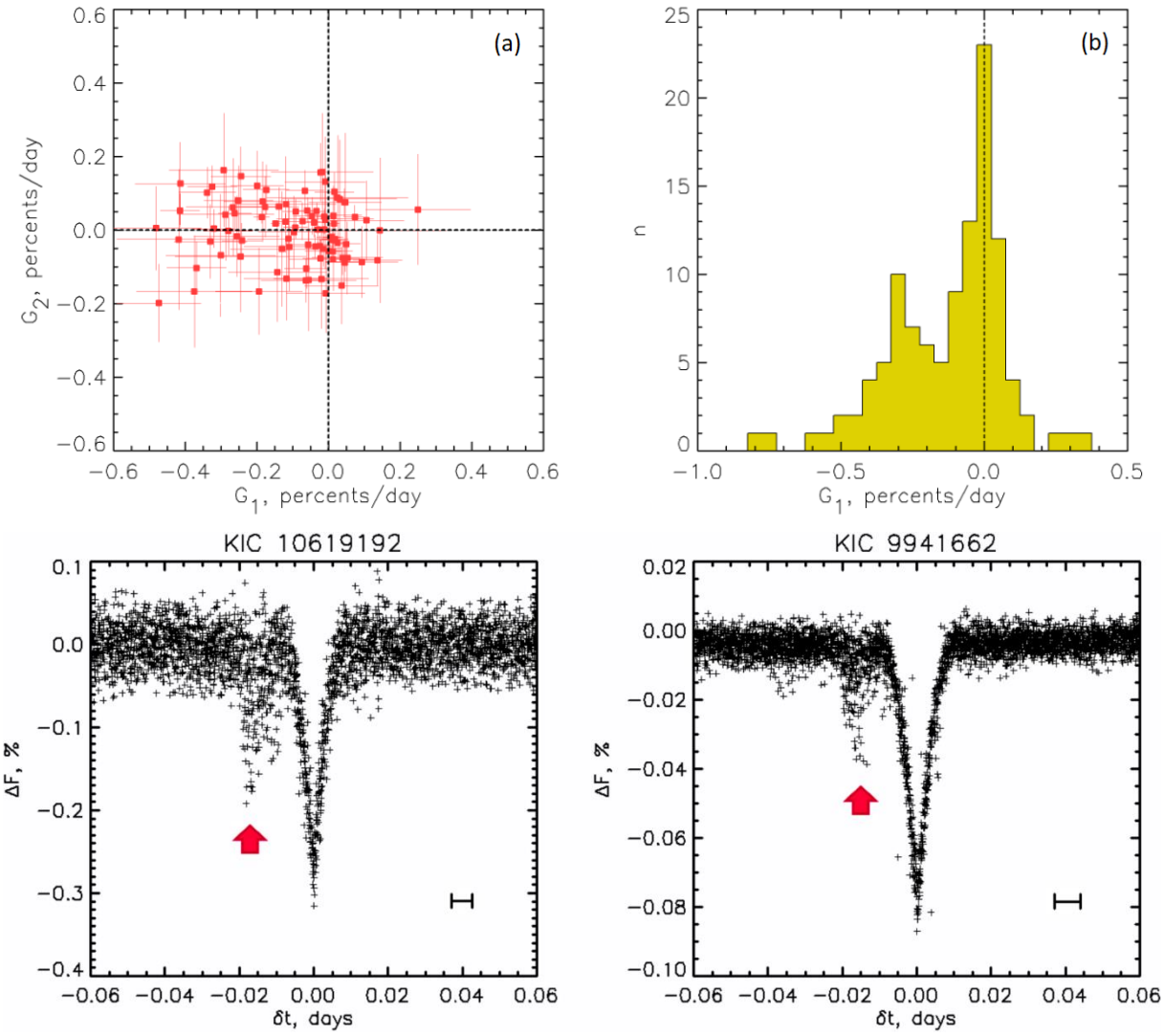


Upper panel: CO_2, N_2, O_2 surface partial pressure evolution on early Earth since about 4 Gyr ago. N_2 rose to the present values, when heterotrophic microorganisms responsible for denitrification led to the modern geobiological nitrogen cycle. Lower panel: Various atmospheric N_2 build up scenarios. Dotted lines: No life and solid lines – with life – scenarios, based on two different crust spreading outgassing models. The jump in N_2 release occurs due to denitrification caused by oxic life forms

DUSTY PHENOMENA IN THE VICINITY OF GIANT EXOPLANETS

Photometric manifestations of dust around different kinds of exoplanets (mainly giants) were detected and investigated with a specially elaborated search and analysis technique applied to the long-cadence light curves recorded by NASA's *Kepler* space telescope. Using linear approximation of pre- and post-transit parts of the light curves of 118 Kepler objects of interest after their preliminary whitening and phase-folding, the corresponding flux gradients G1 and G2, were calculated before and after the transit border for two different time intervals: (a) from

0.03 to 0.16 days and (b) from 0.01 to 0.05 days, which characterize the distant and adjoining regions near the transiting object, respectively. The gradients G1 and G2 in the distant region clustered around zero, revealing the absence of signs of dusty obscuring matter (DOM) there. In the adjoining region, 17 cases of hot Jupiters showed significantly negative gradients G1, while G2 remained around zero (see upper panels). Visual analysis of individual cases also revealed the sporadic pre-transit decrease of flux, which systematically decreases G1 (see lower panels). This effect was reproduced with the models using a stochastic obscuring precursor ahead of the planet. Such phenomena may be caused by dusty atmospheric outflows, erosion and/ or tidal decay of moonlets, or background circumstellar dust accumulated in electrostatic or magnetic traps in front of the mass-losing exoplanet.



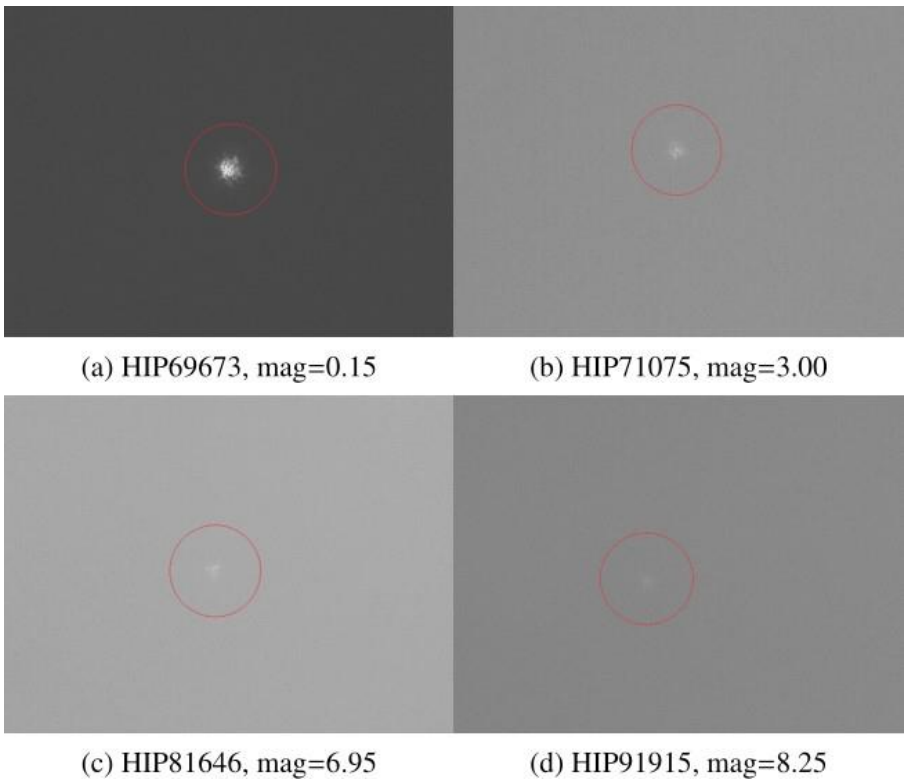
Upper panels: (a): Distribution of pre- (G1) and post- (G2) egress gradients in adjoining regions;
(b): histogram of G1. Lower panels: Examples of DOM manifestations (arrowed) in the pre-ingress parts
of folded and clipped light curves

SATELLITE LASER RANGING

In addition to routinely tracking more than 150 targets, which are equipped with laser retro-reflectors, the Graz Satellite Laser Ranging (SLR) station is working on various projects. Recent highlights include first successful daylight space debris laser ranging, the design of a detection and laser package for ESA's new SLR station on Tenerife, and MHz laser ranging.

DAYLIGHT SPACE DEBRIS LASER RANGING

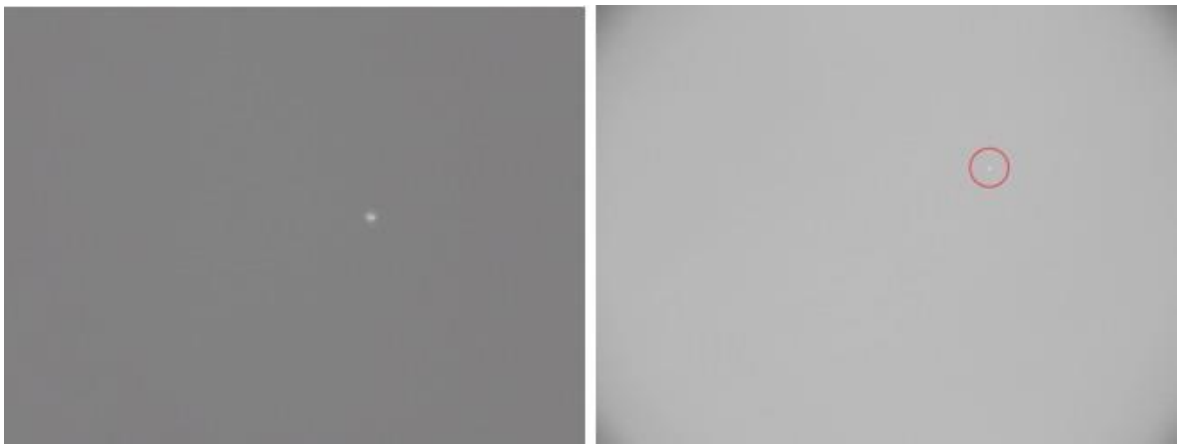
Orbit predictions of space debris objects based on Two Line Elements (TLE) are usually only accurate to within a few kilometers. Before the actual SLR search routine can be started space debris objects have to be centered within the field of view of the SLR station. The object has to be optically detected with an additional telescope using a larger field of view. So far space debris laser ranging was only possible close to the terminator zone, when it is already dark at the SLR station and the object in orbit is still illuminated by sunlight. The reflected sunlight can then be detected to correct inaccurate predictions centering the target in the field of view. To extend the observation times of space debris laser ranging to full daylight it is hence necessary to visualize such targets against the blue sky background. During daylight it was possible to observe stars up to magnitude 8.25 by using a CMOS camera together with a 780 nm edge filter to reduce the sky background noise.



Daylight images of stars of the Hipparcos (HIP) catalog with magnitudes up to 8.25 observed at sun elevations between 10° and 18° with a 4.8 x 3.2 mm CMOS sensor (image cropped to 1.7 x 1.1 arc min).

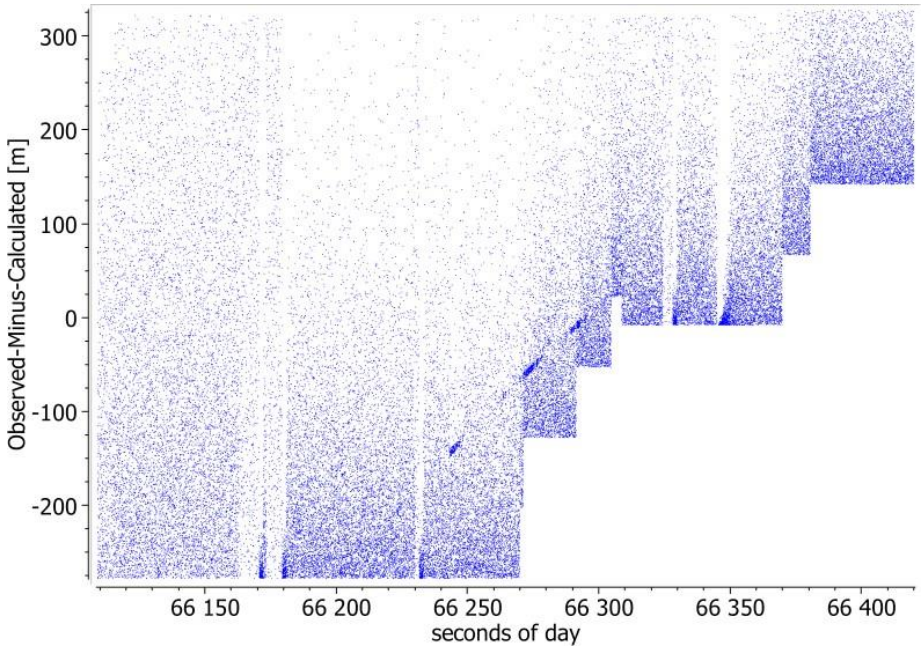
In addition, more than 40 different rocket bodies were visualized (figure below). To be able to correct offsets to space debris objects a real-time image analysis software was developed. With respect to the predicted path the time bias and the azimuth/elevation pointing offsets are calculated. As Low Earth Orbit (LEO) satellite passes only last for a couple of minutes, directly

after detection, the target is centered within the field of view and the SLR search routine is started.



Sunlight reflections of two different rocket bodies imaged during daylight. SL-3 R/B (NORAD ID: 5118, left image) was captured within a sensor field of view of 3.4 x 2.3 arc minutes and SL-12 R/B (NORAD ID: 15772, right image, red circle) within 12.6 x 9.6 arc minutes

Within four sessions six daylight space debris laser ranging passes were successfully observed (figure below, SL-16 rocket body) at sun elevations ranging from 2° to 39°. These first daylight space debris laser ranging results guide the way to significantly extend the potential observation times. Increased coverage will encourage the formation of an observation network similar to the International Laser Ranging Service (ILRS). Such a service could immediately react to improve the predictions in case of conjunctions or future removal missions.

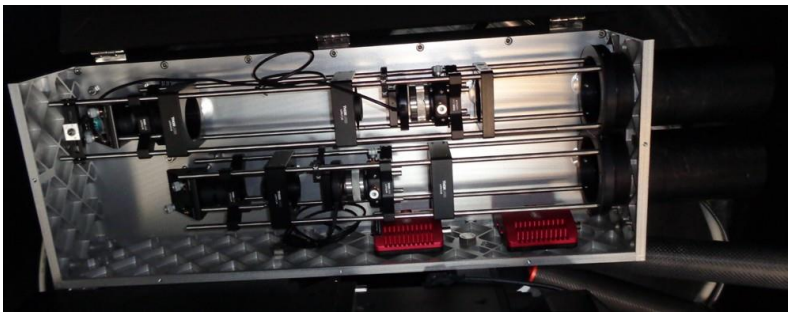


First successful daylight space debris laser ranging results to an SL-16 upper stage rocket body
(NORAD ID: 23705). The figure shows the Observed-Minus-Calculated Residuals [m] vs. the seconds of day on 24 July 2019

A NEW SLR STATION ON TENERIFE

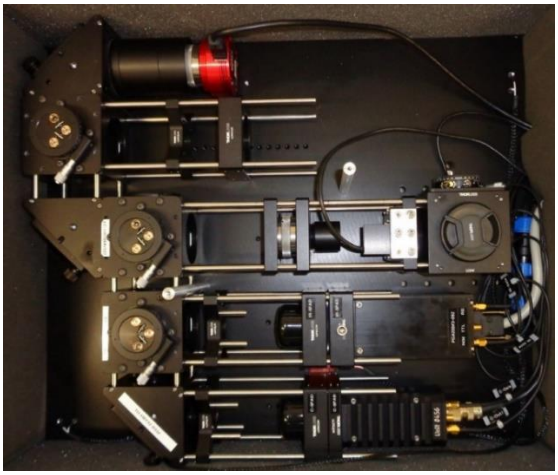
In cooperation with an international consortium from Austria, Germany, Latvia and Switzerland the SLR station Graz is involved in the design and build-up of the first SLR station of the European Space Agency located on Teide on Tenerife. The station consists of an 80 cm Ritchey–Chrétien telescope on an altitude-azimuth mount with two Nasmyth and two folded-Cassegrain foci.

Graz is responsible for the design of the laser system, including laser, beam expansion optics and electronics for start pulse detection. The laser will be mounted directly on the telescope, avoiding any Coudé-path (multiple mirrors directing the laser beam from laboratory to the telescope). This new setup reduces the necessary alignment steps and is very cost effective and easy to handle. All optical components consist of commercial off-the-shelf parts.



Final setup of the two color laser package with expansion optics to be installed on Tenerife in early 2020

Furthermore, Graz develops the detection package consisting of two single photon avalanche diode detectors (SPAD, for green and infrared wavelength), an optical camera (for monitoring reflected sunlight from satellites), and an optional light curve detection system. The Astronomical Institute of Bern will install a highly sensitive optical space debris camera. The whole SLR system is built in a highly modular way, future extensions of the system include e.g. a space debris laser ranging package.

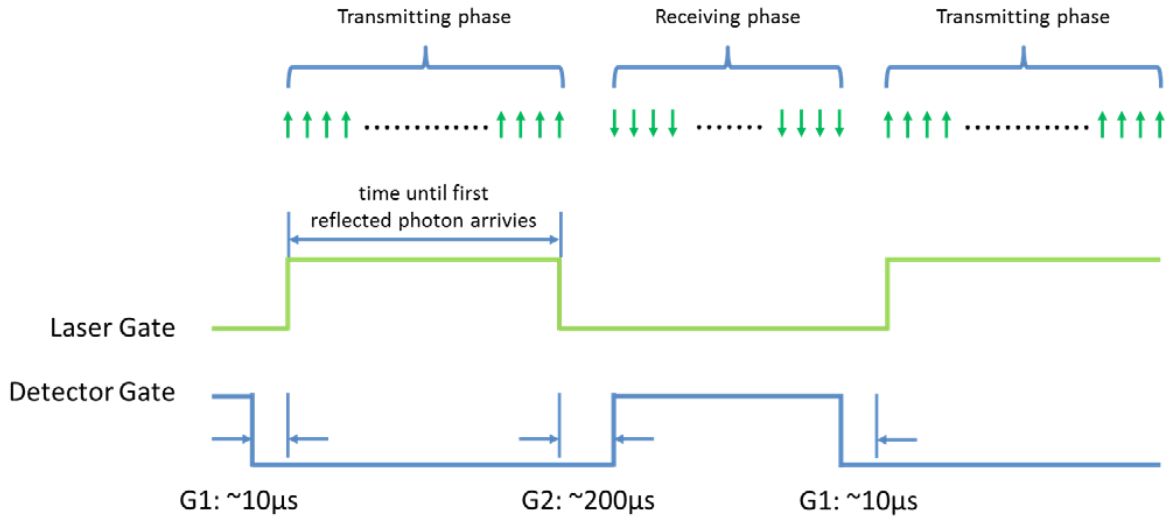


Final setup of the detection package including two SPAD detectors, an optical camera and an optional light curve detection system

TOWARDS MHZ LASER RANGING

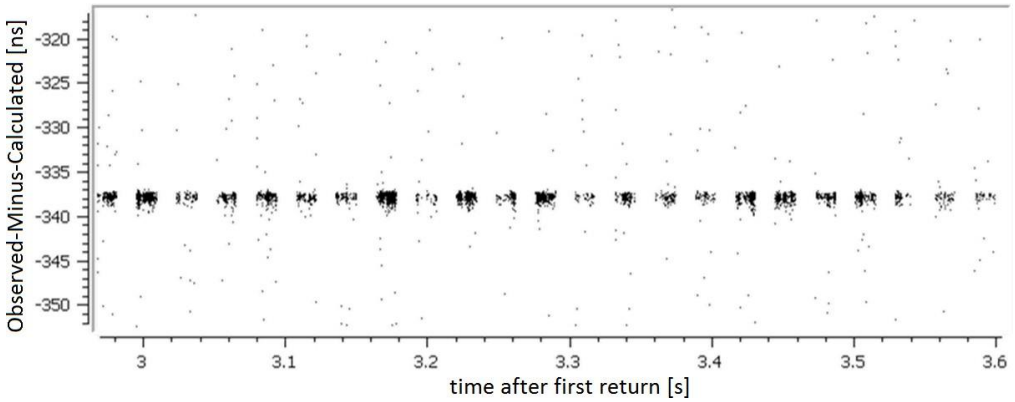
The SLR station Graz has been tracking cooperative targets routinely since 2 kHz SLR was developed in 2004. Ultra- high repetition (≥100 kHz) rate ranging is one of the most promising strategies for future SLR, and only few stations have already started such experiments. It delivers several benefits such as lower pulse energy, better statistical single-shot precision, higher resolution of target signature or shorter acquisition time for each normal point.

Between 8 and 10 August 2019, 500 kHz laser ranging was tested using a demo laser provided by IPG Photonics using a wavelength of 515 nm with pulse energies up to 50 µJ. Technical updates of hardware and software were developed such as a burst mode (see figure) for laser firing and range gate generation. To avoid the detection of backscatter the laser ranging is split into 4 phases: 1) laser transmission phase: laser firing until the first pulse is expected to arrive, 2) gap phase: waiting until atmospheric backscatter has arrived at the station, 3) receiving phase: detection of reflected SLR photons and 4) gap phase: time before the next laser burst is sent.



The burst mode for ultra-high repetition rate satellite laser ranging avoiding the detection of back scattered photons from the atmosphere

Returns were successfully received up to a repetition rate of 500 kHz (limited by the event timer and the single photon detector). A return rate of approx. 2% was achieved for *Jason-2* (see figure), *Sentinel 3a* and *Sentinel 3b*. The accuracy and ranging performance of the laser, was verified ranging up to *GNSS* satellites with the same laser at 2 kHz using our routine setup.



First 500 kHz laser ranging results to *Jason-2* (Observed-Minus- Calculated residuals [ns] vs time [s]). The laser and detector were operated in burst mode

TECHNOLOGIES

NEW DEVELOPMENTS

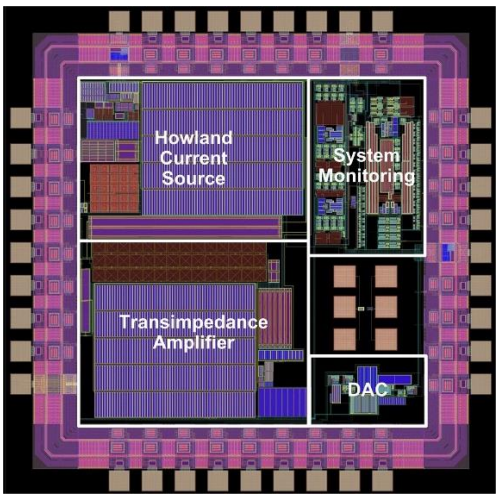
One possible aspect to reduce costs of space exploration and hence allowing for more frequent missions is to reduce the spacecraft size and consequently the launch masses. Scientific instruments also have to decrease their resource requirements such as volume, mass, and power, but at the same time achieve at least the same performance as heritage instruments. Therefore, it is important that especially the instrument front-ends and readout units undergo miniaturization.

MAGNETOMETER FRONT-END ASIC

More than 15 years ago, IWF started to develop a miniaturized front-end electronics based on an Applications Specific Integrated Circuit (ASIC) for the readout of magnetic field sensors. The electronics chip is called Magnetometer Front-end ASIC (MFA).

The MFA flies successfully on NASA's *MMS* mission and on ESA's participation in the South Korean space weather satellite *GEO-KOMPSAT-2A (GK-2A)*. For both missions (*MMS* was launched in 2015 and *GK-2A* in 2018) and in total six flight magnetometers, the MFA shows superior functionality and competitive performance compared to magnetometers with discretely built electronics.

During the last two years, IWF and the Institute of Electronics of the Graz University of Technology have been working on a concept study for an improved version of the MFA in order to overcome dynamic range limitations and the fact that IWF is running out of qualified MFA chips. In 2019, the concept study was finished with the development, production and test of a second test chip (figure) as well as the elaboration of a detailed development and test plan for a space qualified, next generation MFA.



Layout of the second test chip implemented in 180 nm CMOS technology from United Microelectronics Corporation, focusing on a high res. feedback path with a signal-to-noise and distortion ratio > 120dB

ASPOC NEXT GENERATION

For future science missions, active spacecraft potential control down to <10 V is crucial to be able to operate sensitive scientific payload. This does not only apply to large and medium-sized spacecraft, but also to micro- and nano-spacecraft, such as CubeSats. IWF (hardware) together with FOTEC (emitter) 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 operate flawlessly for more than five years.

PROSPECT PERMITTIVITY SENSOR

A sensor prototype was developed for ESA's Lunar Prospect. The permittivity sensor can determine the electrical permittivity (ε_r) of materials in contact with the sensor electrode via a comparison of the electrode current measured for air/vacuum and for contact with the material of interest. The sensor is designed for the expected Luna-27 environment (dry, cold Lunar surface materials).

The whole electrode and electronic package was required to fit within the diameter of the sampling drill developed by ESA. Thus, a major constraint of the development was the limited space available and a thermally uncontrolled cold environment. The sensor electronics is located 60 cm upwards but as well inside the drill tube. The applied electrode signal is a square wave, which contains multiple frequency components. The acquisition and analysis of the sensor output signal therefore allows a concurrent multi- frequency measurement. A fixed frequency square wave of 1.6 Hz is generated and sent into the adjacent soil via a small electrode embedded in the hull of the drill stem. The current return path is via the metallic tube of the drill itself.

