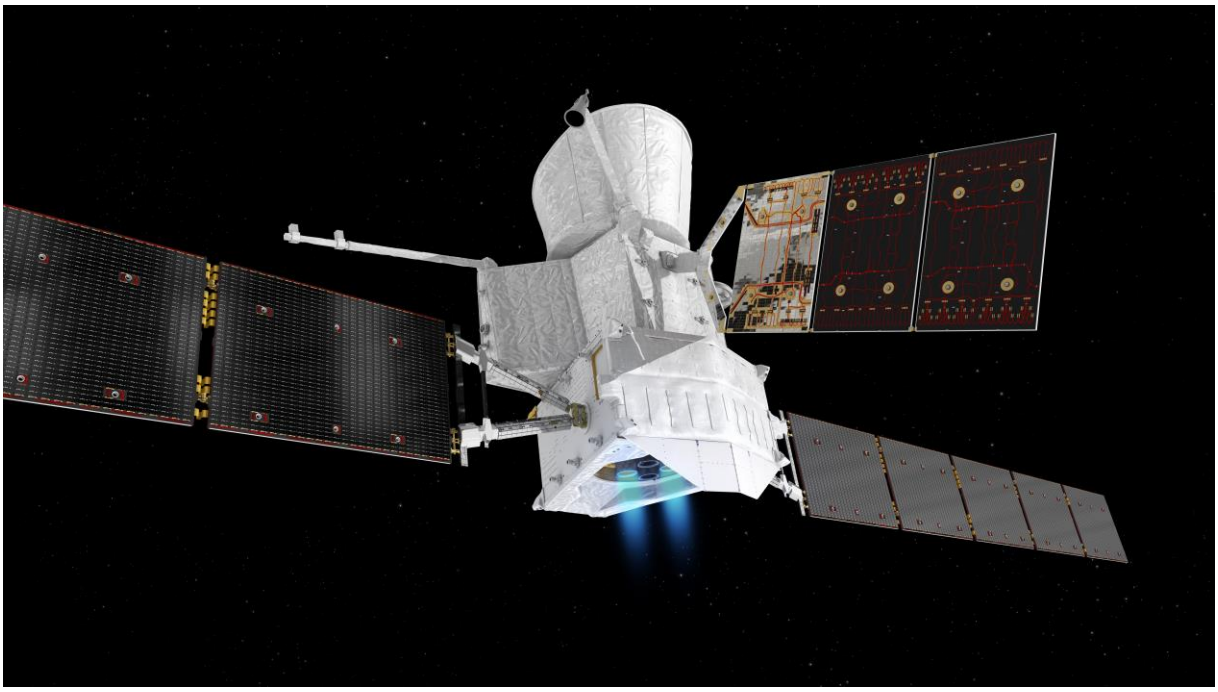
ANNUAL REPORT 2018



Cover picture: BepiColombo Cruise Configuration

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 2018, contributions from industrial members and research organizations about their space activities, and a current list of members with contact information.

Vienna, June 2019

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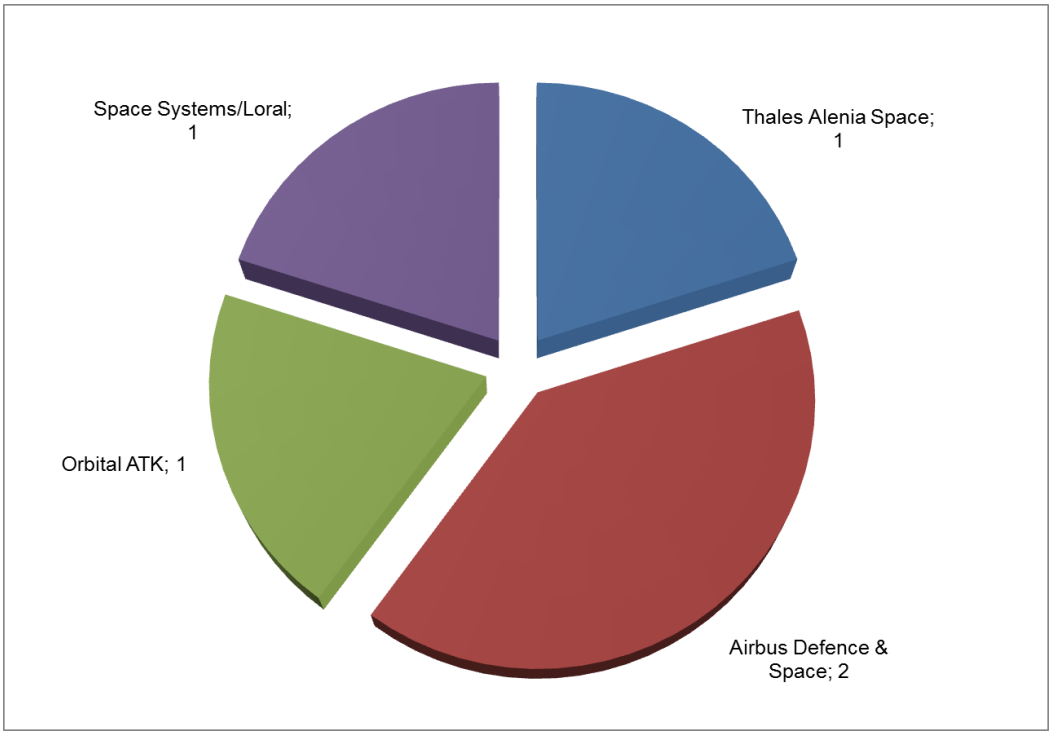
2 Year 2018 Review

In 2018 orders for only five geostationary commercial telecommunications satellites were placed worldwide, which means a further decline compared to the previous year (7). Of the five contracts three were awarded to European satellite manufacturers (Airbus Defence & Space (DS): 2, Thales Alenia Space (TAS): 1) and two to their US competitors (Space Systems Loral (SSL): 1, Orbital ATK: 1). SSL and the US newcomer Terran Orbital each received an order for a small geostationary satellite (Source: Space News, January 21, 2019).

Analysts still see quite some uncertainty in the future investment strategy of the satellite operators, who on one hand are waiting for technological breakthroughs in the area of digital high-throughput satellites (HTS) and on the other evaluate the market potential for constellations of low earth orbit (LEO) small satellites. As a consequence, it is difficult to predict, if and how quickly the market for big geostationary satellites will recover, or if a trend towards smaller satellites or constellations is more likely.

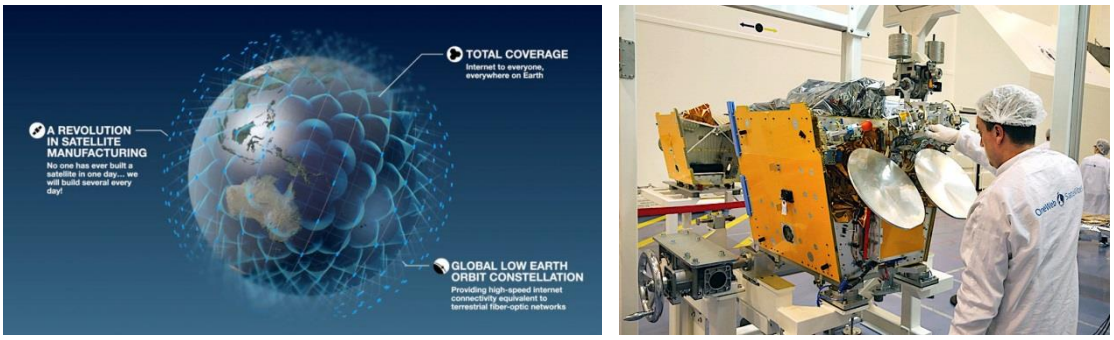


Commercial geostationary telecommunications satellite orders 2018

(source: Space News, January 21, 2019)

The development of OneWeb, a constellation of 648 low earth orbit satellites in the first phase with a planned follow-on extension, has experienced delays, so that the launch of the first test satellites has slipped into 2019. The operator of the system has been facing liquidity problems and needs to convince further investors about the viability of a modified business model. The first launch, expected in spring 2019, is generally seen as a key milestone. The OneWeb satellites are largely based on commercial off-the-shelf technologies and

industrialized production processes and are integrated by Airbus DS in a newly established factory in Florida. The successful realization of OneWeb will mark a breakthrough in the “new space” market.



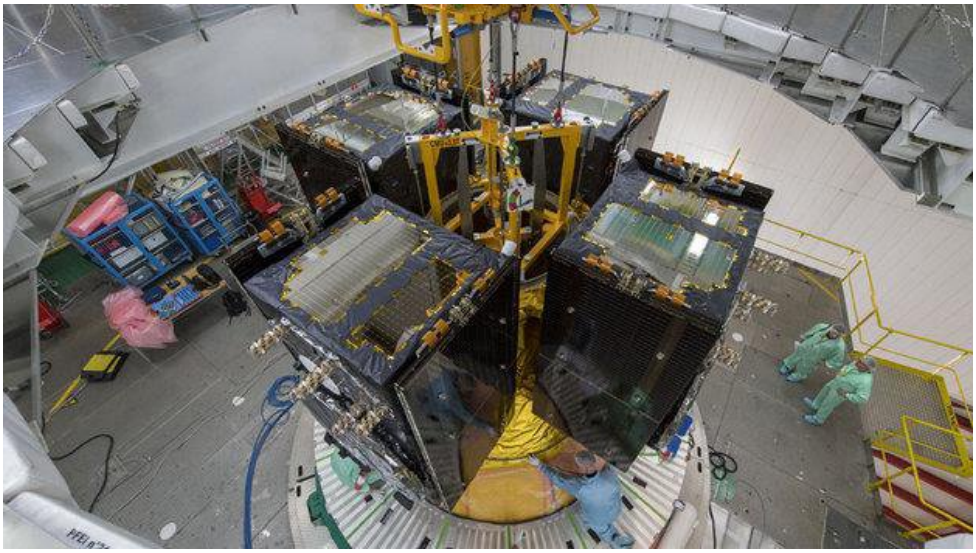
OneWeb constellation and satellite (source: OneWeb)

In February 2018 competitor SpaceX successfully launched two prototypes for a much more complex network of 11.943 satellites (Starlink), which shall be deployed until 2025.

SpaceX’s two prototype Starlink satellites on their carrier (source: SpaceX)

Launch of the final ten Iridium NEXT satellites on a Falcon 9 has been shifted from late December 2018 into January 2019. This will then complete the deployment of the 75 satellites constellation.

The deployment of the European satellite navigation system Galileo has continued with the launch of further four satellites on an Ariane 5 in July. Now the full constellation of 26 satellites is in orbit. However, a few more spares need to be launched. Mid of the year, OHB received an order for additional four satellites.



Galileo quartet placed atop Ariane 5 (source: ESA)

In the frame of the EU environment monitoring program Copernicus Sentinel-3B lifted off on board of a Rockot from the Plesetsk Cosmodrome in April. Sentinel-3 measures systematically Earth's oceans, land, ice and atmosphere to monitor and understand large-scale global dynamics. The mission is based on two identical satellites orbiting in constellation. The first satellite, Sentinel-3A, has been operational since 2016. Production of the C & D copies is progressing.

Sentinel-3B launch from Plesetsk Cosmodrome (source: ESA)

One of ESA's cornerstone science missions, BepiColombo, was launched on Ariane 5 in October and will study the composition, geophysics, atmosphere, magnetosphere and history of Mercury, the least explored planet in the inner Solar System. It consists of two individual orbiters: the Mercury Planetary Orbiter (MPO) to map the planet, and the Mercury Magnetospheric Orbiter (MMO) to investigate its magnetosphere. Austrian industry and scientist have provided major contributions to this challenging mission.

Artist's impression of BepiColombo at Mercury (source: ESA)

In November the launch of MetOp-C on a Soyuz from Kourou completed the first MetOp series in orbit. The MetOp program forms the space segment of Eumetsat's Polar System (EPS) and represents the European contribution to a cooperative venture with the US National Oceanic and Atmospheric Administration (NOAA) for the delivery of meteorological data from polar orbit.

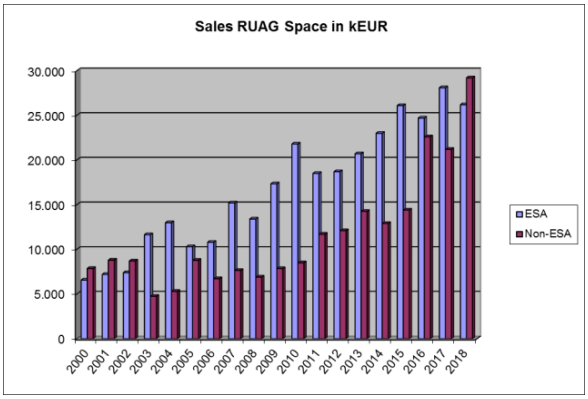
MetOp satellite (source: ESA)

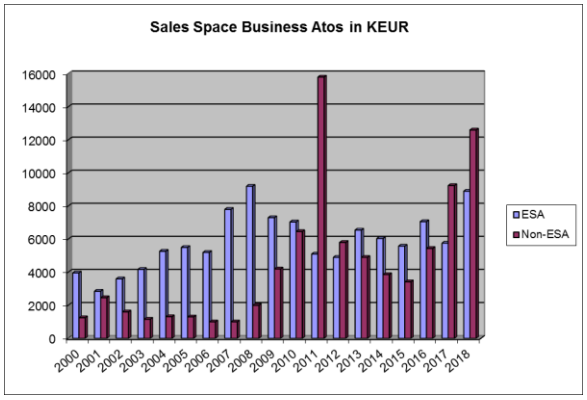
The very successful Austrian Space Cooperation Days, which took place at the University of Applied Sciences Wiener Neustadt on June 7 and 8, attracted more than 200 participants from 20 countries.

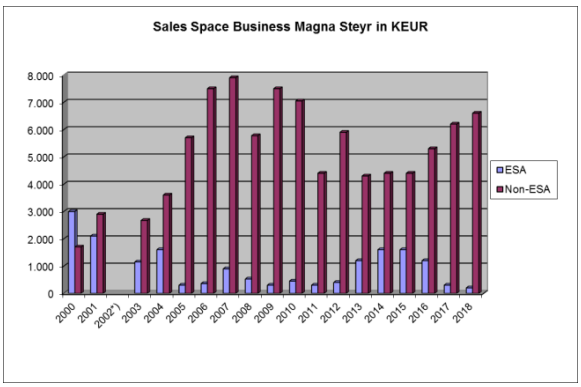
The Austrian Presidency of the Council of the European Union with the support of the European Commission organised the EUSPACE FOR BUSINESS conference in Graz on November 5 and 6. High-level presentations and discussions provided perspectives on the following issues:

- New Space developments and consequences for institutions and industry
- Security challenges to space infrastructures

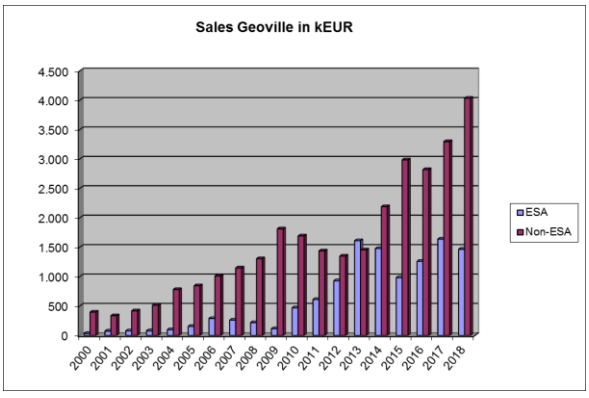
End of 2018 AUSTROSPACE had 21 members. The evolution of sales of the four biggest AUSTROSPACE companies is illustrated on the following page. The figures demonstrate a rather good leverage effect of ESA projects, i.e. a sustainable growth of commercial business.







*) no figures available due to organizational changes



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).

In spring, the entrance to the Victor Franz Hess Research Center, housing IWF Graz, got an impressive "facelift".

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 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 *China Seismo-Electromagnetic Satellite (CSES)* was launched in February to study the Earth's ionosphere.
- NASA's *InSight (INterior exploration using Seismic Investigations, Geodesy and Heat Transport)* mission was launched in May to place a geophysical lander on Mars to study its deep interior.

- *BepiColombo* was launched in October to investigate planet Mercury, using two orbiters, one specialized in magnetospheric studies and one in remote sensing.
- The Korean satellite *GEO-KOMPSAT-2A (GK-2A)* was launched in December to conduct space weather investigations.
- ESA's first Small-class mission *CHEOPS (CHaracterizing ExOPlanets Satellite)* will classify exoplanets in detail. Its launch is expected in 2019.
- Along an innovative trajectory, *Solar Orbiter* is to study solar and heliospheric phenomena, planned for launch in 2020.
- ESA's *JUpiter ICy moons Explorer (JUICE)* will observe Jupiter and three of its largest moons, Ganymede, Callisto, and Europa. It is planned for launch in 2022.
- ESA's third Medium-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 2018

- 2018 broke all records as far as launches are concerned. With *CSES*, *InSight*, *BepiColombo*, and *GK-2A* four missions with contributions from IWF Graz were sent into space.
- Astronomers have detected an excess of massive stars in 30 Doradus, member of the Large Magellanic Cloud. The study was published in "Science".
- In a "Nature Physics" paper, it was shown that the solar atmosphere can be heated through plasma waves.
- A "Nature Astronomy" study concluded that pseudo-shocks can act as an energy source for the solar corona.
- "Science" presented the latest results of NASA's *MMS* satellites, which for the first time captured the 3D structure of electron-scale dynamics also on the nightside of the magnetosphere.

Clockwise, from top left, the launch of *CSES* (© IWF), *InSight* (Credits: NASA/JPL-Caltech), *GK-2A* (Credits: ESA-CNES-Arianespace), and *BepiColombo* (© ESA).

THE YEAR 2018 IN NUMBERS

Members of the institute published 179 papers in refereed international journals, of which 48 were first author publications. During the same period, articles with authors from the institute were cited 5143 times in the international literature. In addition, 85 talks and 41 posters were presented at international conferences by IWF members. Last but not least, institute members were involved in the organization of nine international meetings or workshops.

IWF STRUCTURE AND FUNDING

IWF is structured into four research fields represented by eight research groups. Wolfgang Baumjohann serves as Director, Werner Magnes as Deputy Director.

The bulk of 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.

1 NEAR-EARTH SPACE

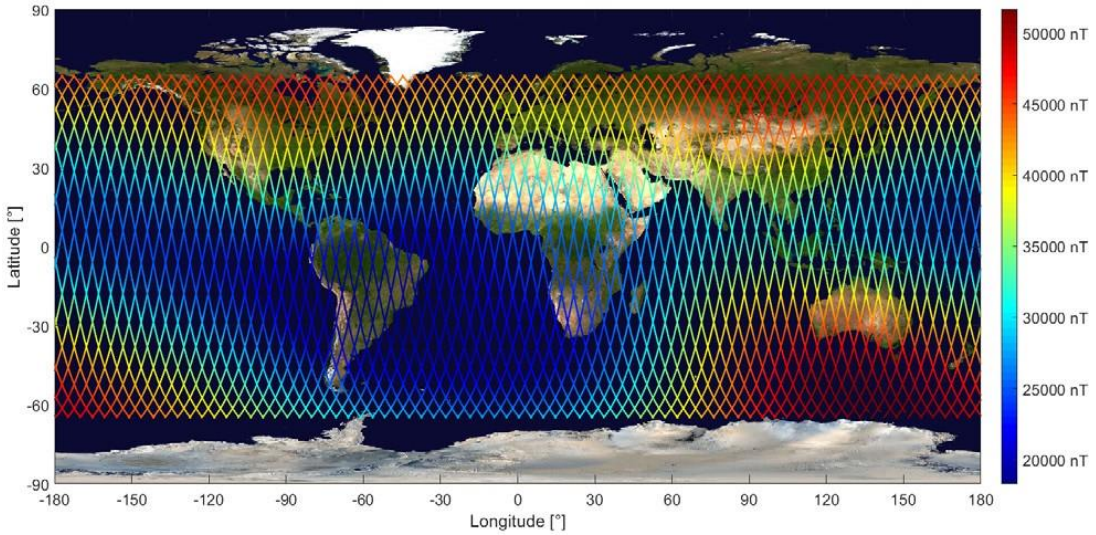
Recent advancements in the in-situ measurements of charged particles together with electric and magnetic fields at high cadence make near-Earth space a most suitable place to study fundamental space plasma processes. IWF has been participating in hardware activities of numerous space missions in the Earth's magnetosphere, now operating, being build, as well as in the planning phase. Data taken from operating missions have been extensively analyzed at IWF by applying different analysis methods and by theoretical modeling. The obtained knowledge contributes to the better understanding of different space plasma processes in our solar system and beyond.

CSES

The *China Seismo-Electromagnetic Satellite (CSES)* was launched in February 2018. It is the first Chinese platform for the investigation of natural electromagnetic phenomena with major emphasis on earthquake monitoring from a Sun synchronous, polar Low Earth Orbit (LEO).

The *CSES* magnetometer was developed in cooperation between China's National Space Science Center (NSSC), the Institute of Experimental Physics of TU Graz (TUG), and IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while IWF and TUG participate with the newly developed absolute scalar magnetometer, called *Coupled Dark State Magnetometer (CDSM)*.

In 2018, the technology readiness of *CDSM* for space application was successfully demonstrated. After its first turn-on beginning of March it has been operational for more than 200 days. Consequently, the accuracy of the magnetic field measurements could be improved by more than a factor of thirty. This is also an important step towards a successful implementation of the *CDSM* technology for ESA's *JUICE* mission to Jupiter.



Strength of the Earth's magnetic field measured by *CDSM* along the *CSES* orbits within a latitude range of ±65°.

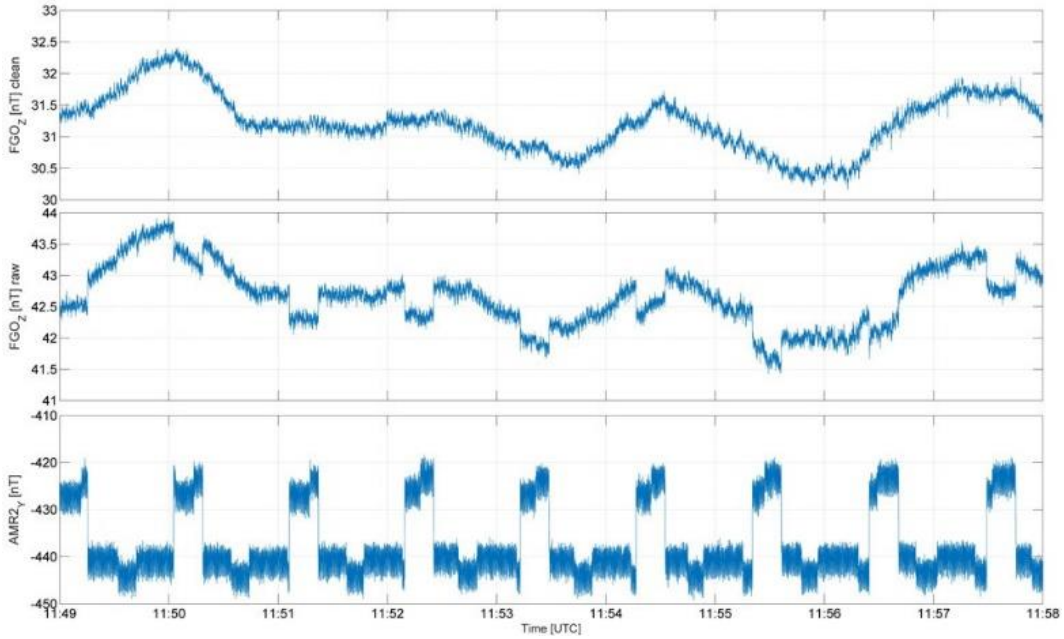
GEO-KOMPSAT-2A

GEO-KOMPSAT-2 (Geostationary Korea Multi-Purpose Satellite-2) consists of two spacecraft, which are built and managed by the South Korean Space Agency KARI. Both satellites focus on meteorological survey measurements from a geostationary orbit above Korea. One of the spacecraft, *GEO-KOMPSAT-2A (GK-2A)*, carries additional instrumentation to investigate space weather phenomena.

In cooperation with ESA and international partners, IWF is engaged in *GK-2A* with a four-sensor magnetometer called *Service Oriented Spacecraft MAGnetometer (SOSMAG)*. It was developed with ESA technology grants and serves as a ready-to-use space weather monitoring system to be mounted on a variety of different spacecraft built without a magnetic cleanliness program. Up to two high-resolution boom-mounted fluxgate magnetometers, the Digital Processing Unit (DPU) and the boom are provided by Magson GmbH and Technische Universität Braunschweig. For detection and characterization of magnetic disturbers on the spacecraft, two magnetometers based on the anisotropic magnetoresistive (AMR) effect were developed in a joint effort by Imperial College London and IWF.

In 2018, the flight model of *SOSMAG* has undergone system level testing (vibration, thermal vacuum, ...) on the *GK-2A* spacecraft as part of the *Korean Space Environment Monitor (KSEM)* instrument suit. On 4 December 2018, *GK-2A* was successfully launched aboard an Ariane 5 from the European spaceport in Kourou, French-Guyana.

The measurements in the figure below perfectly demonstrate that the spacecraft field measured by the AMR sensors can be used for the correction of the magnetic field measured by the outer boom mounted sensor. It enables a much higher quality of the magnetic field measurements and confirms the usefulness of the four-sensor *SOSMAG* design.



Spacecraft interference in the Z component of the outboard sensor is corrected with the Y component of AMR sensor 2.

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 spacecraft mission in space. Currently the mission is planned to be extended to December 2020. IWF is PI/Co-I on five instruments and has maintained the *Austrian Cluster Data Center*. In addition to data analysis, IWF also contributes to data archiving activities at the *Cluster Science Archive (CSA)* by also producing supporting data products such as science event lists.

MMS

NASA's *MMS (Magnetospheric MultiScale)* mission explores the dynamics of the Earth's magnetosphere and its underlying energy transfer processes. Four identically equipped spacecraft carry out measurements with high temporal and spatial resolution. *MMS* investigates small- scale basic plasma processes, which transport, accelerate and energize plasma in thin boundary and current layers. The orbit of *MMS*, launched in March 2015, was dedicated to study dayside magnetopause reconnection during the first two years. The apogee was then raised to encounter near-Earth magnetotail reconnection in mid 2017. The extension phase is proposed for further five years.

IWF has taken the lead for the satellites' 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 in inflight calibration activities.

THEMIS/ARTEMIS

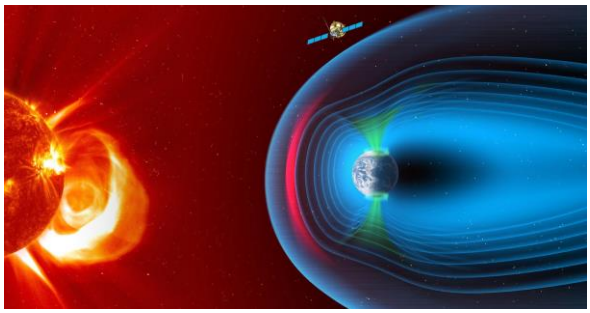
NASA's *THEMIS (Time History of Events and Macroscale Interactions during Substorms)* mission, launched in 2007, consisted of five identical satellites flying through different regions of the magnetosphere. In autumn 2010 the two outer spacecraft became *ARTEMIS* in orbit around the Moon, while the other three *THEMIS* spacecraft remained in their orbit. As Co-I 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). 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 two instruments: the *Soft X-ray Imager (SXI)*, led by the University of Leicester, and the magnetometer *(MAG)*, led by CAS.

The institute, in close cooperation with international partners, contributes to the *SXI* instrument the instrument's control and power unit *EBOX*. 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.

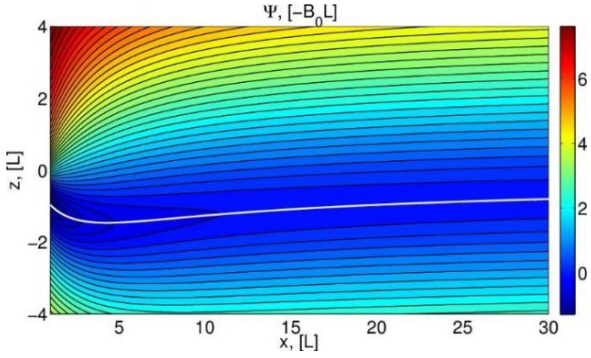
In addition to the hardware activities, IWF is participating in the *SMILE* science preparation such as modeling and in- situ science working group activities.



***SMILE* aims to form an accurate picture of solar-terrestrial magnetospheric physics (© ESA/ATG medialab).**

ANALYTICAL MODEL FOR A BENT MAGNETOTAIL

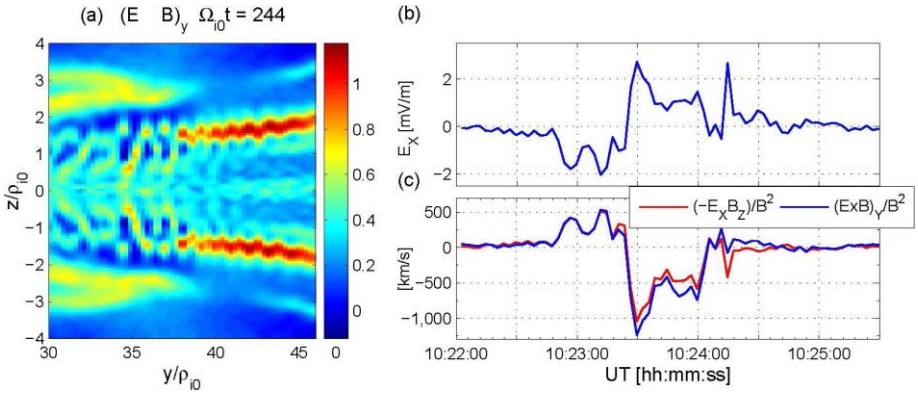
Most of the existing analytical models of two-dimensional magnetotail-like configurations are symmetrical with respect to the equatorial plane. In this study an analytical model is created for asymmetrical configurations and is used to reproduce the current sheet bending and shifting in the vertical plane (see figure). Such an asymmetry is expected to arise from the Earth dipole tilting and non- radial propagation of the solar wind, as observed by spacecraft such as *THEMIS* in the Earth's magnetotail.



Normalized magnetic potential Ψ(x,z) is shown by color in a plane, passing through the Earth and the Sun perpendicular to the ecliptic. The Earth is outside the left boundary. The solid curves plot magnetic field lines and isolines of the plasma pressure and current density. The white curve shows the current sheet center. Normalization constants are L ~1 Earth radius and B0 ~10 nT.

INTERCHANGE HEADS IN THE EARTH'S MAGNETOTAIL

On the anti-sunward side of the Earth, the terrestrial magnetic field lines are stretched out to form an elongated structure called the magnetotail. At the center of this structure the magnetic field strength normally decreases continually with increasing distance away from the Earth. However, periodically, the magnetotail is disrupted in a process called a substorm; the cause of this disruption remains controversial. A fortuitous configuration of five space probes is used to investigate a possible mechanism for this disruption. The probes observed the formation of a substantial region where the magnetic field strength possessed a minimum (rather than always decreasing). By comparing with the results of plasma computer simulations, it is shown that this region should generate an instability that produces dawnward propagating clumps of more dipolar field lines, in agreement with the probe observations. The magnetic field minimum appeared to have radial size of about 2.5 Earth radii (R_E) and azimuthal size that could be as large as 10 R_E. This structure was present for over three hours in the plasma sheet at around -11 R_E. Ballooning/InterChange Instability (BICI) heads were observed tailward of the minimum $\partial B_Z/\partial X \approx -10 nT/R_E$. The BICI heads appeared to drift azimuthally toward dawn, in accord with Particle-In-Cell (PIC) simulations of a charged current sheet (see figure).



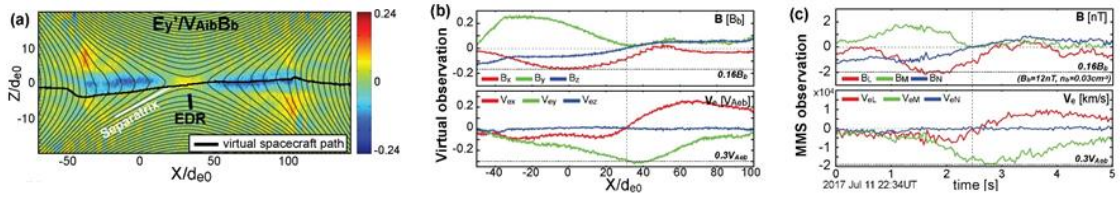
Structure of one BICI head as seen in the cross-product of the electric and magnetic field components that were obtained from Particle-In-Cell simulations of a charged current sheet (left) and from spin-averaged data of the *THEMIS* observations.

The signatures of the latter, e.g., a finite average E_Z directed toward the center of the plasma sheet, are verified by the *THEMIS* data. One dawnward-drifting BICI head is studied taking advantage of the available high-resolution *THEMIS* observations and comparing with the PIC simulation run. A prediction of the earlier PIC simulation for a neutral current sheet, that duskward-drifting BICI heads are subject to a current- driven ion-cyclotron instability, is found to be true also for dawnward-drifting BICI heads in the charged current sheet simulations. This specific prediction and the *THEMIS* data indicate the presence of electromagnetic ion-cyclotron wave activity that ripples the background BICI head shape.

MAGNETIC RECONNECTION RATE IN THE EARTH'S MAGNETOTAIL

In the Earth's magnetotail, magnetic reconnection releases stored magnetic energy and drives magnetospheric convection. The rate at which magnetic flux is transferred from the reconnection inflow to outflow regions is determined by the reconnection electric field Er, which is often referred to as the unnormalized reconnection rate. To better quantify the efficiency of reconnection, this electric field Er is often normalized by the characteristic Alfvén speed and the reconnecting magnetic field. This parameter is generally called the normalized reconnection rate R. A magnetotail reconnection event with weak geomagnetic activity (AE < 200 nT) observed by MMS on 11 July 2017 is extensively studied and relevant simulation is

performed. In this event, the MMS spacecraft crossed the reconnection separatrix boundary, an edge boundary of the region where the reconnected field lines are filled, and then entered the electron diffusion region (EDR), a central reconnection region where the magnetic topology change occurs and the flux is dominantly sustained by Er. To support the observations, two-dimensional fully kinetic simulation of this MMS event is employed (see figure) by using initial simulation parameters from the observations as input.

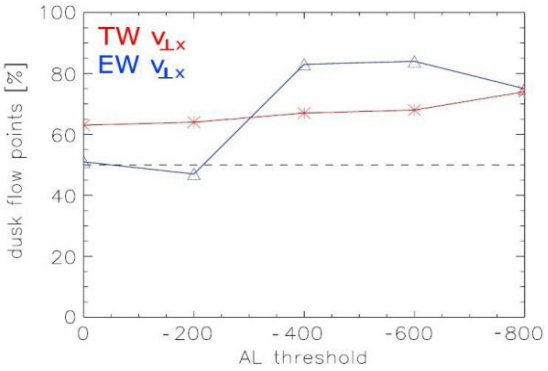


(a) 2D simulation result of out-of-plane component of the electric field $E_y'=E_y+(V_e \times B)_y$ with the orbit path of the virtual spacecraft. (b, c) Plots from virtual observations (b) and *MMS-3* observations (c) of the three components of the magnetic field and the electron bulk velocities.

In both the simulation and the MMS observations, R and Er are successfully obtained from direct measurements in the EDR and indirect measurements at the separatrix using a recently proposed remote sensing technique. The measured normalized rate for this MMS event is R~0.15-0.2, consistent with theoretical and simulation models of fast collisionless reconnection. This corresponds to an unnormalized rate of Er~2-3 mV/m. Based on quantitative consistencies between the simulation and the MMS observations, it is concluded that the estimates of the reconnection rates are reasonably accurate. Given that past studies have found Er of the order ~10 mV/m during strong geomagnetic substorms, these results indicate that the local Er in magnetotail reconnection may be an important parameter controlling the amplitude of geomagnetic disturbances.

MAGNETOTAIL FLOW DIRECTION AND DAWN-DUSK ASYMMETRY

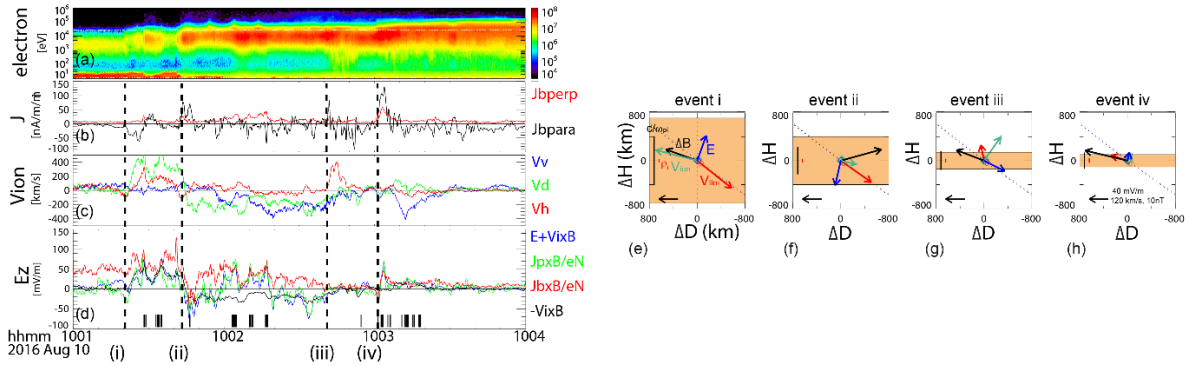
Plasma sheet fast flows are the main transporter of mass, flux, and energy in the Earth's magnetotail and result directly from magnetic reconnection. With limited observations near or beyond lunar orbit during the last decades, these flows were mainly studied within XGSM>-60 RE. Utilizing five years (2011–2015) of ARTEMIS data from around -60 RE, it is found that a significant fraction of fast flows is directed earthward, comprising 43% (vx>400 km/s) to 56% (vx>100 km/s) of all observed flows (see figure). This suggests that reconnection within and beyond -60 RE have a similar occurrence rate. For fast convective flows (vpx > 400 km/s), this fraction of earthward flows is reduced to about 29%, which is in line with reconnection as source of these flows and a downtail decreasing Alfvén velocity. More than 60% of tailward convective flows occur in the dusk sector (as opposed to the dawn sector), while earthward convective flows are nearly symmetrically distributed between the two sectors for low AL (>-400 nT) and asymmetrically distributed toward the dusk sector for high AL (<-400 nT). This indicates that the dawn-dusk asymmetry is more pronounced closer to Earth and moves farther downtail during high geomagnetic activity. It is inferred that near-Earth reconnection is preferentially located at dusk, whereas midtail reconnection (X>-60 RE) is likely symmetric across the tail during weak substorms and asymmetric toward the dusk sector for strong substorms, as the dawn-dusk asymmetric nature of reconnection onset in the near-Earth region progresses downtail.



Percentage of flow datapoints with v_{px} > 200 km/s observed in the dusk sector relative to AL thresholds.

MULTI-SCALE CURRENTS OBSERVED BY MMS IN THE FLOW BRAKING REGION

Earthward high-speed plasma jets from magnetic reconnection are braked in the near-Earth plasma sheet interacting with Earth's dipole field and creating field- aligned currents. Characteristics of current layers in the off-equatorial near-Earth plasma sheet boundary are studied with high time-resolution measurements from the MMS mission. The four MMS spacecraft observed fast flow disturbances (up to about 500 km/s), most intense in the dawn-dusk direction (green lines in figure c). Field-aligned currents (figure b) were initially within the expanding plasma sheet (event i, ii), where the flow and field disturbances showed the distinct pattern expected in the braking region of localized flows.



