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ANNUAL REPORT 2025

IWF
INSTITUT FÜR WELTRAUMFORSCHUNG

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COVER IMAGE

On 24 September 2025, Falcon 9 launched NOAA's *Space Weather Follow On Lagrange 1 (SWFO-L1)* spacecraft along with NASA's *Interstellar Mapping and Acceleration Probe (IMAP)* and the *Carruthers Geocorona Observatory* (© Ben Cooper, www.launchphotography.com).

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THE DIRECTOR'S PAGE 2025

In 2025, the IWF continued to strengthen its position as a leading Austrian institution for space research and technology development. Our mission remains clear: to design and build high-precision instruments for space missions, interpret the data they return, and share knowledge with the scientific community and the public. Our teams of scientists, engineers, technicians, and administrators worked tirelessly to advance fundamental research and technological innovation, laying the basis for future generations of space missions.

The year 2025 started with a major milestone: ESA/JAXA's *BepiColombo* spacecraft completed its sixth and final Mercury flyby in January, setting the stage for the orbital insertion in late 2026. This achievement marks a critical step toward unlocking the secrets of the innermost planet in our solar system. Two new missions joined our portfolio in 2025: *CSES-2*, launched in June, and *SWFO-L1*, launched in September. Both missions are flying with IWF know-how, extending our reach into space weather monitoring and planetary science. In August, ESA's *JUICE* mission successfully executed its Venus flyby, the second of four gravity assists on its eight-year journey to Jupiter and its moons.

Our research teams delivered ground-breaking results across multiple domains. Studies led by IWF scientists appeared in Nature Astronomy and Nature Communications, addressing fundamental questions about planetary formation, habitability, and space debris. Among the highlights were predictions of Earth-like exoplanets with helium-rich atmospheres and the detection of lithium in Mercury's exosphere – findings that reshape our understanding of planetary evolution and chemical diversity. Another study demonstrated the combination of satellite laser ranging and space debris laser ranging systems using megahertz lasers.

Exoplanet research continued to flourish, with data from *CHEOPS*, *JWST*, and other observatories fueling models of atmospheric composition and planetary evolution. The quality of our fundamental research enables us to work cross-disciplinary. Examples include the modeling of sulfur hazes in the lower Venus atmosphere, the prediction of non-LTE effects in the atmospheres of ultra hot Jupiters, and the study of space plasma around different object in the solar system. These efforts contribute to a holistic picture of planetary systems, from their birth in protoplanetary disks to their potential for hosting life.

The synergy between science and technology remains a defining strength of the IWF. In 2025, our engineering teams delivered flight hardware for upcoming missions, including components for ESA's *PLATO* and *SMILE*. These instruments push the boundaries


The IWF as part of the OeAW family.