A particular challenge was the decision to use 3D printed parts for the electrode and PCB (printed circuit board) holder. This decision helped to speed up the manufacturing and implementing design change of the mechanical parts. At the same time, integrating the design constraints for printed PEEK parts required different design approaches in comparison to classical mechanical production.

PUBLIC OUTREACH

IWF is actively engaged in science education and public outreach. In 2019 the emphasis was on the 50th anniversary of the moon landing and the launch of *CHEOPS*.

On 6-7 June, the Fifteen Seconds Festival took place in Graz. IWF presented the *CHEOPS* mission at this conference with 200 international speakers and 6000 visitors from German speaking countries.

***CHEOPS* booth and IWF team at the Fifteen Seconds Festival**

On 25 June, the exhibition on "50 Years Moon Landing" at the Technical Museum in Vienna opened. ESA Director Günther Hasinger talked about the new insights in space research and IWF Director Wolfgang Baumjohann was part of a panel discussion about the Austrian contributions.

In July, IWF was invited for the first time to Kinderuni Wien. Bruno Besser informed the 7-12 years old "university students" about our solar system and Günter Kargl planned a satellite mission with them.

On 28 August, Herbert Lichtenegger, Ferdinand Plaschke, Manfred Steller, and Martin Volwerk talked about Mercury, the Earth's magnetosphere, exoplanets, and comets to the ten-year old participants of the space camp during the summer school of WIKU BRG Graz.

During summer time, five high-school students performed an internship at IWF under the "Talente-Praktika" program of FFG. They worked on *CSES* magnetic field measurements, remote sensing of Earth's ionosphere, processing of weather data, graphical interface for *PICAM*, and the bow shock of Venus and Mars. In the framework of the "FEMtech" program of FFG, five female students from the University of Graz and Graz University of Technology worked at IWF on space weather, magnetotail dynamics, CUTE, Graz climate, and heliospheric dust.

On 27 September, IWF presented ESA's *CHEOPS* mission during the European Researchers' Night (ERN), a mega event that takes place every year simultaneously in several hundred cities all over Europe and beyond.

Hundreds of rockets were cut, glued and then launched during ERN 2019 at the University of Applied Arts Vienna (© PRIA/Simon Kupferschmied)

BRG Kepler invited IWF to participate in the "Long Museum Night" on 5 October. Luca Fossati presented IWF's current space missions with emphasis on *CHEOPS*.

On 6 November, ÖAW invited IWF to the academy's Comics Day, in which the science comics laureates and their work were presented to 8-12 year olds. IWF entertained 200 school kids with a special program on exoplanets. In Volume 1 of the comics series "Akademics" researchers from IWF and other ÖAW institutes answer "1000 Fragen rund um eine Kartoffel" (www.oeaw.ac.at/akademics/kartoffel-im-weltall).

Countdown for *CHEOPS'* "test launch" during the Comics Day held at the ÖAW headquarters (© ÖAW)

On 14 November, the Austrian Federal Ministry of Education, Science and Research (BMBWF), the Zentralanstalt für Meteorologie und Geodynamik (ZAMG), and ÖAW organized a media day, where IWF presented the *JUICE* sensor, which is calibrated in a *3D Merritt coil system* installed at the ZAMG Conrad Observatory (COBS).

Werner Magnes and Michaela Ellmeier presented the *JUICE* sensor to Roman Leonhardt (head of COBS), Federal Minister Iris Rauskala, and ZAMG director Michael Staudinger (from right to left; © ZAMG)

The Austrian Science Fund FWF and "Wiener Zeitung" organized the discussion evening "Am Puls No. 67" on 4 December. Günter Kargl and "austronaut" Franz Viehböck talked about how the settlement of other planets affects our society.

Günter Kargl (left) and Franz Viehböck during the FWF panel discussion (© FWF/Christine Mies)

On 17 December, IWF/ÖAW and FFG organized a launch party for ESA's *CHEOPS* mission in Graz and Vienna. Unfortunately, the 300 guests, including the Federal Ministers Andreas Reichhardt and Iris Rauskala, could not follow the launch live, because it was delayed by one day. Nevertheless, the presentations and guided tours through the laboratory still continued.

One of the many laboratory visits, which IWF offers to young future researchers throughout the year

Throughout the year, Bruno Besser, Philippe Bourdin, Luca Fossati, and Wolfgang Voller participated in three URANIA lecture series, honoring 50 years of moon landing and 30 years of astronomy (at URANIA Graz) and several other public talks were held by IWF members.

Topics discussed in the space blog of the Austrian newspaper "Der Standard" were the launch of *BepiColombo*, space debris, and antenna calibration for *JUICE* (https://www.derstandard.at/wissenschaft/wissensblogs/ub-weltraumblog).

AWARDS & RECOGNITION

ÖAW elected Rumi Nakamura as a Corresponding Member of the Class of Mathematics and the Natural Sciences. She was also elected a member of the Academia Europaea.

Wolfgang Baumjohann received the "Kardinal-Innitzer-Würdigungspreis" for Natural Sciences/ Medicine.

The outstanding achievements of former IWF director Hans Sünkel were acknowledged with the award of a Ring of Honor by the City of Graz.

Mayor Siegfried Nagl (left) and Hans Sünkel during the award ceremony in the Graz town hall (© Fischer - Stadt Graz)

Bruno Besser was awarded with the Werner Welzig Prize of ÖAW, honoring his contribution to the internal cohesion and public prestige of the academy. An interdisciplinary Austrian jury selected Monika Lendl as FEMtech (women in research and technology) researcher of February. Last but not least, AGU selected Takuma Nakamura as an "Outstanding Reviewer".

LECTURING AND MENTORING

In summer 2019 and in winter term 2019/2020 IWF members gave lectures at the University of Graz, Graz University of Technology, University of Vienna, TU Braunschweig, FH Joanneum, and FH Wiener Neustadt.

In the framework of the ÖAW mentoring system, organized by the Working Group on Non-Discrimination of ÖAW, Martin Volwerk served as mentor.

MEETINGS

From 15-18 April, IWF organized the international conference "PLATO Week #8" at TU Graz with approximately 100 participants.

Wolfgang Baumjohann served as Vice Director and chair of the Program Committee of the Summer School Alpbach, which took place from 16 to 25 July and was dedicated to "Geophysics from Space Using Micro- or Nano-Satellite Constellations". Every year, 60

students and about 25 lecturers and tutors from ESA's member states are invited to this meeting.

From 16-20 September, IWF organized a Magnetometer Workshop in Stubenberg am See, Styria, with 45 participants.

Participants of the Magnetometer Workshop in Stubenberg am See

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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 – Latest and largest TVAC in New Clean Room at AAC

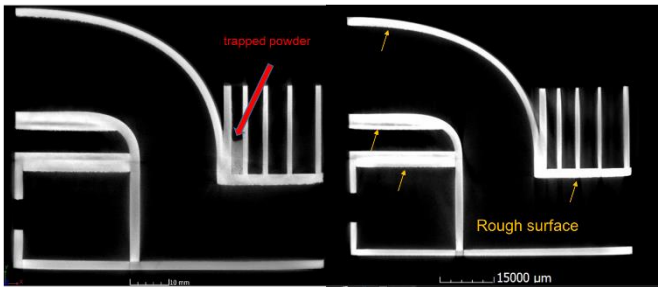
AAC again upgraded its TVAC-test capabilities inside the new clean room (ISO class 7). This enables thermal endurance and -cycling test, and functional tests by TVAC-chambers attached to the clean room. The aim of the new XVC test facility is the simulation of thermal vacuum conditions, e.g. space environment in open space and sun exposure. Furthermore, the thermal vacuum bakeout and the thermal vacuum cycling of flight hardware are key applications for this test facility. With the new device "XVC" temperatures starting at -185°C up to +200 °C can be offered for components in high vacuum. The vacuum chamber is made of stainless steel and offers an inner space of approx. 1,500 mm in width, 1,500 mm in height, and a length of

2,000 mm (volume: approx. 4,5 m^3). Therefore, the test facility is suitable for testing larger sub-elements and components.

Additive Layer Manufacturing

AAC's expertise in characterising materials for use in space is continuously applied to activities in the field of ALM (Advanced Layer Manufacturing).

ne major issue for complex ALM parts is the cleaning of their outer and especially inner surfaces and reduction of surface roughness. Together with Ariane Group (D) and FOTEC (A) as manufacturer of ALM parts and Hirtenberger (A) as solution provider to clean complex ALM parts it has been shown within the ESA-funded SEfAM project that the cleaning and reduction of the surface roughness can be done for complex ALM parts by using the "Hirtisation process".



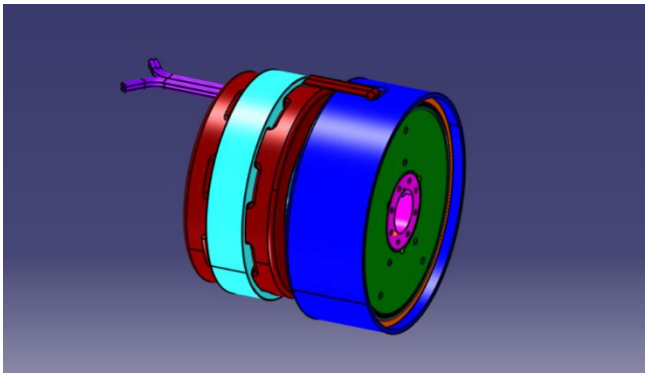
CT of complex ALM Ti64 part before (l) and after Hirtisation (r)

CT scan done at FH Wels

A follow-up activity is planned in the GSTP program GT1A-314MS "Finishing technologies for additively manufactured complex parts."

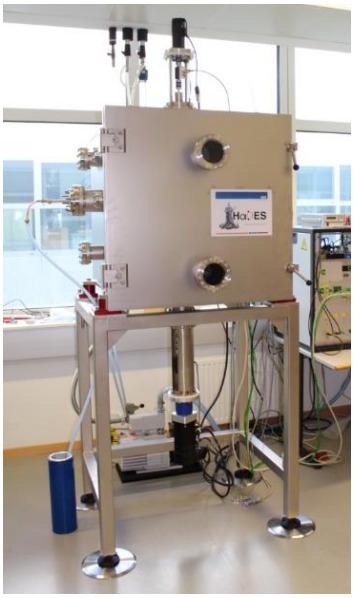
Powerless Position keeping by Magnetic Brake "MADE in AT"

Within ARTES, a project with AAC as prime contractor, with the Austrian SME "IIES" and the LCM (Linz) aims at designing and building a magnetic brake. Testing for space will go up to vacuum conditions.



The magnetic brake aims at keeping stable braking positions on driving units of satellites. Compared to actual situation, the power consumption can be minimized without danger of contamination and without limitation of lifetime due to absence of tribological layers. Braking torque is only generated by means of magnetic forces without consuming electrical power during holding. The brake can be fully integrated into driving units and with regular feedback of potential end users in the development phases it is guaranteed that it fits the customers need. The breadboard is actually being built and will be tested in summer 2020. The project will close in 2021 with testing of an engineering model "made in Austria".

Enhancement of Life for Solid lubrication of Harmonic Drive ® gears, benefitting from new plasma nitriding processes made in AT (ASAP project "harmADES")

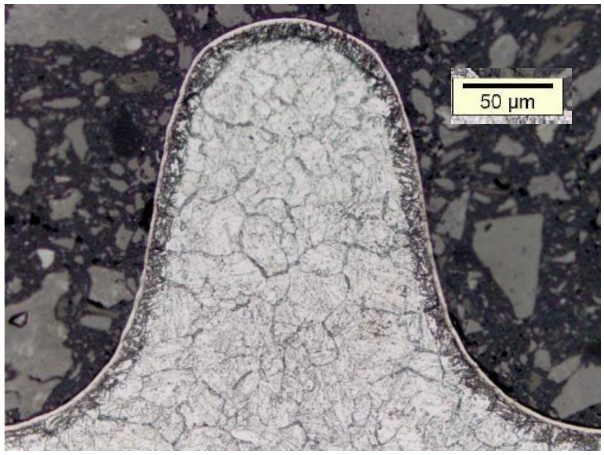


In 2019 an ASAP-project under bi-lateral funding of Austria (FFG) and Germany (DLR) could successfully be finalised. It aimed at enhancement of torque and lifetime for solid lubricated Harmonic Drive ® gears (HDs). Together with the manufacturer Harmonic Drive SE (DE) and an Austrian supplier for heat treatments (HMW), reasonable effort was put in the optimisation of nitriding process towards PH-steels used for gears in space. The main problem was that standard nitriding processes cause formation of so called "white etching layers", which are on PH-steels very brittle. They peel off together with the solid lubricant layer on top, which does not enable long life. The new process aims at avoiding that layer and just improving the subsurface hardness to provide a better mechanical support of the tribologically stressed surface.

Final life tests were done on newly nitrided Harmonic Drive ® gears, having been fully solid lubricated by use of tin coatings in the toothing. They life could be increased from less than 4000 revs to almost 15.000 revs.

Test device HaDES

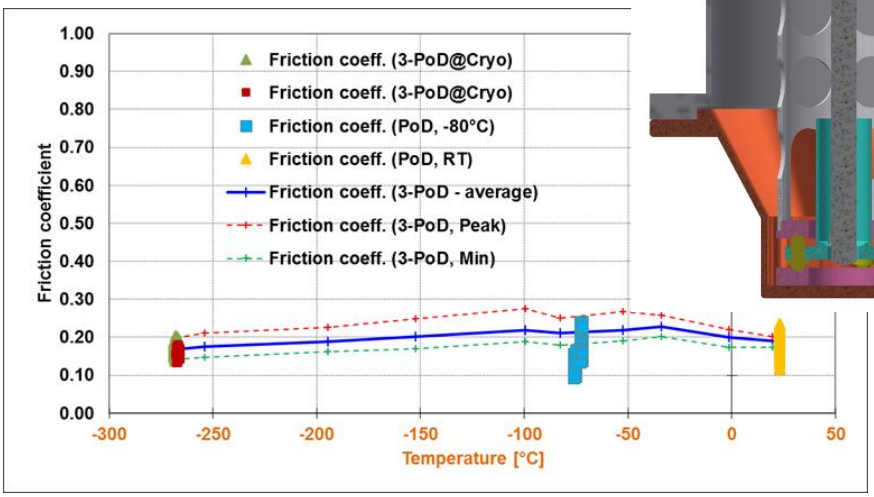
Cross section of a tooth of a Harmonic Drive ® gear, showing proper coverage by the nitriding process (Note the size of the tooth !)

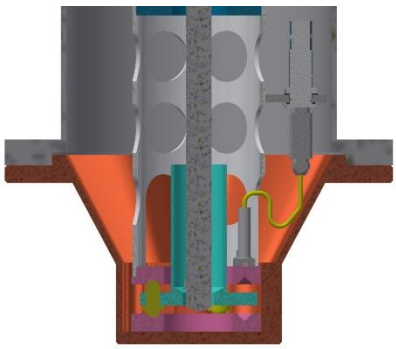


Solid lubrication by TECASINT TSE 8591 at cryogenic temperatures

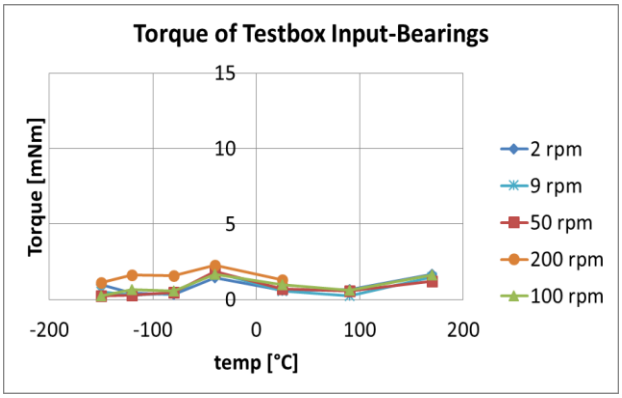
To get non-dependent from non-EU-suppliers, a new material based on PTFE was developed by ENSINGER (AT) under assistance of AAC (Project “SLPMC2”, ARTES). It’s targeted use as cages in ball bearings offers the lubricant to be transferred by the balls from the cage onto the races. Bearings can be equipped only with a cage made of the new PTFE-based material.

A new setup was installed at AAC to measure friction at cryogenic temperatures. It is based on a pin-on-disc method (pin made of PTFE sliding on steel disc). The plot shows that this new SLPMC2 shows an almost constant friction coefficient from -269°C (LHe) up to 20°C. The data fits also to another test method (PoD) which were done at -80°C and +20°C. The PTFE-material is meanwhile available as TECASINT TSE 8591.





Due to its promising performance, this material was selected by AAC for its own test device HADES. Within the ARTES project “HDGSA” Harmonic Drive ® gears should be tested over a wide temperature range from -150°C up to +170°C. Therefore, a gearbox was re-designed and equipped with ball bearings lubricated by cages made of the new material. In order to proof its lubrication efficiency, the gear box was tested in “empty” state (no gear set inside). This enabled to measure the parasitic torques of the support bearings only. The plot beside shows that the solid lubrication by PTFE-cages provides proper lubrication of the support bearings for the whole temperature range from -150°C up to +170°C and speeds from 2 rpm to 200 rpm. Based on that, 4 solid and 2 fluid lubricated Harmonic Drive ® gears were tested over this wide temperatures. Final results are expected for early 2020.



AAC has been (re-)awarded a frame-contract on the ***Space Materials Testhouse*** for ESTEC for another 5 years. The first targets were to extend the cold welding expertise from general testing of coatings / materials to avoid cold welding, where new data was generated. First investigations on stress corrosion cracking on a new type of material made by additive manufacturing were finalized, too:

One of the first studies within the new contract covered testing of the stress corrosion-cracking (SCC) according to ESA standard; ECSS-Q-70-37C. As the safety and reliability of space mechanisms depends strongly on the resistance of the particular components to SCC a determination of this phenomenon is of a great importance. The tests were performed on two novel Sandvik steel grades; Springflex and SAF 3207HD using world-wide approved AAC facility and expertise. The Springflex steel exhibits an unique combination of excellent spring properties and high resistance to corrosion and can therefore advantageously replace ASTM 301, 17-7PH or coated carbon steel. SAF 3207 HD steel has been developed for an application with extreme requirements on pitting and crevice corrosion resistance, mechanical strength and fatigue properties. All specimens of the tested steels exposed to a load level of 75% of the yield strength and to 3.5% NaCl solution passed the 30 days SCC-test. Furthermore, according to metallographic inspection neither Springflex nor SAF 3207 HD steels showed indications of SCC phenomena. Hence, both tested Sandvik steels; Springflex and SAF 3207HD, could be classified as class 1 in terms of susceptibility to stress-corrosion cracking according to ESA standard ECSS-Q-70-37C.

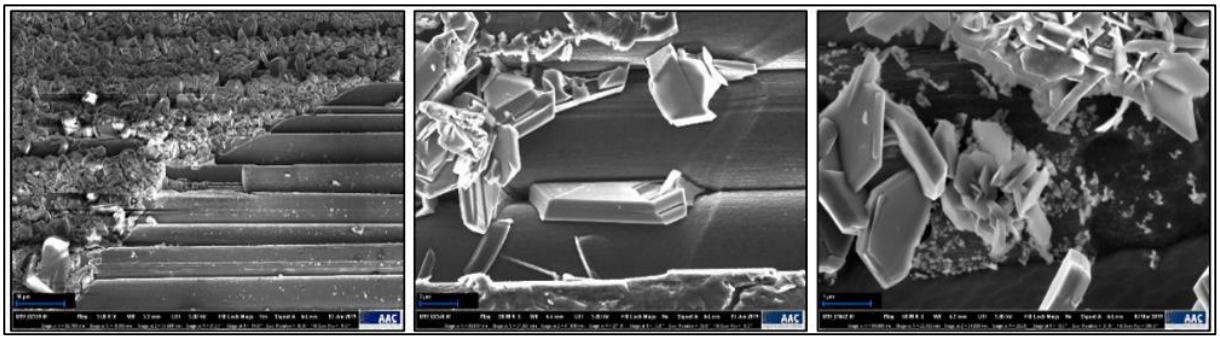
SAF 3207HD steel. Left; stressed and control specimens after SCC test and tensile testing. Right, metallographic cross section of a SCC-specimen without any signs of stress-corrosion cracking.

"SpAACe" – ASAP Project towards fibres reinforced aluminium

In 2019 the ASAP-project "SpAACe" has been finished. In this project LKR acted as the coordinator and AAC was responsible for the tests and characterisations.

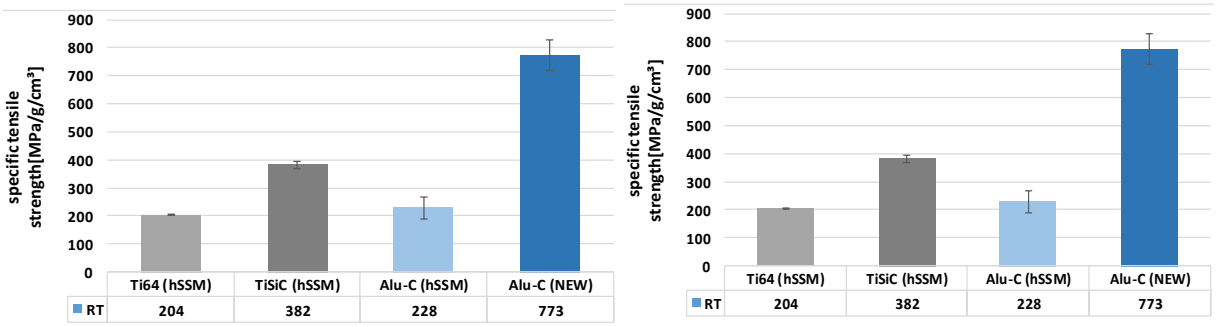
Space structures must operate in harsh environments with limited degradation to fulfil challenging demands and save mass, space and cost. Due to their high-temperature capability, high thermal conductivity, low CTE, and high specific stiffness and strength MMCs are of great interest for space applications. In this project several composite systems with Al, AlSi and AlMg matrixes, reinforced with 60-62vol% continuous carbon-fibres and manufactured by an infiltration process, have been evaluated. The results showed an impact of process parameters, different matrixes and carbon-fibres on the development of interlayer phases and the resulting mechanical performance. AAC performed investigation of the fibres distribution and wetting quality using a Light Microscope (LM) and a High Resolution Scanning Electron Microscope (HRSEM). For characterisation of the interfacial phases and degradation mechanisms of the fibres, AAC developed a unique preparation method enabling partial dissolution of the matrix and analysis of the reaction products by Focused Ion beam (FIB) and Energy Dispersive Spectroscopy (EDS) techniques at high magnifications. Apart from

microstructural characterisation a comprehensive mechanical testing using standardised procedures has been performed at AAC.



Images showing typical interfacial structure with Al4C3 carbides (all images) and very small Al8Mg5 precipitates (right) as well as degradation of C-fibres due to reaction with Al (middle) in the specimens with AlMg-matrix and the new C-fibres

It has been found out that replacing Al by an AlSi alloy matrix suppressed formation of Al4C3 carbides, however due to precipitation of large, brittle Si particles only moderate increase of strength has been observed. Using an AlMg alloy without Si allowed elimination of detrimental Si particles by keeping density of Al4C3 carbides at an appropriate level. Such an approach resulted in a significant improvement of the mechanical properties. The beneficial effects of the matrix could be enhanced by introducing optimised heating/cooling parameters and a damage tolerant carbon-fibres type. A suitable balancing of the matrix with the fibres type and modification of process parameters enabled to achieve outstanding mechanical properties providing specific strength of 770 MPa/g/cm³ combined with specific stiffness of 107 GPa/g/cm³ and fatigue behaviour clearly superior to the well-established MMCs. A range of improvement can be seen in diagrams below which show specific stiffness and specific strength of the latesd Alu-C developed herein (“New”) and former material tested during GSTP--project on “High Specific Stiffness Materials (hSSM)”.



Comparison of mechanical properties of Ti64, Ti-MMC, Al-MMC (hSSM – AAC project conducted in 2014-1015 within GSTP program), and Al-MMC of recent project SpAACe (specific stiffness (left), specific strength (right)).

Sales 2019: 1.4 MEUR

ESA Share: 0.5 MEUR

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3.3 ATOS IT Solution and Services GmbH

After the acquisition in 2018, 2019 was the first entire year of the former Siemens Space Business Unit inside Atos.

Siemens Convergence Creators, including Space, has become part of the Atos Group starting January 1, 2018. Atos has acquired the Holding of Siemens Convergence Creators with all its subsidiary companies, including Siemens Convergence Creators GmbH in Austria.

Siemens Convergence Creators GmbH has been officially renamed to Atos Convergence Creators GmbH, effective March 2, 2018.

At the same time, when the renaming took place, the former Siemens business units Space and Avionics have been merged to become the business practice Atos Space & Avionics.

In 2018, a new business unit within Atos was created named Atos Aerospace Defense and Electronics, where Atos Space & Avionics is now part of. This business unit addresses both, the commercial as well as the defense market, which broadens our addressable market and creates new opportunities in the satellite defense market.

In early January 2019, Atos Convergence Creators GmbH has been fully integrated into the local Atos entity in Austria, Atos IT Solutions and Services GmbH (AT), finalizing the merger & acquisition process. All assets, including experts, management, engineers, IPRs, patents, facilities have been completely transferred to Atos.

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

In general, the Atos Group is a global leader in digital transformation serving a global client base. Atos' revenue in 2019 was €11,588 Billion. Every day 108,000 people in 73 countries are developing and implementing innovative digital solutions that support the business transformation of clients and address the environmental and social challenges we all face.

European number one in cloud, cybersecurity and high-performance computing, the Atos group provides end-to-end orchestrated hybrid cloud, Big data, business applications and digital workplace solutions through its Digital Transformation Factory, as well as transactional services through Worldline (deconsolidated in 2019), the European leader in the payment industry.

