ANNUAL REPORT 2017

Cover picture:

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TABLE OF CONTENTS

1 Introduction

The present AUSTROSPACE Annual Report is composed of a brief review of major space events in 2017, contributions from industrial members and research organizations about their space activities, and a current list of members with contact information.

Vienna, May 2018

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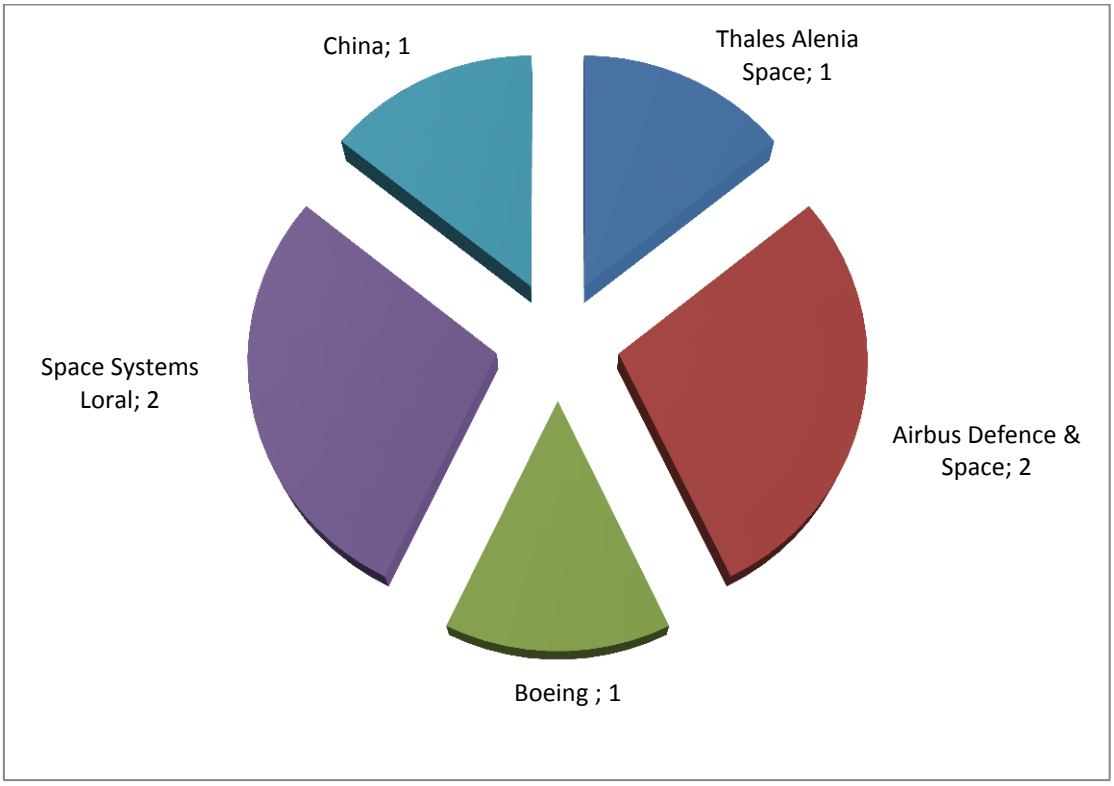
2 Year 2017 Review

In 2017 orders for only seven geostationary commercial telecommunications satellites were placed worldwide, which means a drastic decline compared to the previous year (17). Of the seven contracts three were awarded to European satellite manufacturers (Airbus Defence & Space (DS): 2, Thales Alenia Space (TAS): 1), three to their US competitors (Space Systems Loral (SSL): 2, Boeing: 1), and one went to China. SSL received an order from EchoStar for an extremely powerful satellite, with a price equivalent to that of three to four more conventional geostationary satellites. The biggest telecom order, however, was booked by Boeing with seven satellites for the O3b-mPower constellation of the operator SES (Source: Space News, January 15, 2018). This high-performance network will cover some 80% of the globe from orbits in about 8.000 km.

Analysts see quite some uncertainty in the future investment strategy of the satellite operators. 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. Generally, the market is characterized by increasing price pressure and an evident need for innovation and more efficient production processes.



Commercial Geostationary Telecommunications Satellite Orders 2017

(Source: Space News, January 15, 2018)

The development of OneWeb, a constellation of 648 low earth orbit satellites in the first phase with a planned follow-on extension, has made significant progress, so that the launch of the first ten satellites has been planned for May 2018 and operational status of the system is expected for the following year. These satellites are largely based on commercial off-the-shelf technologies and industrialized production processes and are integrated by Airbus DS in a new newly established factory in Florida. The successful realization of OneWeb will mark a breakthrough in the “new space” market. SpaceX has announced the 2018 launch of two prototypes for a network of 4.425 satellites, which shall be deployed within the next five years.

OneWeb Constellation and Satellite (Source: OneWeb)

During 2017 Iridium NEXT successfully launched 40 of the planned 75 satellites on board of four SpaceX Falcon 9 rockets. The deployment of the constellation will be completed in 2018.

Iridium-NEXT Satellites and Falcon 9 Launch (Source: Iridium)

The deployment of the European satellite navigation system Galileo has continued with the launch of further four satellites, for the first time under the responsibility of the European Global Navigation Satellite Systems Agency (GSA). Now 22 satellites are in their orbits, and

another batch of eight has been ordered from OHB mid of the year. Full operational capability of the system shall be reached in 2020.

In the frame of the EU environment monitoring program Copernicus Sentinel-2B lifted off on board of a Vega rocket from French Guiana in March. Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring, to provide imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 can also deliver information for emergency services. The first satellite, Sentinel-2A, has been operational since 2015. Production of the C & D copies is progressing.

Sentinel-2B during Launch Preparation in Kourou (Source: ESA)

The Copernicus space infrastructure has been further extended with the launch of Sentinel-5 Precursor (P) on board of a Rockot from the Plesetsk Cosmodrome in October. Sentinel-5P is the forerunner of Sentinel-5, to provide timely data on a multitude of trace gases and aerosols affecting air quality and climate. Sentinel-5P has been developed to reduce data gaps between Envisat and Sentinel-5.

Sentinel-5 Precursor and its Launch (Source: ESA)

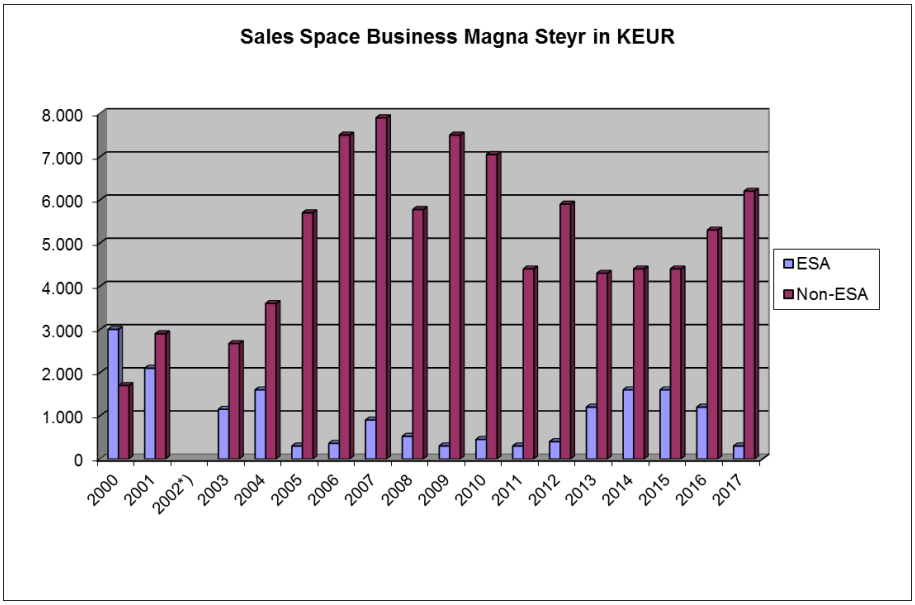
In 2017 Arianespace ordered the final batch of Ariane 5 launchers, which will be replaced with the lower-cost Ariane 6 from 2020 on.

Beginning of October Austria celebrated 30 years of ESA membership with a high-level event in Graz. The program included key note presentations by ESA Director General Jan Wörner and the Chief Executive Officer of OHB, Marco Fuchs, followed by panel discussions with representatives from science, industry and users of space-based applications.

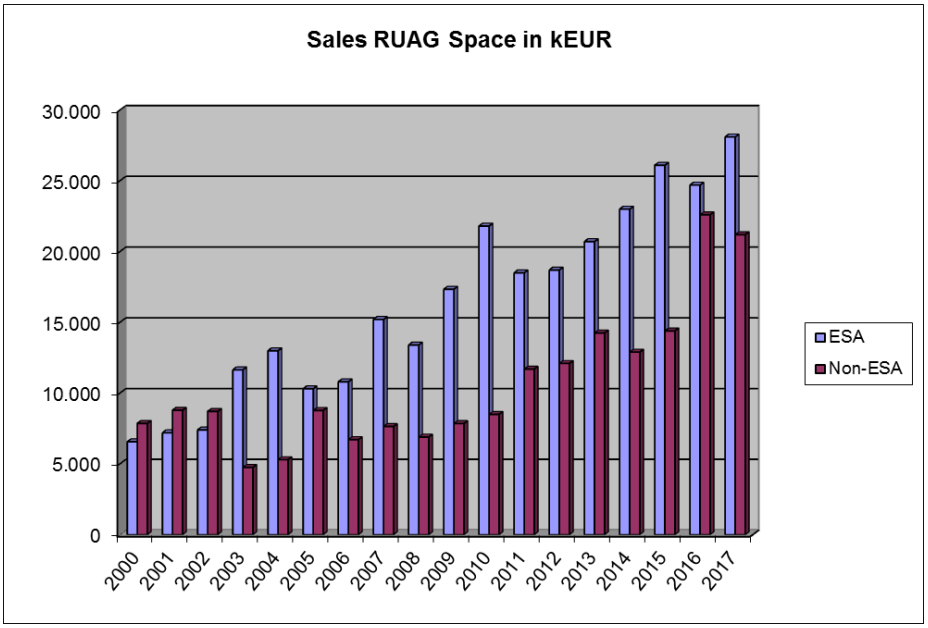
ESA DG Jan Wörner and FFG Managing Director Klaus Pseiner

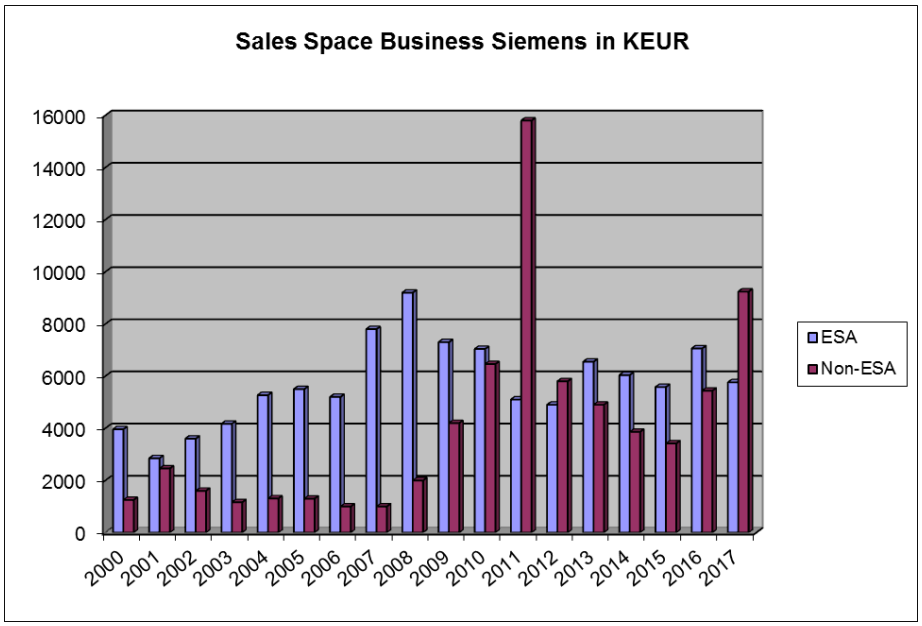
Panel Discussion with Representatives from Industry and Science

End of 2017 AUSTROSPACE had 20 members. The evolution of sales of the three biggest AUSTROSPACE companies is illustrated below:



**) no figures available due to organizational changes*


Sales RUAG Space in kEUR
30.000
25.000
20.000
15.000
10.000
5.000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
ESA
Non-ESA


Sales Space Business Siemens in KEUR
16000
14000
12000
10000
8000
6000
4000
2000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
ESA
Non-ESA

3 Reports of Industrial and Institutional Members

3.1 Austrian Academy of Sciences

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

Most IWF members in the institute's atrium (Credit: Daniel Hinterramskogler/ÖAW).

IWF develops and builds space-qualified instruments and analyzes and interprets the data returned by them. Its core 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, on the upper atmospheres of planets and exoplanets, and on the gravity fields of the Earth and the Moon.

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 **seventeen active and future international space missions**; among these:

- *BepiColombo* will be launched in 2018 to investigate planet Mercury, using two orbiters, one specialized in magnetospheric studies and one in remote sensing.

- ESA's first Small-class mission *CHEOPS (CHaracterizing ExOPlanets Satellite)* will classify exoplanets in detail. Its launch is expected in 2018.
- The *China Seismo-Electromagnetic Satellite (CSES)*, launched in early 2018, studies the Earth's ionosphere.
- ESA's *Cluster* mission still provides unique data leading to a new understanding of space plasmas.
- *GEO-KOMPSAT-2A* is a Korean satellite for space weather investigations due for launch in 2018.
- ESA's *JUpiter ICy moons Explorer (JUICE)* will observe the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto, and Europa. It is planned for launch in 2022.
- *MMS* uses four identically equipped spacecraft to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
- 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.
- *Solar Orbiter* is to study along an innovative trajectory solar and heliospheric phenomena, planned for launch in 2020.
- *THEMIS* has been reduced to a near-Earth three-space-craft mission. The two other spacecraft are now orbiting the Moon in the ARTEMIS mission.

HIGHLIGHTS IN 2017

- 15 September marked the end of one of the most successful space missions of the last decades. NASA's Cassini mission orbited Saturn for 13 years. Launched in 1997, it reached the ring planet in 2004 and had several hundred close encounters with the gas giant and its moons Titan and Enceladus. IWF participated in more than 50 publications in international journals.
- In "Nature Astronomy" an international team with relevant IWF participation reported the discovery of a sun-type star in a close, eccentric binary system with a neutron star, where the non-degenerate star presents strong Ca-rich pollution from the supernova ejecta.
- A "Nature Communications" study, led by IWF, described how magnetic reconnection in vortices at the magnetopause on the flanks of the magnetotail facilitates turbulent mass transfer into the magnetosphere.
- Induction heating can completely change the energy budget of an exoplanet and even melt its interior. In a study published by "Nature Astronomy" an international team led by IWF with participation of the University of Vienna explained how magma oceans can form under the surface of exoplanets as a result of induction heating.

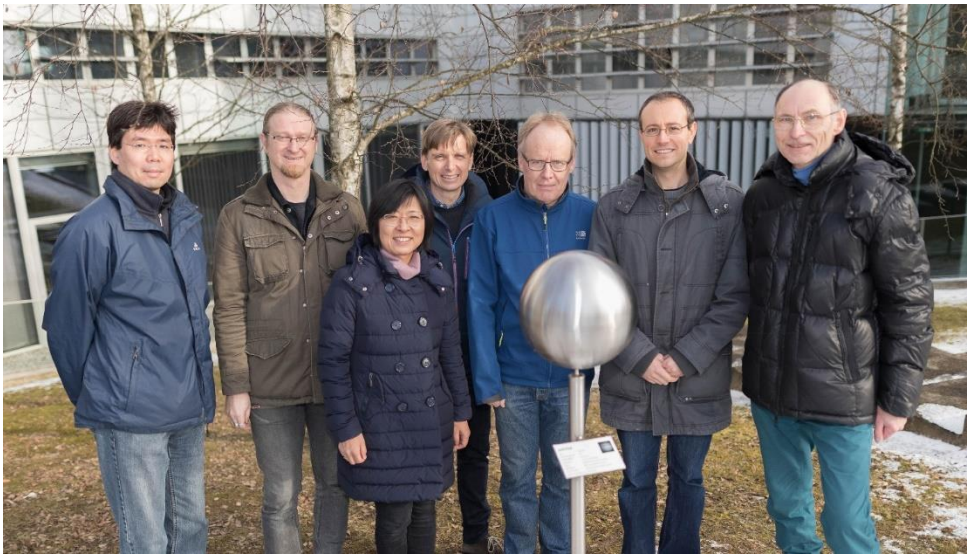
THE YEAR 2017 IN NUMBERS

Members of the institute published 140 papers in refereed international journals, of which 49 were first author publications. During the same period, articles with authors from the institute were cited 4518 times in the international literature. In addition, 90 talks and 41 posters were presented at international conferences by IWF members. Last but not least, institute members were involved in the organization of three 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.



IWF group leaders: Y. Narita, H. Lammer, R. Nakamura, W. Magnes, L. Fossati, and N. Kömle
(absent: G. Kirchner; Credit: Daniel Hinterramskogler/ÖAW).

EARTH & MOON

In the last decades, gravimetric and geometric space geodesy techniques constitute an integral part in Earth and planetary sciences. To improve our knowledge about the environment, state and evolution of the Earth and the Earth's only natural satellite, the Moon, IWF is engaged in terrestrial and lunar gravity field research as well as space weather dynamics, and Satellite Laser Ranging to Earth-orbiting satellites and debris objects.

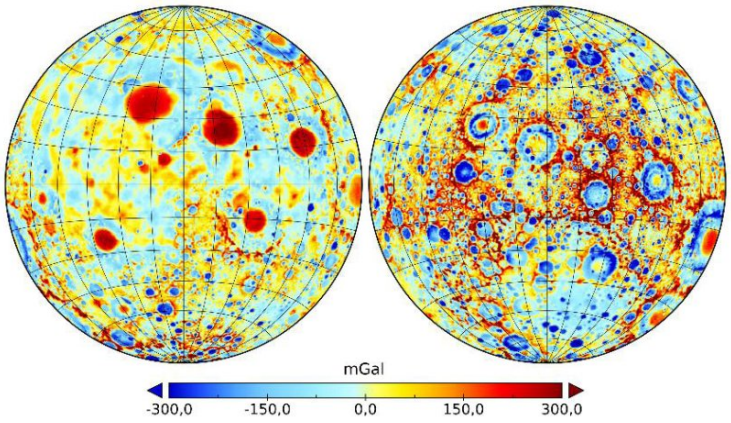
GRAVITY FIELD

Gravity field research includes the analysis of data collected by Earth- and Moon-orbiting spacecraft.

GRAIL

The *Gravity Recovery And Interior Laboratory (GRAIL)* mission aims at answering longstanding questions about Earth's Moon and provides a better understanding of how the Earth and other terrestrial planets were formed. Mapping the structure of the lunar interior gives insight into a variety of geophysical processes, and allows indirectly to shed light on the thermal evolution. The two *GRAIL* spacecraft were orbiting the Moon in nearly circular polar orbits at an average altitude of 55 km during the primary mission phase. As the distance between the two probes changed slightly due to different gravity induced perturbations, the inter-satellite range variations were recorded by means of Ka-band observations. Hence, this type of observations is ideally suited to reveal the lunar gravity field (even at the far side) with unprecedented accuracy.

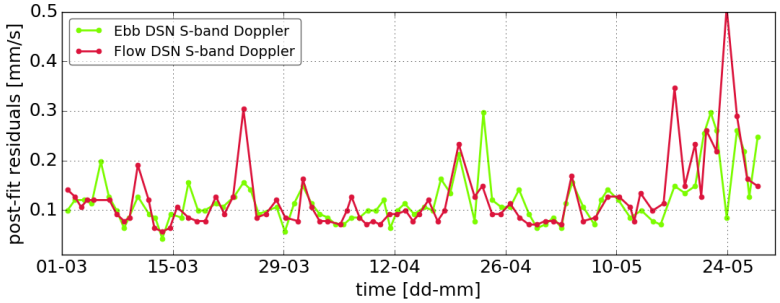
IWF released the first completely independent and most accurate lunar gravity model, based on *GRAIL* mission data, outside the United States of America - denoted as GrazLGM420b. The model is resolved up to spherical harmonic degree 420, which corresponds to a spatial resolution of around 13 km.



Lunar gravity model GrazLGM420b in terms of gravity anomalies with the nearside on the left and the far side on the right.

The reconstruction of an independent gravity field solution requires absolute position information of the satellites. Hitherto, lunar gravity models compiled in Europe relied so far on the orbit products provided by the *GRAIL* Science Team. However, Doppler observations collected by the Deep Space Network (DSN) on Earth allows for determining the *GRAIL* orbits. Through the development of the in-house software package ORCA (Orbit Re-Construction Application) the opportunity was opened to infer the positions of the *GRAIL* probes based on S-band radiometric tracking data collected by the DSN. Based on an iterative process, which initially utilizes a pre-*GRAIL* gravity field as starting point, a final independent solution was created. The nominal accuracy of radiometric 2-way S-band observations to *GRAIL* is estimated to be 1 mm/s.

Though, the achieved accuracy exceeds the assumptions and is in the range of 0.04-0.5 mm/s. The figure below shows the obtained a posteriori fit to the S-band DSN data corresponding to 0.12 mm/s on average. According to the *GRAIL* Science Team the posteriori fit is around 0.13 mm/s, which indicates a good agreement to our precise orbit determination solution.



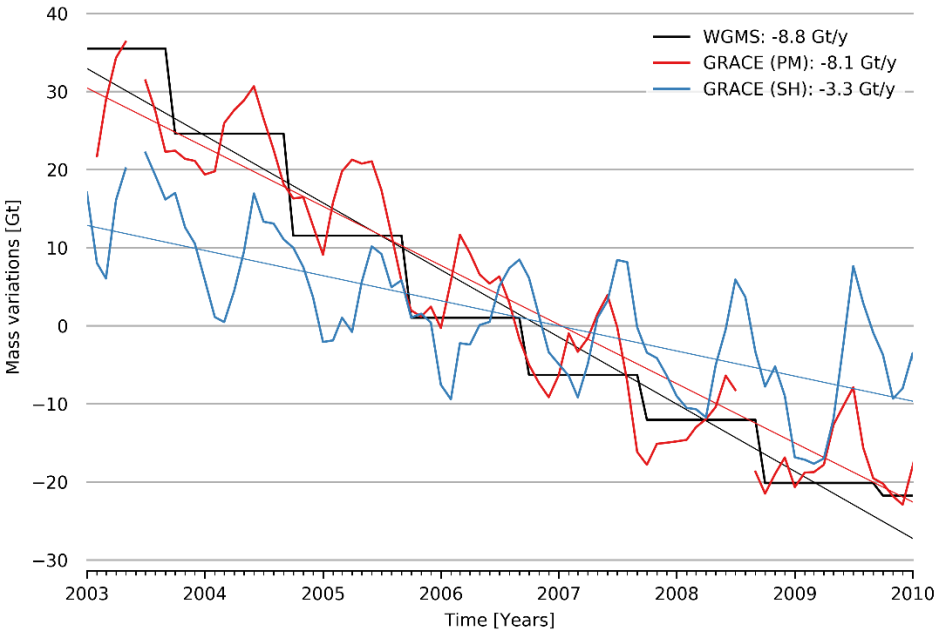
Postfit residuals in the form of root mean square (RMS) from S-band DSN data to GRAIL using GrazLGM420b.

GRACE

The year 2017 marked the end of the scientific operations of the highly successful twin-satellite mission *GRACE* (*Gravity Recovery And Climate Experiment*, NASA/DLR). For more than 15 years, *GRACE* has provided time-variable gravity field information with unprecedented accuracy which substantially contributed to a better understanding of how mass is constantly being redistributed around the Earth. This information is of utmost importance, not only for geophysicists, but also for any researcher studying the effects of global climate change. In this context, a particularly crucial application of *GRACE* resides in the possibility to directly monitor changes in the Earth's cryosphere, i.e., glaciers, ice caps and ice sheets. Besides the thermal expansion of ocean water, presently glacier shrinkage has been identified as the most dominant contributor to global sea level rise.

In the framework of the IWF-led project *SPICE*, a sophisticated analysis approach has been developed to deduce reliable estimates of mass balances of alpine glacier systems (Alps, Alaska, Iceland, Svalbard etc.) from space-gravimetric data. The innovative methodology approximates the regional gravity field in the vicinity of the investigated glaciers with radial basis functions (point masses) and exploits *GRACE* on the level of raw inter-satellite measurements (Level-1B). To stabilize the (naturally ill-posed) gravity inversion, Tikhonov regularization is applied. The selection of an appropriate regularization parameter is done in an exceptional way: the extended Gauss-Markov model is regarded as a multi-objective optimization problem, which is solved by utilizing stochastic optimization methods (Genetic Algorithms). These three measures, as opposed to the typically applied (global) spherical harmonics modeling (see figure below; blue curve), ensure the best possible regionalization of both modeling and data and consequently prevent the solutions from being oversmoothed.

GRACE data have been processed and provided by the project partners at TU Graz. Isolation of the glaciological signal is made more reliable by using both global and regional hydrological models. The final glacier mass balance estimates, based on a novel point mass approach (PM), are validated by comparison with in-situ observations provided by the World Glacier Monitoring Service (WGMS) in Zurich (see figure below; red and black curve, respectively).



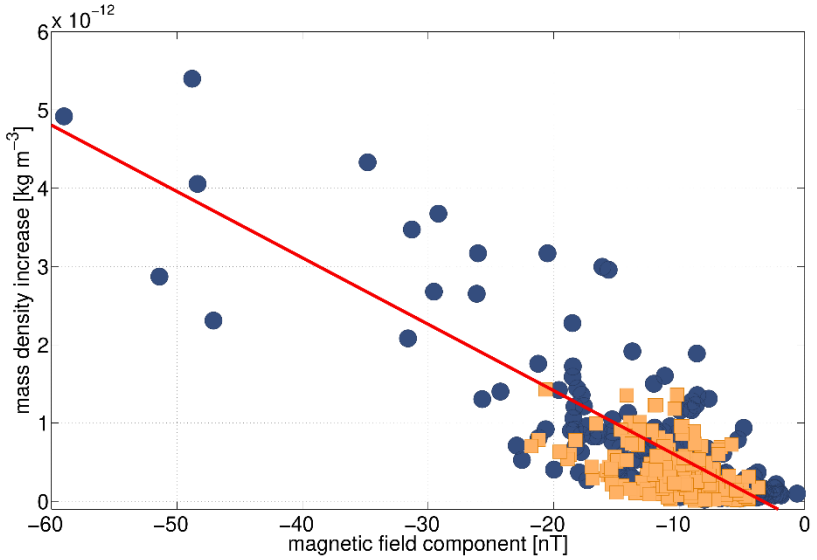
Viability of the presented novel method for the example of Iceland.

SPACE WEATHER APPLICATIONS

Dedicated gravity field missions like *GRACE* or its successor *GRACE* Follow-on (launch date: March 2018) measure all forces acting on a spacecraft to recover the Earth's gravity field. A core instrument aboard this kind of satellites are accelerometers, which enable the measurement of the non-gravitational part of the perturbing forces. In addition to the substantial benefit for the gravity field research, these instruments also allow the determination of time-variable atmospheric mass densities along the satellite trajectory. Since space weather disturbances can affect spaceborne and ground based technologies, the knowledge of the current state of the thermosphere is very important.

For this reason, the impact of nearly 400 solar events on the Earth's thermosphere and the magnetic field in the interplanetary medium have been thoroughly analyzed. The events, which occurred between 2003 and 2015, included 196 coronal mass ejections (CMEs) and 195 corotating interactions regions (CIRs). Atmospheric mass densities have been estimated by means of *GRACE* accelerometer measurements and Bz magnetic field component variations were observed by the *Advanced Composition Explorer (ACE)* satellite, located at the Lagrange point 1 (L1). Thereby, a strong causal link between these two types of observations could be deduced (see figure below). Hence, this comprehensive study provides a solid basis for a future forecasting tool to estimate the expected impact of a solar event on the Earth's thermosphere based on near real-time observations of the Bz component at L1.

In today's modern society, with the steadily increasing technology, these activities show that IWF is aware of the necessity to recognize and face up to the space weather threat.



Scatter plot of the Bz component (ACE) vs. the increase in the neutral density (GRACE). The analyzed CME and CIR events are marked with blue circles and orange squares, respectively.

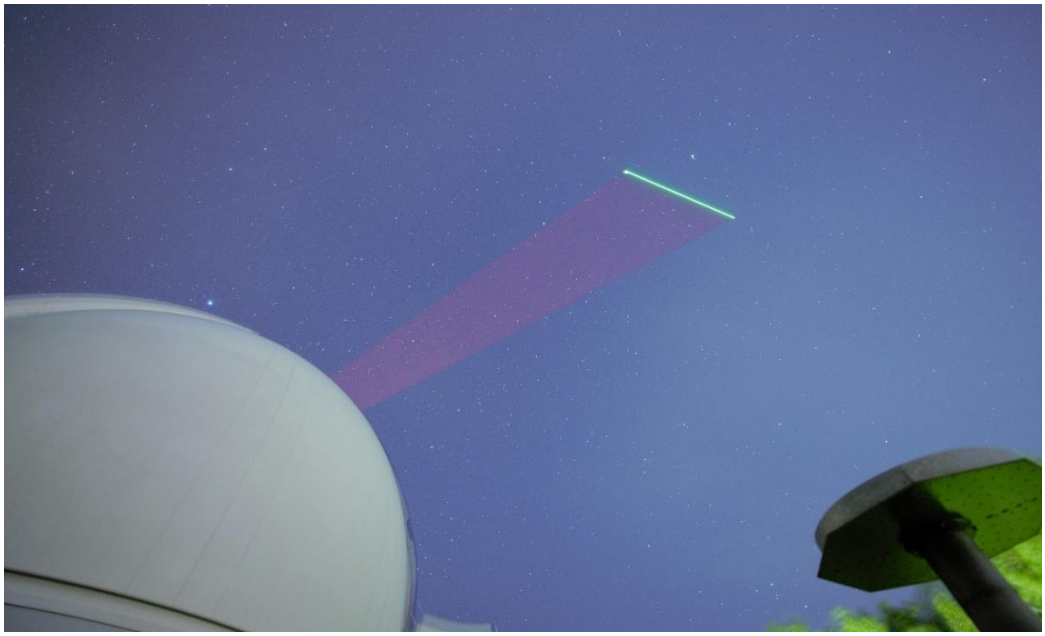
SATELLITE LASER RANGING

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 founding of a space debris expert center, polarization switching measurements to *Galileo* satellites and quantum key distribution experiments in cooperation with the ÖAW Institute for Quantum Optics and Quantum Information (IQOQI) Vienna.

QUANTUM KEY DISTRIBUTION

With the growth of internet use and electronic commerce, a secure global network for data protection is desirable. A drawback of traditional public key cryptography is that it is not possible to guarantee information security. However, quantum key distribution (QKD) offers unconditional security ensured by the laws of physics. QKD uses the fundamental unit of light, single photons, encoded in quantum superposition states, which are sent to distant locations. By proper encoding and decoding, two distant parties share strings of random bits called secret keys.

In a collaborative project between the Austrian and Chinese Academies of Sciences and the University of Vienna, intercontinental QKD has been demonstrated for the very first time in 2017 between ground stations in Austria and China. Therefore, the Graz SLR Station at Lustbühel Observatory was equipped with a dedicated quantum detection package developed by IQOQI. This allowed detecting and analyzing the polarization state of the single photon signal transmitted from the Chinese Low Earth Orbit satellite *Micius*. Furthermore, using the satellite as a trusted relay station, secure quantum keys could be exchanged with the Xinglong and Nanshan ground stations in China. These keys were then used for intercontinental quantum-secured communication by transmitting images in a one-time pad configuration as well as a video conference between Austria and China. The following image shows a long-term exposure picture of the SLR station while tracking the Chinese Satellite.



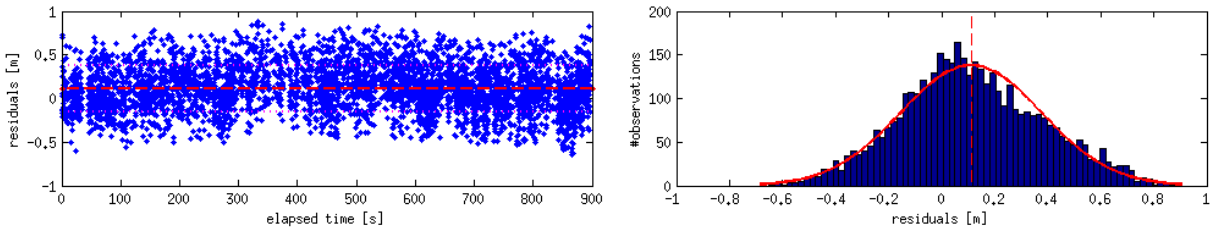
The Graz SLR Station at Lustbühel Observatory tracking the Chinese satellite Micius in a long-term exposure picture. One can see the red uplink as well as the green downlink beacon lasers.

EXPERT COORDINATION CENTER

With ESA's Space Situational Awareness program an Expert Coordination Centre was founded at ESOC, Darmstadt. A consortium was formed 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 Expert Center's main task is to coordinate external stations, in terms of observation scheduling/tasking and data delivery. Furthermore, within the framework of the project several data conversion tools were developed.

The Graz SLR Station developed an acceptance process for SLR candidate stations to become a "qualified" space debris laser ranging station according to pre-defined criteria. The acceptance process was split into three parts: 1) Validation: The candidate sensor has to measure a number of full passes to targets with well-known orbits (e.g. *Lageos-1/Lageos-2*) using a space debris laser. The results are compared to the *Lageos* ILRS reference orbit by applying a validation routine. 2) Qualification: Within the qualification campaign the candidate sensor has to deliver the results of at least three successful observation sessions performing measurements to arbitrary space debris targets. The station has to reach certain success criteria to pass to the next phase. 3) Dedicated campaign: According to a fixed target priority list the station has to deliver a certain amount of passes within a month's time.

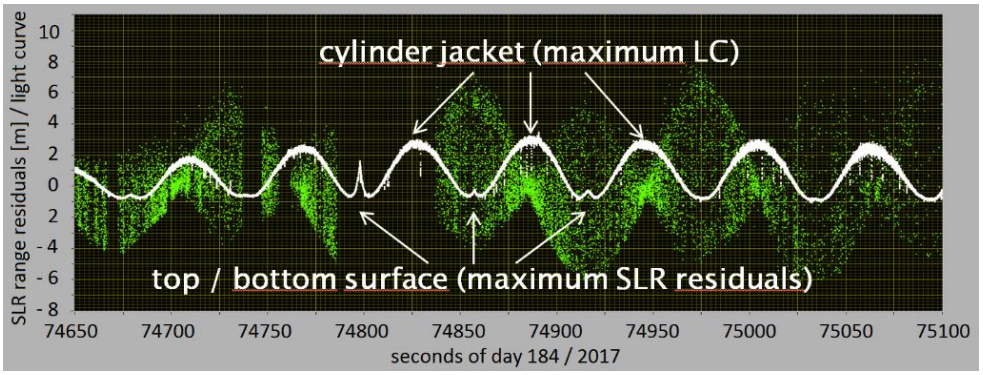
The functionality of the acceptance process was demonstrated successfully for the SLR station in Borówiec, Poland, delivering space debris laser ranging data to *Lageos 1* (figure) and *Lageos 2*.



Space debris laser ranging residuals [m] over time [s] to Lageos 1 for Borówiec SLR station (left). The histogram analysis of the range residuals to Lageos 1 showed a range bias of 0.1 m in comparison with the ILRS reference orbit (right).

SPACE DEBRIS OBSERVATIONS

The upper stage of the Long March 3B rocket body (NORAD ID: 38253) reentered the Earth's atmosphere in August 2017. One month before reentry, light curves (figure below; white) were recorded by using single photon avalanche diodes while simultaneously doing distance measurements via space debris laser ranging (figure below; green). The light curve measurements were taken using the reflected sunlight of the satellite gathered by our receiving telescope with wavelengths other than the 532 nm (which is used for SLR). Space debris laser ranging was performed with a high power laser operating at 20 W / 100 Hz.



Space debris laser ranging range residuals (white, in meters) and light curve measurements (green, proportional to the number of single photon returns within 10 ms intervals) vs. the seconds of day. The light curve is scaled accordingly to fit within the plot of the range residuals.

The simplified shape of the rocket body can be assumed to be cylindrical, with a height of 12.38 m and a diameter of 3 m. Within a single pass of the rocket body it is possible to draw conclusions on the orientation of the space debris part. Since both data sets are oscillating, it implies that the rocket body is rotating – with a rotation period of about 120 s.

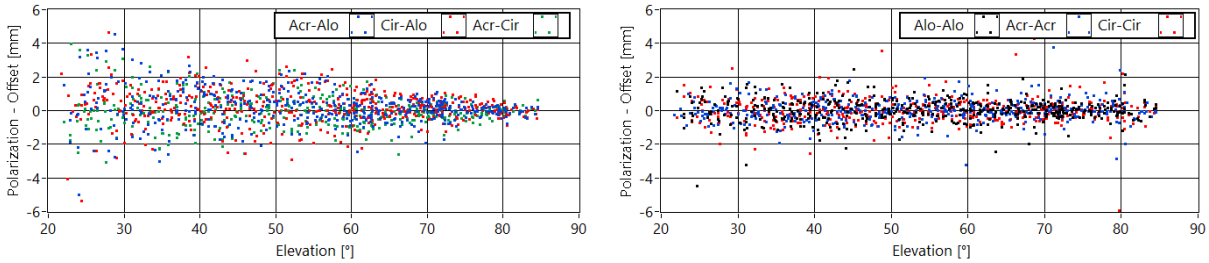
The maximum offset of the SLR range residuals is about 12 m, which corresponds well to the rocket body dimensions. This implies that the cylinder symmetry axis is oriented close to the observer's line of sight. Furthermore, the SLR maxima are aligned with the small and sharp light curve peaks. These arise from the reflection of the sunlight on the top/bottom surface of the rocket body.

At the minimal SLR residuals the light curve shows a broad reflection maximum. These peaks are related to sunlight reflections of the cylinder jacket. The cylinder symmetry axis is hence lying within a plane normal to the line of sight of the observer.