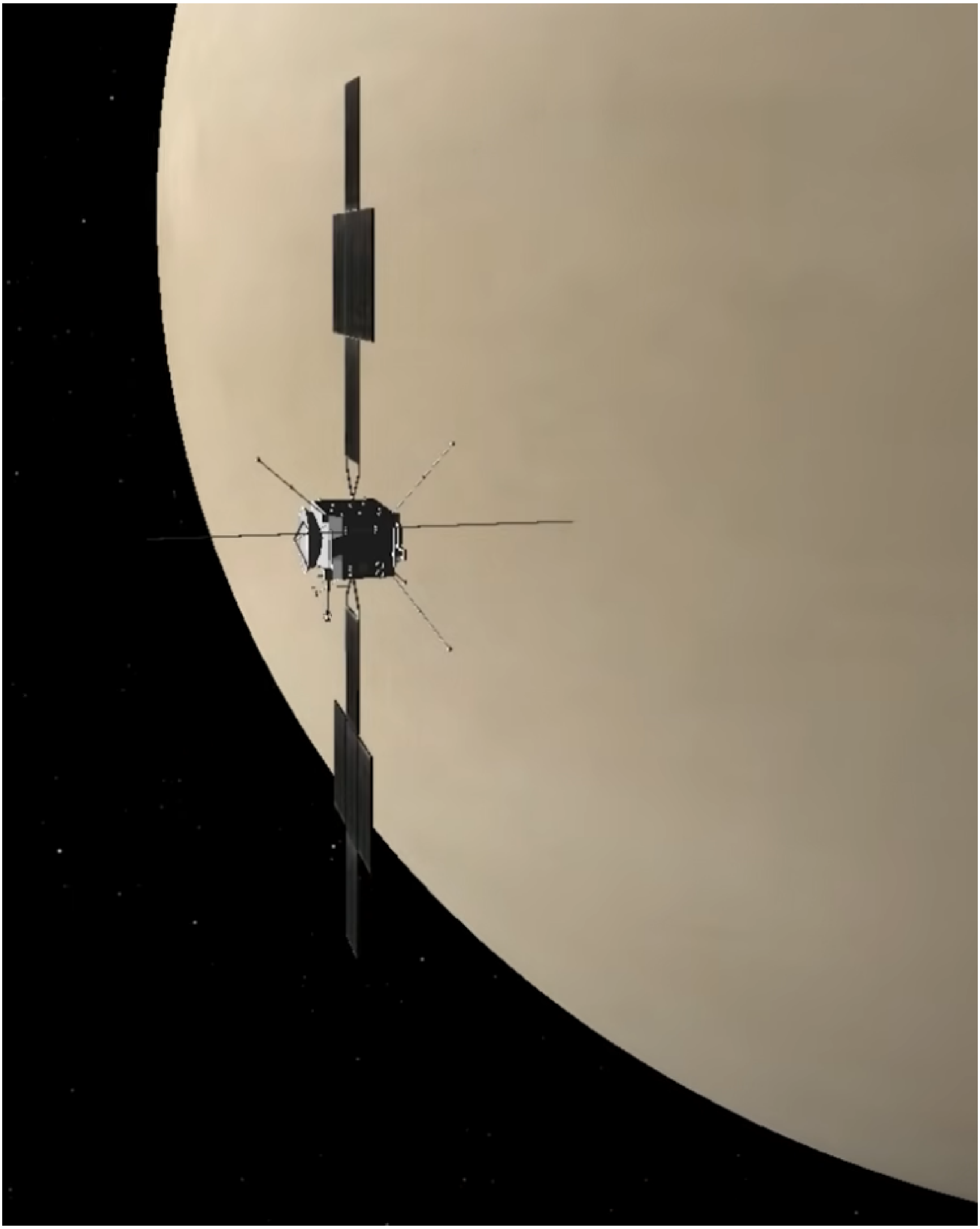
of miniaturization, radiation tolerance, and onboard computing, ensuring that future spacecrafts can operate reliably in harsh space environments. Our work on quantum interference magnetometers continued with successful deployments on missions orbiting Earth and en-route to Jupiter.

Engaging with society is central to our mission. Graz in Space 2025 celebrated ESA's 50th anniversary. The program featured lectures and discussions with experts from ESA, IWF, TU Graz, Uni Graz, and Joanneum Research, fostering the dialogue between science, technology, and the public. Our scientists contributed to URANIA Steiermark lectures, Kinderstadt Bibongo, and the European Researchers Night, sparking curiosity about space among audiences of all ages.

A wholehearted congratulation goes out to former IWF director Prof. Wolfgang Baumjohann for receiving the "Ehrenzeichen des Landes Steiermark für Wissenschaft, Forschung und Kunst I. Klasse" for his outstanding contributions to space plasma physics and instrument development for missions such as *MMS* and *BepiColombo*. The Aerospace Team Graz received the EuRoC Award 2025 and was accepted for the *REXUS/BEXUS* program in collaboration with the IWF. The Alpbach Summer School also marked its 50th anniversary, this year dedicated to small bodies in the solar system. In September, Nobel laureate Didier Queloz visited Graz for the *CHEOPS* Science Team Meeting and delivered a public lecture on the exoplanet revolution and life in the universe.

As we move into 2026, anticipation builds for *BepiColombo's* arrival at Mercury and continued data returns from *JUICE*, *SWFO-L1*, and *CSES-2*. We are looking forward to the launches of *SMILE* and *PLATO* in 2026/27. Our commitment to combining technological innovation with fundamental research remains unwavering, as does our dedication to sharing knowledge with society and inspiring future explorers.

With the best of wishes,
Christiane Helling



On 31 August 2025, ESA's *Jupiter Icy Moons Explorer (JUICE)* made a successful flyby past Venus in a flawless gravity-assist maneuver. During the encounter, *JUICE* passed closest to Venus at a distance of 5088 km while carefully shielding itself from the Sun's heat using its high-gain antenna as a thermal shield. Artist's impression taken from "The journey of Juice (episode 2, © ESA).