***MMS* observations between 10:01-10:04 on 10 August 2016. (a) Energy spectra from electrons, (b) field-aligned (black) and perpendicular (red) components of the currents, (c) ion flow, (d) northward component of the electric field in ion frame (blue), Hall electric field (green, red), and convection electric field (black). Vertical dashed lines in (b-d) indicate the field aligned current events (i-iv). Black bars in (d) show the times of small-scale Hall-currents. (e-h) Average direction of the disturbance vectors of different parameters in northward (H) and duskward (D) direction during event (i-iv). Vertical width of orange area in (e-h) represents the thickness of the field-aligned current sheet.**

Subsequently, intense thin field-aligned currents layers (events iii and iv) were detected together with Earthward streaming hot ions. Average disturbances and thickness of the current layers are shown in figure e-h. Intense Hall- current layers were found adjacent to the field-aligned currents (during times indicated by black bars in figure d). These observations show that both the near-Earth plasma jet diversion and the thin Hall-current layers formed around the reconnection jet boundary are the sites where diversion of the perpendicular currents take place that contribute to the observed field-aligned current pattern as predicted by simulations of reconnection jets. Hence, multiscale structure of flow braking is preserved

in the field-aligned currents in the off-equatorial plasma sheet and is also translated to the ionosphere to become a part of the substorm field-aligned current system.

PLASMA FLOW PATTERNS IN AND AROUND MAGNETOSHEATH JETS

The magnetosheath is commonly permeated by localized high-speed jets downstream of the quasi-parallel bow shock. These jets are much faster than the ambient magnetosheath plasma, thus raising the question of how the plasma reacts to incoming jets. A statistical analysis has been performed, based on 662 cases of one THEMIS spacecraft observing a jet and another (second) THEMIS spacecraft providing context observations of nearby plasma, to uncover the flow patterns in and around jets (see figure).

The following results are found: along the jet's path, slower plasma is accelerated and pushed aside ahead of the fastest core jet plasma (see yellow and orange areas in the figure below). Behind the jet core, plasma flows into the path to fill the wake. This evasive plasma motion affects the ambient magnetosheath, close to the jet's path. Diverging and converging plasma flows ahead and behind the jet are complemented by plasma flows opposite to the jet's propagation direction, in the vicinity of the jet. This vortical plasma motion results in a deceleration of ambient plasma when a jet passes nearby.

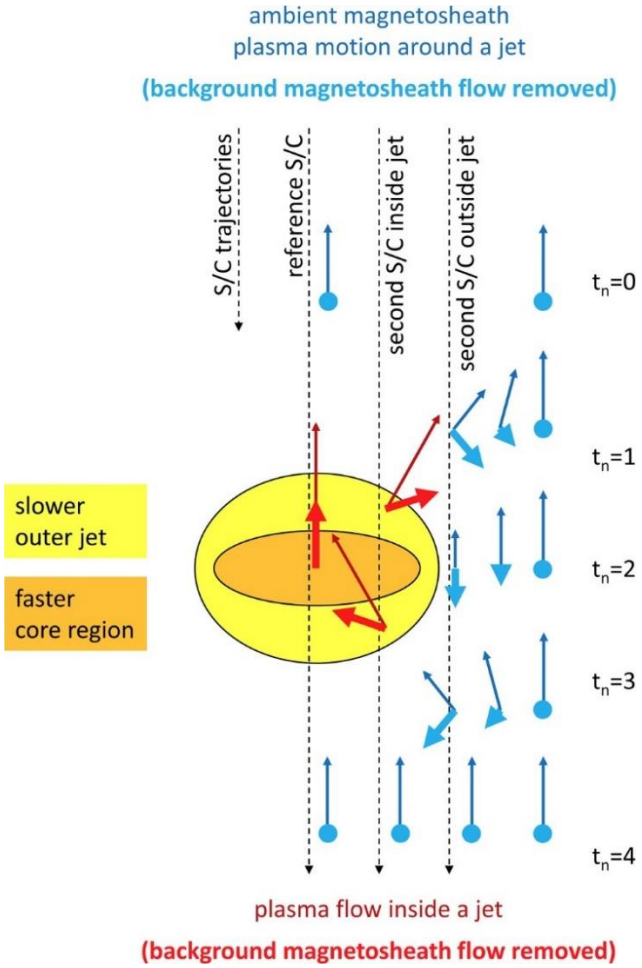
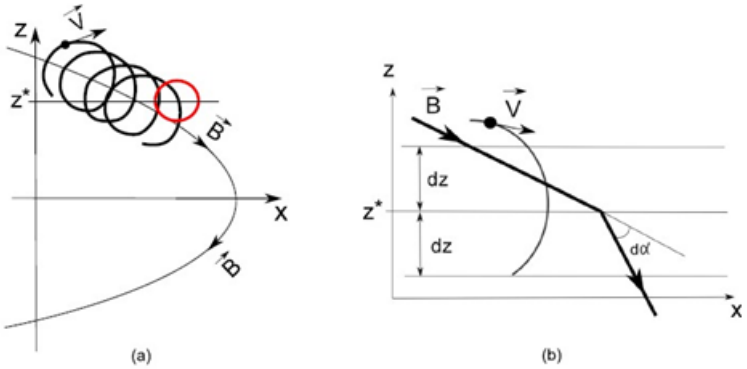


Illustration showing the motion of ambient magnetosheath plasma (blue) and jet plasma (red) within and in the vicinity of a jet. Bold arrows show motion after subtracting the magnetosheath background flow.

SELF-CONSISTENT TANGENTIAL- DISCONTINUITY-TYPE CURRENT SHEET

The description of the dynamics of charged-particles in an inhomogeneous magnetic field is a fundamental problem in space plasma physics. Since this dynamics has the characteristics of a nonlinear oscillator, the traditionally used approaches involve certain limiting conditions regarding the scales of magnetic field, particle motion, and the assumptions about conservation of specific invariants (e.g., the magnetic momentum, integrals of action etc.). Such approaches naturally restrict the details considered in the particle dynamics which are described in terms of integral characteristics and averaged parameters of motion. However, in some regions, the exact account of particle trajectory details and the motion features (e.g., the phase of gyration) are of crucial importance.

A method for the description of particle dynamics, based on a new system of differential equations for the particle pitch-angle and gyro-phase derived from the analysis of the particle trajectory in a given magnetic field (see figure), has been developed. It enables an easy and self-consistent description of a number of elementary problems, which form the basis for more complex natural cases in space physics. The developed method can generalize the case of particle ensembles, which enables finding a set of self- consistent solutions for tangential current sheets in the frame of a kinetic approach.



Example of particle trajectory in a given magnetic field geometry.

2 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 is a future ESA space mission to investigate the Sun, scheduled for launch in 2020. Flying a novel trajectory, with partial Sun-spacecraft corotation, the mission plans to investigate in-situ plasma properties of the near 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.

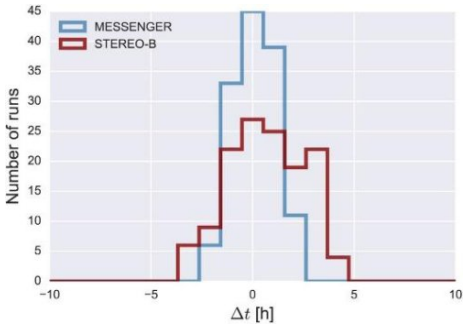
The Solar Orbiter spacecraft at the premises of prime contractor Airbus Defence and Space in Stevenage, UK (© Airbus Defence and Space).

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.

ENSEMBLE PREDICTION OF A HALO CME USING HELIOSPHERIC IMAGERS

The "ELlipse Evolution model based on HI observations" (ELEvoHI) is a prediction utility designed to forecast arrivals of coronal mass ejections (CMEs) at Earth or at other planets in the inner heliosphere. It uses the advantage of side-view observations performed by the heliospheric imagers (HI) aboard STEREO, enabling continuous observations of CMEs throughout their propagation up to 1 AU and beyond. These white-light images are the main input for the ELEvoHI forecasting tool. Other input data come from solar wind in situ observations at 1 AU and from coronagraph observations. The latter provide information on the shape of the CME portion propagating within the ecliptic plane, the region of interest for the prediction.

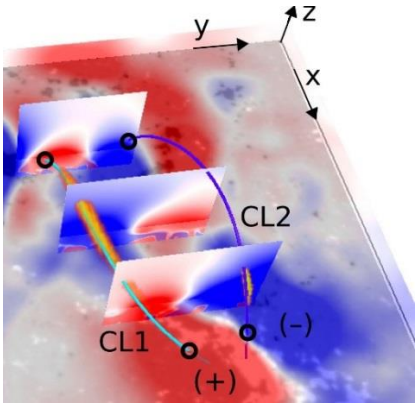
ELEvoHI includes an interaction of the CME with the ambient solar wind leading either to a deceleration or an acceleration of the CME. In the current study, ELEvoHI was enhanced to be able to perform ensemble modeling. This is done by varying the input parameters of the CME frontal shape leading to a set of different prediction runs and therefore to an estimation of the prediction uncertainty (see figure). ELEvoHI ensemble prediction was applied to a halo CME, remotely observed from STEREO-B and in situ detected by the MESSENGER spacecraft and STEREO-B. The almost exact arrival predictions for this event encourage the further development of ELEvoHI to prepare it for real-time predictions in the near future.



Distribution of the ELEvoHI ensemble prediction for *MESSENGER* (blue) and *STEREO-B* (red).

MAGNETIC HELICITY IN THE CORONA OF THE SUN

A long-standing topic in Solar and Heliospheric physics research is the mechanism that heats the corona, the outer atmosphere of the Sun, to millions of °C. The corona is hence much hotter than the surface of the Sun. In particular, there are hot loops in the corona that emit EUV light. Computer simulations have now reproduced several loops in the core of the active region (CL1) at the location where they were really observed. From the model data the magnetic helicity is deduced, which can be understood as a twist within the magnetic fields. This helicity is particularly strong and changes its sense (from left- to right-handed) along the strongly heated loop CL1 in the corona. Magnetic helicity can be determined also in the heliosphere, where the same sign as on the solar surface is expected. But, so far, the heliospheric observations from the Ulysses mission show the opposite sign. A reversal of the helicity within the corona is now found, which can explain the Ulysses observations from the inner heliosphere.

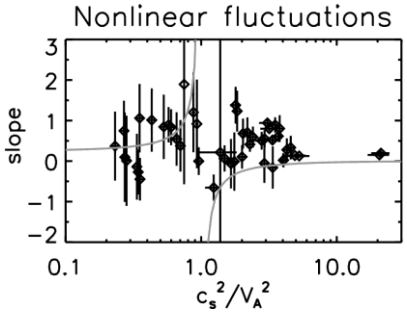


3D visualization of the magnetic helicity (red and blue for positive and negative helicity) above an active region in the solar corona. The gray background is the solar surface, where white and black are patches of strong magnetic fields with opposite polarity. Orange shows where extreme-UV light is emitted along loops (colored lines).

NONLINEAR DENSITY FLUCTUATIONS IN THE SHOCK-UPSTREAM PLASMA

Shock-upstream plasma in interplanetary space exhibits large-amplitude disturbances in the plasma density and the magnetic field, and serves as a natural laboratory of waves and nonlinear processes in space plasma. Using in-situ Cluster spacecraft data, the density fluctuations are found to be largely correlated to the magnetic field fluctuations which justifies the linear-mode picture of plasma dynamics (magnetosonic wave). Moreover, deviations of the density fluctuations from the linear-mode are found to be weakly and nonlinearly

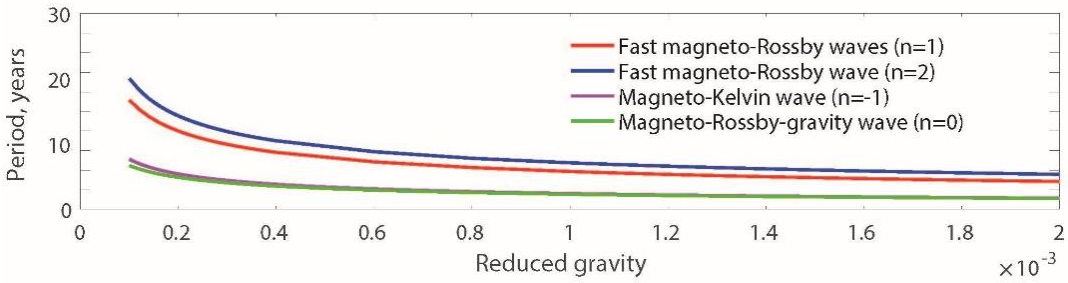
correlated to the magnetic energy density, which supports the theoretical prediction of quasi-static balance; that the nonlinear density response in plasma is controlled by the magnetic energy density and the thermal condition of the plasma (see figure).



Slope value of the nonlinear relation between plasma density and magnetic energy density as a function of the sound speed to the Alfvén speed squared, a measure of plasma thermal pressure. Data points represent the measurements in the shock-upstream plasma and curves in gray represent the theoretical prediction.

EQUATORIAL MHD SHALLOW-WATER WAVES IN THE SOLAR TACHOCLINE

The influence of a toroidal magnetic field on the dynamics of shallow-water waves in the solar tachocline is studied. A sub-adiabatic temperature gradient in the upper overshoot layer of the tachocline provides a negative buoyancy force to the deformed upper surface, which feels less gravitational field compared to the real gravity. This reduced gravity causes a significant reduction of the surface gravity speed, which leads to trapping of the shallow-water waves near the equator. It also increases the Rossby wave period up to the timescale of solar cycles (11 years). It is found that the toroidal magnetic field splits equatorial Rossby waves into fast and slow magneto-Rossby modes. For a reasonable value of normalized reduced gravity, global equatorial fast magneto-Rossby waves have a periodicity of 11 years, matching the timescale of activity cycles (see figure).



Periods of global magneto-Rossby and magneto-Kelvin waves vs the normalized reduced gravity (n is the poloidal wave number).

The solutions are confined around the equator between latitudes ±20°–40°, coinciding with the sunspot activity belts. Equatorial slow magneto-Rossby waves have a periodicity of 90-100 years, resembling the Gleissberg cycle, the observed long-term modulation of the cycle strength. The equatorial magneto-Kelvin waves have a periodicity of 1-2 years and may correspond to the observed annual and quasi-biennial oscillations. It is also found that equatorial magneto-inertia-gravity waves have periods of hundreds of days and may be responsible for the observed Rieger-type periodicity. The equatorial MHD shallow-water waves in the upper overshoot tachocline capture all time-scales of observed variations in solar activity for expected physical parameters of the tachocline. The equatorial waves might play a distinct role in the temporal evolution of the solar magnetic field and hence in the solar dynamo.

MERCURY

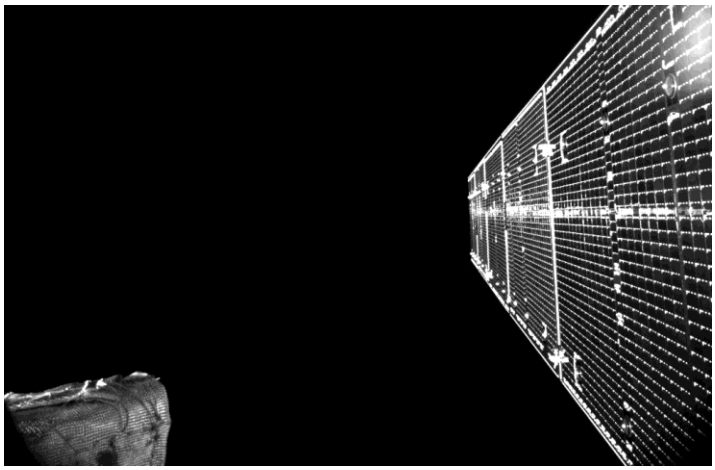
Mercury is now in the center of attention because of the ESA/JAXA BepiColombo mission. The planet has a weak intrinsic magnetic field and a mini-magnetosphere, which strongly interacts with the solar wind.

BEPICOLOMBO

The launch of BepiColombo was one of the great space flight events in 2018. The two spacecraft, JAXA's Magnetospheric (MMO) and ESA's Planetary Orbiter (MPO), which will simultaneously explore Mercury and its environment from 2026, took off from the European spaceport in Kourou, French Guiana, aboard an Ariane-5 rocket on 20 October.

IWF played a major role in developing the magnetometers for this mission: it is leading the magnetometer investigation aboard the MMO (MMO-MGF) and responsible for the overall technical management of the MPO magnetometer (MPO-MAG). For MPO, IWF also led the development of PICAM, an ion mass spectrometer with imaging capability, which is part of the SERENA instrument suite, to explore the composition, structure, and dynamics of the exo-ionosphere.

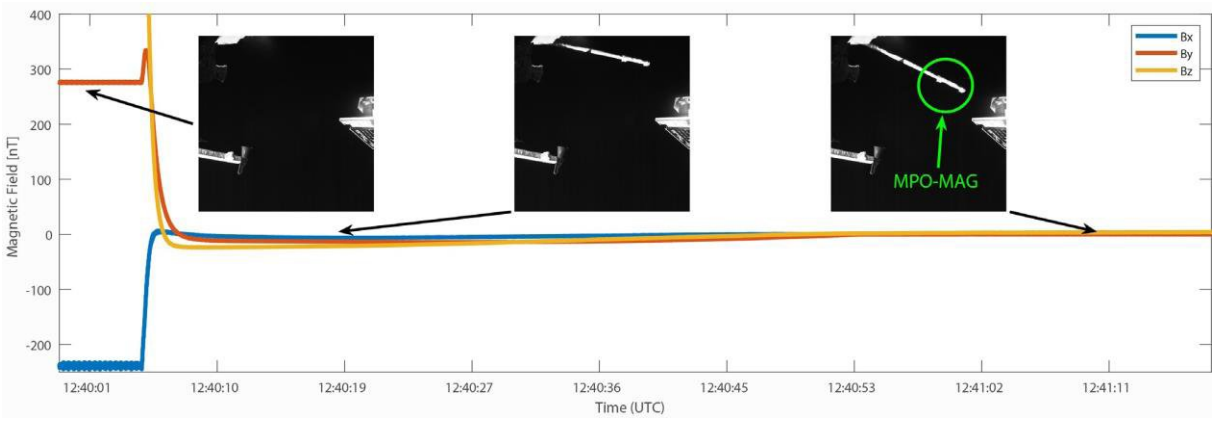
In the months until the launch, the spacecraft systems and their payload saw the final tests in Europe, the transportation to South America on board of two Antonov airplanes, the mating of all BepiColombo elements and finally the installation on the rocket only seven days before launch. The final functional test of the instruments on earth were completed on the first weekend of May and the payload was declared flight ready. The launch, the spacecraft separation, the first acquisition of a signal, the solar array and antenna as well as magnetometer boom deployments all ran according to plan. One of three onboard monitoring cameras provided the first spectacular image from space only a few hours after launch.



First image by the onboard monitoring camera installed on the BepiColombo Mercury Transfer Module (MTM). The view looks along one of the extended solar arrays. The structure in the bottom left corner is one of the sun sensors on the MTM, with the multi-layered insulation clearly visible. (Credits: ESA/BepiColombo/MTM).

The first power-on of the two magnetometers including detailed commissioning took place end of October and beginning of November. MPO-MAG was even turned on before boom deployment, which allowed for a characterization of the spacecraft magnetics during the deployment (see figure below). All magnetic field sensors are in good health and in-flight calibration has already been started. While MMO-MGF was kept on only for a few hours, since the MMO spacecraft is sitting within the Sun shield during the cruise phase, MPO-MAG was already successfully operated over several weeks.

As the last sensor of all, PICAM was turned on in the frame of the SERENA commissioning on 15 December. After the acquisition of the first "Hello, world" from space, checkouts of the low and the high voltage circuits verified, that the sensor survived the launch without damages. Transition to science mode was tested successfully. The received science data contained all zeros as expected due to limitation of high voltage for safety measures. So calibration is left for the delta near-Earth commissioning phase in summer 2019.



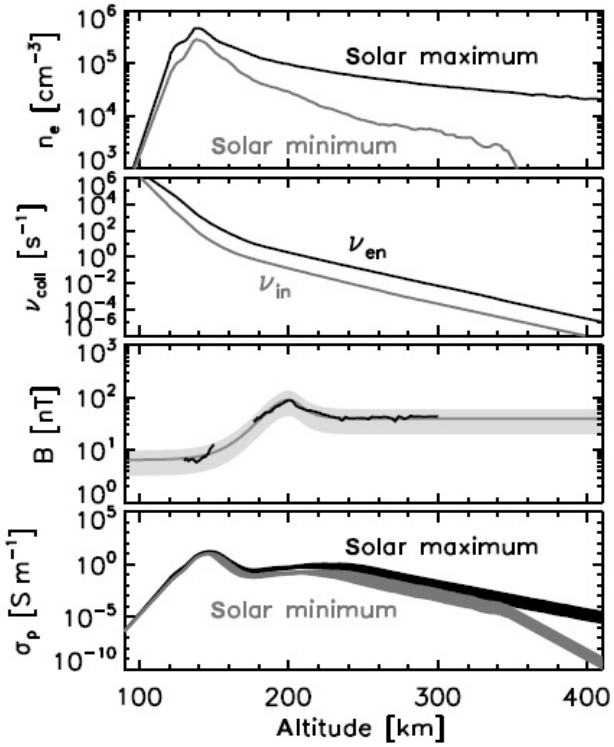
***MPO* magnetometer measurements during boom deployment on 25 October with pictures taken by one of the selfie cameras of the *BepiColombo Mercury Transfer Module* (Credits: data: ESA/*BepiColombo/MPO*/MAG/TUBS-IGeP/IC London/IWF Graz; images: ESA/*BepiColombo/MTM*).**

VENUS

Just inside the Earth's orbit around the Sun at 0.7 AU, the terrestrial planet Venus has a radius slightly smaller than Earth and is differentiated, but does not exhibit an internal magnetic field. Venus is characterized by a very dense atmosphere and generates a so-called induced magnetosphere by its interaction with the solar wind.

IMF PENETRATION THROUGH THE IONOSPHERE OF VENUS

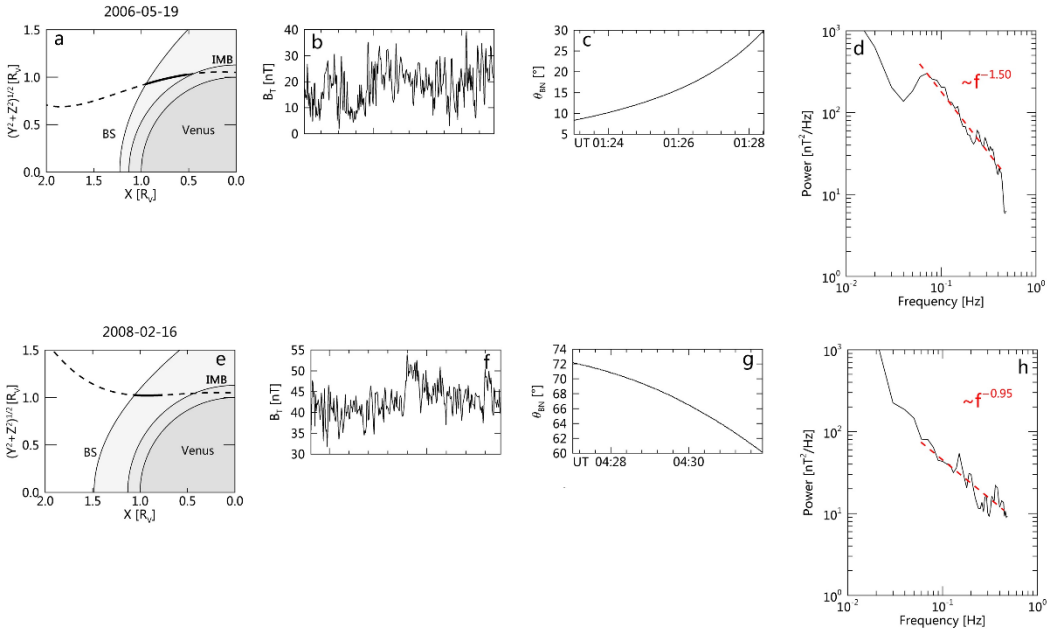
Although Venus does not have an intrinsic magnetic field, interplanetary magnetic field can potentially penetrate the ionosphere of Venus by the diffusion process and permeate the planetary surface and interior. For the first time the magnetic diffusion time is quantitatively estimated. Over this time scale the magnetic field can penetrate the ionosphere of Venus and reach the planetary surface. The calculation is based on the estimate of Pedersen conductivity using the electron density data from Pioneer Venus Orbiter, the theoretical profile for the neutral-electron and neutral ion collision frequencies at Venus, and the magnetic field profile from Venus Express. The magnetic diffusion time falls in the range between 12 hours (under solar minimum conditions) and 54 hours (under solar maximum conditions, see figure). Penetration of the interplanetary magnetic field through the ionosphere of Venus is possible when the solar activity and the solar wind remain undisturbed for a period of several days.



Electron number density n_e from *Pioneer Venus Orbiter* radio occultation measurement, model collision frequency between electrons and neutral particles v_{en} and that between ions and neutral particles v_{in}, magnetic field B from *Venus Express* and model magnetic field with a fluctuation range (in gray), and Pedersen conductivity σ_p as a function of the altitude from the surface of Venus.

TURBULENCE IN THE VENUSIAN MAGNETOSHEATH

The characteristic scaling features of fluctuations in the dayside Venusian magnetosheath downstream of the bow shock were investigated using Venus Express data. A bow shock comes in two different types: the quasi-parallel (Qpar) where the bow shock normal and the interplanetary magnetic field (IMF) are quasi-parallel, and the quasi-perpendicular (Qperp) bow shock where the two are perpendicular. Depending on behind which kind of bow shock the magnetic field fluctuations were measured in the magnetosheath, it was found that the characteristic scaling features of the fluctuations and turbulence were different. Although the Venusian dayside magnetosheath is much thinner than the Earth's magnetosheath, fully developed turbulence can be still observed downstream of the Qperp bow shock (figure a-d), while the turbulence is not dominant downstream of Qpar bow shock (figure e-h). This means that the source of the turbulence in the Venusian magnetosheath is likely to be the Qperp IMF.



***Venus Express (VEX)* trajectories, magnetic fields, the shock normal angles, and power spectrum densities for two downstream intervals of a Q_{par} bow shock on 19 May 2006 (a-d) and a Q_{perp} bow shock on 16 February 2008 (e-h). The left case with α ~1.50 in the bottom panel indicates a developed turbulence during this interval. The right case with α ~0.95 indicates that 1/f noise dominates during this interval.**

MARS

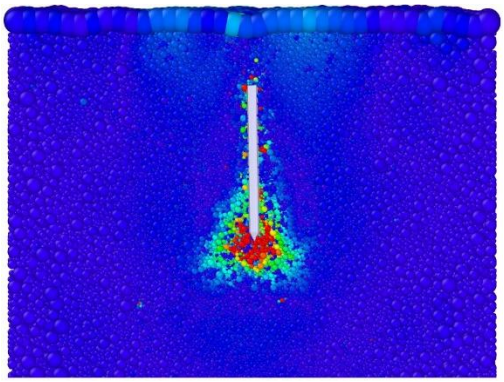
Just outside the Earth's orbit around the Sun at 1.5 AU, the terrestrial planet Mars has half the radius of the Earth. It is differentiated, but only exhibits remnant surface magnetization of a now defunct internal dynamo. Mars is characterized by a very tenuous atmosphere and generates a so-called induced magnetosphere by its interaction with the solar wind.

CHINESE MARS MISSION

China plans a Mars orbiter, lander, and rover mission to be launched in 2020. The main mission will conduct a comprehensive remote sensing of the Red Planet, as well as surface investigation. IWF contributes to a magnetometer, of which the Qualification Model was delivered in summer.

INSIGHT

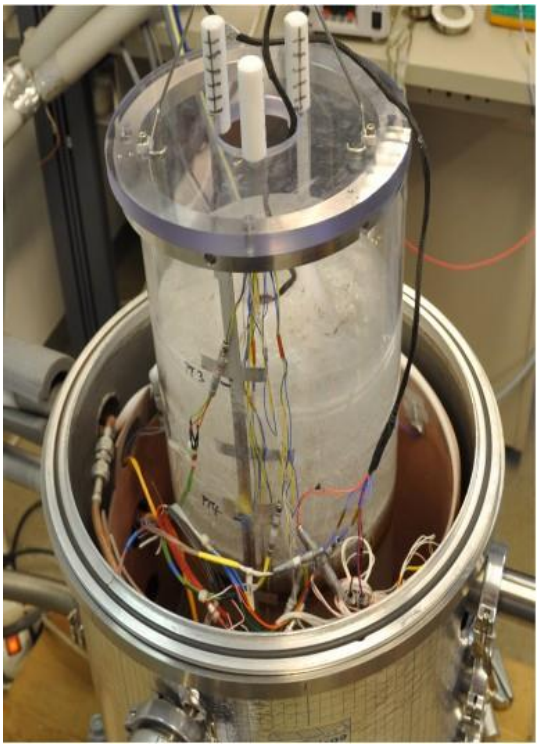
NASA's Mars mission was launched in May and successfully landed in Elysium Planitia on 26 November 2018. After first checkouts the seismometer instrument has already been deployed, while the HP³ (Heat flow and Physical Properties Probe) instrument will be put on the ground and start penetrating by the end of January or begin of February 2019. HP³ will 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.



Discrete element or particle code model describing the soil displacement during one hammer stroke of the *HP³* deployment mechanism.

MELTING PROBE EXPERIMENTS

A series of experiments focusing on the performance of melting probes under Mars surface environmental conditions was performed in the planetary chamber of the IWF. Hereby the influence of sand layers embedded in the Mars polar near-surface ice was studied, as well as the performance in CO2-ice layers. The main result of the performed tests was that, even at surface pressures below the water triple point, the liquid phase exists temporarily around the heated melting tip. This allows for successful ice penetration under Mars surface conditions, with a realistic electrical power demand. Therefore a melting probe would be a useful alternative to mechanical drilling for any lander mission aiming at the exploration of the layered structures of the Martian polar regions, which are considered to contain key information about the evolution of the Martian climate in the recent past. The figure shows an ice sample at the end of a melt penetration experiment.



Ice sample positioned inside the planetary chamber at the end of a melting probe test.

JUPITER

Jupiter, the largest planet in our solar system, mainly consists of hydrogen and helium. It is magnetized and rotates rapidly, leading to a rotationally dominated magnetosphere, where strong sources of radio emissions are located.

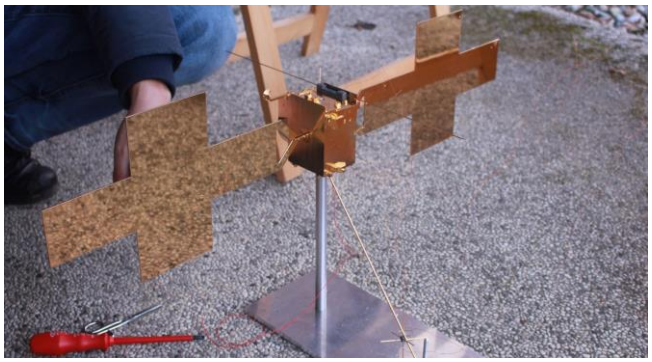
JUICE

ESA's first Large-class mission JUpiter ICy moons Explorer (JUICE) is planned for launch in 2022 and arrival at Jupiter in late 2029 or early 2030. JUICE will spend at least three years orbiting around Jupiter, making detailed observations of the gas giant and three of its largest moons, Ganymede, Callisto, and Europa. At the end of the mission JUICE will go into orbit around Ganymede. IWF is taking part as Co-I for three different selected instrument packages.

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 magnetized bodies. IWF supplies the atomic scalar sensor for J-MAG, which is developed in collaboration with TU Graz. In 2018, the Engineering Model was tested and delivered to the prime contractor, the design of the Qualification Model was finalized and the Critical Design Review was passed.

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-I 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 RWI antennas, which are part of the Radio and Plasma Wave Investigation (RPWI). In 2018, a so-called rheometry measurement with a scaled JUICE spacecraft model (see figure below) was performed.



The *RWI* antennas, which are located on the long magnetometer boom, are adjusted before the gold-plated 1:40 *JUICE* spacecraft model is put into the rheometry tank.

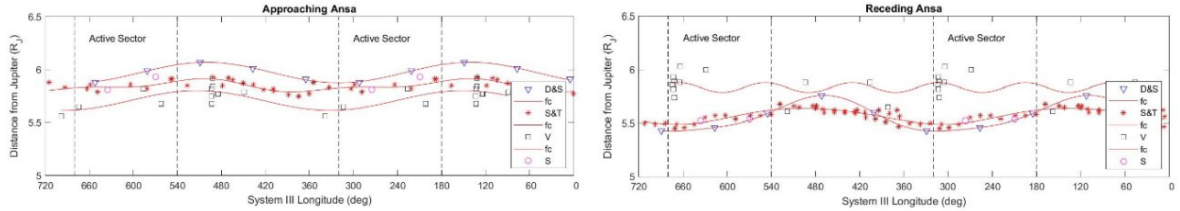
The model was immersed in a water-filled tank with a homogeneous electric field applied to it. By rotation the locations of the maxima and minima of the voltages induced in the RWI dipoles were measured. By using at least two different suspensions of the model, it was possible to derive the so-called effective length vector of each dipole, which describes the reception properties of each antenna in the quasi-static frequency range. The effective length vectors from rheometry were found to be within a few degrees of the result from numerical

computer simulations with JUICE patch-grid models. Only with a calibrated antenna system it will be possible to derive accurate results for the polarization and the incoming wave direction in future radio wave measurements at Jupiter.

THE IO PLASMA TORUS LOCATION: VOYAGER 1 OBSERVATIONS

The Io Plasma Torus (IPT) is a doughnut-shaped gaseous cloud around Jupiter, centered on Io's orbit, consisting mainly of sulfur and oxygen. It is created by the volcanic activity of Io, which spews out 1 ton of SO2 per second into the Jovian magnetosphere. This gas gets dissociated and ionized and thereby creates the IPT. Through unknown processes, this torus is offset from the center of Jupiter, the distances of the approaching and receding side (related to the rotation of Jupiter) of the IPT are different and longitude dependent. Voyager 2 and ground-based observations found average locations of 5.97 RJ (app) -5.59 RJ (rec) and 5.85 RJ (app) -5.57 RJ (rec) respectively. Recently analyzed data from Voyager 1, looking at the IPT from a direction almost perpendicular to Voyager 2, showed again a different location of 5.75 RJ (app) -5.88 RJ (rec). Knowing the average location of the IPT can help to find the reason of the offset.

However, also longitudinal variations in the IPT distance from Jupiter are found, as shown in the figure below. From each observatory the data are fitted by a 2nd order Fourier fit. The approaching side shows that, apart from different average distances, there is a clear similar periodicity in the signals. The receding side, however, shows that the Voyager 1 observations do not follow the periodicity of the other observatories. The reason for this is, as yet, unknown, but it could be related to that the receding side for Voyager 1 is located near the sub-solar point of the Jovian magnetosphere.



Location of the IPT for the approaching (left) and receding side (right) with the data fitted with a 2nd order Fourier fit. For the receding side it is clear that the Voyager 1 observations do not follow the *Voyager 2* or ground based observations.

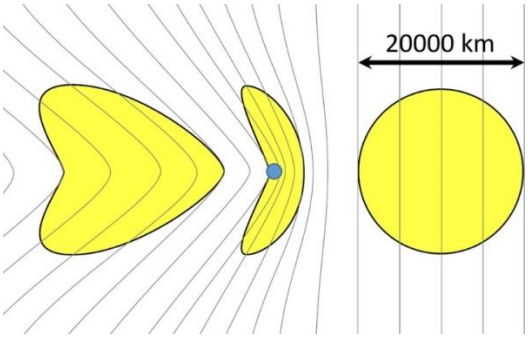
COMETS & DUST

Comets and interplanetary dust are the remainders of the building blocks of the solar system, although dust can also be created by collisions of e.g. asteroids. Rosetta's successful mission at comet 67P/Churyumov-Gerasimenko (67P/CG) gave new life to the study of comets and is the starting point for new future missions to asteroids and comets.

FIRST OBSERVATIONS OF MAGNETIC HOLES DEEP WITHIN A COMET'S COMA

ESA's Rosetta spacecraft made ground-breaking observations of comet 67P/CG and of its cometary environment. Magnetic holes were investigated in that environment. These are significant depressions in the magnetic field strength, measured by the Rosetta magnetometer in April and May 2015. In that time frame of two months, 23 magnetic holes could be identified. The cometary activity was intermediate and increasing because 67P/CG was on the inbound leg toward the Sun. While in April solar wind protons were still observed by Rosetta near the comet, in May these protons were already mostly replaced by heavy cometary ions. Magnetic holes have frequently been observed in the solar wind. It is found, for the first time, that magnetic holes exist in the cometary environment even when solar wind protons are almost absent. Some of the properties of the magnetic holes are comparable to

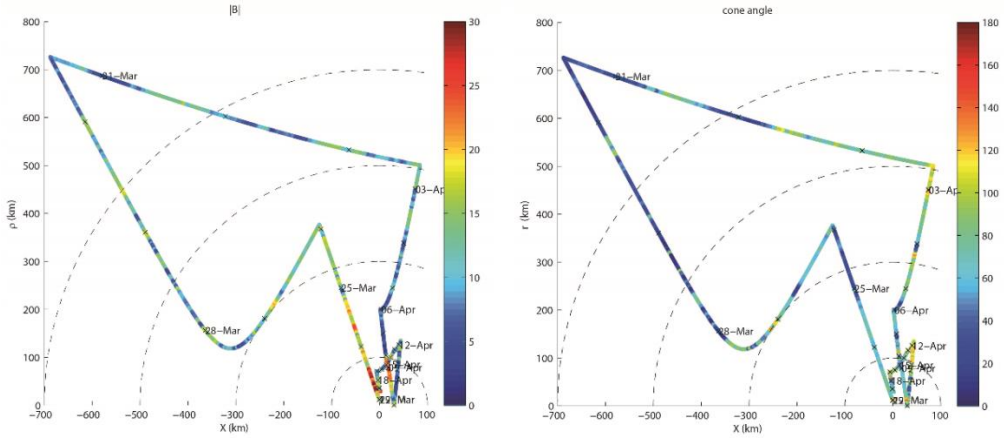
those of solar wind holes; they are associated with density enhancements, sometimes associated with co-located current sheets and fast solar wind streams, and are of similar scales. However, particularly in May, the magnetic holes near the comet appear to be more processed, featuring shifted density enhancements and, sometimes, bipolar signatures in magnetic field strength rather than simple depressions. The magnetic holes are of global size with respect to the coma. Nevertheless, at the comet, they are compressed owing to magnetic field pile- up and draping so that they change in shape (figure). There, the magnetic holes become of comparable size to heavy cometary ion gyroradii, potentially enabling kinetic interactions.



Sketch of the deformation of a magnetic hole (yellow) due to interplanetary magnetic field pile up and draping at the cometary nucleus (position in blue).

ROSETTA TAIL EXCURSION

During Rosetta's two-year mission around comet 67P/CG there were two "far-excursions" from the nucleus, one on the sunward-side and one on the tail-side. The latter took place towards the end of the mission, with the comet already 2.7 AU from the Sun, and therefore at low activity. Nevertheless, some interesting phenomena were found. Close to the comet, i.e. less than 500 km from the nucleus, the magnetic field did not show the classical draping pattern of a bi-lobal tail with magnetic field direction towards and away from the Sun as shown by the cone angle in the figure below.