Based on a cylindrical model of the rocket body simulated light curves and SLR residuals were calculated along the path by using Simplified General Perturbations (SGP4) orbit propagation. The modeled cylinder was rotated along the path using the period from the measured light curve and the SLR data. Different starting conditions regarding the orientation of the cylinder axis and the starting phase angle were simulated. A comparison of experimental results with the simulations allowed to draw conclusions on the rotation parameters of the rocket body with respect to the Earth centered inertial system.

ALCANTARA INITIATIVE

ESA's Alcantara Initiative is a program to build bridges between international research partners by sharing their knowledge. Within this initiative a project was conducted in cooperation with the Argentine-German Geodetic Observatory. SLR measurements to *Galileo* satellites were performed continuously over up to four hours. During this time, the polarization state of the outgoing laser beam was switched, in intervals of one minute, between linear polarization along track, across track and circular polarization. In total 15 *Galileo* passes were analyzed regarding laser polarization induced offsets of the range measurements.



**Polarization offsets [mm] between different polarizations (left; Alo = along track, Acr = across track,
Cir = circular) and between adjacent measurements of the same polarization (right) plotted against the satellite elevation [°].**

In previous studies systematic offsets have been found for retro-reflector arrays of older *Glonass* satellites. These offsets are connected to fabrication errors of the corner cube retro-reflectors shifting the mean reflection point millimeters towards or away from the observing station. The goal of the present study was to investigate if *Galileo* reflector panels show similar effects. The current *Galileo* reflector panels do not show systematics, the offsets between the range residuals of different polarization states (polarization offset [mm]) are distributed evenly around zero (figure above). The RMS of the polarization offset increases for lower elevations (corresponding to a larger incidence angle on the retro-reflector panel). Comparing adjacent measurements of the same polarization state does not show this elevation dependent effect. Thus, the effect was explained by the superposition of the far field diffraction patterns of differently "clocked" (rotated) retro-reflectors on the *Galileo* retro-reflector panel. Depending on the incident angle of the laser beam on the panel polarization-based offsets occur.

NEAR-EARTH SPACE

Near-Earth space is a most suitable place to study fundamental space plasma processes due to recent advancements in the in-situ measurements of the charged particles together with electric and magnetic fields at high cadence. IWF has been participating in the hardware activities of numerous missions, now operating, being built as well as in the planning phase. Data taken from these missions have been extensively analyzed at IWF by applying different

analysis methods to the data and by theoretical modeling to compare with the observations. The obtained knowledge contributes to the better understanding of different processes in space plasma applicable to those in our solar system and beyond.

CLUSTER

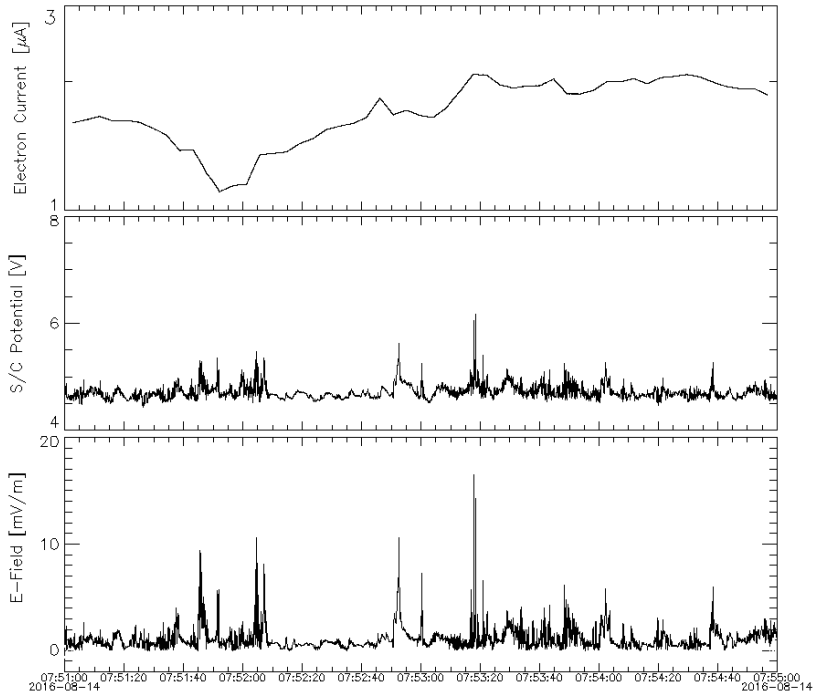
The *Cluster* spacecraft have been providing data since 2001 as the first four spacecraft mission in space for studying small-scale structures of the Earth's magnetosphere and its environment. The mission is currently planned to be extended to December 2018. IWF is PI/Co-I on five instruments and has maintained the *Austrian Cluster Data Center*. In addition to data analysis, IWF contributed to data archiving activities at the *Cluster Science Archives (CSA)* by also producing supporting data products such as science event lists.

THEMIS/ARTEMIS

NASA's *THEMIS* 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.

EFFECT OF ELECTRIC FIELDS ON SPACECRAFT POTENTIAL

It has been a puzzle since the early days of the *Cluster* mission why the spacecraft potential - despite being limited by the ion beam emitted by the *ASPOC* instrument - sometimes exhibits spikes, which are higher than any variation of the ambient plasma could induce. The high-resolution *MMS* data revealed a clear correlation - with squared regression coefficients better than 0.8 - between the spacecraft potential (center panel of example in the figure below) and the ambient electric field (bottom panel) whereby a field of the order of 10 mV/m may already increase the potential by one volt. In comparison, the variation of the plasma electron current to the spacecraft surface (top panel) by a factor of 2 causes no significant reaction of the potential.



Electron current deduced from plasma instrument (top); spacecraft potential (middle); electric field obtained from double probe measurement aboard MMS during an interval when ASPOC was operating (bottom).

MMS

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

IWF, which is the biggest non-US participant in *MMS*, has taken the lead for the spacecraft potential control of the satellites *(ASPOC)* and is participating in the electron drift instrument *(EDI)* and the digital fluxgate magnetometer *(DFG)*. In addition to the operation activities of these instruments and scientific data analysis, IWF is contributing to develop new methods of inflight calibration and an algorithm to produce new science data products.

After removal of the electric field effect, the spacecraft potential becomes a much more accurate indicator of plasma density. The interpretation is subject to ongoing studies and numerical simulations. Most likely, the effect is related to the size of the spacecraft together with its long conductive wire booms (~120 m tip to tip), which form a huge equipotential structure. Due to the electric field, the potential of the body relative to the ambient plasma is no longer a single value but depends on the position. The resulting asymmetry of the sheath around the spacecraft body impedes the return of photo-electrons to the body. This in turn enforces an increase of the spacecraft potential to maintain the equilibrium of currents. The same mechanism should affect the spacecraft potential when *ASPOC* is not operating, but may be hidden behind stronger variations due to the ambient plasma.

CSES

The *China Seismo-Electromagnetic Satellite (CSES)* mission was launched in early 2018. It will be 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 the National Space Science Center (NSSC) of the Chinese Academy of Sciences, the Institute of Experimental Physics (IEP) of TU Graz, and IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while IWF and IEP participate with the newly developed absolute scalar magnetometer, called *Coupled Dark State Magnetometer (CDSM)*. In 2017, the *CDSM* Flight Model was delivered to China, integrated onto the spacecraft and accepted for flight.

CSES team from IWF and Graz University of Technology (TU Graz) ready to launch the CDSM magnetometer.

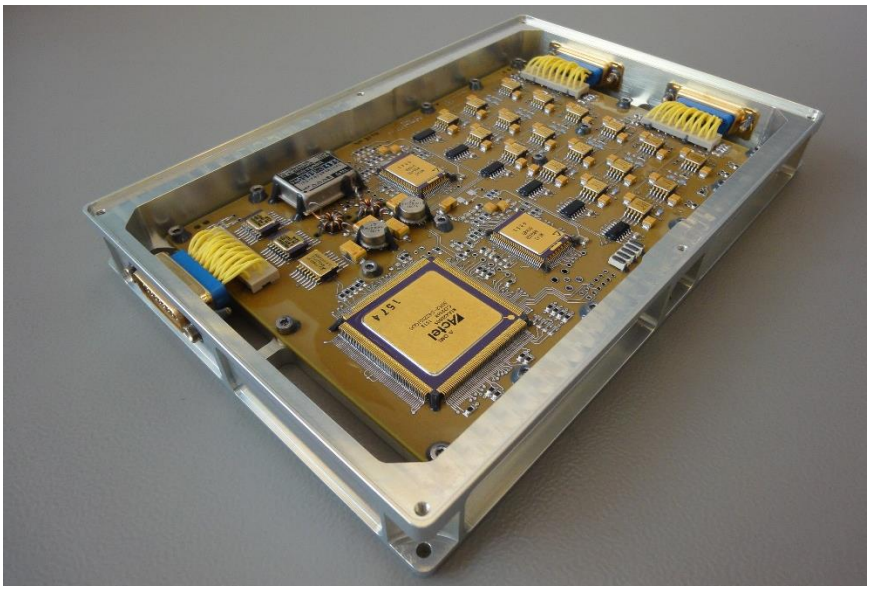
GEO-KOMPSAT-2A

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 (see AMR front-end electronics in the image below).

In 2017, the flight model of *SOSMAG* was assembled, calibrated, acceptance tested, delivered to South Korea and integrated onto the *GK-2A* spacecraft as part of the *Korean Space Environment Monitor (KSEM)* instrument suit. It will be launched in early 2019.



Flight electronics of the two AMR sensors.

SMILE

The *Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)* is a joint mission between ESA and the Chinese Academy of Sciences. 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)* and the magnetometer *(MAG)*.

MAGNETOMETER OFFSET DETERMINED FROM COMPRESSIONAL WAVES

Magnetometers on-board spacecraft need to be regularly calibrated in flight. In low fields, the most important calibration parameters are the three offset vector components, which represent the magnetometer measurements in vanishing ambient magnetic fields. A new method has been developed to determine these three components from magnetic field measurements of highly compressional waves, e.g., mirror modes in the Earth's magnetosheath. Correspondingly, the method is called 3D mirror mode method. Although it shares the same basic working principles with the 1D mirror mode method for spin-axis stabilized spacecraft, it is a completely new development, focused on the calibration of magnetometers on board three-axis stabilized spacecraft.

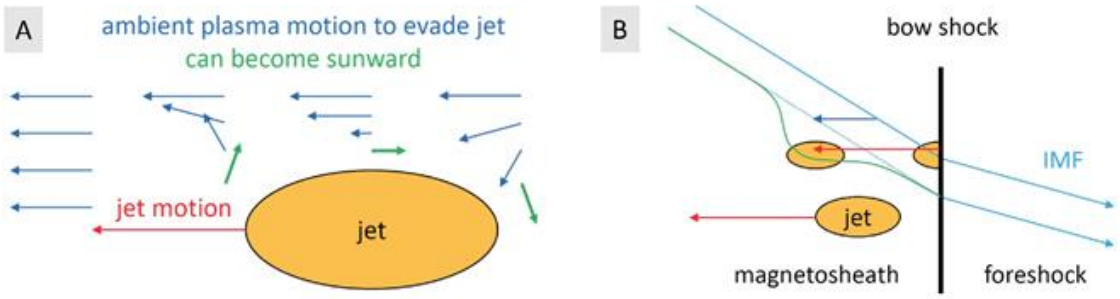
The method has been tested by applying it to magnetic field data measured by the *THEMIS-C* spacecraft in the terrestrial magnetosheath, the *Cassini* spacecraft in the Jovian magnetosheath, and the *Rosetta* spacecraft in the vicinity of comet 67P/Churyumov-Gerasimenko. The tests reveal that the achievable offset accuracies depend on the ambient magnetic field strength (lower strength meaning higher accuracy), on the length of the

underlying data interval (more data meaning higher accuracy) and on the stability of the offset that is to be determined. The method is expected to be applied to the magnetometer data from the *SMILE* spacecraft.

MAGNETOSHEATH HIGH-SPEED JETS

MMS measurements have enabled, for the first time, the study of the rich internal structure of a magnetosheath high-speed jet. Large-amplitude density, temperature, and magnetic field variations inside the jet are revealed. The propagation velocity and normal direction of planar magnetic field structures (i.e., current sheets and waves) have been investigated via four-spacecraft timing. These structures mainly convect with the jet plasma. In the particular jet studied, there are indications of the presence of a tangential discontinuity. At other times, there are small cross-structure flows. Where this is the case, current sheets and waves overtake the plasma in the jet's core region. Ahead and behind that core region, along the jet's path, current sheets are overtaken by the plasma.

Jet structures are found to be mainly thermal and magnetic pressure balance structures, notwithstanding that the dynamic pressure dominates by far. Although the jet is supermagnetosonic in the Earth's frame of reference, it is submagnetosonic with respect to the plasma ahead. Consequently, there is no fast shock. Instead, some evidence is found for (a series of) jets pushing ambient plasma out of their way, thereby stirring the magnetosheath and causing anomalous sunward flows in the subsolar magnetosheath (figure below, A). Furthermore, jets are found to modify the magnetic field in the magnetosheath, aligning it with their propagation direction (figure below, B).



A: Illustration showing the motion of the magnetosheath plasma (blue and green arrows) in the vicinity of a jet; B: Illustration of how the plasma motion of a jet (red arrow) through slower ambient plasma (blue arrow) modifies the magnetic field in the magnetosheath (green line).

PHYSICS

Data from ongoing missions are analyzed and theoretical models are developed to describe the physical processes in near-Earth space. In particular, high-resolution data from *MMS* enabled a number of new studies dealing with interactions between the solar wind and the magnetosphere, internal disturbances in the magnetosphere such as plasma flows, waves, and plasma instabilities including magnetic reconnection and their large-scale consequences.

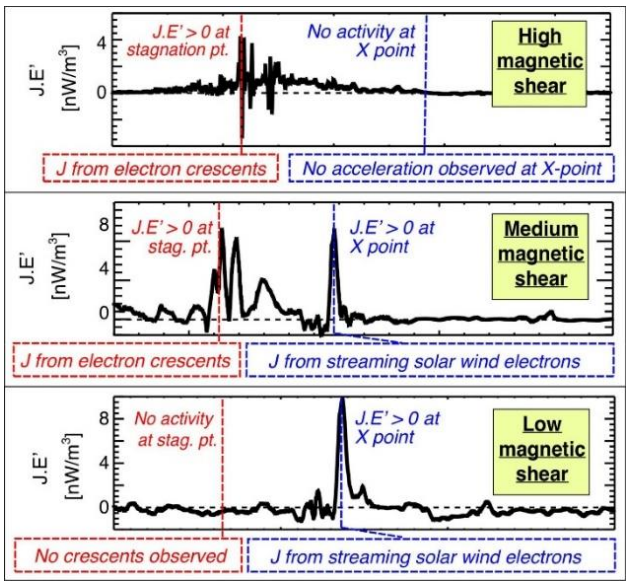
EARTH'S MAGNETOPAUSE

The magnetopause is the magnetic barrier that deflects the solar wind plasma and confines the Earth's magnetic field. Data from *MMS* are combined to demonstrate how the plasma and magnetic forces at the boundary affect the interaction between the shocked solar wind and the Earth's magnetic field. These forces with the plasma pressure are examined together with the electron distribution function. Sublayers with thickness compared to the ion scale are

found. There are also small pockets of low magnetic field strength, of small radius of curvature, and of high electric current that mark the electron diffusion region. The flow of electrons, parallel and antiparallel to the magnetic field reveals a complex topology with the creation of magnetic ropes at the boundary.

GUIDE FIELD EFFECT ON LOCAL ENERGY CONVERSION DURING ASYMMETRIC MAGNETIC RECONNECTION

MMS data were used to investigate small-scale regions where plasma electron dynamics support the splitting and interconnection of the Earth's magnetic field and the shocked solar wind. Magnetic reconnection can create hazardous energetic particle radiation in near-Earth space by dissipating magnetic energy and accelerating nearby plasma particles. A number of cases were examined, where *MMS* observed reconnection in situ, in order to investigate the nature of the dissipation region.



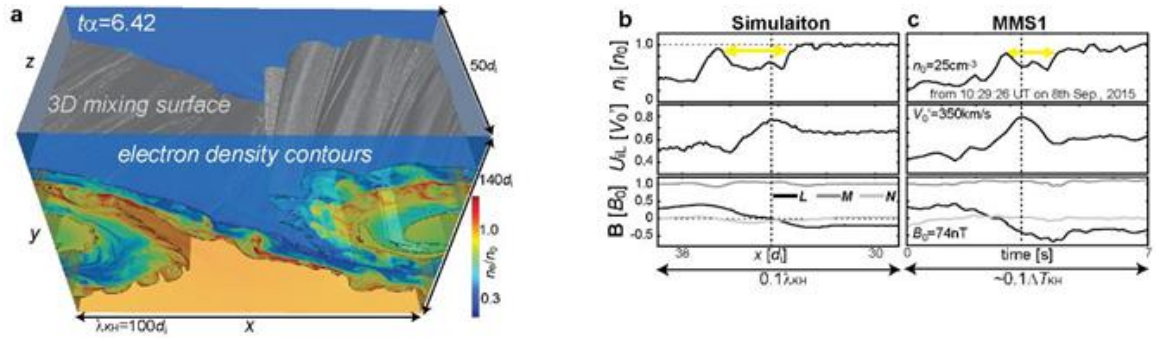
The dissipation measure (J.E') as a function of time for three typical reconnection sites observed by MMS. The top, middle, and bottom plots show reconnection events with very high, moderate, and very low magnetic shear. The vertical red line indicates the time when the electron flow stagnation point was observed. The blue vertical line indicates the time when the magnetic X point was observed. The red and blue boxes describe the source of the current, J, that was associated with the dissipation measure, J.E'.

The results of the study, which are summarized in the figure above, indicated that the location of - and mechanism for - dissipation are partially controlled by the angle between the Earth's and the Sun's magnetic fields. During reconnection with high magnetic shear, dissipation is associated with highly agyrotropic meandering electrons near the inner boundary of the reconnection region, the electron flow stagnation point. For very low shear, dissipation is associated with streaming solar wind electrons near the exact site of reconnection, the magnetic X point. For moderate shear, both mechanisms are active.

TURBULENT MASS TRANSFER CAUSED BY VORTEX-INDUCED RECONNECTION IN MAGNETOSPHERIC PLASMAS

Magnetic reconnection is believed to be the main driver to transport solar wind into the Earth's magnetosphere when the magnetopause features a large magnetic shear. However, even when the magnetic shear is too small for spontaneous reconnection, the Kelvin-Helmholtz instability (KHI) driven by a super-Alfvénic velocity shear is expected to facilitate the transport. Although previous kinetic simulations have demonstrated that the non-linear vortex flows from the KHI gives rise to vortex-induced reconnection (VIR) and resulting plasma transport, the system sizes of these simulations were too small to allow the VIR to evolve much beyond the electron-scale as recently observed by the *MMS* spacecraft.

In this study, based on a large-scale fully kinetic simulation (see figure below; a) and its comparison with *MMS* observations (figure below; b and c), it is shown for the first time that ion-scale VIR jets rapidly decay through self-generated turbulence (figure below; a), leading to a mass transfer rate nearly one-order higher than previous expectations for the KHI.



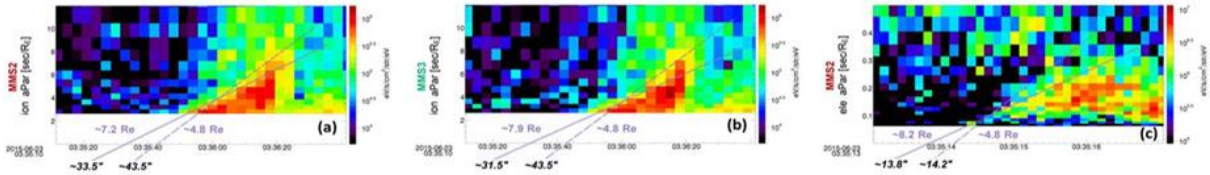
a: 3D view of mixing surfaces with electron density contours in the x-y planes at z=0 (=L_z) in a non-linear growth phase of the KHI (*tα* =6.42). b, c: Virtual observation plots for the crossing of an ion-scale VIR jet (b) and in-situ observations by the *MMS1* spacecraft for a 7s interval from 10: 29:26 UT on 8 Sep. 2015 (c) of ion density n_i, ion bulk velocity along the jet U_{iL} and magnetic field B. Quantitative consistencies between simulation and observation can be seen especially in the ion jet (enhanced U_{iL}) with a density dip (marked by yellow) during the crossing of the current sheet (B_L change).

REMOTE OBSERVATIONS OF INTENSE RECONNECTION IN THE NEAR-EARTH MAGNETOTAIL

Although the consequences of magnetic reconnection can be detected in a large region in the magnetotail, the spatial and temporal evolution of magnetic reconnection is not well understood due to its localized and transient nature. Uncertainties in identifying the characteristics of the reconnection regions have significantly improved based on remote observations of reconnection by *MMS* combined with *DMSP (Defense Meteorological Satellite Program)* observations from the low Earth orbit during a storm-time substorm on 23 June 2015. The energy and pitch-angle dependent signatures of ions and electrons from these spacecraft have been used to determine the location of the source region, i.e. the reconnection sites.

The high-resolution measurements by *MMS* succeeded in detecting for the first time the dispersion of the electrons together with the ions. The dispersion analysis is shown in the figure below. The identified location of the reconnection was at 16-18 R_E, which is consistent with that inferred from low Earth orbit *MMS*. The results from detailed analysis from *MMS*

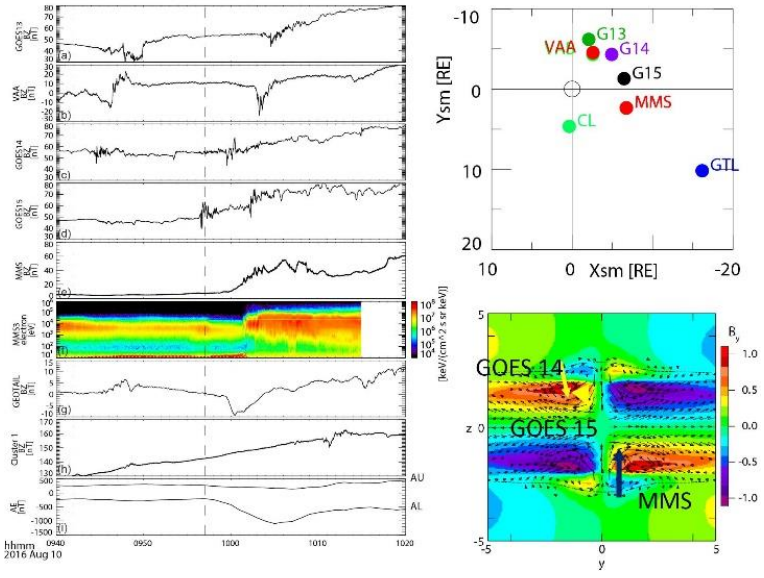
indicated also that the underlying magnetotail magnetic reconnection process was intrinsically impulsive during this active X-line event.



Energy flux of the anti-field-aligned ions (Earthwards) measured by (a) *MMS2* and (b) *MMS3* spacecraft and electrons from *MMS2* (c). The two purple lines demonstrate the min. and max. slope of the dispersion. The estimated maximum distance and the injection times are labeled at the bottom end of the slopes.

LARGE-SCALE DISTURBANCES IN THE MAGNETOTAIL PRODUCED BY A RECONNECTION JET

Although reconnection takes place in a localized region, it creates fast plasma flows, which lead to large-scale disturbances in the near-Earth magnetotail, in particular during a substorm. To study the chain of processes, it is essential to combine *MMS* observations with those of other spacecraft distributed in the magnetosphere. The evolution of the near-Earth plasma sheet during an intense substorm was studied based on multi-point analysis using the measurements from *MMS, Geotail, GOES,* and *Cluster*, and comparison with an MHD model of the reconnection jet.



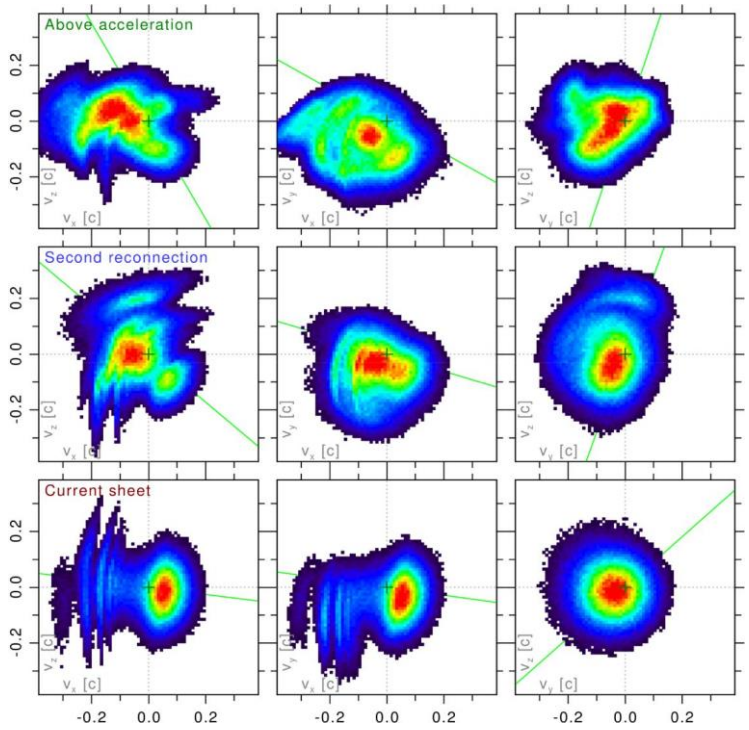
Magnetic field component normal to the current sheet (BZ) from seven spacecraft: *GOES 13, Van Allen Probe-A, GOES 14, GOES 15, MMS3, Geotail, Cluster 1*, together with electron energy spectra from *MMS1* and *MMS3* and auroral electrojet indices (left panel); spacecraft location in equatorial plane (upper right); color-coded By disturbances around the reconnection jets from the MHD simulation. *MMS* and *GOES 14-15* observed disturbances similar to those at the location indicated by arrows (lower right).

Large-scale configuration changes in the magnetotail during a substorm were observed (see left panel of the figure above) when a number of spacecraft was located in the near-Earth

magnetotail (upper right panel). The spatial structure of the high-speed plasma flows and associated field-aligned current pattern were deduced. These disturbances were compared with an MHD simulation (lower right panel). It is found that the dynamics in the boundary region of the near-Earth plasma sheet is controlled both by the Earthward flow braking process and by the accumulated magnetic flux due to near-Earth reconnection evolving tailward.

CATALOG OF ELECTRON VELOCITIES IN THE EARTH'S MAGNETOTAIL

The computation of electron velocity distribution functions in the Earth's magnetotail requires a very large number of particles in order to get a good statistical significance and low noise. Such distributions have recently been observed with the *MMS* mission. The comparison of the simulation results with the observed distributions, when flying through a reconnection region in the Earth's magnetosphere, will foster future research and understanding of reconnection physics. Observers need to know, where in a reconnection region the spacecraft have recorded the data, which cannot be known directly. The comparison to a catalog of predicted electron distribution functions allows to reconstruct the spacecraft trajectory through the magnetotail. In an effort to generate a comprehensive catalog with different plasma conditions, as a first step, an anti-parallel magnetic field case was computed. Samples of highly complex distributions are shown in the figure below. The origin of these highly structured distributions still needs to be explained better from reconnection physics.



Catalog of electron velocity distributions as obtained from 2D particle-in-cell simulations. Each row shows a specific location in the magnetic reconnection region that is similar to the tail (night-side) of the magnetic field of Earth. The maximum probability to find an electron with the given velocities is colored in red, the minimum in blue. The background magnetic field direction is indicated with a green line.

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.

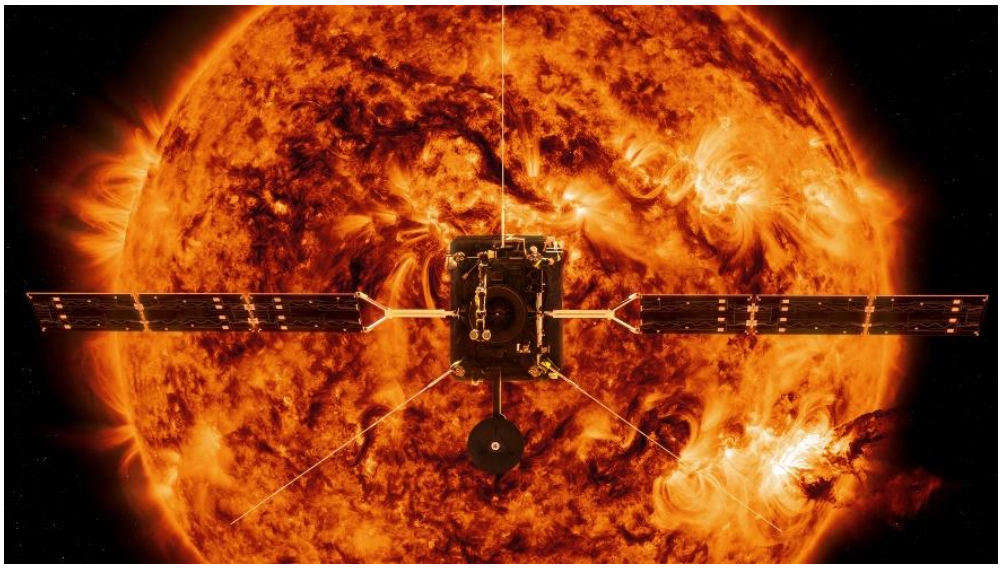
SOLAR ORBITER

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 builds 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 contributes to the magnetometer.

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

In 2017, the so called *Main Electronics Box (MEB)*, containing both DPUs, the power supply and the four analyzers, has been finally integrated under the leadership of LESIA (Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique) and CNES (Centre National d'Etudes Spatiales). The environmental tests have been successfully completed and the instrument has been delivered to ESA for further integration onto the spacecraft.

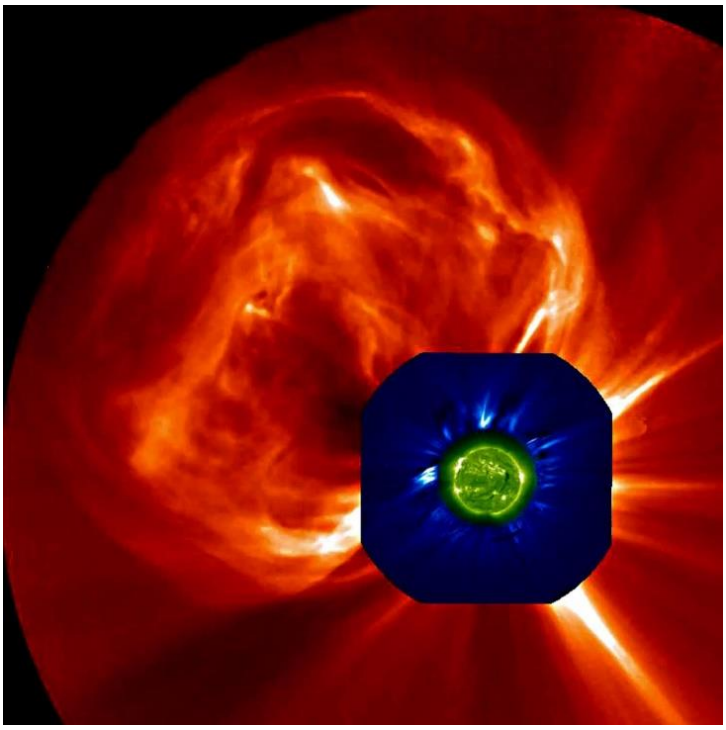


Artist's impression of ESA's *Solar Orbiter* in front of the Sun [not to scale; Copyright: Spacecraft: ESA/ATG medialab; Sun: NASA/SDO/ P. Testa (CfA)].

SPACE WEATHER PREDICTION VERIFIED

Solar storms are formed by incredibly powerful explosions on the Sun and travel as clouds of plasma threaded by magnetic fields through the solar system. Depending on their propagation direction, they may impact planets such as Earth, where they elicit colorful aurorae or, in very seldom cases, can lead to power failures with potentially tremendous economical and societal effects, thus posing a serious natural hazard.

The solar storm impact can be forecasted when using a special type of instrument on the *STEREO* mission that can actually image the solar storms as they propagate toward the planets (see image below) and even as they sweep over them. The analysis included two thirds of a solar cycle with eight years of data, and spacecraft at Mercury, Venus, Earth, and in the solar wind to check on the correctness of our predictions. This includes data from the *Venus Express* magnetic field instrument, which was built at IWF.



A solar storm imaged by the *STEREO* mission (Copyright: NASA/STEREO).

Forecasts of the solar storm arrival time were possible to within about 2.5 hours, with a spread of +/-16 hours, and for one correct impact there are two to three false alarms. These results show that accurate space weather forecasts with a mission at the Sun-Earth L5 point could be possible, although modeling accuracy should clearly be further improved. Data returned by the upcoming missions *Parker Solar Probe, Solar Orbiter* and *BepiColombo* are expected to lead to groundbreaking advances in this field.

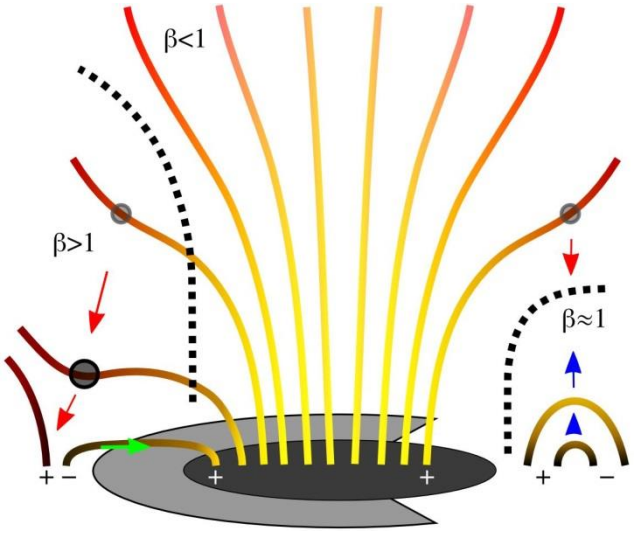
PLASMA BETA AT THE SUN

A crucial physical quantity in a star's atmosphere is the ratio between thermal and magnetic pressure, called plasma beta. With recent 3D simulation results, plasma beta could be

estimated for the solar corona from a magneto-hydrodynamic model of a magnetically active region with some surrounding quiet Sun area.

The new data show that the possible value range for beta is orders of magnitude larger than previously thought if also more quiet regions are considered, which usually cover about 98% of the Sun's surface. In particular, beta may become larger than unity in the whole corona, which is a surprise for magnetic field modeling.

With this fact in mind, a new mechanism for the formation of a penumbra, the gray surroundings of a dark sunspot, could be formulated. The chromosphere surrounding the sunspot is connected to the corona and gets loaded with cooling material. Due to a beta larger than unity, field lines can be dragged down to the surface, where a horizontal magnetic field allows for the characteristic features of a forming penumbra, like the counter-Evershed flows (see green arrow in the figure below), horizontal magnetic field, and hence strongly elongated granules. These features have been observed but had not yet been understood.



Field lines above and around the sunspot (black). Cooling material may drag down the field because plasma beta may well be larger than unity (red arrows). This allows for the formation of the penumbra (gray). Emerging flux hinders the formation of the penumbra (blue arrows).

MERCURY

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

BEPICOLOMBO

Two spacecraft will simultaneously explore Mercury and its environment: the Japanese *Magnetospheric (MMO)* and ESA's *Planetary Orbiter (MPO)*. IWF plays a major role in developing the magnetometers for this mission: it is leading the magnetometer investigation aboard the *MMO (MERMAG-M)* and is responsible for the overall technical management of the *MPO* magnetometer *(MERMAG-P)*. For *MPO*, IWF also leads the development of the *Planetary Ion CAMera (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. The launch on board of an Ariane 5 from Europe's spaceport in French Guiana is confirmed for October 2018.

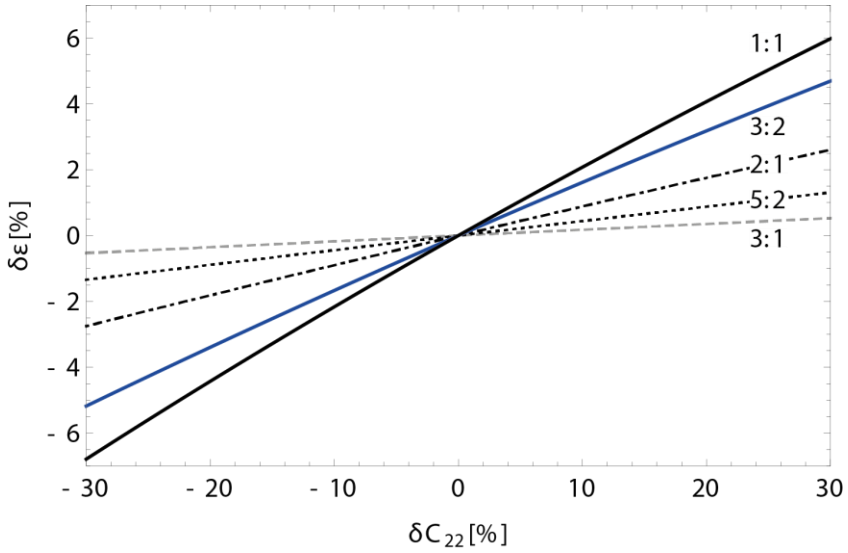
The year 2017 saw the final environmental and detailed functional test campaigns for both spacecraft on ground including EMC testing on *MPO* level as well as acoustic and vibration testing in full flight configuration (see image below). Beside the support of these tests, the instrument teams at IWF participated in other system level testing, in particular in the validation of the autonomous on-board control procedures (OBCPs), which were checked in operational scenarios. In parallel, the procedures for the Near-Earth Commissioning Phase were brought to a mature status, and the detailed planning for the Venus flybys and cruise operations was started. The flight software and the data processing are continuously improved. The *MPO* units, *MERMAG-P* and *PICAM*, passed their Instrument Flight Acceptance Reviews, so they were formally permitted for the journey to Mercury.