INTRODUCTION

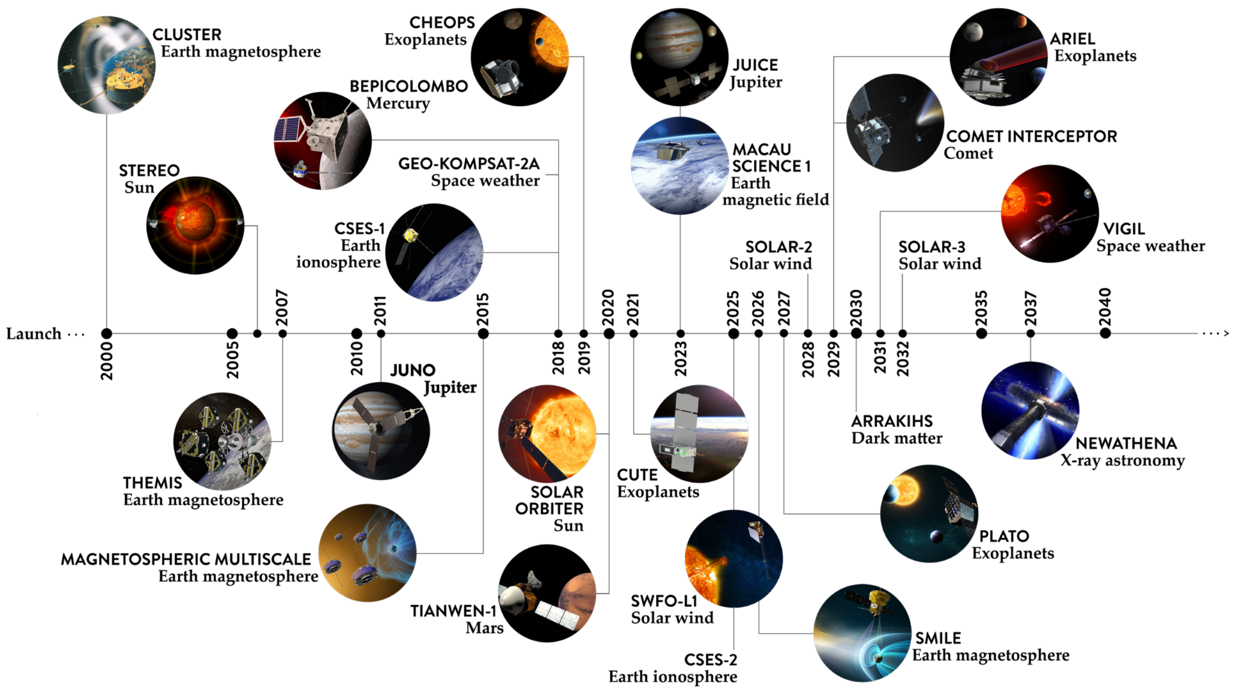
The Space Research Institute (Institut für Weltraumforschung, IWF) in Graz focuses on the physics of our solar system and the diversity of extrasolar planets. With about 100 staff members from 20 nations it is one of the largest institutes of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, OeAW).

The IWF develops and builds space-qualified instruments, analyzes and interprets the data returned by the space missions. Its core engineering expertise is in building magnetometers and on-board computers, as well as in satellite laser ranging, which is performed at a station operated by the IWF at the Lustbühel Observatory. In terms of science, the institute concentrates on the physics of solar and extrasolar planets, planet-forming disks, astrochemistry, and space plasmas.

The IWF cooperates closely with international space agencies and with numerous other national and international research institutions. Tight cooperation exists with the European Space Agency (ESA).

In 2025, the IWF was involved in 25 active and future international space missions; among these:

- The reentry of the second *Cluster* satellite in November 2025 continues the end phase of a this highly successful ESA mission in near-Earth space.
- The four *Magnetospheric MulitScale (MMS)* spacecraft perform multi-point measurements to study the dynamics of the Earth's magnetosphere.
- The first *China Seismo-Electromagnetic Satellite (CSES-1)* is studying the Earth's ionosphere. *CSES-2* followed in 2025.
- On its way to Mercury, *BepiColombo* had its sixth and last planetary flyby in January 2025.
- *CHEOPS (CHaracterizing ExOPlanets Satellite)* continues nominal science operations, characterizing exoplanets around bright stars.
- The NASA CubeSat *CUTE (Colorado Ultraviolet Transit Experiment)* is still delivering scientifically valuable data four years after launch.
- ESA's *JUpiter ICy moons Explorer (JUICE)* is on its way to Jupiter and its icy moons Ganymede, Callisto, and Europa.
- *SMILE* (launch: 2026) will study the interaction between the solar wind and Earth's magnetosphere.
- *PLATO* (launch: 2027) is a space-based observatory to search for planets orbiting alien stars.
- *Comet Interceptor* (launch: 2029) will characterize in detail, for the first time, a dynamically-new comet or interstellar object.



Timeline of IWF's active and future space missions (© *Cluster, BepiColombo, SMILE, PLATO, ARIEL, Vigil, NewAthena:* ESA; *STEREO, THEMIS, MMS:* NASA; *JUNO:* NASA/JPL; *CSES-1:* NSSC/CAS; *CHEOPS, Solar Orbiter, JUICE, Comet Interceptor:* ESA/ATG medialab; *Tianwen-1:* CNSA; *CUTE:* LASP/UCB; *Macau Science Satellite 1:* MUST; *SWFO-L1:* NOAA and BAE Systems).