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

Atos is the Worldwide Information Technology Partner for the Olympic & Paralympic Games and is an SE (Societas Europaea), listed on the CAC40 Paris stock index.

Atos operates under the main brands Atos, Atos Syntel, Atos Consulting, Atos Healthcare, Atos Worldgrid, Bull, Canopy and Unify.

Atos Space provides products, solutions and services

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

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

In financial year 2019 Atos Space sales revenues reached € 17.3 million, based on commercial market, ESA, Galileo, FFG and DLR activities. The share of ESA sales therein accounted for € 6.87 million.

The 2019 business was mainly focused on the following topics:
- Satellite Testing
- Satellite Control
- Satellite Communication

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

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

In addition to the well-renowned Radio Frequency and Power Subsystem 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. Deliveries and upgrades to the RF communication, payload and power testing equipment for Airbus OneWeb Satellites resulted from those efforts.

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 2019, the Atos RF department initiated 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 a software defined modem, the other is to develop a fully digital RF SCOE. Both together are expected to be a game changer. Both developments started in late 2019.

Atos finished to deliver the OneWeb RF SCOEs in 2019 and was awarded with the Airbus Oneweb Satellites '#1 EGSE Supplier Award'. Other projects Atos worked on in 2019 were SolarOrbiter, Metop Second Generation, Juice, Proba 3, Biomass, SARAH, Galileo, H2Sat and OptSat.

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

Power SCOE, Instrument and Payload EGSE Test Systems

In the Power SCOE domain Atos worked on missions such as OneWeb, Sentinel-6 and Juice. The OneWeb Power SCOE is, so far, the largest Power SCOE project for Atos Space in terms of output volume. Atos IT Solutions and Services has been delivering a total of 66 ProUST univerSAS power supply based solutions (see univerSAS product below) as per end of 2019.

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 SCOE
based on univerSAS and Power Multiplexer
(Photos: Atos IT Solutions and Services)

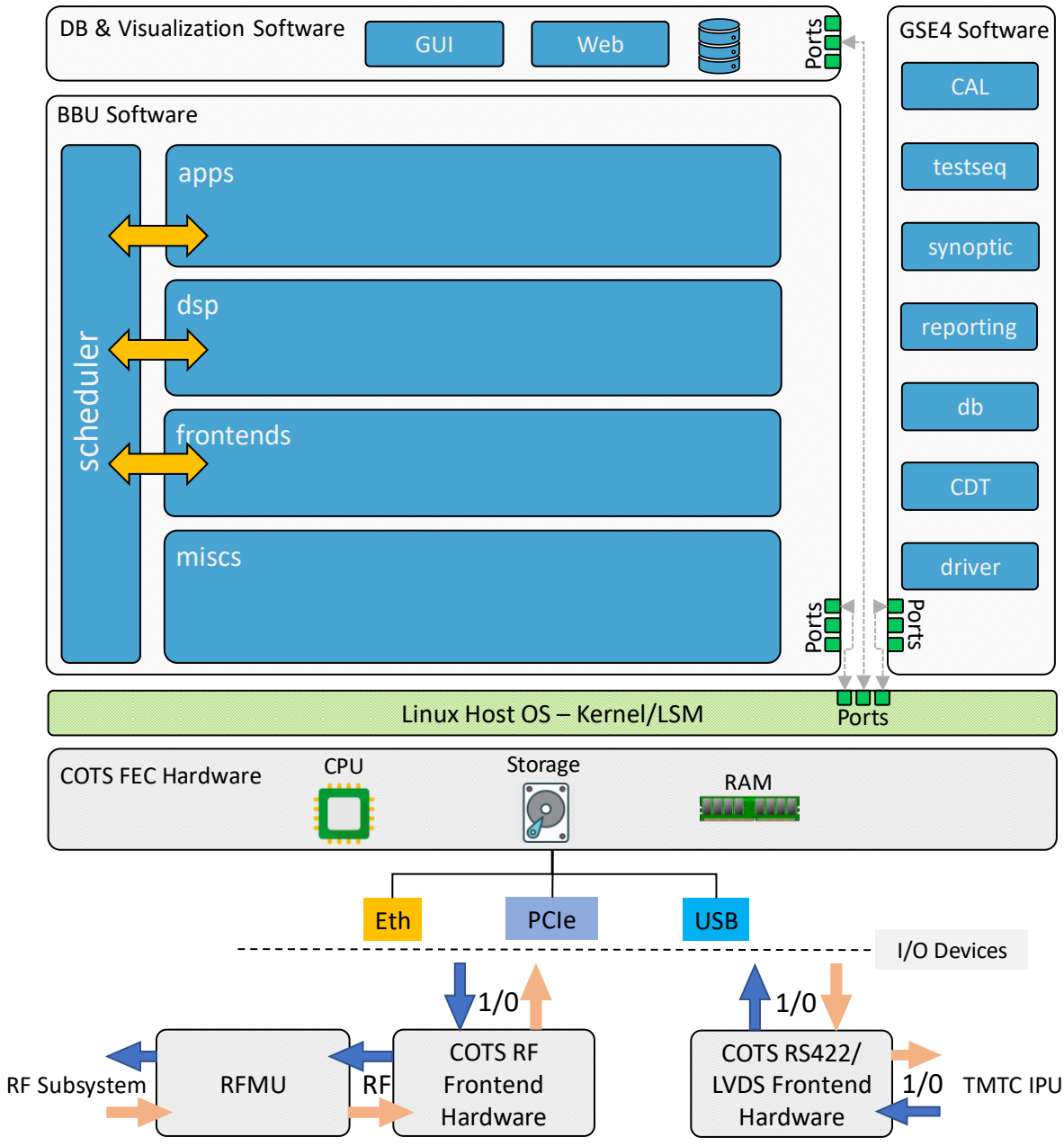
Spacecraft Simulator
(Photos: Atos IT Solutions and Services)

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.

The SDR modem block diagram can be found in the next Figure. Every block, that is defining the function of the modem will be implemented in software. Hardware is just used to convert the analogue RF signal to a digitized signal in the receiver, and vice versa for the sender. Having the functionality in software provides us with a cost advantage and flexibility.

This development was started at the end of 2019.



Block Diagram of SDR modem

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

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

New product: ProUST univerSAS 2.0

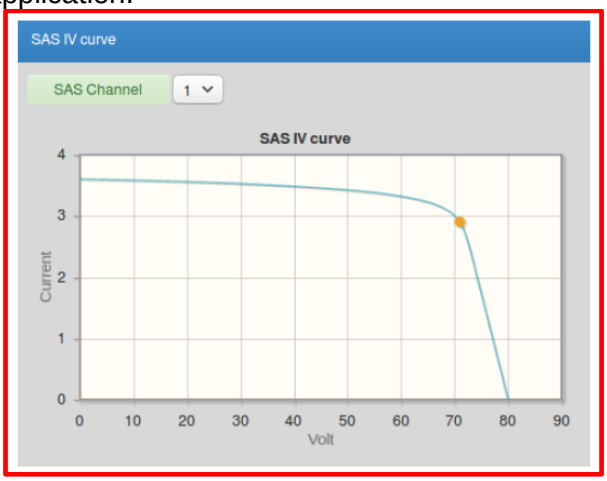
The new product resulting from learnings of the ProUST CSAS study and going towards the development of an operational product is **ProUST univerSAS**.

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

In 2019, univerSAS version 2.0 development was continued.

Performed work in 2019:

- 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.)
- Prototyping of all univerSAS 2.0 boards.
- Prototyping (Engineering Model) of the EMC behavior
- SAS-IV curve and GUI (Graphical User Interface):
    - For scientific satellites a graphical interface is required in order to check the MPPT and SAS-IV curve.
    - The SAS SCOE power supplies are controlled from the SCOE via the GUI software application.



SAS-IV curve

Bring-up, Integration and Validation tests were performed in 2019 as preparation work for system testing and CE and UL certification as a standalone product 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.

Satellite Control:
Ground Segment Systems and Mission Control Software

Also, in the year 2019, 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

The maintenance and evolution contract for the DLR Mission Control System in GSOC (Oberpfaffenhofen, Germany) has expired at the end of 2018.

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

IP Communication becomes more and more important and “always online” is a demand, especially when it comes to mobile phones and internet access. This trend is also a big issue for commercial satellite operators, which make them change their business models – away from the classic TV broadcast to broadband services, as well as the move to LEO constellations.

Some satellite service operators offer services that can be subsumed under the term VSAT (Very Small Aperture Terminal) service providers. They offer services and solutions to establish IP communication and access to the Internet via satellite.

Needless to say, that also criminals and terrorist organisations have quickly realized the capabilities of modern satellite communication services. Usage of commercial satellite

communication equipment unfortunately played a role in nearly all terror attacks, piracy and hostage taking incidents within the last decade like e.g. Algeria 2013, Paris 2015, Brussels 2016 and Istanbul 2016. At the same time mobile satellite communication is also heavily used in all today's asymmetric conflicts and civil war regions like Afghanistan, Libya, Syria, etc.

The strategic monitoring of satellite communication therefore plays an important role in fighting organized crime and thwarting terrorist attacks, but also in remote and independent situation assessment of conflict regions as a foundation for own political decision making.

This was the reason why we worked in 2019 on complementing our offering and to be able to address the needs of the communication intelligence market.

Two main activities were done in this context:

1. Development of a VSAT Geolocation system
2. Complementation of our portfolio with interception capabilities

Development of a VSAT Geolocation system

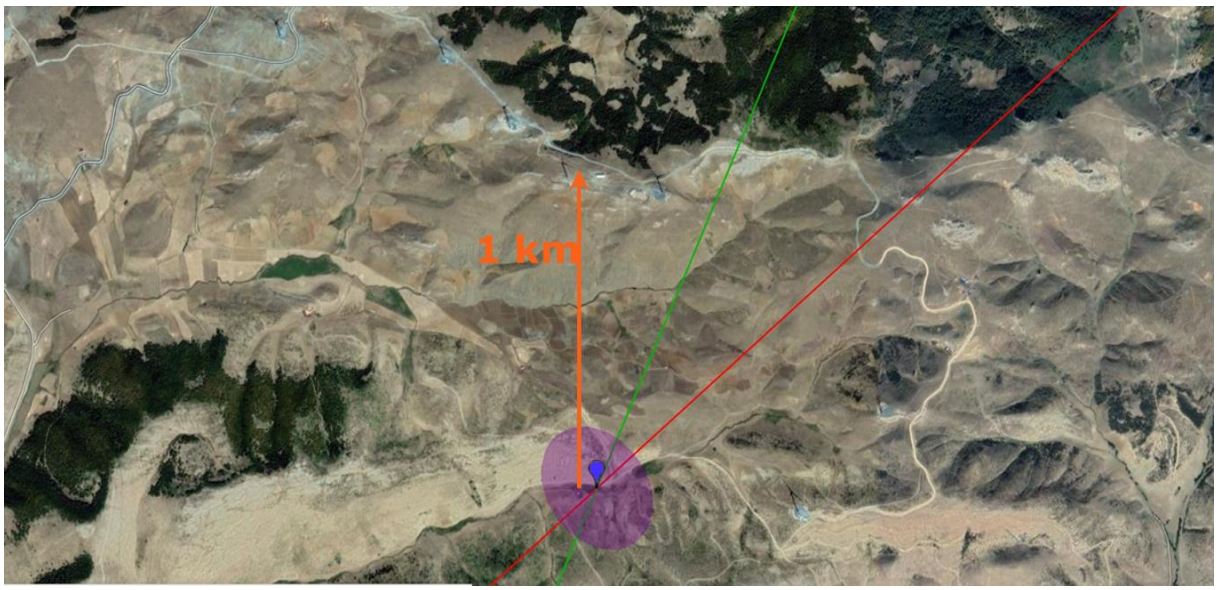
In a typical VSAT network, communication is done via a broadband Forward Link Channel, which is broadcast from a gateway station to all user terminals and with dedicated Return Link Channels, which are using MF-TDMA (Multi Frequency – Time Division Multiple Access).

This Hub Centric star network is accessed with low cost consumer-class terminals using small Antennas. These connections are used for "Always ON" IP communication.

The forward link using the de-facto-standard DVB-S2(x) is easy to monitor when standard modems are used. The challenge comes with the return link, where various proprietary standards must be supported to monitor the most important part of the communication – the return link.

In order to geolocate a specific VSAT station, it is necessary to extract the data coming from this station before applying the correlation methods TDOA (Time Difference On Arrival) and FDOA (Frequency Difference On Arrival) for calculating the position of the terminal.

The following screenshot shows a successful geolocation of a VSAT terminal from a windfarm in an Asian country with an accuracy of about 1km:



Geolocating a VSAT Terminal (Photo: Google Maps)

Zoomed in:

Geolocating a VSAT Terminal – Zoomed in (Photo: Google Maps)

Complementation of our portfolio with interception capabilities

As mentioned above, in 2019 we were also focusing on complementing our SkyMon offering with 3rd party tools to be able to offer a full-fledged satellite monitoring solution for the communication intelligence market.

Subsumed under the term COMINT (Communication Intelligence), the collection of data is key for threat evaluation and target of interest decision.

Intercepting satellite communication can provide a much more complete and higher-quality starting point for communication intelligence.

Therefore, we have integrated a number of 3rd party tools to monitor satellite services. These solutions provide strategic and tactical sensors and analysis tools to intercept, geolocate, process and analyse critical intelligence data.

The Skymon for defence portfolio follow a modular and flexible design concept and can be customized to meet special requirements a customer might have. They are optimized for handling even the highest requirements up to full traffic satellite communication interception at a global scale.

Space Sales 2019: 17.3 MEUR (based on commercial market, ESA, Galileo, FFG and DLR activities)
ESA Share: 6.87 MEUR

Contact

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3.4 ENPULSION GmbH

ENPULSION was founded in 2016 as a product spin-off of FOTEC, the research subsidiary of the University of Applied Sciences Wiener Neustadt, Austria, to produce and commercialize electric propulsion systems for CubeSats using Field-Emission Electric Propulsion (FEEP) technology for the global market. This technology is based on more than 20 years of research and development work in cooperation with the European Space Agency (ESA). The technology uses indium as a propellant, which assures safety, compact size, quick integration in satellites, and excellent quality-to-price ratio of the thrusters.

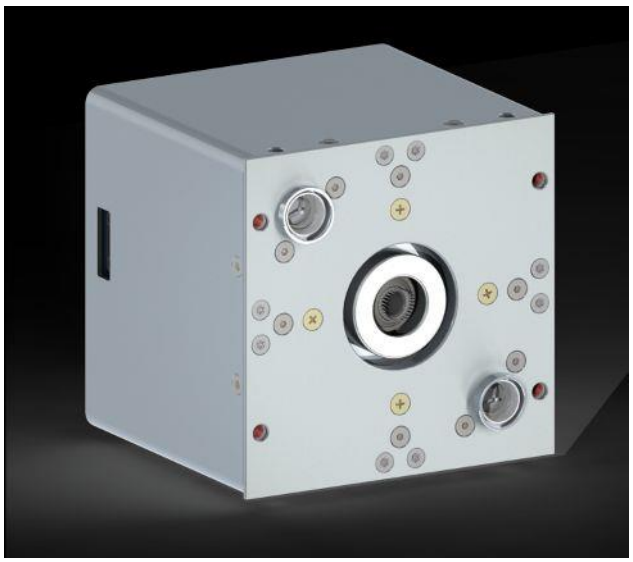
In its own semi-automated production facility, ENPULSION is manufacturing the IFM Nano Thrusters – a compact, scalable, and modular electric propulsion system with commodity pricing as well as ultra-short lead times. The IFM Nano Thruster is used as a compact pre-qualified building block in order to provide modular customized propulsion solutions for nano- and microsatellites. The scaled version – the IFM Micro Thruster – had been developed to target small and medium size space crafts as well. Due to scalability of its products, the state-of-the-art manufacturing processes, and the high competency of its team of almost 30 people ENPULSION can ensure flexibility and quick deliveries for even bigger customers who are planning to launch satellite constellations.

ENPULSION propulsion systems are provided to customers on a global scale and the company has expanded with a representative office in the U.S.A. in 2017. The company's customers range from heritage platform manufacturers to new platform manufacturers, satellite operators, self-build operators, research and educational institutions. Its products are installed on small and medium satellites serving a whole spectrum of satellite applications like weather monitoring, observation, communications, scientific projects, etc.

ENPULSION in 2019

2019 was a busy and successful year for the company. In July it expanded its production facilities with the installation of two new vacuum chambers, increasing its maximum production capacity to five thrusters per week. In December TÜV Austria awarded to ENPULSION the ISO 9015:2015 certificate, placing the company among the first ISO certified propulsion solution manufacturers.

In November ENPULSION announced the launch of the IFM Nano Thruster COTS+, a modification of the IFM Nano Thruster which expands on its advantages such as heritage, low cost and fast delivery cycles by introducing a full lot-control and lot-testing component philosophy.



IFM Nano Thruster COTS+

For this thruster version, large batches of thruster electronics are procured, selected samples of which are then subjected to verification testing including radiation testing. The remaining sets of electronics, from the same batch as the experimentally qualified units, are then used to build the IFM Nano Thruster COTS+. Customer who choose this product will receive an extensive test report on the radiation tests of the lot samples that are representative for their thruster PPUs. By following this lot-controlled philosophy, a maximum applicability of radiation test results onto the flight units can be guaranteed. The IFM Nano Thruster COTS+ can thus offer higher quality levels, while still delivering the same performance as the IFM Nano Thrusters.

In 2019 ENPULSION won several prestigious projects and grants. It was successful in securing an ESA-funded R&D project with RUAG and an ARTES Competitiveness & Growth Element for the development of the IFM Micro 100. It also applied and got accepted for a contract change notice (CCN) for the InCubed IFM Family Qualification project and successfully finished the final audit for the H2020 SME project.

During the year the company also managed to add many important customers, stressing on the establishment of long-term relationships. In March the Zentrum für Telematik (ZfT) in Würzburg decided to select the company as its partner to provide propulsion solutions for the NetSat and TOM missions. In May the company entered into a strategic partnership with Hemeria, the space division of the French company NEXEYA.

Signing With Hemeria

In September, ENPULSION was selected by MIT Lincoln Laboratory to develop the Agile MicroSat thruster technology together with Blue Canyon Technologies (BCT). As per December 2019 there are 27 IFM Nano Thrusters in space with total deliveries approaching 100 thrusters.

Sales 2019: 2.7 MEUR
ESA Share: 1.3 MEUR

Contact

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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 Catalysts 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 offering. Moreover, EODC leads the EO-Pillar activities within the EOSC-hub project proving EO services within the European Open Science Cloud (EOSC). Moreover, EODC is active in the H2020 openEO project and within the Austrian Data Market Austria (DMA) activity.

Project highlights in 2019

The Austrian Space Applications Programme

APP4AQ_p2 - Innovative APPlications for the augmented use of satellite observations to support Air Quality management – phase 2

The project aims to foster new and improved satellite data exploitation techniques, combining them with existing ancillary data to enhance the overall utility the satellite products for air quality monitoring, now, in the near future and beyond.

EODC contribution: 25 k€

Austrian_Data_Cube - Austrian Data Cube: An EODC service for the Austrian EO user community

The Austrian Data Cube (ACube) project aims at developing a proof-of-concept for a data cube system for Austria with the goal to remove technological barriers for the use of Copernicus data in Austria. The ACube shall consist of a time series of highly standardized and harmonized radiometrically and geometrically corrected Sentinel-1 and Sentinel-2 data provided in a data cube defined by the Austrian user needs. The way the data is prepared, e.g. the selected coordinate frame, the digital terrain model for geo-referencing, Sentinel post-processing procedures, and further relevant geodata, will be chosen such as to best meet the requirements of a diverse Austrian user community. The test system will be designed so that users can (1) directly access the data cube via a Web Map Service (WMS), offering thereby the potential for a straightforward integration into existing own workflows or (2) the user can use the ACube

directly on the EODC cloud infrastructure. The development will be guided by a series of user workshops that will ensure optimum uptake of their requirements during initial conception and test implementation.
EODC contribution: 110 k€

BMon - A Cloud-Based System for High-Resolution Soil Moisture Monitoring over Austria

The objective of the BMon (short for “Bodenfeuchte-Monitor”) project is to develop a cloud-based system for real-time monitoring of soil moisture conditions over Austria at high-resolution (100 m). An innovative method of integrating data from multiple satellites and different numerical models will be used to provide reliable soil moisture estimates. The system will be setup in a modular fashion on a cloud platform, which shall guarantee a seamless integration of system components to tailor the data workflow to a diverse set of applications. In view of the three main application domains considered in this project (meteorology, hydrology and agronomy) three different models will be used. Their outputs will be inter-compared with in situ data and other key variables which are known to be closely related to soil moisture (such as precipitation, runoff, vegetation status).
EODC contribution: 45 k€

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.
EODC contribution: 105 k€

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.
EODC contribution: 35 k€

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. The first service (DHR Copernicus), continues the current DHR operated by ZAMG and implements the majority of the CR, delivering relaying the Copernicus data to the ESA member state collaborative GS mirror archives. The second service operated by EODC implements a prototype DHR Service delivering ESA Mission data, specifically SMOS in the first instance, to the ESA member states mirror archives.
EODC contribution: 100 k€

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.
EODC contribution: 108 k€

Gamma2Cloud - Feasibility of using Sentinel-1 terrain-flattened gamma naught backscatter across EO platforms
will evaluate the existing backscatter calculation process of ESA's SNAP software by comparing its performance to the computation times and by studying the impact of using in different workflows over Alpine test regions. This will lead to concrete recommendations for evolving SNAP's processing, if reasonable. The concrete recommendations will also include suggestions for adapting the SNAP's processing to a more time effective utilization in High Performance Computing (HPC) environments.
EODC contribution: 35 k€

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.
Contract Value: 3.0 M€

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.
EODC contribution: 128 k€

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. EODC contribution: 200 k€

Sales 2019: 2.1 MEUR
ESA Share: 182.8 kEUR

Contact

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3.6 EOX IT Services GmbH

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 twelve-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.

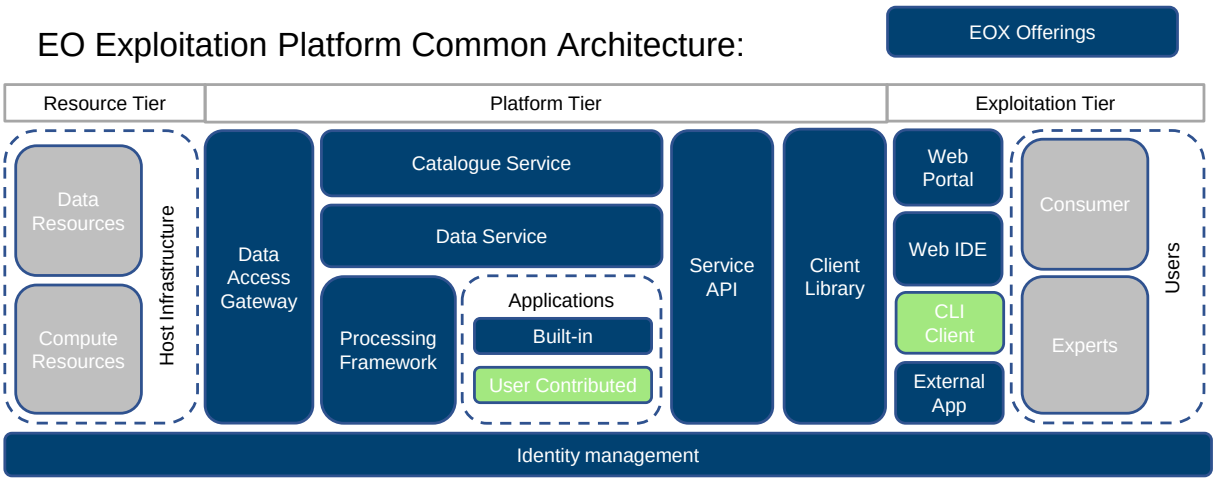
EOX is strongly committed towards utilizing and contributing to Open Source Software for example via the EOX GitHub organization. EOX is further committed to comply to and improve Open Standards particularly those of the Open Geospatial Consortium (OGC). EOX is an active promotor of such standards and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

At present, EOX employs 14 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 2019 highlights are reported.

Technology

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



The following illustrates some of these components.