Examining the *BepiColombo* stack in ESA's test center. The people give a sense of the scale of the full spacecraft stack, which is more than 6 m high (Copyright: ESA–C. Carreau, CC BY-SA 3.0 IGO).

ROTATIONAL HISTORY OF MERCURY

The rotation of Mercury is strongly coupled to its orbital motion around the Sun: while one year on Mercury approximately lasts about 88 days, one mercurial day is very close to 2/3 of this value. Mercury, very probably, was not always situated in this current 3:2 spin-orbit resonance. Planet formation studies usually assume that planets form at much higher rotation rates. Over time dissipative effects like tidal friction slow down the rotation to allow temporary coupling between the orbit and the spin periods. The process stops when the 1:1 spin-orbit resonance is reached, i.e. if the lengths of the planetary "days" and "years" coincide.

While the phenomenon of the coupling between the spin and orbit periods of celestial bodies is well understood, the consequence of the internal gravity field and the coupling on the orientation of their rotation axes in space requires further investigations. The strong influence of the presence of a p:q spin-orbit resonance on its spin axis was shown (see figure below), and present physical theories were extended to include this effect. The *BepiColombo* mission will allow to scrutinize scientific theories about the origin and evolution of planet Mercury including its orbital and rotational history. A large amount of extra-solar planets are found very close to their host star. Subsequently, the same physics related to the spin-orbit coupling applies, and Mercury therefore serves as the best candidate to test new scientific findings before applying them to more distant objects that cannot be reached by space missions in the near future.



Variations of the orientation of the spin-axis (ordinate) versus equatorial mass asymmetry (abscissa) for different p:q spin-orbit resonances.

VENUS & MARS

Two terrestrial planets are located just inside, Venus at 0.7 AU, and outside, Mars at 1.5 AU, the Earth's orbit around the Sun. Venus has a radius slightly smaller than Earth and is differentiated, but does not exhibit an internal magnetic field. Mars has half the radius of the Earth, is also differentiated, but only exhibits remnant surface magnetization of a now defunct internal dynamo. Venus is characterized by a very dense, Mars by a very tenuous atmosphere. Both planets generate a so-called induced magnetosphere by their interaction with the solar wind.

INSIGHT

NASA's Mars mission *InSight* will launch in May 2018. IWF is participating in *HP³ (Heat flow and Physical Properties Probe)*, which consists of a cylindrical body with a built-in hammering mechanism to drive the probe at least 3 m into the ground. It will measure the interior heat flux of Mars as well as the thermal and mechanical properties of the Martian soil. In order to describe and predict the penetration performance of *HP³* , two numerical tools were developed and tested at IWF: a pile driving model able to predict the overall behavior of the mole during penetration and a numerical model (see figure below), allowing to predict the response of the granular medium surrounding the mole and its stress behavior. These models have been validated by comparison with soil-mechanical tests in the lab.

***InSight* spacecraft after landing on Mars with the main instruments in deployed configuration (left) and a comparison of a soil-mechanical lab test with the result of our numerical particle interaction code.**

EXOMARS

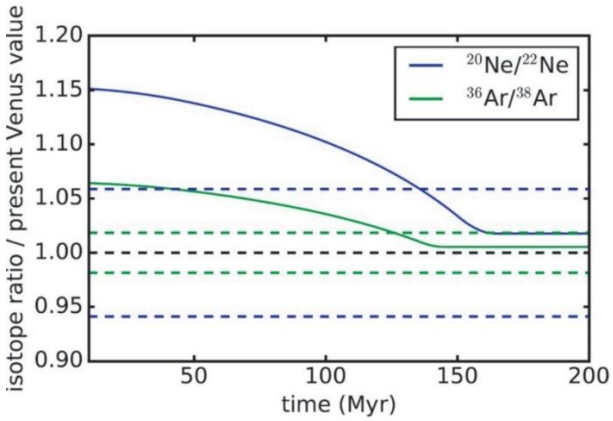
Several mechanisms devoted to retrieval and transportation of drill cores have been tested under Mars environmental conditions at IWF, among them the milling-and-crushing as well as the dosing device responsible for feeding various soil analysis instruments aboard ESA's *ExoMars* rover. In particular, possible cementation of soil samples under the influence of condensing water vapor was investigated.

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 will contribute to a magnetometer.

ESCAPE AND FRACTIONATION OF NOBLE GASES FROM EARLY VENUS

Different early evolution scenarios for Venus have been investigated and realistic cases, by comparing modeled noble gas isotope ratios with present observations in Venus' atmosphere, were used as constraints. Isotope ratios of $^{20}Ne/^{22}Ne$ and $^{36}Ar/^{38}Ar$ could be reproduced (see figure below), starting from solar values, under hydrodynamic escape conditions. Solutions for different solar EUV histories were found, as well as assumptions about the initial atmosphere, either a pure steam atmosphere (i.e., H_2O, CO_2) or a mixture with accreted hydrogen (H_2-dominated) from the protoplanetary nebula.



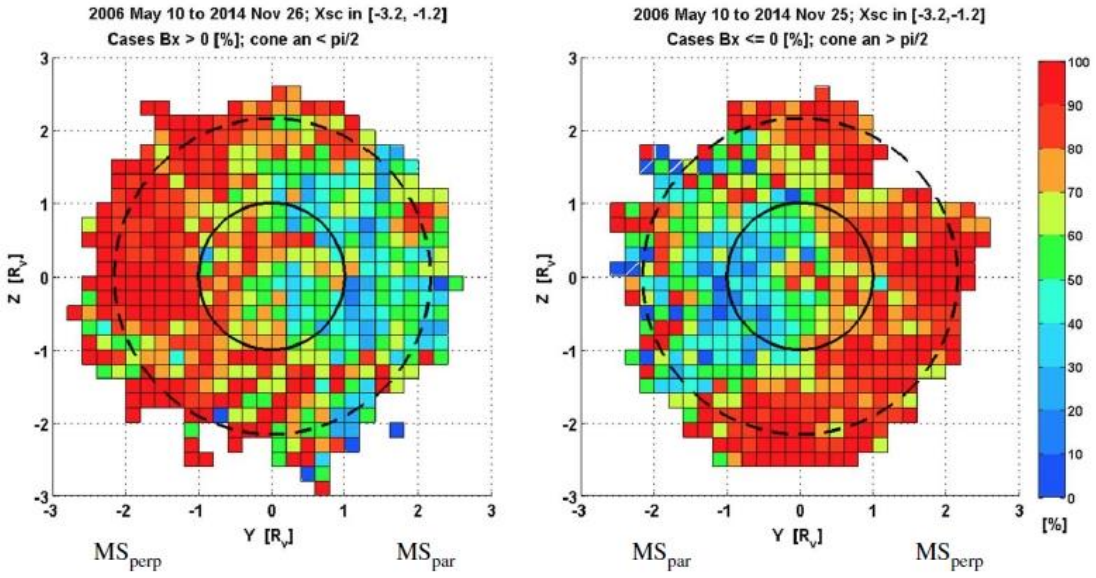
Model results for a weakly active young Sun (slow rotator) of a case in which the atmospheric $^{20}Ne/^{22}Ne$ and $^{36}Ar/^{38}Ar$ isotope ratios of Venus can be reproduced after about 150 Myr of evolution from initially solar ratios. The dashed lines show the uncertainties of the present measurements (black line) in Venus' atmosphere.

The results generally favor an early accretion scenario with a small amount of residual H_2 from the protoplanetary nebula and a low-activity Sun, because in other cases too much CO_2 is lost during evolution, which is inconsistent with Venus' present atmosphere. Important issues are likely the time at which the initial steam atmosphere is outgassed and/or the amount of CO_2 which may still be delivered at later evolutionary stages. A late accretion scenario can only reproduce present isotope ratios for a highly active young Sun, but then unrealistically massive steam atmospheres (few kbar) would be required.

ASYMMETRIES IN THE MAGNETOSHEATH FIELD DRAPING ON VENUS' NIGHTSIDE

Draping features of the interplanetary magnetic field around nonmagnetic bodies have been studied in detail in numerical simulations and also from observations. Existing analytical and numerical work show a kink in the draped field lines in the near magnetosheath on the quasi-parallel side of the bow shock.

Data from the *Venus Express* mission (2006–2014) are analyzed for differences in the draping pattern between the quasi-parallel and quasi-perpendicular side of the bow shock. From these magnetometer data, the kink in the field lines occurring only on the quasi-parallel side is clearly identified from the change of sign in the field component parallel to the solar wind velocity, as shown in the figure below.



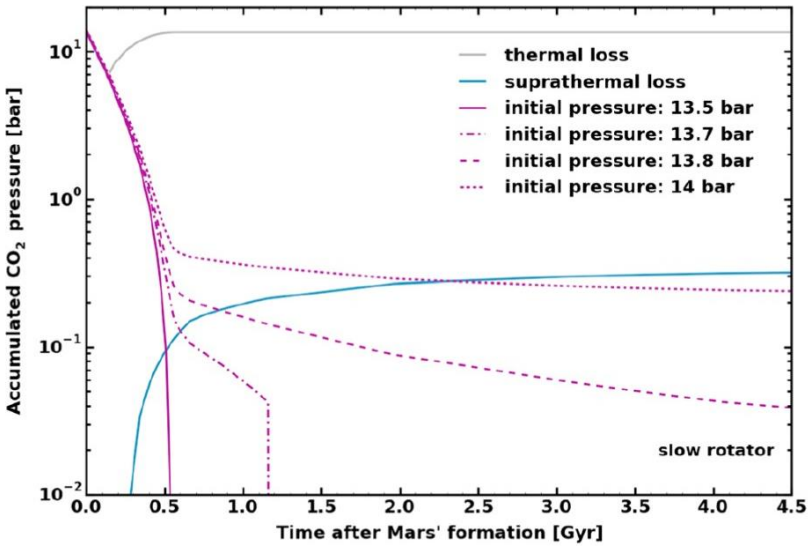
Cases per bin with change in sign of Bx, in % of observed cases, Xsc in [-3.2, -1.2]. Representation as seen from the Sun, in VBE reference frame. The solid circle indicates Venus, the dashed circle the model bow shock at terminator. Left: For inward IMF, θ < 90° and BxSW > 0; the initially positive BxSW value is changed to negative values on the right-hand side of the MS, which here is MS_{par}. Right: For outward IMF, θ > 90° and BxSW < 0; the initially negative BxSW value changes to positive values on the left-hand side, which here is MS_{par}.

ATMOSPHERIC ESCAPE FROM MARS

With a Monte Carlo model the escape of energetic (hot) O and C atoms from the Martian atmosphere was investigated during its history corresponding to 1, 3, 10, and 20 times the present solar EUV flux. The increase of the production rates due to higher number densities resulting from the higher EUV flux competes against the expansion of the thermosphere and

corresponding increase in collisions. The escape due to photodissociation increases with increasing EUV levels. For the escape via some other reactions, e.g., dissociative recombination of O_2^+, this is only true until the EUV level reaches 10 times the present EUV flux and then the rates start to decrease.

Furthermore, the results show that Mars could not have had a dense atmosphere at the end of the Noachian epoch (see figure below), since such an atmosphere would not have been able to escape until today. In the pre-Noachian era, most of the magma ocean and volcanic activity-related outgassed CO_2 atmosphere could have been lost thermally until about 4 Gyr ago, when nonthermal loss processes such as suprathermal atom escape became dominant.



Catastrophic outgassing of an initial steam atmosphere, related to a magma ocean, may have occurred after proto-Mars finished its formation within the first 10 Myr after the origin of the Sun. The surface pressure evolution resulting from thermal and hot (i.e., C, O) CO_2 escape of an initially outgassed CO_2 atmosphere between 13 and 14 bar are shown, if the young Sun was assumed to be a slow rotator. In the beginning of Mars's atmospheric evolution, thermal escape is much higher than hot atom loss. Only initial CO_2 atmospheres with surface pressures <14 bar, most likely reproduce the present CO_2 surface pressure level of about 7 mbar, if one assumes that the subsurface contains only negligible amounts of carbonates.

JUPITER & SATURN

Jupiter and Saturn, the two largest planets in our solar system, mainly consist of hydrogen and helium. They also have layers in their atmospheres with clouds consisting of ammonia, ammonium hydrosulfide and water, in which weather phenomena occur. Both planets are magnetized and rotate rapidly, leading to rotationally dominated magnetospheres, where strong sources of radio emissions are located.

JUNO

The main scientific goal of NASA's *Juno* spacecraft, launched in 2011, is to measure Jupiter's composition, gravity, and magnetic field, and to investigate its polar magnetosphere. IWF has calibrated the antenna system of the *Juno Waves* instrument.

JUICE

ESA's first Large-class mission *JUpiter ICy moons Explorer (JUICE)* is planned to be launched in 2022 and to arrive at Jupiter in 2030. *JUICE* will spend at least three years making detailed observations of the gas giant Jupiter and three of its largest moons, Ganymede, Callisto, and Europa. 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 2017, the Engineering Model was developed 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.

Finally, IWF is responsible for the antenna calibration of the *Radio and Plasma Wave Investigation (RPWI)* instrument. In 2017, a genetic algorithm was used in numerical simulations to find the antenna orientation with the best reception properties. As a result, the orientation of the radio antenna triad (three orthogonal antennas on the magnetometer boom) has now been fixed.

CASSINI

In 2017, the *Cassini* mission was in its final year. From November 2016 until April 2017 the spacecraft made ring-grazing orbits with periapsis passes close to the F-ring and apoapsis passes around Titan's orbit. A slight gravitational nudge by Titan on 22 April (last close Titan flyby) was used to change the periapsis to the unexplored region between Saturn's upper atmosphere and its innermost D-ring. *Cassini* performed 22 of these so-called proximal orbits during the following five months. Finally, on 15 September the spacecraft entered Saturn's atmosphere and burned up and disintegrated like a meteor.

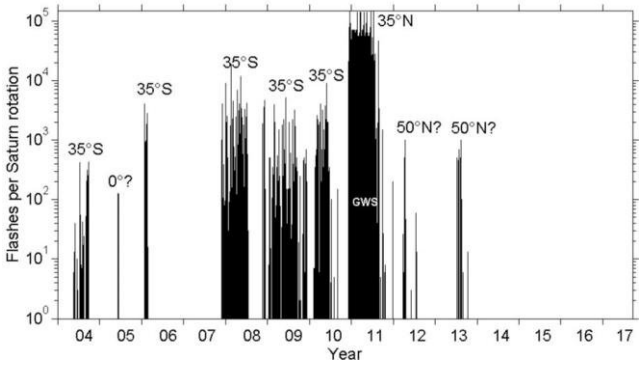
Illustration of Cassini entering Saturn's atmosphere. (Credit: NASA/JPL-Caltech).

During its 20 years in space (7 year cruise plus 13 years in 294 orbits around Saturn) *Cassini* has delivered 635 GB of science data, which to date have been investigated in almost 4000 scientific publications. More than 50 of them include scientists from IWF, who participated in the team of the *Cassini Radio and Plasma Wave Science (RPWS)* instrument.

LIGHTNING ACTIVITY ON SATURN

The radio emissions from lightning have been monitored by the *Cassini RPWS* instrument from 2004 until 2017. The figure below shows that Saturn lightning storms can last from a few days up to several months and that there were also long time intervals with no lightning activity. The latter was the case for the last four years of the mission, and the absence of lightning storms after October 2013 could be explained by a kind of convective inhibition state of the atmosphere after the large thunderstorm of 2010/2011, which was called the Great White Spot (GWS).

Besides sferics at high frequencies in the MHz-range, lightning is known to emit whistler waves at very low frequencies which propagate along magnetic field lines from the source to the observer. The scarcity of whistler observations by *Cassini* (only one reported event in the literature) can be explained by *Cassini's* trajectory, since the stormy regions at latitudes around 35° North and South are connected to low magnetic L-shells which were traversed by *Cassini* only during orbit insertion and the proximal orbits of 2017. However, an intense search for lightning whistlers led to the detection of only three tentative events during the proximal orbits. This is probably due to the absence of lightning storms in 2017 as shown in the figure below.



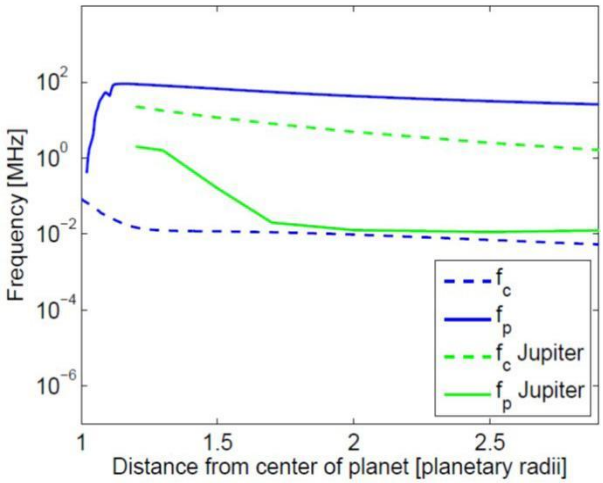
Lightning flash rate measured by *Cassini RPWS* as a function of time (years from 2004 to 2017). The latitudes of the thunderstorms on Saturn are also denoted in the figure.

RADIO PROPAGATION: JUPITER VS. HOT JUPITERS

A study of the plasma conditions in the atmospheres of the Hot Jupiters HD 209458b and HD 189733b and for an HD 209458b-like planet at orbits between 0.2-1 AU around Sun-like stars was performed. It was found that the environmental conditions are such that the cyclotron maser instability (CMI), the process responsible for the generation of radio waves at Jupiter, most likely will not operate at hot Jupiters.

Hydrodynamically expanding atmospheres possess extended ionospheres, which fill-up the whole magnetosphere. This makes the magnetospheric plasma density so large that the plasma frequency is much higher than the cyclotron frequency (see figure below). This prohibits the production of radio emission through CMI and also prevents the escape of radio waves. The structure of the upper atmosphere of gas giants around stars similar to the Sun

changes between 0.2 and 0.5 AU from the hydrodynamic to a hydrostatic regime. This results in conditions similar to Jupiter, with a region of depleted plasma between the exobase and the magnetopause where the plasma frequency can be lower than the cyclotron frequency. In such an environment, highly energetic electrons, accelerated along the field lines towards the planet, can produce radio emission. However, even if the CMI could operate the extended ionospheres of Hot Jupiters are too dense to let the radio emission escape from the planets.



Plasma frequency (solid blue line) and cyclotron frequency (dashed blue line) for HD 209458b for an equatorial surface magnetic field of 10^{-5} T as function of distance starting from the planetary transit radius along the equator. Solid and dashed green lines show the plasma and cyclotron frequency for Jupiter.

COMETS & DUST

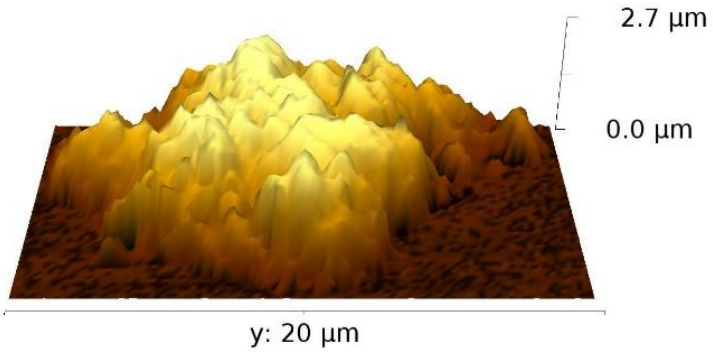
Comets and interplanetary dust are the remainders of the building blocks of the solar system, although dust can also be created by collisions of e.g. asteroids. *Rosetta's* successful mission at comet 67P/Churyumov-Gerasimenko (67P/CG) gave new life to the study of comets and is the starting point for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

ROSETTA

The outstandingly successful *Rosetta* mission carried out the most sophisticated investigation of a comet to date. Between August 2014 and September 2016, eleven instruments analyzed comet 67P/CG, five of which with participation of IWF. The institute was Co-I for the *Rosetta Plasma Consortium (RPC)*, the *Rosetta Lander Magnetometer and Plasma Monitor (ROMAP)*, the *Multi-Purpose Sensor (MUPUS)*, and the *Cometary Secondary Ion Mass Spectrometer (COSIMA)*. Furthermore, IWF held the PI-ship for the *Micro-Imaging Dust Analysis System (MIDAS)*, an especially developed prototype instrument dedicated to the first ever analysis of most pristine cometary dust at the micro- to nanometer scale.

MIDAS was the first spaceborne atomic force microscope (AFM) and the only one to collect, handle and analyze cometary dust particles. Their shapes and spread on the targets indicate different degrees of alteration on collection that are similar to those found by *Rosetta's* other dust analysis instruments. The collected particles were investigated by AFM, i.e. sampling their surfaces with a very sharp tip. The main outcome is the 3D topography that allows to access the surface structure of nearly pristine cometary dust. *MIDAS* data revealed that

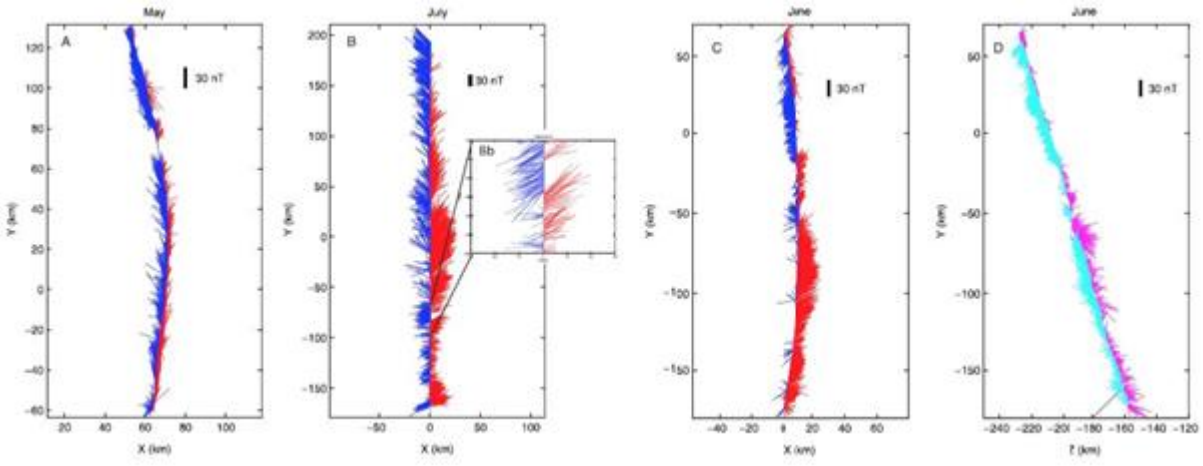
cometary dust particles at the nm to µm scale are all hierarchical agglomerates, independent of size or collection time. Larger, about 10 µm sized particles disintegrate into their next smaller constituents upon investigation, which is a proof of their agglomerate nature and a sign for higher particle strengths at smaller scales. Detailed analyses of subunit strength and sizes are currently ongoing. Pristine structural diversity of cometary dust is found in the arrangement of the agglomerates: Whilst most of them are composed of subunits packed densely enough to prevent transparency (figure below), a minority shows a low packing density that can be characterized by a fractal dimension of <2. The survival of those fragile particles has strong implications for the cometary formation and evolution.



3D view with overlaid color scale of a typical dust particle collected and imaged by *MIDAS*.

CURRENT SHEETS IN 67P/CG'S COMA

The *Rosetta Plasma Consortium (RPC)* data were used to investigate the presence of current sheets in the coma of comet 67P/CG. The interaction of the interplanetary magnetic field (IMF) transported by the solar wind toward the outgassing comet consists amongst others of mass loading and field line draping near the nucleus. The draped field lines lead to so-called nested draping because of the constantly changing direction of the IMF.



Hedgehog plots of the magnetic field for three subsequent flybys. The XY plane for 1–8 May (A) and 24–31 July 2015 (B). The XY (C) and YZ plane for 2–9 June. For (A), (B), and (C) the blue vectors show anti-sun-ward pointing magnetic field and the red vectors show sunward pointing magnetic field. For (D) the cyan vectors show downward pointing magnetic field and the magenta vectors show upward pointing magnetic field.

It is shown that the draping pattern is strongly variable over the period of one month. Nested draping results in neighboring regions with oppositely directed magnetic fields, which are separated by current sheets. There are strong rotations of the magnetic field (see figure above) with associated current sheets that have strengths from several tens up to hundreds of nA/m². Only for June 2015 (panel C) do the data show "classical" large scale, nested draping. For May (A) and July (B) the changes in field direction happen about every hour (inset Bb).

EXOPLANETARY SYSTEMS

The field of exoplanet research (i.e. investigation of planets orbiting stars other than the Sun) has developed strongly, in the past decade. Since the discovery of 51 Peg b, the first detected exoplanet orbiting a Sun-like star, about 3700 exoplanets, most of which 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 of which orbiting in the habitable zone of the cooler stars. However, super-Earths 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 two main exoplanet missions in which IWF is involved are *CHEOPS* and *PLATO*. The former will precisely measure the radii of already known planets to greatly improve their inferred density and hence provide a first characterization. The latter will instead 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. 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 2018, 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.

The *CHEOPS* team at the University of Bern assembles the instrument flight model in the clean room (Copyright: PlanetS).

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 2017, the Flight Model was manufactured and assembled. In cooperation with RUAG Space Austria and the test center at ESTEC the environmental tests at *BEE* level were completed successfully. Finally the unit was delivered to Bern for the mechanical and electrical integration with the *CHEOPS* optical system.

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 2017 were the development of the *RDCU* prototype and the design of the VHDL code for the FPGA. The electronics design and the layout for the prototype was completed and the PCBs were ordered. The FPGA design concentrates on a core for the SpaceWire standard supporting both protocols packet mode and so called RMAP (remote memory access protocol) up to 100 Mbps data rate. These designs were completed and validated.

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 atmospheres of short period extrasolar planets. The aim is to constrain atmospheric escape processes, which are key to understanding planetary evolution, and to 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.

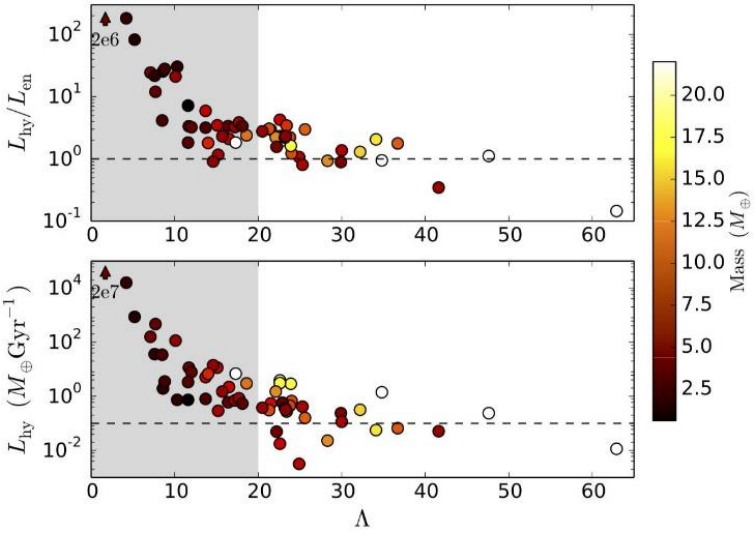
Artist's impression of *CUTE* above the Earth (Credit: University of Colorado, Boulder).

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

OVERABUNDANCE OF LOW-DENSITY NEPTUNE-LIKE PLANETS

The last years have seen an increasing number of detections of close-in, low-density planets. The existence, formation, and evolution of such planets are difficult to understand: their atmospheres should be characterized by very strong escape. It has been shown that planets for which Λ (the value of the Jeans escape parameter calculated at the observed planetary radius and mass, for the planet's equilibrium temperature, and considering atomic hydrogen) is smaller than 15-35 lie in the "boil-off" regime. This means that they experience extremely strong Jeans escape, which is driven by the atmospheric thermal energy and low planetary gravity.

To date 167 close-in, Neptune-like planets, for which both planetary radius and mass (mostly from transit timing variations) have been measured, are known. Upper atmosphere modeling of these planets shows that 25 of them (about 15%) are simultaneously consistent with the presence of H-dominated atmospheres and extremely high escape rates (see figure below). This constitutes a contradiction, since the hydrogen envelopes cannot be retained given the high mass loss rates. Instead, either hydrodynamic models overestimate the mass loss rates, transit timing variation measurements underestimate the planetary masses, optical transit observations overestimate the planetary radii (e.g., high-altitude clouds), or Neptunes have consistently higher albedo than Jupiter planets.



Top: Ratio between the hydrodynamic and energy-limited mass loss rates vs. the Jeans escape parameter Λ. The color scale denotes the planetary mass. The gray area marks the region with dominant extreme thermal mass loss rate. The labeled triangle denotes the mass loss value for the extreme case of Kepler-33c. Bottom: Hydrodynamic mass loss rate vs. Λ.

OTHER TELESCOPES

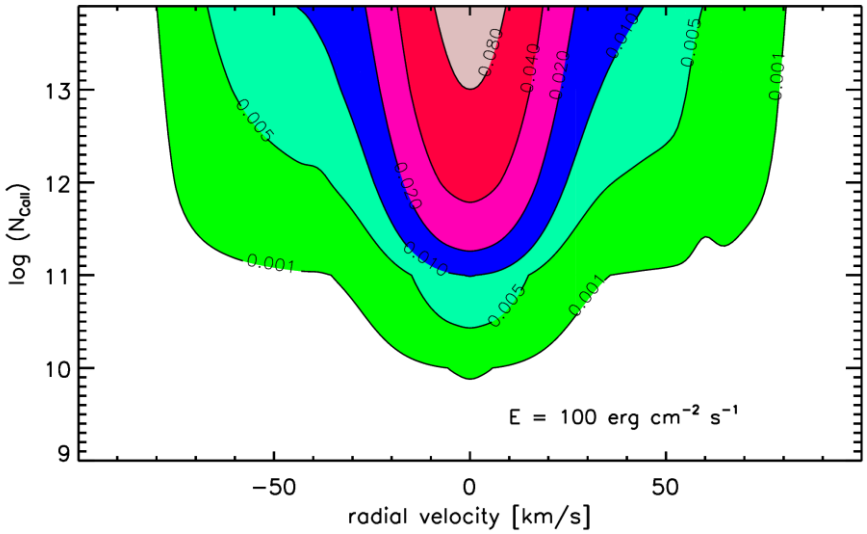
Members of the institute obtained 20 orbits with the *STIS* spectrograph of the *Hubble Space Telescope (HST)* to perform far- and near-ultraviolet transmission spectroscopy of the HD3167c mini-Neptune (5 *HST* orbits) and HD189733b hot-Jupiter (15 *HST* orbits), respectively. Further eight nights of observations were obtained with the *FORS2* instrument at the *Very Large Telescope (VLT)* at the Paranal site of the European Southern Observatory (ESO), in Chile. The majority of these spectroscopic observations, conducted during planetary transits, will be used to study the physical properties of the atmosphere of five close-in giant planets. A small part of the observations will be used to derive the orbital properties of a binary system composed of a late-type star and a neutron star, where the latter is the remnant of an historical Ca-rich supernova.

ISM ABSORPTION EFFECT ON STELLAR ACTIVITY MEASUREMENTS

Past ultraviolet and optical observations of stars hosting close-in Jupiter-mass planets have shown that some of these stars present an anomalously low chromospheric activity level. For the planet host WASP-13, observations have indicated that the anomaly is caused by absorption from the intervening interstellar medium (ISM). Synthetic stellar photospheric spectra were combined with varying amounts of chromospheric emission and ISM absorption. The effect of ISM absorption on CaII line core activity measurements by varying several instrumental (spectral resolution), stellar (projected rotational velocity, effective temperature, and CaII chromospheric emission flux), and ISM parameters (relative velocity between stellar and ISM lines, broadening b-parameter, and CaII ISM column density) have been studied in detail.

For relative velocities between stellar and ISM lines smaller than 30-40 km/s and for ISM CaII column densities larger than 1012, the ISM absorption has a significant influence on activity measurements (see figure below). Direct measurements and three dimensional maps of the Galactic ISM absorption indicate that an ISM CaII column density of 1012 is typically reached by a distance of 100 pc along most sight lines. In particular, for a Sun-like star lying at a

distance of 100 pc, the bias in the measured activity parameter is expected to be of about the same size as the typical measurement uncertainties. Correcting for the ISM absorption bias may allow one to identify the origin of the anomaly in the activity measured for some planet-hosting stars.

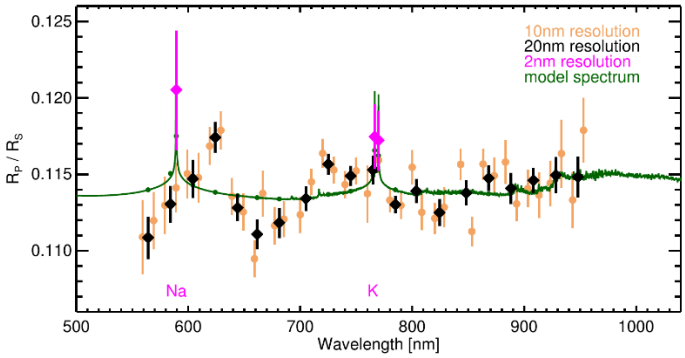


Color-coded difference between the activity parameter measured without ISM absorption and that obtained after adding varying amounts of ISM absorption (y-axis) as a function of the relative velocity between stellar and ISM lines. The total applied CaII chromospheric emission is 100 erg cm^{-2} s^{-1}.

STRONG NA/K ABSORPTION IN THE WASP-103B TRANSMISSION SPECTRUM

Transmission spectroscopy has become a prominent tool for characterizing the atmospheric properties of close-in transiting extrasolar planets. It is sensitive to the absorption features imprinted by the planetary atmosphere on the stellar light that passes through it during transit. In this configuration the planetary day-night terminator region is probed. WASP-103b is one of the hottest (2500 K) and most massive (1.5 Jupiter masses) planets so far studied with transmission spectroscopy. Furthermore, the planet orbits its host star at a separation of less than 1.2 times the Roche limit and is predicted to be strongly tidally distorted.

Three transits of WASP-103b have been observed with the *GMOS-North* spectrograph installed at the *Gemini North* telescope in Hawaii to look for the signature of Na, K, and H_2O in the planetary atmosphere. The data were analyzed making use of the "common noise model" approach, which allows to significantly reduce systematic noise. The three individual transmission spectra agree well among each other and reveal the presence of strong absorption features of both Na and K (see figure below). The lack of a strong scattering slope suggests also the presence of either a clear atmosphere or of a cloud deck at pressures higher than 10 mbar, below the region probed by the observations. These observations corroborate tentative trends between cloud occurrence and planetary properties, in particular the absence of observable clouds for highly-irradiated planets.



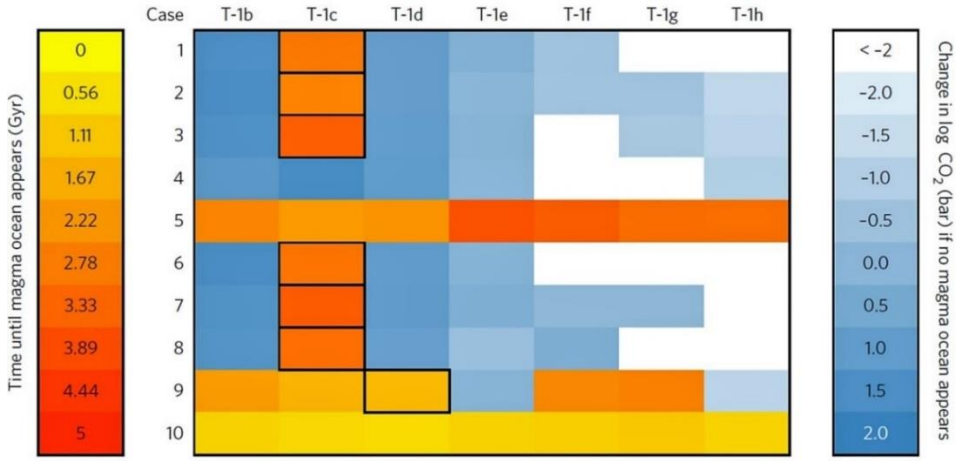
Transmission spectrum of WASP-103b as observed with *GMOS-North*. Measurements obtained with 10 and 20 nm wide bins are shown as brown filled circles and black squares, respectively. Measurements in 2 nm wide bins centered on the Na feature as well as on both components of the K feature are shown in magenta. The best fitting model transmission spectrum is shown by the green line.

STELLAR ROTATION VARIABILITY AND STARSPOT DIAGNOSTICS

The evolution of starspot activity patterns is controlled by a hitherto unresolved mixture of drivers from near-subsurface small-scale plasma flows up to giant turbulence deep inside the star. Manifestations of the related mechanisms were separated using the difference in stability of the starspot distributions on global and hemispherical scales in 1998 main sequence stars observed by the *Kepler* mission. Two main mechanisms were revealed: 1) the diffusive decay of long-living spots in activity complexes of stars with saturated magnetic dynamos, and 2) the spot emergence, which is modulated by gigantic turbulent flow in the convection zones of stars with a weaker magnetism. Subdiffusion in stellar photospheres was also revealed from these observations for the first time. These results open a way for investigation of stellar surface flows as well as deep convection, which is yet inaccessible through asteroseismology. A diagnostic diagram was developed, that allows the differentiation and selection of stars for future studies of starspot phenomenology, magnetic diffusion and deep mixing.

INDUCTION HEATING & MAGMA OCEAN FORMATION ON TRAPPIST-1'S PLANETS

M-type stars often host detectable rocky planets. Seven small planets were discovered in the M star system TRAPPIST-1, which has an observed magnetic field of 600 G. Electromagnetic induction heating (IH) as an energy source inside these planets was proposed for the first time. If the stellar rotation and magnetic dipole axes are inclined to each other, IH can melt the upper mantle and increase volcanic activity, and develop magma oceans below the surface. This process has important implications for habitability.