The magnetic field strength and cone angle plotted along the orbit of Rosetta's tail excursion, in cylindrical coordinates.

The magnetic field was mainly directed perpendicular to the classic tail with a clock-angle (defined as tan-1(Bz/By)) around 100°, indicating a vertical field. This can be explained by the deflection of the magnetic field caused by pick-up of freshly ionized water upstream of the comet, which is transported to the downstream region. Further away from the nucleus the

field reverts to more classical draping. However, also here the field shows something new, the clock angle of the field increases steadily for Rosetta moving away and returning to the comet. This can only be explained by a traveling helical wave moving down the tail at a phase velocity of 136 m/s and an angular frequency around 5.7° per hour. This velocity and frequency does not correspond to any natural values in the plasma around 67P/CG, and thus the origin of this wave is, as yet, unclear.

3 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, the first detected exoplanet orbiting a Sun-like star, about 3900 exoplanets, most in planetary systems, are now known. Improved instrumentation and analysis techniques have led to the finding of smaller and lighter planets, down to Earth-size, Earth-mass planets, some orbiting in the habitable zone of the cooler stars. However, super-Earths 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 in which IWF is involved 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 interactions and carry out atmospheric characterization through the collection and analysis of ground- and space-based observations.

CHEOPS

CHEOPS (CHaracterising ExOPlanet Satellite), to be launched in 2019, will study extrasolar planets and observe planetary systems at an unprecedented photometric precision. The main science goals are to find transits of small planets, known to exist from radial-velocity surveys, measure precise radii for a large sample of planets to study the nature of Neptune- to Earth-sized planets, and obtain precise observations of transiting giant planets to study their atmospheric properties. IWF is responsible for 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. In 2018, IWF participated in the close-out meetings declaring the flight worthiness for the BEE hardware and software. Finally, the CHEOPS spacecraft completed all environmental tests at spacecraft level successfully.

The *CHEOPS* science instrument is ready for shipment after completion of the calibration (© University of Bern).

CUTE

CUTE (Colorado Ultraviolet Transit Experiment) is a NASA- funded 6U-form CubeSat to be launched in the first half of 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 constraining atmospheric escape processes, which are key to understand planetary evolution, and detect heavy metals, which inform on the strengths of the atmospheric vertical velocities. 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, and to measure their strength.

IWF is the only technological contributor to the mission outside of the University of Colorado (Boulder), where CUTE is being developed. IWF has finalized the development of the CUTE data simulator, following a detailed analysis of the optical system and tolerances, and has started to develop the data reduction pipeline.

PLATO

PLATO (PLAnetary Transits and Oscillations of stars) is ESA's third Medium-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 in stars, enabling the precise characterization of the host star, including its age. IWF contributes to the development of the Instrument Controller Unit (ICU) with the development of the Router and Data Compression Unit (RDCU). Launch is expected in 2026.

PLATO consists of 24 telescopes for nominal and two telescopes for fast observations. Each telescope has its dedicated front-end-electronics, reading and digitizing the CCD content. 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 2018 were the finalization of the RDCU prototypes, the continuation with the design of the VHDL code and the development of the test environment. In total three

prototypes have been built, two delivered to the project partners. The FPGA design concentrated on further tests of the SpaceWire core, and the development of the FPGA internal bus system and the memory handler. Thus the preliminary design, providing the full functionality of the compressor, has been completed.

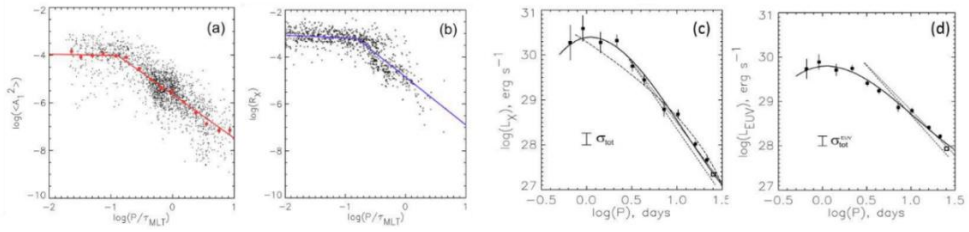
ARIEL

ARIEL (Atmospheric Remote-sensing Exoplanet Large-survey) is ESA's fourth Medium-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.

PHOTOMETRIC STELLAR ACTIVITY AND STARSPOT DIAGNOSTICS

Stellar X-ray emission plays an important role in the study of exoplanets as a proxy for stellar winds and as a basis for predictions of the EUV flux, unavailable for direct measurements. These are crucial factors, affecting the mass-loss of planetary atmospheres. The detection thresholds limit the number of stars with directly measured X-ray fluxes. In spite of that, the known connection between the sunspots and solar X-ray sources enables the development of an accessible proxy for the X-ray emission on the basis of the starspot variability. To realize this approach, the light curves of 1729 main-sequence stars from the Kepler data archive with rotation periods 0.5 < P < 30 days and effective temperatures 3236 < Teff < 7166 K have been analyzed. The squared amplitude of the first rotational harmonic of a stellar light curve A12 may be used as an activity index, related to a varying number of starspots (figure a). Being averaged, A12 reveals practically the same connection with the Rossby number as the commonly used ratio Rx of the X-ray to bolometric luminosity (figure b). As a result, the regressions for stellar X-ray luminosity Lx(P) (figure c) and its related EUV analogue, LEUV(P) figure d), were obtained for the main-sequence stars. These regressions predict the average values of log(Lx) and log(LEUV) with typical errors of 0.26 and 0.22, respectively.



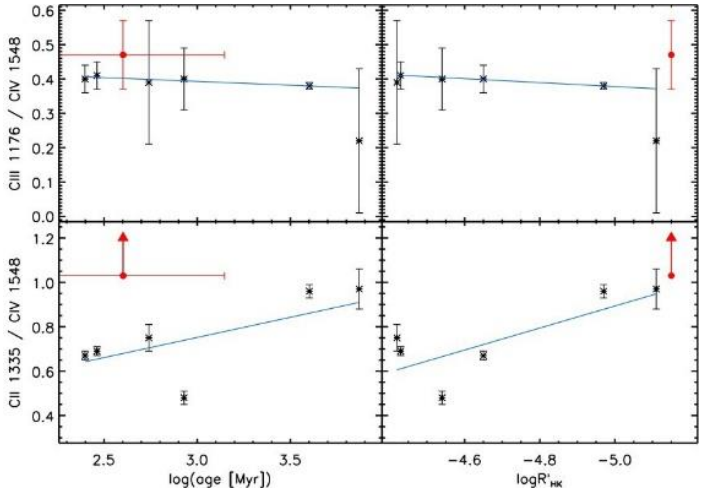
Stellar activity indexes vs. the Rossby number averaged over the squared amplitude of the first rotational harmonic of the stellar light curves (a) and normalized to the X-ray luminosity (b). Solid line: predicted $L_x(P)$ (c) and $L_{EUV}(P)$ (d) for stars with T_{eff} = 5770 K; solid squares: averaged predictions for individual stars with 5500 < T_{eff} < 6000K.

SUPPRESSED FUV STELLAR ACTIVITY AND LOW PLANETARY MASS LOSS

WASP-18 hosts a massive, very close-in Jupiter-like planet. Despite its young age (< 1 Gyr), the star shows an anomalously low stellar activity level: the measured logR′HK activity parameter lies slightly below the basal level, there is no significant time-variability in the logR′HK value, and there is no detection of X-ray emission. Far-ultraviolet Hubble Space Telescope (HST) observations of WASP-18, obtained with the Cosmic Origins Spectrograph (COS) have been used to explain this anomaly.

The interstellar extinction, E(B-V), towards the star's line of sight has been measured, deriving a low value of 0.01 mag. This result has then been used to derive the interstellar medium (ISM) column density for a number of ions, concluding that ISM absorption is not the origin of the anomaly. The COS data have been used to measure the flux of the four stellar emission features detected in the spectrum, namely C II, C III, C IV, and Si IV. Comparisons of the C II/C IV flux ratio measured for WASP-18 with that derived from spectra of nearby stars with known age and similar spectral type showed that the far-UV spectrum of WASP-18 resembles that of old (>5 Gyr), inactive stars, in stark contrast with its young age (see figure).

Therefore, it is most likely that WASP-18 has an intrinsically low activity level, possibly caused by star–planet tidal interaction. Re-scaling the solar irradiance reference spectrum to match the flux of the Si IV line, yielded a high- energy integrated flux at the planet orbit of 10.2 erg s−1 cm−2. A hydrodynamic upper atmosphere code has been used to derive the planetary mass-loss rate obtaining a value of 10−20 Jupiter masses per Gyr. For such high-mass planets, thermal escape is not energy limited, but driven by Jeans escape.

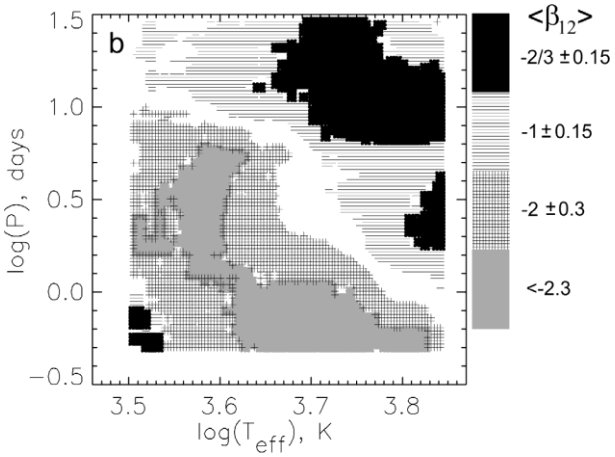


Top panel: C III/C IV flux ratio as a function of stellar age (left) and logR′$_{HK}$ value (right). WASP-18 is marked by a red circle, while the comparison stars are marked by black asterisks. The blue solid line shows the linear fit obtained by fitting the position of the comparisons stars. Bottom panel: same as the top panels, but for the C II/C IV flux ratio. Because of the possible contamination by the ISM, the C II/C IV flux ratio of WASP-18 is a lower limit.

STARSPOT VARIABILITY TIMESCALES

The stability of starspot distributions over hemispherical scales was studied by the analysis of the rotational spot variability of 1998 main-sequence stars observed by Kepler. It is found that in cool and fast rotators the large-scale activity patterns are much more stable than the small ones, whereas for hotter and/or slower rotating stars such difference is less pronounced. This effect is explained in terms of two mechanisms: (1) the diffusive decay of long- living spots in activity complexes of stars with a saturated magnetic dynamo, and (2) the spots emergence, modulated by turbulent gigantic convection flows in stars with weaker magnetism. This opens a way for the investigation of stellar deep convection, which is inaccessible for astroseismology. Moreover, an effect of sub-diffusion in stellar photospheres, characterized by the nonlinear dependence of the squared displacement of a magnetic element with time, was revealed from observations for the first time.

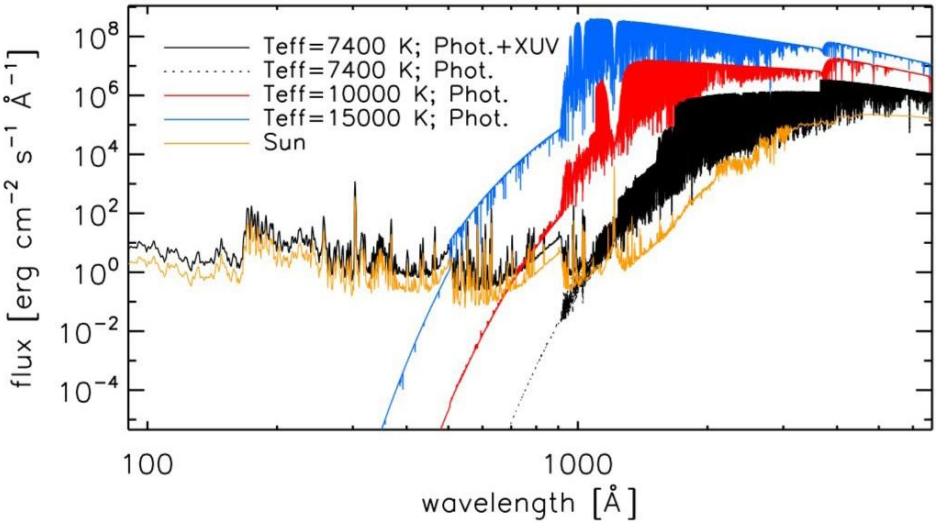
A diagnostic diagram (see figure) was proposed that differentiates stars in the P-Teff parameter space with respect to the dominating mechanism of their spot variability quantified in terms of the gradient function β12 = [log(τ2) – log(τ1)]/log(2), where τ2 and τ1 are the time-scales of variability of the squared amplitudes of first and second rotational harmonics of the stellar light-curve. The values of β12 = -2/3, -2, < -2, and -1 correspond to the domination of Kolmogorov-like turbulence, magnetic diffusion, sub-diffusion, and differential rotation, respectively.



Diagnostic diagram of stellar sample with respect to a dominating mechanism of spot variability.

EUV RADIATION FROM A-TYPE STARS: EFFECTS ON ULTRA-HOT JUPITERS

Extremely irradiated, close-in planets to early-type stars might be prone to strong atmospheric escape. A thorough literature review of X-ray-to-optical measurements has been performed, showing that for intermediate-mass stars (IMS) cooler than about 8250 K, the X-ray and EUV (all together XUV) fluxes are on average significantly higher than those of solar like stars, while for hotter IMS, because of the lack of surface convection, it is the opposite. Spectral energy distributions (SEDs) for prototypical IMS have been constructed and compared to solar (see figure). The XUV fluxes relevant for upper planet atmospheric heating are highest for the cooler and lowest for the hotter IMS, while the UV fluxes increase with increasing stellar temperature.



Comparison between non-LTE SEDs computed for IMS with temperatures of 7400 K (black) and 10000 K (red), and for the Sun (orange) and a 15000 K star (blue).

The influence of this characteristic of the stellar fluxes on the mass loss of close-in planets has been evaluated by simulating the atmospheres of planets orbiting EUV-bright (WASP-33) and EUV-faint (KELT-9) A-type stars. For KELT- 9b, the atmospheric expansion caused by heating due to absorption of the stellar UV and optical light drives mass- loss rates of the order of 1011 g s−1, while heating caused by absorption of the stellar XUV radiation leads to mass-loss rates of the order of 1010 g s−1, thus underestimating mass loss. For WASP-33b, the high XUV stellar fluxes lead to mass-loss rates of the order of 1011 g s−1. Even higher mass- loss rates are possible for less massive planets orbiting EUV-bright IMS. It has been concluded that it is the weak XUV stellar emission, combined with a relatively high planetary mass, which limit planetary mass-loss rates, to allow the prolonged existence of KELT-9-like systems.

PRIMORDIAL ATMOSPHERES

Evidence that the growth time of proto-Venus and -Earth determined whether they originated after the nebular gas evaporated or whether they grew to larger masses while they were embedded in the nebula was investigated. In the later case, hydrogen could be captured around the protoplanet before the disk disappeared. Significant amounts of noble gases have been trapped from the protoplanetary disk, and were left in solar composition in the interiors of early Venus and Earth. Solar-like isotopes, which are embedded in the nebular gas, can enter the planetary interior via magma oceans that formed below the accumulated H2-dominated envelopes. That early Venus and Earth evolved from primordial atmospheres is also in agreement with measurements of Ne isotopes in today's Earth atmosphere and the discovery of a huge number of exoplanets with masses slightly larger than the terrestrial planets but with over-sized radii. This indicates that nebular-based H2-envelopes are a common phenomenon on small planets.

The figure below illustrates the disk-captured protoatmospheres. The massive H2/He atmospheres of large planets such as Jupiter, Saturn, Uranus and Neptune were formed because of gas capture onto rock and ice-dominated cores, while a much smaller H2-envelope was lost via thermal escape from early Venus and Earth.

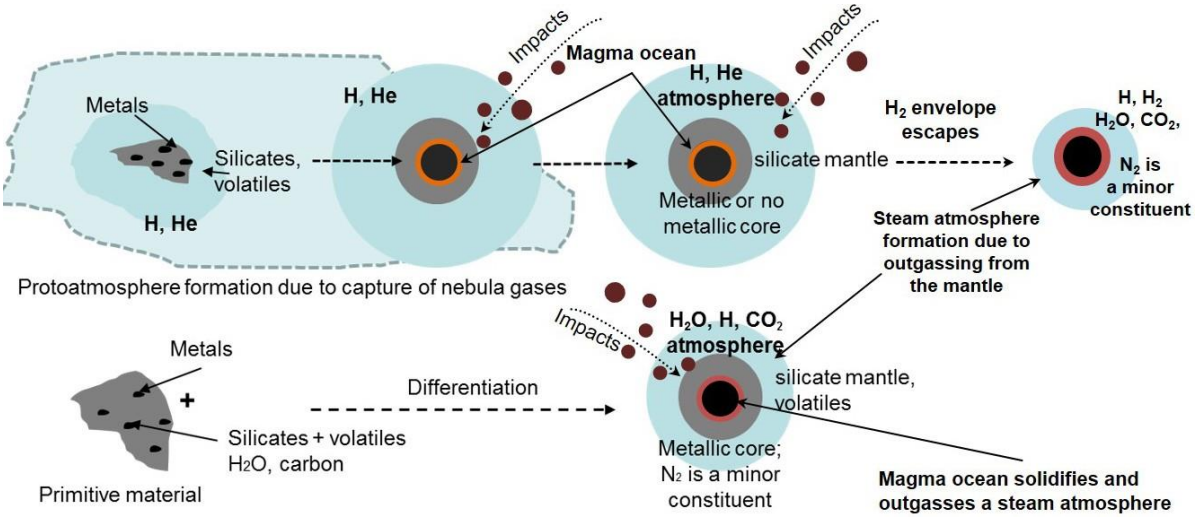
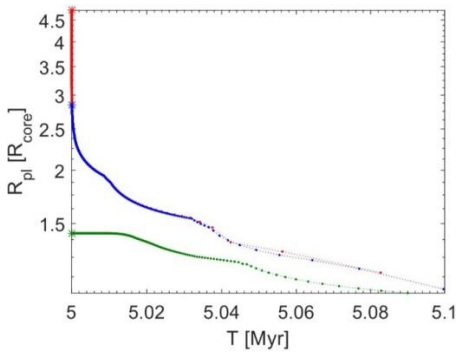


Illustration of two protoatmosphere formation scenarios for terrestrial planets. The upper scenario illustrates the capture of nebula gases and the accumulation of H_2-dominated protoatmospheric layers around a protoplanetary core. In the case of protoplanet core masses that are < 1 M_{Earth}, the nebular gas can be lost to space via thermal boil off and EUV-driven hydrodynamic escape.

GRID OF UPPER ATMOSPHERE MODELS FOR EARTH-MASS PLANETS

There is growing observational and theoretical evidence suggesting that atmospheric escape is a key driver of planetary evolution. Commonly, planetary evolution models employ simple analytic formulae (e.g., energy limited escape) that are often inaccurate, and more detailed physical models of atmospheric loss usually only give snapshots of an atmosphere's structure and are difficult to use for evolutionary studies. To overcome this problem, an existing upper atmosphere hydrodynamic code has been employed and updated to produce a large grid of about 7000 models covering planets with masses ranging between 1 and 39 Earth masses with hydrogen-dominated atmospheres and orbiting late-type stars. The modeled planets have equilibrium temperatures ranging between 300 and 2000 K. For each considered stellar mass, three different values of the high-energy stellar flux (i.e., low, moderate, and high activity) have been accounted for.

For each computed model, the atmospheric temperature, number density, bulk velocity, X-ray and EUV (all together XUV) volume heating rates, and abundance of the considered species as a function of distance from the planetary center have been derived. From these quantities, the positions of the maximum dissociation and ionization, the mass-loss rate, and the effective radius of the XUV absorption have been derived. The obtained results are in good agreement with previously published studies employing similar codes. An interpolation routine capable to extract the modeling output parameters for any planet lying within the grid boundaries has been developed. The model grid has been used to identify the connection between the system parameters and the resulting atmospheric properties. Finally, the interpolation routine has been employed to estimate atmospheric evolutionary tracks for the close-in, high-density planets CoRoT-7 b (see figure) and HD 219134 b,c. Assuming that the planets ever accreted primary, hydrogen-dominated atmospheres, the three planets must have lost them within a few Myr.

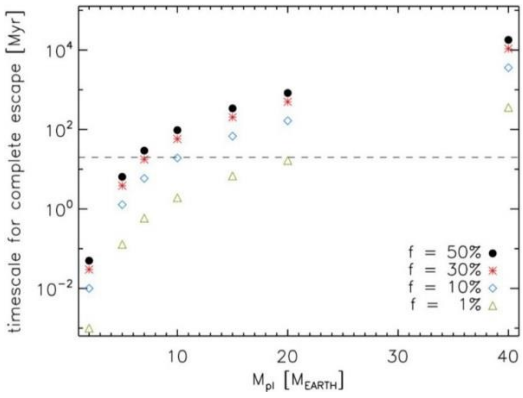


Evolution of the planetary radius of CoRoT-7 b as a function of time. The colors indicate different initial radii, marked by the asterisks, which correspond to the values obtained by setting the restricted Jeans escape parameter Λ equal to 3 (red), 5 (blue), and 10 (green). The small dots placed along each line indicate the time steps.

YOUNG EXOPLANETS UNDER EXTREME UV IRRADIATION

The K2-33 planetary system hosts one transiting 5 Earth radii planet orbiting its young M-type host star. The planet's mass is still unknown, with an estimated upper limit of 5.4 Jupiter masses. The extreme youth of the system (< 20 Myr) gives the unprecedented opportunity to study the earliest phases of planetary evolution, at a stage when the planet is exposed to an extremely high level of high-energy radiation emitted by the host star. A series of 1D hydrodynamic simulations of the planet's upper atmosphere have been performed, considering a range of possible planetary masses, from 2 to 40 Earth masses, and equilibrium temperatures, from 850 to 1300 K, to account for internal heating as a result of contraction.

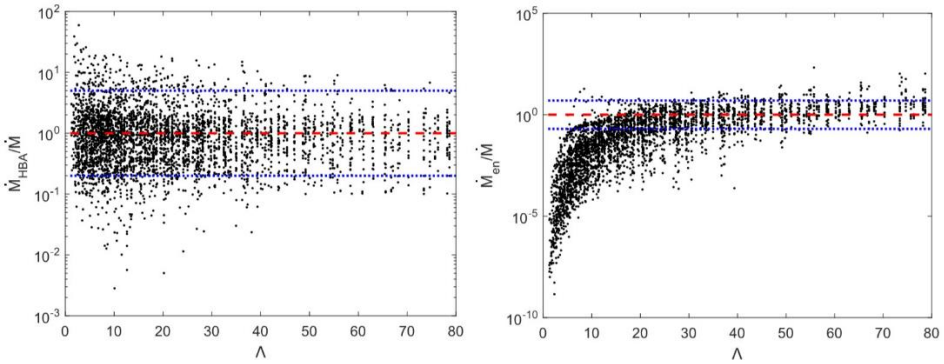
The main result is that the temperature profiles are mostly controlled by planetary mass, while the equilibrium temperature has a secondary effect. For planetary masses below 7-10 Earth masses, the atmosphere is subject to extremely high escape rates, driven by the planet's weak gravity and high thermal energy, which increase with decreasing mass and/or increasing temperature. For higher masses, the escape is, instead, driven by the absorption of the high-energy stellar radiation. A rough comparison of the timescales for complete atmospheric escape and age of the system indicates that the planet is more massive than 10 Earth masses (see figure).



Timescale, in Myr, estimated for the complete escape of a hydrogen- dominated atmosphere as a function of planetary mass, assuming four different values of the atmospheric mass fraction f of 50% (black dot), 30% (red asterisk), 10% (blue diamond), and 1% (green triangle). The horizontal dashed line indicates the maximum age (i.e. 20 Myr) derived for the K2-33 system.

ENERGY-LIMITED APPROXIMATION FOR PLANET ATMOSPHERIC ESCAPE

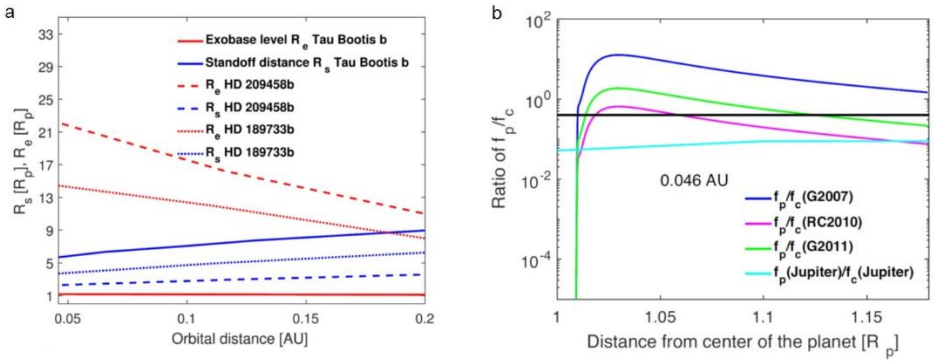
Studies of planetary atmospheric composition, variability, and evolution require appropriate theoretical and numerical tools to estimate key atmospheric parameters, among which the mass-loss rate is often the most important. In evolutionary studies, it is common to use the energy- limited formula, which is attractive for its simplicity, but ignores important physical effects and can be inaccurate in many cases. To overcome this problem, a recently developed grid of about 7000 one-dimensional upper- atmosphere hydrodynamic models has been considered to extract the mass-loss rates. An analytical expression for the atmospheric mass-loss rates based on a fit to the values obtained from the grid has been then derived. The expression provides the mass-loss rates as a function of planetary mass, planetary radius, orbital separation, and incident stellar high-energy flux. It has been shown that this expression is a significant improvement to the energy-limited approximation for a wide range of planets (see figure). The analytical expression enables significantly more accurate planetary evolution computations without increasing computing time.



Left: Ratio between the mass-loss rates obtained from the approximation based on hydrodynamic models and from the hydrodynamic grid as a function of the restricted Jeans escape parameter Λ. Right: Same as top, but for the mass-loss rates derived from the energy-limited formula. In both panels, the red line is at one, while the blue lines are at values of 5 and 0.2. Note the difference in the scale of the y-axis between the two plots.

RADIO PROPAGATION: SUPERMASSIVE HOT JUPITER

It was investigated if supermassive hot Jupiters such as Tau Bootis b provide better conditions for radio emission than less massive hot Jupiters. Planets like Tau Bootis b at different orbital locations (between its actual orbit of 0.046 and 0.2 AU) were studied. Due to the strong gravity of such planets and efficient radiative cooling, the upper atmosphere is (almost) hydrostatic and the exobase remains very close to the planet. The figure shows that hot supermassive planets are expected to have conditions that are more favorable for the generation of radio emission via the cyclotron maser instability than ordinary hot Jupiters such as HD 209458b and HD 189733b.



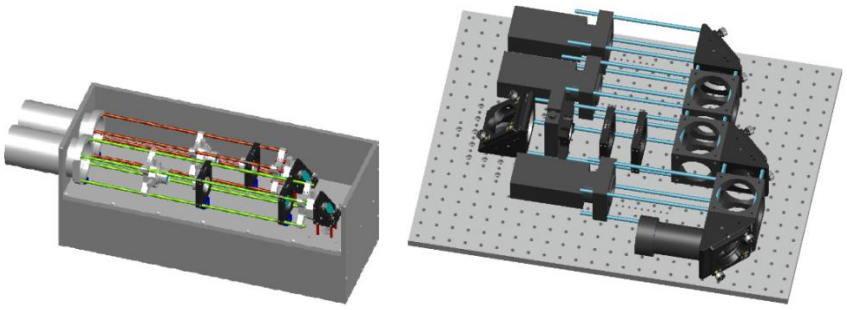
Panel a: Exobase levels R_e compared to magnetopause standoff distances R_S as a function of magnetic moments predicted for Tau Bootis b and the ordinary hot Jupiters HD 209458b and HD 189733b.
Panel b: Ratio of plasma to cyclotron frequency for Tau Bootis b with different estimated magnetic moments compared to Jupiter at 5 AU.

4 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. Highlights include the Expert Coordination Center, the build-up of a new SLR station on Tenerife and attitude measurements to Galileo satellites within the Alcantara Initiative.

NEW SLR STATION ON TENERIFE

In cooperation with an international consortium from Austria, Germany, Latvia, and Switzerland the Graz SLR station is involved in the design and build-up of the first ESA SLR station located in 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. IWF 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 a 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. Furthermore, IWF develops the detection package, which consists of two single photon avalanche diode detectors (for green and infrared wavelength), an optical camera (for monitoring reflected sunlight from satellites) and an optional light curve detection system. The whole SLR system is built in a highly modular way, future extension of the system includes e.g. a space debris laser module (laser and dedicated single photon detector).



Final design of the detection package and the laser package with expansion optics (left image) to be installed in Teide on Tenerife.

EXPERT COORDINATION CENTER

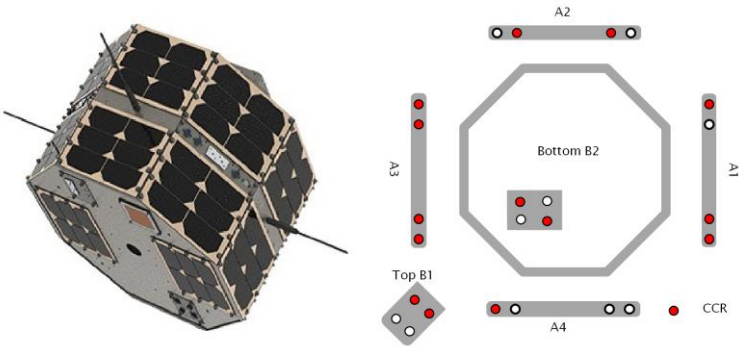
The second phase of the Expert Coordination Center started in 2018 consisting of experts for optical observations (Astronomical Institute of Bern, Czech Technical University in Prague, SpaceDys) and space debris laser ranging (Graz SLR Station). The main task of the Expert Center is to coordinate external stations, in terms of observation scheduling/tasking and data delivery.

The Graz SLR station is currently developing a validation routine for "passive-only" SLR stations. Within bi- or multi- static measurements, it is firing its new space debris laser (directly mounted on the telescope, less alignment, easier handling) to a target with well-known orbit (e.g. Envisat). Passive stations receive diffusely reflected photons by opening their detector exactly correlated to the starting and travel time of the photon in Graz. For passive stations there is no need to act as a fully operating SLR station, they only monitor incoming photons from other stations. The offsets with respect to the Envisat reference orbit (calculated by using highly accurate standard SLR measurements) are determined and RMS and standard deviation calculated. The developed validation tools run on a virtual machine at IWF and can be easily accessed by Expert Center operators. Further software developed by IWF includes a conversion tool from Two Line Element to Consolidated Prediction Format data sets, which are commonly used by SLR stations. Additionally an ftp download tool for the retrieval of SLR data is provided.

TECHNOSAT AND S-NET DESIGN

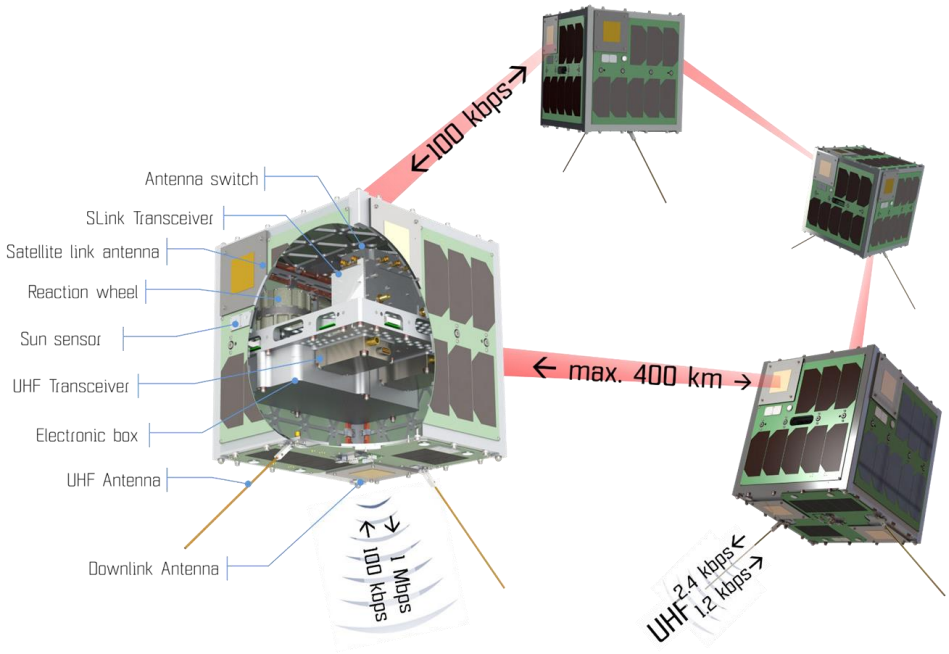
The interest in small spacecraft has been rising rapidly over last years. The application of miniaturization techniques, compact designs, and low-cost COTS (commercial off-the- shelf) components brings more affordable opportunities in space activities for small institutions and companies. Laser ranging is used not only for traditional precise orbit determination, but also for attitude and attitude motion analysis during or even after the spacecraft's lifetime. Satellites are equipped with an exclusive distribution of Corner Cube Retroreflectors (CCRs) on different sides.

TechnoSat (see figure below) and the S-Net series (four satellites) are developed and built by the Technical University of Berlin and were launched into a lower Earth orbit in 2017 and 2018, respectively. The Graz SLR station designed and simulated the ideal distribution of CCRs, which was tested before launch at a remote location outside of Graz. In orbit, the attitude of TechnoSat varies from freely spinning, nadir- pointing or off-nadir-pointing alternately according to the demands of different tasks. The attitude results based on Graz kHz SLR data are analyzed and compared to the records from its on-board gyroscope.



***TechnoSat:* 14 small CCR (fused silica, COTS) are distributed on six different surfaces of its octagonal prism structure giving the satellite a unique kHz SLR signature.**

For S-Net series, in addition to precise orbit and attitude determination, Graz kHz SLR is used to identify single satellites shortly after their separation from the launcher even when the individual satellites are close together.

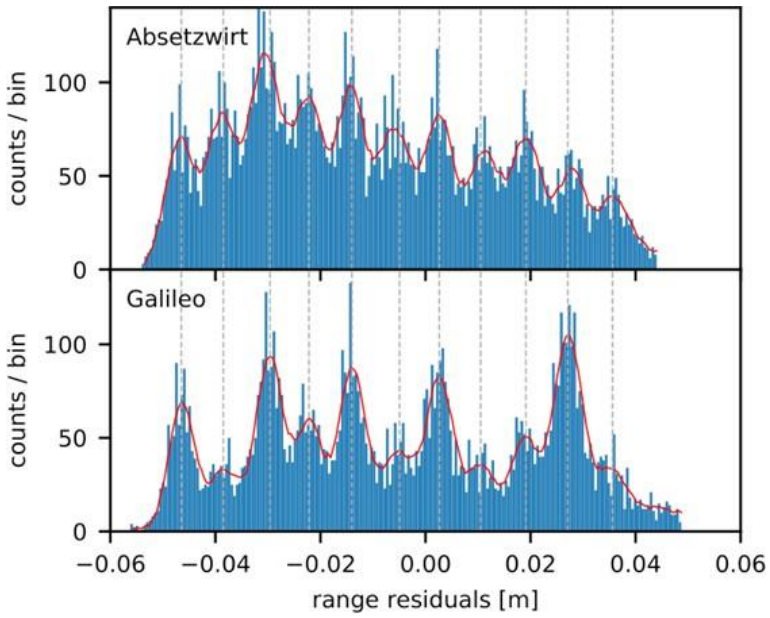


S-Net: **Five sides of each of the four satellites are identical and equipped with one CCR. The sixth side of each satellite has a different and unique pattern to distinguish the satellites from each other.**

GALILEO ATTITUDE DETERMINATION

Within the ESA Alcantara Initiative the Graz SLR station at Lustbühel had the chance to perform ground-based measurements to a spare Galileo retroreflector panel. The panel was mounted on an astronomical tripod and could be rotated between 0 and 18° with steps of 0.1°. It was placed on a hill 32 km outside of Graz (Absetzwirt), and ground-based range measurements were performed. The histogram of the measurement (with a tilt angle of 12.4° around the panel z-axis) is presented in the figure below. It shows the number of detected photons within range bins of 500 µm. Due to the tilt of the panel 11 distinguishable peaks appear at distances of up to 6 cm with respect to the panel center. The distances between each of these peaks is determined and from that the panel tilt can be calculated with high accuracy.

Galileo satellites pass in various different tilt angle conditions over Graz. Navigation satellites are continuously rotated around their nadir pointing axis to ensure alignment to the sun (Yaw-steering). A specific orientation (elevation 11.38°, azimuth 90°, station seen from the satellite reference frame) was chosen exactly corresponding to the incident angle conditions measured with the spare panel. The peak positions of the measurements to Galileo match very well compared to the ground-based tests. From the peak distances the panel tilt was verified to be 11.37° which is accurate within 0.1° to the calculations. The variation in peak height at the Galileo measurement results from reflections from differently clocked (rotated) retroreflectors. The proposed method gives unique way for validating attitude accuracy of Galileo satellites.



Comparison of the ground-based range measurements to the *Galileo* spare panel (Absetzwirt) to *Galileo* 103 with similar incident angle conditions.

5 PUBLIC OUTREACH

IWF is actively engaged in science education and public outreach. In 2018, many different groups and school classes visited the institute and were guided through the labs and the planetary garden.

IWF was partner in the "FFG-Talente-Regional" project "Freiflug - Die Geheimnisse des Fliegens". From January through March, the traveling exhibition on aerospace for children and young adults was displayed at the institute. Several schools and individual visitors spent time investigating the history of (space)flight.

Man at work during the "Freiflug" exhibition at IWF.

The Austrian "Lange Nacht der Forschung" on 13 April broke all records. With more than 3000 people, IWF doubled the number of its visitors with respect to 2014. Different stations offered a taste of research for each age category: The youngest could build rockets and design their own planets whereas for the older visitors space physics was experimentally explained. Non-stop lectures and laboratory tours completed the program. The Austrian broadcasting service ORF sent its "Radio Steiermark Kinderreporter", who made a report on

"adventures in the solar system". IWF would like to say "DANKESCHÖN" to Petra Huber and her team from Kinderbüro and Johannes Kügerl and his students from BG/BRG Kirchengasse, who helped coping with the enormous stream of visitors.

The crowded IWF headquarters during the "long night of research".

Starting in May, IWF were invited to write monthly science blogs for the Austrian newspaper "Der Standard", which had a great response from online readers. Topics discussed so far were InSight, magnetometer testing for JUICE, cometary tails, extraterrestrial life, and MMS.

During summer time, seven high-school students performed an internship at IWF under the "Talente- Praktika" program of FFG. They worked on space weather, comet Halley, PICAM calibration, solar type III radio bursts, Rosetta/MIDAS data archiving, and VLF data analysis. In the framework of the "FEMtech" program of FFG, six female students from KFU Graz and University of Vienna worked at IWF on space debris, MMS data analysis, dust, and preparations for the exoplanet missions CHEOPS and CUTE.