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

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

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

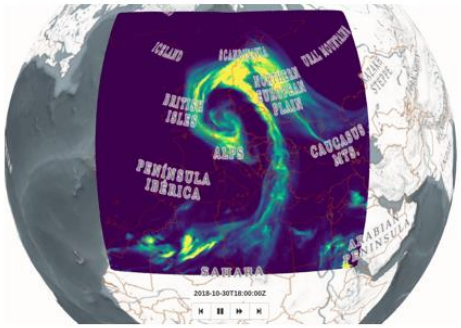
[1] https://mundiwebservices.com/geodata/S2_MSI_L2A

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

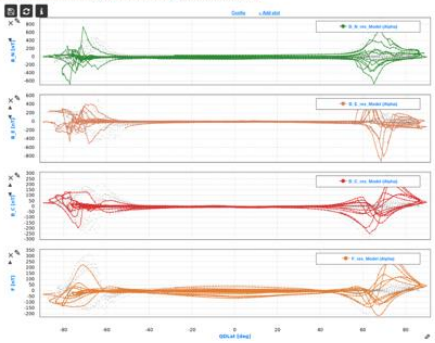
plotty & graphly - Interactive graphics and high-end plotting in Web browser

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

plotty
WebGL colorscale rendering



graphly
WebGL based graph library



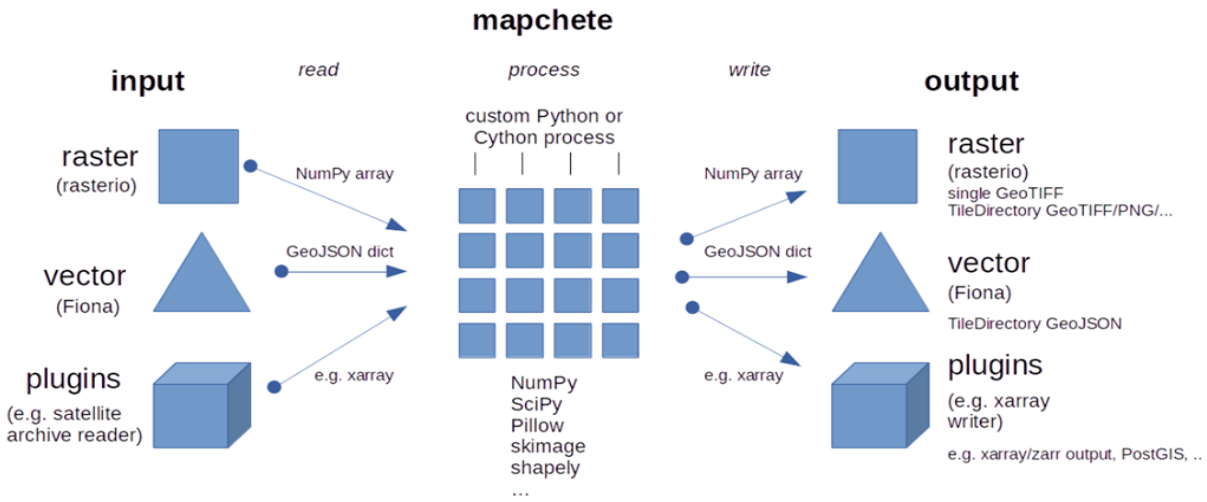
Example instances of graphly and plotty are being used in VirES for Swarm [6], VirES for Aeolus [7] and TOP [8] services.

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

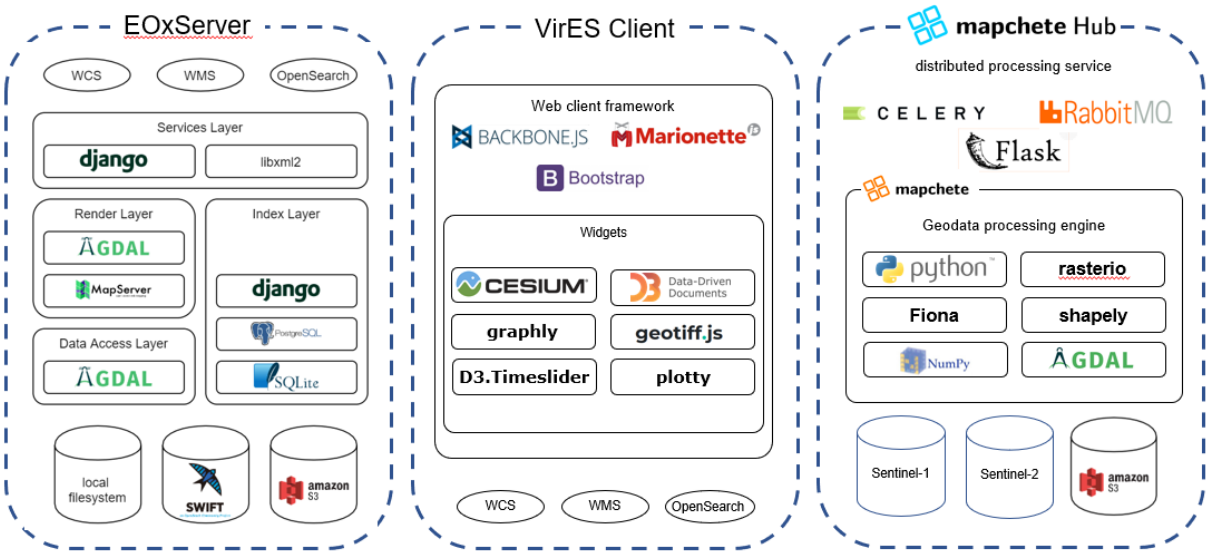
[6] https://vires.services/ [7] https://aeolus.services/ [8] http://top-platform.eu/

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

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



Software zoo - EOX excels in know-how about EO-relevant FOSS and its integrability. 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].



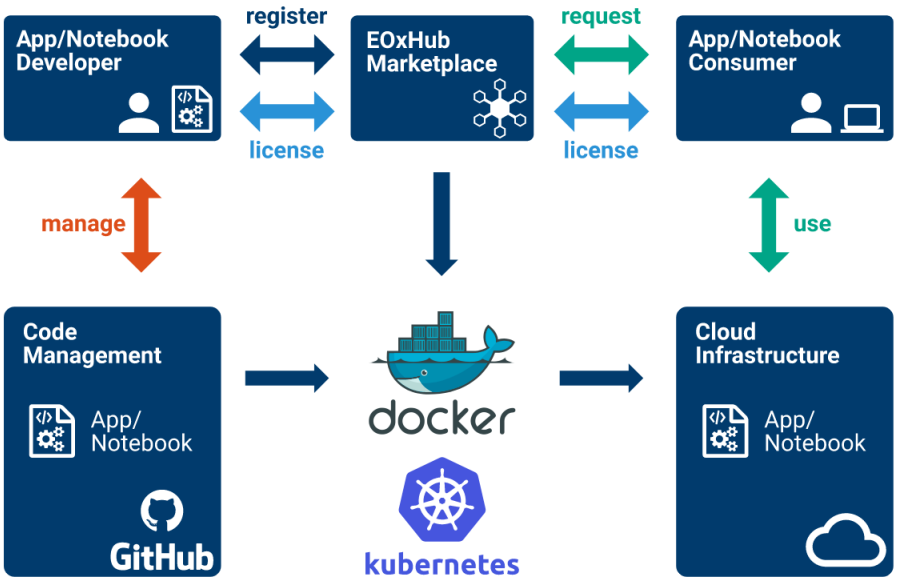
[9] https://ows.eox.at [10] https://github.com/ESA-VirES [11] https://github.com/eox-a

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.

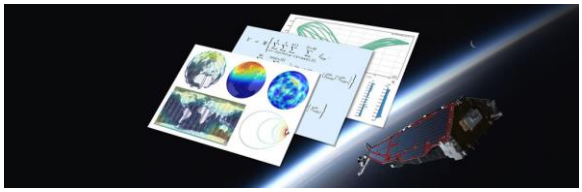


Through EOxHub [12] also optimal data access strategies (e.g. those implemented in Euro Data Cube [13]) are offered in a pluggable and unified way.

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

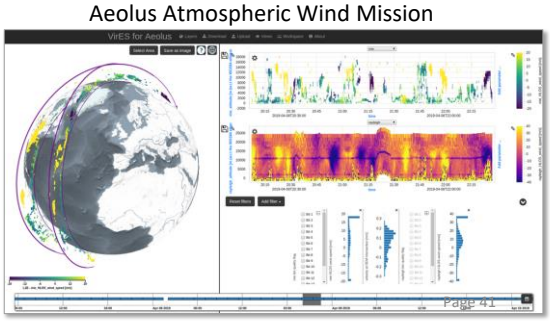
Virtual Research Environments

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.

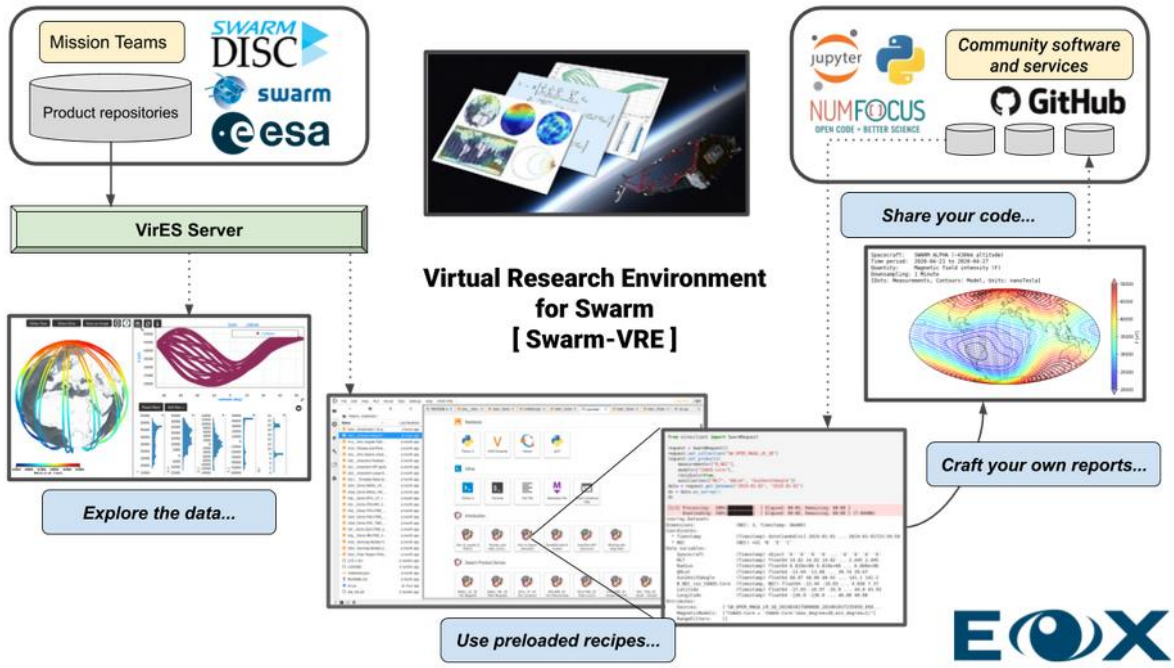


Swarm Earth Magnetic Field Mission

Aeolus Atmospheric Wind Mission



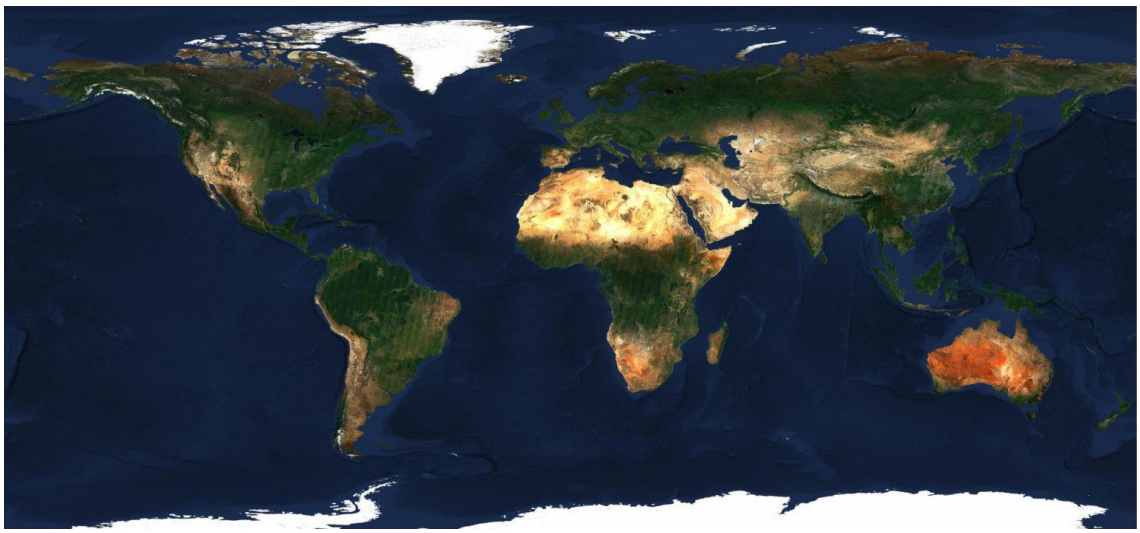
EOX is continuously synchronizing the entire Swarm and Aeolus mission data archives and provides data access to them via VirES Server. Besides the direct access via the dedicated Web GUI for data exploration, a workflow which supports flexible scientific data analysis and collaboration by code sharing using Jupyter Notebooks has been implemented, as shown in the following figure [16].



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

Open Geospatial Data

Sentinel-2 cloudless - EOX was the first company to produce a global, 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 2018 & 2019)

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 2019: 1.23 MEUR

ESA Share: 1.01 MEUR

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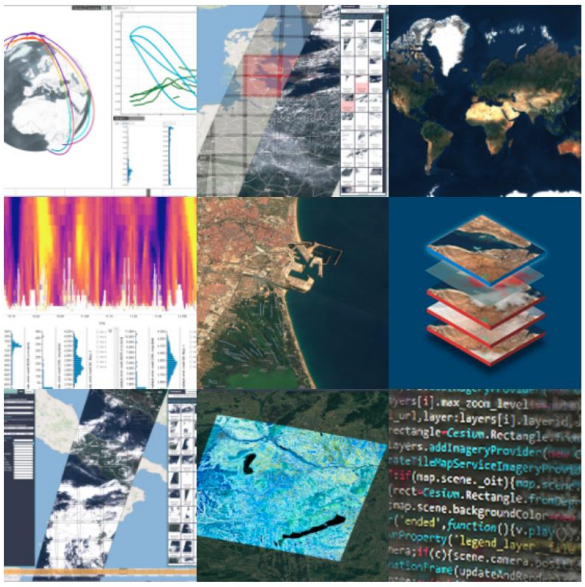


3.7 Fachhochschule Wiener Neustadt – University of Applied Sciences Wiener Neustadt (& research company FOTEC)

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

Electric Propulsion

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 can control the reservoir temperature and integrated high voltage sections 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)

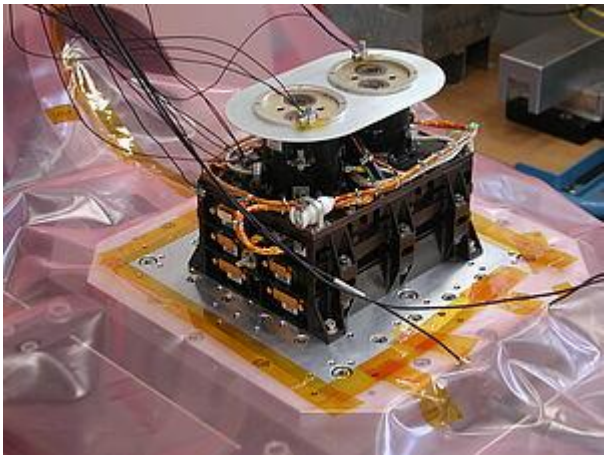
In 2018 the first IFM Nano Thruster, manufactured by FOTEC, was successfully operated onboard of a 3U CubeSat of a US constellation operator. Two burn maneuvers have been performed and the thruster telemetry was used to compute the expected orbit raise which was later confirmed by GPS.

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.

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.



Engineering model of the ion emitter module for the NASA MMS mission
(Credits: Institute for Space Research Graz)

Chemical Propulsion

Two internally financed projects were initiated to make the chemical propulsion group fit for the future.

The first project is the design and construction of a new test facility for thrusters in the thrust range from 1 to 20 N. The facility is capable of testing monopropellant as well as bipropellant thrusters. Two aspects of the facility received particular attention. Firstly, testing can be performed in vacuum, ensuring realistic conditions during firing. Secondly, impulse bit measurements as well as pulse train measurements can be performed with pulses as short as 5 ms. An investment in high precision flow meters was one to enable this type of measurements while maintaining a high accuracy.

The focus of the second project is on the manufacturing of high-temperature resistant ceramic powders. In particular hexaaluminate-based powders received attention. This type of ceramic is particularly suitable for ADN- and HAN-based propellants. The typical combustion temperature of these propellants is so high that alumina-based catalysts, the standard for hydrazine thrusters, cannot be used. The powders will subsequently be used as base material for the 3D printing of catalysts.

Energy Systems

Within a research project started in 2018, FOTEC developed processes for the controlled fabrication of porous aluminium structures with additive layer manufacturing (ALM). This enabled the manufacturing of first prototypes of a 3D-printed heat pipe, which is intended 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.

FOTEC is also participating in an ESA project started in 2019 that is concerned developing a miniaturized in-plane radiator technology for cubesat applications. FOTEC is responsible for environmental tests of the radiator prototype.

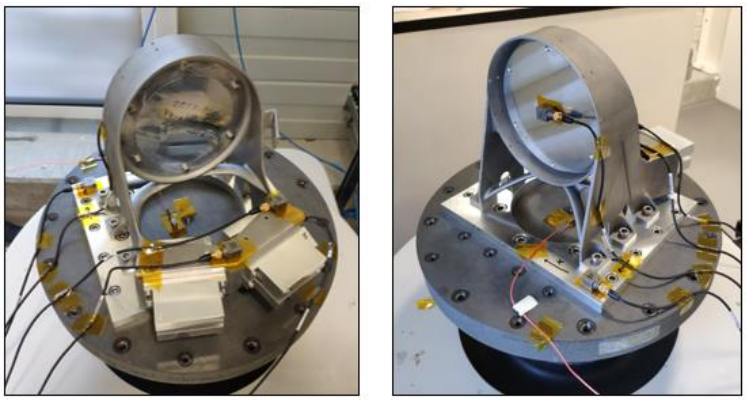
Additive Layer Manufacturing (ALM)

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.

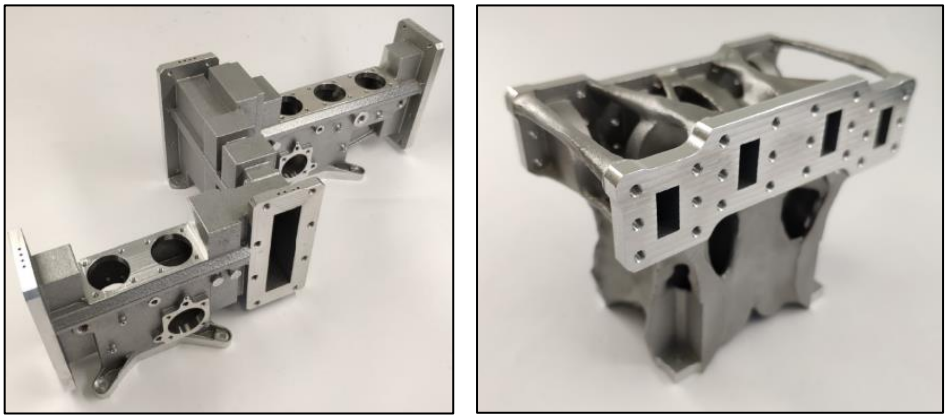
In the NEOSAT PHASE C project a primary structure from Thales Alenia Space (France) was used to investigate the applicability of ALM hardware for space. ECSS compliant procedures and documents required for manufacturing, post-processing and testing were developed and reviewed by ESA and the European industry partners in the consortium (Airbus Defense & Space and Thales Alenia Space). During the test campaign different requirements for space qualification as part of the specification document provided by Thales Alenia Space were measured, e.g. the dynamic behavior during random vibration. The verification of the simulation results and the impact of typical surface and sub-surface imperfections of ALM hardware were covered by this campaign. The project was finished successfully in December 2019.



ADPM Type 1 bracket mounted on the shaker for random vibration testing
(Source: FOTEC)

After the first development phase in 2018, 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. The objective of this additional effort is the optimization and production of another TESAT RF antenna demonstrator.



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 which will be CT scanned and tested by Aerospace & Advanced Composites GmbH (AAC). Results will be incorporated in simulation models for mechanical analysis of ALM components.

Sales 2019: 2.98 MEUR

ESA Share: 0.89 MEUR

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www.fotec.at

3.8 GeoVille Information Systems and Data Processing GmbH

WHAT WE DO

We at GeoVille do the spatial job through satellite's eye and deliver reliable, quality controlled operational monitoring products and solutions for complex resource management issues.

Our sectors


Agriculture & Rural


Energy & Infrastructure


Environment & Natural Resources

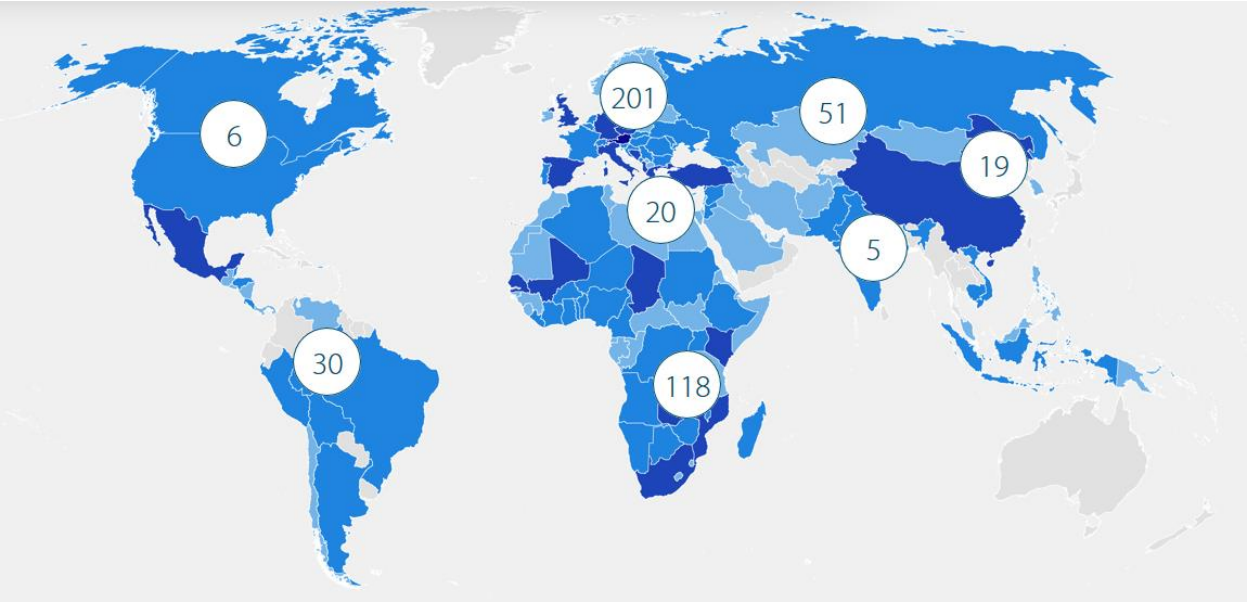

Transport & ICT


Population & Urban

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

THE AUSTRIAN SPACE APPLICATIONS PROGRAMME

LandSTATS EO

National Statistical Offices (NSOs) in Europe are confronted with the challenge of an ever-increasing number of reporting obligations, rapidly expanding from National, European to international level through the Sustainable Development Goal (SDG) targets. Earth Observation, in particular the European Copernicus programme, could significantly support and relieve the burden related to the collection of statistical data on changes on the Earth surface. The goal of LandSTATSeo is to develop and verify an early prototype of a land dynamics information service based on advanced cloud services and new machine learning methods with data stream access through statistical analysis software using an application programming interfaces (API) via the Austrian Data Cube. LandSTATSeo will provide critical components required for the development of a future Copernicus DIAS third party service applicable by NSOs worldwide, representing a significant market opportunity for the Austrian EO application industry.

Contract Value: 96K €

ESA EO APPLICATIONS

AgeSpot

The ESA funded project “AgeSpot” develops and demonstrates key technologies for an innovative satellite-assisted service, which uses data derived from satellite imagery as input to a sophisticated demographic mode. This model can, in turn, determine precisely where and how many age-specific population classes currently live - and will live in the future – in a given location in order to achieve a high impact market entry on regional, national and global scale. As such, it is responding to the requirements of a variety of users for timely and reliable granular information on population and their age structures. AgeSpot offers a unique service proposition by providing a technical solution covering all sectors building their business model on timely and highly precise population information like i.e. age, income, health.

Contract Value: 485K €

EO Best Practise – Agri Insurance

Earth observation is a powerful technique for continuously providing geospatial information across the agricultural value chain, including the agro-insurance sector. This insurance sector, in general, is facing several key issues, such as increased control and financial regulation, as well as an increasing frequency and size of loss events in the recent years, coupled with falls in investment income within the insurance industry. The objective of this project is to produce a roadmap for the development of agro-insurance guidelines for the use of EO data by the agro-insurance sector. The key activities undertaken include an analysis of the geoinformation needs of the sector, an analysis of current EO capabilities relevant to needs, and the capability gap which exists and the formulation of a roadmap for developing EO guidelines for the sector. The aim of this project is to open up the EO market to the agro-insurance sector and increase the awareness of the value of EO-based solutions.

Contract Value: 230K €

WorldWater – Surface Water Dynamics (SWD)

The ultimate objective of the WorldWater – Surface Water Dynamics (SWD) project is to empower national and regional stakeholders with the data and tools required to monitor and report on inland water resources in an independent manner using EO technology. This high-level objective is fulfilled through the development of synoptic and cost-effective methods for large-area and high-temporal monitoring of all water bodies in both extent and volume and demonstrate its suitability and scalability over selected national and regional demonstration sites. The SWD products and tools will be integrated in a data analytics platform to foster the wider usage of EO data and SWD products for country and basin scale water resource monitoring and reporting. WorldWater SWD is therefore, supporting the Sustainable Development Goals (SDGs) and is addressing the need for authorities at all levels to

adapt and formulate water policies and report on water resources in a timely manner and act in response to the global water agenda based on valid scientific information.

Contract Value: 420K €

EO4SDLAB

The objective of the ESA funded EO4SDLAB project is to define, implement, demonstrate and validate a platform for effective EO data exploitation, which is meeting the high-priority environmental information needs of the Development Aid User community (i.e. National Aid Agencies, IFIs, Government organisations in developing countries). The project aims at providing a single e-collaboration framework with easy access to up-to-date European EO missions data to support increased awareness and acceptance of EO within Development Assistance activities (e.g. project design, planning, implementation, policy-making, strategic planning, monitoring and safeguards). This will also include publication, sharing and persistent access to information.