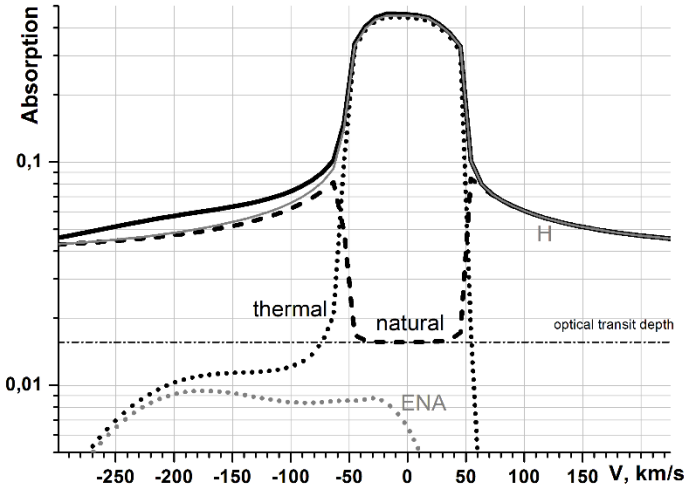


Different parameters such as initial thermal boundary layer thickness, viscosity pre-factor, surface temperature, and initial mantle temperature are studied. The yellow–red color coding refers to the cases where a magma ocean appears. Thick lines indicate cases where a magma ocean forms when induction heating is considered, but is absent without. The blue color scale shows the log increase in total outgassed CO_2 in bar with respect to an evolution without induction heating after 5 Gyr of thermal evolution for cases in which no magma ocean appears.

LYMAN-ALPHA ABSORPTION AT TRANSITS OF HD209458B

To shed more light on the nature of the observed Ly-α absorption during transits of HD209458b and to quantify the major mechanisms responsible for the production of fast hydrogen atoms (so-called ENAs) around the planet, a 2D hydrodynamic multi-fluid modelling of the expanding planetary upper atmosphere has been performed, driven by the stellar XUV and its interaction with the stellar wind. The model self-consistently describes the escaping planetary wind and the generation of ENAs due to particle acceleration by radiation pressure and by charge-exchange between the stellar wind protons and planetary atoms.

The calculations in a wide range of stellar wind parameters and XUV flux values showed that under typical Sun-like star conditions the amount of generated ENAs is too small, and the observed absorption at the level of 6-8% can be attributed only to non-resonant natural line broadening. For lower XUV fluxes, e.g., during activity minima, the number of planetary atoms that survive photo-ionization and are the source of ENAs, increases resulting in up to 10-15% absorption at the blue wing of the Ly-α line, caused by the resonant thermal line broadening (see figure below). It has been found, that radiation pressure has a negligible contribution to the production of ENAs and the corresponding absorption.



The absorption profile of Ly-α line (thick solid line) under the typical conditions by HD209458b and slow stellar wind. A decomposition of the total absorption onto the resonant thermal (black dotted) and non-resonant natural line broadening (black dashed) parts is shown. Gray dotted and gray solid lines represent the contribution to the absorption of ENAs and planetary atomic hydrogen, respectively.

OUTREACH

IWF is actively engaged in science education and public outreach. In 2017, many different groups and school classes visited the institute and were guided through the labs and the planetary garden.

On 1 March, BMWFW invited IWF to take part in "YO!TECH - Lust auf Technik". More than 300 highschool students had the chance to learn about job profiles and educational possibilities in technology and natural sciences. Among the eleven exhibitors, IWF presented a functional model of the *CHEOPS* telescope.

During summer time, seven high-school students performed an internship at IWF under the "Talente-Praktika" program of FFG. They worked on aurora, cometary surfaces and planetary materials, radio wave propagation, weather data, and VLF data analysis. In the framework of the "FEMtech" program of FFG, two young ladies from KFU Graz and TU Graz worked at IWF on meteorological time series and magnetospheric plasma physics.

IWF opened its doors on 29 September in honor of the Austrian Astronomy Days, offering a series of six lectures and a dedicated children's program (see image below).

Children answering questions about our solar system during the Austrian Astronomy Days at IWF.

IWF is partner in the "FFG-Talente-Regional" project "Freiflug - Die Geheimnisse des Fliegens". Its core is a travelling exhibition on aerospace for children and young adults, which was "launched" on 25 October at FH Joanneum in Graz.

On 9 October, ESA, IWF, and others celebrated 30 years of Austrian membership in Graz (see image below). IWF director Baumjohann participated in the round table "Space4Industry" and the institute presented its contributions to the *BepiColombo* mission.

IWF members at "30 Jahre ESA-Österreich - Eine Erfolgsgeschichte".

AWARDS & RECOGNITION

In September, IWF director Baumjohann was elected as a member of „Academia Europaea" and IWF group leader Rumi Nakamura into the „Board of Trustees" of the „International Academy of Astronautics".

MEETINGS

Since more than 30 years, top researchers from all over the world have come to Austria in the framework of the "Alexander von Humboldt Colloquium" in order to discuss recent topics in astronomy and space physics. Christoph Lhotka organized this year's conference, chaired by IWF and University of Vienna, took place in Bad Hofgastein, Salzburg, from 19 to 25 March.

From 24 to 26 July, the institute hosted the 5th *CHEOPS* Science Workshop at Schloss Seggau. The workshop, which saw 89 international participants, aimed at bringing together the community interested in the mission, providing information about its current status and preparing its scientific exploitation. The workshop was organized by Luca Fossati, in collaboration with the IWF exoplanet team.

Wolfgang Baumjohann served as Vice Director and chair of the Program Committee of the Summer School Alpbach, which took place from 18 to 27 July and was dedicated to "The Dusty Universe". Every year, 60 students and about 25 lecturers and tutors from among ESA's member states are invited to this meeting.

In addition, M.Y. Boudjada, G. Fischer, G. Kargl, M. Lendl, C. Möstl, and R. Nakamura were members of scientific program and/or organizing committees at three international conferences and/or workshops.

PUBLICATIONS

For refereed articles, proceedings and book chapters, books and special issues, oral presentations, and posters please refer to the ”Publications” menu on www.iwf.oeaw.ac.at.

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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.

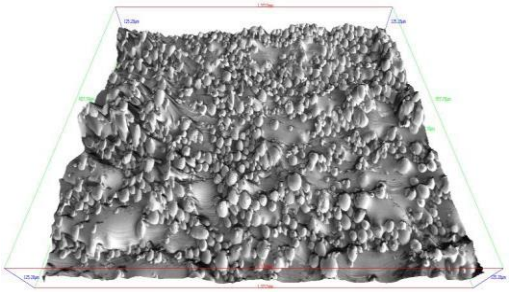
AAC new facilities at TFZ in Wiener Neustadt (Left: hall and labs with offices)

In frame of the ***Space Materials Testhouse*** for ESTEC several studies on material for space were performed. One study targeted the extension of the cold welding expertise from general testing of coatings / materials to avoid cold welding towards a test procedure that simulates "life" of hold down contacts, showing that solid lubricants in combination with proper surface treatments can be reliable solutions. A new initiative was started on stress corrosion cracking on hard chromium steels, but also on the influence of surface treatments on austenitic and PH steels. Several new kinds of materials made by additive manufacturing techniques were tested too.

A detailed investigation on SCC-effects on welded tubings was done in cooperation with Magna-Steyr Aerospace. MAGNA develops lightweight cryogenic feed lines for launcher propulsion systems made from Al-alloy, which offer a mass saving potential of ~30%. Compensations elements make the use of Al-alloy/steel transition joints necessary, which were tested at AAC in the frame of Future Launchers Preparatory Programme under ESA material testing contract. In this study joints between tubes made of AISI 316L and EN AW6061 produced using friction welding (FW) technique have been evaluated with respect to stress-corrosion cracking (SCC) and microstructural characteristics. The determination of the susceptibility to SCC has been performed according to ESA standard ECSS-Q-70-37C at a stress level of 75 % of the yield strength Rp0.2 using a specific fixation designed by AAC. The FW joints inclusive heat-mechanically affected zones (HMAZ) have been characterised by means of Light Microscope (LM), High Resolution Scanning Electron Microscope (HRSEM) and Vickers hardness measurements.

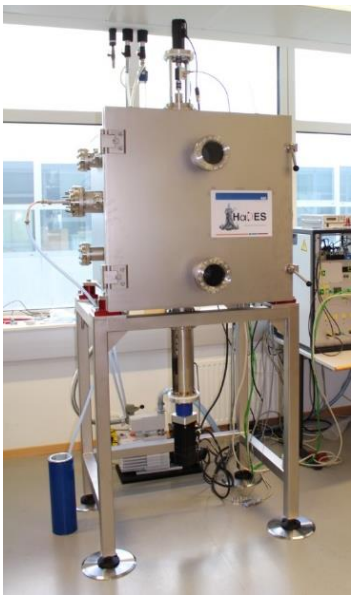
Additive Layer Manufacturing

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), Airbus DS, The main **objective** of one ESA-funded activity is to propose and evaluate surface finishing techniques for parts made by the AM technologies providing the highest geometrical accuracy, i.e. SLM and EBM, in order to derive guidelines for future applications.



High roughness after ALM-processing

Gear test device HaDES (**Ha**rmonic **D**rive **E**xperimental **S**etup)



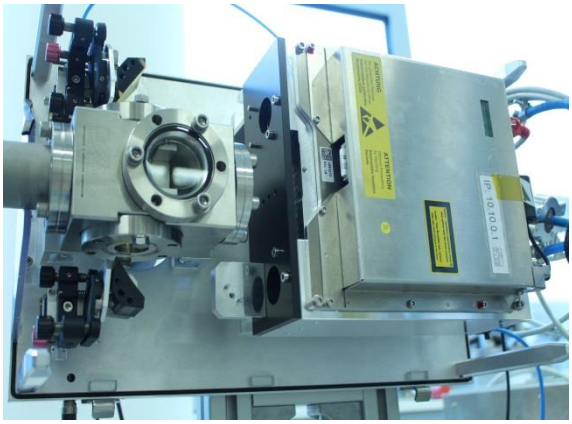
HaDES

Within its development activities on solid lubricated Harmonic Drive ® Gears, AAC has developed and implemented a new device for testing of Harmonic Drive ® Gears. The new test facility is named HaDES (**Ha**rmonic **D**rive **E**xperimental **S**etup). It enables to test harmonic-drive ® gears in a very efficient way: gear sets may be inserted to an existing "standard gear box", several ones being owned by HDAG and AAC and fitting to test facilities in both companies. This enables to test lubrication concepts under certain load cases in a very efficient way, and early states of projects so that EMs can later take benefit. Environments at HaDES may vary from vacuum, non-aggressive gases (e.g. CO_2) under controllable pressures (e.g. to simulate Martian environment) or to air with controlled humidity. The tests can be performed at temperatures from -150°C to +200°C. Besides simple lifetime testing, several characteristics can be measured "in-vacuo" at HaDES, like stiffness, transmission accuracy, NLDBT. The device is fully PC-controlled. Control

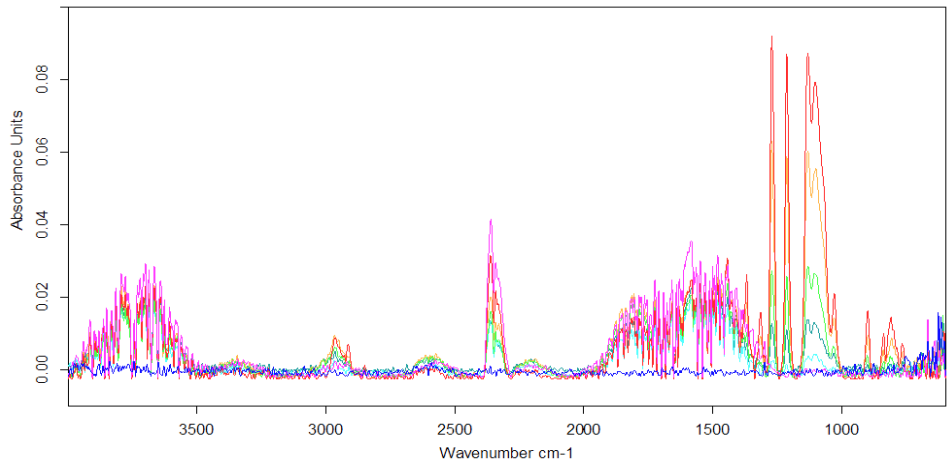
parameters, e.g. sliding distance, motion profiles (unidirectional, oscillating) can be selected. On-line-data acquisition offers automatic calculation of efficiency or stiffness.

Advanced In-situ/Real Time on Ground Contamination Monitoring

For space applications the functionality of assemblies under high vacuum conditions is an important field of research. The functionality of assemblies and materials may change under space conditions – that means vacuum and a wide temperature range – and has to be investigated in detail before use in space. An important aspect is the outgassing and/or sublimation of solid parts: porous materials like polymers may contain volatile solvents which stay inside as long as the ambient pressure in air is acting. But they are released as soon as those materials are exposed to vacuum. This effect is called outgassing. It's called sublimation if the material itself is ejected. Both effects are the worse the higher the temperature of the materials gets.
The problem of this effect is twofold: on one hand the materials may lose their functional properties, but even more dangerous is that the evaporated molecules may re-condense on other sensitive components, for example optical parts like lenses. The worst case is a failure of whole instruments.
The main goal of the project ConMon was the development of an analysis method for qualitative and quantitative in-situ measurement of molecular organic containment (MOC) under high vacuum conditions. It is state of the art to use a quartz crystal microbalance (QCM) for quantitative determination of condensing mass and mass spectrometers to determine the molecules in the residual gas. There is no method to determine on surfaces the amount of condensed mass and the molecular nature simultaneously. Not all species being present in the residual gas condense on surfaces, therefore, a method for on-line inspection of the surface itself is necessary. Following a trade-off, a combination of a TQCM and Fourier transform infrared reflection absorption spectroscopy (FT-IRRAS) was chosen. While the QCM measures the quantitative amount of condensed mass on its surface, the FT-IRRAS will be used for on-line analysing the type of MOC on the surface of the QCM. The goal of this ESA funded project was the development and testing of a fully stand-alone measurement module, called ConMon FT-IRRAS module. The picture on the right side shows the module, which was tested successfully and is in use for qualifying the sublimation behavior of materials for space applications.



ConMon FT-IRRAS module



Chronological sequence of IR spectra over 48 hours (starting with blue=no contaminants, ending with red=organic contaminants on the QCM-surface)

AAC has continued it's activities in development of new composite materials for ***dry lubrication*** of mechanisms. Following recent problems with existing self lubricating PTFE based materials used in cages in ball bearing, an action plan was established by ESA ("***duroid replacement***"). Within that, AAC together with Ensinger Sintimid GmbH have recently succeeded in developing a composition based on European raw materials. New compositions were manufactured and tested up to ball bearing tests. It could be confirmed that modifying the composition, the torque can be decreased even beyond the state of the art (PGM-HT).

Cage made of new PTFE composite

Sales

ESA Share: ~0.4 MEUR

Space Industry:~1 MEUR

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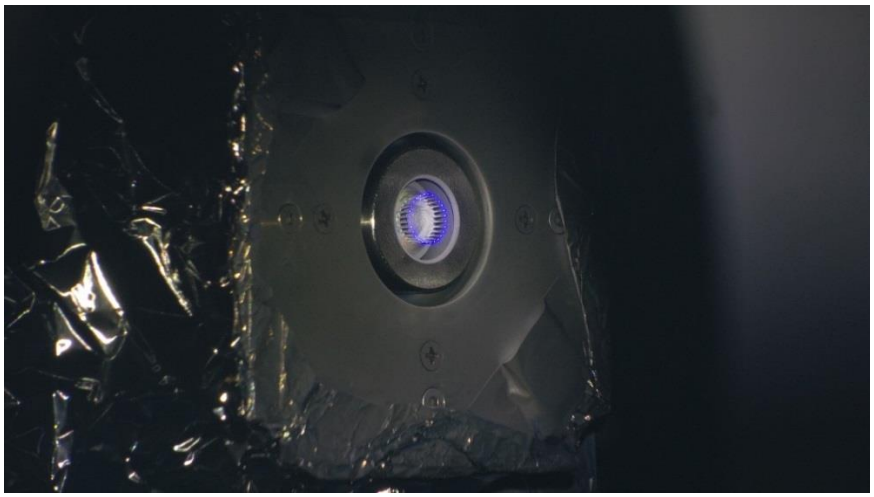
3.3 ENPULSION GmbH

ENPULSION ist ein Spin-out der Fotec GmbH zur Kommerzialisierung der FEEP Satellitentriebwerkstechnik. Die verwendete Flüssigmetall FEEP Technologie wurde im Rahmen langjähriger Entwicklung für ESA Wissenschaftsmissionen etnwickelt und qualifiziert. Baseriend auf dieser Technolgie wurde ein miniaturisiertes Triebwerk zum Einsatz auf Klein- und Nanosatelliten entwickelt, das klein genug ist, mit Treibstoffreservoir und Hochspannungselektronik in einen Würfel mit 10cm Seitenlänge zu passen: der IFM Nano Thruster.



FEEP Ionenemitter während der Ionenemission

Der IFM Nano Thruster wurde im ersten Qartal 2018 erfolgreich im Orbit getested. In dieser Mission fliegt der erste IFM Nano Thruster an Board eines amerikanischen, kommerziellen Kunden. Im Rahmen der ersten Tests konnte neben der problemlosen Funktionsweise aller Subkomponenten des Ionentriebwerkes auch der Schub anhand von Veränderuneng der Umlaufbahnhöhe verifiziert werden.

IFM Nano Thruster basierend auf FEEP Technologie

Modularität, kompetitive Triebwerksleisung vor allem bezüglich sehr hoher Treibstoffseffizienz und einfache Integration des Triebwerkes aufgrund des metallischen Treibstoffs haben in der Industrie großes Interesse an dieser Technologie entfacht. Für 2018 sind die Starts von weiteren 21 IFM Nano Triebwerken auf sechs Satelliten von vier verschiedenen kommerziellen Kunden geplant.

Zusätzlcih zum sehr erfolgreichen IFM Nano Thruster entwickelt Enpuslion derzeit gemeinsam mit Fotec eine skaliertes Treibwerk für größere Satellitenklassen, mit insgesammt 16 Ionenemittern die in parallel betrieben werden um höhere Schübe zu erreichen.

Sales: ***0.2 MEUR***
ESA Share: ***MEUR***

Contact:

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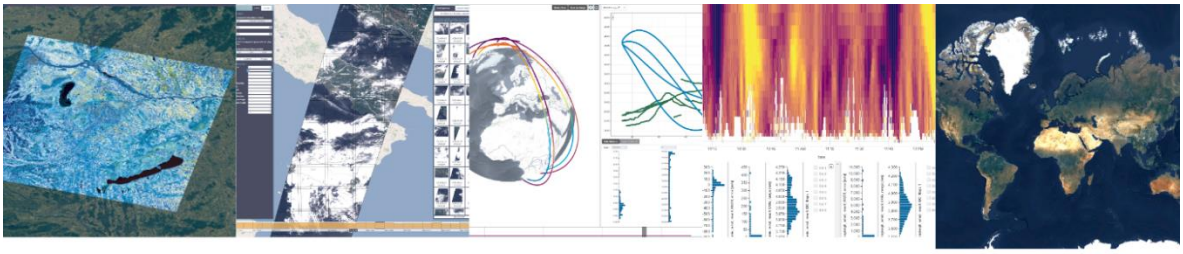
Tel: +43(0)2622 4170121-200
E-mail: alexander.reissner@enpulsion.com
Web:www.enpulsion.com

3.4 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 be-ing 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 2017 highlights are reported.

Earth Explorer Data Online

The visualisation and manipulation of multidimensional EO data is one specialization areas in which EOX has been conducting partially leading a number of activities. 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.

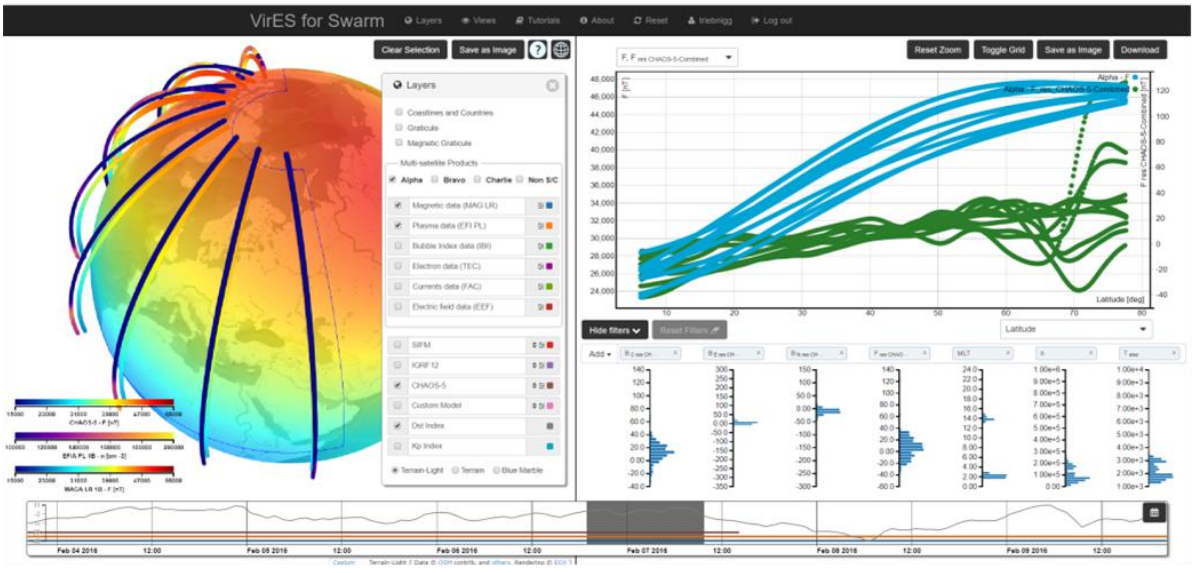


Figure: Web User Interface of VirES for Swarm Service

The service is 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). EOX is currently the sole committer to the code repository (hoping that other developer will be joining soon). The site is hosted on the servers of EOX. It is worth to mention a few of the many necessary steps and measures performed to evolve from prototype system to operational service: Continuous testing and deployment set-up; Multiple-server operations, failover, and load balancing configuration; OAuth authentication with major social providers.

The successful development and operation of VirES for Swarm has led to an extension contract covering also the forthcoming Earth Explorer “wind mission” Aeolus (launch date August 2018).

Open Geospatial Data

Sentinel-2 cloudless (https://s2maps.eu) is the first global, (almost) cloud-free mosaic of the world

Figure: Sentinel-2 cloudless – https://s2maps.eu by EOX IT Services GmbH (Contains modified Copernicus Sentinel data 2016 & 2017)

Almost 250 Terabyte of Sentinel-2 data were crunched fully automated pixel by pixel using EOX homebrew software combined with further Open Source tools. Supported by the processing power of Amazon Web Services (AWS) and catalogue services by Sinergise, the EOX team was able to craft this cloudless map of the world in a fast and inexpensive manner.

In the first days after Sentinel-2 cloudless was published towards end of August 2017 (see Figure above) its Web site was loaded by over hundred thousand of unique visitors per day.

Thanks go to the European Commission and the European Space Agency for the free, full, and open Sentinel-2 data. Sentinel-2 cloudless by EOX IT Services GmbH is licensed under a Creative Commons Attribution 4.0 International License. Everybody is invited to freely use the provided service endpoints (WMTS orWMS). Data may also be downloaded either as

rendered tiles from these services or as source GeoTIFFs from the AWS S3 bucket eox-s2maps in the eu-central-1 region.

"**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.

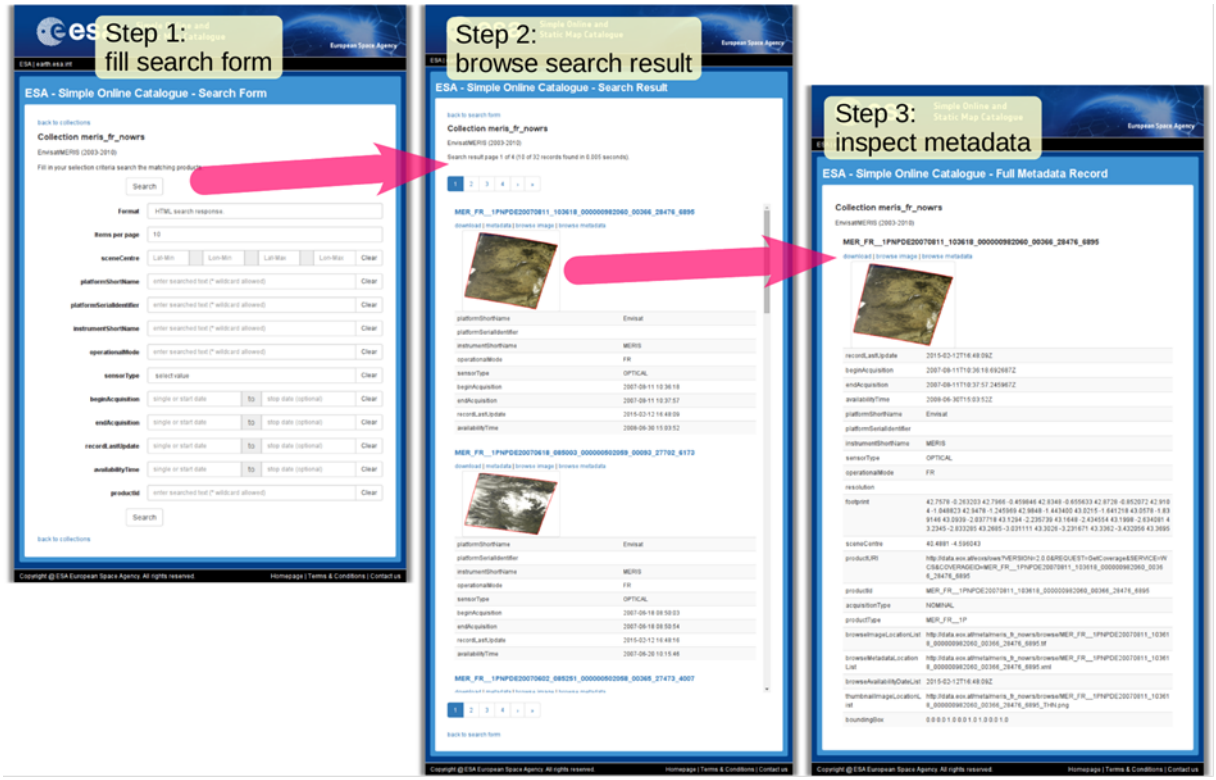


Figure: Simple On-line Catalogue

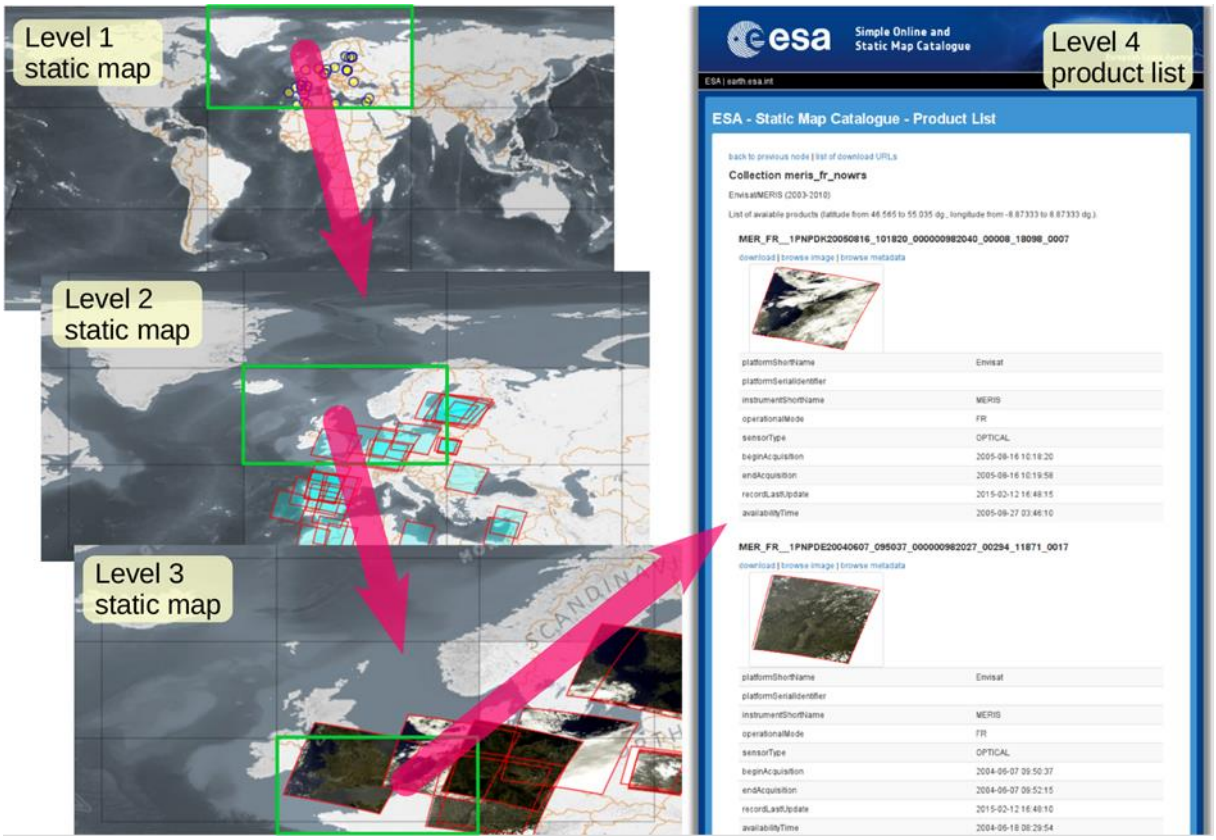


Figure: Static Map Catalogue (principle)

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.

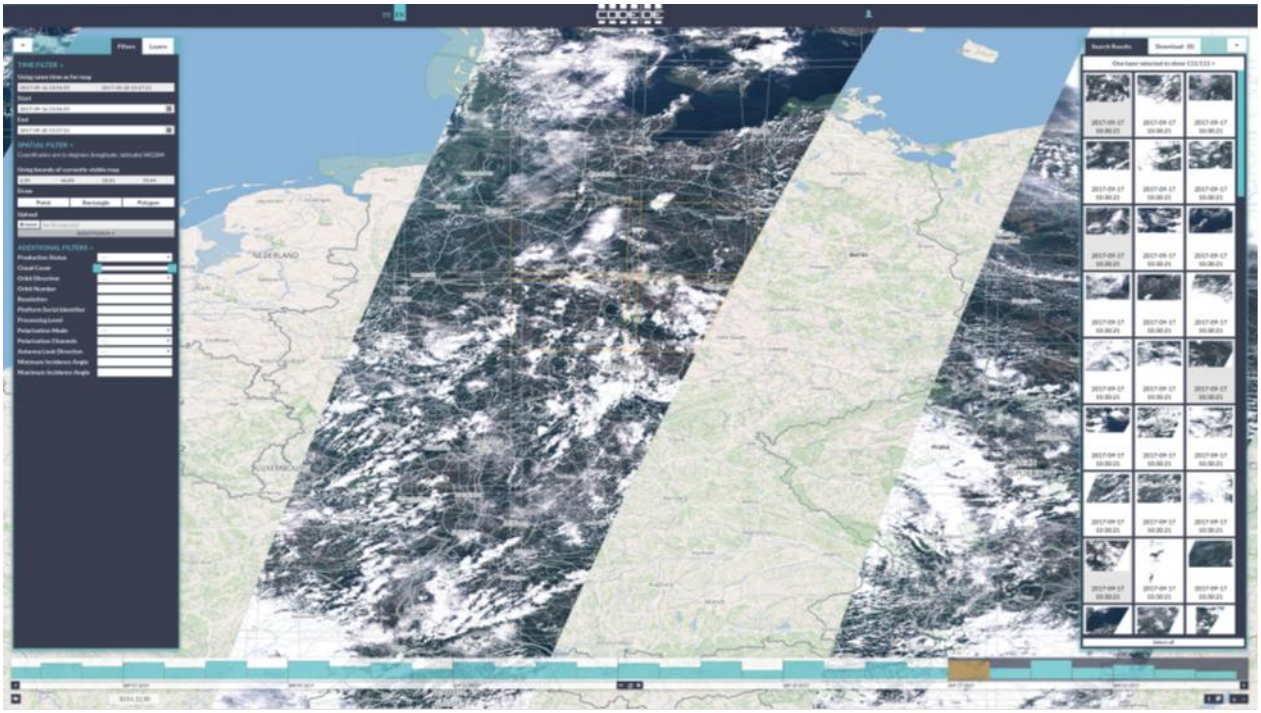


Figure: EOxC client for Sentinel-2 catalogue and map services provided by EOxServer

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 downloading large volumes over the network and spending non-research time on developing ICT tools, sourcing data, etc.

As a major highlight in 2017 EOX has been successfully selected as subcontractor in the Copernicus DIAS consortium 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: ***0.84 MEUR***
ESA Share: ***0.76 MEUR***

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3.5 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

Activities in the field of Electric Propulsion were focused on the IFM Nano thruster, which has been developed as a commercial product for small satellites. This integrated ion propulsion system fits into a volume of less than a single unit CubeSat. In 2017, the first flight model has been manufactured to be flown on an in-orbit demonstration mission, supported by the ESA IOD program ATLAS. Activities included an extensive test campaigns on proto-flight model level, including efficiency mapping of all subsystems and the validation of the neutralization strategy. The results show that the IFM Nano thruster design is fully functional and provide an outlook on the performance to be expected during in-orbit operation.

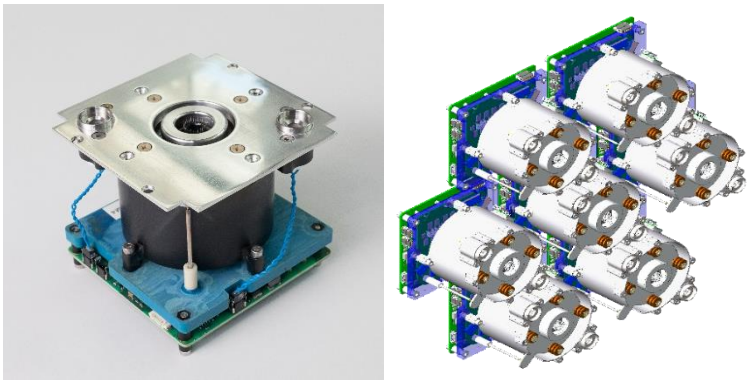

Figure: The IFM Nano thruster (left) and a cluster of individual thruster modules (right).

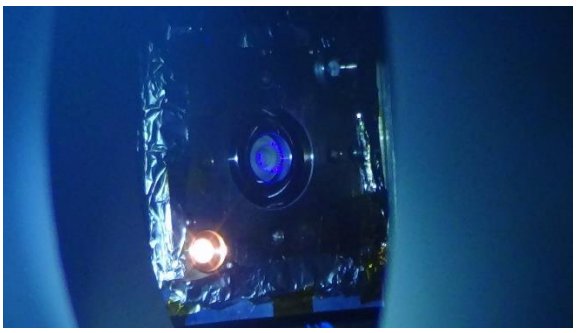

Figure: Picture taken during the IFM Nano thruster IOD acceptance test.

The conclusion from these tests allowed to finalize the design for the upcoming flight missions of the IFM Nano thruster in 2017. To commercialize this product on the market, a spin-off company has been founded in 2016. More information on this can be found on www.enpulsion.com

Energy Systems

FOTEC and the FHWN are engaged in several activities to develop future energy storage and conversion technologies for satellites. For one, an activity concerned with a combined hydrogen and heat storage solution targeted at fuel cell systems in telecommunications satellites is still ongoing, with an extension of the hydrogen storage capacity of the facility happening in 2017. In addition, FOTEC is part of a consortium investigating challenges related to the design of a reservoir for the transport of hydrogen. Furthermore, FOTEC participates in a system study investigating the feasibility of thermoacoustic electricity generators for telecommunication satellites.

Additive Layer Manufacturing (ALM)

The Clean Space activity 'Surface Engineering for Parts Made by Additive Manufacturing (Step 1) – SEfAM' has started in 2016. The aim is to investigate the impact of different surface finishing techniques on AM parts and to identify suitable surface finishing scenarios for Aluminium (AlSi10Mg), Titanium (Ti6Al4V) and Stainless Steel (316L). Aerospace and Advanced Composites (AAC) GmbH is the prime contractor and FOTEC is involved as subcontractor of AAC. It is planned to close the project by the end of 2018.

In November 2017 another ESA activity with FOTEC participation has been started. 'SME4ALM' is a 12 months project helping SMEs such as RHP Technology GmbH (Seibersdorf, AT) to increase the majority of their Additive Manufacturing capabilities. RHP uses plasma-arc welding for manufacturing parts out of Titanium alloy Ti6Al4V. FOTEC is involved for tactile geometry measurements and heat treatment (stress relieve annealing).

In June 2018 another RF related activity 'Development of one single part integrating waveguide filter, bends, coupler, supporting structures by Additive Manufacturing' in cooperation with TESAT Spacecom (Prime contractor, D) and Lithoz GmbH (Vienna, AT) will start.

Additive Manufacturing using Mars or Moon soil

Launch mass is a very important cost and complexity driver in space missions. To minimize launch mass of missions to extra-terrestrial bodies, it would be useful to use resources available at the destination instead of bringing these resources from Earth. This concept is called In-Situ Resource Utilization (ISRU). For example, it would mean creating habitat structures or spare parts from local soil or creating propellant from the Mars atmosphere.

In 2017, FOTEC successfully concluded an activity investigating approaches for creating structures like walls or support frames from Mars or Moon soil (regolith). A novel process using regolith and a binder liquid was developed from ideation to technical demonstration at TRL 3, with small sample structures having been printed. The results have been published in *C. Buchner et al., A new planetary structure fabrication process using phosphoric acid, Acta Astronautica 143 (2018) 272–284*.