On 20 October BepiColombo was started, which was celebrated with a (pre-)launch event at IWF. On the eve of the launch, around 100 people listened to several talks about IWF's contribution to this mission. Andreas Geisler, head of FFG's Aeronautics and Space Agency, conveyed supporting greetings from Federal Minister Norbert Hofer. About 50 "night owls" followed the institute's invitation to watch live BepiColombo's take-off at 03.45 CEST.

During November, ESA Director General Jan Wörner invited the European space family to promote with a new outreach experience called "Space Talk". IWF sent out Irmgard Jernej, Günter Kargl, Werner Magnes, Harald Ottacher, and Martin Volwerk to present their work in three Austrian states.

AWARDS & RECOGNITION

In January, Rumi Nakamura was elected as a regular member of the European Academy of Sciences and Arts and in December she was elected as Fellow of the American Geophysical Union (AGU).

In May, the Styrian government awarded IWF director Baumjohann the Decoration of the province of Styria for science, research and art and in October the International Academy of Astronautics (IAA) awarded him the "Basic Science Award".

IWF reached the top five nominations for the Styrian WKO (Austrian Economic Chambers) PR Panther in the category "science" with the PR project "Mit Bepi zum Merkur".

Part of the IWF *BepiColombo* team during the PR Panther ceremony (Photo: Jorj Konstantinov).

MEETINGS

From 6-7 September, the Summer University "Graz in Space" was organized by IWF, the Commission for Astronomy, and the Institute of Physics of the University of Graz. The program concentrated on extrasolar planets, the Sun and space weather, and on Rosetta.

Wolfgang Baumjohann served as Vice Director and chair of the Program Committee of the Summer School Alpbach, which took place from 17 to 26 July and was dedicated to "Sample return from small solar system bodies". Every year, 60 students and about 25 lecturers and tutors from among ESA's member states are invited to this meeting.

From 23 to 25 October, IWF organized the MMS Fall Science Working Team (SWT) Meeting at Schloss Seggau.

Participants of the MMS SWT Meeting (Photo: James F. Spann, NASA).

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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 new facilities at TFZ in Wiener Neustadt (new tank for liquid nitrogen)

New Clean Room based Thermal vacuum test capabilities at AAC

AAC recently upgraded its TVAC-test capabilities by a new clean room (ISO class 7) allowing handling of hardware under clean conditions. This enables thermal endurance and -cycling test, and functional tests by TVAC-chambers attached to the clean room. Usual temperatures are between -150 to +150 °C, and can be offered at AAC in two vacuum chambers TVC and XVC for materials and components in high vacuum. The different sizes of the chambers allow tests from small material samples up to large satellite components of around 1 m³.

New Clean room Class 7 at AAC, one of two attached TVAC-chambers

AAC has been (re-)awarded a frame-contract on the ***Space Materials Testhouse*** for ESTEC for another 5 years. The first targets is to extend the cold welding expertise from general testing of coatings / materials to avoid cold welding. Also a new initiative was started on stress corrosion cracking on a new type of material made by additive manufacturing.

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). AAC is contributing to several (national) and ESA-funded projects, among others with partners FOTEC (A), RHP(A). The main objective of one ESA-funded activity (ALM4SME) is to evaluate the manufacturing of large structures for space applications, in this case a part of the support structure for the ATHENA mirror manufactured by RHP, measuring the dimensional accuracy at Fotec and testing the mechanical properties of cut-out samples at AAC.

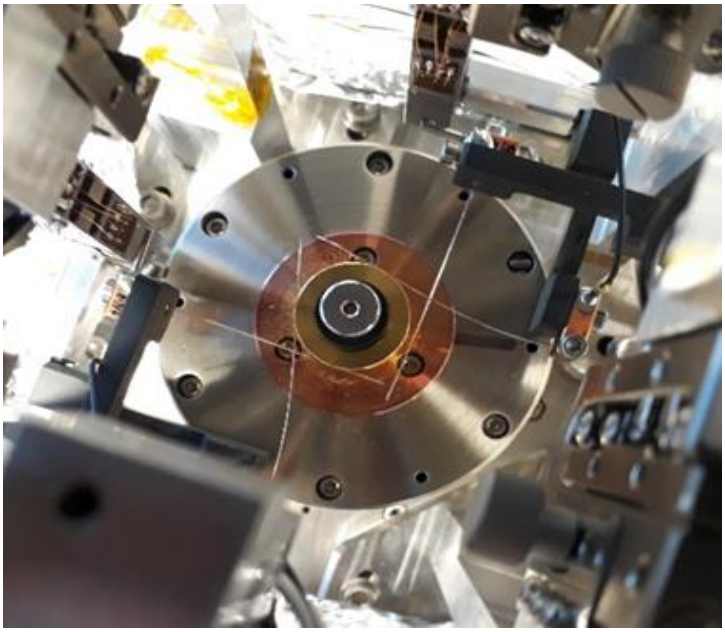
ATHENA mirror support structure courtesy of RHP

New electrical contact materials selection and assessment for sliding electrical transfer applications

Currently several activities on investigation of electrical properties of contact materials / material pairings are running at AAC. One of them focuses on the development of the pair of materials/coating to be used for sliding electrical contact (both on the stator and rotor sides) in slip-rings for space. This activity proposes to identify, select and finally test the most promising European material pairs that could be used for future sliding electrical contact applications.

Previously AAC did investigations in order to select suitable material pairings for slip-rings and potentiometers of high temperature rotary joint ("HTRJ") for BepiColombo project, followed by testing of BB and EM containing promising material pairings. In HTRJ, the feasibility of a slip-ring BB under high vacuum and 300 °C could be shown. A further activity was "Advanced Slipring Solutions - ASR". Within ASR, some complete slip-ring stacks were tested under vacuum and elevated temperature.

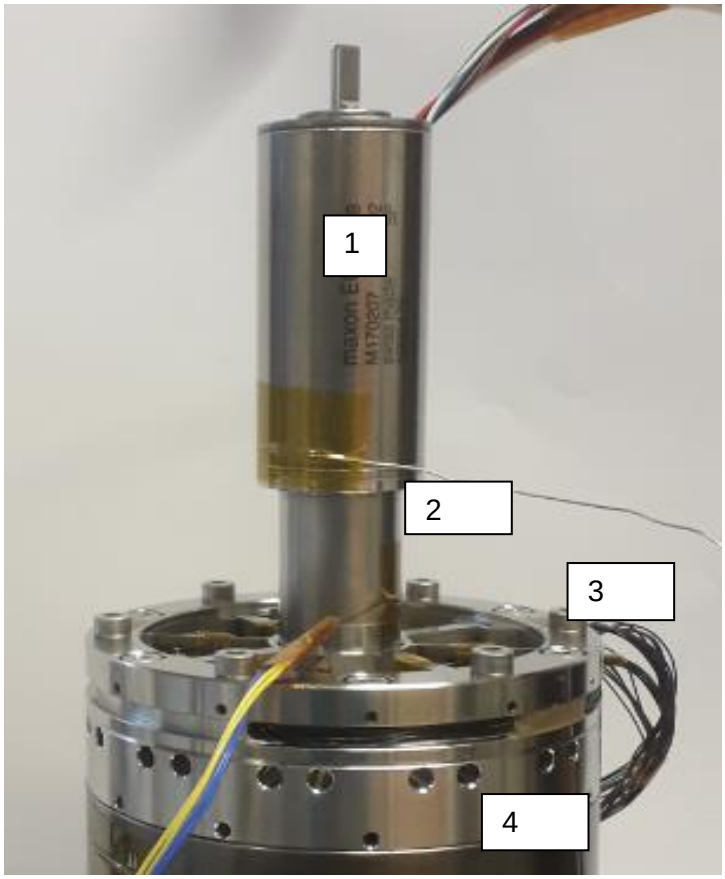
For more than 10 years, AAC is testing sliprings in an still ongoing project which had several new products as an outcome.



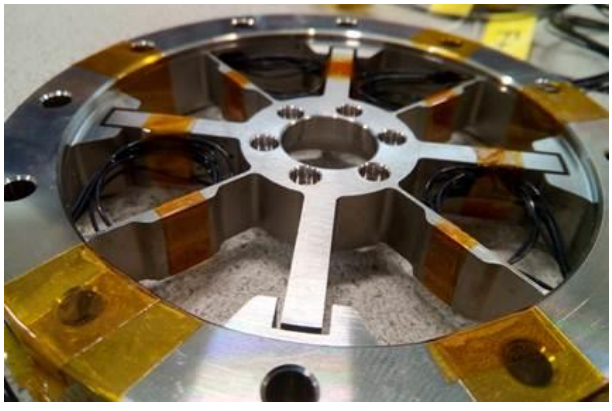
Test device for sliprings in thermal vacuum: SALOTTE 2

Advanced components and gear testing at low temperatures

With further progress in gear testing done for high and low temperatures, vacuum (<10^{-6} mbar) and Martian conditions (~15 mbar atmosphere of CO_2) new fields of testing were opened. A combination setup ("Full combo") containing an electrical motor, a planetary gear and a harmonic drive gear was tested under Martian conditions as mentioned above and a temperature range of -5 to -80 °C. To simulate a typical cycle at Mars, a temperature cycling and a periodical stop & go for the electrical motor was done. During this test, the temperatures of the motor, the housing of the planetary gear and the housing of the harmonic drive gear was logged to determine any thermal influence of the motor. For a detailed analysis of the efficiency it was not only necessary to measure the input and output torque of the whole setup, also the torque in between the output of the planetary gear and input of the harmonic drive ® gear was important. Without this parameter, it wouldn't have been possible to determine if either a decrease of efficiency was caused by motor, planetary gear or harmonic drive ® gear. For this application, no "off-the-shelf" solution could be found. For this reason, AAC decided to design and manufacture a custom made torque ring sensor for static measurement based on strain gauges. Simulations were made to determine dimensions of the torque sensors and adjust the sensitivity of the sensor to the desired measurement range of +/- 500 mNm. The application of the strain gauges consisting out of 4 full bridges was done successfully. Find below a picture of the described torque ring sensor in its final state.

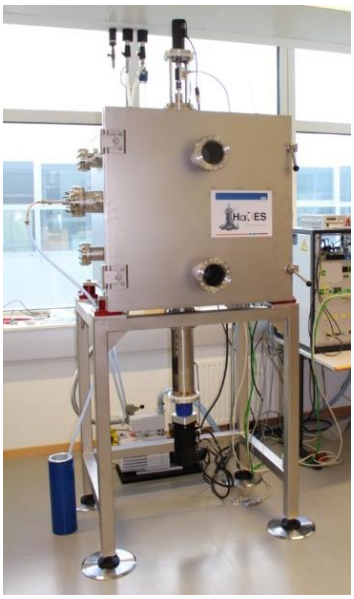


"Full Combo"
1 … Motor
2 …Planetary gear
3 … AAC Torque ring
4 … Harmonic drive gear with test box



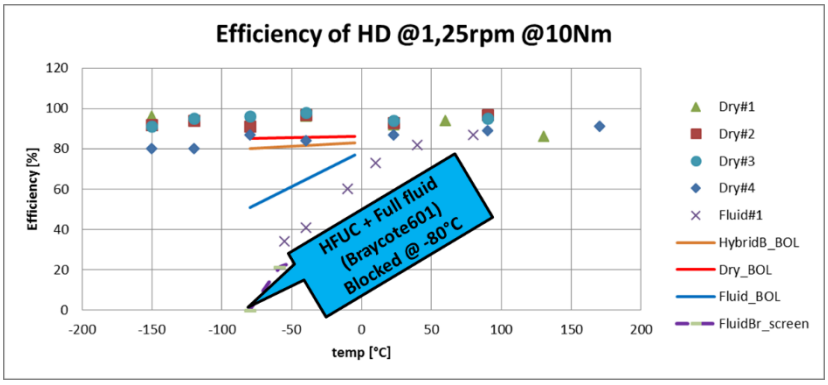
AAC Torque ring sensor

Lubrication at low temperatures



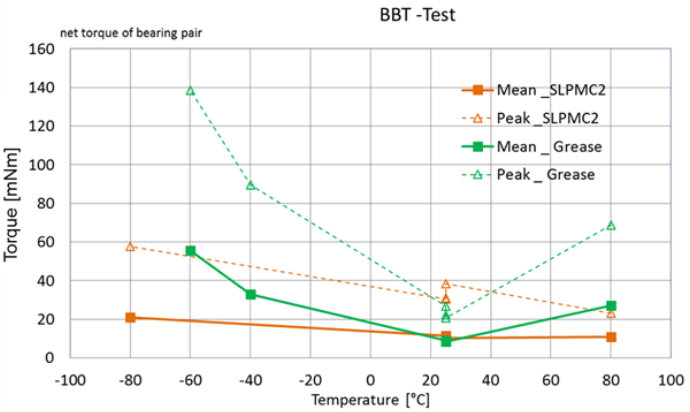
HaDES

AAC is involved in several ESA-projects which deal with the development of lubrication concepts for low temperatures. The new device named HaDES (**Ha**rmonic **D**rive **E**xperimental **S**etup) enables to test harmonic-drive ® gears in a very efficient way by use of an existing “standard gear box”.



Efficiency of Harmonic Drive ® gears

Within the project HDGSA several Harmonic Drive ® gears in different configurations are characterised in detailed for their efficiency in wide temperature ranges (from -150°C to +170°C). The project “Mechanisms working at low temperatures” is focusing on the temperature for Martian rovers (-80 to -5°C). It could be proven that the high efficiency of solid lubricated HDs is maintained over the whole temperature range. Fully fluid lubricated gears show a clear decrease of efficiency when temperature decreases. On the other hand, compromise can be achieved when combining solid and fluid lubrication: “hybrid” means that the interfaces are either fluid or solid lubricated. The De-Risk-project “A3Lub” has shown that replacing fluid lubrication in ball bearings by solid lubrication can widen also the temperature range of deployment mechanisms: no need to heat the bearing before deployment. BEarigns were only equipped with a cage made of a new PTFE-based material by ENSINGER SINTIMID.



Low torque of ball bearings using solid lubrication: no need to heat before deployment

Sales 2018: 1.3 M€
ESA Share: 0. 4 M€

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3.3 Atos Convergence Creators GmbH

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.

Atos Convergence Creators GmbH acts as an independent company that combines end-to-end IT and Industry Solution and Service competence for Communication, Media, Space, Avionics & Technology. Among the four Business Units of Atos Convergence Creators, the Space Business Unit 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.

At the same time when the renaming took place, the former business units Space and Avionics have been merged to become the business practice Atos Space & Avionics. All assets, including experts, management, engineers, IPRs, patents, facilities have been completely transferred to Atos and remain unchanged.

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 will broaden our addressable market and will create new opportunities in the satellite defense market.

Atos is a global leader in digital transformation serving a global client base. Atos' revenue in 2018 was €12,258 Billion. Every day 122,000 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, 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, Unify and Worldline.

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 25 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 2018 Atos Space sales revenues reached € 21.5 million, based on commercial market, ESA, Galileo, FFG and DLR activities. The share of ESA sales therein accounted for € 8.95 million.

The 2018 business was mainly focused on the following topics:

- Satellite Testing
- Satellite Control
- Satellite Communications

SatelliteTesting:
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 Convergence Creators provided Electrical Ground Support and Special Check-Out Equipment for various institutional and commercial 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 including co-funding 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 these solutions.

Strong focus was again put 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 Convergence Creators)

Radio Frequency, Telemetry/Telecommand and RF Suitcase Test Systems

In 2018, the Atos Convergence Creators Radio Frequency (RF) and Telemetry/Telecommand (TM/TC) Test System business included work for missions such as OneWeb, Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-6, BioMass, Metop Second Generation, Proba-3, SARah, NGSAR, Electra, EUCLID, Exomars and JUICE. The OneWeb PTS (Payload Test System)/TCR (Telecommand Ranging) project is, so far, the largest RF project for Atos Space in terms of output volume. At the end, Atos Convergence Creators has delivered as baseline a mix of 19 sets of PTS and TCR standalone, PTS-TCR combined, PTS DITL (for Day in the Life tests) and TCR Lite.

The Solar Orbiter Suitcase was closed-out in 2018 and paved the way for further RF Suitcase projects, such as the Galileo and Sentinel-6 RF Suitcases.

Power SCOE, Instrument and Payload EGSE Test Systems

Apart from recurring activities for Solar Orbiter and the European Navigation System GALILEO in its FOC phase, which will continue to pop up also during the next years, various missions and programmes were supported.

In the Power SCOE domain Atos Convergence Creators worked on missions such as OneWeb, Sentinel-6, JUICE and BepiColombo. The OneWeb Power SCOE is, so far, the largest Power SCOE project for Atos Space in terms of output volume. At the end, Atos Convergence Creators will have delivered as baseline 53 sets including 61 ProUST univerSAS power supplies (see univerSAS product below).

The Instrument EGSE projects that were started in previous years were continued, among those were Instrument EGSEs for Sentinel 4, Sentinel 5, Metop Second Generation, and SARah,

OneWeb DITL Power SCOE based on univerSAS

(Photo: Atos Convergence Creators)

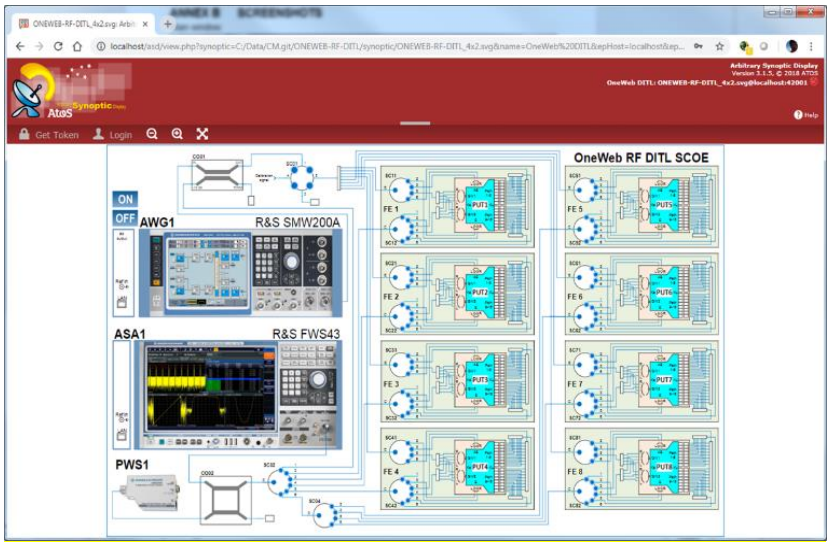
Sentinel-6 Power SCOE based on univerSAS

(Photo: Atos Convergence Creators)

Innovation: Telco EGSE (ARTES)

In the frame of the Telco EGSE study contract, our EGSE controller Software (GSE3) was enhanced with highly sophisticated features to become GSE4.

One of the main achievements was the introduction of parallel execution of testing and measuring having available only mutually shared measurement and testing resources. In the following picture one can see the synoptic display of the OneWeb DITL SCOE allowing for testing 8 payloads at the same time.



GSE4 Synoptic Display allowing for testing 8 payloads in parallel

A special note must be drawn to the fact that Telco EGSE is not a single application, but rather a complete and comprehensive SW framework and test-environment with modular applications that are designed to work together, like the Hypertet Reporting tool, Synoptic Display Configurator, Configuration and Maintenance Editor, Test Definition and Debugger;

GSE4 is ready to run in virtual appliances, even in headless modes for less resource consumption.

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

The motivation of this innovation project was to gain the possibility 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

The new product resulting from learnings of the CSAS study and going towards the development of an operational product is **ProUST univerSAS**. In 2018, univerSAS version 1.2 was CE and UL certified on rack level and qualified with the help of the OneWeb mission and the support of ESAs Mega-constellation (ARTES) programme. A real game-changing technology building block, 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.

In 2018 we started the design and development of univerSAS version 2.0 that will further improve the capabilities and power density of univerSAS.

ProUST UniverSAS 2.0

Satellite Control:
Ground Segment Systems and Mission Control Software

Also, in the year 2018, the main focus of Atos Space activities in the Ground Segment Systems and Mission Control Software domain was in the following areas:

- Mission Control System maintenance and evolution
- 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 been continued in 2018.

Apart from regular corrections, the contract also foresees adaptations for e.g. new DLR missions. The DLR SMCS had initially been derived from ESA SCOS, but in the meantime has undergone some significant evolution including removal of 3rd party dependencies and is now DLR-internally used and evolved under the name GECCOS. As such, it is now used more widely than ever, which also means the maintenance and evolution work is now spreading over a considerable number of missions in parallel.

Specifically, the launch and LEOP (an older version developed for TerraSAR-X was used) of PAZ, a Spanish Earth Observation satellite, and the launch, LEOP and operations of Eu:CROPIS (Euglena and Combined Regenerative Organic-Food Production in Space) – also called the Greenhouses for the Moon and Mars - were supported.

GSOC Mission Control Room (Photo: DLR)

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

2018 was dominated by the full integration of the Siecams product line into the Atos portfolio. As part of the integration, Siecams was rebranded to SkyMon.

As mentioned above the Aerospace Defense and Electronics 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, specifically for the SkyMon product.

This is important, facing the fact that the traditional commercial satellite market is currently struggling due to competition coming on the one hand from the upcoming new mobile communication technology 5G, which will provide data rates of up to 20 Gbit/sec and very low latencies, and on the other hand from the planned satellite mega-constellations, for example OneWeb, SpaceX, Telesat, etc. These mega-constellations will provide Internet access on any location on the earth with hundreds of low earth orbit satellites. These threads led to a dramatically decrease in the order of new geostationary satellites from traditional satellite operators like Eutelsat, Intelsat or SES followed by a decrease of the annual revenue figures by most of these companies.

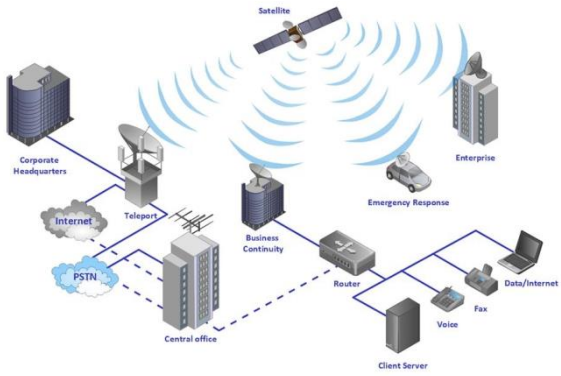
As we were mainly addressing the commercial satellite market with our SkyMon product, this development was also a direct thread on our business. With the integration into Atos and the new possibility to address also the defense market, we are very confident that we cannot just compensate the losses in the commercial satellite market but even increase our market share.

This is because of two reasons:

- First, the defense market in general, but specifically also the satellite defense market, is heavily investing in new technologies to counteract cyber-attacks, to increase the security and reliability of military communication networks (MILSATCOM). In a world of crisis and conflict, and as part of measures to fight crime and terrorism, the interception and analysis of satellite communication has a significant role to play. Satellite communication channels are used intensively by persons and organizations that are of interest to intelligence services, armed forces and police authorities. Consequently, such channels must be subject to analysis using modern detection systems.
- Second, because our SkyMon product already perfectly meets these requirements of the satellite defense market for **I**ntelligence **S**urveillance & **R**econnaissance of satellite communication links.

The performance and accuracy of the SkyMon geolocation system ILS was continuously improved over the last years and especially with the development of the first real working single satellite geolocation system ILS ONE it is now one of the most comprehensive satellite monitoring and geolocation systems in the world.

In 2018 we could close the last gap in the fight against interference with the development of SkyMon VSAT - a system to monitor VSAT networks and to identify VSAT stations causing interference. This was a challenging task, as VSAT networks usually use TDMA technology, where several users are sharing one signal.



In order to monitor specific VSAT stations, it is necessary to extract the data coming from one specific station and then to apply the corresponding measurements. With the help of the ESA ARTES C&G program we could successfully implement this technology and release the first version of SkyMon VSAT at the end of 2018. The current version provides the operator with a list of terminals causing interference, which is mainly useful for satellite and network operators. This kind of customers have access to the VSAT gateway database, which provides a correlation between the terminal id and the information about the owner of the terminal including the information about its location.

Other customers, like national space regulation authorities, government entities like MoDs, DoDs or military institutions normally do not have access to such information. For those customers it is necessary to perform a geolocation of the terminals and to show their geographical location on a map. And this is exactly what we have done by developing a VSAT Geolocation system on top of the VSAT Monitoring, which is also part of the ESA ARTES C&G project.

More often MILSATCOM services are provided by VSAT networks or Communication On The Move (COTM) terminals that operate in remote and often challenging environments. Many times, terminals are unmanned, adding yet another complex issue to the interference puzzle. Even when terminals are manned, moving through difficult terrain can easily cause misalignment of antennas.

The development of SkyMon VSAT is a door opener for the defense market. The SkyMon product with all its integrated monitoring and geolocation applications is now addressing the challenges of both, the commercial and the defense satellite market for detecting, collecting, processing and locating of information in real time and harsh environments.

Space Sales 2018: 21.5 M€
ESA Share: 8.9 M€

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3.4 ENPULSION GmbH

On June 7th, 2018, the new production facility of ENPULSION had been officially opened around the "Austrian Space Cooperation Days" in Wiener Neustadt, Austria. The opening had been accompanied by Dr.Josef Aschbacher, Director of Earth Observation Program of the European Space Agency ESA and Dr. Andreas Geisler, from the Austrian Research and Promotion Agency FFG.

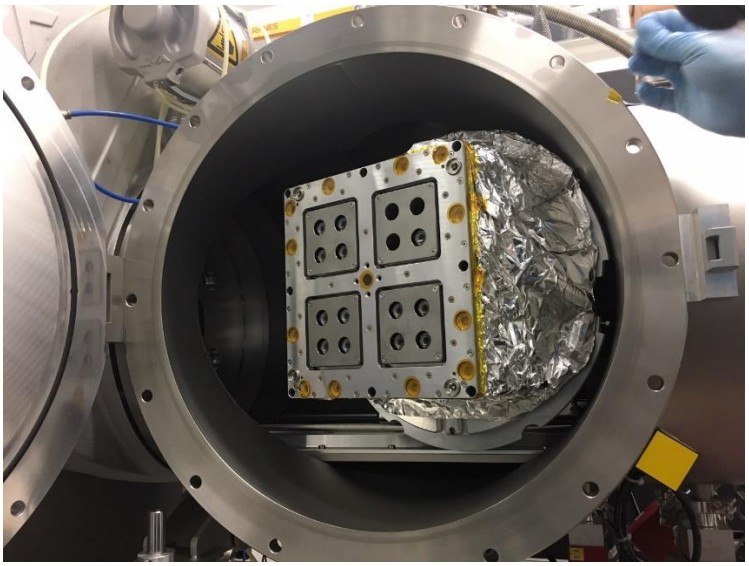
Opening of ENPULSION's production facility at TFZ Wr. Neustadt

Based on a product designed for high-rate production, ENPULSION has implemented an adaptable production line, that enables different scalability steps. Created on a heritage laboratory process of thruster production, a first scalability step has already been performed by the introduction of batch processes. These processes have increased production capability from 1 ion emitter per week to 5 per week. Reviewing of statistical evaluation for ongoing production processes had allowed us to optimized selection at early production steps.

With semi-automatization we increase the capacity to 2 ion emitters per day. Further increasing batch sizes by scaling production equipment at the existing production facility allows production rates of 6 ion emitters per day.

New product developments in 2018

Building on the heritage of the IFM Nano Thruster, ENPULSION is developing a scaled version of the technology to target small and medium size spacecrafts. The IFM Micro 100 Thruster is engineered in a modularity approach, with units clustering easily together to form building blocks that can be arranged for various mission profiles. You can thus combine four IFM Micro 100 Thrusters in an IFM Micro 400 Thruster. The first prototype of the IFM Micro 400 had already been successfully tested in November 2018.



IFM Micro 400 tested in vacuum chamber

ENPULSION customer development an in-orbit demonstration

Early 2018 ENPULSION signed its first constellation contract which number increased to 3 signed contracts by end of 2018. Meanwhile 40 IFM Nano Thrusters had been sold to international customers and seven thrusters are operating in space.

Sales 2018: 1.1 M€
ESA Share: 20 k€

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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 2018

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€

QA4SM-AVTB - Quality Assurance for Soil Moisture – Automatic Validation Testbed & Experiments

Soil moisture data products retrieved from remote sensing microwave satellites are subject to a statistically rigorous evaluation to determine uncertainties quantitatively, and for checking consistency to reference data at globally representative locations and time periods. This qualifies them for stage 3 of the CEOS validation hierarchy, though the evaluation process is manual and takes about one year of time after the product release. The goal of this project is to explore the feasibility of reaching the final stage 4 of the CEOS validation hierarchy, defined as follows: “Validation results for stage 3 are systematically updated when new product versions are released and as the timeseries expands.” Previous attempts to solve the problem on the drawing board did not succeed, therefore, this project aims to perform systematic experiments and studies by setting up a testbed for statistical and technical evaluations, in order to make a first step towards an automatic validation service for soil moisture. The project is crucial for the Quality Assurance for Soil Moisture (QA4SM) programme by EODC in the light of their operational Copernicus Climate Change Service (C3S), via the provision of Earth Observation (EO) derived Soil Moisture Essential Climate Variable (ECV) products and their support to the C3S Evaluation and Quality Control (EQC) functions.

EODC contribution: 14 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€

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 2018: 1.8M€
ESA Share: 56.6 K€

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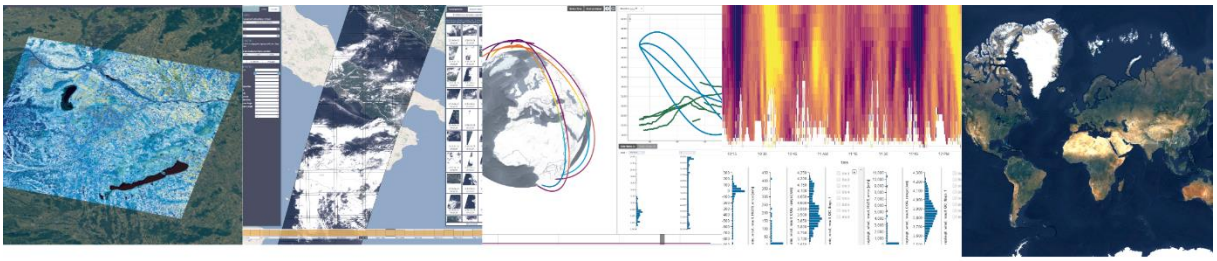
3.6 EOX IT Services GmbH



VIEW THE WORLD THROUGH OUR EYES

10 years EOX 2008-2018

Overview

The main area of EOX activities concerns the development and advancement of e-environment and geospatial information infrastructures with a particular focus on satellite Earth Observation systems and next generation applications.

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 technology partner of choice in major European environment monitoring and space programs like the European Copernicus initiative. EOX is a limited liability company under Austrian law. It is privately owned and fully independent from other organizations. EOX has currently seven full-time all academic staff.

EOX is specialized in information technology infrastructures for hosting of, and providing access to, large volumes of geospatial data. Such data include GIS vector layers, Earth Observation (satellite borne, airborne) datasets, and in-situ geophysical measurements (point, profile, volume) acquired at sensor or remotely.

Currently most of EOX' business is generated in developments of complex infrastructure systems which are capable of handling Petabyte/Terabyte of data volumes stemming from new and planned satellite missions. The EOX contribution to such developments is mani-fold: project acquisition, set-up and management; requirements identification, assertion with customers and management; engineering through the software development lifecycle along well-defined review milestones up to formal transfer to operations at customer facili-ties; maintenance and warranty of the software components delivered by EOX; user doc-umentation and support (administrator and end-user).

EOX acts as a major software developer for the Payload Data Handling Ground Segment (PDGS) of non-commercial European Earth Observation satellite missions as they are being set-up and prepared by the European Commission (EC) and the European Space Agency

(ESA). The family of the new Sentinel satellite missions and the legacy or historic missions operated by ESA as well as some 40 different “Contributing Missions” from other operators are all supposed to be managed in a coherent and coordinated environment in order to provide access to the user community.

Under the following headlines the 2018 highlights are reported.

Earth Explorer Data Online

The visualisation and manipulation of multidimensional EO data is one specialization areas of EOX. ESA Swarm data is available for anyone to use via the virtual research platform “**VirES for Swarm**” (https://vires.services). A highly interactive data manipulation and retrieval interface is provided for the magnetic products of the European Space Agency (ESA) Swarm Earth Explorer Mission. It includes tools for studying various Earth magnetic models and for comparing them to the Swarm satellite measurements and given solar activity levels. A similar capability has been added for ESA’s Aeolus Earth Explorer Mission which has been launched on 22 August 2018. The “**VirES for Aeolus**” service (see following figure) is currently available for Calibration/Validation Users and will be opened up to the general scientific public in 2019.

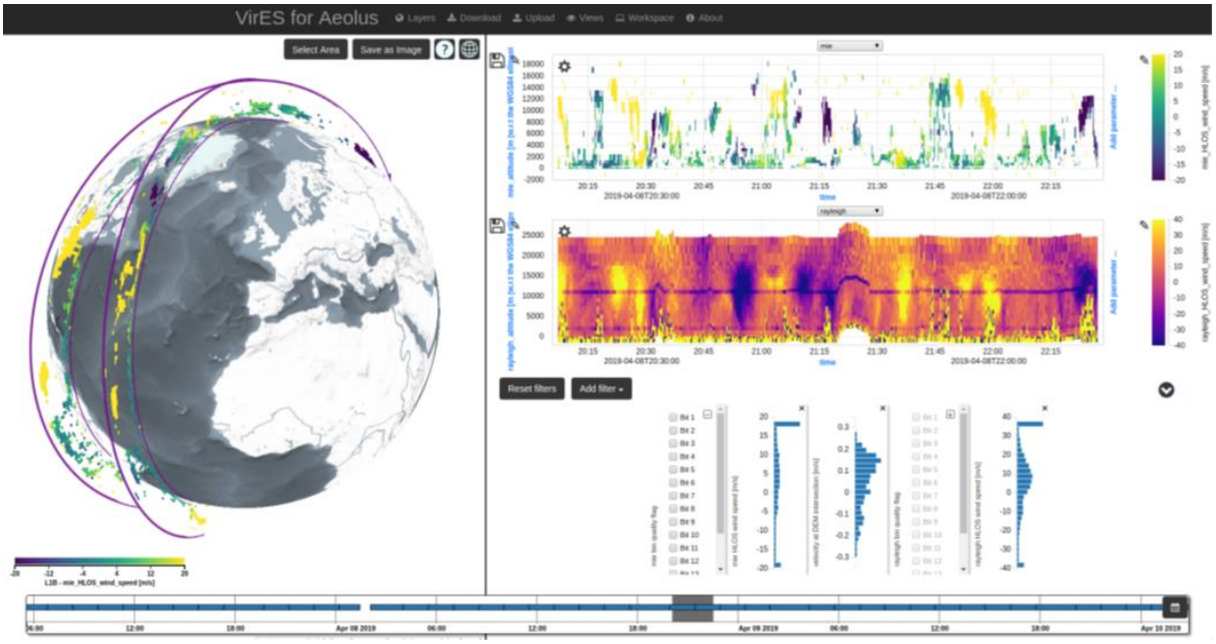


Figure: Web User Interface of VirES for Aeolus Service

The services are required and implemented by the Earth Observation Directorate of ESA and designed and operated by EOX. The technical framework entirely consists of Free and Open Source Software (FOSS, MIT style licence).

Open Geospatial Data

Sentinel-2 cloudless (https://s2maps.eu) EOX was the first company to produce a global, cloudfree mosaic from Sentinel-2. The target was to create a pure visual product to be used for mapping applications as a background layer. A special algorithm was created to eliminate 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 distributed processing platform was created by EOX which can handle hundreds of terabytes.

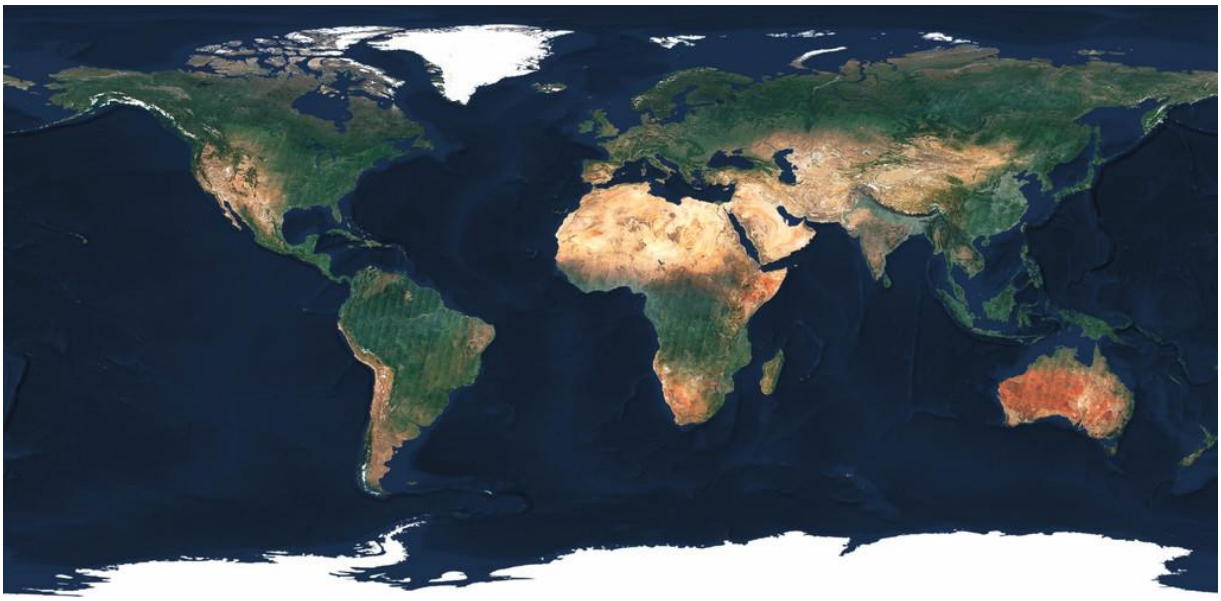


Figure: Sentinel-2 cloudless – https://s2maps.eu by EOX IT Services GmbH (Contains modified Copernicus Sentinel data 2017 & 2018)

Using its own processing platform, EOX is able to create mosaics tailored for 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.

"**EOX::Maps**" (https://maps.eox.at) is EOX' contribution to open data by offering global topographic online maps.

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

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

Special customers, such as ESA, are served by EOX via the provision of dedicated instances of the map services.

Catalogue and Browse

EOX is supplier of ESA with operational software for the Multi-Mission Payload Data Ground Segment. Under an evolutions framework contract a catalogue software package named "**Sx-Cat**" has been put online and is maintained by EOX. It combines service functions illustrated in the following two figures.