Contract Value: 160K €

EU – COPERNICUS OPERATIONS

Copernicus - Production of Very High Resolution Land Cover/Land Use dataset for coastal zones of the reference years 2012 and 2018

The scope of this project is to implement the Land Cover and Land Use mapping of coastal areas with the typical specifications of the thematic hotspot family of products, namely: Urban Atlas (UA), Riparian zones (RZ) and the Natura 2000 (N2K) keeping consistency across all the mapping products. The challenge to achieve thematic vector maps across Europe with high accuracy and high user and producer accuracies is addressed within the project by a common processing method based on a proven heritage of products using similar methodologies, validated across Europe at similar scales, and networking of specific image pre-processing and data-handling capacities with local capacities across Europe to enable economics of scale for common work-steps.

Contract Value: 395K €

Copernicus Land Monitoring Service CLC+ Backbone

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. As a first step the CLC+ Backbone is produced, which consists of a raster and vector product, expected to become new High Resolution CLMS products, significantly complementing and enriching the currently existing CLMS pan-European and Hotspot products.The CLC+ Backbone raster product covers 11 land cover classes and is anticipated to

synergistically complement the existing five High Resolution Layers. The main scope of the project is to generate the CLC+ Backbone products, which are fully compliant with the EAGLE data model and nomenclature.

Contract Value: 2.4M €

EU – H2020

Copernicus for Urban Resilience in Europe (CURE)

The project CURE (Copernicus for Urban Resilience in Europe) is a joint effort of 10 partners from 9 countries to synergistically exploit the Copernicus Core Services to develop an umbrella cross-cutting application for urban resilience. CURE consists of individual cross-cutting applications for climate change adaptation and mitigation, energy and economy, as well as healthy cities and social environments at several European cities. These applications cope with the required scale and granularity by also integrating or exploiting third-party data, in-situ observations and modelling. CURE is expected to increase the value of Copernicus Core Services for future emerging applications in the domain of urban resilience, exploiting also the improved data quality, coverage and revisit times of the future satellite missions.

Contract Value: 253M €

UNITED NATIONS

United Nations Development Programme – Urban Mobility Plan Moldova

The objective of this project is to support the development of an Urban Mobility Plan for the Municipality of Chisinau, in order to tackle the problems related to insufficient and inadequate public transportation and related infrastructure, impediments to urban mobility, safety, and planning. The project aims at the exploration of people's mobility behaviors and attitudes, and the changes over time, as well as look at patterns of urban development and mobility. In order to derive adequate information datasets, several input sources are used and integrated. Satellite imagery is used for urban mapping and monitoring, combined with in-situ data for mobility analysis. Furthermore, EO-based information and electricity consumption data is used to identify where people live and how dense the city is populated. The generated information is used to analyse the mobility behaviour of people living in Chisinau and the extent to which the existing public transportation infrastructure is being used, leading to the identification of bottlenecks and derivation of specific patterns and insights of urban development.

Contract Value: 38K €

Sales 2019: 6.3 MEUR

ESA Share: 2.08 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 2020 panoramic camera system as well as the NASA Mars 2020 Mastcam-Z instrument. Developed systems are validated and optimised in field trials.

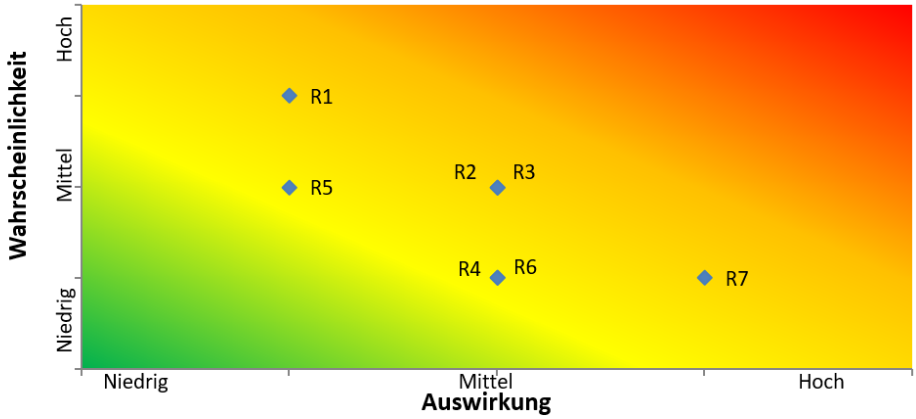
Communications & Navigation Technologies

A) Be Aware

Considering the increasing number of dependency on GNSS (Global Navigation Satellite System) as well as the enormous influence in all areas of everyday life, it is obvious that threats, be it unintentional or intentional, also occur in this area of satellite navigation systems and have an impact on critical infrastructures. In general, the main benefits of GNSS are mainly known for positioning and navigation. Nevertheless, GNSS is also used for time synchronization of financial transactions and in communication- or electricity networks.

The main goal of the project Be-Aware was to provide a comprehensive overview of the critical infrastructure in Austria in relation to GNSS threats. Due to their low signal strength, GNSS signals are relatively easy to be attacked by cybercrime like jamming or spoofing. The project team – consisting of JOANNEUM RESEARCH, IGASPIN, Karl-Franzens University Graz, Wiener Netze and the Ministry of Defense - had a structured program within the research project. At the beginning, an intensive state-of-the-arte analysis was accomplished to find out which information is relevant for the stakeholders, which types of interference are known in Austria and to gain experience in multi-frequency spoofing to enhance the algorithms already developed in a former FFG ASAP project TACTIC.

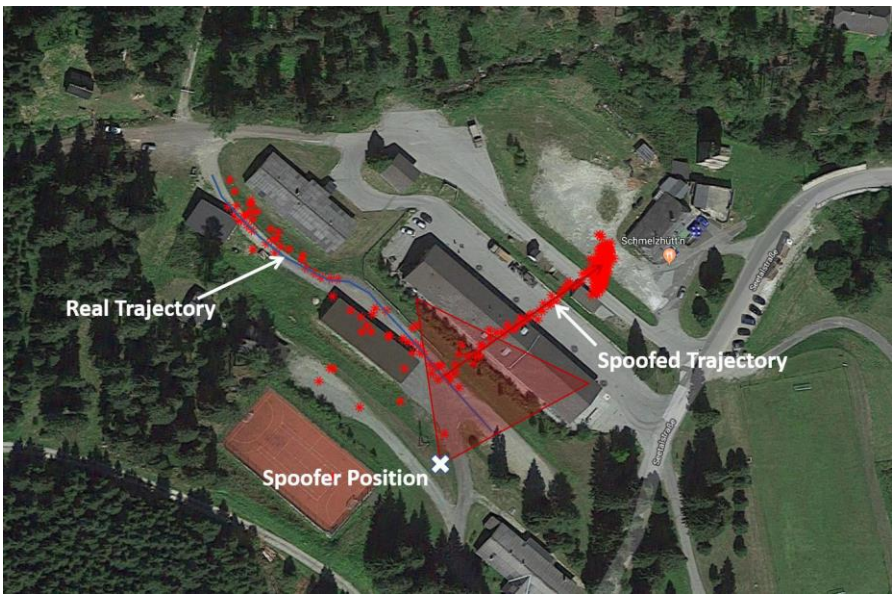
In order to answer the question - which information is relevant for threat analysis - the development of a building block system was foreseen. The aim of these modules is to create a tool that enables critical infrastructure operators to map their own system. The focus is exclusively on the GNSS-based applications within the company. The building blocks should be designed as atomically as possible in order to guarantee the same starting point for everyone and to obtain comparable results. In a first step, modules were defined that should cover all possible threats. This primarily includes conscious and unconscious interference, jamming and spoofing attacks on different frequency bands and systems as well as natural disturbances such as solar storms, poor wiring, snow or ice covered antennas, to name a few. In contrast, modules have been created that can be used to map an internal system. There are modules that can characterize a GNSS receiver and others that describe sensors and system requirements. After entering the specifications into a data sheet, the individual systems are assessed and the user receives a risk analysis to what extent a GNSS malfunction could affect his company.



Risk analysis that characterizes GNSS-based applications

Another goal of the project was to conduct interviews with critical infrastructure operators. The focus of the interviews was on the energy- and the financial sectors. Both areas are primarily concerned with time-critical synchronization processes in which GNSS time is used. A malfunction or deliberate attack on such systems could have unforeseeable consequences and great economic damage. It turned out that most are not aware of the dangers posed by GNSS interference. Still, it is comforting that many systems are secure that it is practically impossible to cause serious damage depending on implemented redundancy and plausibility routines. Through these discussions with responsible persons from critical infrastructures, a certain awareness could also be created, which was an aim of the project too.

Beside these activities, a multi-frequency spoofer has been developed and tested in different field tests together with the Austrian Armed Forces at TÜPL Seetaler Alpe. These tests culminated in a live demo in October 2019 where representatives from various departments within the Austrian Armed Forces were able to follow the successful distraction of a military vehicle.



Results of the direct take-over of a moving receiver

In summary, the project offered very good opportunities to come into contact with operators of critical infrastructures in order to create a certain level of awareness that GNSS threats really exist and that they can have serious consequences.

B) System Study of Optical Communications with a Hybridised Optical/RF Payload Data Transmitter

Communications at optical wavelengths (optical communications) are being considered for various space missions as an alternative to conventional radio frequency (RF) communications in the microwave frequency bands, given the expectation of realizing significantly higher data rates. But despite their important progress, optical communications present a higher mission risk to a long term space mission due to the lower reliability of equipment as a result of the much lower maturity of the technology compared to RF systems.

Under ESA contract a project was carried out to study synergies between RF and optical payload data transmitters (PDT) for deep space communications, further to find an optimum modulation and coding scheme for the optical link, to execute tests in an end-to-end breadboard and to summarize the findings in an appropriate roadmap towards future operational systems.

JOANNEUM RESEARCH (JR) was the prime contractor, coordinating the consortium including Thales Alenia Space Switzerland, Graz University of Technolopgy, AIRBUS Defence and Space France and RUAG Space Sweden. In the following the results of the project are concisely mentioned, being generated by the full team.

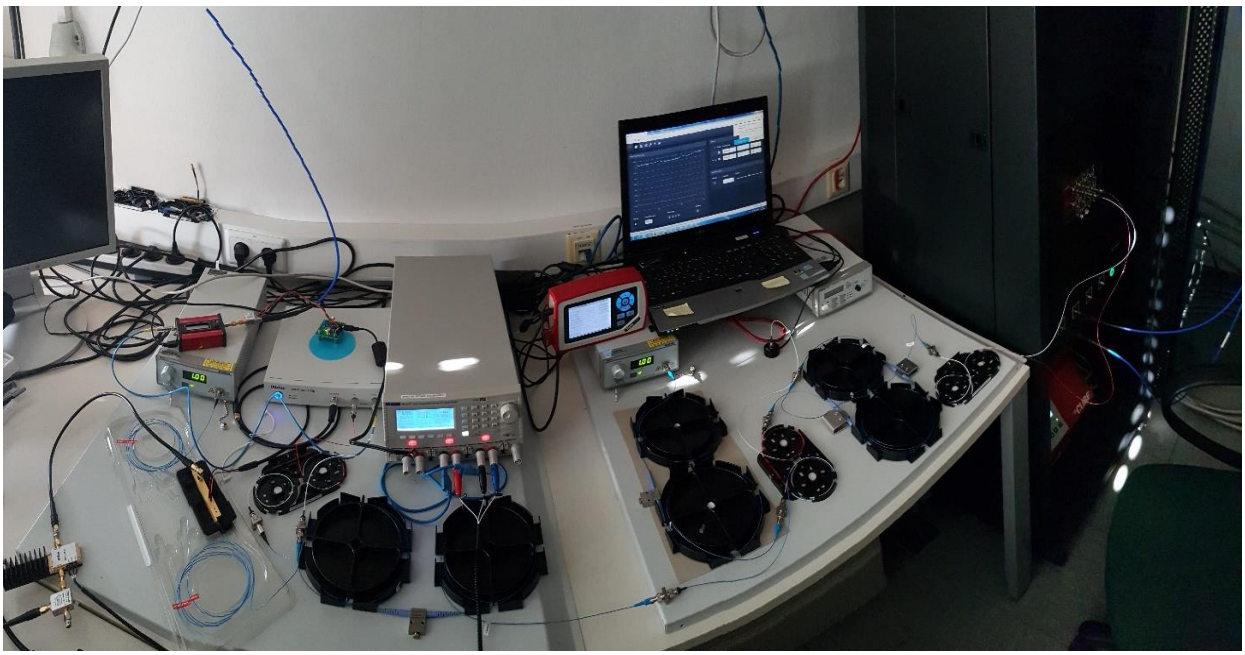
Synergies between onboard optical and RF PDT may be obtained in the front end mainly with common steering mechanisms for antenna and telescope. In the electronics some sections of the signal chain may be shared, especially when the RF and optical part are employed alternately with a Software define Radio design approach.

Regarding the signal structure, the physical layer elements for the optical part of the hybrid optical/RF payload data transmitter have been studied. The performance of the coding and

modulation scheme SCPPM (serial concatenated pulse position modulation) proposed by the CCSDS SLS-OPT working group (consultative committee for space data systems – space link services area - optical communications working group), for high-photon efficient regime was compared channel codes loke LDPC to identify alternative schemes. A simulation environment was implemented in a C++ high performance simulator developed by JR to analyze the end to end performance. The model comprises the full communication chain defined in the according CCSDS standard for downlink signalling and contains all the physical layer elements required for successful link operation, including data encoding, PPM modulation (pulse position modulation), channel interleaving, demodulation and timing synchronization, and SCPPM decoding. In addition, the simulation framework contains the model of an SNSPD array (superconducting nanowire single-photon detector), which is able to detectsingle-photon detector technology and is the choice for future deep space missions. The communication performance depending on the average received photons per second was evaluated for the predefined signaling sets for short and long distances to Venus with varying parameters like PPM slot width, modulation order, code rate, channel interleaver depth and noise levels under the consideration of practical detector properties such as SNSPD detector array size or blocking time. Pulse-position modulation (PPM) combined with serially concatenated PPM (SCPPM) forward error-correction coding achieves excellent performance close to the Shannon limit of the optical deep space channel. So the CCSDS recommended signaling scheme has been taken as baseline for the hybrid PDT.

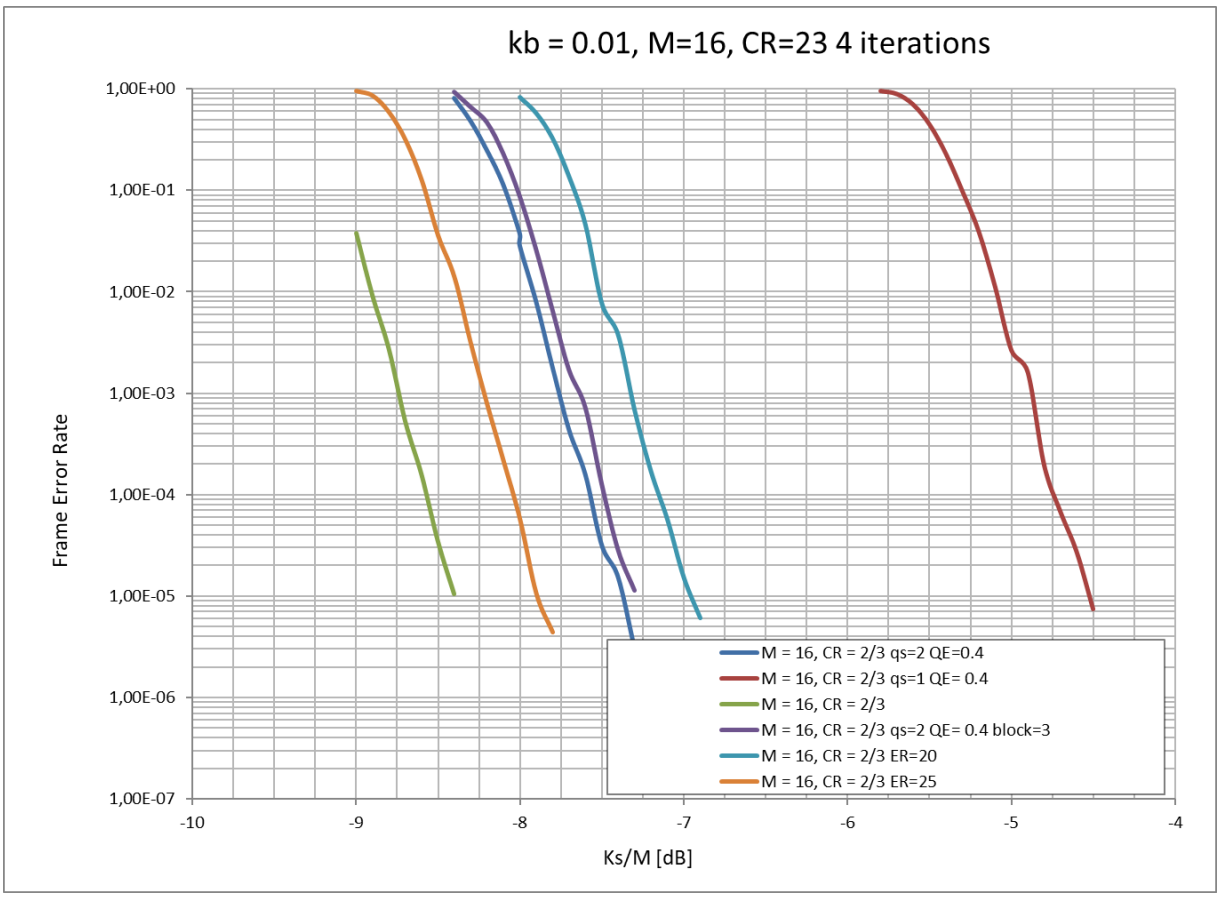
The end-to-end breadboard was setup (cf. Figure 1) with the key component superconducting nanowire single photon detector (SNSPD) and various configuration possibilities. The signal processing part was implemented with compliance to the CCSDS 142.0-B-1 “Optical Communications Coding and Synchronization” standard. Performance results for the bit error rate (BER) and the frame error rate (FER, cf. Figure 2) were generated and confirmed by reference simulations. The given FER rates represent the short distance scenario to Venus with Reference Performance and setups (different Quantum efficienies, number of channels) of the the SNSPD. Finally the relevant deep space use cases, for instance the EnVision mission to Venus, were studied and feasibility was proven. It is understood, that this is the first end-to-end breadboard of this type in Europe, in particular one that implements the SCPPM waveform and uses a superconducting nanowire single photon detector.

In programmatic terms the achievements can be summarized as follows: space missions of interest were identified and the system requirements for the hybrid payload data transmitter were



End-to-end breadboard for a deep space optical link. Left hand side shows the TX part, right hand side shows the RX part with the rightmost 19 inch rack containing the SNSPD

setup. In various aspects a trade-off is given for configurations between hybrid systems and RF systems only or a pure optical solution. With development and use of the breadboard realistic experiences and results were obtained, including a few lessons learned. These results can very well be extrapolated to operational systems. Finally a roadmap was established for the development of the key technologies and components of the system.



Frame Error Rate results of a deep space link, for various signal configurations over the link quality / channel characteristics

Remote Sensing

C) ASAPXIV Project SuLaMoSA

With the launch of the Sentinel satellites constellation as a space component of the European Copernicus programme, the European Space Agency (ESA) offers a variety of freely available satellite data. The SuLaMoSA project is dedicated to the monitoring of surface deformation and is being carried out in a joint cooperation between, the Research Group for Remote Sensing and Geoinformation of JOANNEUM RESEARCH Forschungsgesellschaft mbH as project coordinator, EODC GmbH, Vienna and GBA, Vienna.

Landslides are one of the most widespread geohazards in Europe, responsible for significant social and economic impacts. Landslides can be defined as almost all varieties of mass movements on slopes including rock falls, topples and debris flow. A landslide in its strict sense is a relatively rapid mass wasting process that causes the down slope movement of mass of rock, debris or earth triggered by variety of external stimulus. Subsidence may occur gradually over many years as depressions form on the ground surface and can be a serious issue for the urbanization construction, and the transit constructions like rapid railways or highways. In addition, land subsidence does serious harm to the sustainable development of the society and the economy.

These hazardous processes are usually accompanied by intensive human activities and changing land use that triggers social adjustment processes. In this context, the potential consequences of landslide and subsidence hazard and their possible development trends are of significance. In contrast to flooding risk, when dealing with gravitative natural hazards (especially rock falls and landslides) there are far-reaching deficits and gaps in the fundamental

information available with respect to hazard analysis, sectoral planning (hazardous zone planning) as well as risk management in Austria. The biggest challenge consists in the development of an integrative method for documentation and evaluation of the threats and risks (security level, protection objectives), a uniform system for the cartographic depiction of gravitative natural hazards as well as the use in spatial planning.

Regarding to the identification, documentation and effective assessment of landslide/subsidence hazards no universal method is accepted. In recent years, several attempts have been made to apply different methods of landslide hazard assessment and to compare results in order to find the best-suited model. The advanced multivariate techniques are proved to be effective in spatial prediction of landslides with high degree of accuracy. Remote Sensing and Geographical Information System (GIS) are powerful tools to assess landslide hazards and are being used extensively in landslide researches since last decade. The use of advanced differential SAR interferometry (D-InSAR) techniques is nowadays well-established in the field of subsidence and landslide monitoring. Proposed advanced D-InSAR techniques can mostly be grouped into two main categories:

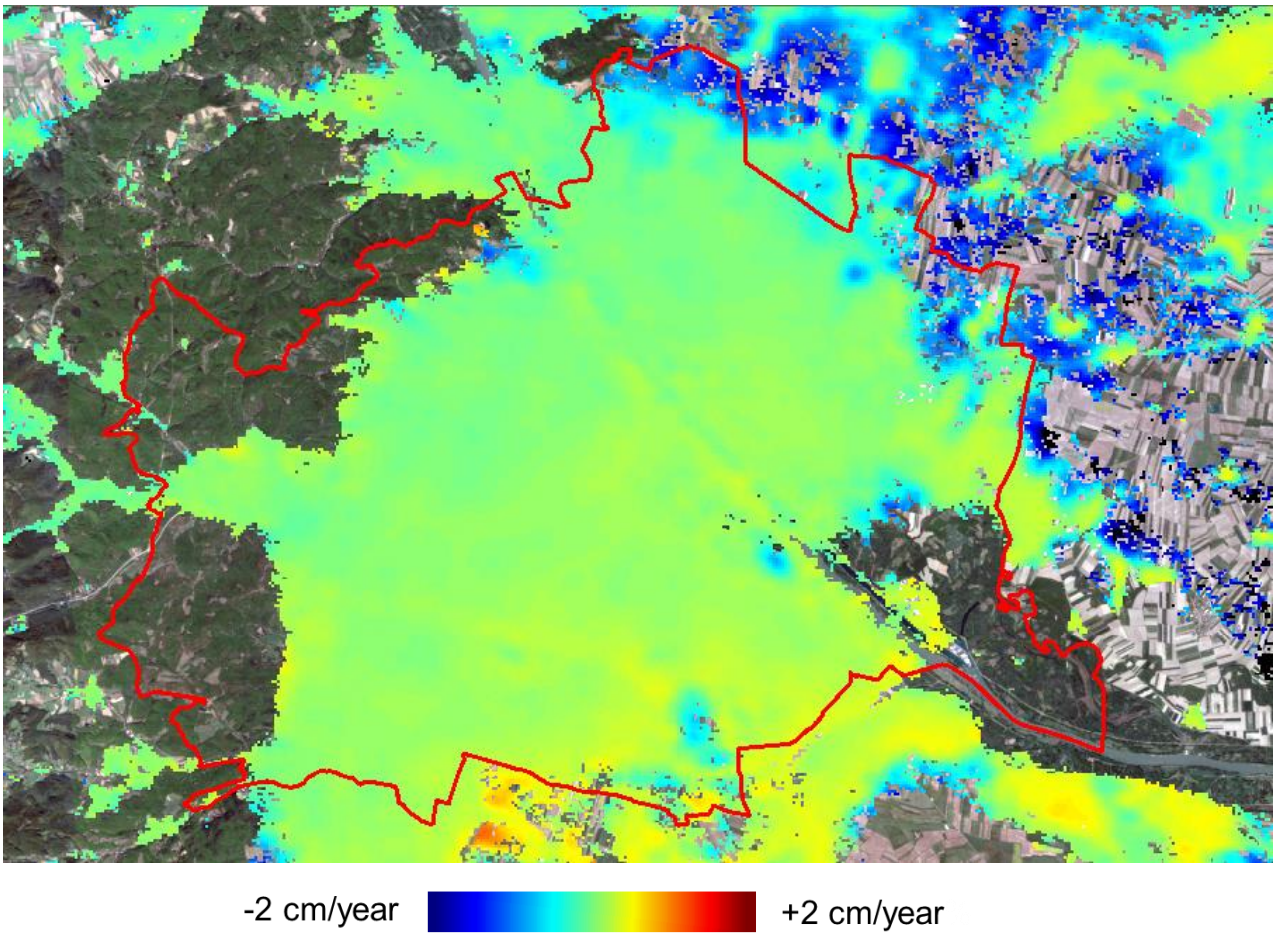
I. Techniques referred to as persistent scatterer interferometry (PSI), that work on dominant localized targets (i.e. persistent scatterer – PS) by operating on single-look interferograms generated with respect to one reference scene.

II. Techniques referred to as small baseline interferometry (SBI) that investigates the extended targets or distributed scatterers (DS) by generating a network of interferograms characterized by a small spatial and short temporal separation or baseline. Additionally, a two-step variant exploiting the full single-look resolution was developed.