3D-printed reduced-scale ISRU fabrication demonstrator structures

Sales: ***2.6 MEUR***
ESA Share: ***1.2 MEUR***

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3.6 GeoVille Information Systems and Data Processing GmbH

WHAT WE DO

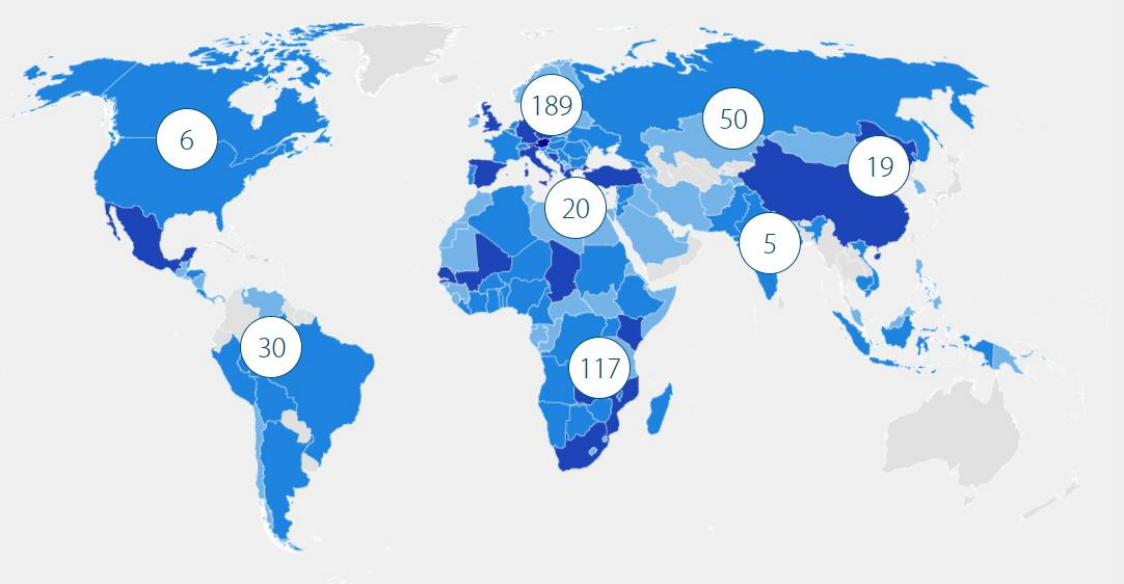
We at GeoVille do the spatial job through satellite's eye and deliver quality controlled geo-information for geographic accounting. Simple monitoring and customized geoinformation solutions for comprehensive applications.

Our services provide geo-information solutions for the following sectors:

OUR CUSTOMERS

Since its foundation in 1998, GeoVille has successfully carried out more than 440 projects in over 130 countries worldwide. GeoVille is an expert SME company providing satellite derived Earth observation and geo-information products and services in a user-friendly way to end users.

International & Transboundary	**International Development Banks**	**National & Regional Authorities**	**Private Sector**
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)

PROJECT HIGHLIGHTS IN 2017

THE AUSTRIAN SPACE APPLICATIONS PROGRAMME

VegetationDynamics4.0 - Towards automatized, scale independent, high resolution, high temporal dynamic vegetation water content monitoring 4.0 (ASAP 13)

VegetationDynamics4.0 aims at analysing the capacities of Sentinel-1 cross-polarized (CR) data for monitoring vegetation water content, its relationship to Sentinel-2 based vegetation indices, ASCAT VOD and in situ measurements of vegetation condition (height, water content, biomass). The proposed activities should lead to scientific evidences for multi-scale indices of vegetation water content.

Contract Value: 170K €

QuinJunSAT (BeyondEurope)

QuinJunSAT (QuinJun, Chinese for Crowd), shall improve the capacity of crisis managers before, during and after disaster events through an innovative approach, in which EO and crowdsourced information are automatically integrated to obtain quick response and accurate assessment information of damages.

Contract Value: 190K €

ESA EO APPLICATIONS

AgeSpot (ESA Kickstart Activities)

Within AgeSpot a new generation of population dynamics modelling was developed that transforms high resolution satellite Earth observation (EO) data into blueprints of where age groups live and significantly improves

existing census data. EO derived land use and population density data was applied with state-of-the art demographic and econometric modelling techniques.

Contract Value: 30K €

Earth Observation for the Sustainable Development Goals (EO4SDG)

The EO4SDG 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. The aim of the project is to maximise the contribution of EO data to the 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.

Contract Value: 90K €

Large Scale Earth Observation EO4SD - Exploitation Activities for International Development Initiatives, Agriculture and Rural Development

The project EO4SD Agriculture and Rural Development demonstrates to International Financial Institutions (IFIs) that the effectiveness of their technical and financial investments in developing countries to reduce poverty and increase economic growth, can be measurably enhanced by using EO based services; and to increase the uptake and usage of EO data and information at all stages of the project/programme cycle. The project aims at defining which EO-based information is most needed and how it can be used in Official Development Assistance (ODA) activities and working practices, providing a cost-benefit analysis based on the demonstrations and uptake assessments. GeoVille contributes to the thematic areas of Agriculture and Rural Development by providing products such as land cover and land use in agricultural ecosystems, drought indices, land surface parameters and supply chain assessments to support sustainable agricultural and rural development planning.

Contract Value: 380K €

Large Scale Earth Observation EO4SD - Exploitation Activities for International Development Initiatives, Water Resources Management

The EO4SD is an ESA initiative with the objective to achieve a step increase in the uptake of satellite based information in the International Financial Institutes (IFIs) regional and global programs, aiming at a more systematic data user approach in order to meet longer-term strategic geospatial information needs in the individual developing countries as well as international and regional development organizations. GeoVille contributes to the thematic areas of Water Resources Management. The successful implementation and monitoring of Integrated Water Resource Management (IWRM) initiatives requires access to reliable data and information on water related issues. GeoVille provides products such as monthly surface water monitoring, soil erosion potential and vegetation dynamics.

Contract Value: 400K €

EU – COPERNICUS OPERATIONS

Copernicus Land Monitoring Services (LMS) - 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, GeoVille was responsible for the production of a variety of essential high-resolution datasets (at 20m/100m spatial resolution) including the main land cover types such as artificial surfaces, forest areas, grasslands, wetlands and permanent water bodies as well as small woody features. For the Copernicus Local Land Monitoring Service GeoVille supports the production of even more detailed information focusing on specific types of hotspots, namely: Riparian zones and the Natura 2000 family of products for the reference year 2012 and 2018.

Contract Value: 3.900K €

Copernicus Sentinel-2 Global Mosaic (S2GM) (EC Copernicus Land Service)

The overall objective of the S2GM Service is to provide global mosaic data of atmospherically corrected reflectance from Sentinel-2, as input to further scientific and commercial applications. These mosaics shall be Analysis Ready Data (ARD), which refers to satellite data that can be readily used also by non-experts, because typical pre-processing and correction steps have been applied and because data and meta-information are provided in a common format.

Contract Value: 540K €

EU – H2020

LandSense - A Citizen Observatory and Innovation Marketplace for Land Use and Land Cover Monitoring

The LandSense project develops an innovative citizen observatory in the field of Land Use Land Cover (LULC), which collects data both actively (through citizens) and passively (from authoritative, and open access sources) and integrates them to provide valuable quality-assured in-situ data for SMEs, larger businesses, government agencies, NGOs and researchers.

Contract Value: 350K €

EO-VAS - Earth Observation Adding Value Services

The EO-VAS project reshapes EO value chains by breaking “downstream” components and significantly simplifying developments and deliveries of EO Adding Value Services. The major technological delivery of the project is an EO toolset, that is seamlessly connected with the Copernicus midstream component, exploiting free and open

access to Sentinel data. Furthermore, the EO-Toolset provides users with a high level of pre-processed data (Level 2), suitable for immediate time-series analysis and delivers free-of-charge cloud solutions.

Contract Value: 890K €

Perceptive Sentinel

The Perceptive Sentinel project will deliver a platform - an intermediate EO service which will allow seamless access to highly pre-processed data. Thereby it will provide: i) modeling and publishing capabilities, ii) design, exposure and exploitation of EO-processing chains, iii) forecasting, monitoring and historical analysis in different domain fields and iv) multi-temporal and multi-spectral EO-Data and Non-EO Data modelling.

Contract Value: 440K €

EU – EUROPEAID

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

The objective of the LULUCF project is 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 €

INTERNATIONAL ORGANIZATIONS

Liberia Land Cover and Forest Map (World Bank)

The project includes a comprehensive study and analysis of Reducing Emissions from Deforestation and Degradation (REDD) for developing Liberia's national REDD strategy for sustainable management of forests, as well as assist Liberia with the development of a Monitoring Reporting and Verification (MRV) system that will track the temporal and spatial changes in forest cover and associated drivers of deforestation and degradation.

Contract Value: 200K €

São Tomé and Príncipe - Adaptation to Climate Change Project (World Bank)

The São Tomé and Príncipe project has the objective of increasing the adaptive capacity of

coastal communities to the impacts of climate variability and change. Key issues are the assessment of the impact of climate change on specific areas of interest at the coasts of Sao Tomé and Príncipe. The project aims at generating coastline/shoreline maps for the selected locations in São Tomé and Príncipe.

Contract Value: 140K €

AUSTRIAN CUSTOMERS

Clutter Data – Supporting the telecom sector (T-Mobile)

GeoVille was commissioned to produce clutter data for T-Mobile Austria covering entire Austria and the border areas of its neighbourhood countries with 11 classes at 20m resolution. Our customizable, end-to-end production workflow, covering all aspects from data acquisition to final product validation, allowed us to service this request within a short period of time and with an accuracy and precision that more than satisfied user requirements.

Contract Value: 80K €

Sales: ***4.9 MEUR***
ESA Share: ***1.3 MEUR***

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3.7 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.

A) Communications & Navigation Technologies

a. DESIGN AND VERIFICATION OF ANTENNA TRACKING SYSTEM FOR Q/V BAND HUBS

The antenna tracking system is an important element of current satellite communication systems operating at C, Ku, K and Ka band. It will also be an important element in the Q/V-band, which is, for instance, foreseen for the feeder link of future broadband satellite services.

New space communication missions like GEO SatCom Q/V band systems and Ka band systems operating from non-GEO orbits (i.e. LEO orbits for Earth Observation Satellites, MEO satellites or HEO orbits for communication services with polar regions) pose issues on antenna tracking systems, which can be more critical than experienced with current systems.

Especially at Q/V band, the tracking system will have to cope with atmospheric propagation effects which are more severe than those experienced at K and Ka band. These effects include an increase of clear air (i.e. gaseous), rain and cloud attenuation, and stronger scintillations caused by tropospheric turbulence.

Furthermore, propagation issues can become relevant also in the case of a ground station for a satellite in a non-geostationary orbit, where the propagation effects are enhanced by the long propagation path along the atmosphere. In addition at low elevation angles refractive effects, multipath, de-focusing and ray bending/deviations can become relevant. In the case of non-GEO satellites the tracking system has to cope with rates of changes of the signal that are higher than in the case of GEO satellites. This is due to the fact that signal dynamic results from the combination of atmospheric fade slopes with variations of the free space loss due to the variable link geometry.

Therefore, the antenna tracking system for satellites operating at Q/V-band has required a specific development and optimization. This optimization had taken into account propagation effects, orbit parameters and all the key elements of the tracking system. This includes the type of tracking algorithm (step track, orbit prediction tracking, mono-pulse, program track) along with selection of the key parameters of these algorithms. Furthermore, the ground station design in terms of antenna, RF front end or mechanical subsystem is used for the optimization as well.

The antenna tracking simulator developed in this project (figure) permits the design and verification of the performances of the antenna pointing control unit taking into account all the contributions to the pointing error, e.g. the time response of the servo mechanism, propagation effects and signal noise in the tracking receiver. Also, the simulator incorporates an orbit generator in order to support the design for both GEO and non-GEO missions. Furthermore, assessment of the losses of a potential communication service with respect to the tracking system is supported by the simulator.

The teams of JOANNEUM RESEARCH and VERTEX Antennentechnik, together have significant experience in the fields of antenna tracking systems, ground station design, atmospheric propagation and satellite communication.

In 2013 a QV-band ground station in Graz, Austria, dedicated to the Alphasat TDP5 communication and propagation experiment, commenced operation under ESA contracts.

Since the communication antenna is a tracking antenna at Q/V-band, we were able to verify the simulator results, e.g. in terms of pointing losses, directly on the Alphasat TDP5 communication antenna taking into account the Q/V-band channel conditions measured by the Alphasat TDP5 propagation experiment. In addition, this allowed

the verification of the atmospheric models developed and implemented in the course of the project.

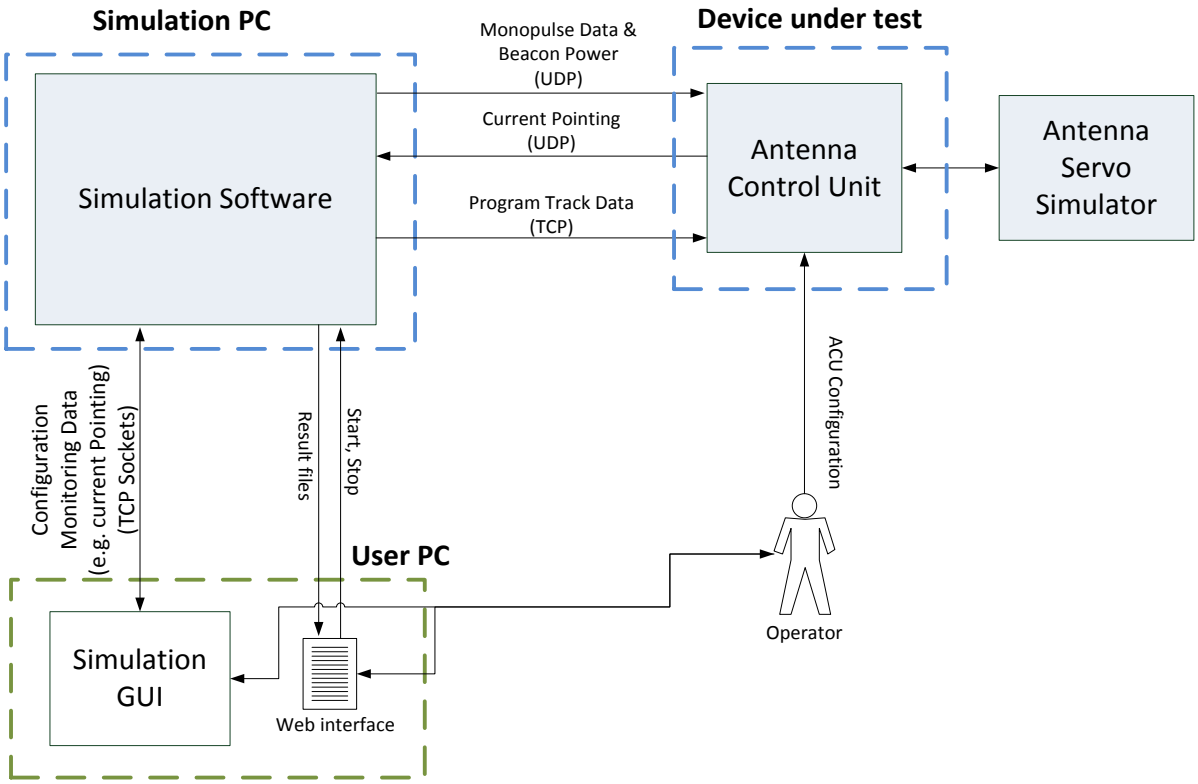


Figure: Architecture of the antenna tracking simulator

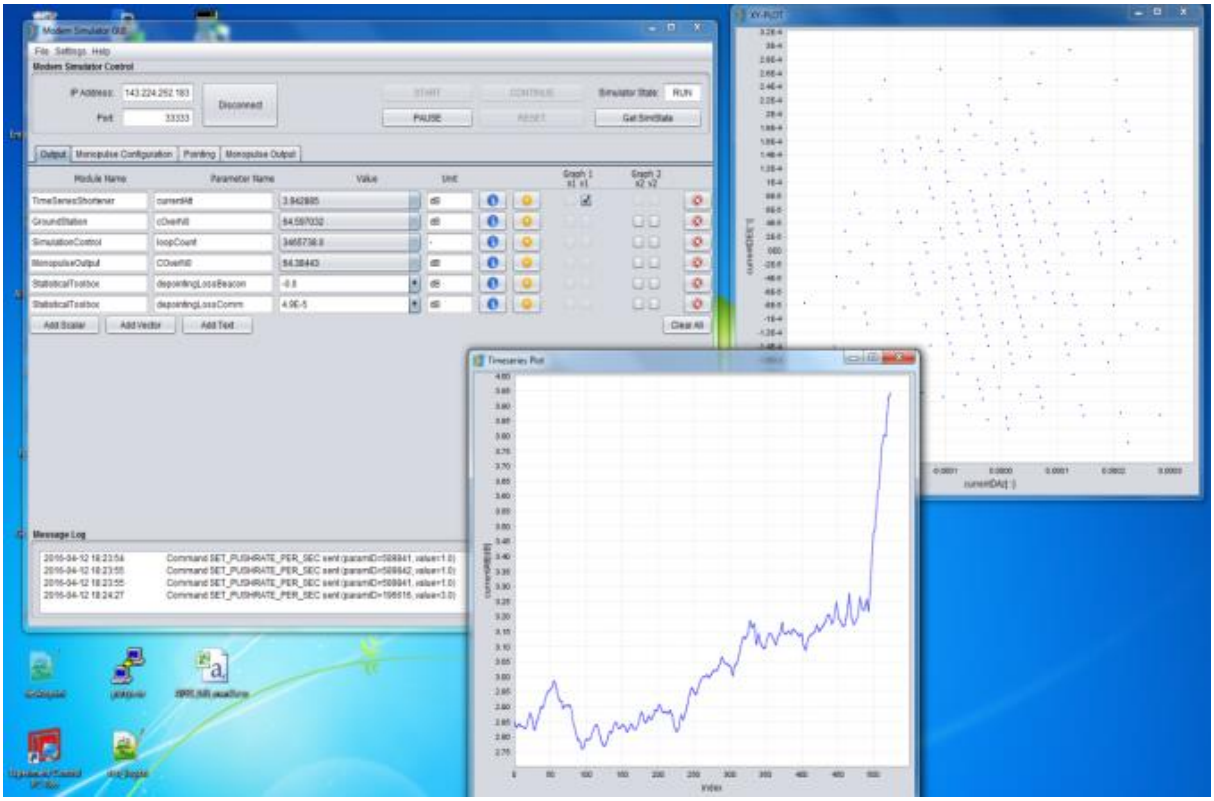


Figure: Screenshot of the GUI

b. Particle Filter Algorithms and Experiments for High Sensitivity GNSS Receivers

A particle filter is an innovative algorithm for robust high sensitivity GNSS receivers where ‘particles’ refer to independent system states of a GNSS user as e.g. 3D position, 3D velocity and internal receiver states like clock error and clock drift. The particle filter is capable to output a probability density function of the user states as a realistic estimate of the positioning process and allows incorporating environmental information like building maps or road maps for the purpose of narrowing down the solution.

In the particle filter correlation values with the satellite signal are accumulated to form a particle weight for each state which forms also the input to each next processing step. The process requires initial approximate knowledge of the user state as well as knowledge of the satellite ephemeris. No independent tracking or channel processing is performed and all correlation results contribute to the updated PVT (position-velocity-time) estimate, with the key advantages of the method being:

- All available correlations and therefore all available signal energy are accumulated
- Only correlation with the Line-of-Sight (LOS) signal will be performed

The figure shows a schematic diagram of the processing steps applied to the particle cloud that are performed within the ‚user vector tracking module' of the GNSS receiver. The particle states are weighted according to how well they fit with a line-of-sight projection of the particle state, i.e. how well they fit with the measurement. The ‚Update State' block represents all state variables and establishes the feedback to the GNSS receiver.

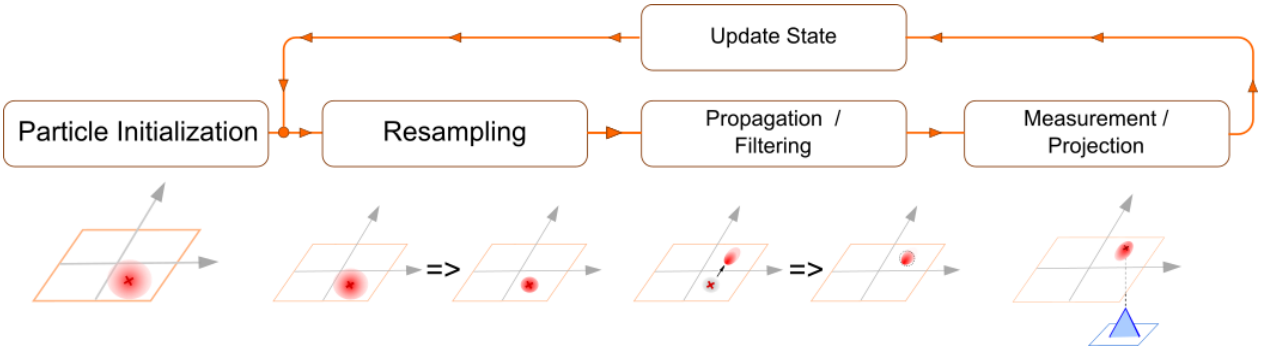


Figure: Block diagram of the particle filter showing a symbolic representation of the development stages of the particle cloud (in red) starting with an initial distribution of the particles

Applications refer to situations with weak GNSS signal reception, like indoor navigation or outdoors with situations of partial signal blockage or multipath, e.g. during underpasses or urban street canyons.

The project started 2015 and was finished in 2017. The project consortium consisted of JOANNEUM RESEARCH, IFEN GmbH and IGASPIN GmbH, where IGASPIN continued the work of IFEN from May 2016 to the end of the project. The particle filter algorithm was developed and implemented as an independent user library for the SX-3 software GNSS receiver of IFEN GmbH. Project goals were also to establish the cooperation between the consortium partners and to increase their expertise in GNSS receiver simulation, architecture design and signal processing.

The figure shows a visual representation of the time evolution of the particle cloud during line-of-sight projection and update of states.

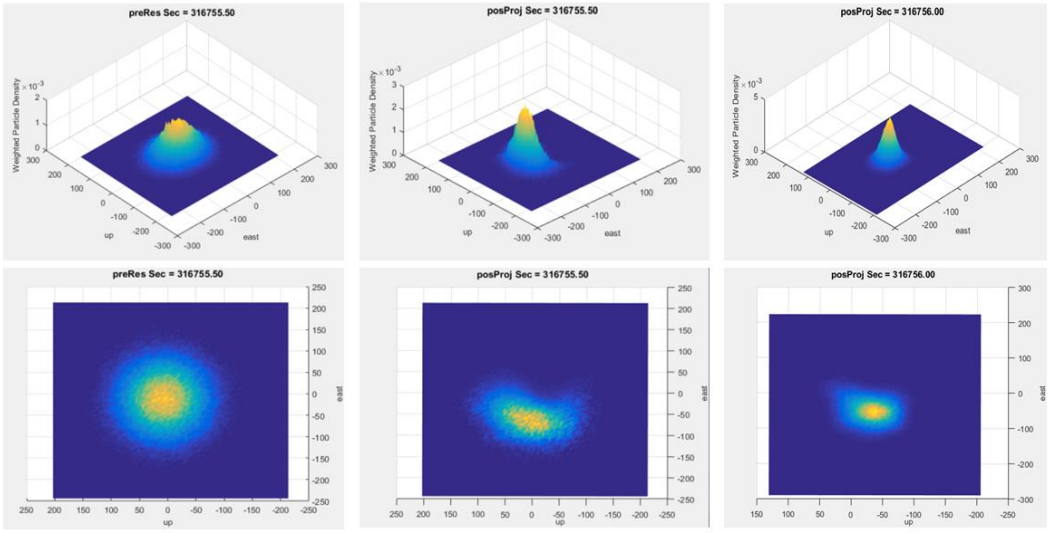


Figure: The first three steps of the time evolution of the weighted particle density distribution in 3D and top view as a result of the weighting process due to the measurement in a static scenario

Figure: Measurement van with roof mounted antennas

c. Development of the next generation High Fidelity Channel Model for Land-Mobile Satellite Navigation

The availability and accuracy of the positioning via satellite navigation receiver strongly depends on the environment. Especially in built-up areas effects like signal shadowing, multipath reception, and blocking impair the quality of a position fix. The understanding and modelling of such propagation conditions is a key element on all aspects of global navigation

systems development. A precise description of the wave propagation mechanisms is hence crucial for the test of satnav receivers and the development of mitigation techniques.

Within the Basic Technology Research Program (TRP) ESA launched an activity with the goal to research, model, and simulate the multipath propagation channel for satellite navigation in a realistic way. The main goal of the activity is to scrutinize hardware GNSS receivers' performances in challenging multipath-prone environments under controlled conditions.

Environments are defined in terms of the dominant wave propagation and multipath propagation effects which are frequently encountered by GNSS receivers which operate in them, e.g. urban, sub-urban, and rural scenarios. Additionally, the scenarios are defined by the respective users who make use of the GNSS services, namely vehicle-mounted receivers, hand-held receivers carried by pedestrians, and stationary receivers placed in sensor stations. Effects are caused by objects (e.g. buildings, trees, vehicles, electricity poles) present in the respective environment which cause shadowing and blockage due to obstruction of the wave propagation path and which cause multipath propagation due to scattering, reflection, and diffraction.

A consortium led by JOANNEUM RESEARCH with the partners AIRBUS Defence & Space, and the Universities of Aalborg/Denmark and Vigo/Spain was awarded this contract for developing such a high-fidelity channel model based on real-world measurements. The model design uses canonical objects and thus is of geometric-stochastic nature. A number of diffraction computation methods such as Physical Optics as well as raytracing techniques, reverberation effects, and rough surface scattering are taken into account to find the most suitable approach.

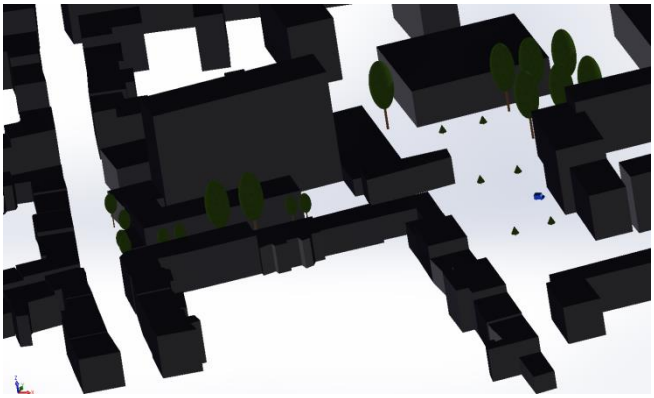


Figure: Simplified 3D-model of real city for comparison of measurements with simulation results

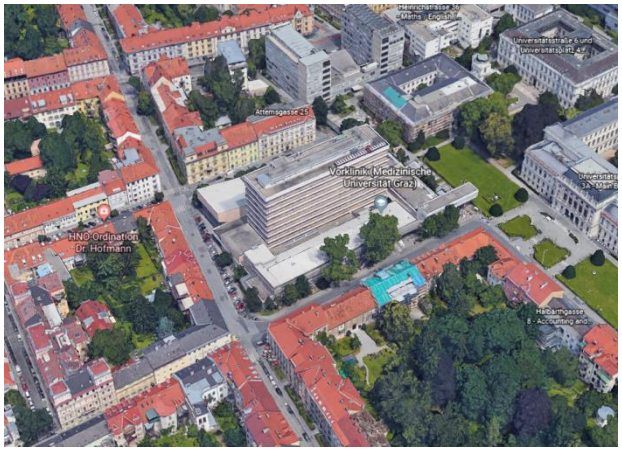


Figure: Real environment

The channel model will allow to realistically emulate shadowing and multipath effects based on stochastic and deterministic virtual scenarios, and to feed the resulting signal to a number of hardware receivers under controlled conditions. Performing the experiments under controlled conditions means that the wave propagation effects imposed on the received signals are reliably repeatable so that a bank of hardware receivers can be evaluated under the same conditions, e.g. in a laboratory or an anechoic chamber.

Separate measurement campaigns will be performed for the model's calibration and validation. The model's output can be used in software simulations as well as for hardware signal generators.

Figure: Measurement vehicle with wizard-head-like measurement antennae for high resolution spectral recordings and navigation antennae for high precision positioning

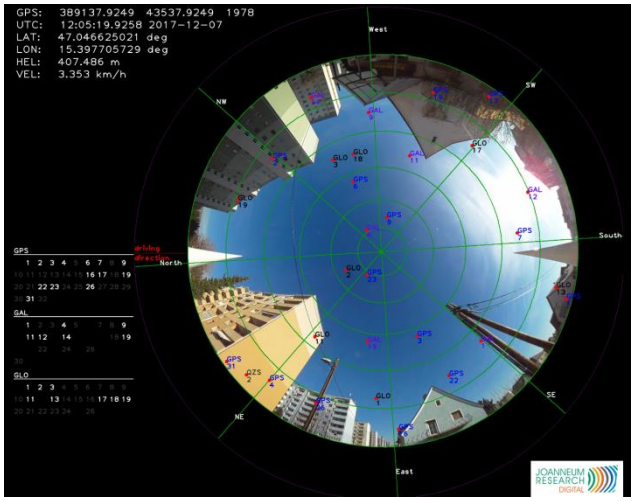


Figure: Ultra-high resolution video recordings showing the real-time satellite positions allow the interpretation of the measured signals

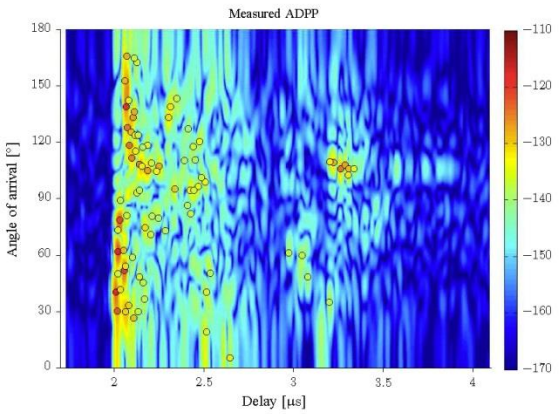


Figure: Measured delay-azimuth spectrum of the radio channel, and estimated multipath parameters (dots) computed from the data using the robust super-resolution estimator developed by Aalborg University. The colour of the dots codes the magnitude of the components

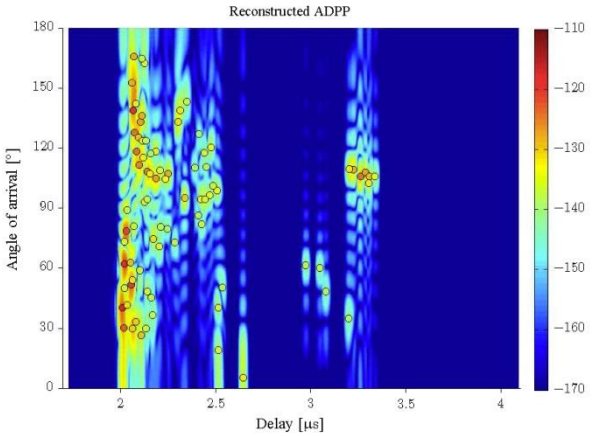


Figure: Estimated multipath components (dots) computed from the robust super-resolution estimator developed by Aalborg University and delay-azimuth spectrum reconstructed from these path estimates by limiting the frequency and spatial apertures to those of the measurement equipment. The colour of the dots codes the component magnitude of the components.

B) Remote Sensing

a. ASAPXIII Project SynSent

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 SynSent project is dedicated to the synergetic analysis of these satellite data and is being carried out in a joint cooperation between ENVEO IT GmbH, Innsbruck, as project coordinator and the Research Group for Remote Sensing and Geoinformation of Joanneum Research Forschungsgesellschaft mbH, Graz as project partner.

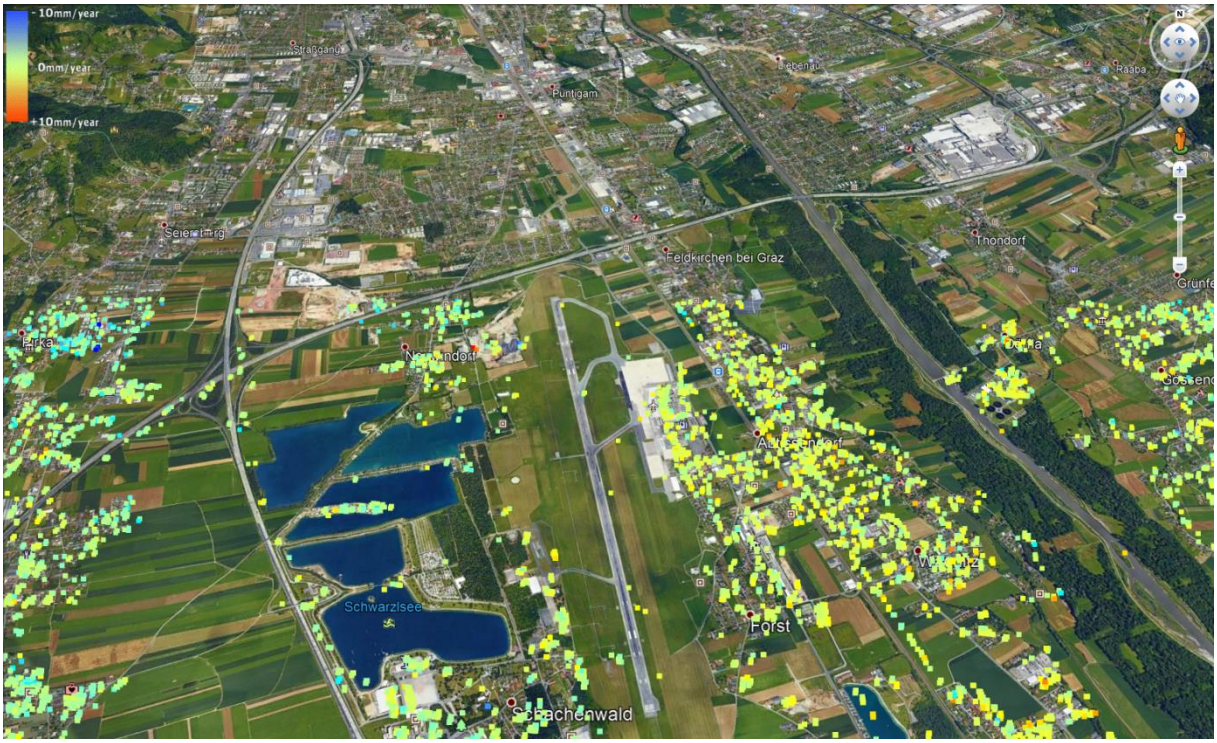
In the SynSent project JOANNEUM RESEARCH focuses on the multi-temporal analysis of interferometric Sentinel-1 SAR data series. Such analysis is a useful tool for detecting and measuring land movements as a result of landslides or/and ground subsidence. The enhancement of measurement accuracy and detail, and the extension of spatial coverage of interferometric measurements stay foreground as the primary goals of the present research. These are achieved by incorporating high-resolution optical data from the Sentinel-2 and other satellites, as well as involving atmospheric models and data.

The JOANNEUM RESEARCH activities are devoted to algorithmic development for eliminating the propagation delay of the interferometric signal due to atmospheric impacts. The main tasks to be solved include, on the one hand, the modeling of this propagation delay, and on the other hand the determination of the spatial and temporal variability and availability of the standard atmospheric parameters for this modeling. The methodological developments are tested in the course of several case studies, and the results are validated against existing solutions and new developments in the project. The project builds on ongoing development in interferometric time series analysis and pursues the strategic objectives in the research field of SAR interferometry and related applications.

In the past, JOANNEUM RESEARCH has worked extensively with InSAR technologies to address the demands of potential users for methods that can reliably identify terrain motions and land subsidence. To date, the processing techniques of persistent-scatterer interferometry available at JOANNEUM RESEARCH are applicable in e.g. urban areas with predominantly pointwise scatterers, but are not yet matured for using in alpine and rural areas with the occurrence of distributed scatterers.

In the first project year, an original approach referred to as "method of better half" was developed and partially programmed for estimating and eliminating atmospheric impacts on Sentinel-1 interferometric products. The method was successfully tested and validated in four different alpine and rural areas. The careful analysis, interpretation, visualization and documentation of the obtained results will be carried out in the second project year. With the developments realized and the results achieved in the project frameworks, JOANNEUM RESEARCH will fulfill the requests on widening the area of InSAR applications in terrains with heterogeneous land cover and will be able to act as a technology provider for measuring and mapping land deformations (keyword "land subsidence").

The illustration below represents an atmospherically corrected Sentinel-1 PS interferogram generated by the project team for the "Thalerhof" test site south of Graz. The interferometric time series includes 74 Sentinel-1 SAR scenes taken in the period from October 2014 to December 2017. In the middle of the figure, the runway of the airport "Graz-Thalerhof", numerous ponds and agricultural fields can be recognized. The yellow-green marked points denote invariable objects. Based on this product, a reliable model of land subsidence in the area can be provided.



Textsource: SynSent Angebotsdatenblatt (11.11.2015)

C) Space Robotics Vision / Space Science & Exploration

a. 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 started in 2017, 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, Figure), 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.