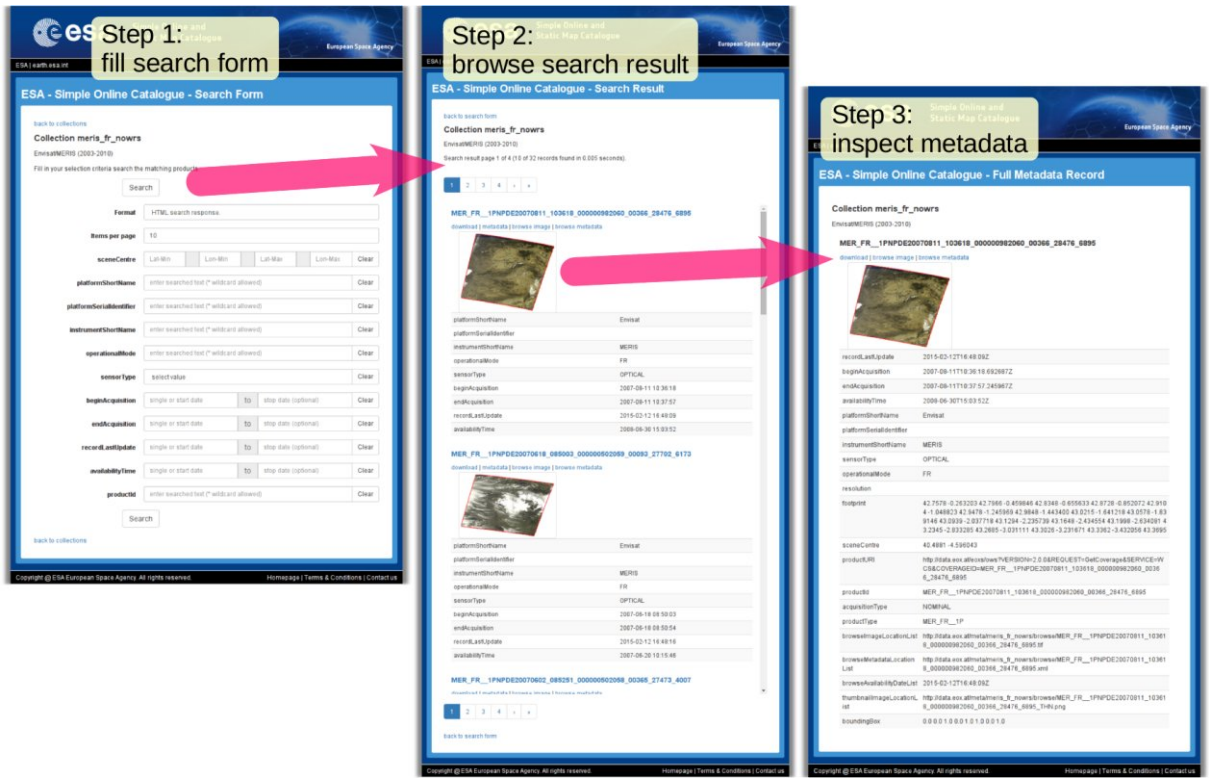


Figure: Simple On-line Catalogue

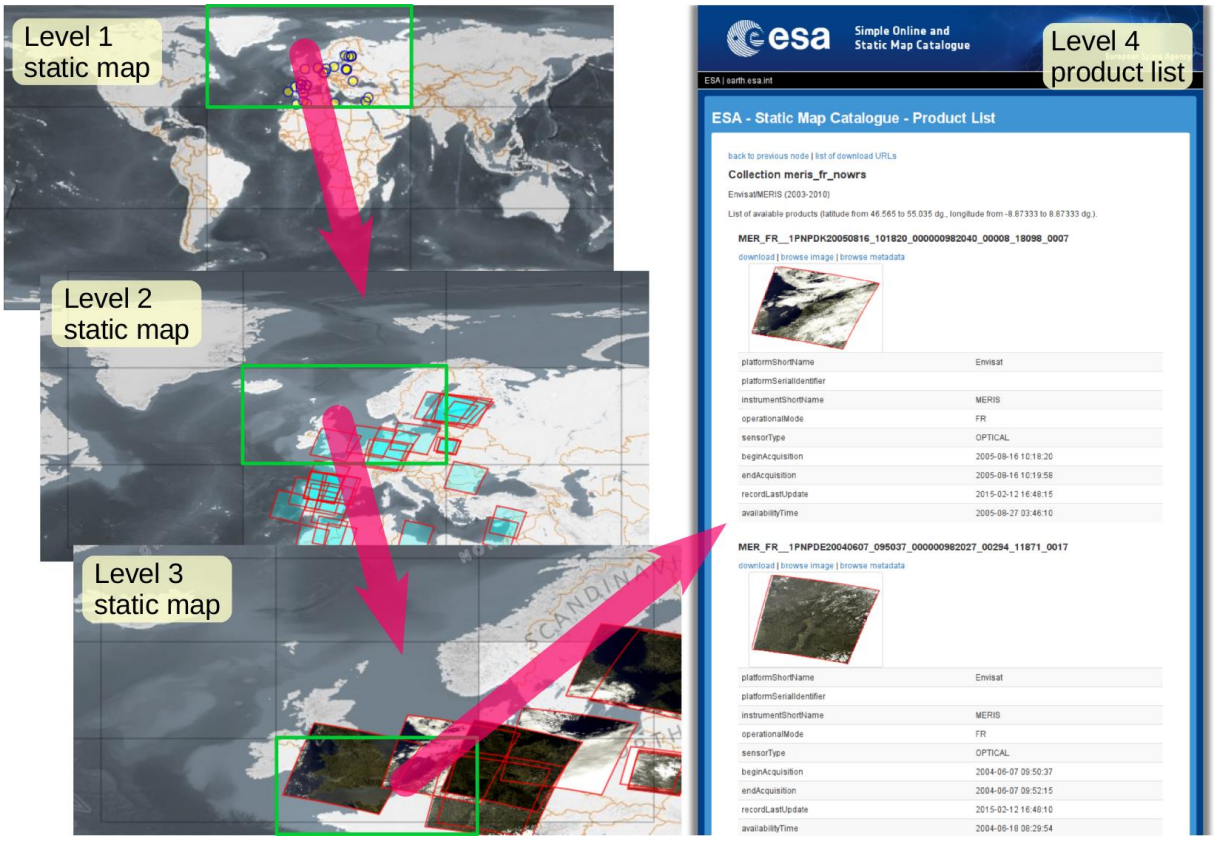


Figure: Static Map Catalogue (principle)

The catalogue is the discovery front-end which provides the links to the EO products for download. The technological solution provided by EOX convinces because of its performance, scalability and easy operations so that more and more of ESA's EO data collections are migrated to Sx-Cat like the following examples of operational catalogues:

https://landsat-ds.eo.esa.int/smcat/LandsatTMCloudFreeCoverage/

https://landsat-ds.eo.esa.int/smcat/LandsatETMCloudFreeCoverage/

EOX is also supplier of powerful geospatial data management tools named **EOxServer and EOxC**, the Open Source client-server pair (https://ows.eox.at). These free and open source tools are the result of many years of insights into the earth observation data formats and related protocols for providing access to them. EOxServer provides a one-size-fits-all solution for publishing Earth Observation products. EOxC is a catalogue client for earth observation data products. It is highly configurable to allow a wide variety of server and protocol types. is operationally deployed as discovery and download front-end of the German Copernicus Collaborative Ground Segment System named CODE-DE.

The EOxC client is purely browser based and only uses open and standardised web interfaces and can be used with any HTML-5 compatible web browser.

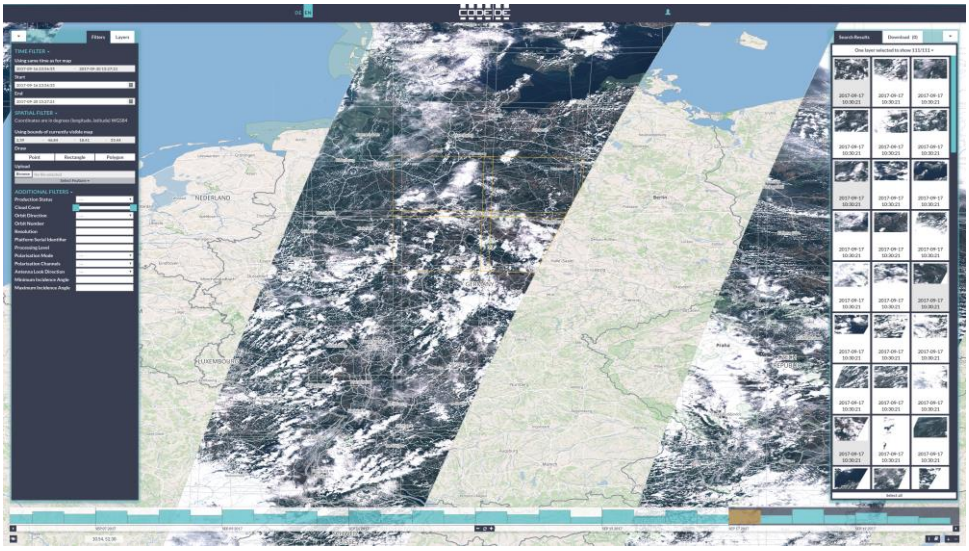


Figure: EOxC client for Sentinel-2 catalogue and map services provided by EOxServer

Data Logistics and Process Chaining

EOX participates in various research initiatives and projects building multi-mission data access and exploitation platform technology for large collections of geospatial data. The platforms in scope provide a work environment for its' users, enabling them to effectively perform data-intensive research by running dedicated processing software close to the data, thereby avoiding downloacontinuedding large volumes over the network and spending non-research time on developing ICT tools, sourcing data, etc.

EOX has evolved in its role as subcontractor in the Copernicus DIAS consortium "Munid" led by Atos France. DIAS stands for Data and Information Access Service and is the conceived as the EC's and ESA's workhorse platform for Copernicus Big Data hosting and exploitation. EOX role is to implement and operate major parts of the data access service functions in DIAS.

Sales 2018: 1.3 M€
ESA Share: 0.8 M€

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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

In recent years, FOTEC has developed the IFM Nano Thruster which is based on LMIS (Liquid Metal Ion Source) and FEEP (Field Emission Electric Propulsion) technology. After multiple test campaigns on ground, including thermal, vibrational and shock tests, performance characterization, plume diagnostics and direct thrust measurements by FOTEC, the first successful in-orbit demonstration of a FEEP thruster was performed early 2018. For that purpose, the IFM Nano Thruster module was integrated into a 3U CubeSat operated by a US constellation operator. For the first time, a FEEP propulsion system was successfully demonstrated in orbit!

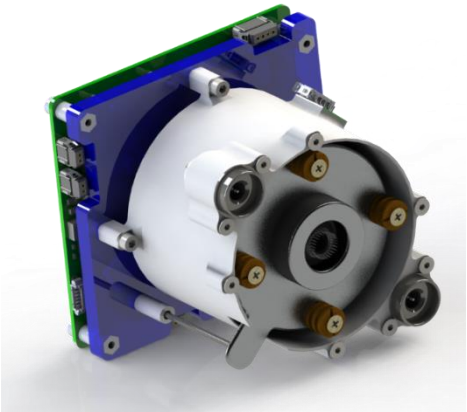

Figure 1: The IFM thruster which underwent a IOD in 2018

In 2018 the FFG funded project NanoPPU100 started to improve the thermal management of the IFM Nano Thruster and to improve the integrated power processing unit (PPU) for higher output power levels. In addition, the ESA funded project InCubed started which deals with the qualification testing of the IFM Nano and IFM Micro thruster, which is a scaled-up version of the IFM Nano Thruster with four crown emitters instead of one.

Chemical Propulsion

A project was initiated to study the possibility to integrate several functions in one element/assembly of elements. In this particular project the aim is to store liquid and/or gaseous propellants in the load carrying structure of a satellite. Typical mission for which such an approach would be beneficial are studied. Also technologies that enable such an approach, such as storing the propellant in a physi-sorbed or chemi-sorbed way inside the load-carrying structure, are investigated.

An important part of the work is the design of a structural panel that can handle the typical mechanical loads, provides storage volume for propellants and results in an overall reduction of the satellite mass. For this a mass-optimization scheme is employed. Manufacturability is

taken into account. Technical expertise on certain aspects of satellite structural design is provided by OHB Germany.

Energy Systems

FOTEC and the FHWN are engaged in several activities to develop future energy storage and conversion technologies. An activity concerned with a combined hydrogen and heat storage solution targeted at fuel cell systems in telecommunications satellites was successfully concluded. A system study investigating the feasibility of thermoacoustic electricity generators for telecommunication satellites, was also successfully concluded in 2018. A project concerned with a significant power upgrade of a FEEP electronics board and the parallel development of advanced 3D-printed heat pipes to ensure proper heat dissipation was started.

Additive Layer Manufacturing (ALM)

The development of manufacturing strategies for large metallic structures such as the optical bench of the ATHENA project or the International Berthing Docking Mechanism (IBDM) is the objective of a study in cooperation with RHP Technology (Austria, Prime contractor). The optical bench has a diameter of 3.0 m and via plasma-arc welding several segments (Titanium alloy Ti6Al4V) of it are manufactured, machined and tested. One of the challenges is the optimization of the heat treatment to ensure minimum distortion due to internal stresses.

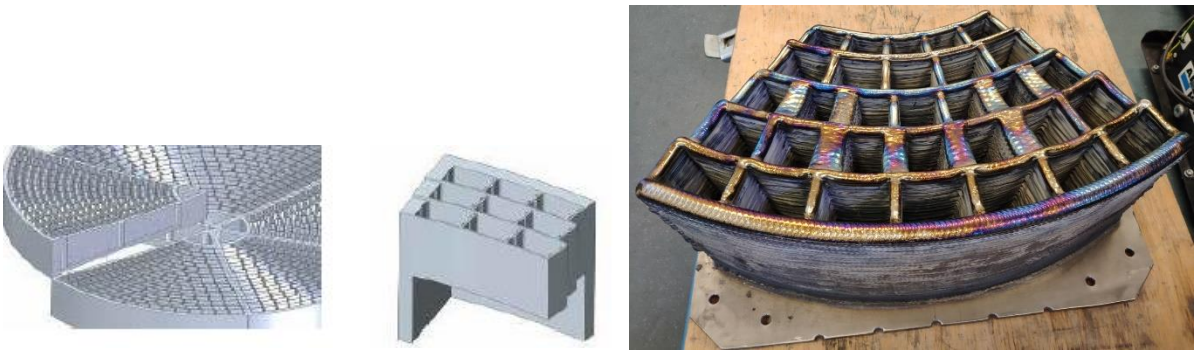

Figure 2: Optical bench from the ATHENA project (left), Ti64 demonstrator made by plasma-arc welding (right)

The know-how in additive layer manufacturing of RF antenna components was transferred in a follow-on activity with TESAT Spacecom (Germany) and Lithoz (Austria). The study aims on the design, manufacturing and testing of three RF components, which are an assembly using two different ALM technologies. Dielectric filters made of ceramic material are combined with Aluminium alloy housings. For the ceramic filters Lithoz (Austria) uses their Lithography-based Ceramic Manufacturing (LCM) technology and the FOTEC (Austria) is responsible for the Aluminium alloy parts. The compliance with the specification regarding precision of the inner channels and accurate silver plating are challenges in this study.

A national funded project aims on deepening the knowledge about the correlation between internal defects and mechanical properties of parts made by ALM. To determine these defects the non-destructive testing method computer tomography (CT) is used, which is the core competence of the University of Applied Sciences Upper Austria (Wels, project lead).

Since the effect of defects shall be investigated it is important to find a procedure to place certain defects in typically fully-dense samples reproducibly.

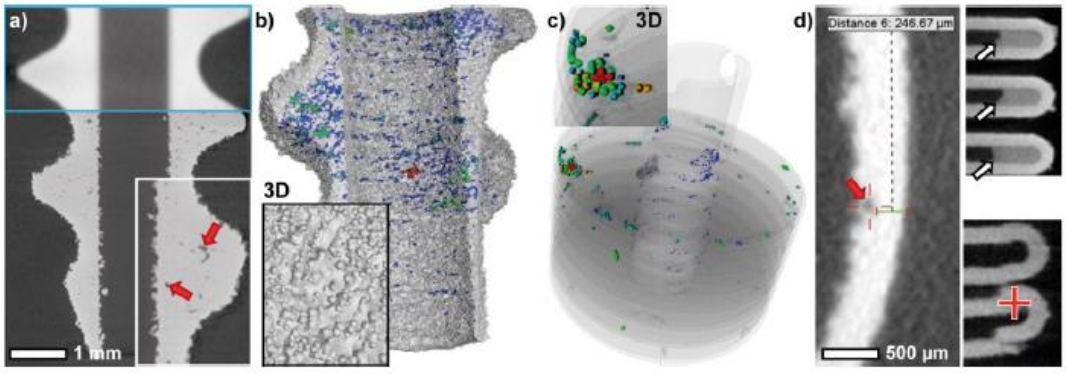

Figure 3: XCT scans of Ti64 parts indicating internal defects, surface roughness and metal powder residues

Sales 2018: 3.04 M€
ESA Share: 0.58 M€

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3.8 GeoVille Information Systems and Data Processing GmbH

WHAT WE DO

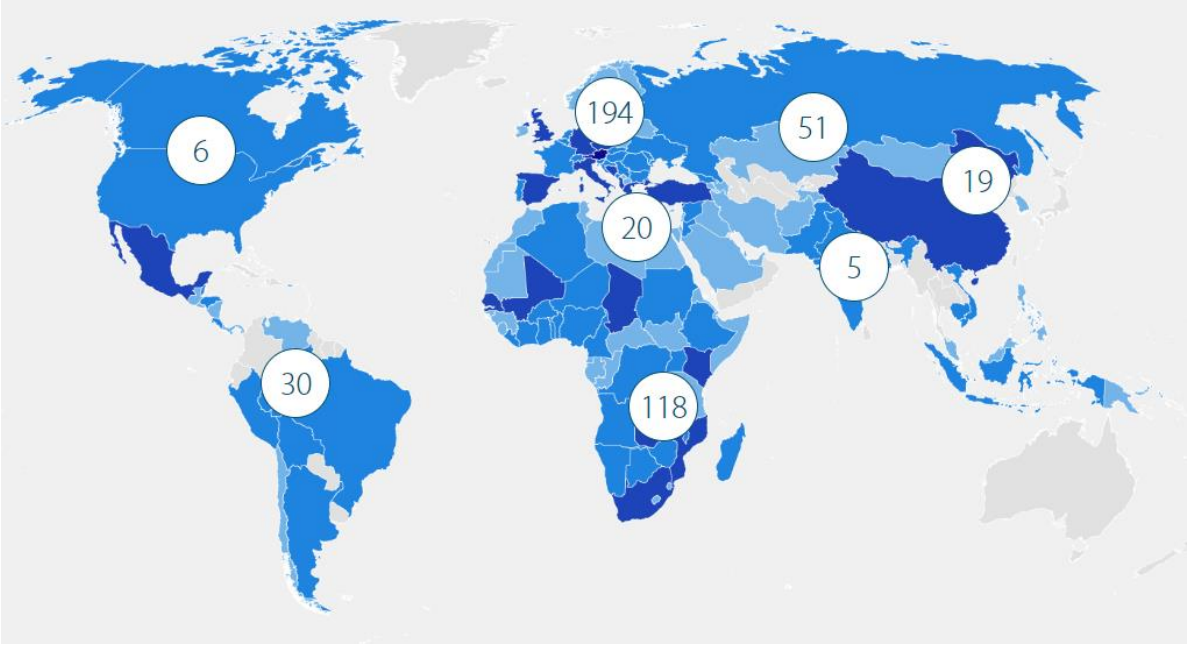
We at GeoVille do the spatial job through satellite's eye and deliver reliable, quality controlled operational monitoring products and solutions for complex resource management issues.

Our sectors

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)

OUR HIGHLIGHTS 2018

20 YEARS OF GEOVILLE

GeoVille celebrated its 20 years anniversary together with partners, customers and friends at the Bergisel SKY restaurant in Innsbruck. Since its foundation in 1998, GeoVille has successfully completed more than 430 projects in 130 countries worldwide.

EUROPEAN LAND MONITORING AT ITS CROSSROADS

In October 2018, GeoVille hosted the conference "European land monitoring at its crossroads - opportunities and challenges" in Innsbruck.

During the conference, high level representatives from European institutions, the public sector and industry from more than 40 countries discussed the state and future of European land monitoring.

FOUNDATION OF GEO4A

GEO4A B.V. has been founded by a team of entrepreneurs from the space and agricultural industries. GEO4A is a full subsidiary of GeoVille and provides geospatial information solutions to the potato sector.

GEO4A.com

PROJECTS

THE AUSTRIAN SPACE APPLICATIONS PROGRAMME

InfraBase

The aim of InfraBase is to set up an automated process which combines a highly efficient data access via cloud environments and the extraction of high-quality building footprints from VHR satellite imagery. Moreover, InfraBase aims to evaluate how machine interaction-based detection and delineation of buildings complies with the requirements of accuracy and processing time.

Contract Value: 159K €

ESA EO APPLICATIONS

EO PLUGIN

EO PLUG-IN aims to achieve EO competitiveness through a market evolution development by providing an easy access HUB for satellite-based information solutions to industry operations via industrial IT standards.

EO PLUG-IN is based on Big Data IT backend infrastructures, with fundamentally complex software architectures and multi-source data stream integrations requiring state-of-the art deep learning processing algorithms. EO PLUG-IN will be launched via high market value chain operators of the AgroFood industry in order to demonstrate the operational impacts.

Contract Value: 750K €

EO4SD – Climate Resilience

EO4SD Climate Resilience encapsulates heterogeneous and multi-disciplinary knowledge to provide answers about the real potentialities of Earth observation (EO) in supporting Climate Resilience (CR) decision making at regional / national scale.

The work is not simply based on providing EO-based quantifiable climate related indicators, but to deeply evolve the downstream phase of the chain. This implies to know all the stages of CR decision making from a procedural point of view and with independence of the technology that would be selected to monitor and support this process. This inherently links with all the initiatives that all the major actors (at all levels from local to international scale and from

research to purely day-by-day urgent practical operations) are promoting, coordinating and running in regions of interest, which are considered vulnerable and with risk of receiving impact of adverse climate-related events.

Contract Value: 134K €

EO4SDG

EO4SDG aim of the project is to maximise the contribution of EO data to the Sustainable Development Goal (SDG) agenda by producing targeted high-quality indicator monitoring guidelines and effective outreach material, and by showcasing the usability of EO data in country demonstrations studies and in dialogue with UN stakeholders.

Thereby, the project supports the utility of satellite EO in the 2030 Agenda on Sustainable Development and in particular in the Global Indicator Framework adopted by the UN Statistical Commission (UNSC) at its 48th session in March 2017.

Contract Value: 99K €

EU – COPERNICUS OPERATIONS

Copernicus Land Monitoring Services (CLMS) – High Resolution land cover characteristics

Copernicus is the European Programme for the establishment of a European capacity for Earth observation (EO). Under the Copernicus umbrella, users in the field of environment and other terrestrial applications are provided with invaluable information based on EO data in combination with other sources. Hence, Copernicus addresses a wide range of EU level policies including environment, agriculture, regional development, transport and energy and corresponds to European commitments to International Conventions. For the Copernicus Pan-European Land Monitoring Service 2018, GeoVille is responsible for the production of lot 1 – Imperviousness, lot 3 – Water & Wetness und lot 4 – Grassland.

Contract Value: 1,9M €

EU – H2020

EnviroLENS – Copernicus for law enforcement support

EnviroLENS aims to demonstrate and promote the use of Earth observation (EO) as direct evidence for environmental law enforcement, including in a court of law and in related contractual negotiations. By using European satellite capacities, such as those provided by Copernicus, EnviroLENS responds to the demands of the environmental legal sector in the context of evidence-based decision-making processes.

EnviroLENS is the first EU – H2020 project coordinated by GeoVille.

Contract Value: 1,07M €

EO4AGRI

The main target of EO4AGRI is the preparation of the European capacity for improving operational agriculture monitoring from local to global levels based on information derived from Copernicus satellite observation data as well as through the exploitation of associated geospatial and socio-economic information services.

Thereby, EO4AGRI enlarges and further systematizes the knowledge about Copernicus for agriculture and identifies gaps related to the utilisation of EO in the agri-food industry.

Contract Value: 250K €

EU – EUROPEAID

Technical Assistance for Developed Analytical Basis for Land Use, Land Use Change and Forestry, Turkey (LULUCF)

LULUCF aims to reduce anthropogenic GHG emissions to contribute to the global efforts to mitigate climate change in line with the scientific evidence. The project is focusing on the improvement of the calculation, reporting and monitoring system of Turkey to catch up with the EU and Kyoto Protocol levels. GeoVille solves the inconsistency in the land use data by producing a high precision land use matrix through historic satellite data and by overlapping the databases, and their verification, as well as the development of a monitoring and verification IT system that will enable improvement and update the land use matrix.

Contract Value: 660K €

Sales 2018: 5.5 M€
ESA Share: 1.47 M€

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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

➢ CubeSat-based W-band channel measurements

The activity includes the design and development of the W-band beacon transmitted from a Cubesat platform, together with the propagation receiver terminal. The objectives are the undertaking of atmospheric channel propagation measurements of the signal from this beacon and to analyze and deliver the processed propagation data at W-band. This work will help to prepare for future High-Through-put satellite communication systems.

For large broadband satellite networks, the number of gateways may be such that the cost of the ground segment exceeds the cost of the satellite, even when using Q/V band in the gateway feeder link. The usage of the spectrum available in W-band (70/80 GHz) for Satcom systems feeder link in future High-Through-Put systems will significantly reduce the number of required gateways and consequently the overall cost of the ground segment. However, the atmospheric channel- propagation models available from the ITU are known to be accurate up till 30~40 GHz. Therefore, new measurement campaigns are needed to characterize the atmospheric channel propagation at W-band.

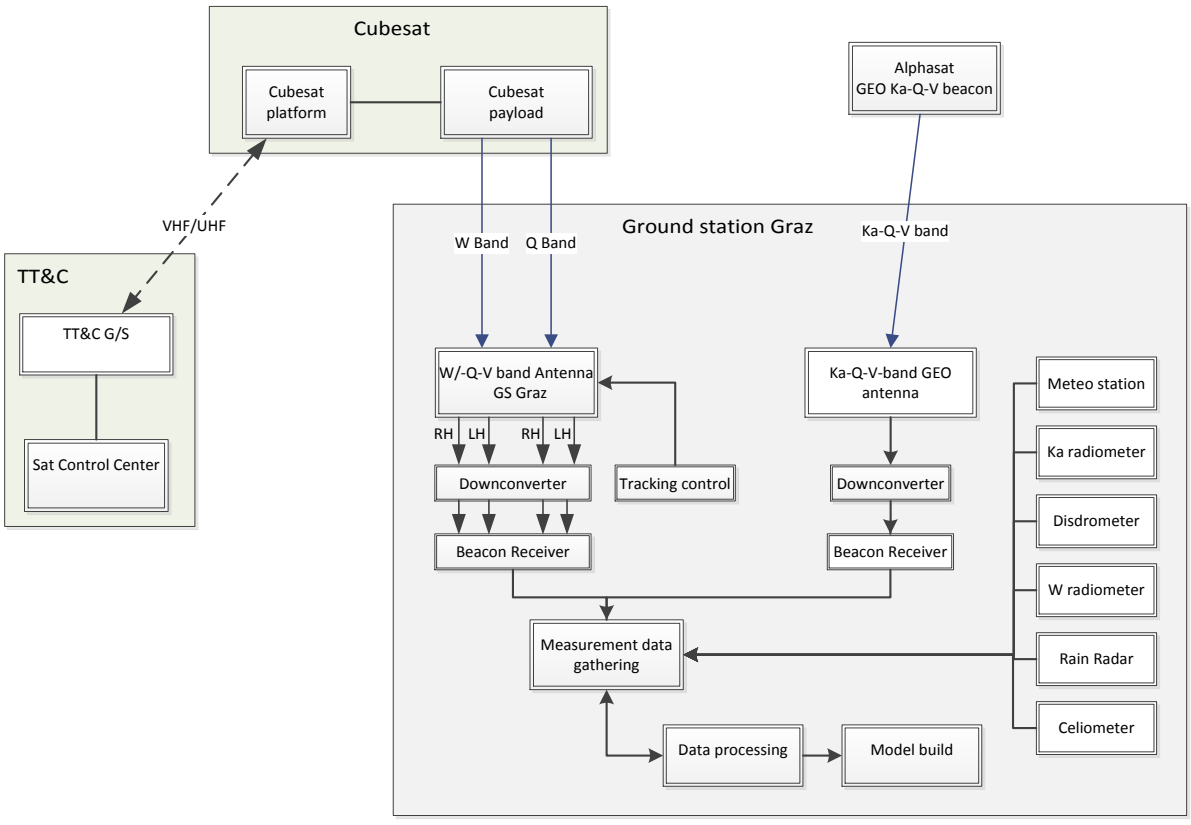


Figure: Architecture of the complete system including TT&C and measurement ground station and the Cubesat transmitting the W and Q band beacon

In this activity, a Cubesat-like nanosatellite is used to embark a beacon transmitting in W-band in order to perform channel propagation measurements. The LEO orbit of the nanosat, although different from the geostationary orbit of future operational satellites exploiting W-band, will allow the project to characterize the major satellite channel impairments. In addition, supporting software tools will be used to bridge the gap between the relatively short

LEO measurements and the statistical reliability needed for GEO propagation measurements, in particular an atmospheric channel simulator. The collected channel measurements will be used to tune the atmospheric channel simulator and the satellite movement effects will be de-convolved from measurements in order to extrapolate the equivalent GEO propagation channel characteristics.

The activity includes the design and development of the W-band beacon together with the propagation receive terminal. A measurement campaign of at least two years of duration is in the final phase of the project.

- **Simulation Study on Mobile Ka-Band Multimedia Receiver for Vehicles**

TV receivers for vehicles like busses or yachts are a well established technology. Solutions exist for on-the-move user terminals and from a variety of manufacturers. While this is a profitable business, it is not regarded as high volume in comparison to the general satellite TV-receiver market. This is partly due to the size of the antenna and the overall cost of the user equipment.

With meanwhile Ka-band satellite services being operational, advancements to smaller antennas and higher throughput seem possible. There are however considerable challenges for the establishment of mobile Ka-band multimedia receivers.

Thus a study was carried out considering signal transmission and technical performances, the users' quality of experience and also the commercial feasibilities of mobile Ka-band multimedia receivers for vehicles. High speed end-to-end simulations were carried out, producing reliable statistical results. The project team was led by JOANNEUM RESEARCH and included the satellite operator EUTELSAT and their consultant Ernst Eberlein.

Regarding signal transmission the focus of investigations was laid onto various antennas and their behavior, on tropospheric propagation conditions in certain climatic conditions and on environmental effects caused by buildings and vegetation. For modelling purposes the environmental conditions were categorized into urban, suburban and rural types. As illustration for the environmental effects Figure presents a schematic sketch of blockages by buildings and Figure shows the statistics within certain time windows. Clearly the probability for blockages increases, the shorter the time windows under consideration are.

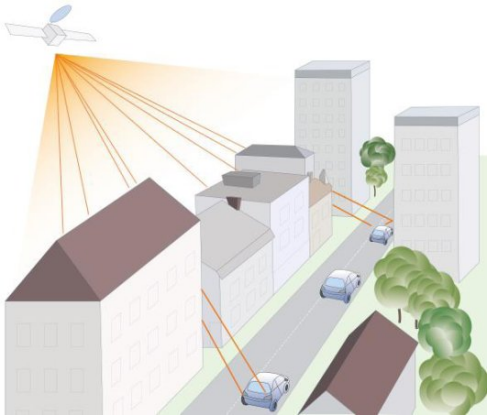


Figure: schematic sketch for signal blockages by environmental conditions

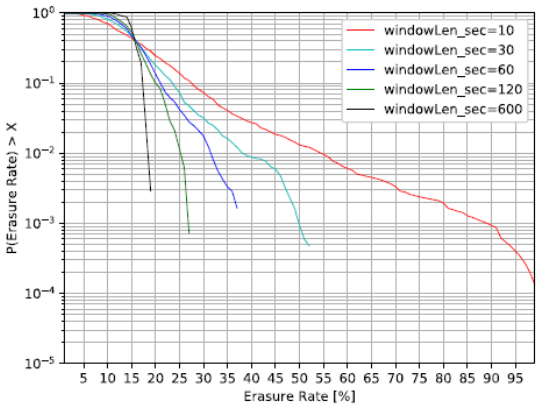


Figure: cumulative distribution function (CDF) of blockages within time windows of a certain length, in suburban environment

The selected air interface was based on the DVB-S2(x) technology with two potential extensions and their behavior being compared, i.e. forward error correction on the link layer

(LLFEC) and physical layer interleaving (PHY-ILV). The LL-FEC coding scheme used is a Staircase LDPC CODEC which is characterized by a good trade-off between computational complexity and error i.e. erasure correction capability and can be implemented in software. For both schemes, various code rates were tested.

As an objective assessment of the end-to-end signal transmission quality the ESR5 parameter (erroneous-second ratio with 1 out of 20 seconds - 5% - with errors) was used. The Table shows some examples of ESR5 and packet error rate (PER) results, according to various parameter settings and correction schemes. The results clearly reflect the scenarios, for example it is seen, that in dry rural conditions the transmission conditions are perfect.

Table: some examples of ESR5 and packet error rate (PER) results, according to various parameter settings and correction schemes.

	R_{PHY}	R_{LL}	R_{Total}		Suburban		Rural	
					ESR5	PER	ESR5	PER
LL-FEC	1/3	1/2	1/6	Dry	100%	0%	100%	0%
				Rainy	91%	4.4%	92%	3.7%
	1/2	3/4	3/8	Dry	2.5%	24%	100%	0
				Rainy	1%	40%	56%	21%
PHY_ILV	1/4	1	1/4	Dry	100%	0%	100%	
				Rainy	96%	0.3%	100%	
	1/3	1	1/3	Dry	100%	0%	100%	
				Rainy	83%	11%	???	

The transmission capacity is directly related to useable code rates, yielding the trade-off shown in the figure. Herein it is shown, that the achievable transmission capacity clearly depends on the complexity of the scenario, up to which the system is targeted.

Beyond objective assessments it is the user's and customer's experience, which determines the commercial success. Thus a subjective assessment of the quality of experience is necessary. In order to measure the audio and video quality, a quality metrics was applied, which aims to provide a quality score that correlates with human perception. In particular methods were used following the recommendations ITU-T Rec. J. 247(2008) and ITU-R BS.1387.

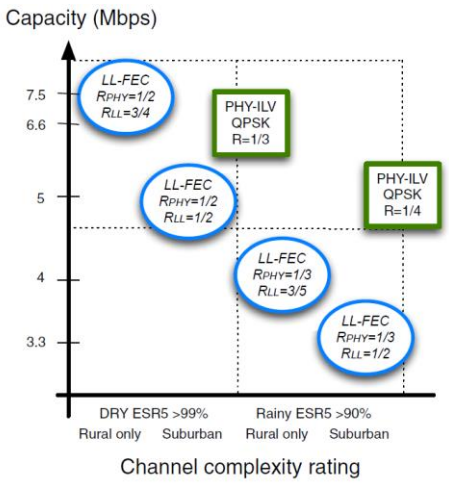


Figure 1: Trade-off capacity versus supported receive scenarios

The study was concluded with a roadmap towards establishment of a relevant system on the market. A market analysis was carried out, and development costs and total costs of ownership considered. Conclusion was, that it is finally a development risk decision, which market should be addressed.

Up to here the project's results were presented in the following conference contributions:

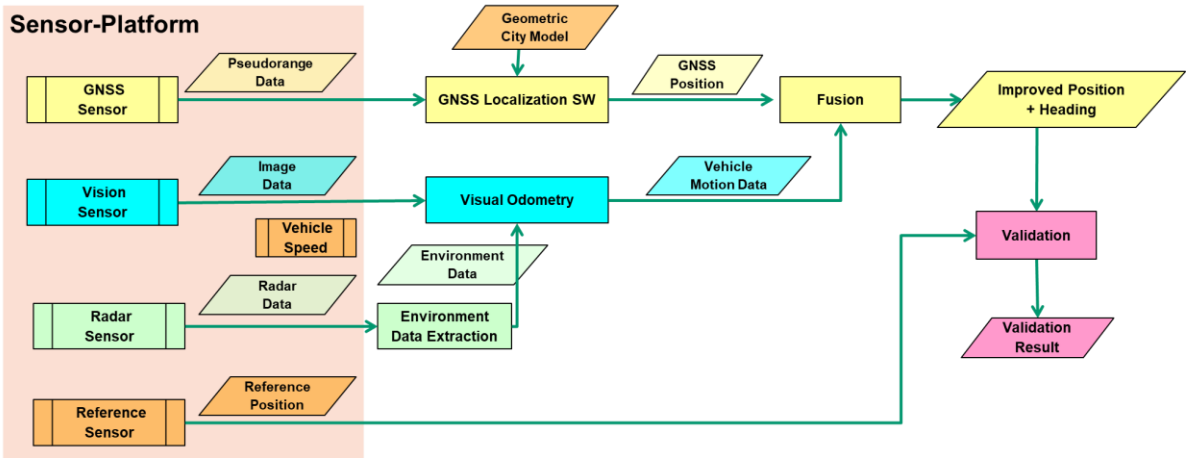
Eberlein E., M. Bergmann; N. Stamenic, I. Markovic, M. Schönhuber and F. Pérez-Fontán (2018) „Mobile Ka-band Receiver for Vehicles - A Detailed Trade-off Analysis" 9th Advanced Satellite Multimedia Systems Conference (ASMS) and 15th Signal Processing for Space Communications Workshop (SPSC), Berlin, Sept. 10-12, 2018

Stamenic N., W. Bailer, E. Eberlein, St. Wechtitsch, I. Markovic, M. Schönhuber, M. Bergmann (2018), "Assessing the Quality of Video Delivery over KaBand to Mobile Terminals" 9th Advanced Satellite Multimedia Systems Conference (ASMS) and 15th Signal Processing for Space Communications Workshop (SPSC), Berlin, Sept. 10-12, 2018

❖ Satellite Communications & Navigation

➢ FUSION

The main goal of the project FUSION was to find algorithms and a sensor setup how to improve the accuracy and robustness of urban localization for highly automated driving. Therefore, low-cost sensor data shall be incorporated in a sophisticated sensor fusion algorithm to reduce the error budget of the single sensors. The interdisciplinary topics of this project were GNSS-based localization, computer vision, remote sensing, geomatics and statistics.



The developments in the radar field (indicated in green) had the goal to create geometric information about the environment, namely static and dynamic objects as well as information about the amount of dynamics in front of the vehicle. This information will be used during the processing of the stereo visual odometry (VO) to calculate a measure for the scene dynamic and hence the expected VO performance. The goal of the VO (cyan) was to derive relative motion information in 6 DOF to replace precise but expensive inertial measurement systems. The calculated relative vehicle motion information from the combined radar / vision system afterwards was fused with GNSS information to improve the limited GNSS performance especially in urban regions. The goal was to improve the GNSS performance in terms of accuracy, reliability and availability whenever the GNSS performance is limited because of

partial or full signal blockage. The goal of the validation process (pink) was to compare the achieved results with highly-accurate reference information to describe the performance of the investigated algorithms. The position errors were described with respect to the satellite number, the percentage of sky visibility in the different cardinal directions, the dynamics and brightness in the scene etc. With the statistic results, predictive algorithms were developed to extend the driven test datasets by scenarios which cannot be found in Graz.

For the execution of the project, a sensor platform was developed carrying cameras, a radar sensor, a low-cost GNSS receiver, a high-cost GNSS/IMU system as reference, a fisheye sky-camera for obstruction analysis, and additional sensor to measure the brightness, the temperature and humidity. This sensor setup was expected to be available in consumer cars in the near future.

Photo: JR, ©Bergmann

The result of the project was a validated demonstrator of a GNSS/VO/radar based localization system for an improved localization in urban environments. An exemplary result is presented in the following figures where an urban scenario in Graz, the Andreas-Hofer-Platz, is shown. Because of a high building placed in the south of the trajectory (see right figure), the GNSS performance suddenly degrades dramatically (red line in the left figure). The green line indicates the true trajectory. In orange, one can see that the results can be significantly improved by introducing the additional information from the vision and radar sensors.