SuLaMoSA will introduce for the first time in Austria a national monitoring service regarding subsidence and landslide mapping based on D-InSAR-technologies. It will deliver unprecedented homogeneity of deformation products with an update rate of few weeks down to couple of days. Based on systematic utilization of Sentinel-1 data the service will guarantee consistent products for a very long period of time.

In a first project phase the user requirements were assessed in a systematic approach, including questionnaires, interviews and a dedicated workshop. The results of this phase constituted a concise user requirements catalogue and design document of the service but also should raise the user awareness of the potential and limitations of the service. In the currently running, second phase a prototype service is developed and installed in the EODC collaborative IT infrastructure. To demonstrate and ensure a maximum quality of the delivered products and results the prototype service will be tested and validated in specific test areas. In the final project phase the service products and results will be presented to the user forum and the user requirements which are met as well as open issues or new research issues will be assessed in a workshop.

The user requirements workshop held at GBA premises last autumn for sure was the first highlight within the SuLaMoSA project. But also the presentation of the project at various conferences, workshops and forums already raised awareness of the SuLaMoSA service and a better understanding of the applicability of the D-InSAR methods in general. This is also manifested in several enquiries extending from support to master theses to requests for consulting to anticipated feasibility studies and “real” application projects



Preliminary mean deformation rate for Vienna

Space Robotics Vision / Space Science & Exploration

D) ExoMars PanCam 3D Vision

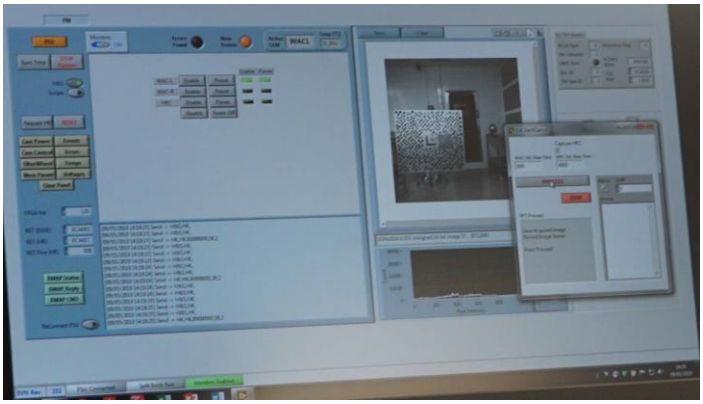
The joint ESA/Roscosmos ExoMars Rover Mission is scheduled for launch in Summer 2020 and landing on the Red Planet in early 2021 to search for signs of past and present life on Mars. One important scientific sensor is a panoramic imaging system (PanCam), mounted on the Rover Mast. It consists of a wide 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.

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 2019 such processing was 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. Camera calibration of the PanCam Proto Flight Model (PFM) was finalized in 2019 (Figure (1)), both for the intrinsic and extrinsic

parameters, including pointing parameters w.r.t. the Rosalind Franklin Rover's robotic pan-tilt device.

Quality estimation of the expected results and the interfaces to other mission elements and instruments such as operations planning, rover navigation system and global Mars mapping or fusion with data from the WISDOM ground penetrating radar and the CLUPI Close-Up Imager are other specific elements of the current work. 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 is supporting in terms of scientific exploitation, with emphasis on impact structures (e.g. meteorites, shatter cones). Large parts of the work in 2019 were dedicated to testing in realistic environment.

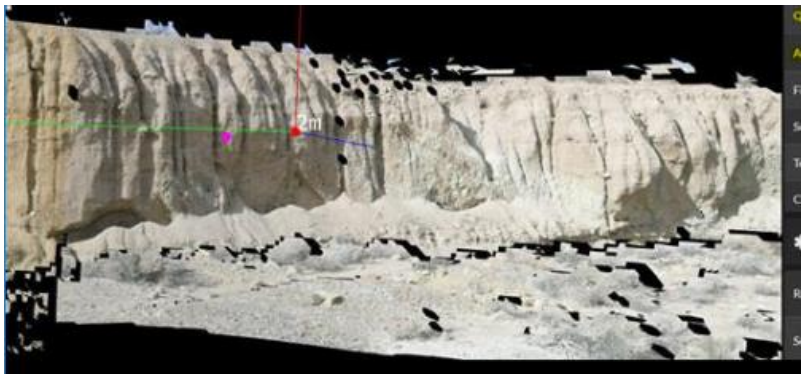
Piluca Caballo from JR performing PanCam PFM calibration



EGSE (Electronic Ground Support Equipment) by MSSL displaying the PanCam calibration target as seen from PanCam. Credits: UCL/MSSL

Mastcam-Z 3D Vision

The NASA Mars 2020 mission will launch the *Perseverance* Rover – similar to the currently operational Mars Science Laboratory Rover *Curiosity* – to undertake the next key steps in our understanding of Mars' potential as a habitat for past or present life. Among other instruments, Perseverance will carry Mastcam-Z, a stereoscopic zoomable multispectral camera coordinated by Arizona State University. In the frame of an ESA PRODEX Contract, JOANNEUM RESEARCH and VRVis are developing 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 in 2021 and 2022. In 2019 the components underwent thorough testing using breadboard equipment in representative environment (Figure (2)), and Mastcam-Z Flight Model (FM) geometric calibration was supported.



JOANNEUM RESEARCH (G. Paar) capturing field data in Mojave Desert (US) using Mastcam-Z emulator MAZE by Arizona State University.

PRo3D visualization of 3D reconstruction using PRoViP 3D vision pipeline.

Panorama gained by PRoViP. Credits: Arizona State University

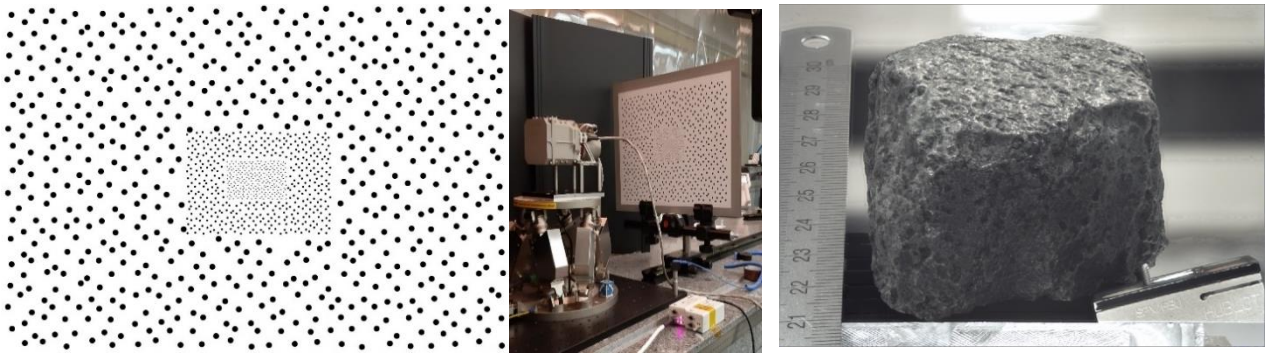
a. ExoMars NavCam/LocCam 3D vision processing

The ExoMars-2020 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 being 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. In Spring 2019, testing of the components was accomplished using the GEPE (Geometric PanCam/NavCam Emulator, developed by JOANNEUM RESEARCH) in Mars-analogue environment (Figure (3)).

Geometric PanCam/NavCam Emulator GEPE by JOANNEUM RESEARCH, deployed in Mars-analogue environment (MTS: Mars Terrain Simulator at ALTEC / I) used for testing and validation of the NavCam/LocCam processing chain. Credits: ALTEC/TAS-I/ESA

b. ExoMars CLUPI geometric calibration

The ExoMars CLUPI Instrument is a camera system designed to acquire high-resolution, color, close-up images of outcrops, rocks, soils, drill fines and drill core samples. To employ CLUPI in a wide range of distances, the instrument employs a dedicated focus mechanism. In 2018, JOANNEUM RESEARCH had implemented the flight system- as well as autofocus-algorithms for CLUPI. To provide a perfect mapping between the images in 3D coordinate space, as well as for seamless combination of images with different focus settings to a fully focused image ("z-stacking"), precise geometric calibration is necessary. JOANNEUM RESEARCH together with ESA and the CLUPI PI-team from the Space Exploration Institute (SEI) of CH performed CLUPI calibration end of June 2019. A triple-scale calibration target was designed with a dimension of 420x297 mm (Figure (4), left). Different sizes of its dots were calculated considering the sensor FOV and the different spatial resolutions at its working distances on Mars. Geometric calibration used different placements and poses of the calibration target (Figure (4), middle) and the DIGROS geometric calibration software chain by JOANNEUM RESEARCH to determine intrinsic parameters (focal length, principal point and distortion parameters) for more than 40 CLUPI focus settings. The results were validated using a test object captured with 16 different focus settings, resulting in one single fully focused z-stacking image (Picture 97).



CLUPI geometric calibration target, consisting of three different resolution layers to cover very close range to medium and large range.

The CLUPI instrument being calibrated at ESA/ESTEC in June 2019.

Test object (Martian meteorite) assembled as z-stacking from 16 differently focused images. Credits: ESA / SEI

c. ExoFit Processing & Data Archive Support

In parallel to the developments on-going within the ExoMars programme, field testing activities are considered necessary to prepare for the rover surface operations, in particular in terms of science and remote control aspects. The ExoFit study (*Exomars-like rover and science operations simulation through field-trials*) aims at bringing the experience of ESA and industry in such field tests to the next level in preparation to the mission.

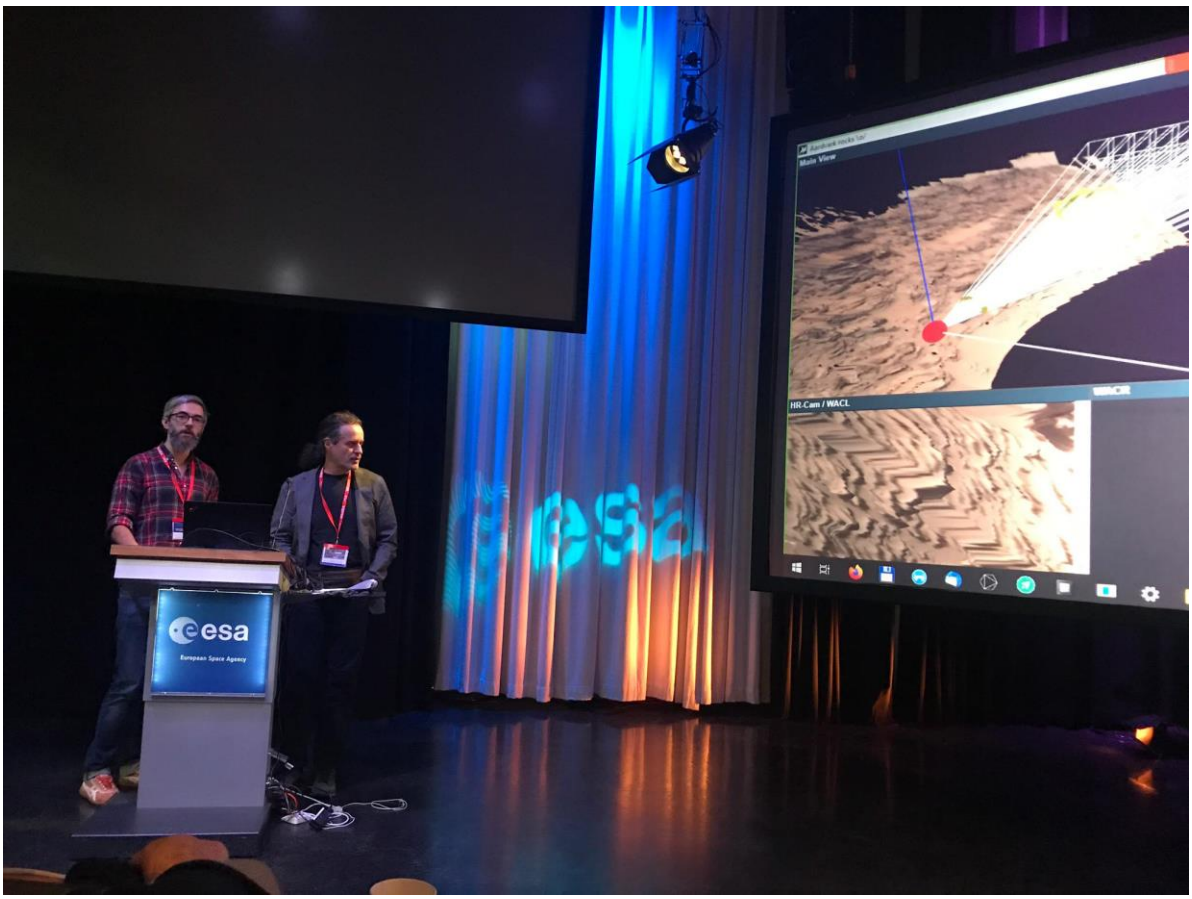
ExoFit equipped a representative breadboard of the ExoMars Rover *Rosalind Franklin* with field-ready replicates of ExoMars science and engineering instruments of varying maturity. JOANNEUM RESEARCH within ExoFit was responsible for the 3D vision processing of the PanCam scientific panoramic stereo camera instrument, as well as the NavCam engineering stereo camera. During the field trials (October 2018 in Tabernas, Spain, and February 2019 in Atacama desert, Chile) image data captured by these instruments within the operational chain was uploaded to a processing server at JOANNEUM RESEARCH premises in Graz, Austria, being automatically processed into 3D vision products, and made available for download within minutes by the Rover Operations Centre located in Harwell, UK, where further planning based on such data took place.

As a long-term vision, intended to be beneficial both to ExoMars and to future ESA exploration missions, JOANNEUM RESEARCH prepares the ExoFit science data sets to support future field surveys, field trials, simulated datasets and eventually planetary measurements to be used by organizations conducting simulations of mobile robots in “off-road” terrain in future.

d. MINERVA

MINERVA is a framework for a collaborative, holistic planetary science data infrastructure access & analysis to allow members of different space exploration instrument teams to cooperate synergistically in virtual workspaces by sharing observation information and by analysing and annotating the data. Its interoperable and collaborative components include an interactive 3D Viewer with 3D-GIS functionality, a database that maintains the knowledge about spatiotemporal data products’ relationships, and a visual analytics platform that will help find new interconnections between the data coming from different instruments to discover new modes of scientific exploitation. MINERVA will be usable for ExoMars, where it will enable new ways of analysing the wealth of heterogeneous data. MINERVA used major portions of the MSL mission instrument data archive to demonstrate its ability to display a full mission’s data

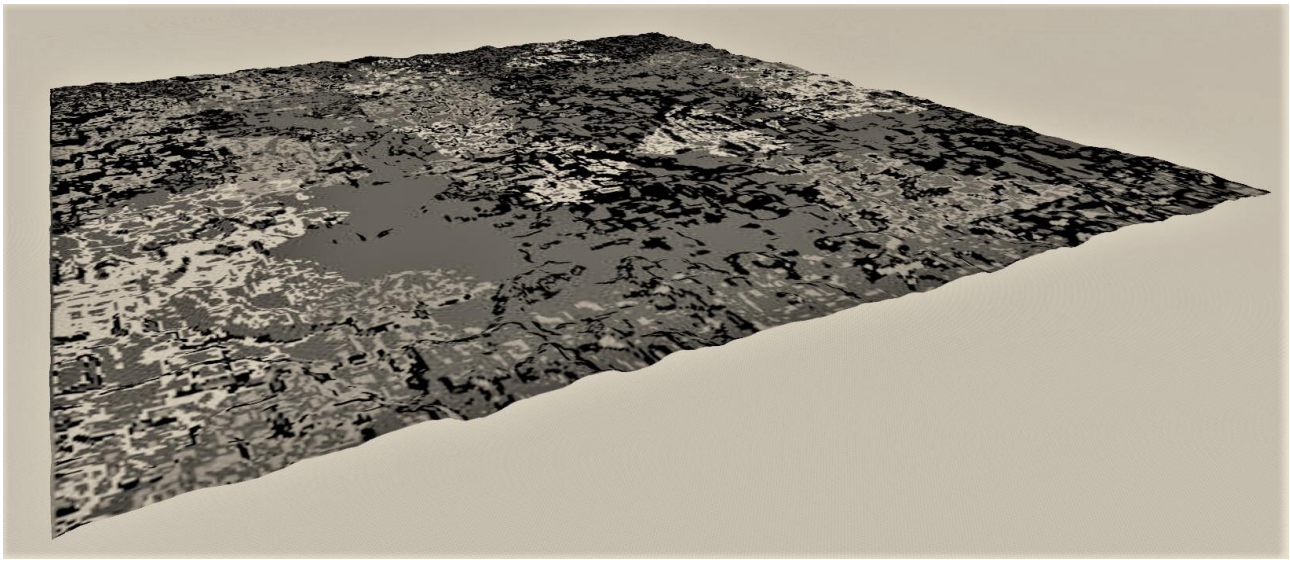
set in 3D GIS environment, with the ability to combine instrument data by visual analytics methods. The framework was demonstrated at the ExoMars Science Working Team Conference on Dec 17th, 2019 at ESA/ESTEC (Figure (5)).



MINERVA demonstrated by VRVis (T. Ortner) and JR (G. Paar) at the ESWT at ESA/ESTEC, Dec. 17, 2019

e. Sample Fetching Rover Phase A/B1

The Mars Sample Return (MSR) series of exploration missions to our outer neighbour planet will start with the Mars 2020 Mission Rover Perseverance, designed in 2021 to collect samples at promising locations, cache them within sample tubes and dispose them on the Martian surface. A European Rover (SFR: Sample Fetch Rover) will fetch them later in the coming decade to bring them back to a Mars Ascent Vehicle that will bring them back into Earth Orbit for further capturing and analysis on Earth. SFR in 2019 underwent its preliminary design phase, trading-off various locomotion options, which require a concise analysis of the envisaged Mars 2020 landing site (Jezero Crater, which is interpreted to have hosted a deep lake in former Martian days). JOANNEUM RESEARCH in 2019 was embedded in the SFR development team under Airbus D&S lead, being responsible for the analysis of the Mars 2020 landing site morphology. Beside simulations of possible Rover paths in the landing site area, the compilation of a synthetic reference terrain (Figure (6)) took place, which will allow fully-synthetic tests to be executed by the rover development team at Airbus D&S.



Simulated reference terrain (100*100m patch), reproducing morphologic statistics of the JEZERO landing site as planned for the Mars 2020 Rover mission. It is being used for the design of the Sample Fetch Rover by the UK entity Airbus D&S. The differently colored areas are different types of terrain (e.g. bedrock, loose soil, firm regolith, …)

Outlook

In summer 2020, both ExoMars and Mars-2020 are designed for launch. Further testing of processing and visualization assets will be elaborated by JOANNEUM RESEARCH, VRVis and the Vienna Museum of Natural History, fostering the applicability and integration of the solutions in mission environment and for training. 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. In 2019 the Horizon 2020 SPACE Project “ADE” (Autonomous Decision Making), dealing with Rover autonomy in terms of navigation, planning and science autonomy, has been launched under GMV (E) coordination for a 24 Months’ period, with relevant contributions by JR in terms of field trials definition, ground truth provision, and test assessment in late 2020. In terms of a further mission involvement, JR and Austrian Partners have started their developments for tactical 3D reconstruction for the HERA Asteroid mission to support the spacecraft’s rendezvous with the double Asteroid system Didymos – 2020 will settle the main technologic background for 3D vision processing, simulation and tools for scientific visualization. Following up for ExoFit, during 2020 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 2019: 3.4 MEUR

ESA Share: 1.6 MEUR

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3.10 MAGNA STEYR Aerospace

Magna Steyr Aerospace is producing propellant lines for more than 25 years for customers all over the world. Hereby the focus lies on development and manufacturing of compensation elements which are necessary to compensate linear and angular deflection of respective propellant line parts.

Ariane 5
MAGNA STEYR - Aerospace has produced the cryogenic fuel lines for Ariane 5 for 25 years. This was celebrated with melancholy in November 2019 with the delivery of the last flight hardware, see picture of the MAGNA Ariane 5 team.

Magna-Steyr Ariane 5 Team

Vega E
Magna started a collaborative work with AVIO on the engine lines of the methane/oxygen powered engine for the upcoming launcher Vega E. In 2019, the overall engine design is converging to a preliminary design status which meets the challenging requirements of the new upper stage engine.

Vega E (Source: ESA)

SLS (Space launch System) – Flexible Joints
The project Flexible Joints is a production project for The Boeing Company. In the first lot 19 flexible Joints are to be produced for NASA´s Space Launch System (SLS). The flexible joints will be directly integrated into the Pressurization Lines, which are also built at MAGNA for Boeing for the second flight.
Depending on their purpose and layout, the flexible joints compensate angular movement of the lines or axial movement of the tank structure in relation to the lines mounted along the core stage. The flexible joints for axial compensation shall be used for the first SLS flight.

The very thin sheets for the plies are longitudinal welded at MAGNA by a new developed Laser beam welding process. The Bellow for the flexible joints is manufactured from multiple plies and hydroformed at MAGNA. The complete assembling and testing (incl. qualification testing) is made by MAGNA.

Space Launch System (Source: NASA)

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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
- Defence
-

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
- Defence Sector
- Strategic Industry
-

Our offices

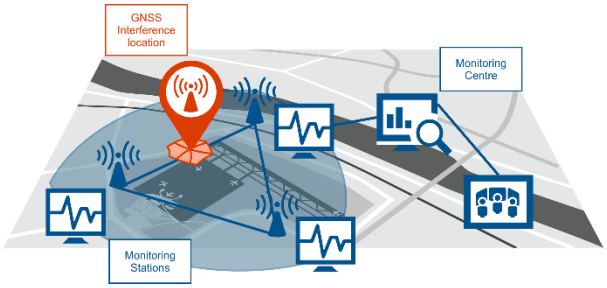
Head Office Address Graz:
OHB Digital Solutions GmbH
Rettenbacher Straße 22
8044 Graz
Austria

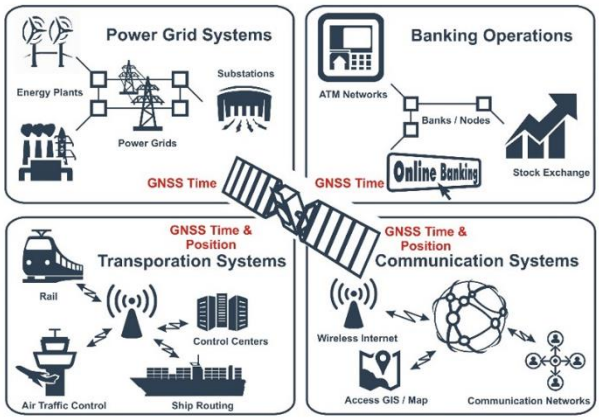
Branch Office Address Vienna:
OHB Digital Solutions GmbH
Lothringerstraße 14/3
1030 Vienna
Austria

Project Highlights in 2019

GIDAS – GNSS Interference Detection & Analysis System

OHB Digital Solutions GmbH develops systems for monitoring the GNSS frequency bands as well as detection, classification and localization of intentional or unintentional interference sources.





Many stakeholders and applications as well as critical infrastructure providers rely on GNSS to provide their services. Since Global Navigation Satellite Systems (GNSS) are widely used in safety and value critical applications, **GIDAS** detects, classifies and localizes any GNSS interference signals and thus reduces the already existing threat of receiving worse GNSS accuracies or even denial of GNSS service.

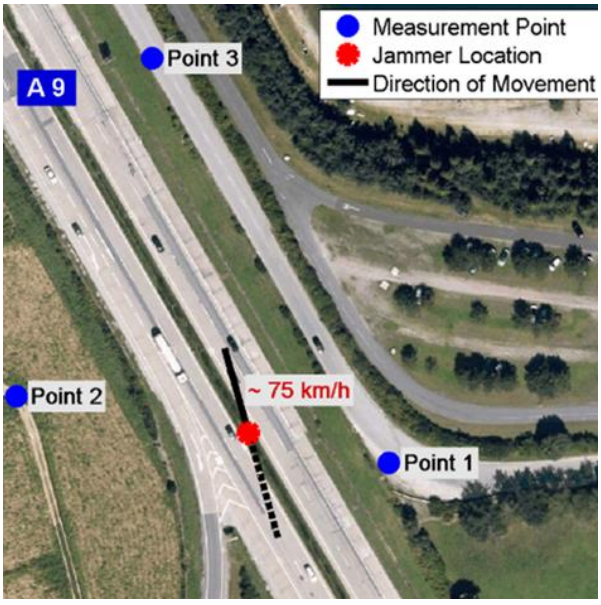
GIDAS considerably improves save and robust operation of GNSS receivers, terminals, and GNSS-based applications by offering the capabilities for reliable detecting, classifying and localizing GNSS jamming and spoofing attacks in real-time.

GIDAS addresses private companies and public / governmental authorities, which are involved in

- regulate safety critical infrastructures and/or operations
- operate safety critical infrastructures and/or operations
- operate systems or services where global navigation satellite system (GNSS) is key to achieve a required high quality of service (QoS)

GIDAS is a scalable real-time GNSS Interference Detection & Analysis System, used as a standalone monitoring station for interference detection and classification. The system can be upgraded to a more complex network of standalone stations, which allows interference localization in addition. The product offers the following main features.