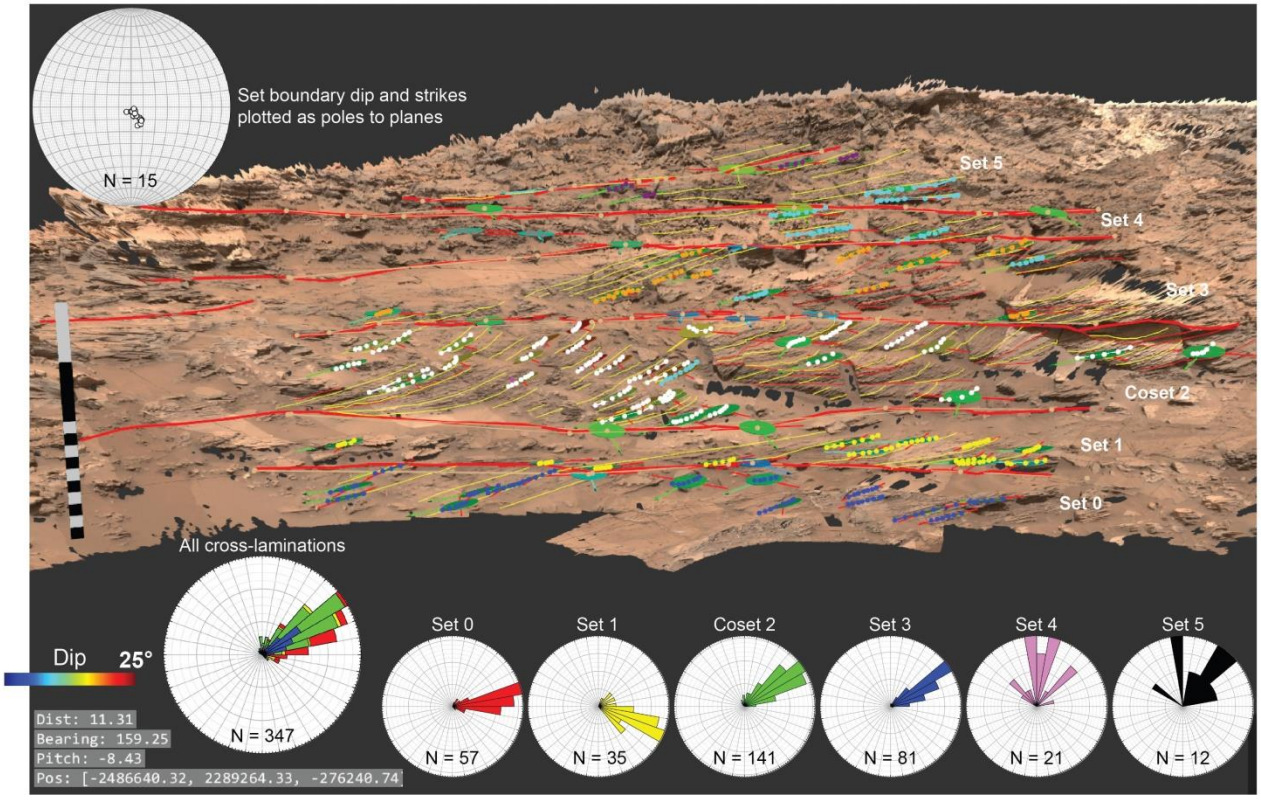


Figure: The MSL Williams outcrop (Sol 1087) digital outcrop model (DOM), reconstructed in 3D using PRoViP from MSL Mastcam stereo images, analysed in PRo3D with interpreted set boundaries (thick red lines) and a subset of the measured dip and strikes (dotted lines with colored disks, the small red line indicates strike direction). Lamination contacts have been mapped onto the DOM and can be seen to shallow in inclination in Sets 4 and 5. Equal distance rose diagrams with 10° bins are inset into the DOM, showing unimodal NE dip directions for Sets 0 to 3 and a more polymodal N dip direction for Sets 4 and 5. The poles to planes of the set boundaries have been plotted and show a general NW dip direction. Scale bar is 2 m. Credits: Imperial College London / Rob Barnes

b. Mars Terrain Simulator 3D Vision System

ALTEC in Torino (Italy) will operate the Mars Terrain Simulator (MTS) during the ExoMars Mission 2020 / 2021. The MTS is an environment that allows a realistic rehearsal of ExoMars operations in Mars simulating terrain, within an area of 20m * 16m, using Mars simulating soil. It was developed by DATASAT and Aberystwyth University (both UK) with JOANNEUM RESEARCH being in charge of a photogrammetric system using high resolution cameras on the ceiling of the MTS area to generate a dense high resolution 3-dimensional reconstruction of the terrain (Digital Elevation Model – DEM, Figure). The definition of the system, its

calibration, and a push-button Software toolchain for DEM generation are major results of the JOANNEUM RESEARCH contribution.

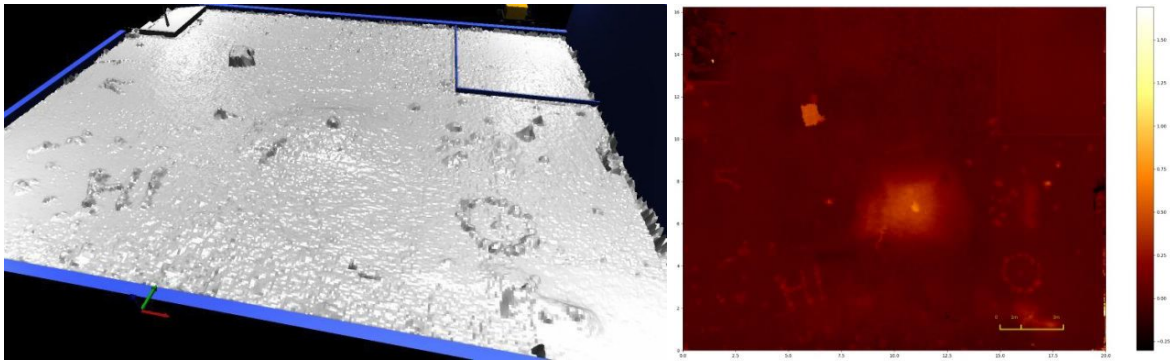


Figure: 3D reconstruction of Mars Terrain Simulator set-up: A 20m * 16m indoor region is viewed by dozens of cameras, a 3D model is built to monitor ExoMars rover model testing during the mission, using a 1:1 duplication of the current rover's environment. Left: Rendered shaded DEM, right: DEM elevation color coded

c. Mars 2020 Mastcam-Z 3D Vision

The NASA Mars 2020 Rover 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 and visualization pipeline, and geometric calibration support) to be able to assemble 3D models from Mastcam-Z stereo pairs during the mission in the operational time frame in 2021. One essential component is also view planning for so-called "Wide Baseline Stereo" from different rover positions to gain accuracy at larger distances (Figure). Beside VRVis being in charge of visualization, the Vienna Museum of Natural History (Prof. Koeberl) is contributing in the Austrian team with science exploitation.

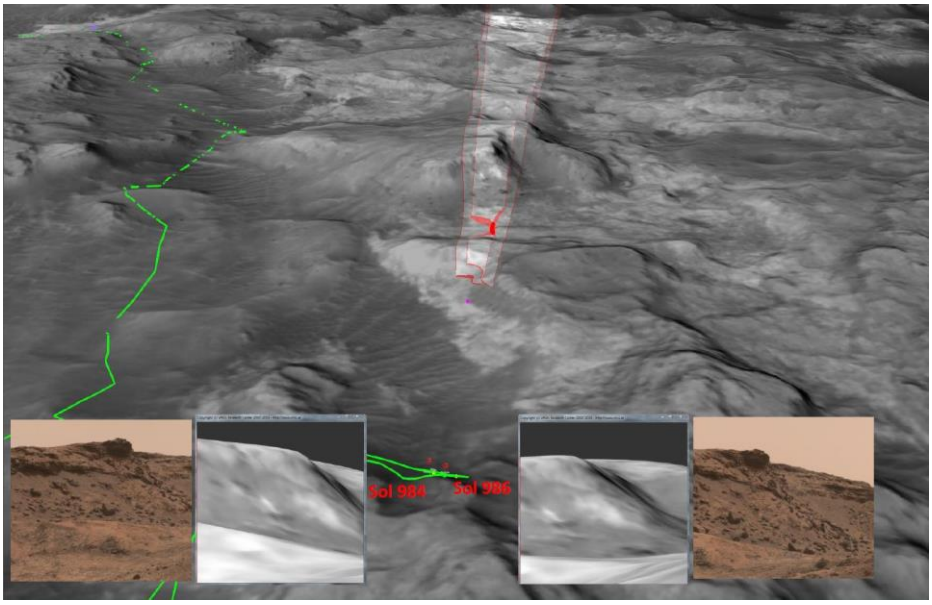


Figure: PRo3D (visualization component provided by project partner VRVis) view planning example from Wide Baseline Stereo MSL (Mars Science Laboratory) Mastcam pair configuration from Sols 984-986 with 7m base length (comparing real images and virtual renderings of HiRISE satellite base map from the same position); the displayed distance to main portions of the scene is about 170m. The green polygon is the true trajectory of the MSL Rover

d. LUCID – LUnar scenario Concept Validation and Demonstration

The principal objective of this activity was to assess the combinations of tools and techniques required to operate in the environmental and operational constraints of the polar Lunar environment, by means of a test campaign that mimics the mission scenario of a Lunar Prospecting Rover. The test was to simulate in realistic conditions (terrain and illumination) the operation of a rover in an analogue near-polar lunar location. The project was coordinated by GMV located in Tres Cantos / Madrid / Spain who have significant experience in the operation of the envisaged testing hardware environment (RAT: Robotic Autonomy Testbed), as they had been main RAT developer in prior ESA activities. JOANNEUM RESEARCH was responsible for a stereo 3D Vision system embedded in the LUCID sensor suite to operate during day- and night-time (Figure) and provide a geometric 3D model of the environment of the rover for navigation and scientific purposes.

Figure: Left: JOANNEUM RESEARCH GEPE (Geometric PanCam Emulator) mounted on the mast of the LUCID rover by GMV (Credits: GMV). Top right: Night time data capturing scenario in the caldera of Tenerife with visible laser projection tracks. Bottom right: 3D reconstruction form GEPE stereo images

e. HRAF – Harwell Robotics Autonomy Facility Pilot 2

The Harwell Robotics and Autonomy Facility (HRAF) aims at supporting the validation, verification and integration of autonomy components and its key functionalities for Planetary Robotic exploration, targeting Mars Sample Return. This technology activity aimed to demonstrate the performance of the SPARTAN autonomy algorithm during a field trial, embed the SPARTAN algorithm within the Harwell Robotics and Autonomy Facility Core Architecture, compare the field trial data with the HRAF synthetically generated data set and continue the population of the HRAF dynamic archive through the implementation of semi-automated image import tools.

JOANNEUM RESEARCH defined the navigation scenario for SPARTAN validation as initially planned to be performed in 2018 during a field trial campaign in relevant scenario. The adaptation and validation of synthetic image generation tools for ground truth provision was designed (Figure), and semi-automatic importers for populating the HRAF infrastructure were provided. For the field trials context, an airborne DEM generation tool is provided.

Figure: Synthetically rendered images in various illumination & optical conditions as designed for visual odometry (VO) testing in HRAF Pilot 2

f. ExoMars CLUPI z-Stacking and autofocus

The Close-UP Imager (CLUPI) will be part of the instrument payload on the ExoMars rover, scheduled for launch in 2020. CLUPI is a camera system designed to acquire high-resolution, colour, close-up images of outcrops, rocks, soils, drill fines and drill core samples[1].

JOANNEUM RESEARCH for the CLUPI industrial team designed and developed engineering model (EM) software to stack multiple focus images taken by CLUPI to a multi-focus output image and derive 3D information from the image stack ("z-stacking", Figure). Another important contribution is an autofocus function (EM software) that makes sure that images are automatically captured with an optimum focus position.

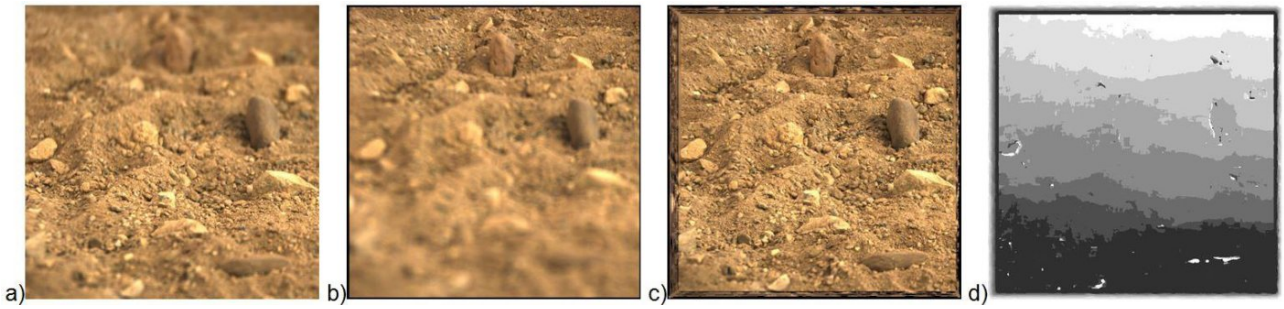


Figure: a) and b): z-stacking images with different focus settings. c) "Ideally" focussed image assembled from 8 differently focused images. d) Grey levels indicating the source image (darkest: nearest focus, brightest: far focus)

[1] http://exploration.esa.int/mars/45103-rover-instruments/?fbodylongid=2301

Outlook

In 2018 the mission interfaces and calibration for ExoMars and Mars 2020, as well as scientific use cases and visualization will be further elaborated by JOANNEUM RESEARCH, VRVis and the Vienna Museum of Natural History in the respective instrument PRODEX contracts PanCam 3D Vision and Mastcam-Z 3D Vision. For the ExoMars ROCC (Rover Operations Control Centre) in 2018 and 2019 the 3D vision data processing for the NavCam and LocCam engineering rover camera systems for tactical mission planning will be developed, and JOANNEUM RESEARCH will contribute with 3D vision and data archiving activities to the ExoFit planetary rover field campaign which will prepare for ExoMars operations and cooperation of scientific instruments.

Sales: ***3.7 MEUR***
ESA Share: ***1.7 MEUR***

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3.8 MAGNA STEYR FAHRZEUGTECHNIK AG & CO KG AEROSPACE

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

The first flight hard ware for US Space Launch System (SLS) has been built. The lines have been delivered to NASA Michoud Assembly Facility (MAF) in New Orleans.

Magna got another two contracts to develop and manufacture flexible elements for the new SLS upper stage (EUS). The Know-How Magna gained during Ariane 5, FLPP and ISRO GSLV development was a door opener to get this contracts.

“Special NDI processes” able to detect extremely small defects have been qualified. For qualification purposes NASA owned samples with hidden defects have been used.

NADCAP certifications welding X-Ray and dye-penetrant inspection are planned end 2018.

In 2018 Magna will invest in machinery in order to be able to produce such flexible elements in house.

As result of the good performance 2017, being among the 90 best Boeing suppliers (out of 13.000 suppliers) Magna Aerospace was invited to join Boeing Global Supplier Conference 2018 in Portland.

Future Launcher Preparatory Program (FLPP) activities

Aluminum Lines:

Development light-weight aluminum cryogenic feed lines has been continued. The compensation elements have been successfully tested. As the compensators are a material mix aluminum/steel joined by friction welding, a campaign to develop adequate NDI methods for testing of such weld seams has been started.

Magna will propose this technology to the new launcher VEGA-E, but could be used also on future evolutions of Ariane 6.

Polyimide Lines:

As a further step in direction light weight lines, Magna started research and development of “polyimide thermo-plastic” lines. After a wide research the right material for building Feed Lines from polyimide has been found. Testing of this carbon fiber reinforced thermoplastic polyimide has been started and will be completed 2019.

Polyimide offer a mass saving potential of 50% compared to the state of the art steel lines. Furthermore this technology leads to a significant cost reduction, as no expansion joints are necessary.

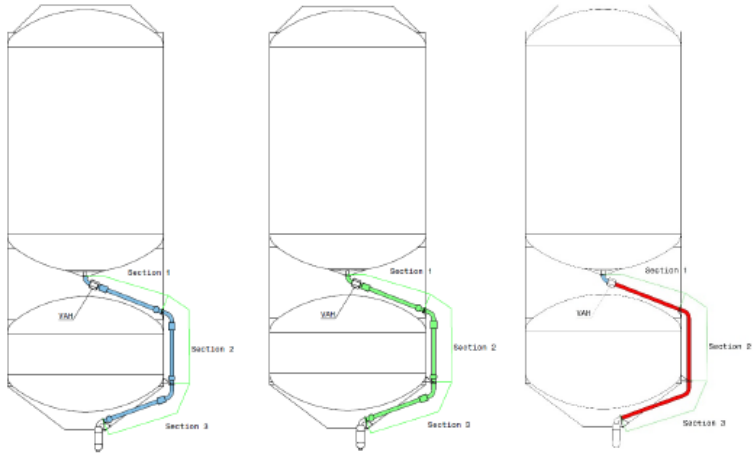


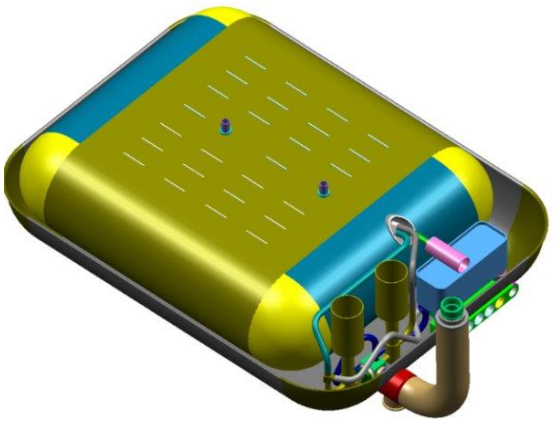
Figure 1: HFL option 1 concept comparison

Table 4-3: HFL mass comparison

Section	Option 1 Stainless Steel	Option 1 Aluminium	Option 1 Fiber Reinforced Polyimide	Option 1 Neat Polyimide
	kg	kg	kg	kg
Section 1	18.4	12.8	11.0	10.6
Section 2	17.4	11.6	7.0	6.7
Section 3	16.2	9.8	6.9	6.6
Additional Support	-	-	-	2.4
Total	52	34.2	24.9	26.3
Mass saving [%]		34.2	52.1	49.4

Liquid Hydrogen Storage:

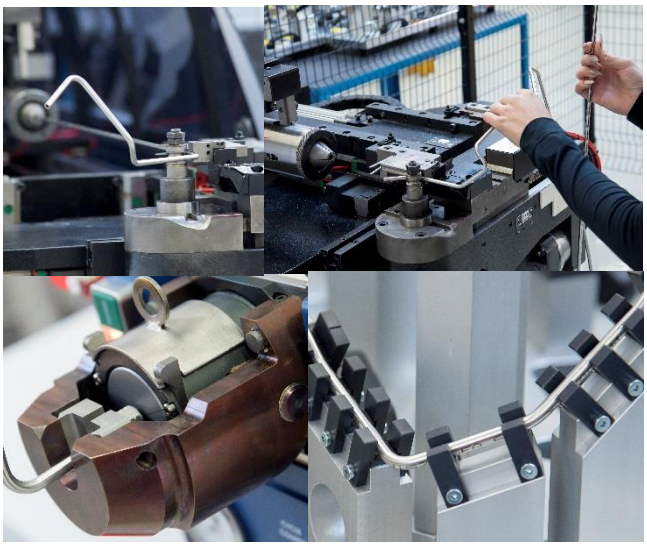
Magna Aerospace tested Hydrogen Storage Systems which have been developed by Magna Aerospace in the past. The test evaluated the thermodynamic behavior especially the phenomena of thermodynamic resonances.



Based on the results Magna will improve it thermomechanical model, in order to be able to avoid such phenomena in future developments.

Manufacturing of small lines for automotive production

Magna Aerospace successfully qualified the small piping's (for alternative propulsion).
Sufficient lifetime, high cleanliness level , pressure and temperature cycles and a burst pressure in the near of 2000 bar have been demonstrated.



Sales: ***6.5 MEUR***
ESA Share: ***0.3 MEUR***

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3.9 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 1.400 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.



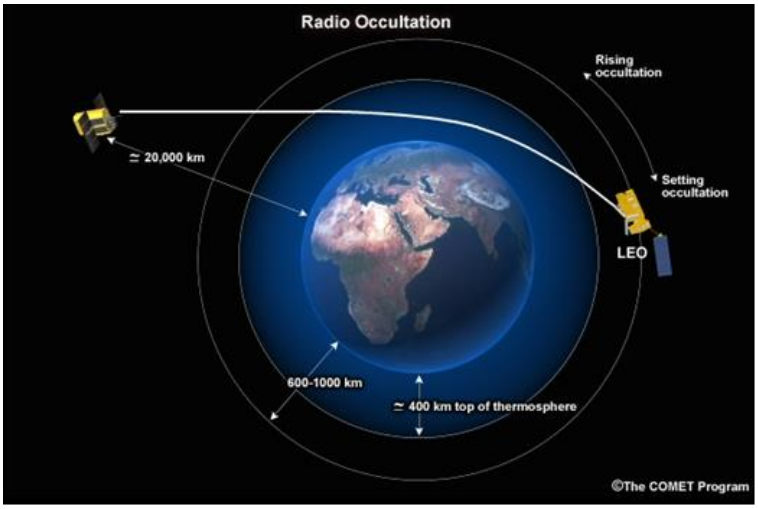
Products of high strategic importance for RSA are Global Navigation Satellite System (GNSS) Precise Orbit Determination (POD) Receivers. GNSS POD uses high-quality carrier and code measurements of a dual-frequency receiver on-board of a satellite, to achieve measurement of its position with an accuracy of a few centimeters in on-ground processing. As of December 2017, 22 flight models have been delivered, of which 16 are operating in orbit. The three **SWARM satellites** and all **Sentinel A&B** satellites of the joint ESA/EU Copernicus program have been equipped with the RSA product.

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, and 32 flight models are on order already. This 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%. Several recently acquired contracts from customers in the US and in Asia demonstrate the strong position on the global market.

The development of lower cost GPS & Galileo single-frequency receivers for LEO as well as GEO satellites is fairly advanced, with the currently developed all-electric GEO telecom platform **Electra** of OHB being among the first applications.

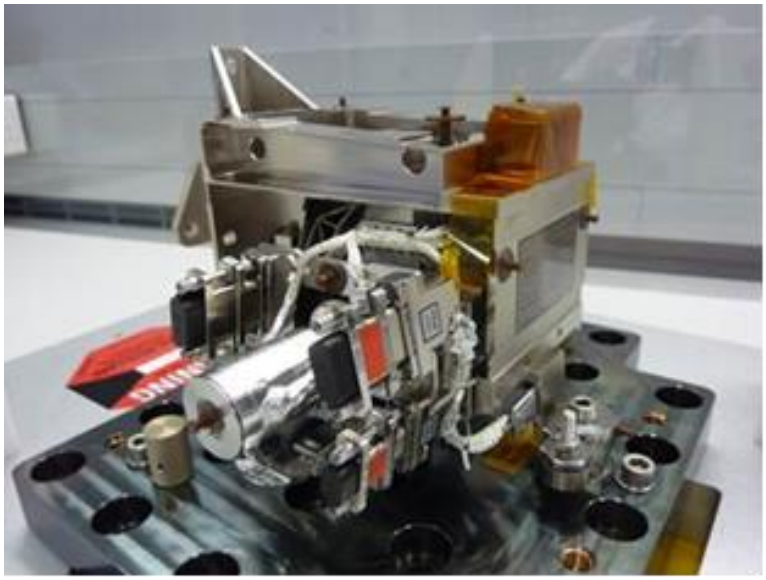
RSA GNSS Receiver Product Family

RSA GNSS Receiver Modules also form the basis of the advanced radio occultation (RO) instrument of the **Metop Second Generation** satellites. RO uses GNSS signals to provide profile information of temperature and humidity at high vertical resolution.

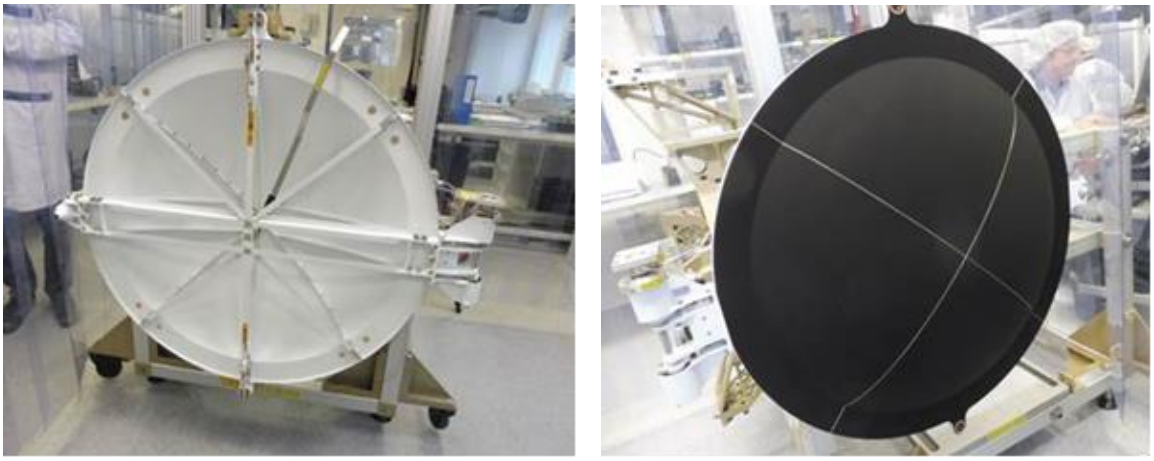


Radio Occultation for Atmospheric Sounding (Source: EUMETSAT)

Other major activities concerned projects in the frame of the **Meteosat Third Generation (MTG)** program, carried out by ESA on behalf of EUMETSAT. The first Flight Models of the Solar Array Drive Electronics (SADE), the Antenna Deployment and Pointing Mechanism Electronics (ADPME) and electronics modules for the central computer of all six satellites were delivered. The development of the Refocusing Mechanism and the Solar Baffle Cover for the main meteorological instrument as well as for the motorized Aperture Cover of the Sentinel-4 instrument has been completed.

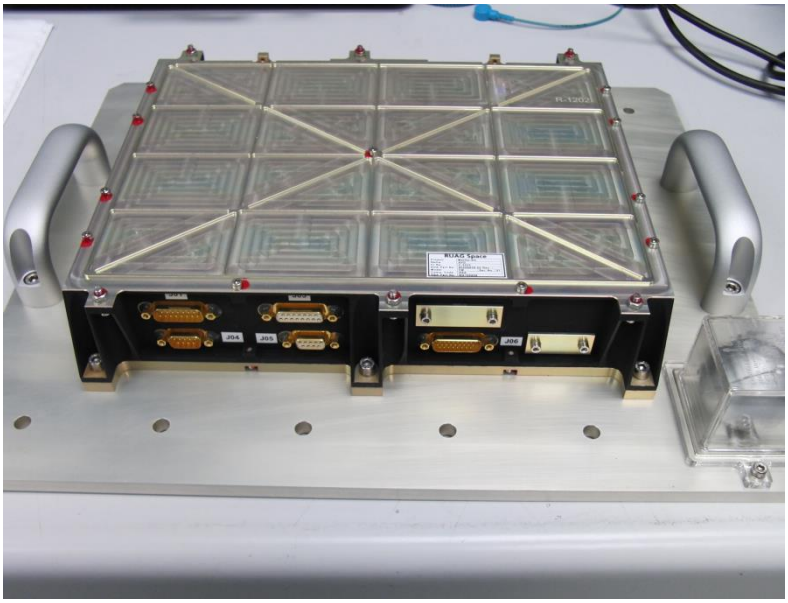


MTG Refocusing Mechanism Flight Model



MTG Solar Baffle Cover Qualification Model in Deployment 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).

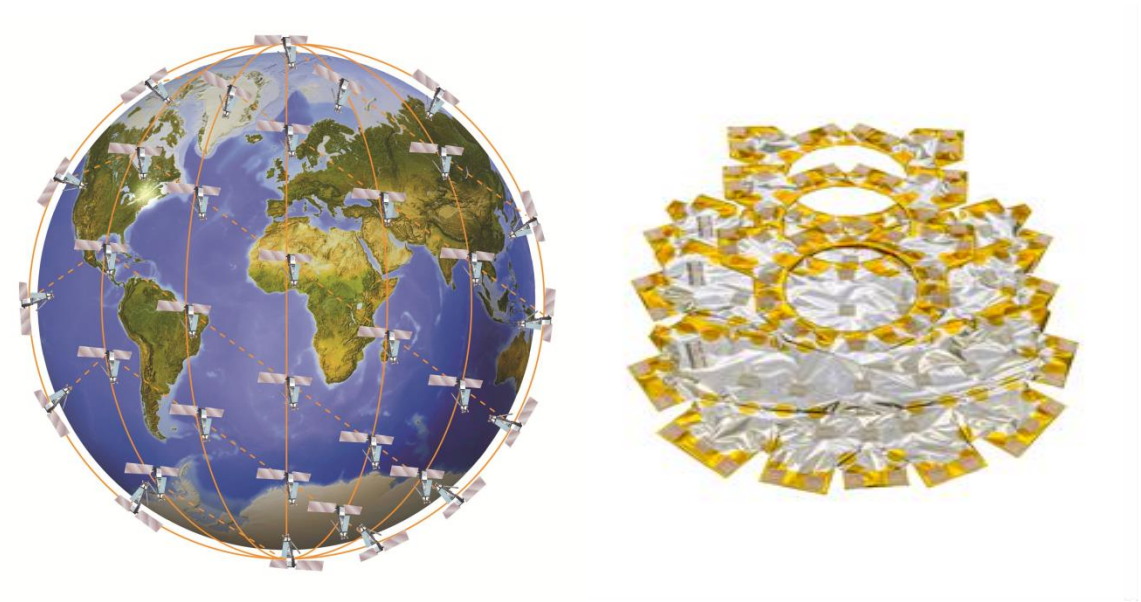


Engineering Model of Metop Second Generation APD

A major milestone was the contract from Thales Alenia Space (TAS) for the development of an Electric Propulsion (EP) Pointing Mechanism (EPPM) for the all-electric Spacebus-Neo platform. Now RSA is supplying EP mechanisms to all three European system integrators (Airbus DS, TAS, OHB).

Sales of thermal insulation products increased by some 25% and reached one third of total RSA sales. Significant contributions came from the ESA projects Solar Orbiter, Metop Second Generation, Juice and MTG. Solar Orbiter is of particular interest, because, for the first time, RSA has the responsibility for a complete subsystem.

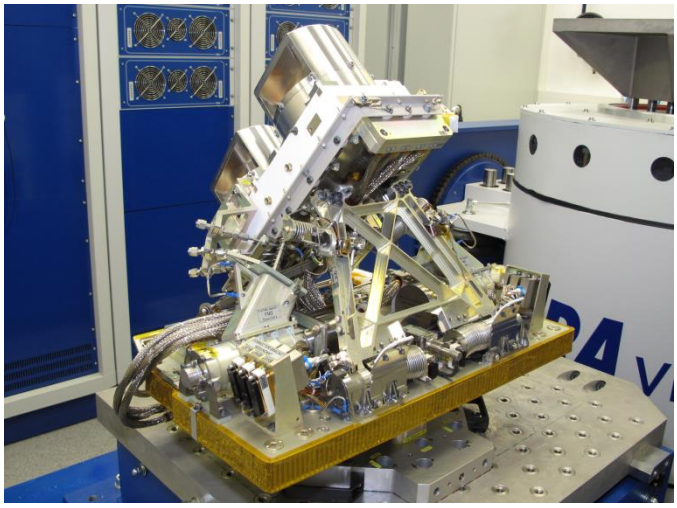
Of even bigger strategic relevance is the successful completion of the thermal insulation deliveries for the 81 satellites of the Iridium NEXT constellation to TAS. The production of more than 12.000 insulation blankets represented a real technical as well as logistic challenge and established the basis for competing in emerging mega-constellation programs like OneWeb.



Iridium NEXT Constellation and RSA Thermal Insulation Elements

Sales in the area of **cryogenic insulation** for terrestrial applications, a spin-off of the company's space business, increased by 2% in 2017, and contributed 11% to the total company sales.

The year 2017 brought a number of satellite launches with key RSA contributions on board. End of January Hispasat H36W-1, the first geostationary telecom satellite built by OHB, was lifted into its orbit by a Soyuz from Kourou. The satellite is protected against the extreme temperatures in space by RSA thermal insulation. The company also delivered electronics modules for the central computer as well as for the payload management unit. In February and March the EP pointing mechanisms developed for the Eurostar E3000 platform of Airbus made their in orbit debut on SKY Brazil-1 and SES-10, respectively. So far, RSA has received orders for ten mechanisms.



Eurostar E3000 Electric Propulsion Pointing Mechanism during Vibration Testing

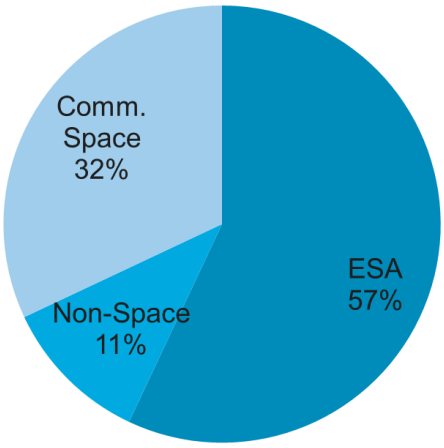
With the launch of Sentinel-2B on a Vega rocket from Kourou in early March another two RSA GPS POD Receivers started their in orbit life, bringing the number of operational units to 16.

Sentinel-2B Liftoff (Source: ESA)

In October a Rockot carried Sentinel-5P from the Plesetsk Cosmodrome into space. Like most of European institutional satellites, this forerunner of Sentinel-5 is protected by RSA thermal insulation.

In December, finally, further four satellites joined the Galileo constellation, and RSA has contributed electronics modules for the Command and Data Unit as well as multi-layer insulation (MLI).

Total RSA sales increased by 4% compared to 2016. The non-ESA share reached 43%.



Sales 2017: 49.3 MEUR
ESA Share: 28.1 MEUR

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3.10 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 three topics:

- Space weather and services for aeronautic dosimetry,
- Radiation hardness assurance of EEE components, and
- 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 2017:

- **AVIDOS** Aviation Dosimetry service in space weather context
- **REDI** Radiation evaluation of digital isolators for JUICE mission
- **MUSRAS** MultiScreen Radiation Shield

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

Seibersdorf Laboratories hosted also 2017 the **RADHARD Symposium** with topics on:

- CubeSat Space Mission
- Practical Aspects of Radiation Hardness Assurance, and
- Innovative Testing Developments and Future Needs

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

AVIDOS

Aviation Dosimetry service in space weather context

Introduction

The term space weather refers to environmental conditions in Earth's magnetosphere, ionosphere and thermosphere, as well as on the sun and in the solar wind that can influence the functioning and reliability of technological systems in space and on the Earth or endanger human health. Radiation is a natural part of our environment and therefore its presence and levels are part of space weather. Galactic Cosmic Radiation (GCR) coming from outside of our solar system has the greatest influence on radiation environment at aviation altitudes. However, Solar Cosmic Radiation (SCR) coming from our sun cannot be neglected due to possible effects of occasional solar phenomena like solar flares or coronal mass ejections (CME). Some of these 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.

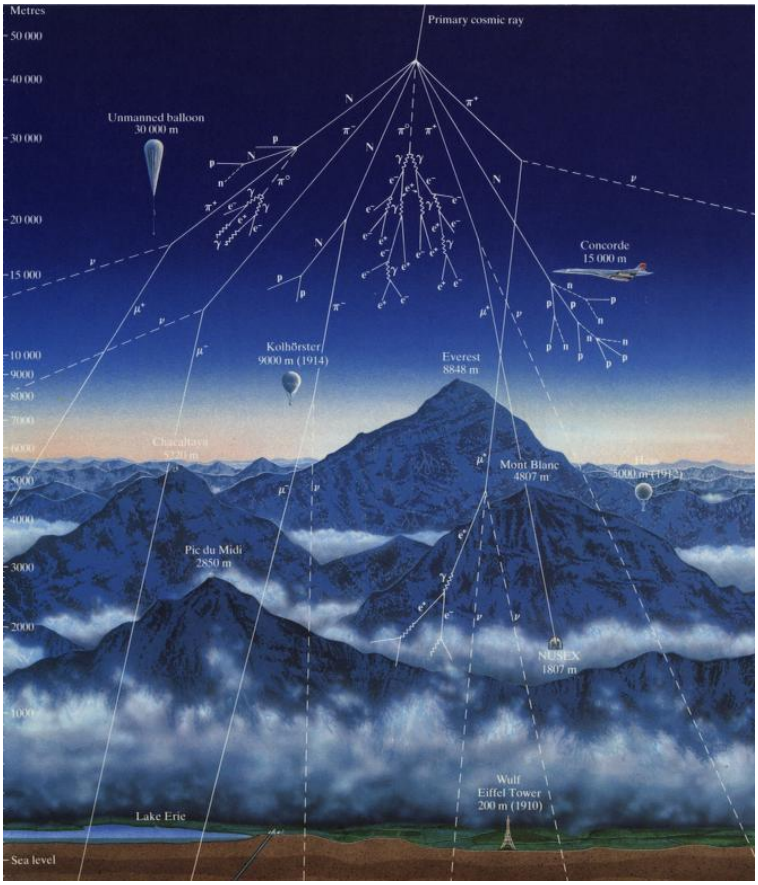

Figure: Cosmic rays from outer space impinge on Earth's atmosphere, and by nuclear interaction produce a shower of radiation composed of photons, protons, electrons, neutrons, muons and other particles.

AVIDOS

In the framework of ESA's Space Situational Awareness (SSA) programme in its Space Weather segment, Seibersdorf Laboratories provides the public with an real-time aviation dosimetry service AVIDOS. AVIDOS is an informational and educational software to increase public awareness of space weather and its effects on radiation environment at aviation altitudes. Its current version 2.0 is federated with ESA's Space Weather portal (http://swe.ssa.esa.int/web/guest/avidos-federated). Following contemporary advancements in web technologies and planned evolution of the ESA Space Weather Portal, we started to improve AVIDOS availability and user experience. In 2017, we set up a pilot project to update the technology of AVIDOS interface. In this pilot phase, we conducted a study on a technology choice and performed initial re-programming works. We intend to finalize this project in 2018 and to continue these improvements on a larger scale in a forthcoming second phase finally ending up with a new version AVIDOS 3.0 available at the ESA SSA Space Weather portal in the next years.

In 2017, Seibersdorf Laboratories concluded the ESA-supported programme P2-SWE-I, where we enhanced our presence on the ESA SSA Space Weather portal by providing an animated map of current cosmic radiation exposure. The map is accessible to everyone in the introductory section of the ESA SSA Space Weather portal under the Current Space Weather tab: http://swe.ssa.esa.int/current_space_weather. Concluding the P2-SWE-I

programme, we simultaneously kicked-off the new P3-SWE-III project with a focus on a further development of Space Weather Expert Service Centres. Seibersdorf Laboratories is one of the Expert Service Centres (ESC) that deals with space radiation. Within the P3-SWE-III programme, we continue to maintain the availability of AVIDOS 2.0 as our federated service. We also support the ESA Space Weather Coordination Centre (SSCC) with our expert knowledge on space radiation at aviation altitudes and the use of the service AVIDOS 2.0.