- **TACTIC - creaTing Awareness of galileo prs at CriTical InfrastruCtures**

The main goal of the project TACTIC was to investigate the actual benefits of the Galileo Public Regulated Service (PRS), an encrypted signal that is designed to be more robust against interference and especially spoofing attacks compared to open signals. Whereas many research and evidence of jamming has been gained in the past, the awareness about spoofing threats may still further be stressed for the navigation community and GNSS user groups. Within the project TACTIC, it was foreseen to gain practical real-world experience in the field of GNSS jamming and spoofing and to raise awareness of intentional or unintentional threats against critical infrastructures. Therefore, a major goal in TACTIC was to successfully demonstrate a GNSS spoofing attack on a set of GNSS receivers to investigate current receiver technologies. Beside from the technological point of view, the creation of awareness about the vulnerability of GNSS with respect to spoofing was another major goal of the project.

At the project start, an intensive state-of-the-art review was conducted to get the latest information about current R&D activities, threats and innovations in the field of GNSS interference, jamming and spoofing. With this information in mind, the project team together with the Austrian Ministry of Defence and the Energie Steiermark worked out several use cases, which should be addressed within the project TACTIC. These use cases comprised GNSS position and time spoofing.

In the next step, the spoofing demonstrator design was initially defined and continuously refined during implementation. In parallel, a detailed planning of the experiments including a coordinated time schedule was carried out. During the spoofing developments, continuous lab tests as well as field tests at TÜPL Seetaler Alpe using the SX3 software receiver from iFEN were performed.

As soon as the GPS spoofing functionality was guaranteed, the time spoofing experiments together with Energie Steiermark were executed. Energie Steiermark during the project wanted to know about the possible threats of GNSS timing. Therefore, Energie Steiermark provided a PMU (phasor measurement unit), which derives its timing information from a GNSS timing receiver. The experiment showed that the time information of the GNSS receiver and hence the PMU can be manipulated. For Energie Steiermark, this information

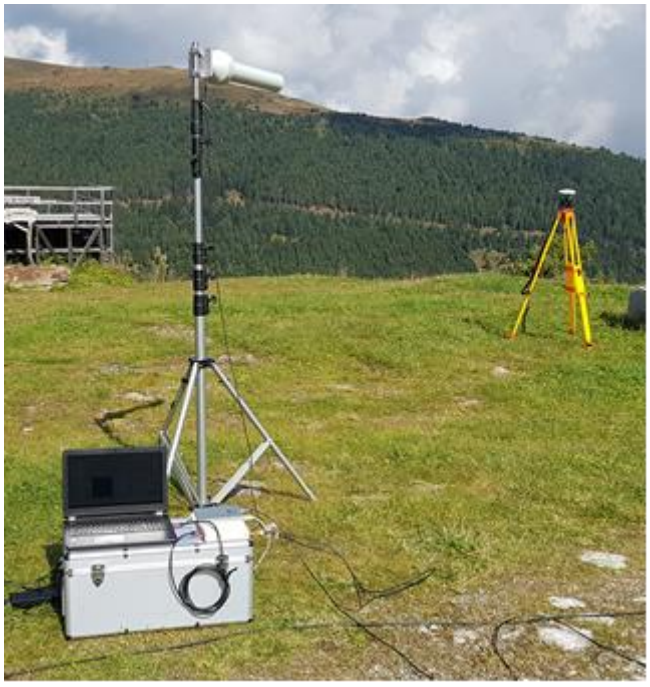
was very impressive and important for further decisions on the integration of these PMUs and future system designs.

For the Austrian Armed Forces and the Austrian Ministry of Interior, position spoofing was more of interest. The use cases especially of interest where how a convoy can be misled into a trap or how a drone can me spoofed to be forced to land. These experiments were executed at TÜPL Seetaler Alpe. The project team could impressively demonstrate a successful position spoofing of several commercial GNSS receivers, as well as a DJI S1000+ drone.

With the finalization of the spoofing demonstrator, the project team could start investigating the benefits of Galileo PRS. Therefore, a pseudolite creating PRS-like signals and a tracking capability of the PRS-like signals had to be implemented for the SX3. A first test was to investigate the robustness of OS (Open Service) and PRS during GNSS interference. Because of the high-order BOC modulation of the PRS signal, and hence the more spread signal spectrum, the PRS-like signal could be tracked while all OS signals were lost. The second test was a spoofing test. During this test, it is obvious that the PRS-like signals cannot be spoofed because the signal is not known in sufficient detail. Hence, while the OS could be manipulated, the PRS-like signal remained untouched.

In May 2017, the Austrian Armed Forces organized an info day at TÜPL Seetaler Alpe to demonstrate possible attacks and threats against GNSS users. Representatives from different national ministries had the chance to see several live demos in the context of jamming and spoofing attacks. The TACTIC consortium could successfully demonstrate at this time a spoofing attack on a significant quantity of different smartphones. Hence, very important stakeholders in Austria could be convinced about the existing GNSS threats.

Summarizing, with a real-time GNSS L1/E1 receiver spoofer, the GNSS vulnerability of GNSS open signals could be demonstrated, the benefits and importance of Galileo PRS could be underlined, and the awareness of the GNSS vulnerability could be strengthen.



❖ Remote Sensing

➢ ASAPXIII Project ALPMON

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 ALPMON project is dedicated to the monitoring of alpine forests and is being carried out in a joint cooperation between EODC GmbH, Vienna, as project coordinator, Catalysts GmbH and the Research Group for Remote Sensing and Geoinformation of JOANNEUM RESEARCH Forschungsgesellschaft mbH.

Alpine forests have been subjected to damaging natural and anthropogenic influences. Catastrophic storm events, bark beetle calamities, as well as impacts of climate changes have weakened the resilience of alpine forests. This results in a reduction in the functionality of the forests and leads to a decrease of the protection function regarding flooding and landslides, and to a reduction in wood production.

The success of far-sighted planning and preventive measures by forest administrations depends on the availability of information about the status and development dynamics of alpine forests. These also need to be available in short time intervals and easily accessible. Current methods for forest mapping focus to a large extent on the interpretation of aerial photos or terrestrial surveys, which are intensive in terms of man power and cost in-efficient. Area-wide mapping is not carried out for economic reasons. Forest inventories provide statistical figures for larger areas, but do not provide information on spatial distribution of the forest parameters required.

The objective of this project was to develop a proof-of-concept for an Alpine monitoring system implemented at the EODC. The system is based on satellite image data from the Copernicus Sentinel-2 (S-2) mission in combination with Landsat-8 (L-8) imagery, which in combination form an ideal basis for the establishment of a large-scale monitoring system through high spectral, spatial and temporal resolutions.

The implemented information system demonstrators provide two different services to the forestry user community: Service 1: a near real-time alert system for abrupt forest changes based on time series analyses. The target parameters provided to the user in near real-time are storm damage, insect calamities, clear cuts and snow break. Service 2: a mapping service of static forest parameters each 3 - 5 years, dependent on requirements.

The mapping service builds upon the already existing Copernicus High Resolution Layer Forest, but integrates further differentiation of the tree species by considering forest phenology, as well as a more precise recording of the alpine forest boundary. Novel methods and processing lines for data pre-processing, time series analysis and classification are integrated into the EODC processing environment. A prototype for a user-friendly web service is created, which allows users to have the results of the near real-time system available as promptly as required. The conception of the entire system will be geared to the user needs, which are assessed in detail. At the end of the project, the entire demonstrator system will be tested in a proof-of-concept phase in co-operation with the users and possible weaknesses will be identified and corrected in multiple user feedback loops to the developers.

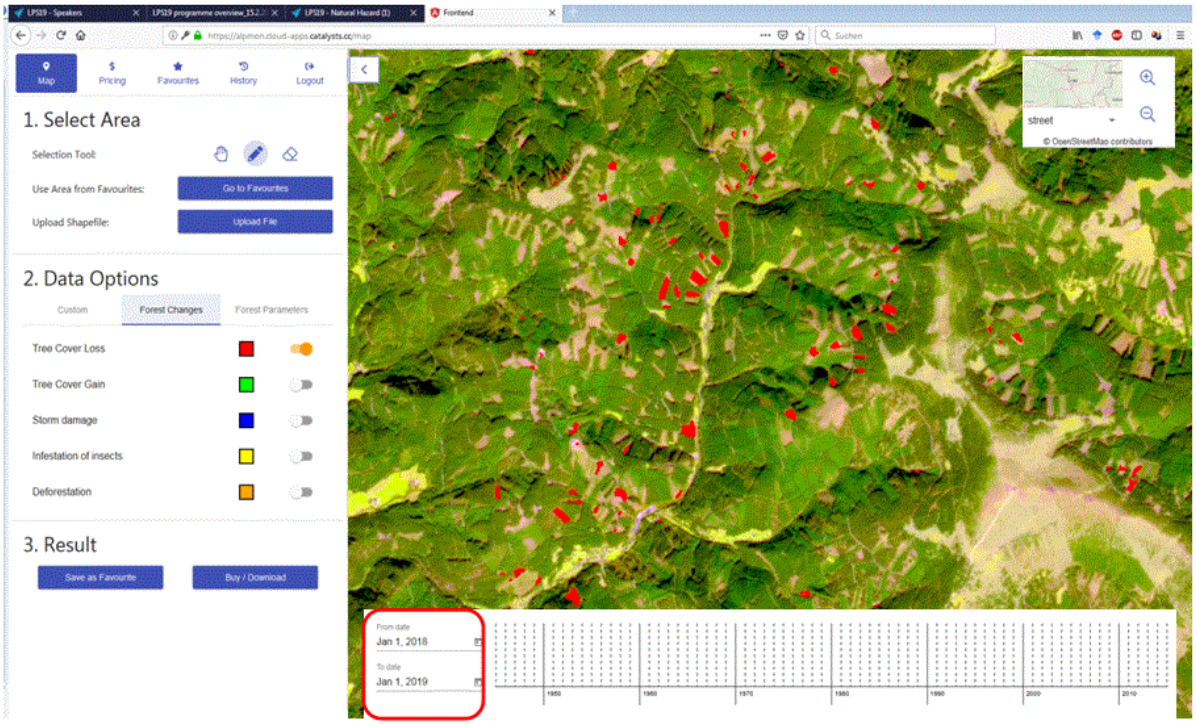


Figure: Near real time change detection system (Sentinel 2 image with changed areas)

❖ Space Robotics Vision / Space Science & Exploration

➢ ExoMars PanCam 3D Vision

The joint ESA/Roscosmos ExoMars Rover Mission is scheduled for launch 2020 and landing on the Red Planet in 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 (Figure). Standard ground vision processing products will be digital terrain maps, panoramas, and virtual views of the environment. Such processing is currently developed by the PanCam 3D Vision Team under JOANNEUM RESEARCH coordination (PRODEX Contract). Camera calibration of the PanCam Engineering Model (EM) was finalized in 2018, 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 the data from the ExoMars WISDOM ground penetrating radar 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). Parts of the work in 2018 therefore were dedicated to shatter cone simulations within PRo3D (Figure), to test their appearance within realistic Martian environment in order to be prepared for such phenomena showing up during the mission.

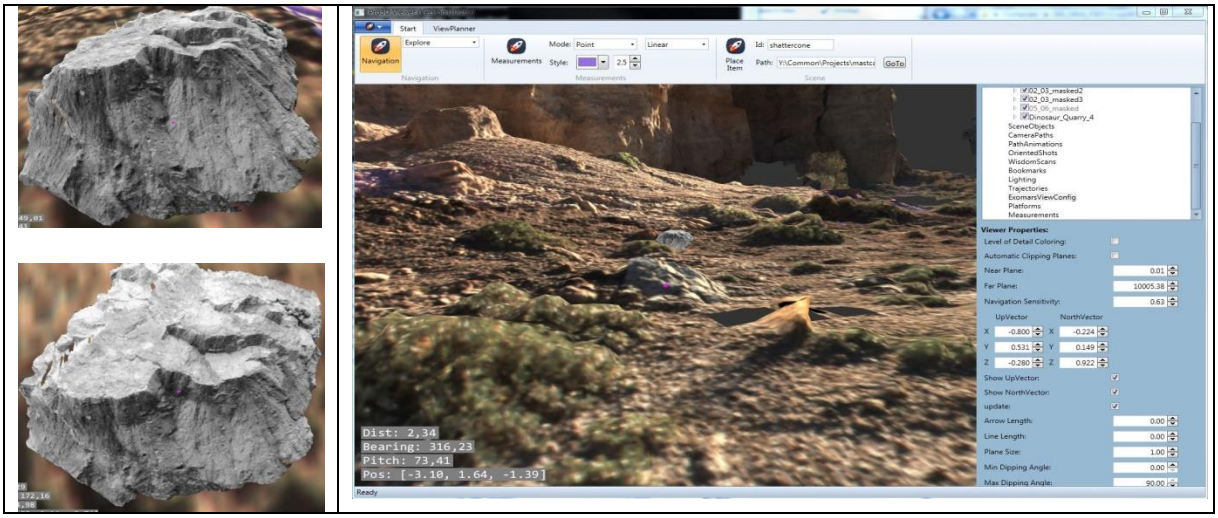
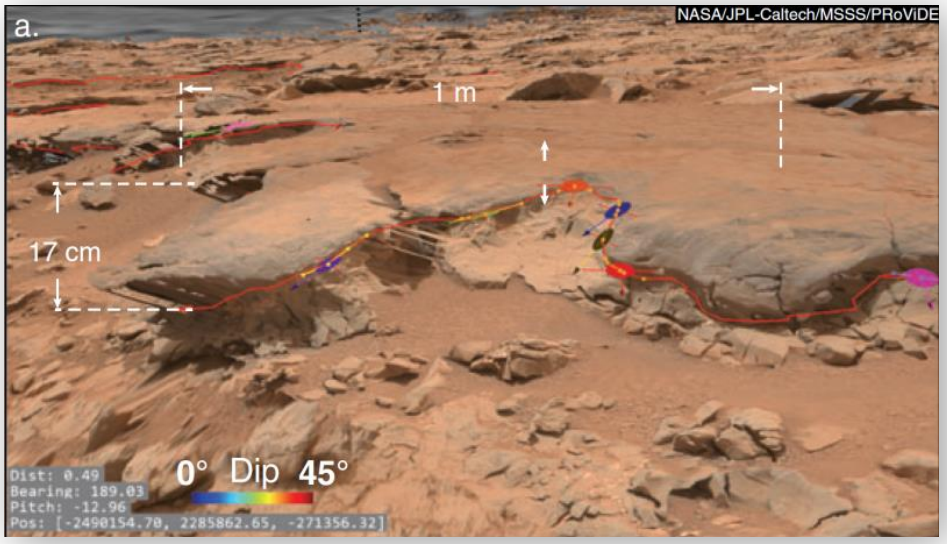


Figure: Left: Shatter cone as photogrammetrically reconstructed in 3D, rendered from different positions. Right: Shatter cone (middle of image) placed in rendering of a real scene used for geologic annotation

➢ Mars 2020 Mastcam-Z 3D Vision

The NASA Mars 2020 mission will launch a 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 the rover 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 (Figure (2)) during the mission in the operational time frame in 2021. In 2018 the components underwent thorough testing using breadboard equipment, and Mastcam-Z geometric calibration was prepared with



calibration of the EM (Engineering Model) and a concise plan for the Flight Model (FM) calibration as foreseen in the first quarter of 2019.

Figure: PRo3D (visualization component provided by project partner VRVis) geologic annotation of MSL Mastcam stereo data

➢ 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, Figure (3), left) 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. Testing of the components is accomplished using

the GEPE (Geometric PanCam/NavCam Emulator, Figure (3), right), developed by JOANNEUM RESEARCH.

Figure: Left: Control room within the ExoMars ROCC (Rover Operations Control Centre), being the operational environment of NavCam/LocCam 3D vision processing. Right: Geometric PanCam/NavCam Emulator GEPE by JOANNEUM RESEARCH, used for testing and validation of the NavCam/LocCam processing chain.

- **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 following the successful completion of the SAFER (Sample Acquisition Field Experiment with a Rover) as conducted in Chile in 2013.

ExoFit equips a representative breadboard of the ExoMars Rover *Rosalind Franklin* with field-ready replicates of ExoMars science and engineering instruments of varying maturity (Figure (4), left). JOANNEUM RESEARCH within ExoFit is 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 planned for February 2019 in Atacama desert, Chile) image data captured by these instruments within the operational chain is uploaded to a processing server at JOANNEUM RESEARCH premises in Graz, Austria, being automatically processed into 3D vision products (panoramas, 3D reconstructions, Figure (4), right), and made available for download within minutes by the Rover Operations Centre located in Harwell, UK, where further planning based on such data takes place.

ExoFit is linked to the trials support and operation preparation support aspects of the Harwell Robotics and Autonomy Facility (HRAF) and will also contribute to the construction of the facility itself by carrying out the integration (i.e. formatting and archiving for re-use in the context of HRAF) of the field tests dataset into the archiving system. 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.

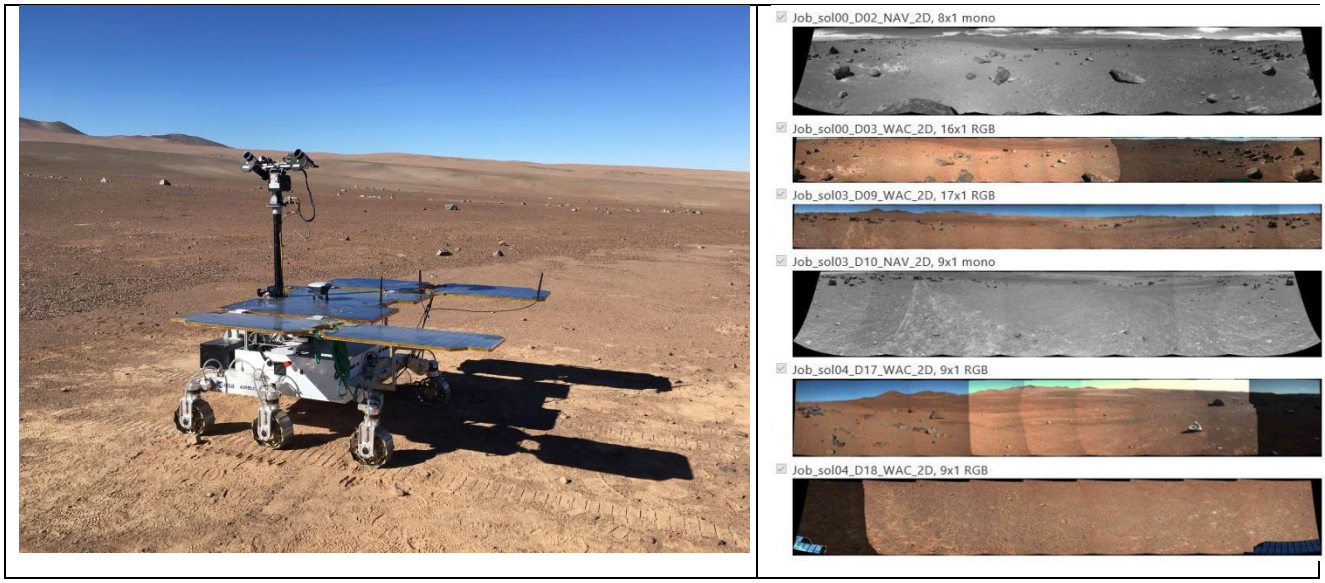


Figure: Left: ExoFit Rover in representative environment (Credits: ESA). Right: Examples of 3D vision data products as processed by JOANNEUM RESEARCH 3D vision processing chain in the operational / tactical processing workflow of the ExoFit field trials in Tabernas, Spain, October 2018 (data credits: Aberystwyth University, Airbus D&S)

- **MINERVA**

MINERVA is a framework currently under development for a collaborative, holistic planetary science data infrastructure access & analysis to allow members of different 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. The figure shows an example for the interoperability between the visual analytics component and the 3D viewer. MINERVA will be usable for ExoMars, where it will enable new ways of analysing the wealth of heterogeneous data. During 2018, MINERVA development was based on major portions of the MSL mission instrument data archive further details fostering usability within ExoMars workflows and instrument collaboration will be developed in the course of 2019.

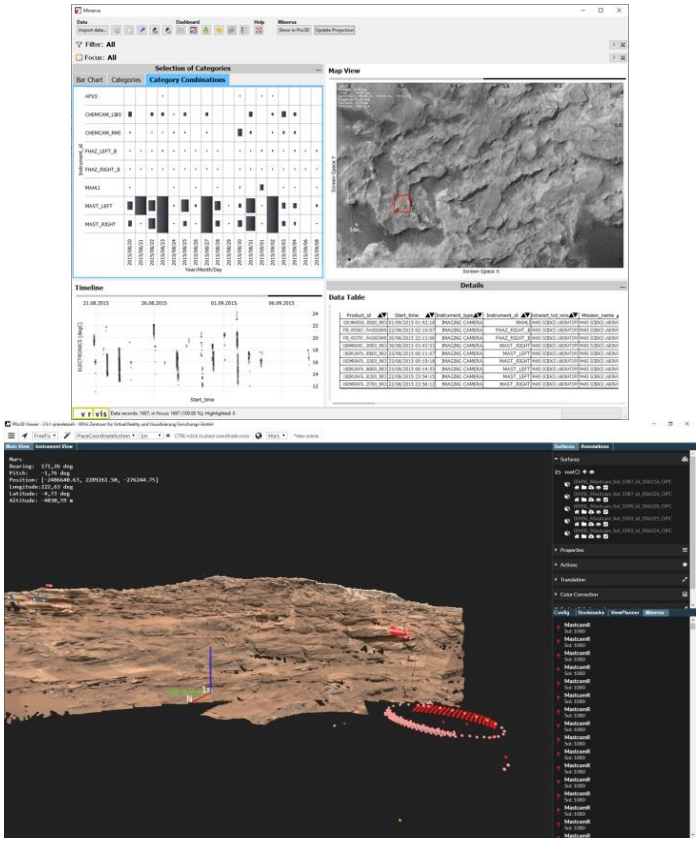


Figure: Selection of products in the visual analytics component Visplore (left) and their localisation relative to a Martian surface reconstruction in the 3D viewer PRo3D (right). Data Credits: NASA/CalTech/MSSS/ASU

- **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, being 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 currently undergoes its design phase, trading-off various locomotion designs which require a concise analysis of the envisaged landing site of Mars 2020 (Jezero Crater, which is interpreted to have hosted a deep lake in former Martian days). JOANNEUM RESEARCH is embedded in the SFR development team under Airbus D&S lead, being responsible for the analysis of the Mars 2020 landing site morphology. Such analysis uses simulations of possible Rover paths (taking into account various locomotion cost factors such as slopes, roughness and obstacles) to optimize rover design w.r.t. building blocks such as size, mass, energy consumption and navigation complexity. In 2018, JOANNEUM RESEARCH conducted comprehensive path simulations between combinations of sample cache depots and tentative landing spots (Figure), including statistical analysis of these paths w.r.t the SFR design criteria. In 2019 the compilation of a synthetic reference terrain will allow fully-synthetic tests to be executed by the rover development team at Airbus D&S.

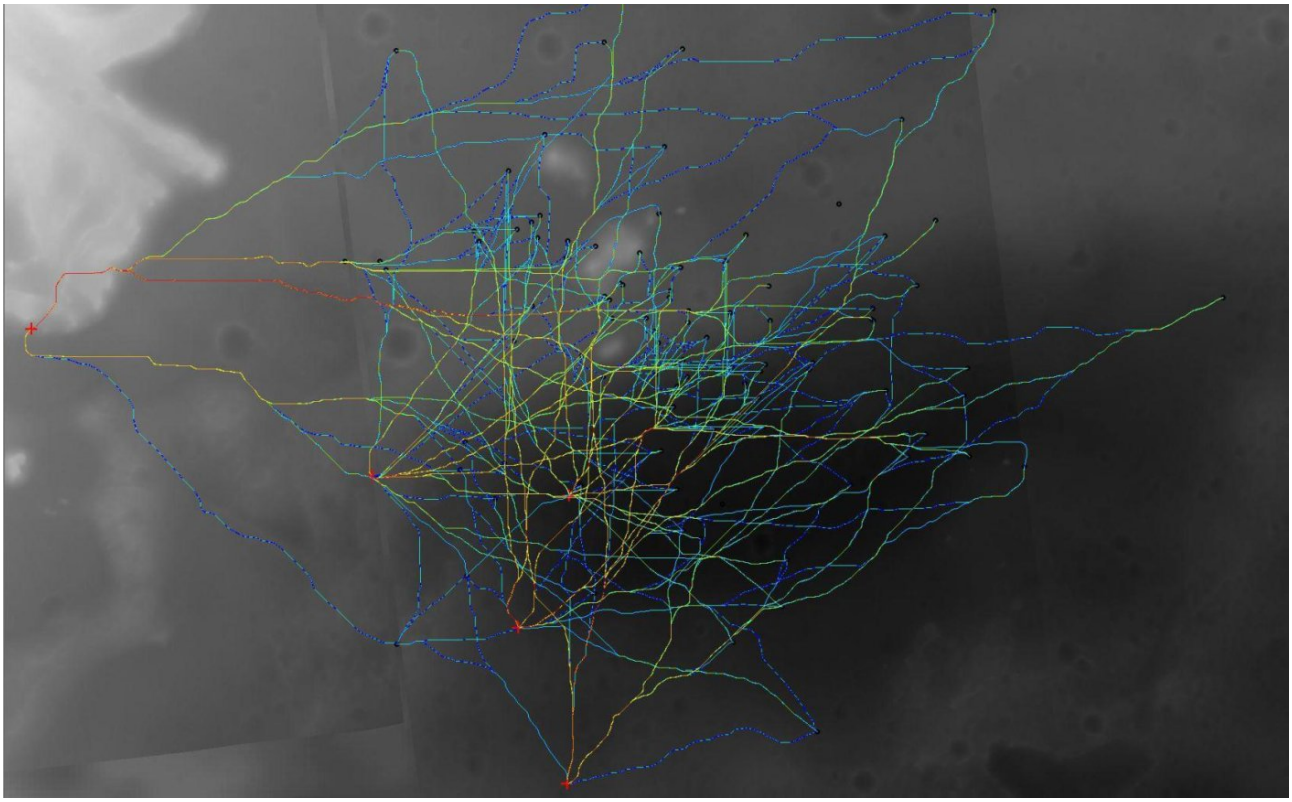


Figure: Simulated Rover paths on top of a Digital Elevation Model (DEM; grey coded with brightness indicating elevation) of the JEZERO landing site as planned for the Mars 2020 Rover mission which will cache samples and deploy the sample tubes for later collection by the European Sample Fetching Rover

Outlook

2019 will be the main year of calibration for ExoMars PanCam & CLUPI, as well as Mars 2020 Mastcam-Z, all three instruments being geometrically calibrated by JOANNEUM RESEARCH. Further testing of processing and visualization assets as elaborated by JOANNEUM RESEARCH, VRVis and the Vienna Museum of Natural History will be fostered in the respective instrument PRODEX contracts PanCam 3D Vision and Mastcam-Z 3D Vision. For the ExoMars ROCC (Rover Operations Control Centre) in 2019 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 mission-relevant environment, and some support will be given for the ROCC Mars Terrain Simulator 3D reconstruction system. For all such 3D vision activities, in 2019 testing and validation of the processing & visualization chain will be of high emphasis. JOANNEUM RESEARCH will finalize 3D vision and data archive preparation activities to the ExoFit planetary rover field campaign (Atacama field trials in Chile). Beyond ExoFit, the development of further archiving capabilities are envisaged. For Sample Fetch Rover Phase A/B1 the reference terrain with traverse characteristics representative for the Mars 2020 landing site will be developed. The MINERVA Project will go into its demonstration phase attaching to ExoMars instruments' test data. In February 2019 the Horizon 2020 SPACE Project "ADE" (Autonomous Decision Making), dealing with Rover autonomy in terms of navigation, planning and science autonomy, will be launched under GMV (E) coordination for a 24 Months' period. Within ADE, JOANNEUM RESEARCH will cover test data provision, science assessment, ground truth data provision and field data result assessment.

Sales 2018: 3.3 M€
ESA Share: 1.3 M€

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3.10 Magna Steyr Fahrzeugtechnik AG & Co KG Aerospace

Nadcap Accreditation

In December 2018 and February 2019 Magna successfully performed its initial Audits for Nadcap accreditation for Non-Destructive Testing (Penetration Inspection) and Welding. Magna was therefore awarded the Nadcap accreditation for these processes.

This accreditation certifies Magna to work according to the highest industry standards and is an important step to stay competitive in the challenging aerospace industry.

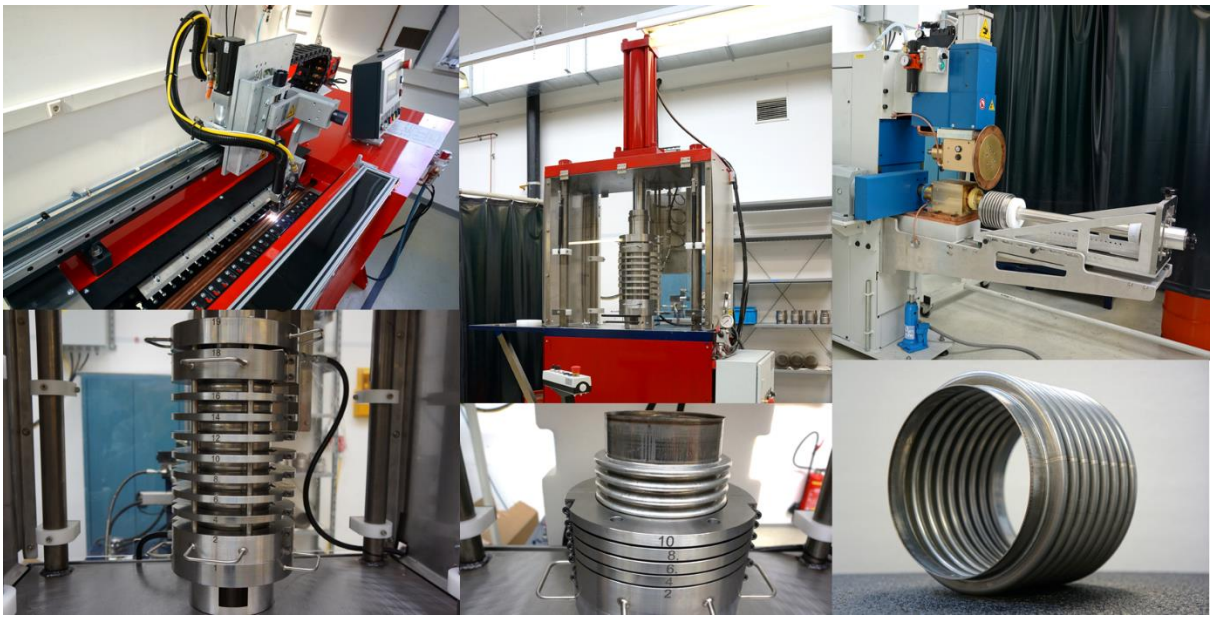
SLS (Space launch System) – Pressurization Lines, Flexible Joints

Further Flight Hardware has been built for NASA Space Launch System's (SLS) inaugural flight and delivered to Prime Contractor The Boeing Company at NASA Michoud Assembly Facility (MAF) in New Orleans. The manufacturing on hardware for the second flight, Exploration Mission 2 (EM2), has been started.

Preliminary Design Review has been completed for SLS Exploration Upper Stage (EUS) Projects concerning flexible elements for the propulsion System. Magna was able to prove its high technical competence by achieving this first important milestone in a development project together with The Boeing Company.

Implementation of Bellows Manufacturing Capability

Due to customer demand in the field of flexible elements the decision was made, to in-source the competence to develop and manufacture metallic bellows. Investment in new machinery for longitudinal welding, hydroforming and resistance welding has been made.



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

AVIO VEGA E

Magna started work on propellant piping for AVIOs for the future VEGA E launch vehicle. Magna has the task to develop the lines based on customer requirements and to provide prototypes for engine testing. This is the first step into this important and promising program which will play a key role in Magna's future activities in the launcher industry.

Source: ESA

Future Launcher Preparatory Program (FLPP) activities

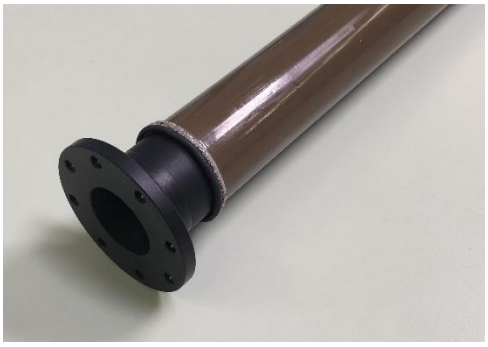
Aluminum Lines:

Magna's innovative Aluminium Compensators (flexible pipe element) is the key enabler to a 30% mass reduction of future propellant line systems. The fact that this technology comprises the joining of dissimilar materials (stainless steel and aluminum) requires dedicated Non-destructive Inspection (NDI) methods to prove that all products are flawless. Therefore multiple NDI methods have been investigated for their capability to find flaw in the dissimilar material joint.

Polymer Lines:

Magna's goal is to be able to offer a tailored material mix for the piping in future propellant systems. A range of high performance plastics has been screened and subjected to material testing to finally choose the right material/compound for each component of a propellant line. Finally a demonstrator pipe has been manufactured and is undergoing testing.

Polymer Lines are a viable option for cryogenic piping and promises a high potential for mass reduction and reduction in complexity of future launch systems.



Sales 2018: 6.6 M€
ESA Share: 0.2 M€

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3.11 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 2018, 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 more than 30 flight models could be booked until end of 2018, and 18 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. In Europe, the RSA market share for dual-frequency receivers exceeds 90%. Recently acquired contracts from South Korea demonstrate the strong market position also outside Europe.



RSA GNSS Receiver product family

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. Four LEO Receivers

were delivered to South Korea already. Additional 20 units, currently in various stages of assembly and test, will be used by customers in Europe and in the US. The GEO version, successfully qualified in 2018, will find its first application in the new all-electric telecom platform Electra of OHB.

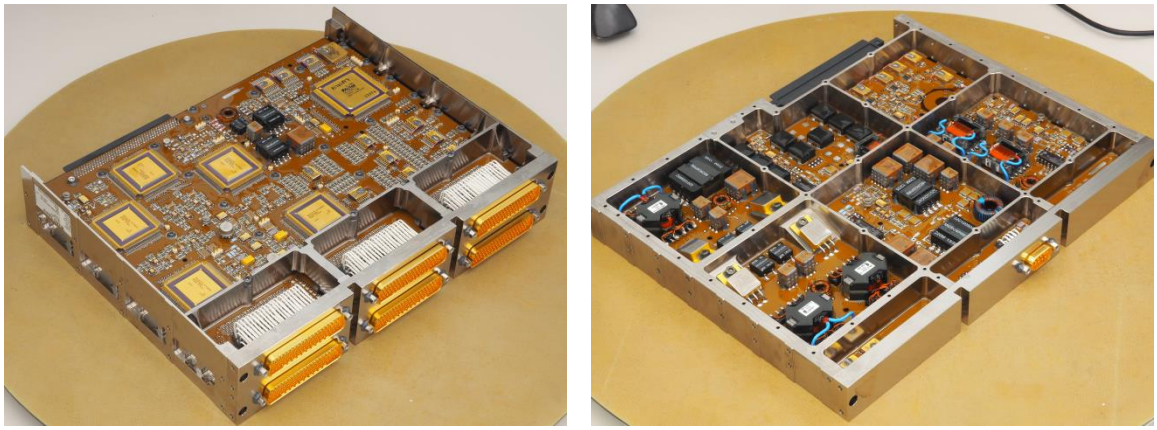
A remarkable success in the US institutional market is the selection of the RSA receiver for NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission to be launched in the 2022-2023 timeframe. The decision of the Goddard Space Flight Center (GSFC) in favor of RSA against domestic competitors is a real breakthrough and a strong indicator of the excellent position in the global space market.

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

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.

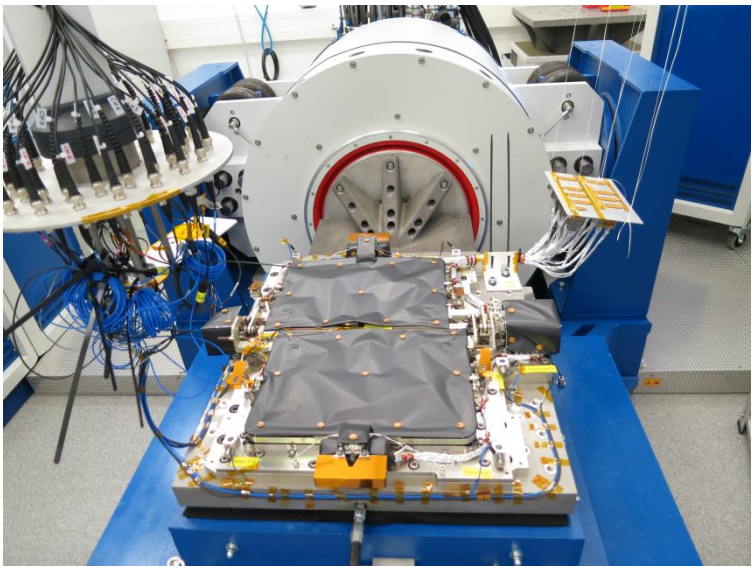
GNSS receiver products contributed one third to the RSA total sales in 2018.

Other major activities concerned projects in the frame of the Meteosat Third Generation (MTG) program, carried out by ESA on behalf of EUMETSAT. Flight model (FM) activities for the Antenna Deployment and Pointing Mechanism Electronics (ADPME) and electronics modules of the Satellite Management Unit for all six satellites were completed, while for the Solar Array Drive Electronics (SADE) three out of six FMs have been delivered until end of 2018.



Electronics modules of MTG Satellite Management Unit

The development of the Refocusing Mechanism and the Solar Baffle Cover for the main meteorological instrument as well as of the motorized Aperture Cover for the Sentinel-4 instrument has been completed.



Flight model of Sentinel-4 Aperture Cover during vibration test

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). An APD Engineering Model (EM) and RIU Protoflight Model modules were delivered in 2018.

A major milestone in 2018 was the successful qualification and delivery of the first flight set (4 units) of an Electric Propulsion (EP) Pointing Mechanism (EPPM) for the all-electric Spacebus-Neo platform of Thales Alenia Space (TAS).

Assembly of EPPM for TAS Spacebus-Neo platform

Sales of thermal insulation products increased by some 3% and reached nearly one third of total RSA sales. Significant contributions came from the ESA projects Solar Orbiter, BepiColombo, Euclid, Juice, Metop Second Generation and MTG. Solar Orbiter is of particular interest, because, for the first time, RSA has 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.

Of big strategic relevance is the entry of the launcher thermal insulation market in the frame of the Ariane 6 development.

Sales in the area of cryogenic insulation for terrestrial applications, a spin-off of the company's space business, slightly declined in 2018, but still contributed almost 10% to the total company sales.

The year 2018 brought a number of satellite launches with key RSA contributions on board. The launch of Sentinel-3B on board of a Rockot from Plesetsk brought the number of operational GPS POD Receivers to 18. The satellite is protected against the extreme temperatures in space by RSA thermal insulation. In July another Galileo quartet was launched on an Ariane 5, with electronics modules of the spacecraft computers and thermal insulation supplied by RSA on board.