- Real-time GNSS signal monitoring (detection, classification and localization)
- Reliable, configurable, flexible, scalable and joinable system
- Multi-signal band monitoring
  - GPS: L1, L2 and L5
  - Galileo: E1 and E5
  - GLONASS: G1 and G2
  - BeiDou: B1 and B2
  - SBAS and regional systems on L1 (e.g. EGNOS, QZSS)
- GNSS interference detection (jamming, spoofing including automatic alarm generation)
- Classification of GNSS interference signals
- Analysis and comparison of interference events in post-processing
- Easy adaptable to new upcoming signals and systems
- User definable as well as predefined (e.g. ICAO, RTCA) threshold masks
- Graphical user interface and network solution

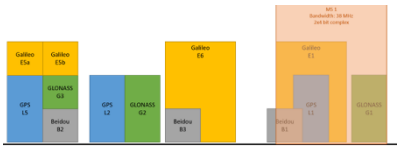


GIDAS will support both, safety critical and mission critical GNSS applications. Depending on the users´ needs and requirements three different main target areas are foreseen:

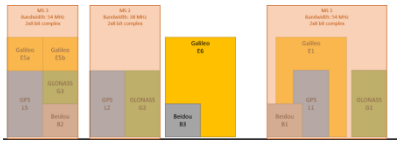
1. Static (regional) GNSS interference monitoring for safety critical GNSS applications with high demanding interference monitoring requirements
2. Static (regional) GNSS interference monitoring for safety critical GNSS applications with less demanding requirements
3. GNSS interference monitoring for mission critical (dynamic) GNSS applications

Four example configurations of **GIDAS** are possible for individual requirements:

- Single frequency wideband monitoring (high signal dynamics)
- Multi-frequency narrowband monitoring (low signal dynamics)
- Multi-frequency wideband monitoring (high signal dynamics)
- Multiple monitoring stations, either narrow- or wideband for localization



Single frequency - Narrowband



Multi-frequency - Wideband

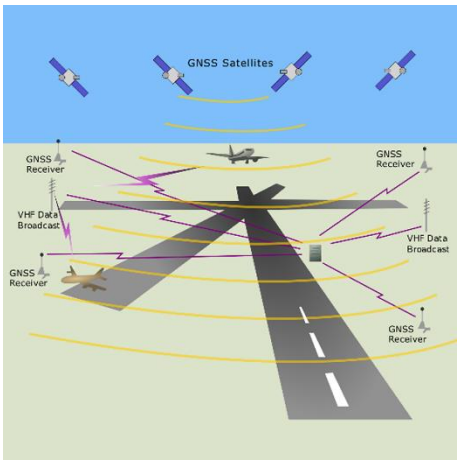
Even small interruptions of GNSS can cause severe damages. **GIDAS** helps you to make your GNSS application more robust and reliable.

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

GNSS Quality Assurance

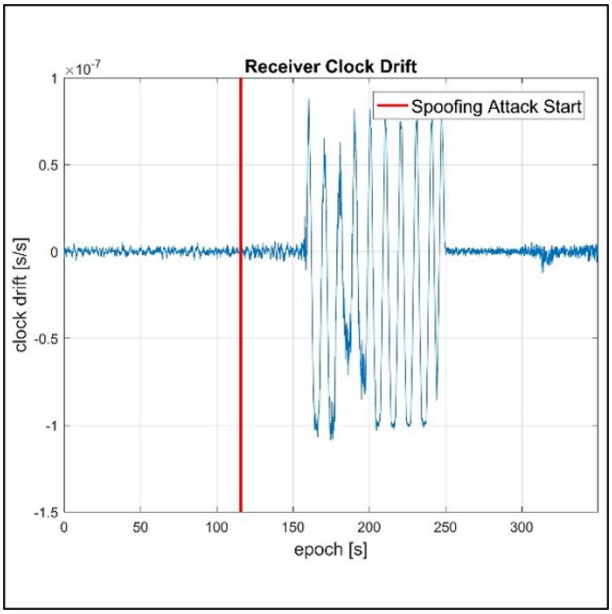
OHB Digital Solutions GmbH provides services for quality assurance for your GNSS data.
If you have a need for an effective quality assurance system for GNSS-based positioning, navigation or timing services (safety critical applications, aviation or maritime control, time-synchronised networks, deployment systems, …) these services are indispensable.
Many applications, systems and users rely on GNSS (GPS, Galileo, GLONASS,…) signals. GNSS failures or distorted GNSS signals can cause severe problems.
OHB Digital Solutions is capable of detecting problems of such kind (and beyond that) and thereby facilitates appropriate reactions by customers.
In concrete terms problems of such kind can be avoided and / or brought under control more quickly by

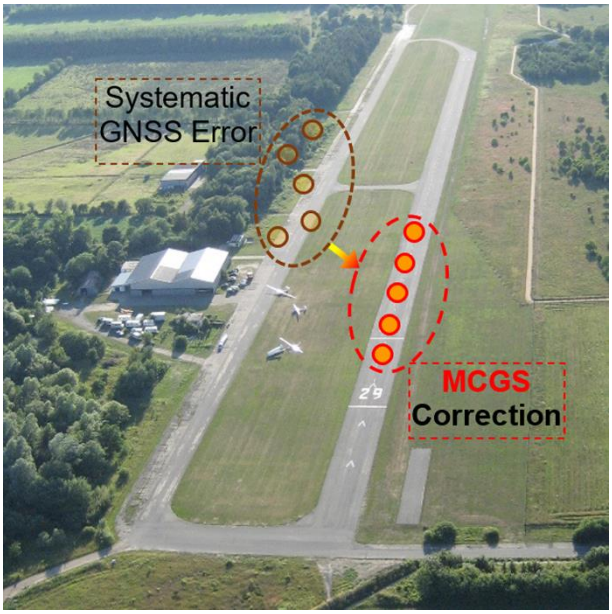
- Sweeping receiver tests beforehand
- Deployment of relevant GNSS-monitorings



Services for quality assurance of your GNSS data comprise efficient system implementation based on a multi-stage model, which is specifically tailored to the respective customer application and users´ needs.

Our initial approach is to identify the potential risk and contingent implications. Part of this stage is the thorough testing of GNSS receivers and the corresponding documentation by means of the **GIPSIE®** – GNSS Multisystem Performance Simulation Environment. The result of this activity is a detailed understanding on the performance of specific GNSS receivers under well-defined circumstances at the customer site.
Based on this findings, OHB Digital Solutions can implement a real time GNSS interference monitoring (**GIDAS** – GNSS Interference Detection & Analysis System) for comprehensive GNSS quality assurance. This monitoring can reliably detect, classify and localise jamming and spoofing attacks, generate automatic reports, send alert messages and facilitate a detailed analysis in post processing.





The so installed GNSS quality assurance system enables users to monitor GNSS measurements and raw data (IF signal) as well as test quality, authenticity and performance of GNSS signals in real time. This can be used by the customer to take appropriate measures.

CONTACT

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Digital Solutions

Turnover 2019: 1.7 MEUR
ESA Share: 0.6 MEUR

3.12 RUAG Space GmbH

RUAG Space GmbH (RSA) belongs to the Swiss RUAG Group since 2008. The company is part of the RUAG Space Division, which employs some 1.300 people in Switzerland, Sweden, Austria, Finland, Germany and USA, thus forming the largest independent space product supplier in Europe. RSA, with 250 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.

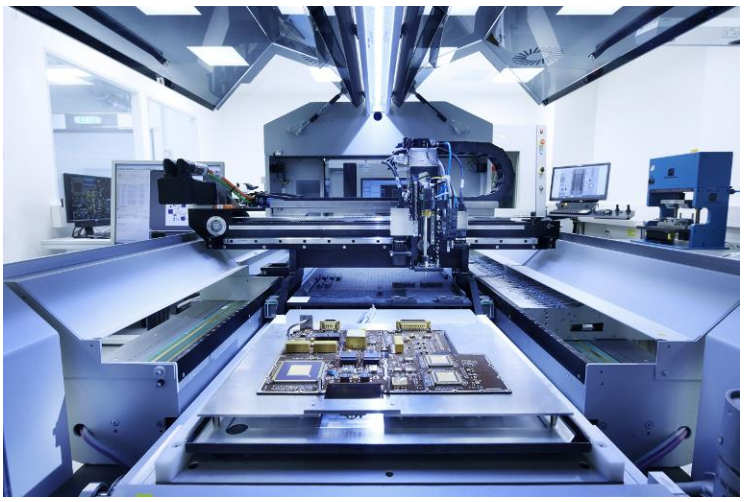


Products of high strategic importance for RSA are Global Navigation Satellite System (GNSS) Precise Orbit Determination (POD) Receivers. GNSS POD uses high-quality carrier and code measurements of a dual-frequency receiver on-board of a satellite, to achieve measurement of its position with an accuracy of a few centimeters in on-ground processing. As of December 2019, 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 36 flight models could be booked until end of 2019, and 26 units have been delivered already. The new receiver will fly on the German SARah military reconnaissance satellites developed by OHB as well as on the Sentinels 1, 2, 3 C&D and Sentinel-6.

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 good market position also outside Europe.



Automated assembly of Navigation Signal Processor

The development of lower cost GPS & Galileo single-frequency receivers for low earth orbit (LEO) as well as geo-stationary (GEO) satellites has been completed. LEO Receivers were delivered to customers in the US and in South Korea already. Additional units, currently in various stages of assembly and test, will be used by customers in Europe, the US and the United Arab Emirates. 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.

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 2019.

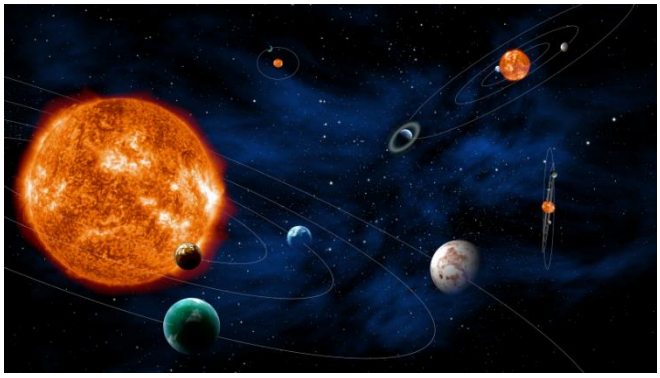
In the frame of the Meteosat Third Generation (MTG) program, carried out by ESA on behalf of EUMETSAT, all Flight Model (FM) activities were completed and most of the units delivered. This includes the Solar Array Drive Electronics, the Antenna Deployment and Pointing Mechanism Electronics, electronics 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.

MTG Solar Baffle Cover during assembly and quality inspection

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). A number of FMs were delivered in 2019.

Important new contracts concern PLATO, the PLAnetary Transits and Oscillations of stars mission of ESA, will 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 as well as electronics modules for a Remote Terminal Unit.

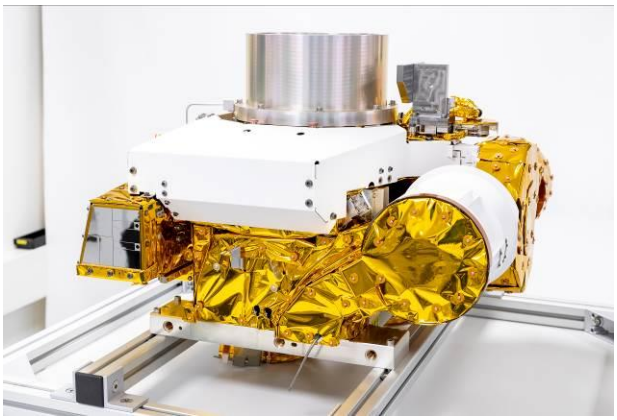


Searching for exoplanetary systems with PLATO (source: ESA)

In a strategic cooperation with TTTech a very promising development of high-performance data network space electronics has been initiated. The jointly offered products are based on the Time-Triggered Technology invented by TTTech. First contracts from a US customer in the frame of the NASA Gateway development are expected for next year.

In the product segment Mechanisms, assembly of the second 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 completed. The first set, delivered end of 2018, in the meantime has been integrated in the propulsion system of the all-electric EUTELSAT KONNECT satellite, which will be launched beginning of 2020 and provide broadband services

to Europe and Africa. In a further contract the development of a Thruster Orientation Mechanism for the Electra platform of OHB has been continued.



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

The dominating contribution to the 2019 sales in the mechanical area came from the completion of the Mechanical Ground Support Equipment (MGSE) for integration and transport of the OneWeb satellites. This activity is the biggest MGSE contract in the history of RSA so far.

Transport Containers for OneWeb satellites

Sales of thermal insulation products reached more than one third of total RSA sales. Significant contributions came from the ESA projects Ariane 6, Juice, Solar Orbiter, Metop Second Generation and MTG. Solar Orbiter is of particular interest, because, for the first time, RSA had the responsibility for a complete subsystem.

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 introduced in the already completed Iridium NEXT program.

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 order to optimize the production flow for launcher insulation, which requires the processing of special materials withstanding extremely high temperatures, a dedicated area in a new extension of the Berndorf facility became operational in September. The opening ceremony was attended by high-ranking political and ministry/agency representatives. A special media briefing together with ALR and RUAG management resulted in excellent media coverage of the event.

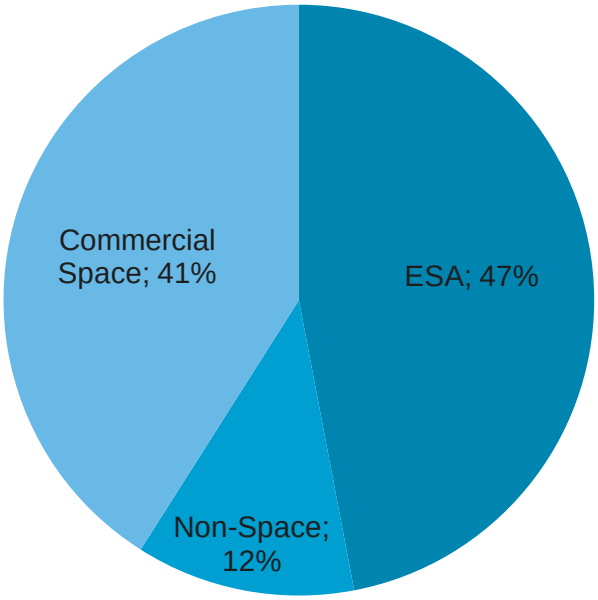
Opening ceremony in Berndorf faciltiy extension

Sales in the area of cryogenic insulation for terrestrial applications, a spin-off of the company's space business, remained stable in 2019 and contributed 12% to the total company sales.

The year 2019 brought a number of satellite launches with key RSA contributions on board. The highlight certainly was the launch the CHaracterising ExOPlanets Satellite (CHEOPS), developed under the direction of the University of Bern and ESA, on a Soyuz-Fregat from Kourou on December 18. RSA delivered the electronics for the high-precision power supply of the optical sensor in the CHEOPS telescope and the heating elements required for stabilization of its temperature. Together with the data processing electronics, developed and built by the Space Research Institute of the Austrian Academy of Sciences in Graz, this forms the so-called back-end electronics.

CHEOPS liftoff on December 18

Total RSA sales declined by 17% compared to 2018, due to a lack of development workload from major new institutional programs. The non-ESA share reached 53%.



Sales 2019: 45.7 MEUR
ESA Share: 21.4 MEUR

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3.13 Seibersdorf Labor GmbH

SPACE ACTIVITIES

SEIBERSDORF LABORATORIES

Seibersdorf Labor GmbH, offers high-quality laboratory analyses and measurement technology under the brand name Seibersdorf Laboratories with 140 employees and is located on the Tech Campus Seibersdorf. Seibersdorf Labor GmbH is a subsidiary and spin-off of AIT Austrian Institute of Technology GmbH, a commercial service provider for industry, medicine, national and international organisations, founded in 2009.

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 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 2019:

AVIDOS	Aviation dosimetry service in space weather context
^{2}CAMRAD	Two components additive manufacturing for space radiation dosimeter
PRETTY	Passive reflectometry and dosimetry on-board CubeSat space mission
CORHA	Radiation screening of COTS components and verification of COTS radiation hardness assurance approach

Seibersdorf Laboratories maintain EN ISO IEC 17025 accredited space radiation testing using the **TEC-Laboratory** at the Tech Campus Seibersdorf for testing of electronic components and systems.

Seibersdorf Laboratories organised 2019 the **4th RADHARD Symposium** with topics on:

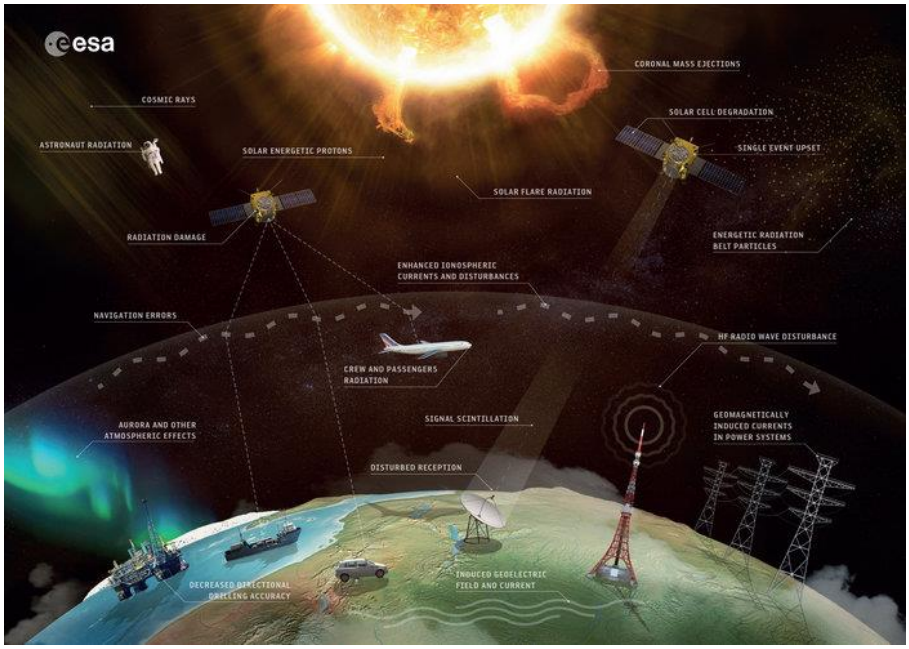
- SmallSats and COTS Components
- Practical Aspects of Radiation Hardness Assurance
- Innovative Testing Developments and Future Needs

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

AVIDOS - AVIATION DOSIMETRY SERVICE IN SPACE WEATHER CONTEXT

Introduction

The term space weather refers to environmental conditions in Earth's magnetosphere, ionosphere, and thermosphere, as well as on the sun and in the solar wind that can influence the functioning and reliability of technological systems in space and on the Earth or endanger human health. Radiation is a natural part of our environment and therefore its presence and levels are part of space weather. Galactic Cosmic Radiation (GCR) coming from outside of our solar system has the greatest influence on radiation environment at aviation altitudes. However, Solar Cosmic Radiation (SCR) coming from our sun cannot be neglected due to possible effects of occasional solar phenomena like solar flares or coronal mass ejections (CME). Some of these solar events may affect Earth and lead to temporary enhanced radiation levels in atmosphere or even on ground – so called Ground Level Enhancements (GLE). Therefore, for a careful assessment of radiation exposure during such events a real-time aviation dosimetry service is required. Nowcasting and forecasting of space weather induced radiation environment in Earth's atmosphere is of great importance for research, governmental organizations, and aviation. The World Meteorological Organization (WMO) together with International Civil Aviation Organization (ICAO) recognized that space weather effects have critical impacts on aviation. WMO and ICAO launched a process to select and designate centres providing space weather information services in support of international aviation business.

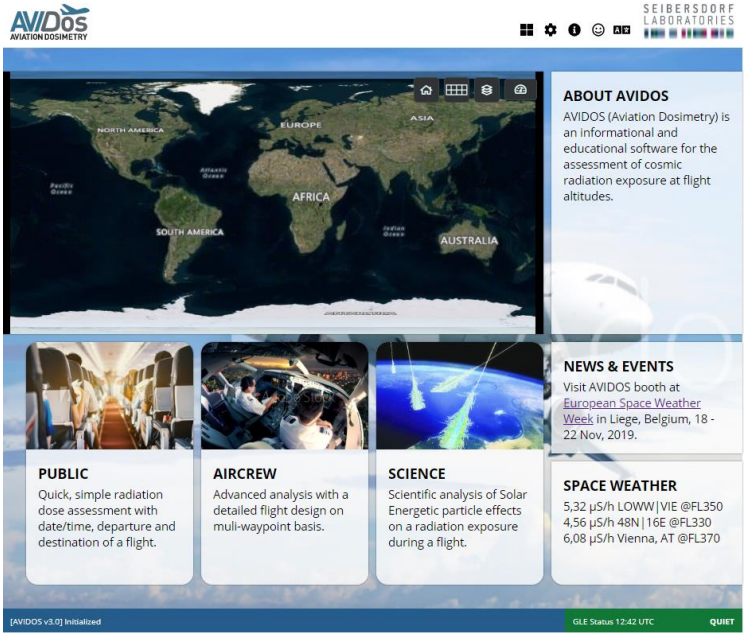


Cosmic rays from outer space impinge on Earth's atmosphere, and by nuclear interaction produce a shower of radiation composed of photons, protons, electrons, neutrons, muons and other particles.

Methods and Results

Seibersdorf Laboratories is a key player of the European Expert Groups that form Radiation Expert Service Centres (R-ESC) within ESA's Space Situational Awareness (SSA) Programme in the segment of Space Weather (SWE). Seibersdorf Laboratories provides the public with the real-time aviation dosimetry service AVIDOS federated with ESA's Space Weather portal (http://swe.ssa.esa.int). AVIDOS is an informational and educational online software to increase public awareness of space weather and its effects at aviation altitudes. In 2019, Seibersdorf Laboratories continued maintaining the availability of the AVIDOS 2.0 at the ESA's SWE portal (http://swe.ssa.esa.int/web/guest/avidos-federated), supported the ESA's Space Weather Coordination Centre (SSCC) with expert knowledge on space radiation at aviation altitudes and operation of AVIDOS, and contributed to the development of R-ECS network.

Following advancements in web technologies and planned evolution of the ESA SWE portal, we are improving AVIDOS availability and user experience. The first, pilot phase has been concluded in 2018. In 2019, we continued that effort aiming at a new version AVIDOS 3.0 available at the ESA SSA SWE portal in the next years.



A snapshot of the AVIDOS 3.0 graphical user interface as developed for the AVIDOS 3.0.

In 2017, the International Civil Aviation Organization (ICAO) issued a State Letter requesting for interest in providing a space weather information service to support international air navigation. Seibersdorf Laboratories is part of PECASUS (Pan-European Consortium for Aviation Space weather User Services) consortium that has been formed to respond to the ICAO call. In autumn 2018, the ICAO council designated PECASUS as one of the three global space weather information centers. In 2019, Seibersdorf Laboratories conducted preparatory works and started 24/7 provision of customized aviation dosimetry services in accordance with the requirements formulated by ICAO.

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.

^{2}CAMRAD - TWO COMPONENTS ADDITIVE MANUFACTURING FOR SPACE RADIATION DOSIMETER

Introduction

Radiation dose assessment in mixed radiation fields requires complex instrumentations such as tissue-equivalent (TE) proportional counters (TEPC). For a construction of such instrument, conductive and insulating materials, both tissue-equivalent, are required. For conductive parts with TE properties, one typically uses an expensive, custom made and poorly available material (A-150) that, however, exhibits undesired physical properties. Moreover, the overall classical construction of such instrument is expensive and mechanically complex. Seibersdorf Laboratories coordinated the ^{2}CAMRAD proof-of-concept that aimed at a two-component additive manufacturing (AM) process based on fused deposition modelling (FDM) to improve construction of a space radiation dosimeter.

Objectives

- To re-design the geometry of a TEPC detector in order to take advantages of two-component AM process for its construction
- To propose and characterize conductive and insulating materials and investigate the applicability of those materials in an two-component AM process to construct a space radiation dosimeter
- To perform initial tests

Method, Results, and Conclusion

The original detector geometry was successfully re-designed to take advantages of two-component AM process. For conductive material, a custom material (A-150) was proposed and characterized. Based on that, for insulating material, polyamide (PA) was proposed. Filaments of both materials were successfully produced. Due to high crystallinity of A-150 its AM processing did not result in satisfactory parts. Instead, the new detector geometry was AM processed using polylactic acid (PLA) (conductive and insulating version) material, which is known for good behaviour in AM process. Initial electrical tests were performed. A further investigation on conductive, tissue-equivalent material that is suitable for two-component AM process is strongly suggested. After construction, radiation tests on an assembled TEPC are planned for a follow-up activity.

Spooled filaments of PA 6 (left) and A150 (right) materials.

Two-component (PLA materials) AM processed TEPC detector.

Acknowledgements

This project was coordinated by Seibersdorf Laboratories and funded by the European Space Agency (ESA Contract Nr. 4000124904/18/NL/CRS). We acknowledge project partners Montan University Leoben (Austria) and HAGE Sondermaschinenbau GmbH & Co KG (Austria).

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. In 2019, Phase B of the PRETTY project was successfully completed with the Preliminary Design Review (PDR) and preparations for the next phase, PRETTY Phase C/D including design finalization, system assembly, and integration were initiated.

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

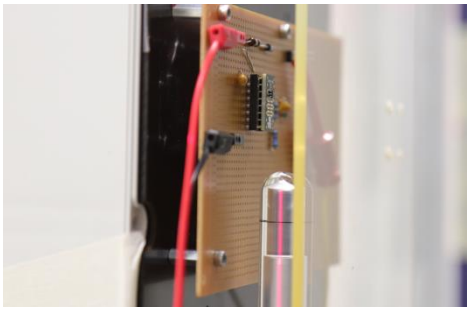
reference dosimeter system based on RADEFT is that we will take into account the fading effect due to temperature fluctuations as well as the ELDRS sensitivity.