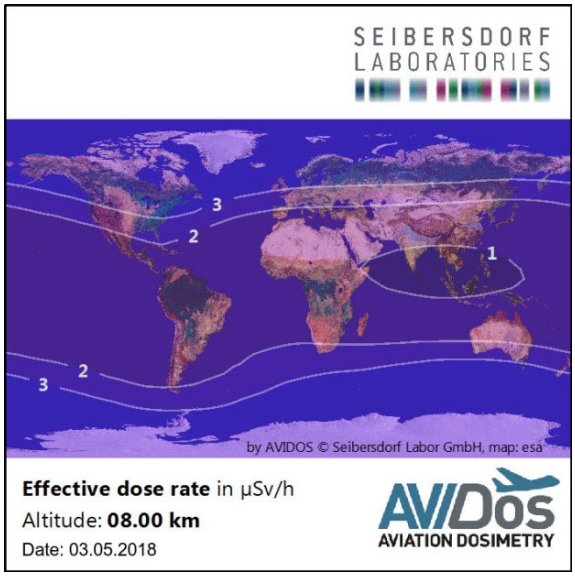

Figure: A snapshot of the animated global map of effective dose rate due to galactic cosmic radiation at 8 km of altitude on 03.05.2018

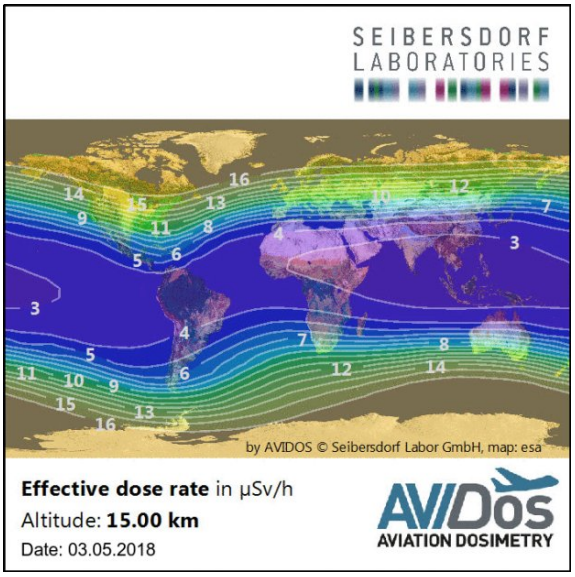

Figure: A snapshot of the animated global map of effective dose rate due to galactic cosmic radiation at 15 km of altitude on 03.05.2018

Nowcasting and forecasting of space weather induced radiation environment in Earth's atmosphere is of great importance for research, governmental organizations, and aviation. Our service AVIODOS 2.0 federated with the ESA SSA Space Weather 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 2017, in collaboration with International Foundation "High Altitude Research Stations Jungfraujoch and Gornergrat", Switzerland, we have begun the AVIDOS-SEP-Nowcast project. The goal of this project is to explore possible improvements of nowcasting of radiation exposure at aviation altitudes during anisotropic SEPs. For this purpose, in September 2017 at Seibersdorf Laboratories we have organized the SEPRAD workshop - a platform for open debates between international experts. Additionally, we co-organized a scientific session devoted to aviation dosimetry at the 14th European Space Weather Week that was held in Belgium in November 2017. A broad literature study performed so far complemented by discussions with experts will help to work out a roadmap identifying needs for future forecast of radiation effects due to space weather.

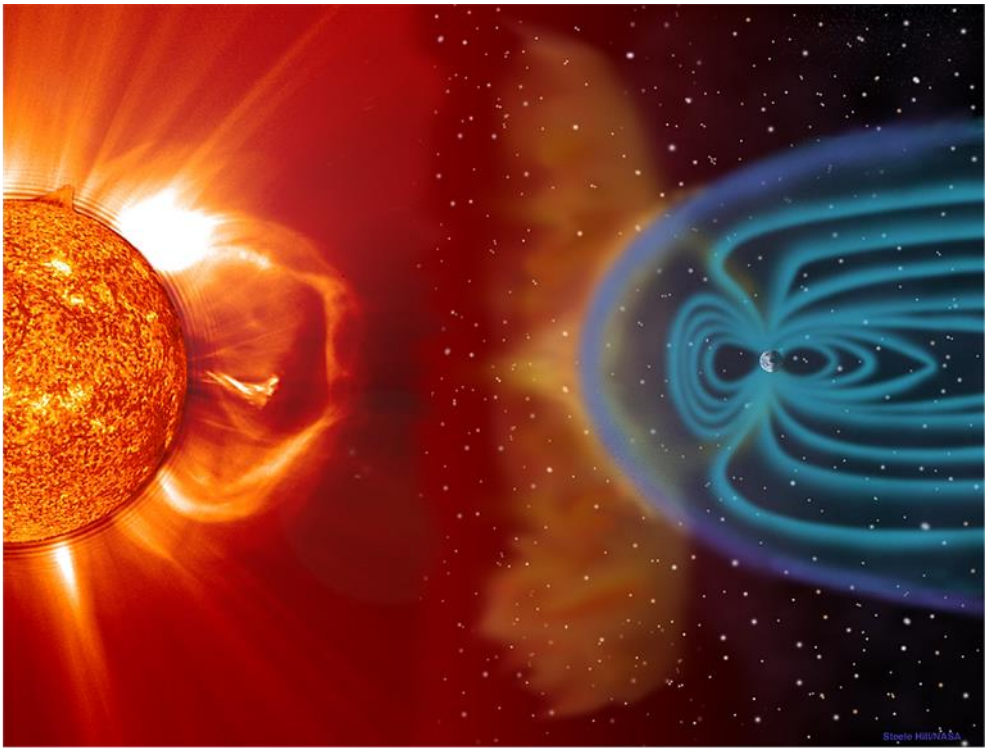

Figure: Coronal mass ejection (CME) blasting from the sun towards Earth's magnetosphere. Such events may affect satellite-based navigation systems, radio communication, and human health in space and at aviation altitudes. Strong solar events may lead to Ground Level Enhancements (GLE). Image credit: NASA/Steele Hill.

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 is conducted in collaboration with International Foundation "High Altitude Research Stations Jungfraujoch and Gornergrat", Switzerland, and supported by Austrian Research Promotion Agency (FFG) and Swiss Space Center (SSC).

Authors acknowledge also Space Weather Coordination Centre team in Belgium, neutron monitor station in Oulu, Finland, http://cosmicrays.oulu.fi, GLE-alerting service ANEMOS http://swe.ssa.esa.int/web/guest/anemos-federated, and NMDB – Neutron Monitor Database http://www.nmdb.eu.

REDI
RADIATION EVALUATION OF DIGITAL ISOLATORS

Introduction

ESA initiated the project REDI (Radiation Evaluation of Digital Isolators) within the framework of Technology Research Program (TRP) activities for the ESA Jupiter Icy Moon Explorer (JUICE) mission. Seibersdorf Laboratories is coordinating the ESA project REDI and in

collaboration with the Fraunhofer INT Institute (Germany) performs radiation hardness assurance testing.

Figure: ESA's Jupiter Icy Moon Explorer Mission JUICE (artist's impression) (Credit: ESA).

Digital isolators are becoming popular as signal isolation solution and are more and more an alternative to traditional solutions such as opto-couplers. The excellent performance of digital isolators, their high reliability and high degree of integration make them an attractive alternative – also for space applications. However, so far there is little knowledge about the radiation tolerance of such devices; neither with respect to Total Ionizing Dose (TID) effects nor with respect to Single Event Effects (SEE). Before such devices can be used in space applications, a better knowledge about their radiation response needs to be gathered. Thus, the objective of the study is to investigate the space relevant TID radiation tolerance and SEE susceptibility of different digital isolator technologies, i.e. to perform a detailed radiation evaluation (TID and SEE) allowing an assessment of their suitability for space applications. The following figure shows an exemplary de-capsulated digital isolator.

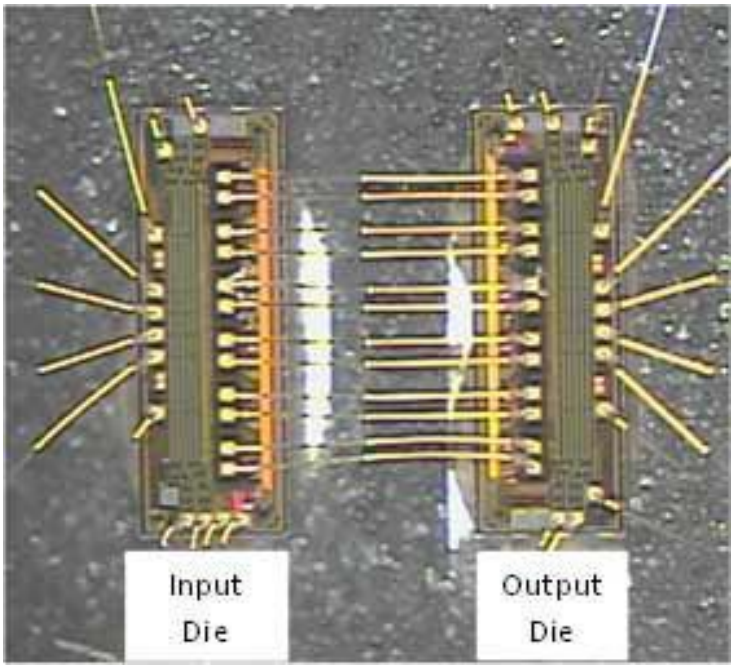

Figure: An exemplary de-capsulated digital isolator.

Scope of the Study

Several suppliers offer commercially available digital isolators working according different isolation technologies such as: capacitive coupling, inductive coupling and the giant magnetoresistance effect. In the course of the presented work, we investigated the radiation sensitivity of a set of digital isolators that represents a digest of the technologies being present on the market. We performed radiation testing in Co-60 gamma, high-energetic electron and neutron radiation environments assessing the total ionizing dose (TID) sensitivity of the selected isolator components. Here, we laid the focus of testing on the degradation of electrical parameters that characterize the performance of the digital isolator such as supply currents, output voltage levels (i.e. logic high and logic low), rise time, fall time, propagation delay, pulse width distortion and the isolation leakage current. We used high-energetic proton and heavy ion exposures for the characterisation of single event effect (SEE) sensitivity of such devices. We monitored the occurrence of Single Event Transients (SET) and Single Event Latch-Up (SEL) at various values of Linear Energy Transfer (LET) of the incident particle radiation. The investigated LET ranges from a few MeV·cm^2/mg to 60 MeV·cm^2/mg. Following this strategy we are providing a good overview of the digital isolator technologies available on the market that are suited for space applications and their performance in TID and SEE radiation fields.

Material and Methods

The following table shows all procured test samples, their manufacturers, isolator technologies, packaging, and lot codes in compliance with specifications of the ESA testing standard ECSS-Q-ST-60-13C. During the procurement process for each device type, we paid special attention to obtain test samples from a single lot.

Part	Manufacturer	Technology	Package type	Lot code
ISO7220MDR	Texas Instruments	capacitive	SOIC	4286983TW4 4662957TN4
ISO15DW	Texas Instruments	capacitive	SOIC	404323 2TN4
MAX14850ASE+	Maxim Integrated	capacitive	SOIC	0001755035
SI8261ACC-C-IP	Silicon Labs	capacitive	DIP	1333CF600U
ADuM1201ARZ	Analog Devices	monolithic transformer	SOIC	1TAK96092.9
ADuM1100URZ	Analog Devices	monolithic transformer	SOIC	AJ60138.5
IL715-3E *	NVE (Isoloop)	giant magneto resistant	SOIC	132361, 135210

Table: Procured Digital Isolators for testing.

Test	Test Facility	Source
TID with gamma	Accredit Standard Radiation Laboratory, Seibersdorf Laboratories, Austria	Cobalt-60
	TK1000A, Fraunhofer INT, Euskirchen, Germany	Cobalt-60
TID with electrons	MEDISCAN, E-Beam Technology, Kremsmünster, Austria	10 MeV electrons
TNID with neutrons	D711 n-generator, Fraunhofer INT, Euskirchen, Germany	14 MeV neutrons
SEE with protons	Proton Irradiation Facility, Paul Scherrer Institute, Villigen, Switzerland	24 to 200 MeV protons
SEE with heavy ions	Radiation Effects Facility, University of Jyväskylä, Finland	Heavy ions: N, Si, Fe, Kr, Xe LET: 1.87 to 60.0 MeV cm²/mg

Table: Overview of used Radiation Testing Facilities

Radiation Testing Performed

We performed total ionizing dose (TID) testing at two different Co-60 testing laboratories with all seven digital isolator component types, and with the component type ISO7220MDR 10 MeV electron tests only. Total non-ionizing dose (TNID) testing was performed with the component type ISO7220MDR with 14 MeV neutrons. Single event transients (SET) and single event latch-up (SEL) tests were performed except for IL715-3E, using protons (24 to 200 MeV) and heavy ions (LET: 1.87 to 60.0 MeV cm²/mg). The following table shows an overview of used irradiation testing facilities during the REDI project.

Results

The following table shows a summary of all TID, TNID and SEE test results for all tested digital isolator components investigated during the project REDI. The table uses the following color code: GREEN indicates that the respective parameter is within the limits as specified in the data sheet, while RED indicates that the value measured exceeds the specification limits (parametric failure). GREY indicates that additional explanation is provided in the test report (e.g. deviations of the expected device behaviour or the occurrence of failure mechanisms), while BLACK indicates a functional failure.

Summary and Outlook

We could show the feasibility of using digital isolators in space applications and encourage further testing activities. Comparing three digital isolator technologies (1) capacitive coupling, (2) monolithic transformer, and (3) giant magnetoresistance, two promising candidates (ISO7220MDR, MAX14850ASE+) are using capacitive coupling. However, we cannot recommend this technology in general, as the other capacitive-coupled devices show high sensitivity to SEL. We recommend extending TID tests from standard dose rates, (3.6 krad/h(Si) to 36 krad/h(Si)) as carried out during this study, to low dose rates (36 rad/h(Si) to 360 rad/h(Si)), as time-dependent or rebound effects may explain some observations e.g. functional failures after annealing at 100°C. For components with the monolithic transformer technology (ADUM1201ARZ, ADUM1100URZ) we observed that de-lidding was not possible without damaging the devices. In addition, we observed, that the coupling coils are shielding a significant part of the die thus preventing the heavy ions penetrating into some active sections of the die. The proton tests hint towards threshold LETs concerning SEL or SET of more than approximately 15 MeV·cm^2/mg. Due to lack of heavy ion data we cannot provide a worst-case analysis for SET and SEL for those components. We recommend considering heavy ion testing at higher energies providing a reasonable penetration for components and technologies that show difficulties during de-lidding. However, only some heavy ion accelerators (e.g. GANIL and GSI in Europe, NSRL in Brookhaven, USA) supply heavy ions of sufficient high energy and LET. The restricted availability and high costs of beam time at these facilities need to be considered. We tested components only from a single lot or trace code. Most likely, this information is limited to traceability for COTs components. Consequently, this study cannot conclude about the lot-to-lot variance of the radiation hardness of digital isolators. We recommend further testing considering potential lot-to-lot variations. For investigation of part-to-part variation of commercial components, testing with elevated sample sizes might be considered.

Technology		Capacitive Coupling				Monolithic Transformer		Giant Magneto Resistant
Manufacturer		TI Texas Instruments		Maxim Integrated	Silicon Labs	Analog Devices		NVE[1] (IsoLoop)
Investigated Part		ISO7220MDR	ISO15DW	MAX14850ASE+	Si8261ACC-C-IP	ADUM1201ARZ	ADUM1100URZ	IL715-3E
Lot Code		4286983TW4[2] 4662957TN4[3]	4043232TN4	0001755035	1333CF600U	1TAK96092.9	AJ60138.5	132361, 135210
Date Code		-/1419	-	1406	-	-	1351	-
Numbers tested		50 / 15	44	52	57	51	57	45
TID	Parametric failure level	> 300 krad(Si)	10 krad(Si)	50 krad(Si)	30 krad(Si)	20 krad(Si)	20 krad(Si)	30 krad(Si)
	Functional failure level	> 300 krad(Si)	> 300 krad(Si)	100 krad(Si)	168 h @100°C	100 krad(Si)	N/A [4]	> 300 krad(Si)
	Dielectric withstand	100 krad(Si)	100 krad(Si)	> 300 krad(Si)	> 300 krad(Si)	>300 krad(Si)	> 300 krad(Si)	FAIL at 0 krad(Si)
	Recovery	No	No	No	No	168 h @100°C	N/A [4]	partially yes
SEE	Delidding							N/A
	SEL	None	Yes $\sigma(Xe) = 10^{-6}$ cm²	None	Yes $\sigma(Xe)=2 \cdot 10^{-4}$ cm²	None @protons	None @protons	N/A
	SET	Yes $\sigma(Fe) = 10^{-3}$ cm²	Yes $\sigma(Fe) = 10^{-3}$ cm²	Yes $\sigma(Xe)=4 \cdot 10^{-5}$ cm²	Yes	None @protons	None @protons	N/A
	Dielectric withstand	N/A	N/A	Pass	Pass	Pass @protons	Pass @protons	N/A
Electrons	Parametric failure level	46.9 krad(Si)	-	-	-	-	-	-
	Functional failure level	95.2 krad(Si)	-	-	-	-	-	-
	Recovery	24h @RT	-	-	-	-	-	-
Neutrons	Parametric failure level	$> 9 \cdot 10^{11}$ n(1MeV)·cm^{-2}	-	-	-	-	-	-
	Functional failure level	$> 9 \cdot 10^{11}$ n(1MeV)·cm^{-2}	-	-	-	-	-	-

Table: Summary of Results for all Tested Components

Acknowledgements

The project was carried out within the scope of the radiation evaluation of digital isolators project (contract number: 4000112480/14/NL/SW) in the framework of TRP activities for the ESA Jupiter Icy Moon Explorer Mission (JUICE) coordinated by the European Space Agency (ESA). We acknowledge the support of ALR under FFG. We are grateful for the financial students support from ARDENT (Marie Curie Initial Training Network, contract number: PITN-GA-2011-28198-ARDENT). We wish to thank the staff at the HIF proton facility (PSI, Switzerland), the staff at the RADEF heavy ion facility (Univ. Jyväskylä, Finland) and the MEDISCAN for their support during the experiments.

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. During the past several years of shielding-code development, it has been established that aluminum space structures would make poor shielding for humans. The need to look at new ways of constructing spacecraft is now evident because current estimates indicate aluminum to be an ineffective protection material. This conclusion comes when analyzing the secondary particle production processes colliding with target nuclei within the shielding material. The most natural choice for an alternative shielding material are polymeric materials due to advances in their development through many last years and because of their mechanical properties. Their further development as a base construction material for future manned missions will add them a potential of minimizing the health risk to the astronaut from space radiations. Seibersdorf Laboratories is coordinating the ESA ITI (Innovation Triangle Initiative) project MUSRAS (Multiscreen Radiation Shield) in collaboration with CTNM, PTS, HPS and ESA. We started the project with the end of 2016 and will present the final report after 12 months.

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).

Objectives

The Objectives of the MUSRAS Study are:

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

Objectives of this study are related to the conception and the verification of a novel efficient space multi-screen radiation shield (MUSRAS) particularly designed for human long-term space missions. In contrast to conservative concepts, which apply metals for structural and shielding purposes, the proposed MUSRAS concept is based upon a multilayer/multimaterial approach. In our concept, we propose a specific layout of a multilayer stack, composed of single screens. The outermost shell is water providing the first shielding against energetic space radiation. Nest shells are specifically designed for efficient interaction with secondary particles, and therefore, have high specific damping properties for those radiation species. Proper design of multilayer shielding includes the identification and selection of the different composite materials composed of filler material with low atomic number Z-low, and also an optimization of the sequence of screens in order to achieve the best shielding performance for secondary particles.

Used Method and interim Results

We are defining a space mission to Mars and identify the relevant particle spectral data for solar cosmic radiation, galactic cosmic radiation and heavy ions in a worst case scenario. The following figure shows the proton data for solar cosmic protons, galactic cosmic protons and galactic cosmic heavier ions such as iron, carbon and helium for the worst case of the space mission to Mars. For this mission, we are modelling the shielding performance of different selected material candidates. For the most promising candidate we are producing the shielding demonstrator and perform experimental verification of the Monte Carlo simulation in high energy proton environment.

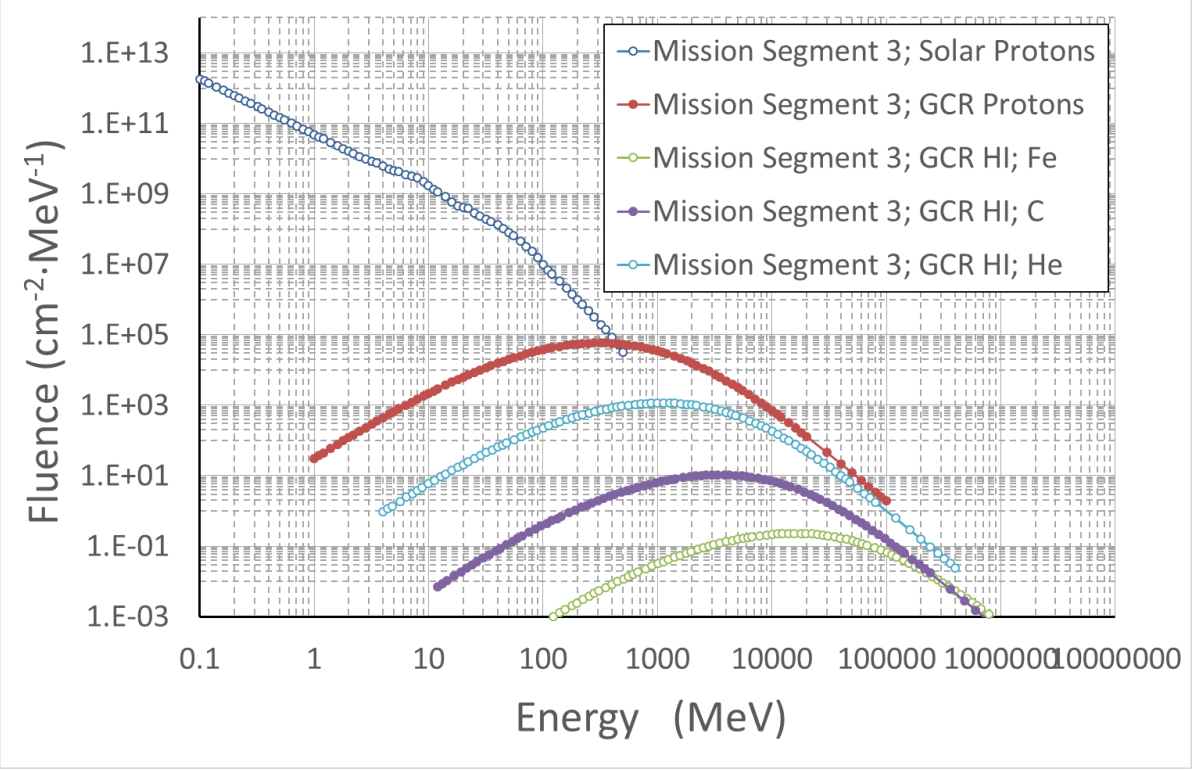

Figure: Particle spectra for solar cosmic radiation, galactic cosmic radiation and heavy ions for a worst case scenario to a space mission to mars (Mission Segment 3).

Summary and Outlook

We have successfully defined a space mission to Mars and have established the relevant Monte Carlo models for calculating effective dose equivalent, H_E behind shielding materials. The used radiation quantities comply with the document ICRP 123 on the *Assessment of radiation exposure of astronauts in space.* A comprehensive investigation of the shielding performance using Monte Carlo modelling has been conducted showing the capabilities of the MUSRAS shielding approach. Further, a demonstrator has been manufactured and experimental results have been compared successfully with the simulation data.

The project has been finished and a patent for the MUSRAS shielding approach is pending.

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 PRETTY (Passive Reflectometry and Dosimetry) mission is an Austrian Cubesat mission currently under development in a Phase B study for the European Space Agency (ESA). The PRETTY Project is coordinated by RUAG Space and carried out in collaboration with Seibersdorf Laboratories and Graz University of Technology. The CubeSat platform will host two different scientific payloads: A passive reflectometer, exploiting signals of opportunity for passive bistatic radar measurements and a reference dosimeter system, continuously assessing the ionizing dose on-board the PRETTY spacecraft. Seibersdorf Laboratories is responsible for the reference dosimeter system. The reference dosimeter system is described in the following in detail.

Dosimetry on-board CubeSat

Radiation environment at CubeSat orbits (typically sun-synchronous, 400-600 km altitude and >95° inclination) is composed of several components like trapped radiation (electrons and protons), solar particle fluences (from protons to heavy ions), and galactic cosmic radiation (GCR). 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 are less sophisticated.
In principle, one can distinguish two different kinds of active radiation sensors, which are interesting for CubeSat space missions: (1) integrating radiation sensors and (2) particle counting systems. Regarding integrating radiation sensors the RADFET is a well-known radiation sensor. Regarding particle counting systems, the market offers several sensors types, mostly pin-diodes are used. Seibersdorf Laboratories carried out together with DLR, PTB, Tyndall and MIRIAM a very detailed survey of dosimeter systems for the use in space during ESA's dosimeter project EuCPAD. While the RADFET provides assessment of the total ionizing dose (TID) in silicon gate oxide, pin-diodes enable pulse height analysis for the assessment of the distribution of energy deposition in silicon.

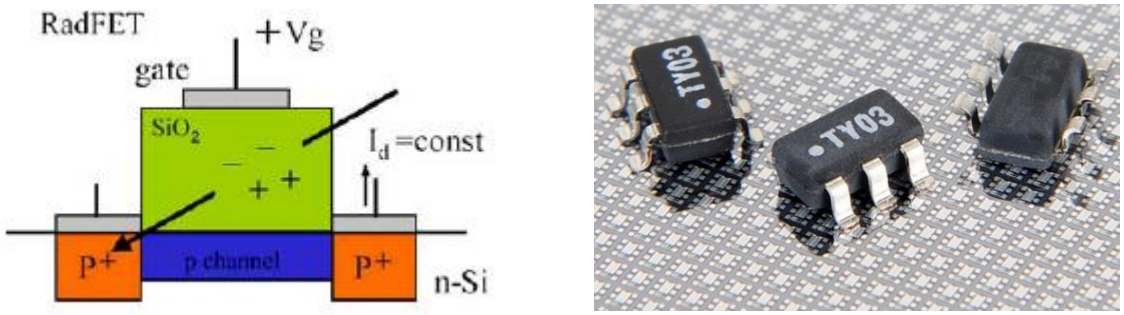

Figure: Left: Schematic principle of radiation sensitivity of a RADFET. **Right:** RADFET Type as provided by Tyndall

CubeSat space missions are an excellent opportunity for testing and demonstrating technology that will be used in more expensive space missions - but with lower costs. Very interesting candidates for such tests are electronic components, in particular COTS

(commercial components of the shelf). For reasonable testing of electronic components, Seibersdorf Laboratories is proposing a reference dosimeter systems on-board CubeSat. RADFETs as well as pin diodes are promising concepts for a reference dosimeter system.

Objectives

The objectives of the proposed radiation dosimeter payload for the PRETTY mission are:

- to assess the radiation mission dose and dose rate during the whole CubeSat space mission
- to provide a technology demonstration of a reference dosimeter system based on a RADFET radiation sensor on-board CubeSat

The assessment of the radiation mission dose and dose rate during the whole satellite's space mission is a main objective for the radiation sensor payload. The radiation sensor will provide information regarding total ionizing dose deposited in electronic components. 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.

Summary and Outlook

Seibersdorf Laboratories propose an appropriate TID reference dosimeter 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. Further it will provide a technology demonstration of a reference dosimeter system based on a RADFET radiation sensor on-board CubeSat. The gathered data will enable us to correct for temperature and ELDERS influences on the RADFET response. We will be able providing a reliable radiation hardness assurance testing of electronic components on-board future CubeSat missions using a reference dosimeter system based on RADFET.

Acknowledgements

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

RADHARD SYMPOSIUM 2017

Introduction

On 16th May 2017, Seibersdorf Laboratories organized their 2nd RADHARD-Symposium, which focused on Radiation Hardness Assurance Issues related to CubeSat space missions.

Objectives

The RADHARD-Symposium focused on:

- CubeSat Space Mission
- Practical Aspects of Radiation Hardness Assurance
- Innovative Testing Developments and Future Needs

The RADHARD Symposium was addressed to space systems integrators, EEE manufacturers, stakeholders from industry, research and science as well as students interested in radiation hardness topics. International experts presented new results and highlighting reviews.

Figure: Photo of the RADHARD 2017 Symposium participants with the TEC Laboratory in the background. The TEC Laboratory is Seibersdorf Laboratories' Co-60 irradiation facility for testing of electronic components.

Programme Summary

- One Keynote
- Two Talks on Space Radiation Environment
- Seven Talks on CubeSat Space Missions - Radiation Hardness Assurance Experiences and Challenges

- Five Talks on Selected Topics - Components and System Testing
- Four Talks on Selected Topics - Radiation Hardness Assurance

The RADHARD Symposium 2017 in Numbers

- One day event
- 40 participants
- 1 Keynote lectures
- 18 international presentations
- Lot of fruitful discussions and collaborations

Book of Abstracts

The book of abstracts is available for download online at https://www.seibersdorf-laboratories.at/en/radhard/archive/2017-radhard-symposium/ (ISBN for print: 978-3-902780-07-2, ISBN for e-book: 978-3-902780-08-9)

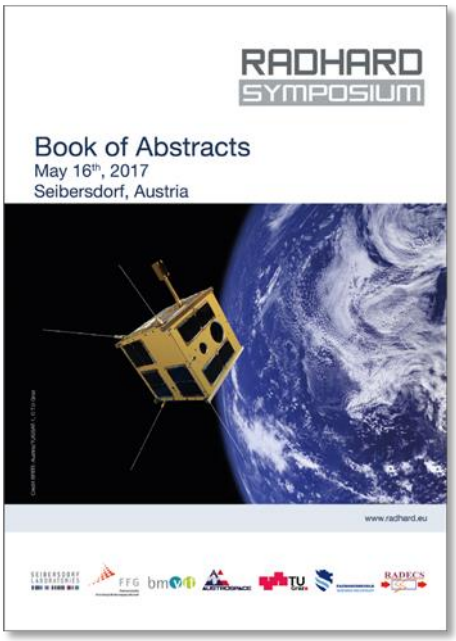

Figure: Book of abstracts of Seibersdorf Laboratories' 2nd RADHARD Symposium on 16th May 2017.

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 2017!

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

Introduction

The 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. TID tests are of particular interest to electronic applications in space. The exposure of the DUT (device under test) is performed in accordance with accredited procedures that are compliant with the EN ISO/IEC 17025 standard for test labs. To achieve the accreditation, the TEC-Laboratory has been fully characterized and subsequently audited by the Accreditation Austria - an independent governmental body certified for accreditation of test facilities. The Accreditation Austria is a full member of the International Laboratory Accreditation Cooperation ILAC and a signatory of the Mutual Recognition Arrangement MRA for “Testing, Calibration and Inspection”. The EN ISO/IEC 17025 standard specifies technical as well as management requirements that have to be satisfied.

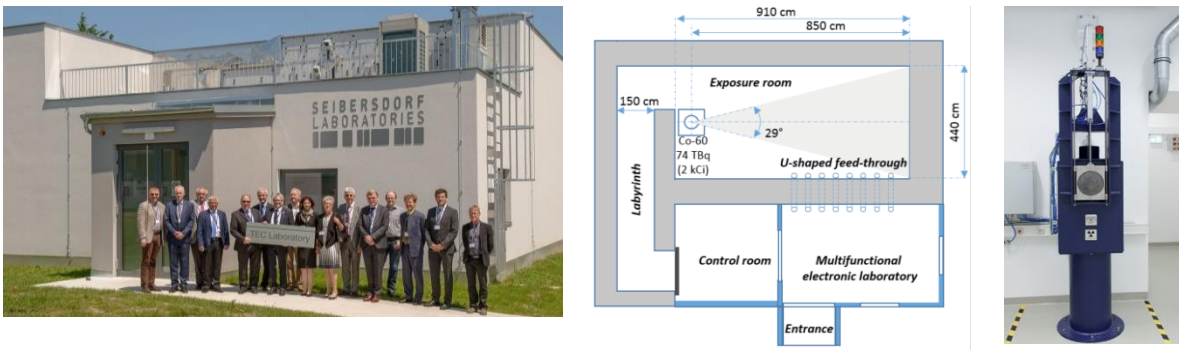

Figure: Inauguration of the TEC-Laboratory (left); floor plan of the TEC-Laboratory (middle) and the Cobalt-60 irradiation system (right).

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 (dose rate) level to which the DUT is exposed by the use of ionization chambers positioned closely to the DUTs

- Traceability of dose (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 electric lab, hardware (e.g. voltage sources, oscilloscopes, frequency generators, SMUs, etc.) 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 [6] and MIL-STD-750, Steady-State Total Dose Irradiation Procedure [7]. 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. In the following we give an overview of the implementation of the 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). The validation and technical competences in dose assessment are demonstrated by participation in intercomparison programs and regular 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 an accredited operating procedure. 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.

Characterization of the Co-60 photon field

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).

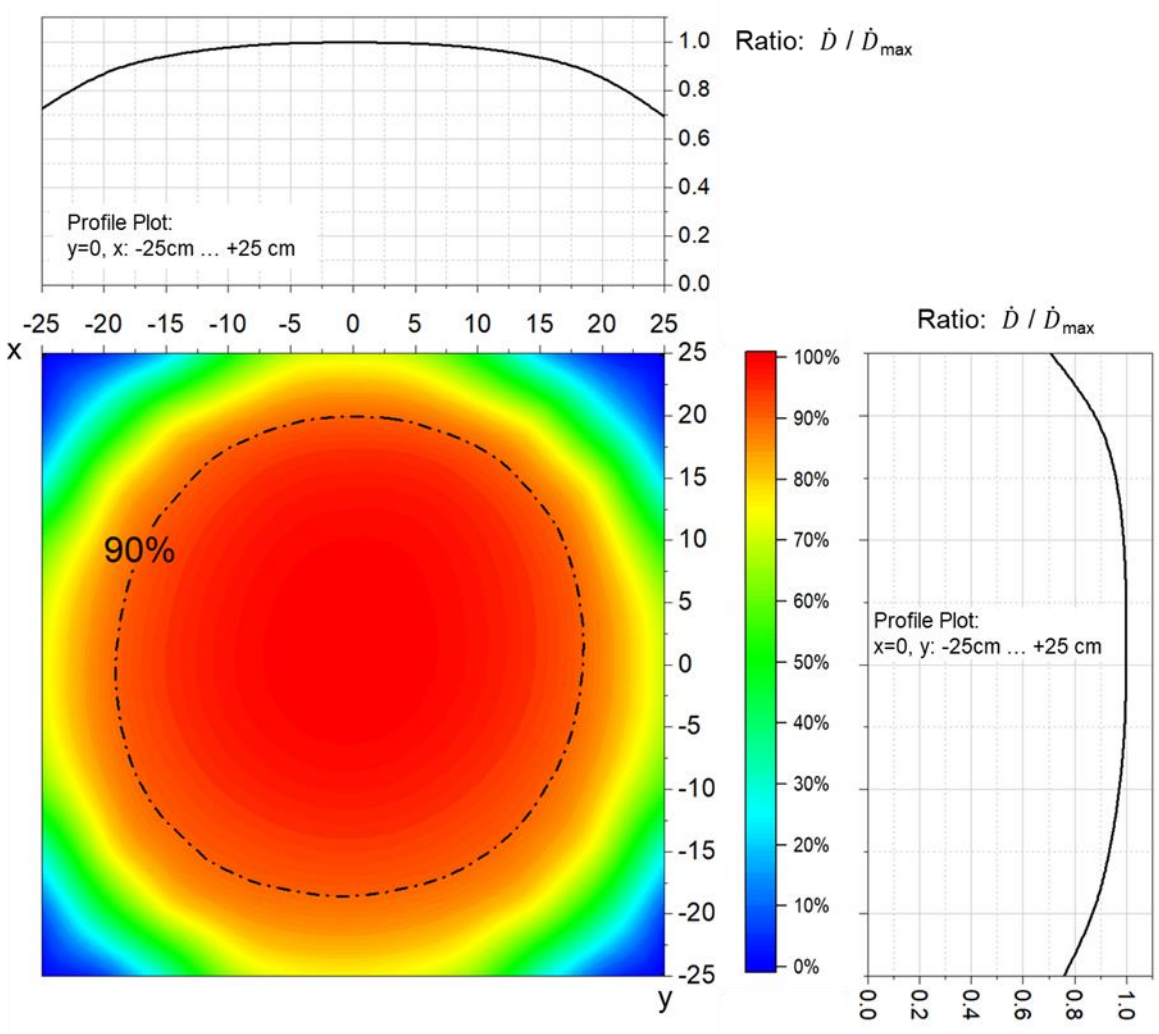

Figure: Measured spatial distribution of the dose rate, $\dot{D}$ compared to the maximum, $\dot{D}_{max}$ in a plane of 25 cm x 25 cm perpendicularly to the beam axis, in a distance of 100 cm to the radiation source. The area of dose rate > 90% of the maximum is indicated. Dose rate profiles are shown for y=0, x: -25 cm to +25 cm and x=0, y: -25 cm to +25 cm.

Summary and Outlook

The Seibersdorf Laboratories have developed accredited procedures 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 Cobalt-60 photon field of the TEC-Laboratory is characterized and shows a wide range of possible dose rates with large uniform cross sections. The TEC-Laboratory is ready for accredited TID exposure testing of electronics for space applications.

Total share for space projects 2017: 0.5 MEUR

Contact:

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3.11 Siemens Convergence Creators GmbH (Atos Convergence Creators since May 2018)

Siemens is a global powerhouse in electrical engineering and electronics. One of the world's largest producers of energy-efficient, resource-saving technologies, Siemens is a leading supplier of systems for power generation and transmission as well as medical diagnosis. In industry automation solutions the company plays a pioneering role for the factory of the future. The company has 377,000 employees (as of September 30, 2017) working to develop and manufacture products, design and install complex systems and projects, and tailor a wide range of services for individual requirements. In fiscal year 2017, Siemens generated revenues of €83.1 billion.

Siemens Convergence Creators, represented in Austria through the Siemens Convergence Creators Holding GmbH and the Siemens Convergence Creators GmbH, acts as an independent company that combines end-to-end IT and Industry Solution and Service competence for Communication, Media, Space & Technology.

Headquartered in Vienna, Siemens Convergence Creators engineers solutions and services for over 300 customers in 70 countries, across industries, with an international footprint of 19 locations in 11 countries, and an industry experience of over 5 decades.

Among the four Business Units of Siemens 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.