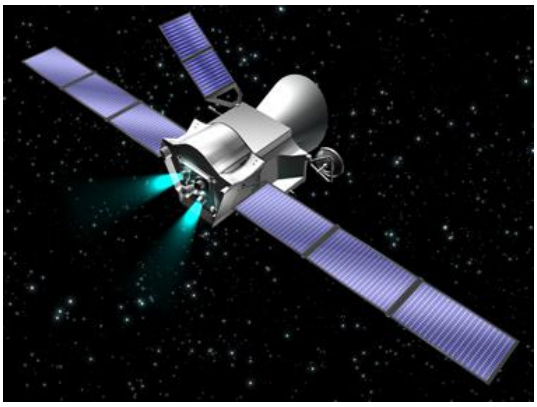
In September NASA's Ice, Cloud and land Elevation Satellite-2, or ICESat-2 lifted off on board of a Delta II from Vandenberg Airforce Base in California. This marks the first operational use of the RSA GPS POD Receiver in an US earth observation mission and is a highly valuable reference for further sales in this promising market.

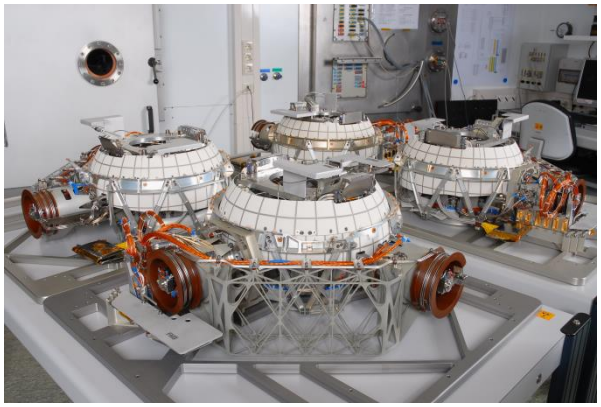
IceSat-2 and its launch on Delta II from Vandenberg Airforce Base (source: NASA)

One of the highlights of the year in space certainly was the launch of the ESA cornerstone mission BepiColombo on an Ariane 5. The joint mission between ESA and the Japan Aerospace Exploration Agency (JAXA) will study Mercury, the least explored planet in the inner Solar System. RSA provided major contributions to this especially challenging mission:

- During the voyage to Mercury the composite spacecraft, consisting of the two orbiters and a transfer module, will use the gravity of Earth, Venus and Mercury in combination with the thrust provided by solar-electric propulsion. RSA delivered the Thruster Pointing Assembly of the transfer module, which comprises four pointing mechanisms and the associated drive electronics.
- As Mercury is very close to the Sun, BepiColombo will be exposed to extreme temperatures. RSA developed and produced multi-layer thermal insulation tailored to these extreme conditions.
- The Mercury Planetary Orbiter needs to very precisely align its solar array, and RSA is the supplier of the Solar Array Drive Electronics.
- The Mechanical Ground Support Equipment (MGSE) required for handling the spacecraft during integration and test activities was supplied by RSA.

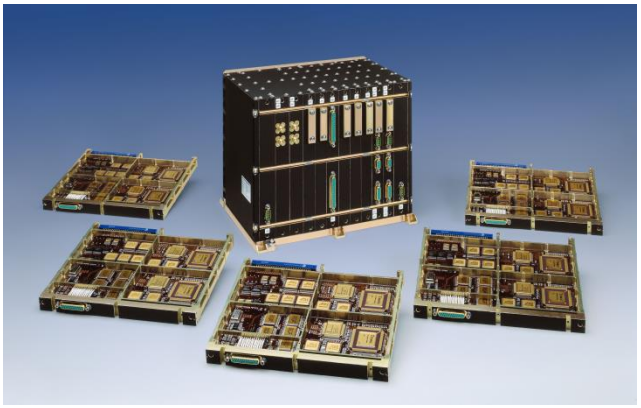
BepiColombo during preparation for launch on Ariane 5 (source: Arianespace)





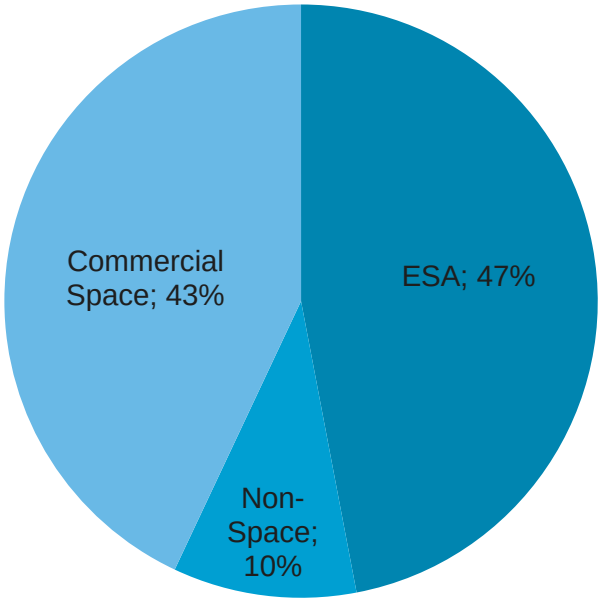
Artist's impression of BepiColombo in cruise phase (source: DLR) and RSA Thruster Pointing Mechanisms

Finally, in November a Soyuz from Kourou lifted MetOp-C into its orbit. RSA hardware and software plays a significant role in the signal/data processing of two major meteorological instruments on board of the first MetOp series: the GNSS Receiver for Atmospheric Sounding (GRAS) and the Infrared Atmospheric Sounding Interferometer (IASI).



MetOp IASI Data Processing Subsystem

Total RSA sales increased by 12% compared to 2017. The non-ESA share reached 53%.



Sales 2018: 55.4 M€
ESA Share: 26.2 M€

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3.12 Seibersdorf Labor GmbH

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 2018:

- **AVIDOS** Aviation Dosimetry service in space weather context
- **MUSRAS** MultiScreen Radiation Shield
- **PRETTY** Passive Reflectometry and Dosimetry

Further, Seibersdorf Laboratories undertook activities on the accreditation of the space relevant testing facility, the **TEC-Laboratory** for testing of electronic components and systems.

Seibersdorf Laboratories organised 2018 the **RADHARD Symposium** with topics on:

- Standards for Radiation Hardness Assurance
- Space Radiation Environment and Effects
- Test Laboratories and Practical Aspects of Testing

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 of interest. 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 can lead to critical impacts on aviation. WMO and ICAO launched a process to select centers providing a space weather information service to support international air navigation. In 2018, first global and local space weather information service centers were designated.

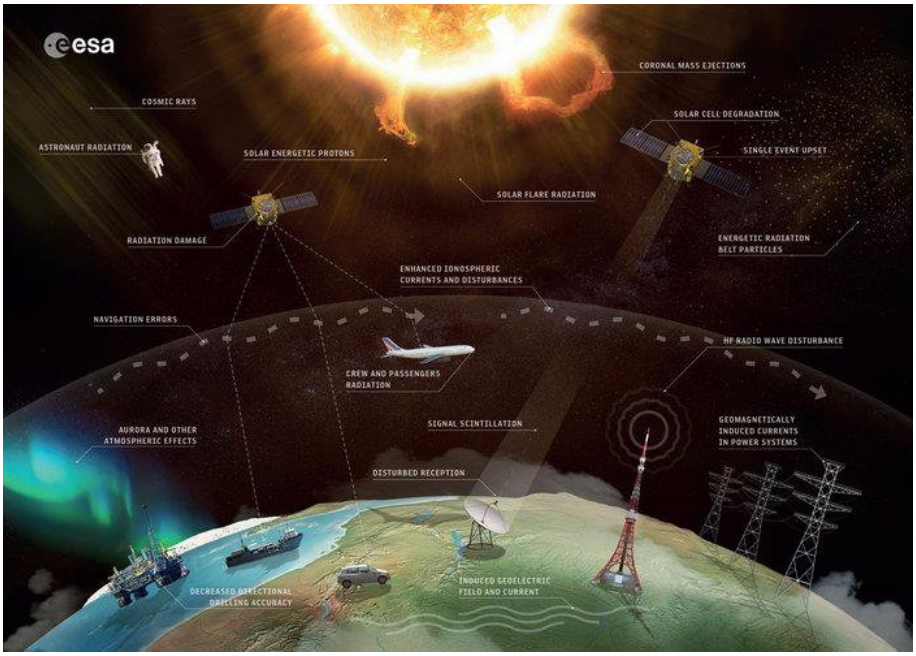

Figure: Cosmic rays from outer space impinge on Earth's atmosphere, and by nuclear interaction produce a shower of radiation composed of photons, protons, electrons, neutrons, muons and other particles.

Used Method by AVIDOS

Seibersdorf Laboratories is one of the expert groups that form Expert Service Centres (ESC) in the ESA's Space Situational Awareness (SSA) programme in its Space Weather (SWE) segment. Seibersdorf Laboratories belongs to Radiation Expert Service Center (R-ESC) and provides the public with a 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 on aviation altitudes. In 2018, Seibersdorf Laboratories continued maintaining the availability of the AVIDOS 2.0 service at the ESA's SWE portal (http://swe.ssa.esa.int/web/guest/avidos-federated), supported the ESA SSA Space Weather Coordination Centre (SSCC) with expert knowledge on space radiation at aviation altitudes and operation of AVIDOS 2.0, as well as contributed to the overall development of R-ECS network.

Following contemporary 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. During that phase, we conducted a study on a technology choice and performed initial re-programming works. At the end of 2018, we prepared a bigger activity to be launched early 2019 where we planned advancements on a larger scale to end up with a new version AVIDOS 3.0 available at the ESA SSA SWE portal in the next years.

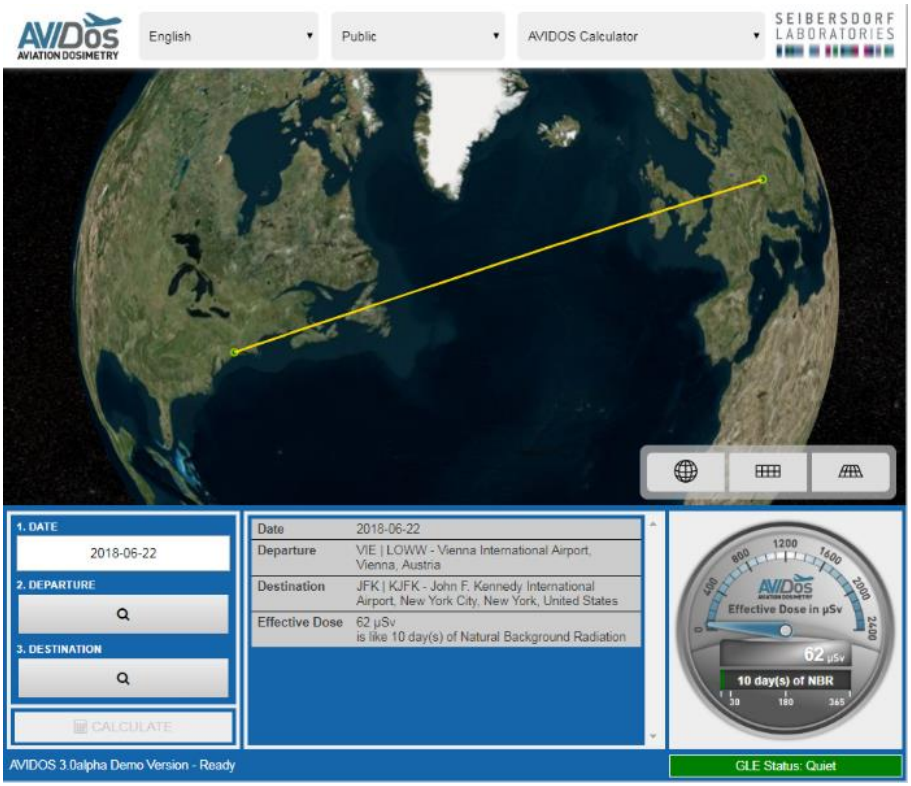

Figure: A snapshot of the AVIDOS 3.0 graphical user interface as developed within the AVIDOS 3.0 pilot phase.

Our service AVIDOS 2.0 federated with the ESA SSA SWE portal offers nowcasting and forecasting of Galactic Cosmic Radiation for up to 1 year in advance. AVIODOS 2.0 is also able to perform a rough real-time dose assessment during isotropic Solar Energetic Particle events (SEP) with uncertainties of up to one order of magnitude. In 2018, we concluded the

AVIDOS-SEP-Nowcast project (a collaboration with International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat, Switzerland) that was focused on possible improvements of nowcasting and forecasting of SEP induced enhanced radiation levels. Additionally to the results reported earlier for 2017, in 2018 we have shown how data from the worldwide neutron monitor network can be used to characterize the temporal development of the solar proton spectrum during an anisotropic SEP event. In a successful proof-of-concept we have shown how such SEP characterization can be used for an improved radiation dose assessment at aviation altitudes. An example of the achieved results is presented in the figure below where we show a global map of effective dose rates at an altitude of 10 km as calculated for GLE69 on 20 January 2005 at 07:00 UT. We also studied whether the warning times for SEP induced elevated radiation levels in atmosphere of existing alert systems that base on measurements of the neutron monitor network can be significantly improved. This survey has shown that a major progress to increase alert times (typically few minutes in advance before the SEPs affects the dose rates at aviation altitudes) is very challenging to achieve and needs further effort.

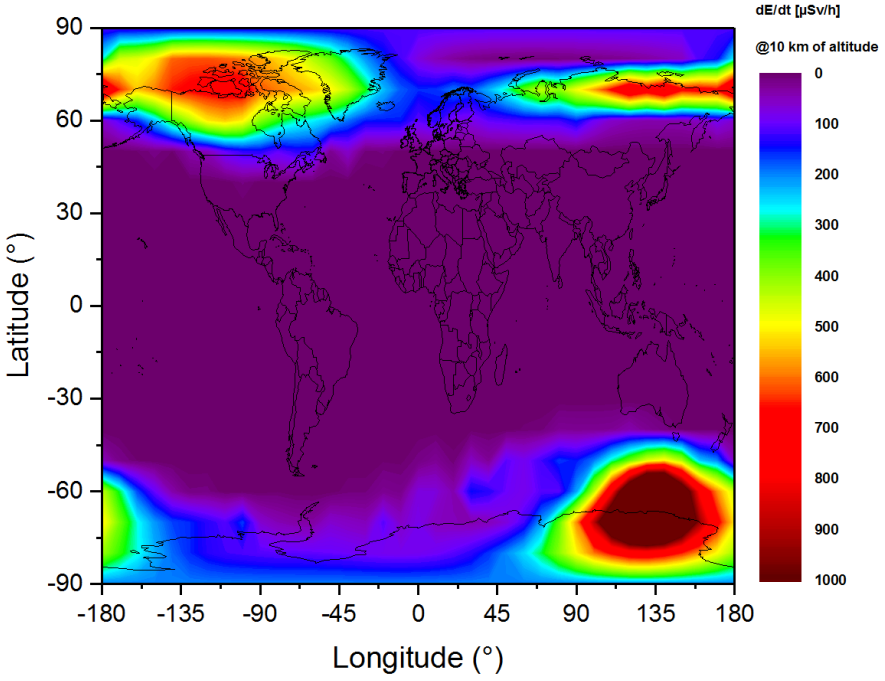

Figure: Map of effective dose rates at an altitude of 10 km as calculated for GLE69 at 07:00 UT.

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. Worldwide, 22 different states responded to that letter expressing their interest in becoming a prospective space weather information provider either jointly or separately. 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 early 2018, the WMO on behalf of ICAO conducted on-site audit and confirmed PECASUS compliant to all ICAO requirements. In autumn 2018, the ICAO council designated PECASUS as one of the three global space weather information centers. Seibersdorf Laboratories contributes to PECASUS with a customized aviation dosimetry services in according space weather requirements formulated by ICAO.

Acknowledgements

P2-SWE-I and P3-SWE-III projects are supported by ESA (ESA Contract No.: AO/1-7234/12/D/MRP - Task1, and 4000113187/15/D/MRP respectively), the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT), the Austrian Aeronautics and Space Agency (ALR) as part of the Austrian Research Promotion Agency (FFG). AVIDOS-SEP-Nowcast project (a collaboration with International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat, Switzerland; https://www.hfsjg.ch) was supported by Austrian Research Promotion Agency (FFG) and Swiss Space Center (SSC). Authors acknowledge SSCC team at the Space Pole in Belgium, 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.

MUSRAS - MULTISCREEN RADIATION SHIELD

Introduction

Space radiation exposure is the primary limiting factor in space exploration and in establishing a permanent human presence in space. The need to look at new ways of constructing spacecraft is now evident as current estimates indicate that aluminium is an ineffective protection material. This is because of the secondary particle production originating from collision of the incident radiation with target nuclei of the shielding material itself. The present project aims at the development and characterisation of a novel multilayer shielding concept. The ESA Innovation-Triangle-Initiative (ITI) project MUSRAS (Multiscreen Radiation Shield) is coordinated by Seibersdorf Laboratories in collaboration with CTNM, PTS, HPS and ESA.

Figure: NASA's Orion spacecraft for providing astronauts into space using a module based on Europe's Automated Transfer Vehicles (ATV). The ATV-derived service module, sitting directly below Orion's crew capsule, will provide propulsion, power, thermal control, as well as supplying water and gas to the astronauts in the habitable module. (Credit: NASA, ESA).

Motivation and Objectives

The motivation of the MUSRAS project is to identify innovative shielding concepts to mitigate radiation exposure on interplanetary space missions. Such improved shielding strategies are beneficial for the ESA manned mission programme, the European service vehicle contribution to NASA ORION Mission ESM EM-2 (trip and flyby to the Moon; for artists impression of ORION spacecraft see figure above) and for the NASA InnoCentive Seek to Reduce Radiation Exposure on Deep Space Missions.

The MUSRAS study plan therefore implements the following objectives:

- Investigate MultiScreen Radiation Shield Concept for interplanetary Human Spaceflight Missions by means of Monte Carlo Simulation and manufacturing of material samples.
- Test a demonstrator in radiation environment relevant for space mission.
- Compile a marketing study of a possible application for the multiscreen radiation shielding.

Methods and Results

A multi-screen radiation shield (MUSRAS) concept has been developed and its effectiveness has been evaluated by numerical means at hand of a model short stay mission to mars. We investigated three segments of that space mission with regard to maximum radiation exposure. (1) Mission segment MS-1: journey to Mars, (2) mission segment MS-2: stay on Mars, and (3) mission segment MS-3: return to earth. For the modelling of the radiation environment, we used fluence proton spectra of solar cosmic radiation (SCR), galactic cosmic radiation (GCR) and three representative heavy ions from He, C, and Fe during the most exposed space mission scenario: mission segment MS-3. The superior performance of the MUSRAS shielding concept over the classical aluminium shielding is demonstrated in the figure below. The graph presents the ratio of the effective dose equivalent $H_{E,\,MUSRAS}$ behind a MUSRAS shielding and the effective dose equivalent $H_{E,\,AlRef}$ behind an aluminium shielding as a function of the shielding depth when using SCR of mission segment 3 as incident particles.

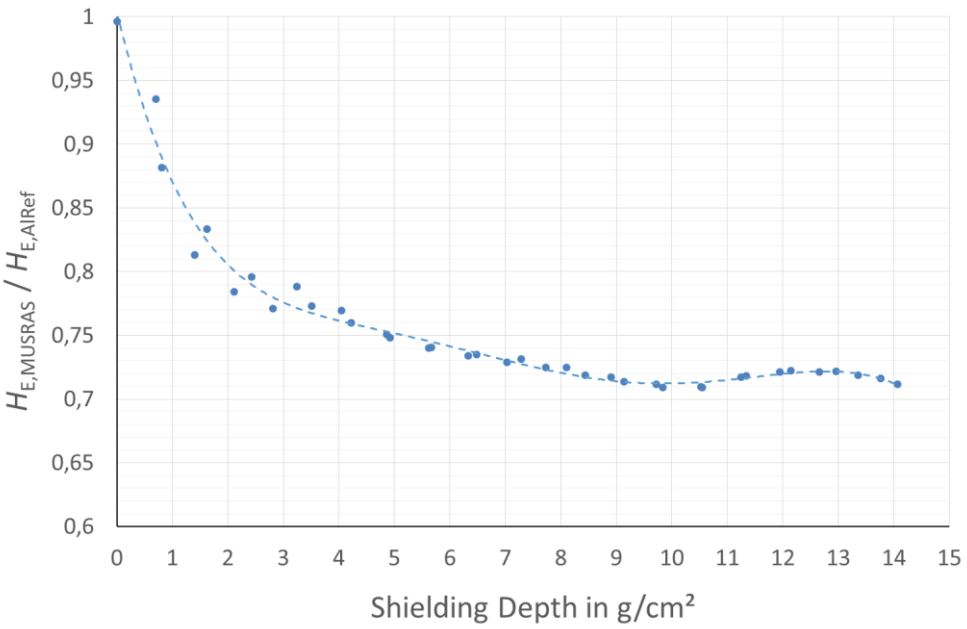

Figure: The ratio of the effective dose equivalent $H_{E,\,MUSRAS}$ behind the MUSRAS shielding and the effective dose equivalent $H_{E,\,AlRef}$ behind an aluminum shielding as a function of the shielding depth. Incident particles are solar cosmic radiation of the mission segment MS-3.

Proton exposure experiments have been performed in addition to the numerical evaluation. For the experimental approach, MUSRAS demonstrators have been manufactured and tested in the proton irradiation facility (PIF) at the Paul Scherrer Institute (PSI) in Villigen, Switzerland. The experimental results support the numerical findings very good.

Summary and Conclusions

- A MUSRAS shielding demonstrator was successfully developed
- Modelling of the effective dose equivalent, H_E for a interplanetary mission spectrum (MS3) have been done for shielding depth between 0 g/cm² and 16.2 g/cm²
- Measurements with incident proton energies of 75 MeV, 100 MeV, and 150 MeV have been carried out for shielding depth between 4.4 and 16.2 g/cm².
- Modelling of the measurements with incident proton energies of 75 MeV, 100 MeV, and 150 MeV have been done for shielding depth between 4.4 and 16.2 g/cm²
- Experimental as well as simulation results for dose equivalent show better shielding properties of MUSRAS shielding compared to aluminium by a factor of about 1.6 (incident protons: 75 MeV, 100MeV) for the same shielding depths between: 4.4 g/cm² – 16.2 g/cm².
- Calculated effective dose equivalent, H_E for a selected interplanetary mission segment return from Mars to the Earth show better shielding properties for MUSRAS compared to Aluminium by a factor of 1.4 at a shielding depth of about 10 g/cm².
- Human space missions (Moon, Mars) as well as the aviation sector need innovative concepts of passive radiation shielding.
- The performance potential of the MUSRAS concepts has been successfully demonstrated for suitable shielding approaches for existing space vehicles.
- Follow-on activities and further investigation are suggested on heavy ions and atmospheric radiation fields.

Acknowledgements

The project is part of ESA's ITI Innovation Triangle Initiative (contract 4000118162/16/NL/MH/GM), supported by the Austrian Ministry for Transport, Innovation and Technology (BMVIT). The Aeronautics and Space Agency (ALR) as a part of Austrian Research Promotion Agency (FFG) is responsible for the administrative coordination of the Space Technology Programmes in Austria.

PRETTY - PASSIVE REFLECTOMETRY AND DOSIMETRY

Introduction

The Space Mission on Passive Reflectometry and Dosimetry (PRETTY) is an ESA Cubesat space mission 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. The preliminary design review (PDR) of the PRETTY Phase B study was held end of 2018.

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 onboard 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. The target dose uncertainty for the proposed reference dosimeter system under laboratory conditions is about 10%. This is comparable with the testing conditions of electronic components according to ESCC 22900. 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.

Dosimetry Method On-board CubeSat and Preliminary 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 uses his expertise in space radiation dosimetry and will characterize the sensors in terms of dose rate and temperature dependency for providing a reference dosimeter system. Further, the 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.

Although the project budgets forces the project team to use commercial components of the shelf (COTS) for the PRETTY payload, Seibersdorf Laboratories is undertaking a significant effort on radiation hardness testing of all used electronic components of their payload. Radiation hardness testing at Seibersdorf Laboratories shows, that some components-of-the-shelf (COTS) shows already at about 5 krad (50 Gy) significant failures, which is 1/3 of a typical mission dose for PRETTY of about 15 krad (150 Gy) in one year. 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 will be identified and replaced. The figure below shows radiation exposure experiments using the Cobalt-60 source of the TEC-Laboratory of Seibersdorf Laboratories.

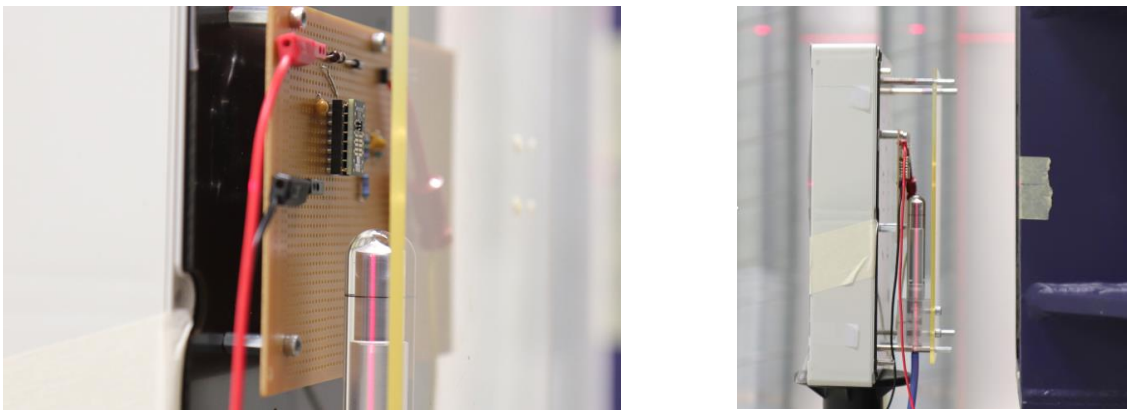

Figure: Radiation measurements of electronic components at the TEC-Laboratory of Seibersdorf Laboratories.

During the PRETTY Phase-B study it became evident that the mission can gain significantly scientific value by improvements to the dosimeter payload. Seibersdorf Laboratories investigated and identified solutions to majorly increase the scientific value of the dosimeter payload, by supplementing observation data from total ionizing dose with an energy-dependent spectral analysis of the space radiation environment in orbit. The derived linear energy transfer (LET) spectrum allows the assessment of the radiation environment responsible for single event effects (SEE). Single, energetic particles can lead to a broad variety of soft to fatal errors in electronic devices. The LET-spectrometer by Seibersdorf Laboratories will assess the radiation environment during the PRETTY space mission allowing to predict SEE rates (error and failure rates) of electronic components. This is a

major improvement of the PRETTY space mission and Seibersdorf Laboratories is convinced of the international reputation that will arise from that improvement.

Summary and Outlook

Seibersdorf Laboratories propose a TID reference dosimeter and LET assessment system concept 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, the dose rates at geographic regions of interest with elevated radiation levels and the linear energy transfer (LET) distribution of the space radiation environment - data that can be linked to damaging effects in electronic devices. Further it will provide a technology demonstration of a reference dosimeter system 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.

Acknowledgements

The Phase B study for the PRETTY mission was funded by ESA GSTP Program.

RADHARD SYMPOSIUM 2018

Introduction

On 24th and 25th April May 2018, Seibersdorf Laboratories organized their 3rd RADHARD-Symposium, on Radiation Hardness Assurance Issues related to CubeSat space missions.

The mission of the RADHARD Symposium is to provide you, complementary to the RADECS conference, with a forum for exchanging practical experiences in radiation hardness assurance, relevant for industrial applications as well as for science and research.

Our vision is that the RADHARD Symposium offers a space with plenty of room for conversation, initiating new joint projects and inviting you to attend the RADECS Conference.

The RADHARD-Symposium focused on:

- CubeSat Space Mission
- 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.

Figure: Photo of the RADHARD 2018 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 2018 in Numbers

- 2 days event
- 40 participants
- 2 Keynotes
- 3 Training lectures on Space Radiation Environment, Radiation Effects and RHA Testing Facility
- 7 Lectures on Practical Aspects of COTS in Space and RHA 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/2018-radhard-symposium

Reference: ISBN for print: 978-3-902780-12-6, ISBN for e-book: 978-3-902780-13-3.

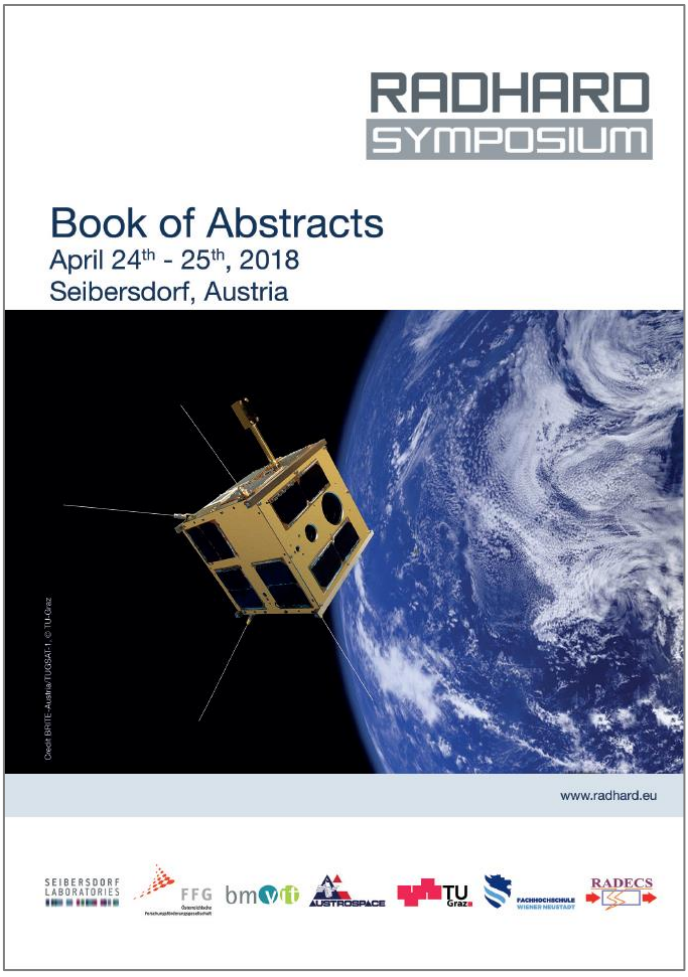

Figure: Book of abstracts of the 3rd RADHARD Symposium on 24th – 25th May 2018

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 2018.

TEC-LABORATORY - ACCREDITATION COMPLIANT WITH EN ISO/IEC 17025

Introduction

Seibersdorf Laboratories extended its accredited testing capabilities by the TEC-Laboratory (Testing of Electronic Components) for total ionizing dose (TID) exposure tests of electronics, systems and materials with a Cobalt-60 source. The radiation exposure is performed in accordance with accredited procedures compliant with the EN ISO/IEC 17025 standard for test labs. For achieving the accreditation, the TEC-Laboratory has been fully characterized and subsequently audited by an independent governmental body, the Accreditation Austria, which is a full member of the International Laboratory Accreditation Cooperation, ILAC. The EN ISO/IEC 17025 standard specifies technical as well as management requirements that have to be satisfied. In the following, the technical characterization of the TEC-Laboratory and the required management procedures are described.

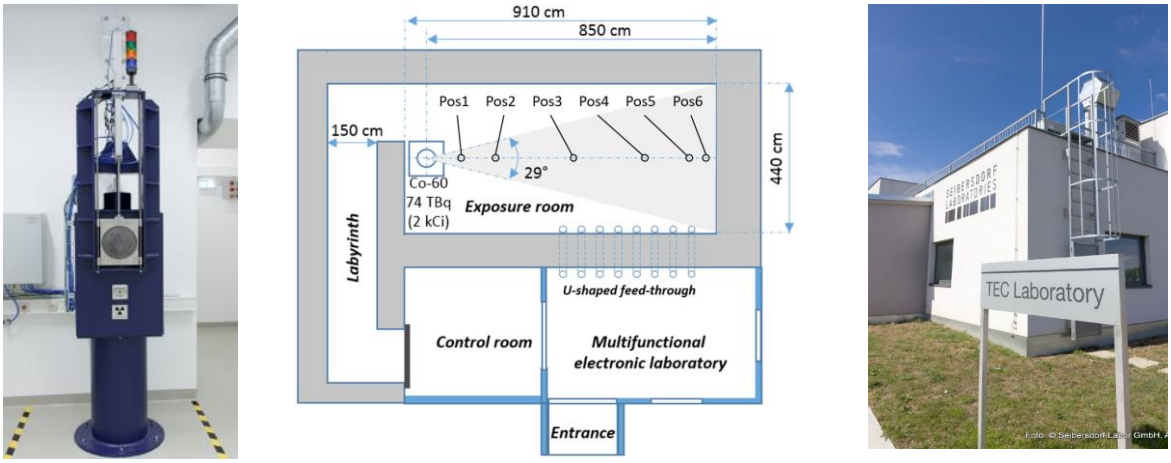

Figure: The Cobalt-60 irradiation system (left), floor plan with indicated positions for simulations (middle) and view of the TEC-Laboratory (right) located at the campus of Seibersdorf Laboratories in Austria.

The TEC-Laboratory

The TEC-Laboratory is designated for testing the susceptibility of electronic components to total ionizing dose effects. It consists of an exposure room with a cone shaped Cobalt-60 photon field (total opening angle 29°), a control room and a multifunctional electronic laboratory. The TEC-Laboratory enables accredited testing and provides experimenters with:

- Uniform Cobalt-60 irradiation field
- Wide range of dose rates from 0.3 Gy/h to 100 Gy/h
- Spacious exposure room (length: 9.1 meters, width: 4.4 meters, height: 4 meters) with plenty of space available for multiple exposures of various set-ups
- On-line monitoring of the dose and dose rate level to which the DUT is exposed by the use of ionization chambers positioned closely to the DUTs
- Traceability of dose and dose rate data by the use of accredited procedures

- ESD protected area compliant with the requirements of the EN IEC 61340-5-1 standard throughout the entire TEC-Laboratory
- An electronic test lab that allows remote and offline testing
- Multiple workstations in the electronic laboratory, instrumentation such as power supplies, oscilloscopes, frequency generators, SMUs, and plenty of space to arrange the required equipment for carrying out the experiments.

The TEC-Laboratory in compliance with EN ISO/IEC 17025

The Seibersdorf Laboratories have developed procedures for the determination of the DUTs dose that are compliant with EN ISO/IEC 17025 as well as the ECSS 22900 basic specification and MIL-STD-750, Steady-State Total Dose Irradiation Procedure. The EN ISO/IEC 17025 requires not only technical but also management compliancy. The Seibersdorf Laboratories has a transparent and sustainable quality management system that is regularly audited by independent governmental bodies. The implementation of the standard require the following technical compliancy.

- **Operating Staff:** the TEC-Laboratory is operated exclusively by experienced personnel. The competence of the personnel is gained in trainings, continued education and daily practice. All training arrangements are conducted and documented in compliance with EN ISO/IEC 17025.
- **Premises and Environmental Conditions:** a key-code security system ensures that only authorized testing personnel has access to the TEC-Laboratory. Environmental conditions in the TEC-Laboratory are ideally suited for testing of electronic components and systems. Temperature, humidity and atmospheric pressure in the exposure room are continuously monitored and stabilized by an air conditioning system.
- **Validated Test Methods:** accredited operating procedures ensure that any dose assessment in the TEC-Laboratory has an uncertainty of less than 2.5% (coverage factor 2, 95% confidence level). The validation and technical competences in dose assessment are demonstrated by participation in intercomparison campaigns and recurring audits.
- **Traceability of Measurement Equipment:** The metrological traceability of the used measurement equipment is certified by periodical calibrations performed by accredited calibration laboratories.
- **Sample Handling:** The handling of samples that are to be exposed is defined in accredited operating procedures. These procedures ensure traceable receipt, marking, treatment, and storage of samples. A sample submission sheet documenting all relevant steps is filled out and kept for every sample or group of samples.
- **Control of Data:** The dose measurement system determining the radiation exposure dose to the DUT is examined periodically. The examination is documented traceable in an accredited working procedure.
- **Test Reports:** A standardized test report – that is showing the accreditation body's certification mark as an indication of compliancy – documents the total dose and dose rate level exposed to the DUT. It is provided for every irradiation performed at the TEC-Laboratory.

Radiation characterization of the TEC-Laboratory

We investigated the irradiation field of the TEC-Laboratory with regard to (A) the uniformity of the dose rate distribution and (B) in terms of backscattering of photons from the walls of the irradiation room.

A) Uniformity of the Dose Rate Distribution

When electronic components and systems are tested in an irradiation field at a certain dose rate the uniformity of the dose rate across the exposed area has to be within specified limits. According to ESCC 22900, MIL-STD-750F (Test Method 1019.5) the non-uniformity of the dose over the exposed area has to be less than 10%. A characterization of the field's dose rate uniformity is consequently inevitable. The photon field present in the exposure room of the TEC-Laboratory is cone shaped with a total opening angle of 29°. The source itself is a point source, the cone shape is realized by the shape of the collimator of the irradiator. As the dose rate is governed by a $1/r^2$ law the dose rate seen by the DUT can be adjusted with the distance of the DUT from the source. The area being available for radiation tests is the cone cross-section in a specified distance in which the dose rate non-uniformity is less than 10%. The figure below presents a measured contour plot of the dose rate uniformity in a cone cross section in a distance of 100 cm from the Cobalt-60 source. The dose measurements are taken in an area of 25 cm x 25 cm that is oriented perpendicularly to the beam axis. The figure shows also dose rate profiles for the horizontal and vertical axis. The measurement uncertainty is less than 2.5% (coverage factor 2, 95% confidence level).

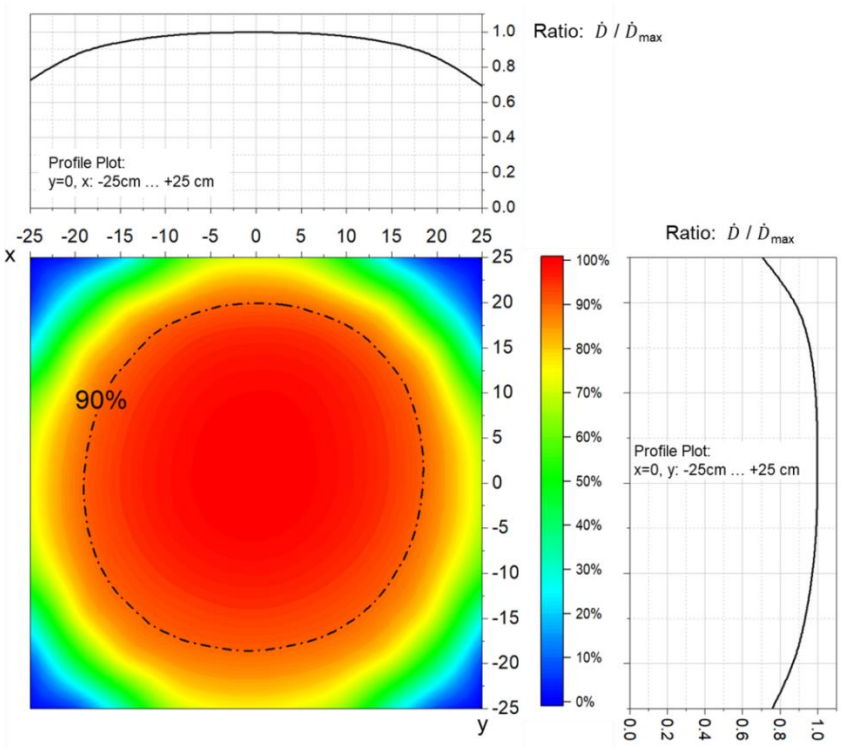

Figure: Measured spatial distribution of the dose rate, $\dot{D}$ compared to the maximum, $\dot{D}_{max}$ in a plane of 25 cm x 25 cm perpendicularly to the beam axis, in a distance of 100 cm to the radiation source. The area of dose rate > 90% of the maximum is indicated.