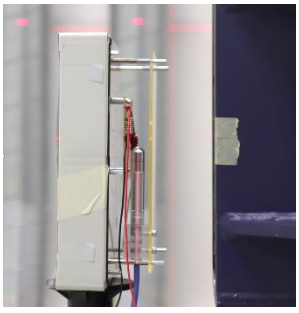
Method and Results

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.





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

During the Phase B study of the PRETTY project, it became evident that the space mission can gain significantly scientific value by improvements to the dosimeter payload. The original baseline of the dosimeter platform contained no dedicated microcontroller, no dedicated

analogue data conversion, and no dedicated data storage. The control of the radiation measurement, the analogue data conversion, and the data storage was assigned to an ADC and the microcontroller on the satellite experimental processing platform (SEPP). In the course of the system development during PRETTY Phase B, it became evident that the tasks assigned to the controller have significant impact on the SEPP processor load. Thus, Seibersdorf Laboratories' dosimeter shall be equipped with a dedicated analogue data conversion, data storage and microcontroller as well as a dedicated communication interface to the on-board computer at a dedicated dosimeter payload board (PCB). This is a major improvement of the PRETTY space mission. The updated concept was successfully approved by ESA during the preliminary design review (PDR).

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. 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 upcoming PRETTY Phase C, the design of the dosimeter will be finalized. Further, we will assemble and test the dosimeter payload and prepare for the launch of PRETTY.

Acknowledgements

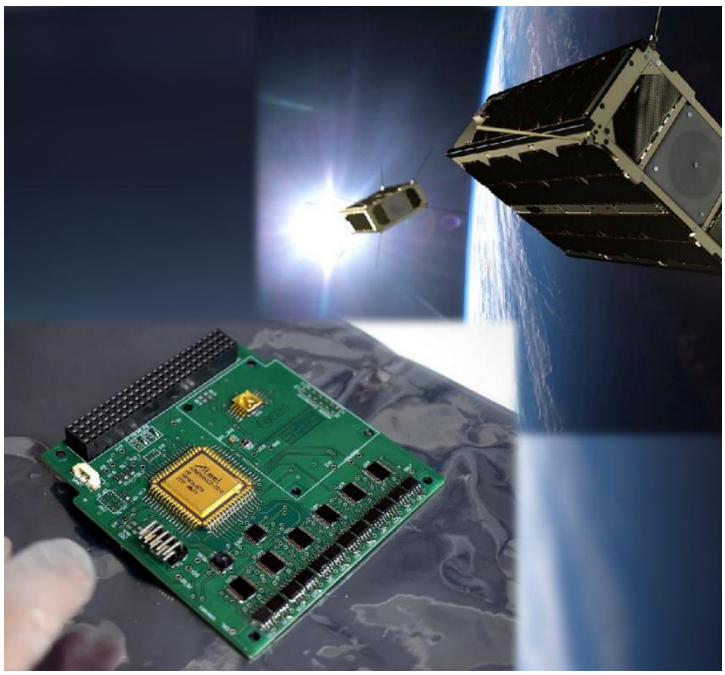
The Phase B study for the PRETTY mission was funded by ESA GSTP Program under the ESA Contract No. 4000121960/ 17/ NL/GLC, coordinated by the European Space Agency (ESA).

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

Introduction

Using COTS offers great benefit 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 ESCC25100.

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.

Summary and Conclusion

Twelve commercially available parts, such as 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.

Acknowledgements

The project was 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 2019

Introduction

On April 9th to 10th, 2019, Seibersdorf Laboratories organized their fourth 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 offer a stimulating atmosphere for technical conversation and initiating new space projects.

The RADHARD-Symposium 2019 focused on:

- Small satellites and COTS Components
- Practical aspects of radiation hardness assurance
- Innovative testing developments and future needs

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.

Photo of the RADHARD 2019 Symposium participants with the TEC Laboratory in the background. The TEC-Laboratory is the Co-60 irradiation facility from the Seibersdorf Laboratories for testing of electronic components.

The RADHARD Symposium 2019 overview

- Two days event
- 40 participants
- One Keynote Presentation by ESA
- Three training lectures on space radiation environment, radiation effects and radiation hardness assurance databases
- Eighth international lectures on practical aspects of COTS in space and radiation hardness assurance testing

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/en/radhard/archive/2019-radhard
Reference: ISBN for print: 978-3-902780-16-4, ISBN for e-book: 978-3-902780-17-1.

Book of abstracts of the 4th RADHARD Symposium on 9th – 10th April 2019

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 2019.

Total share for space project 2019: 0.6 MEUR

Contact

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3.14 Graz University of Technology (TU Graz)

Graz University of Technology focuses on Space experiments and Space technologies and has been active in national and international Space projects since 1969. The current activities by the Institute of Communication Networks and Satellite Communications, the Institute of Geodesy and the Institute of Experimental Physics cover nanosatellite missions, satellite communications, satellite navigation, satellite geodesy and the development of Space-qualified hard- and software.

INSTITUTE OF COMMUNICATION NETWORKS AND SATELLITE COMMUNICATIONS (IKS)

Nanosatellite Missions

OPS-SAT

The highlight of the activities by IKS in 2019 was the successful launch of the OPS-SAT nanosatellite on 18 December on board of a Soyuz-Fregat from Kourou (together with CHEOPS). OPS-SAT is an advanced triple Cubesat which was developed under an ESA contract (within GSTP) by a consortium led by the Institute with partners in Austria (UNITEL, MAGNA STEYR), Poland (GMV and SRC), Germany (MEW Aerospace and BST), Denmark (GomSpace), France and the UK.

After an intensive test and qualification campaign the Flight Acceptance Review took place in summer 2019. The environmental tests (thermal vacuum and vibration) were conducted at RUAG Space GmbH with free-of-charge support by RUAG experts.

OPS-SAT demonstrates and validates new operational concepts which shall be later used on operational ESA missions. Core of the satellite is a very powerful processor with a large Field Programmable Array, developed by the Institute. A variety of hardware and software experiments will be conducted, covering on-board autonomy, attitude control, radio signal monitoring using a software-defined radio receiver, optical data communications and remote sensing with on-board processing using the on-board HD camera. An exciting free-space optics experiment is prepared in cooperation with the Space Research Institute in Graz: cryptographic keys will be sent via the Laser station at the Lustbühel Observatory which can subsequently be used to encrypt the X-band downlink.

OPS-SAT behaves like any other ESA spacecraft and is fully compatible with ESA's communications infrastructure. It is operated by ESOC's ground station with support by the UHF station at TU Graz. OPS-SAT has the highest S-band telemetry uplink data rate of all ESA satellites so far. The X-band transmitter provides very high downlink data rates of up to 50 Mbit/s.

After launch contact was established using the TU Graz and the LeafSpace station in Cork, Ireland. The secondary UHF telemetry is using the amateur radio bands and the very active participation by the amateur radio community world-wide helped significantly in the initial check-out of the satellite.

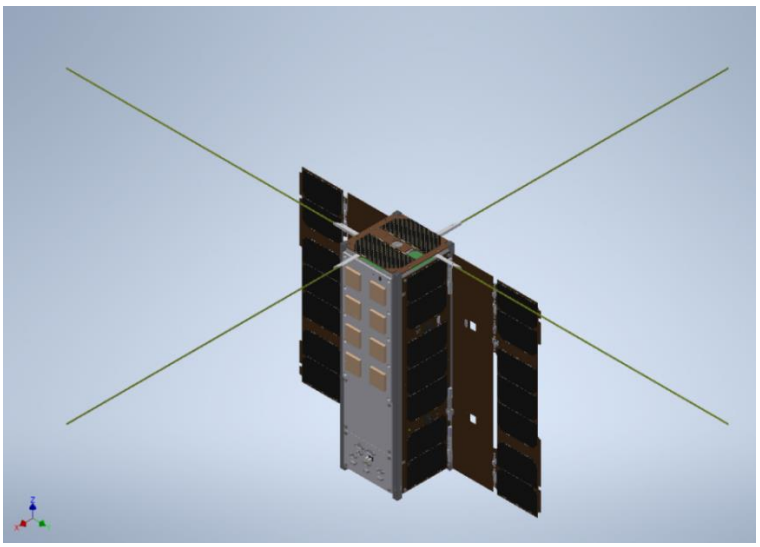
All systems are working properly. After completion of the spacecraft commissioning, the experimental phase starts in 2020.

OPS-SAT Spacecraft

PRETTY (Passive Reflectometry and Dosimetry) is a new nanosatellite mission carried out under an ESA contract in the framework of the GSTP program. Prime contractor is RUAG Space GmbH with TU Graz and Seibersdorf Laboratories as subcontractors. PRETTY is a triple Cubesat, based on the OPS-SAT design, using the Payload Processor and a software-defined front-end developed by the Institute. PRETTY has the purpose to demonstrate and validate passive reflectometry in Space as well as measuring the radiation environment in the LEO orbit.

Correlating direct and ground-reflected GNSS signals provides means for precise altimetry. The altimeter may be used to survey glaciers or the height of sea waves and could thus contribute to climate research using a small, inexpensive payload. TU Graz is responsible for the spacecraft system design and integration as well as the ground segment and operations. The reflectometer experiment and associated software development is under RUAG's responsibility, the novel dosimeter is developed by Seibersdorf Laboratories.

Phase B was successfully completed and Phase C/D/E prepared for start on 1 January 2020.



3D Model of PRETTY

TUGSAT-1/BRITE-Austria

BRITE-Constellation (BRight Target Explorer) consists of five nano-satellites aiming at studying the variability of the brightest stars in the sky. Austria with BRITE-Austria/TUGSAT-1 and UniBRITE, Poland, and Canada contribute to the constellation of nanosatellites which all have been launched into LEO orbits between February 2013 and August 2014. The core scientific objective is to obtain high precision two colour photometry, with a time base of up to 180 days, of stars brighter than 4.5 mag in order to study stellar pulsations, spots, and granulation, eclipsing binaries, search for planets and more.

In 2019 during their 7th year of operations, five years beyond design lifetime, BRITE satellites continued to collect data from selected target stars of high quality, exclusive quantity and typically for up to 6 month per observing campaign. The collective results based on BRITE observations and in the context of other leading space mission, such as NASA's Kepler and TESS, were discussed at the "Stars and their Variability, Observed from Space – Celebrating BRITE Constellation" conference held in August 2019 in Vienna. More than 270 participants from all over the world attended this event which was by far the largest meeting about stellar variability in that year.

Group picture of the conference participants of "Stars and Space" taken on August 8th 2019 at the University of Vienna

In summary BRITE satellites have collected data from more than 650 stars some of those were re-observed each season such as brightest stars in the ORION constellation. Making those among the longest high quality data sets ever obtained from individual stars overall. So far, about 185 publications appeared on BRITE data and the according scientific analysis, 35 in refereed journals including one in Nature Astronomy about the Nova Carina which was covered by BRITE satellites in unprecedented quality and time coverage.

Satellite Communications

The Institute is active in the H2020 project "EO-ALERT" led by DEIMOS (Spain) with OHB Italia, DLR (Germany) and Politecnico di Torino (Italy) as partners. EO-ALERT has the aim to design the next generation of Earth Observation Satellites. In contrast to the traditional data processing strategy, processing of SAR and optical images takes place on board of the satellite in a very powerful processor system. Main applications are the detection of severe weather events and ships. Alerts are generated by the on-board processor and can be delivered globally with a latency of maximum 5 minutes.

The Institute is responsible for the communications system design. Bulk data are delivered via Ka-band or optical terminals using data relay satellites (EDRS) at data rates of up to 1.8 Gbit/s. A communications link emulator has been designed and is currently implemented on an FPGA-based system. It includes also a demonstrator for the alert link via S-band to hand-held terminals or via an INMARSAT-based relay system. The emulator will be integrated in OHB's test bench in 2020.

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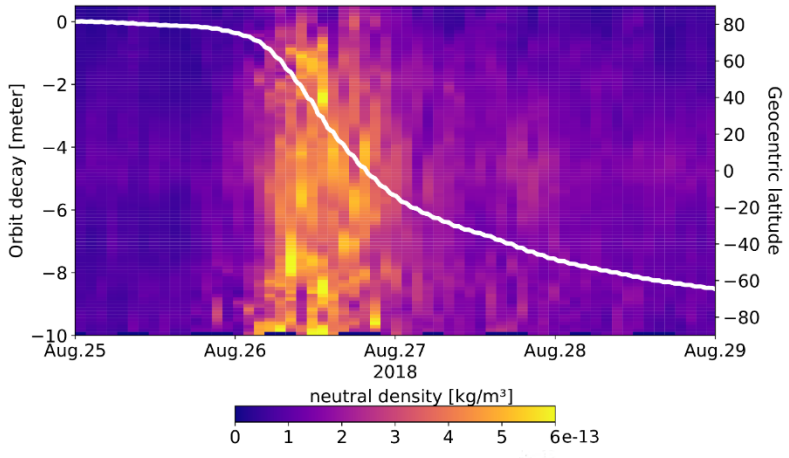
INSTITUTE OF GEODESY (IFG) - WORKING GROUP THEORETICAL GEODESY AND SATELLITE GEODESY

Exploration of thermospheric variations triggered by severe geomagnetic storms

With the successful launch of the GRACE Follow-On satellite mission (GRACE-FO) in May 2018 the opportunity arises to resume the analysis of accelerometer data regarding space weather induced perturbations of the Earth's thermosphere. On August 21, 2018 a complex interplanetary coronal mass ejections (ICME) occurred on the Sun, which subsequently triggered an unexpected large geomagnetic storm five days later. The ICME eruption caused perturbations of the neutral mass density in the upper Earth's atmosphere and led to an additional storm induced orbit decay due to the increased drag force acting on the spacecraft. Based on the utilization of accelerometer measurements from GRACE FO the working group thoroughly analyzed the specific impacts on the satellite. In this context, the modeling of disturbing non-gravitational forces revised and a new physical shadow function, which incorporates the Earth's oblateness and the atmospheric refraction and extinction implemented in the in-house software. The computed atmospheric densities and orbit decays were

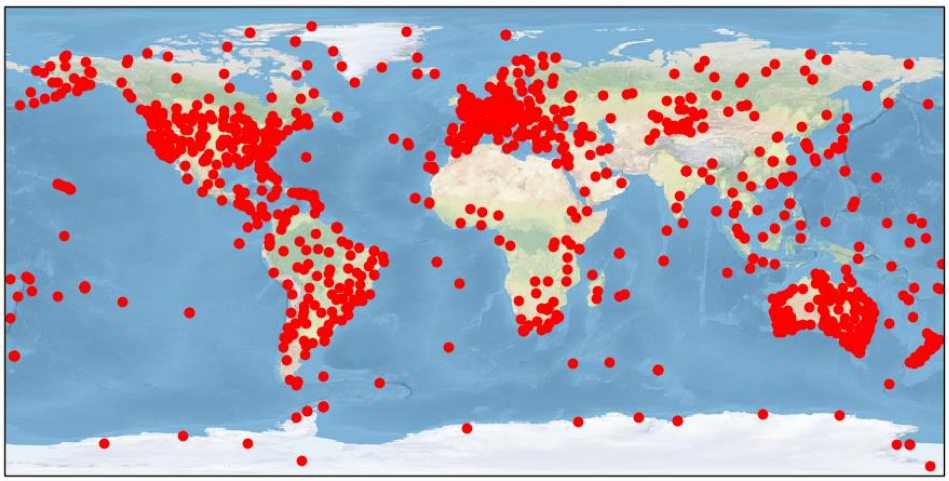
subsequently compared with predictions from an in-house thermospheric forecasting tool. The evaluation showed that the maximum estimated orbit decay was in good accordance with the forecasted value, which had a lead time of about 60 minutes.



Estimated thermospheric neutral densities along the GRACE-FO trajectory together with the storm-induced orbit decay (white line) during the perturbed period starting on Aug. 26, 2018

GNSS processing for the International Terrestrial Reference Frame 2020

The working group is a participating analysis center in the third reprocessing campaign of the International GNSS Service (IGS). This campaign aims to produce a GNSS product time series covering the period from 1994 to 2020 based on state-of-the-art models and techniques. These products are going to be combined with time series from other space geodetic techniques to determine the next version of the International Terrestrial Reference Frame, the ITRF2020. The ITRF is the foundation of various geoscientific applications, as it provides a highly accurate global reference frame. For the contribution to the IGS reprocessing campaign, the working group is processing observations from up to 800 ground stations per day to three GNSS constellations. For the first time, this also includes the European GNSS constellation Galileo, next to GPS (USA) and GLONASS (Russia). Processing these hundreds of millions of observations per day is enabled by a highly optimized in-house processing software. The working group utilizes an undifferenced and uncombined GNSS processing approach, which allows full exploitation of the information contained in each individual observation type and preserves the original measurement accuracy. The in-house software and its underlying processing approach are continuously developed and enhanced to further improve the quality of the resulting GNSS products.



Geographic distribution of GNSS ground stations used in the IGS reprocessing campaign

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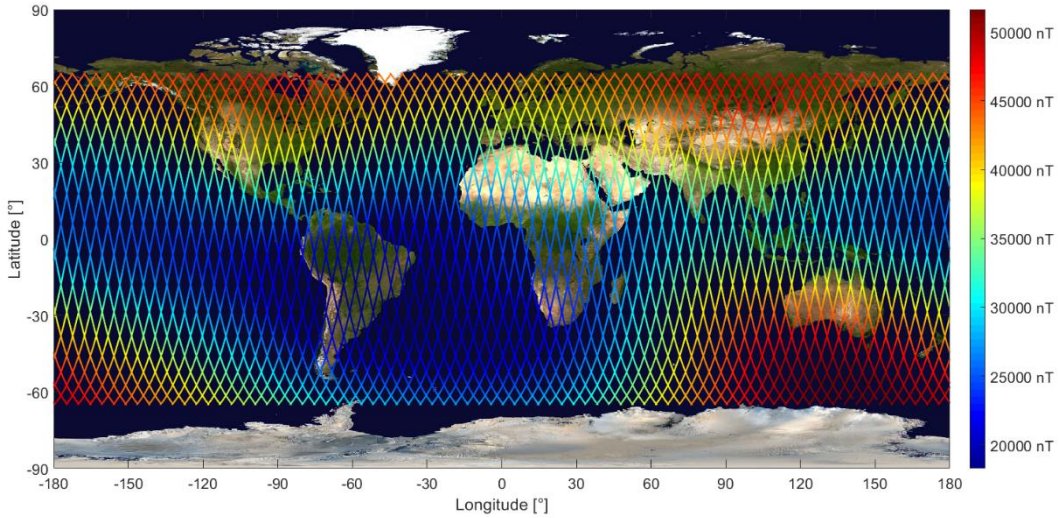
INSTITUTE OF EXPERIMENTAL PHYSICS (IEP)

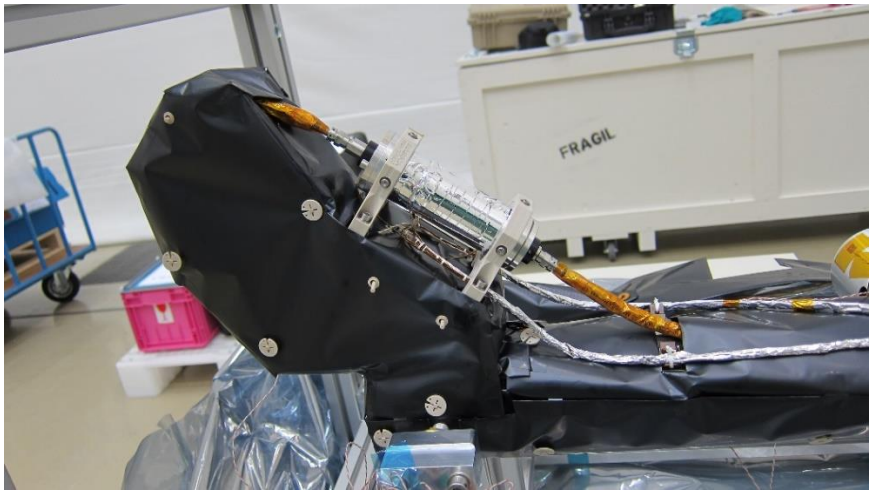
The Institute of Experimental Physics (IEP) at Graz University of Technology is in joint collaboration with the Space Research Institute (IWF) of the Austrian Academy of Sciences. Both institutions are concerned with the development of a scalar Quantum Interference Magnetometer based on the Coherent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

For the first time this new (patented) approach allows the application of a CPT magnetometer as precise (absolute) reference magnetometer especially on space missions where a so- called “in-flight” calibration of the commonly used fluxgate magnetometer is not possible (e.g. missions in the magnetosphere of a planet). Compared to other state-of-the-art reference magnetometers, the CPT magnetometer’s unique property of the omni-directionality (i.e. magnetic field measurement is independent of the sensor-orientation) is superior, as in each mission phase magnetic field data are available.



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

According to these potential space applications the CPT magnetometer is prepared for an ESA large-scale mission to the Jupiter Icy Moons (JUICE) and the Chinese Seismo Electromagnetic Satellite (CSES) in low Earth's orbit which has meanwhile passed the two-year continuous operation without any problems. The performance of the Instrument was externally evaluated by the SWARM-Team with top grades! The contribution to CSES II mission is accepted. The activities are planned to start in 2020.



Sensor of Coherent Population Trapping (CPT)-Magnetometer developed for ESA's JUICE-Mission. Here, mounted on the Boom of the spacecraft at ESA.

Activities in 2019 regarding both missions (JUICE and CSES):

- Evaluation of the data (operational and magnetic field data) obtained from CSES scalar Magnetometer since Launch (see Figure)!
- Magnetic field data analysis and error-budget estimation of the CSES-Magnetometer
- Development / engineering of the qualification model (QM)-electronics for the JUICE-mission.

- Engineering and manufacturing of a new sensor concept calling dual-transition-sensor (DTS) for the coupled dark state magnetometer (CDSM) instrument of the JUICE-mission. Building of the JUICE sensor Qualification Model (QM)
- Thermo-vacuum tests (TV) of DTS in Boom-mounted configuration at ESA (see Figure).
- Assembly, Test (Thermo-, Thermo-Vacuum, Radiation-Test) and Qualification of the In- and Outbound optical fibres connecting the DTS to the electronics box.

Sales 2019(TU Graz total): 0.9 MEUR
ESA Share: 273 kEUR

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3.15 TTTech Computertechnik AG

Leading global supplier of dependable networking solutions and modular safety platforms. The company's products simplify and reduce development cycles while enhancing the reliability of networked electronic systems in transportation and industrial automation markets.

TTTech was established in 1998 as a spin-off of the Vienna University of Technology (TU Wien). The TTTech Group employs already 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's Business Unit Aerospace is an industrial segment handled within TTTech Computertechnik AG itself.

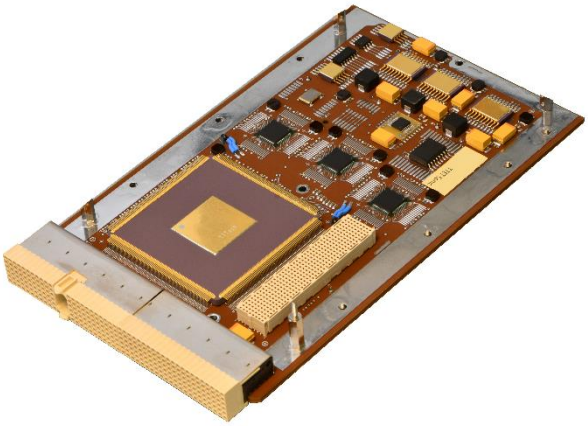
European Space Activities 2019

TTTech successfully completed the TTE-Controller ASIC qualification for the Ariane 6 program including a number of final software changes requested by ArianeGroup. Most avionics partners have completed the design-in of TTTech's ASIC and started the series production of avionics equipment using the chip to interface with the deterministic data backbone in Europe's new flagship launch vehicle.

Other launch vehicle programs that TTTech worked on in Europe are VEGA (avionics upgrade) and several German micro-launcher developments as Ethernet is the well accepted choice for data-handling in space transportation replacing MIL-1553 in most new programs.

The standardization of Time-Triggered Ethernet in particular for use in space applications continued (ECSS working group, ESA-GSTP funded compliance tester) and TTTech became a member of Eurospace.

TTTech invested heavily in its close co-operation with RUAG Space GmbH on the development of space grade TTEthernet switches and interface cards in the compact PCI form factor. An ESA GSTP de-risking activity was successfully concluded and Thales Alenia Space became the most important new customer with projects in both Italy (Torino) and France (Cannes) – in preparation of the International Habitat and other European contributions to the Lunar Gateway for which TTEthernet has been specified as single data communication backbone. The key advantages of this approach were presented to an international audience at the European



TTEthernet Switch Card (breadboard developed in cooperation with RUAG Space GmbH)

Space Tech Expo in Bremen at which TTTech was one of the most prominent Austrian exhibitors.

Outside Europe

In North America TTTech's local subsidiary intensified its work with NASA, Lockheed Martin, Boeing, Blue Origin, Maxar, MDA and Northrop Grumman Innovation Systems (former Orbital ATK). Projects range from launch vehicles and human spacecraft (Gateway, lunar landers) to advanced satellite architectures. A second office in Houston. Texas, will be operated in addition to the one in Andover, Massachusetts.

Additionally opportunities were pursued in China, Japan and India. With iSpace TTTech serves a well-known "New Space" company which develops a lunar lander next to a line of lunar rovers.

Revenue

Total European space revenue declined further to Euro 1.34 million with an ESA share of 0.6 million (the lowest in years). Still Europe represented almost half the total space revenue of TTTech Group. As the Ariane 6 development activities were completed, while the Lunar Gateway development program has not fully started, yet, this trend was actually expected.

Sales 2019: 1.34 MEUR

ESA Share: 0.6 MEUR

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4 Executive and Members

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