The Siemens Convergence Creators Holding GmbH was acquired by Atos on January 1, 2018. For the subsidiary Siemens Convergence Creators GmbH, this means that with the new shareholder the company name will be changed to Atos Convergence Creators GmbH in March 2018.

Siemens Space provides products, solutions and services

- For Satellite Operators
  - Carrier Monitoring Systems
  - Interference Localization Systems
- 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

With over 25 years of experience, Siemens Space has successfully executed far more than 200 projects for ESA, DLR, commercial satellite operators and satellite manufacturers.

In financial year 2017 sales revenues reached € 15.0 million, based on commercial market, ESA, Galileo, FFG and DLR activities. The share of ESA sales therein accounted for € 5.76 million.

The 2017 business was mainly focused on the following topics:

- Satellite Testing
- Satellite Control
- Satellite Communications

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

Continuing to provide valuable solutions to support our customers' Assembly, Integration and Testing (AIT) processes, Siemens 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 Siemens, 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 programme 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 satellite manufacturing market. Contract signatures 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: Siemens Convergence Creators)

Radio Frequency, Telemetry/Telecommand and RF Suitcase Test Systems

In 2017, the Siemens Convergence Creators Radio Frequency (RF) and Telemetry/Telecommand (TM/TC) Test System business included work for missions such as OneWeb, Metop Second Generation, Quantum, SARah, NGSAR, Sentinel-6, EUCLID and Exomars. The OneWeb PTS (Payload Test System)/TCR (Telecommand Ranging) project is, so far, the largest RF project for Siemens Space in terms of output volume. At the end, Siemens Convergence Creators will have delivered as baseline a mix of 18 sets of PTS and TCR standalone, PTS-TCR combined, PTS DITL (for Day in the Life tests) and TCR Lite.

The BepiColombo and MTG RF Suitcases were closed-out in 2017 and paved the way for further RF Suitcase projects, such as the JUICE RF Suitcase.

BepiColombo RF Suitcase
(Photo: Siemens Convergence Creators)

Power SCOE, Instrument and Payload EGSE Test Systems

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

In the Power SCOE domain Siemens Convergence Creators worked on missions such as OneWeb, Sentinel 6, Aeolus, BepiColombo and Solar Orbiter. The OneWeb Power SCOE is, so far, the largest Power SCOE project for Siemens Space in terms of output volume. At the end, Siemens Convergence Creators will have delivered as baseline 28 sets including 39 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 1, Sentinel 4, Sentinel 5, Metop Second Generation, and SARah,

Artist's impression of the JUICE mission exploring the Jupiter system (Source: ESA)

JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme. Planned for launch in 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.

For the JUICE mission, several projects were started, among those the Communication Subsystem EGSE, the RF SCOE and the Power SCOE projects.

Innovation: Next Generation Generic Spacecraft Interfaces (GSTP)

Going beyond the point of the successful innovation, which led to the ProUST Second Level Protection (SLP) and ProUST Front-End (FE) product development, we identified a number of further evolution and innovation points which, further analyzed and exemplarily implemented in the scope of a GSTP activity triggers the next level of excellence in the ProUST product family, and thereby provide optimum AIT support for upcoming missions and programmes.
The ProUST Front-End development project was finished in 2017.

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

The motivation of this innovation project is 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 name for the new product resulting from learnings of the CSAS study and going into the development of an operational product is **ProUST univerSAS**. It was available as a first version in 2017. 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.

ProUST UniverSAS (Photo: Siemens Convergence Creators)

- **Satellite Control:**
  Ground Segment Systems and Mission Control Software

Also in the year 2017, the main focus of Siemens 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 2017 and will be extended into 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.

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

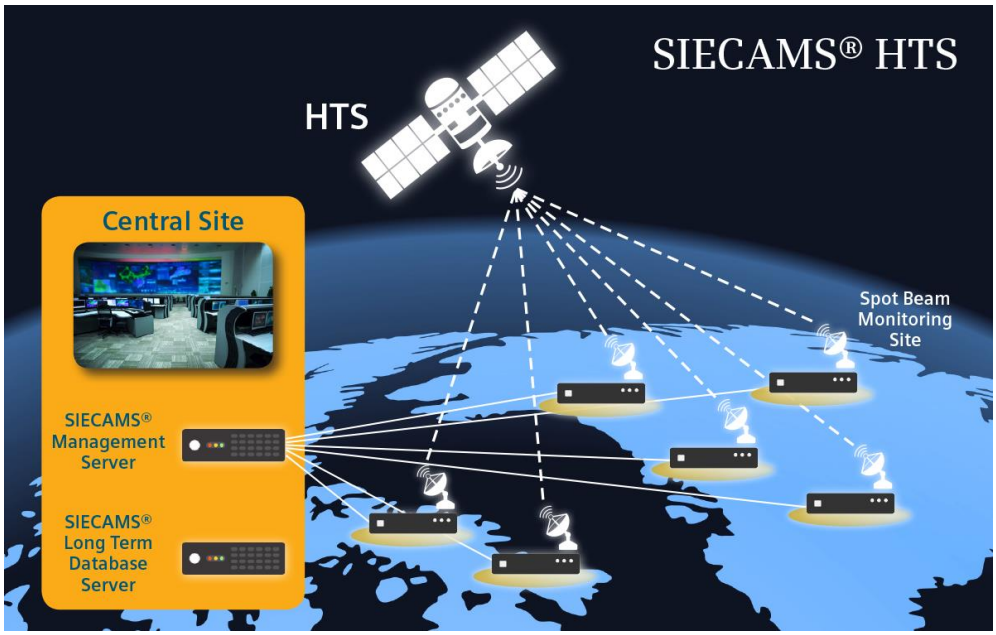
ESOC Mission Control Room (Photo: ESA/J.Mai)

Siemens 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.

In the Austrian Space Program (ASAP) research context, an ASAP-10 study for a High-Data-Rate Modem (led by Siemens, with Joanneum Research as partner) was finished. The ASAP-11 study Advanced Telemetry using Q/V Band (ATUQ, led by Joanneum Research) was finished as well.

- **Satellite Communications:**
  Carrier Monitoring and Geolocation Systems

The year 2017 was all about VSAT. VSAT's are very small satellite stations for bi-directional communication using satellite links. Because VSAT stations are very cheap and easy to install, hundreds of thousands are currently deployed and numbers are constantly increasing. Unfortunately, VSAT's are causing most of satellite interference and therefor the industry was eagerly looking for solutions to identify and localize VSAT stations causing interference.



HTS Monitoring showing the principle of VSAT Monitoring

That is why Siemens Space has started a research project to enlarge our state-of-the-art carrier monitoring and geolocation product SIECAMS with this capability. The activity is supposed to be co-funded by the ARTES C&G program.

The goal is to have a first version available by mid of 2018. The product shall be able to monitor all major VSAT networks independent from the used VSAT technology, to identify those stations which are exceeding pre-defined limits for cross-talking to other frequencies respectively satellites.

The support of this new technology shall ensure the leading technological position of SIECAMS in the satellite industry.

Space Revenue: 15.0 MEUR
ESA Share : 5.7 MEUR

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3.12 TeleConsult Austria GmbH

Field of Work

The major activities of TeleConsult Austria GmbH cover the field of precise positioning and reliable navigation, 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 telematics consultancy, system design and analysis, software development and testing, mobile computing, project preparation and management, marketing and development strategies for new products and services, business development and general management support.

International Partners

The expertise of the company team members is complemented 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 are working tightly together with TeleConsult Austria.

Our Customers

Governmental Agencies
Public Service Providers
Industry and SME

Our Offices

Office Address Graz
TeleConsult Austria GmbH
Rettenbacher Straße 22
8044 Graz
Austria

Office Address Liezen
TeleConsult Austria GmbH
Wirtschaftspark A
8940 Liezen
Austria

Project Highlight in 2017

SafeSki – Safety and Information Services for Ski Resorts

Initial Situation

Alpine winter sports such as skiing, snowboarding or cross-country skiing have been established for many years. The Alps comprise around 1,100 ski areas with around 27,000 kilometres of slopes. Every year, almost 9 million practice alpine skiing in Austria, which suggests 30 to 40 million skiers a year in the Alps.
Ski resorts are in constant competition for the favour of winter sport enthusiasts and are investing in the safety and comfort of skiers in addition to infrastructure such as snowmaking, lifts, access systems, catering services and slope equipment. Particularly in the latter area, new technologies and service concepts are providing athletes with personalized information

to enhance the traditional skiing experience. This approach is complemented by more and more modern provisions concerning the safety of winter guests.

SafeSki Services

Based on the situation described above, the SafeSki project team has been implementing and demonstrating the following two services since the end of 2016:

CHIS (Consumer Habits Identification Service)

This service enables the ski resort operators to answer the fundamental question of how winter athletes spend their time. For this purpose, anonymously collected data on ski resort visitors are used. Such information is gained from available local systems (e.g. ticketing systems) and from end user systems (e.g. ski resort or third party smartphone apps). On this basis, CHIS provides tools for data evaluation and analysis in relation to the information needs of different ski resort members (e.g. marketing, local administration and operations). The results are visualized to the ski resort operators in the service environment as corresponding statistics and graphics as well as in regional maps. The content includes

- Structured analysis of individual or grouped trajectories taking into account the time of day and weather conditions.
- Elaboration of heat-maps and speeding-maps to optimize lifts and the use of slopes and to guarantee the safety of the skiers with appropriate measures and
- Detailed understanding of individual and average length of stay, such as at lifts and ski huts.

The following figure is an exemplary screenshot of the SafeSki CHIS web interface, which shows the length of stay on selected lifts and points of interest in defined time periods.

Figure 1: Exemplary information in the CHIS web interface

DSS (Documentation Support Service)

The focus of the DSS is the simple documentation of a wide variety of activities in the operation of a ski resort, such as the recording of rescue operations, maintenance and control activities or avalanche blasting's with seamless subsequent data processing and communication. The system allows the semi-automatic filling of the required reports based on the mobile SafeSki app and allows the operator to efficiently edit and follow the relevant

work steps and the associated reporting. Due to that, the loss of information between the on-site activities and the documentation is sustainably minimized.
A primary added value of SafeSki over legacy systems is the improved availability and accuracy of the collected location information due to the use of EGNOS/EDAS data and the envisaged integration of the solution with third-party systems such as slope management, snowmaking systems or central avalanche portals.

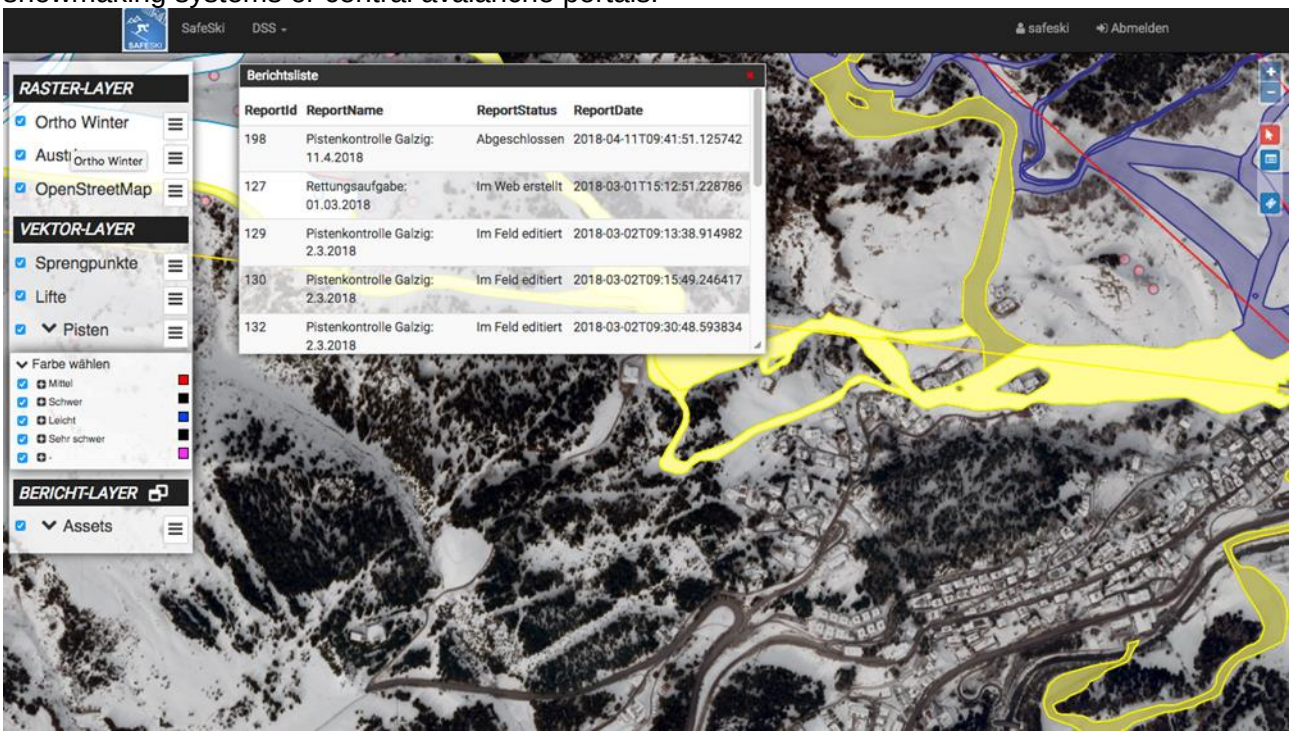


Figure 2: Exemplary information in the DSS web interface

Used Space Technologies

SafeSki uses the following space technologies:

- GNSS as a key technology for geo-referenced data in ski resorts and the collection of information on the movement behaviour of winter sports enthusiasts.
- EGNOS/EDAS to increase the accuracy, availability and integrity of collected GNSS data.
- Earth observation for the collection of comprehensive information about the snow cover within the ski areas.

Demo Regions

The following four ski resorts are actively involved as demonstration regions:

- Téléverbier (Switzerland)
- Crans-Montana (Switzerland)
- Ski amadé (Austria)
- Arlberger Bergbahnen (Austria)

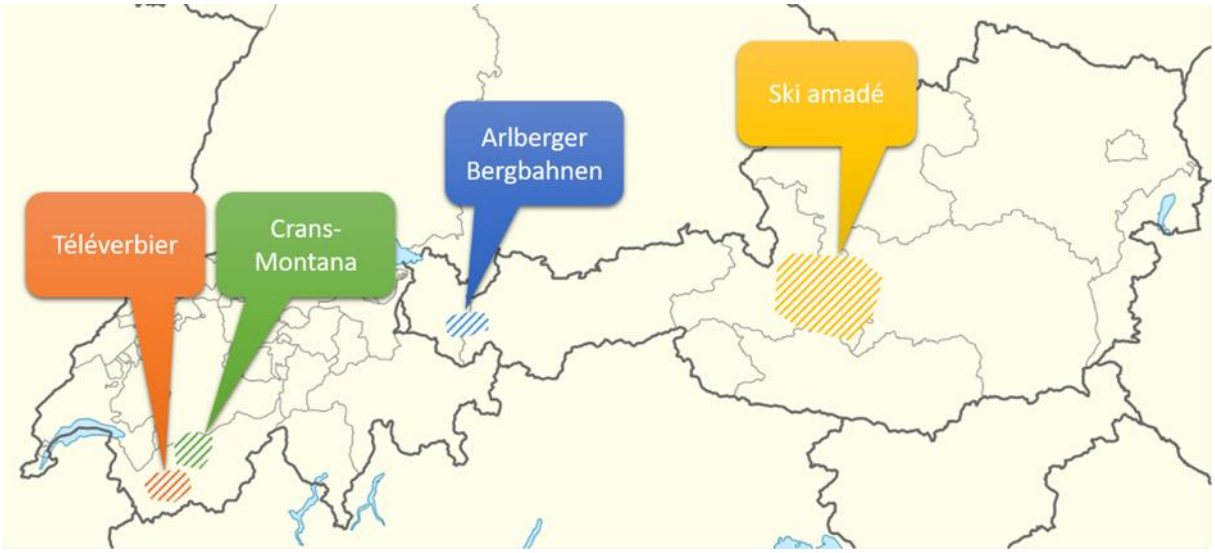


Figure 3: SafeSki Demo Regions

In addition to the coordination of user requirements and the implementation of CHIS and DSS, the services were installed in the regions listed for the 2017/2018 season and used on a daily basis in operation. On the basis of this demonstration, a validation of the defined KPIs, the collection of potential improvements and the coordination with regard to the future use of the SafeSki services will take place.
In this context, the following benefit chains should be opened during the demonstrations and future use of SafeSki Services:

- Detailed understanding of the behaviour of winter athletes.
- Increasing customer numbers through optimized processes and shorter waiting times.
- Increased safety by immediate identification of critical slope sections.
- Time savings in data collection through fast and easy documentation in the field and efficient post-processing in the operations centre.
- Reduced staff and operating costs by optimizing work processes and infrastructure.

In order to ensure this, especially with CHIS, the position data of SafeSki are prepared as shown in the following figures. This is done by smoothing and interpolation of the trajectories in position and height and their correlation with ticketing information (known positions of the gates and transit times). The result is a detection probability of individual trajectories of over 90%.

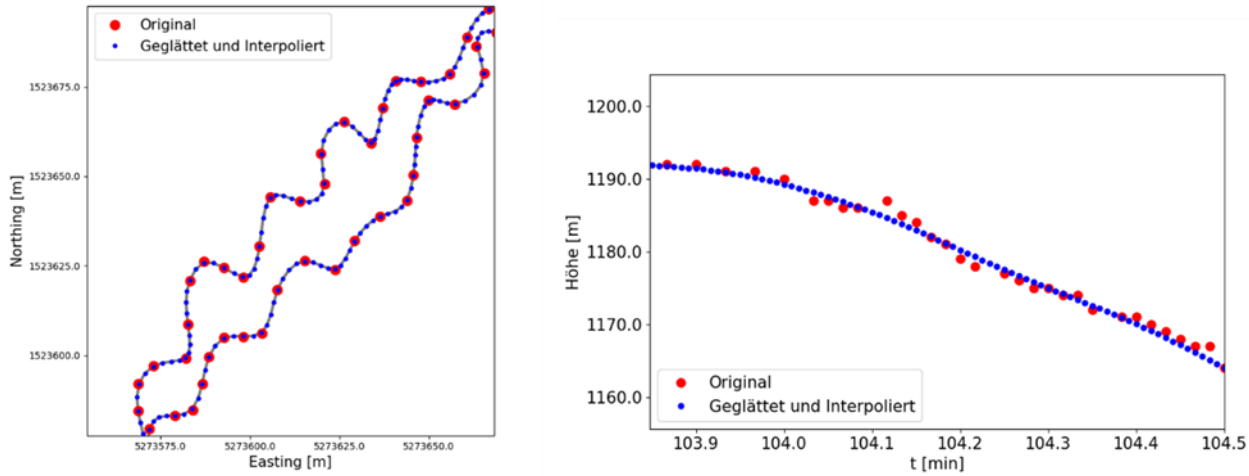
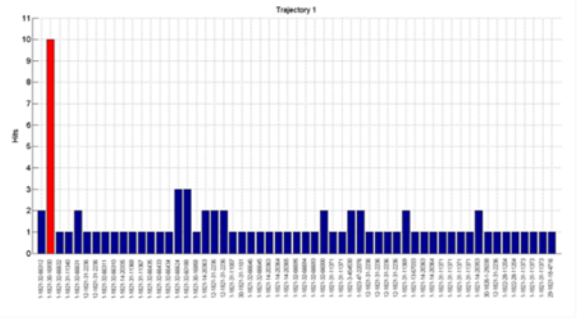


Figure 4: Improvement, smoothing and interpolation of the trajectories in position and height



Ticket ID	Tickettyp
1-1821-30-169307	Tageskarte
1-1821-30-169308	Partnerkarte

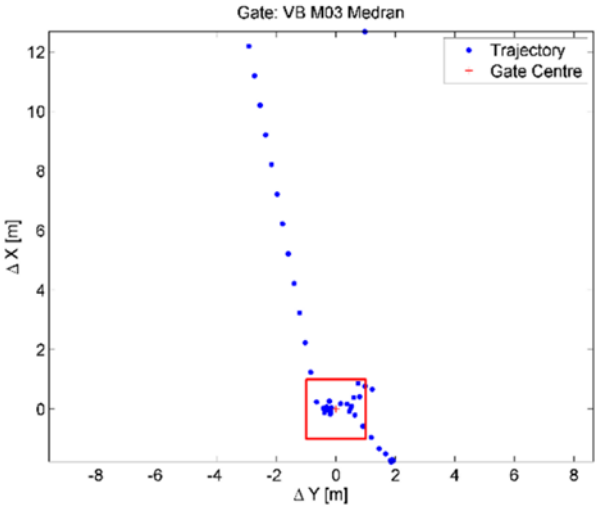


Figure 5: Correlation of position and ticket data

Marketing

The market potential of the SafeSki Services is defined primarily by the number of ski resorts. These add up to just over 800 in the DACH (Germany, Austria & Switzerland) region. Based on the demonstration regions, the first marketing phase focuses on the top 10 ski areas in Germany, Austria and Switzerland. Due to the reference tests conducted in the winter season 2017/2018, the next step will be the licensing of SafeSki CHIS and DSS. For CHIS, the marketing departments of the ski resorts addressed are the primary contact persons for a possible implementation, so for DSS it is the local operation of the ski area or individual lift operators.

Brief information about the SafeSki project

SafeSki is a European Space Agency (ESA) partially funded demonstration project under the Integrated Applications Promotion (IAP) program based on the previous ESA SafeSki Feasibility Study. The demonstration project has a duration of 24 months beginning November 2016 and consists of the following partners:

- TeleConsult Austria GmbH, Austria, http://www.teleconsult-austria.at
- BRIMATECH Services GmbH, Austria, http://www.brimatech.at
- GEOSAT SA, Switzerland, http://www.geosat.ch
- esc Aerospace GmbH, Germany, http://www.esc-aerospace.com
- TeleOrbit GmbH, Germany, https://teleorbit.eu/de/

Contract Value: 625,- k€

Sales: ***1.3 MEUR***
ESA Share: 0.5 MEUR

Contact:

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3.13 Graz University of Technology (TU Graz)

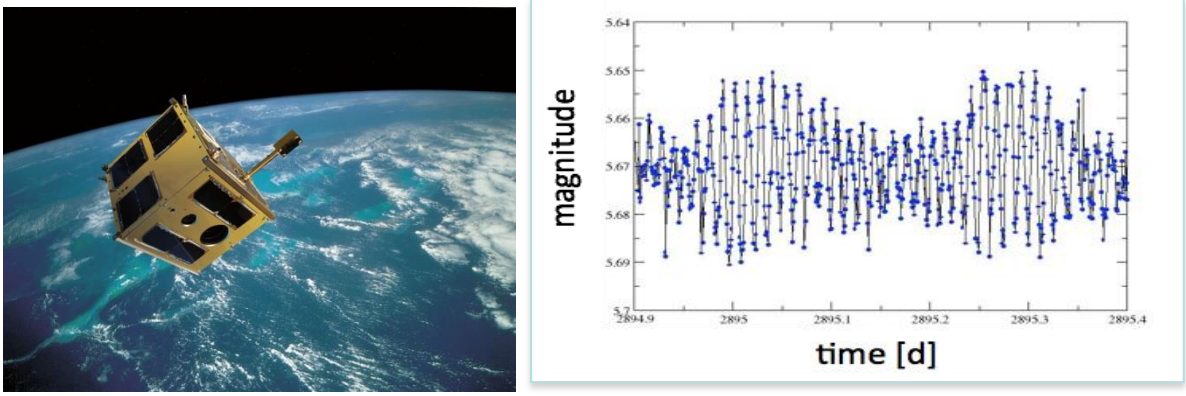
Graz University of Technology has been active in Space technology and Space experiments since the late 1960ies. The current activities by the Institute of Communication Networks and Satellite Communications, the Institute of Geodesy and the Institute of Experimental Physics are concerned with satellite communications, satellite navigation, satellite geodesy, remote sensing and the development of Space-qualified hard- and software, especially small satellites including their operations. The Institute of Experimental Physics (IEP) at TU Graz is in joint collaboration with the Space Research Institute (IWF) of the Austrian Academy of Sciences. Both institutions develop a novel scalar Quantum Interference Magnetometer based on the Coherent Population Trapping (CPT) effect ready for space missions. More recently, projects by TU Graz have included robotics and speech recognition in support of Space missions. The following sections show some examples of the Space activities by TU Graz:

Institute of Communication Networks and Satellite Communications (IKS)

<u>Nanosatellite Missions BRITE, OPS-SAT and PRETTY</u>

TUGSAT-1/BRITE-Austria by TU Graz (funded by FFG) and its sister satellite UniBRITE (owned by the University of Vienna) have been successfully in orbit since February 2013 as part of “BRITE Constellation”, consisting of five nanosatellites from Austria, Canada and Poland. They deliver excellent scientific data from photometric measurements of massive luminous stars.

BRITE is the world‘s first nanosatellite constellation dedicated to asteroseismology. The smallest Space telescopes detected the biggest stellar heartbeat.

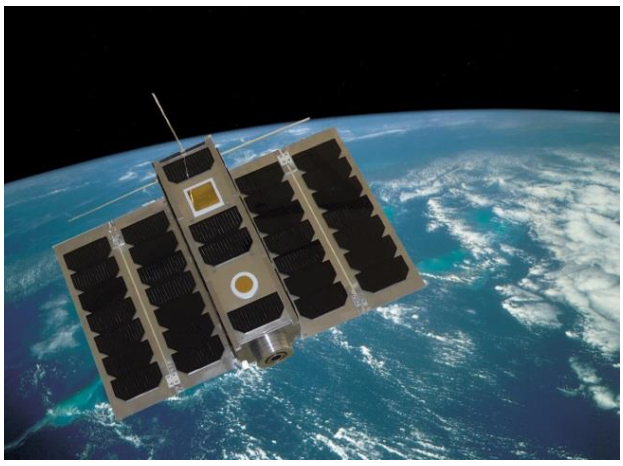


TUGSAT-1 Satellite (left); measured stellar pulsations (right)

More than 30 star fields with about 450 stars, selected by the international BRITE Executive Science Team (BEST), have been observed so far by BRITE Constellation, resulting in about 3.5 million measurements.
BRITE results were presented at highly successful BRITE Science Conferences in Gdansk (2015), Innsbruck (2016) and Montréal (2017). The publication rate of the BRITE Science Team is about one peer-reviewed publication every 6 weeks..

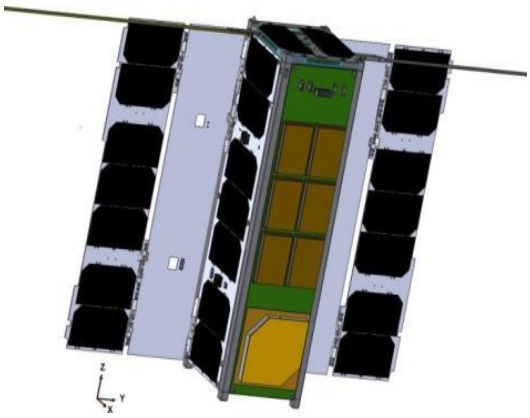
OPS-SAT is ESA's first fully owned nanosatellite mission. It is 100% compatible with ESA's ground infrastructure and fully implements the CCSDS communications standard, a novelty for CubeSats which traditionally re-use amateur radio technology. The main objective of the mission is to stimulate innovation in the area of mission operations. OPS-SAT will be the first in-orbit demonstration of a spacecraft with the new MO (Mission Operations) services defined by CCSDS. OPS-SAT is also a hardware/software laboratory in Space, providing means for experiments in the area of radio and optical communications, remote sensing, on-board image processing, attitude control and on-board autonomy. ESA offers experimenters an open policy to encourage fast and easy access to experimentation in Space.
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. OPS-SAT is currently in Phase D, will be launched in early 2019 and operated by ESOC with back-up by TU Graz.

A powerful Satellite Experimental Processing Platform was developed and qualified by TU Graz which is the primary OPS-SAT payload. It is a fully reconfigurable platform on which all major experiments will be processed.
In terms of communications the S-band telemetry provides a variable downlink data rate of up to 1 Mbit/s and an uplink rate of 256 kbit/s (the highest uplink data rate of all ESA spacecraft so far). This allows fast uploading of software images to the processor payload in flight. A CNES-funded miniaturised X-band transmitter is capable of transmitting up to 50 Mbit/s allowing fast download of large data volumes. A programmable software-defined radio front-end provides a "spectrum analyser in the sky" to measure interference in the UHF band.
A small on-board optical receiver will facilitate for the first time an optical data uplink to a nanosatellite. Whenever the spacecraft is in contact with the Laser station at the Lustbühel Observatory, a new cryptographic key will be transmitted and used to encrypt the X-band downlink. This is expected to provide a very secure way of communications.



OPS-SAT Mock-up (left), Processor Payload (right)

PRETTY (Passive Reflectometry and Dosimetry) is an ESA-funded nanosatellite mission developed by RUAG Space Austria as Prime Contractor and designer of the passive reflectometer, TU Graz as satellite designer/integrator and Seibersdorf Laboratories as provider of the dosimeter payload. In 2017 the consortium won the Austrian CubeSat competition within the GSTP program. PRETTY will demonstrate passive reflectometry and altimetry using a small and inexpensive CubeSat. The payload evaluates the direct and indirect GNSS signals (reflected by ice or water). Thus, glaciers and sea wave heights can be measured. Thus PRETTY has the potential to contribute to climate change research. The nanosatellite builds upon technology developed for OPS-SAT and previous studies carried out by RUAG and TU Graz within the ASAP Program. The dosimeter will help to better understand radiation effects on non-radhard components and to develop mitigation techniques.



3D Model of PRETTY

Satellite Communications

In cooperation with Space Analysis as Prime Contractor, Catalyst GmbH, Ubimet GmbH (all in Austria) and Avanti plc (UK) the ESA project Satcom Weather was successfully completed. The link quality of Very Small Aperture Terminals (VSATs) is highly dependent on the tropospheric conditions along the fixed slant path between the terminal and the satellite. A variety of additional parameters such as the orbital motion of the satellite, the pointing accuracy of the terminal, and thermal drifts of the transmitter/receiver degrade the link quality. Satellite network operators are interested in optimization of the service quality and their network operation. The Satcom Weather project supports VSAT operators. Hundreds of millions of measured VSAT signals and throughput records have been investigated to optimize thresholds for installations, and to derive weather data from the VSAT measurements. It could be demonstrated that propagation measurements from a VSAT network can be used to collect reliable weather data across very large geographical areas. Furthermore, it could be shown that the accuracy of short/medium-term weather forecasts provide means for satellite operators to adjust the power levels of individual spot beams, thus meeting the desired quality of service requirements.

VSAT Measurement Installation at TU Graz with self-pointing antennas

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E-mail: Koudelka@tugraz.at
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Institute of Geodesy (ifG) - Working Group Navigation

In general, the Working Group of Navigation within the Institute of Geodesy (ifG) at Graz University of Technology focuses its teaching and research on the complete aspect of navigation, which means that the thematic work goes beyond the determination of positions and trajectories, and also covers the sub-aspects of route planning and guidance**.**

As far as Global Navigation Satellite Systems (GNSS) are concerned, ifG was involved in research and development from the very beginning. Regarding trajectory determination, the current topics mainly cover multi-sensor systems, i.e., the sensor fusion of GNSS, INS (Inertial Navigation System) and filtering (Kalman filter, particle filter). ifG owns a highly accurate Inertial Measurement Unit (IMU) which can be used as a sensor in multi-sensor environments and helps to verify cheaper and smaller sensors (MEMS, etc.). Since earth-related navigation is subject to the earth's gravity field, another research area is the determination of the earth's gravitational field with the necessity of the provision of geoid heights with high accuracy for local to regional applications.

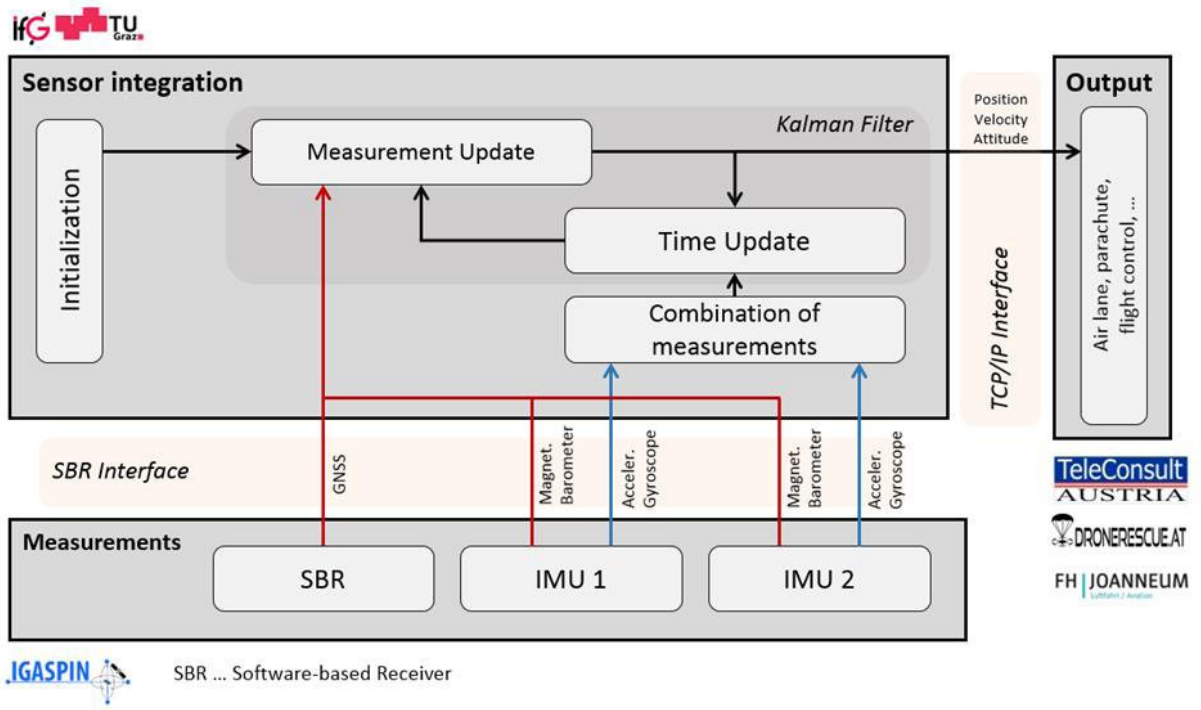
Similar to previous years, in 2017, space-related R&D-projects at ifG mainly covered GNSS-based navigation applications focusing on GNSS processing techniques like Precise Point Positioning (PPP) or Real-Time Kinematic (RTK) and on integration of GNSS and INS with respect to vehicles (cars, UAVs – Unmanned Aerial Vehicles) and pedestrians. In the sequel, two representative projects are shortly described.

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

DEMONA is an FFG/TAKE OFF project which started in October 2016. 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).



RADIAL2017 *(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 project RADIAL2017, a rotating synthetic aperture GNSS antenna is developed by *IGASPIN GmbH* and *Blickwinkel design & development*, in order to detect Jamming and Spoofing signals. *IGASPIN* is developing an algorithm, which not only detects the Jammers and Spoofers, but is able to measure the azimuth from the synthetic aperture antenna to them.

If these derived azimuth measurements are conducted from at least two locations, the position of the Jammers and Spoofers can be estimated in real time, see figure above. The demonstrator developed within the project is the basis for a future self-standing GNSS monitoring solution.

Sales (TU Graz total): 1.086 kEUR
ESA share: 442 kEUR

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3.14 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 the transportation and industrial segments according to a wide variety of functional safety standards. Key customers include the Volkswagen group, Intel, Kuka, Arianegroup, Boeing, General Electric, Lockheed-Martin and UTAS.

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 600 employees worldwide of which the majority works in engineering and development departments (hardware and software development, chip IP design, project management). Largest work location is still Vienna, Austria.

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 2017

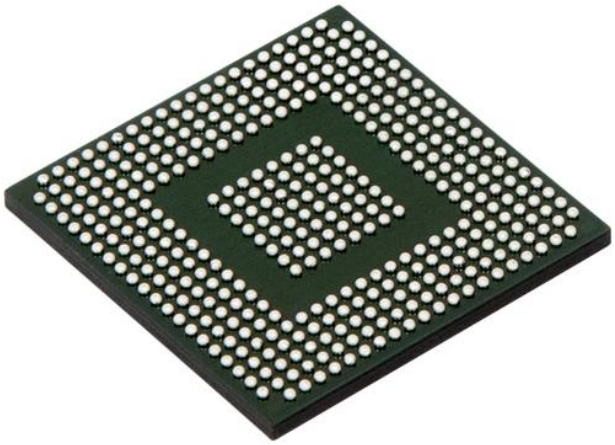
2017 marked the successful completion of TTTech's ESA FLPP-3 chip development activity, its largest ESA-funded project to date.

After that the dominating activity was chip firmware development, chip production and qualification as well as software tooling adaptations – all for the Ariane 6 launcher family. TTTech works as subcontractor/supplier to ArianeGroup and Airbus Defence & Space, but also to GTD in Spain which is responsible for the Ariane 6 ground control segment.

Our R&D project with ELV (financed by ASI, the Italian space agency) was also completed.

The ECSS working group for TTEthernet continued its work and the EtherSpace Alliance, co-founded by TTTech, continued to expand. At Space Tech Expo Europe, which took place in October 2017, TTTech was the most prominent Austrian exhibitor.

Total European space revenue increased further to Euro 2.7 million with an ESA share (including Ariane 6) of about 2.1 million.



TTEthernet Controller Hi-rel (currently being integrated by various equipment providers to Ariane 6)

Beyond Europe

In North America TTTech continued to pursue large opportunities with Lockheed Martin (prime contractor for the NASA MPCV), Boeing and Orbital ATK, as NASA has baselined TTEthernet for global "Deep Space Gateway" program. Also Blue Origin and SpaceX are targets of TTTech's North American office near Boston.

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

Being a space player primarily driven by commercial business, TTTech also continued to be active in Japan and China promoting the benefits of using Ethernet in space applications.

Key co-operations and shareholders

- Audi – main shareholder (about 30%), key partner in the automotive field
- Samsung, Infineon and GE – strategic investors
- NXP and Renesas – partners and licensees for the automotive market
- NASA – space act agreement

Total European space revenue increased further to Euro 2.7 million with an ESA share (including Ariane 6) of about 2.1 million.

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