B) Characterization of Photon Backscatter

Radiation backscattering from the walls influences the uncertainty of the dosimetry. Knowledge of the photon low energy backscatter component is therefore required. We investigated the spectra by numerical means based on FLUKA Monte Carlo calculations. For this purpose, we implemented a numerical model of the TEC-Laboratory that precisely reproduces the geometry of the exposure room. We calculated the photon spectra along the beam axis at various positions indicated in the floor plan shown earlier. The figure shows the spectral photon distribution in the central beam axis at a distance of 100 cm from the source (Pos1) and 20 cm from the walls (Pos6). While Pos1 shows the initial Co-60 beam spectrum with a single peak at 1.2 MeV, the photon spectrum at Pos6 shows a distribution of low-energy backscatter photons.

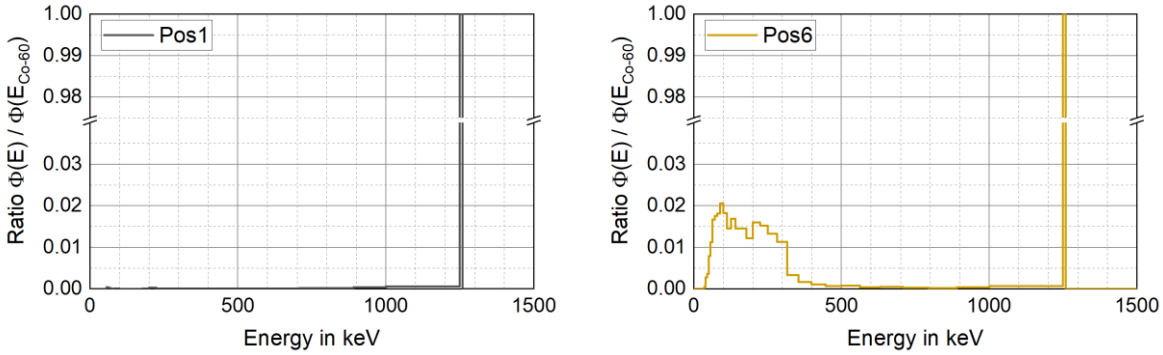

Figure: Photon spectra during exposure calculated for Pos1 (left) and Pos6 (right) normalized to the fluence of the primary Co-60 photons.

From the numerical results, one can calculate the contributions of backscatter photons to the dose in terms of air kerma, K_{Air} and absorbed dose in silicon, D_{Si}. Backscatter photons contribute typically by less than 1%, while in close proximity to the walls the contribution increases to 6-8%. Additionally, we calculated the ratio of D_{Si} and K_{Air} along the beam axis. From our data it can be concluded that K_{Air} is a reasonable dose quantity for assessing the DUT's dose inside the TEC-Laboratory.

Summary and Outlook

Seibersdorf Laboratories has been successfully accredited on procedures compliant with EN ISO/IEC 17025, ECSS 22900 and MIL-STD-750 with regard to TID radiation testing of electronic components and systems at the TEC-Laboratory. The TEC-Laboratory shows wide and uniform photon exposure, and provides high dose rate and economic ELDRS testing. Effects of backscatter photons about 50 cm away from the walls are negligible in the TEC-Laboratory. We could demonstrate, that at the TEC-Laboratory air kerma, K_{Air} is a reasonable dose quantity for the dosimetry of the radiation exposure in silicon. Further, we could illustrate, that backscatter photons play an important role in small exposure facilities due to the proximity of the walls, and in particular in closed irradiation chambers, where the absorbed dose in silicon deviates up to 35% from air kerma. We strongly suggest detailed dosimetric analyses for small exposure facilities.

Total Sales Share for space projects 2018: 0.5 M€

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3.13 TeleConsult Austria GmbH

Field of Work

TeleConsult Austria GmbH has expert know-how in the field of 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.

Field of Expertise

Topics of work include technical consultancy, system design and analysis, mobile computing, 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 external experts. 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 TeleConsult Austria. Since December 2018 TeleConsult Austria is member of OHB S.E.

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Public Service Providers

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1030 Vienna, Austria

MCGS – Multipurpose Cooperative Navigation Service

Today, Global Navigation Satellite Systems (GNSS) plays a notable role in numerous fields of our daily lives, ranging from leisure, sports and automotive to transport and precise surveying applications, to name but a few. A vast range of GNSS receivers is being utilized. These include cheap mass-market devices (e.g. within smartphones or trackers) as well as high-end multi-frequency receivers as they are used within professional industrial applications. For many fields, the positioning accuracy of a standard stand-alone GNSS receiver is not sufficient. Consequently, differential or relative GNSS techniques have been developed. Although these approaches provide highest accuracy, the cost is enormous and handling is difficult in many applications.

Since there is a strong need for high accurate and reliable position, navigation and timing information, TeleConsult Austria developed the Multipurpose Cooperative GNSS Server (MCGS). The basic idea is to increase the positioning accuracy of all GNSS users within a specified region by organizing them by means of a cooperative network. For this, all GNSS receivers transmit their raw observation or coordinate (in case of very low-cost receivers) data to a central processing facility. Thereafter, sophisticated data management and GNSS solver algorithms at the server side are used to compute the position of every single receiver. This is conducted in near-real-time and only the final and enhance position solution is returned to the individual users. By this strategy, the positioning accuracy of all connected users is increased by either using the best available a priori data or by applying differential or relative GNSS techniques, which would not have been possible for stand-alone receivers. MCGS automatically selects the best-suited data processing approach for each incoming user data set and combines data sets of different users.

MCGS is able to receive and process data from a wide range of client devices, like devices providing position, velocity and time output only (e.g. smartphones, trackers etc.), devices providing single-frequency raw GNSS measurements or advanced geodetic grade equipment providing multiple-frequency measurements. Therefore, MCGS supports multiple industry standard protocols (e.g. RTCM 3.1, NMEA 0183, NTRIP 2.0, ESA SISNeT 3.1) or provides a proprietary application programming interface (API). MCGS is capable of using various types of GNSS information:

- Position, velocity and time results (e.g. NMEA 0183)
- Multi-frequency multi-system GNSS raw measurements (i.e. pseudoranges, Doppler, phase measurements)
- Measurements and corrections from permanent GNSS station networks
- EGNOS data access service (EDAS) streams
- Precise satellite ephemeris and clocks
- Local meteorological parameters (e.g. air pressure, humidity/water vapor pressure and temperature)
- Sophisticated models for signal delay in the troposphere (e.g. GPT2w, GALTROPO, Niell)
- Different models for signal delay in the ionosphere (Klobuchar, NeQuick, Global Ionosphere Grid, SBAS ionospheric data)
- Antenna phase center offset and variation models for different satellite types

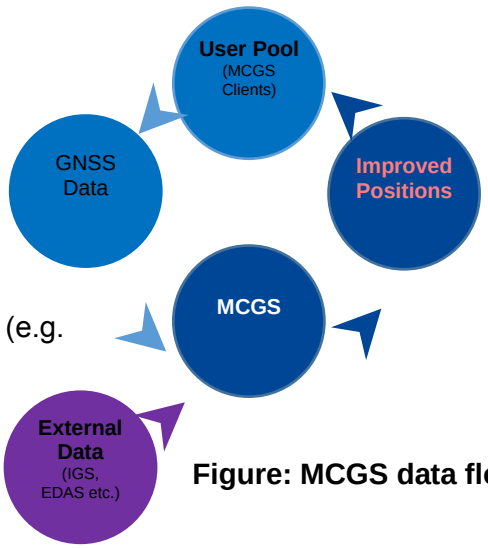


Figure: MCGS data flow

MCGS implements several data processing modes and techniques:

- Position corrections for devices without raw measurements
- Single point positioning (SPP)
- Enhanced SPP using differential corrections from local providers
- Precise Point Positioning (PPP) using precise satellite orbit and clock data, satellite instrumental biases
- Relative and differential network techniques

All received data are tested and validated by a sophisticated pre-processing module aiming to remove anomalies within the data, detect and repair phase cycle slips and compensate receiver clock offsets and drifts.

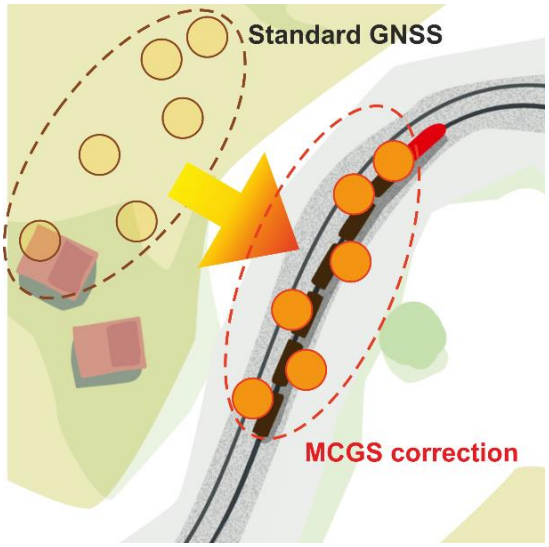


Figure: MCGS compensating systematic errors

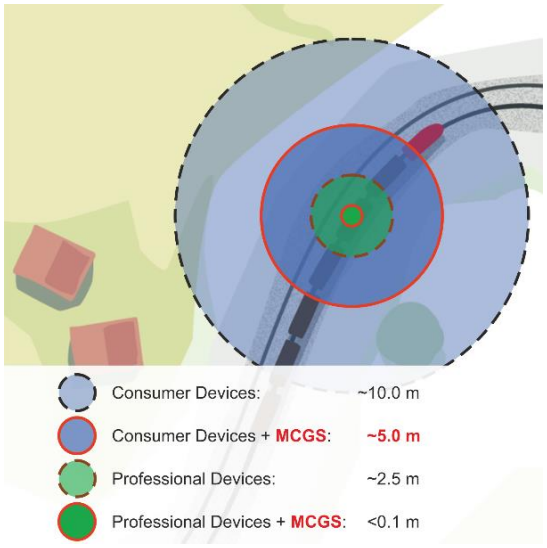
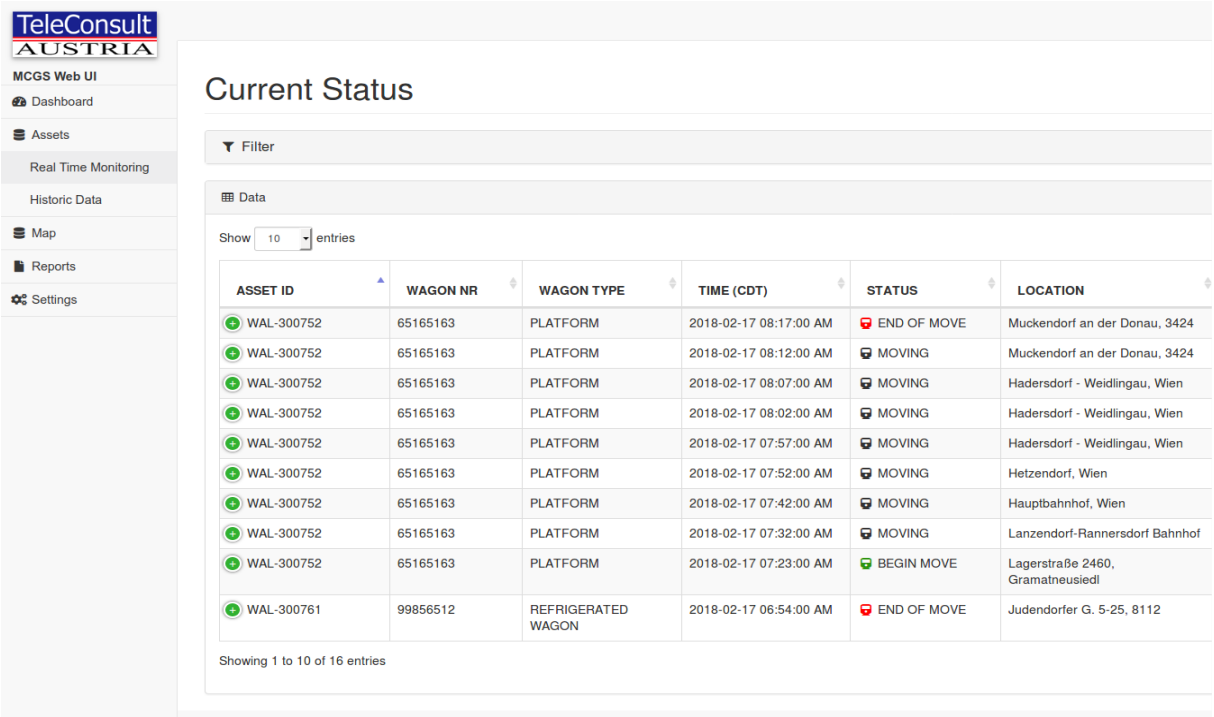


Figure: MCGS improving accuracy

The server-side cooperative GNSS data processing has several advantages over classical (stand-alone or differential positioning) positioning techniques:

- Increased positioning accuracy and quality for mass-market receivers or Location Based Service providers and users using the benefits of cooperative data processing
- Applying advanced processing techniques to low-cost user devices (e.g. applying Precise Point Positioning (PPP) techniques)
- Best possible data processing approach for each type of user device
- The server has access to the additional data (e.g. corrections, precise models, measurements from other users) unavailable at the stand-alone user side
- The user devices are often limited in hardware, processing power and power consumption and hence cannot implement very sophisticated algorithms
- All user data are processed by MCGS using the same models which removes common biases for different users
- The service can easily be integrated into existing infrastructure
- MCGS is able to store any type of additional data (e.g. data from additional sensors, event markers etc.). The stored data can be transferred via MCGS protocol.

The figure below shows the Web user interface communicating with the MCGS server using API.



ASSET ID	WAGON NR	WAGON TYPE	TIME (CDT)	STATUS	LOCATION
WAL-300752	65165163	PLATFORM	2018-02-17 08:17:00 AM	END OF MOVE	Muckendorf an der Donau, 3424
WAL-300752	65165163	PLATFORM	2018-02-17 08:12:00 AM	MOVING	Muckendorf an der Donau, 3424
WAL-300752	65165163	PLATFORM	2018-02-17 08:07:00 AM	MOVING	Hadersdorf - Weidlingau, Wien
WAL-300752	65165163	PLATFORM	2018-02-17 08:02:00 AM	MOVING	Hadersdorf - Weidlingau, Wien
WAL-300752	65165163	PLATFORM	2018-02-17 07:57:00 AM	MOVING	Hadersdorf - Weidlingau, Wien
WAL-300752	65165163	PLATFORM	2018-02-17 07:52:00 AM	MOVING	Hetzendorf, Wien
WAL-300752	65165163	PLATFORM	2018-02-17 07:42:00 AM	MOVING	Hauptbahnhof, Wien
WAL-300752	65165163	PLATFORM	2018-02-17 07:32:00 AM	MOVING	Lanzendorf-Rannersdorf Bahnhof
WAL-300752	65165163	PLATFORM	2018-02-17 07:23:00 AM	BEGIN MOVE	Lagerstraße 2460, Gramatneusiedl
WAL-300761	99856512	REFRIGERATED WAGON	2018-02-17 06:54:00 AM	END OF MOVE	Judendorfer G. 5-25, 8112

Figure: MCGS Web Interface for asset tracking

With the recent Android OS versions, it is possible to access the raw measurements from GNSS chips. Currently, TCA investigates the quality of raw GNSS measurement from smartphones and the possibility of achieving decimeter-level accuracy using PPP approach. The Android client able to transfer raw GNSS measurements using MCGS protocol has been developed.

MCGS is a multipurpose service supporting any kind of user application from location-based services using mass-marked devices to high-precision system based on the most advanced receivers. With MCGS any type of GNSS-receiver will get a higher positioning accuracy in real-time by avoiding investments in high end devices or expensive infrastructure. Service providers (e.g. mobile providers) use MCGS to address new customers by lowering the price entrance level in comparison to high priced GNSS equipment. MCGS is designed for B2B solution providers and B2B service providers and can be used in a wide range of applications like advanced real-time precise positioning, monitoring applications involving GNSS measurements, assistance server applications or asset tracking and vehicle fleet management.

Figure: MCGS Android client software

Sales 2018: 1.5 M€
ESA Share: 0.5 M€

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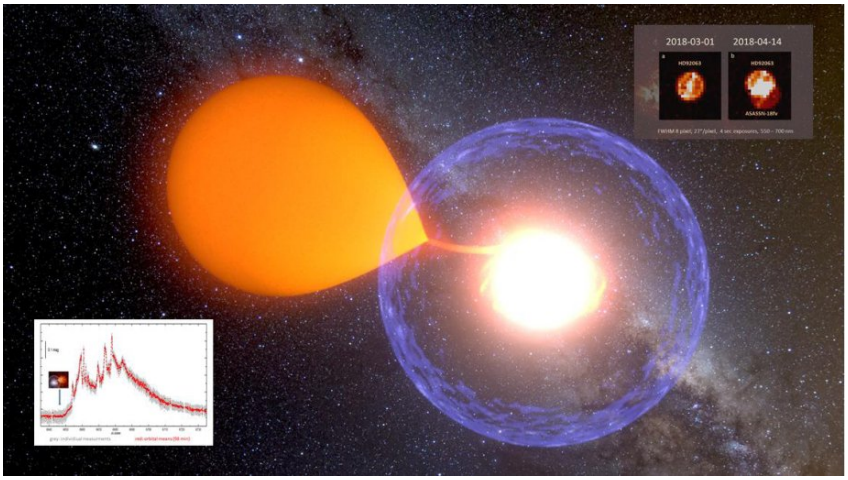
3.14 Graz University of Technology (TU Graz)

Graz University of Technology has been active in Space technology and Space experiments for five decades. The current activities by the Institute of Communication Networks and Satellite Communications, the Institute of Geodesy and the Institute of Experimental Physics focus on satellite communications, satellite navigation, satellite geodesy, remote sensing and the development of Space-qualified hard- and software, especially small satellites including their operations. The following sections describe examples of the Space activities by TU Graz:

Institute of Communication Networks and Satellite Communications (IKS)

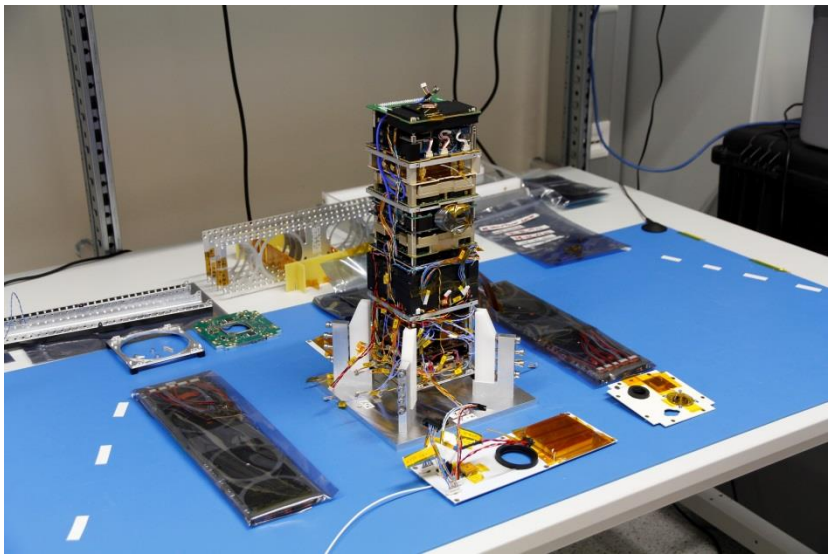
Nanosatellite Missions BRITE, OPS-SAT and PRETTY

BRITE (Bright Target Explorer) is the world's first nanosatellite constellation dedicated to an astronomy mission. Currently, five small satellites are in Space, two from Austria, two from Poland and one from Canada. The main purpose of the BRITE mission is to observe the brightness variation of hot, massive and luminous stars of the visual magnitude brighter than +4. During their 5th year of operations, three years beyond design lifetime, both Austrian 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 most impressive highlight during 2018 was the 'in-situ' capture of a rare Nova event. While BRITE-Constellation conducted regular observations in the constellation of Carina which began in February 2018, one of the 18 bright stars in this field, the red giant star HD 92063, appeared to show unusual brightness changes after March 22nd. At an angular separation of only two arc-minutes from the red-giant star, a nova had unexpectedly turned up on the detector, a month after the observing session in Carina had started (see figure, top right). The nova rapidly increased in brightness as seen in the figure (bottom left). The BRITE-Constellation photometric data are the best in coverage and precision thus obtained from a nova eruption. The data are currently analyzed by world leading experts in that field.



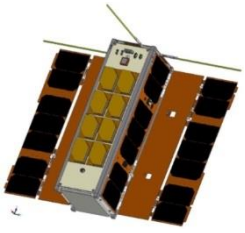
The background is an artist conception of a nova eruption (courtesy: K. Ulaczyk, Warsaw University Observatory). Top right are the BRITE images before and after the nova explosion. The bottom left diagram shows the brightness variations caused by the nova process over time as measured by BRITE-Constellation satellites.

OPS-SAT is an ESA nanosatellite mission to demonstrate and validate new operational concepts and to carry out hardware and software experiments in space with flexible programmable on-board platforms. OPS-SAT is developed by a team from Austria (Graz University of Technology as technical lead, UNITEL, MAGNA STEYR), Poland, Denmark and Germany under an ESA contract within the GSTP program. In 2018 the subsystems (flight avionics and payloads) were completed and underwent detailed qualification tests which were successful. The software and hardware was verified on a so-called “flatsat” before integration and environmental testing. The launch is scheduled in the time-frame October – November 2019. OPS-SAT is fully compatible with ESA’s ground infrastructure and will be operated by ESOC with a backup ground station at TU Graz.



OPS-SAT Spacecraft During Assembly

PRETTY (Passive Reflectometry and Dosimetry) is a nanosatellite mission with the objective to demonstrate and validate passive reflectometry in space. PRETTY includes a demonstrator payload for passive reflectometry focusing on very low elevation angles, whereby the direct and reflected signal from a GNSS satellite will be received via the same antenna. By correlating the two signals height measurements can be performed. Furthermore, a novel dosimeter payload for measuring the space radiation environment during the PRETTY space mission is included. The hardware platform is composed of a software-defined front-end and a powerful system-on-chip processor with a large FPGA providing sufficient resources for the implementation of the correlating receiver, developed by TU Graz, the altimeter software is a development by the Prime Contractor RUAG Space Austria and the dosimeter is produced by Seibersdorf Laboratories. The altimeter will be used to survey i.e. the height of sea waves and may thus contribute to climate research using a small and low-cost nanosatellite. PRETTY will be a 3U CubeSat with deployable solar arrays to provide up to 24 W effective power. Phase B was successfully completed in Fall 2018 and will be followed by Phase C/D/E starting in 2019.



3D Model of PRETTY

Satellite Communications

Since January 2018 the Institute is member of a consortium led by DEIMOS (Spain) with OHB Italia, DLR (Germany) and Politecnico di Torino (Italy) in a H2020 project, called EO-ALERT. The goal is to design the next generation of Earth Observation Satellites with powerful on-board processing of visual and SAR images and the generation of alerts for applications like ship and severe weather event detection. The innovation and challenge is that alerts must be delivered globally with a maximum latency of 5 minutes. The Institute is responsible for the communications system design and the development of a demonstrator of the bulk data communications and the alert link. This system will be integrated into a test bench at OHB premises.

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Institute of Geodesy (ifG) - Working Group Navigation

Similar to previous years, in 2018, space-related R&D-projects at ifG mainly covered GNSS-based navigation applications focusing on GNSS processing techniques like Precise Point Positioning (PPP) or Real-Time Kinematic (RTK) and on integration of GNSS and INS with respect to vehicles (cars, UAVs – Unmanned Aerial Vehicles) and pedestrians. In the sequel, two representative projects are shortly described, recent results included.

DEMONA *(Demonstration of UAS Integration for VLL Airspace Operations):*

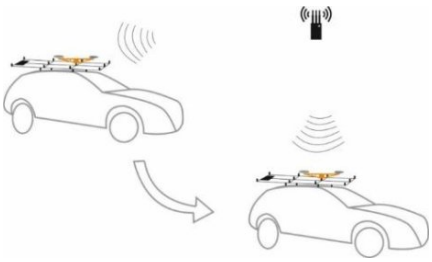
DEMONA is a FFG/TAKE OFF project which started in October 2016 and lasts till June 2019. The consortium is composed of FH JOANNEUM (Institute of Aviation) being the project lead, ifG, AIT (Austrian Institute of Technology), Austro Control, Drone Rescue Systems, IGASPIN and TeleConsult Austria. The project goal is to perform a UAS (Unmanned Aerial System) flight beyond the visual line-of-sight of a pilot on the ground. Currently, there are no standards defined related to the Command-and-Control link (C2 link) of the unmanned aircraft, related to collision avoidance against terrain and other aircraft (Detect & Avoid), as well as related to the required navigation performance to stagger the flight path from air traffic.

The task of ifG is to provide the navigation module in order to generate an accurate and reliable navigation solution which is necessary to perform UAS flights beyond the visual line-of-sight of a pilot. Special focus is given to the following topics: Using the L1 and L5 frequency (multi-frequency) of GPS and Galileo (multi-system) to get rid of the systematic offset caused by the ionospheric signal delay, integrating the GNSS solution with a magnetometer, barometer and inertial sensors, and combining the measurements of two redundant IMUs (Inertial Measurement Units).

In 2018, test flights with an ultralight aircraft were carried out to test the robustness and reliability of the navigation module developed for UAVs. An ultralight was chosen for two reasons: first, it shows similar flight behaviour as fixed-wing drones; second, it can take enough payload to carry reference equipment for verification. The test flights showed that the developed navigation module is robust and also yields accurate position, velocity and attitude estimates in the case of GNSS outages.

RADIAL *(Real Time GNSS Signal Jamming/Spoofing Detection and Localization)*

The increased use of GNSS for safety-critical applications requires constant monitoring of GNSS interferences. Especially, intentional interferences like jamming or spoofing are a serious problem. Within the ASAP project RADIAL2017, a rotating synthetic aperture GNSS antenna was developed by *IGASPIN GmbH* and *Blickwinkel design & development*. *IGASPIN* was developing an algorithm to detect the direction of origin of jamming and spoofing signals. The task of ifG in 2018 was the following: If these direction measurements are taken from multiple positions, e.g. from a car moving between different positions, the location of the jamming or spoofing origin can be estimated. The demonstrator currently developed within the project will be tested in real time in spring 2019.



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Working Group Theoretical Geodesy and Satellite Geodesy

Primary research focus of the Working Group Theoretical Geodesy and Satellite Geodesy at the Institute of Geodesy is the development of analytical and numerical techniques with a strong focus on gravity field recovery, space-borne sensor data analysis and Global Navigation Satellite System (GNSS) data processing.

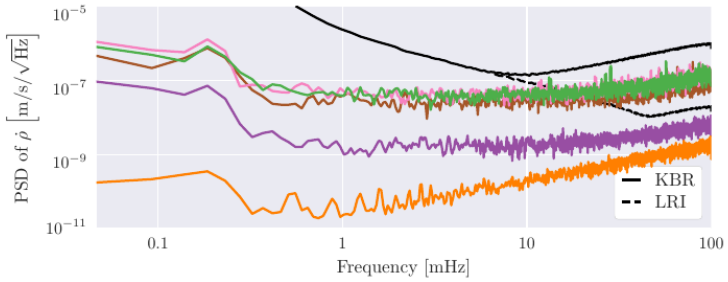
The groups' expertise in these research areas has led to the involvement in various initiatives, for example, the Gravity Observation Combination (GOCO) consortium, the International Combination Service for time-variable Gravity Field Solutions (COST-G) and ESA's Climate Change Initiative. Furthermore, research and development projects funded by national and international agencies have been successfully acquired and completed in order to maintain and expand the existing know-how.

Time-variable gravity field recovery from GRACE and GRACE Follow-On

The Gravity Recovery And Climate Experiment (GRACE) satellite mission was in orbit for over 15 years and provided an invaluable data record for climate and Earth system sciences. Its primary data product was a time series of monthly gravity field snapshots -a proxy for mass distribution in the Earth system. These time-variable gravity field observations have been used to study a variety of geophysical processes, such as ice mass loss, the global water cycle, and sea level rise. GRACE was implemented and operated as a cooperation between the National Aeronautics and Space Administration (NASA) in the United States of America and the German Aerospace Center (DLR).

The measurement principle of GRACE relies on extremely precise ranging measurements between a leading and a trailing satellite in the same orbit. The twin-satellites were launched aboard a Rokot/Briz-KM launch vehicle from Plesetsk, Russia on March 17, 2002. Both spacecraft were placed in a near-circular, polar orbit at an initial height of about 500~km with a separation of about 220 km. Following a battery failure in September 2017, science operations were terminated in October 2017. Both satellites were subsequently decommissioned and re-entered the atmosphere on December 24, 2017 and March 10, 2018 respectively.

The successor to GRACE, GRACE Follow-On (GRACE-FO) was successfully launched on May 22, 2018 from Vandenberg Air Force Base aboard a SpaceX Falcon 9 rocket. The instrumentation of GRACE-FO is an evolution compared to its predecessor, driven by technical advancements and lessons learned from the GRACE mission. Within the FFG funded project MAGIC, the challenges arising from the new sensors have been tackled by developing new and improved processing techniques. A highlight of this new instrumentation is a technical demonstrator for a Laser Ranging Interferometer (LRI), which has provided the first ever optical interferometry between two satellites. This novel instrument is able to determine the range rate between the spacecraft with an accuracy below 0.6 nm/s compared to the 0.2 µm/s accuracy from the GRACE K-Band microwave ranging instrument. This poses numerical challenges within the processing chain. In order to keep the numerical errors arising during the orbit integration below the extremely high measurement accuracy, a tailored numerical orbit integration method has been developed. A key feature of the new approach is the use of best-fitting Kepler ellipses, which significantly reduces the power of the remaining integral.

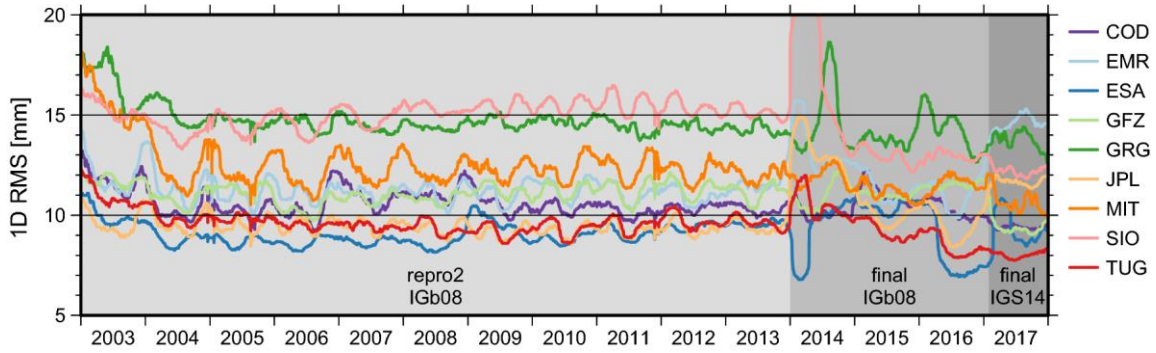


Range rate residuals for K-Band and LRI measurements (black solid and dashed lines) and range rates derived from integrated orbit using various orbit integrators. The orange line is the result of the novel integration approach developed within the project MAGIC.

Furthermore, an accelerometer aboard one of the GRACE-FO satellites was damaged following a power cycle, resulting a degradation of the data quality. To improve on existing approaches, state-of-the-art non-gravitational force models are employed to alleviate the “transplant” of data from the working accelerometer to the degraded one.

Processing of GNSS constellations and ground station networks

The working group is working on their own GNSS processing software based on the raw observation approach. This enables the working group to independently compute GNSS products like satellite orbits, clocks, and station positions, similar to those of the analysis center of the International GNSS Service (IGS). The key difference of the raw observation approach compared to well-established GNSS processing approaches is the fact that observations are used directly as observed by the receiver. This allows full exploitation of the information contained in each individual observation type and preserves the original measurement accuracy. Observation equations are set up individually for each observable without explicitly forming any linear combinations or differences. This simplifies the inclusion of new observables provided by the new (Galileo, BeiDou) and modernized GNSS. To assess the performance of the approach, a long time series of GPS products was computed. Comparing the products of the working group to products of the IGS analysis centers showed that they are of at least equivalent quality. After confirming the performance of the raw observation approach, the main focus has been the extension to multi-GNSS processing to allow a combined processing of the GPS, GLONASS, Galileo, and BeiDou satellite constellations.



Daily GPS orbit RMS relative to IGS combination for different analysis centers and the Institute of Geodesy (TUG). Limited to orbits computed by all institutions. Reference frame differences corrected. 91-day median-filtered for clarity.

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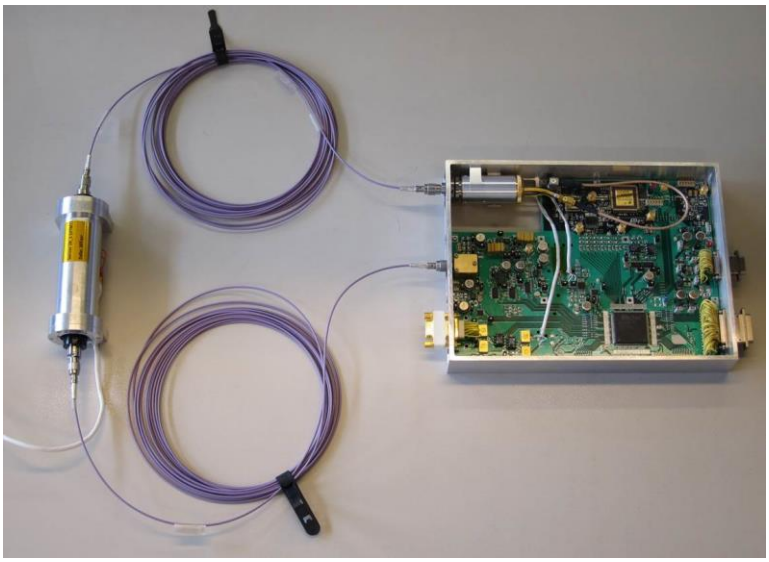
Institute of Theoretical Physics (IEP)

IEP 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.

Launch of CSES1-Satellite Zheng-Heng1. On board the CDSM-Magnetometer

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

According to these potential space applications the CPT magnetometer is 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 one-year continuous operation without any problems. The performance of the Instrument was externally evaluated by the SWARM-Team with top grades!



Coherent Population Trapping (CPT)-Magnetometer developed for ESA’s JUICE-Mission and the Chinese Electromagnetic Satellite (CSES)-Mission.

Activities in 2018 regarding both missions (JUICE and CSES):

- Finalization of the two flight models FMI and FMII for the CSES mission including manufacturing, aligning, testing and calibrating of the sensor, the sensor optics and the electronics box (see picture).
- Launch of the Zheng-Heng 1 Satellite on board of Long March 5 rocket in Feb 2018.
- Successfully passing of commissioning phase of the CDSM
- 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.
- Thermo-vacuum tests of vertical surface emitting laser-diodes (VCSEL) and the optical fibres used in the JUICE-Instrument.
- Burn-in testing and electro-optical characterization of the VCSEL's in the (developed) test facility.

Sales 2018: 0.9 M€ (TU Graz total)
ESA Share: 0.26 M€

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3.15 TTTech Computertechnik AG

Leading global supplier of dependable networking solutions and modular safety platforms. The company's products 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). Time-triggered technology has been developed over more than 30 years by the TU Wien and TTTech in cooperation with industrial partners and leading research institutions. The TTTech Group currently employs more than 1500 employees worldwide of which the majority works in engineering and development departments (hardware and software development, chip IP design, project management). The Group is headquartered in Vienna, Austria. TTTech Auto AG is the largest subsidiary.

The company is now closely associated with the development of advanced driver assistance systems ("ADAS") enabling future autonomously driving cars. The list of partners for such complex, safety-critical integration platforms includes Samsung, Infineon, Nvidia and Renesas. Deterministic Ethernet is needed at board level to achieve first time integration success and to allow shortened development cycles.

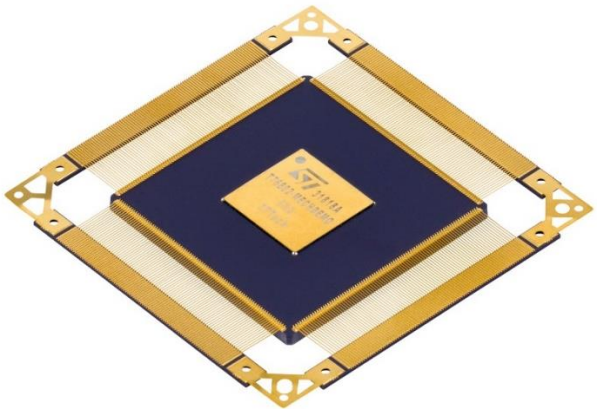
European Space Activities 2018

The main European activity was the completion of the TTE-Controller ASIC firmware development and qualification as well as the ASIC production and qualification for the Ariane 6 program. Here TTTech works as key subcontractor to ArianeGroup and supplier to its avionics partners like Airbus Defence & Space.

The standardization of TTEthernet for use in space applications continued (ECSS working group, ESA-funded compliance tester, CCSDS meetings, International Avionics System Interoperability Standards – IASIS), and the EtherSpace Alliance, co-founded by TTTech, expanded further.

In 2018 TTTech started a co-operation with RUAG Space Austria on the development of space grade TTEthernet switches and interface cards in the compact PCI form factor. The extent to which this investment into a long-term sustainable equipment business will be supported by ESA is still unclear, but a GSTP de-risking activity was set up that includes alignment with European primes on their detailed requirements (Thales Alenia Space, Airbus Defence & Space).

2018 also saw the completion of TTTech's deliverables for the German DLR project "iBOSS 2" (mainly software). TTTech will continue to look for opportunities within Europe for this secondary "COTS-based" product line.



TTEthernet Controller Space (to be used in various TTEthernet equipment within the Gateway)

Outside Europe

In North America TTTech's local subsidiary mainly worked with NASA, Lockheed Martin (prime contractor for the NASA MPCV), Boeing, Blue Origin and Northrop Grumman (former Orbital ATK). Projects range from launch vehicles and human spacecraft to advanced satellite architectures.

Once more TTTech was the only Austrian exhibitor at the annual Space Symposium in Colorado Springs, the world's largest commercial space event.

Significant opportunities were pursued in China, Japan and India. With iSpace one of the most well-known "New Space" companies was won as a customer.

Revenue

Total European space revenue declined to Euro 1.8 million with an ESA share of 1.4 million. This represents a reduction by 1/3 compared to 2017 as TTTech had the peak of its Ariane 6 related activities already in 2017.

Space Sales 2018: 1.8 M€
ESA Share: 1.4 M€

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