HIGHLIGHTS IN 2025

In 2025, four "Nature" papers were published with major IWF contributions.

- In "Nature Communications" Michael Steindorfer et al. show the usage of Megahertz lasers to combine the strengths of both satellite and space debris laser ranging within one setup.
- In "Nature Communications" Daniel Schmid et al. used the magnetometer data from *MESSENGER* to analyze Mercury's exosphere and identified the presence of lithium, which has been predicted to exist, but had not been detected until now.
- In "Nature Astronomy" Helmut Lammer et al. found that Earth-like planets with masses between ~0.95 M_E and 1.25 M_E inside the habitable zone of Sun-like stars can end up with He-dominated primordial atmospheres. This has important implications for the evolution of Earth-like habitats.
- In "Nature Astronomy", an international team, with relevant IWF participation, reported the first detection of variability in the temperature and chemistry in the atmosphere of an ultra-hot Jupiter across latitude, longitude, and height. Previous observations have hinted at these variations, but the existing data have been fundamentally restricted to probing hemisphere-integrated spectra, thereby providing only coarse information on atmospheric gradients. Instead, the *JWST* observations presented in this work enabled to extract a spectroscopic eclipse map of WASP-18 b, resolving the atmosphere in multiple dimensions simultaneously. The mapping reveals weaker longitudinal temperature gradients than were predicted by theoretical models, indicating the importance of hydrogen dissociation and/or nightside clouds in shaping global thermal emission.

THE YEAR 2025 IN NUMBERS

Members of the institute published 136 papers in refereed international journals, of which 34 were first author publications. During the same period, articles with authors from the institute were cited 10671 times in the international literature. In addition, 95 talks (32 invited) and 39 posters were presented by IWF members at international conferences. Institute members lead or co-organized 13 international meetings, e.g. EGU General Assembly, EPSC-DPS Joint Meeting, EXOHOST Final Conference, *CHEOPS* Science Team Meeting, and two *PLATO* Workshops.

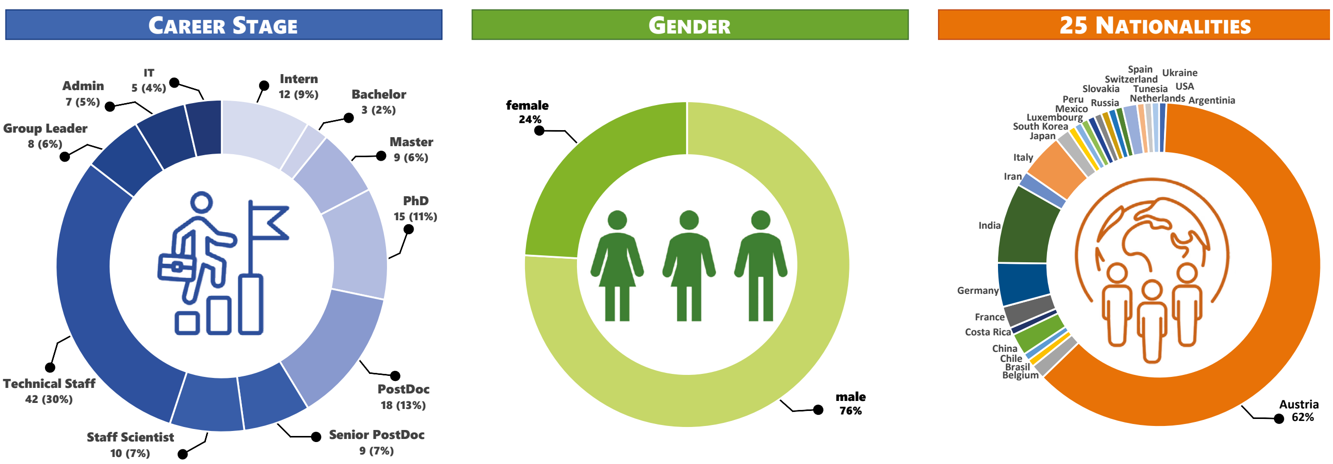
IWF STRUCTURE AND FUNDING

The institute is led by Prof. Dr. Christiane Helling and Doz. Dr. Luca Fossati serves as Deputy Director.

The IWF hosts eight research groups:

- Exoplanet Weather and Climate
  (Lead: Christiane Helling)
- Exoplanet Characterization and Evolution
  (Lead: Luca Fossati)
- Planet-Forming Disks and Astrochemistry
  (Lead: Peter Woitke)
- Solar System Planetary Physics
  (Lead: Helmut Lammer)
- Space Plasma Physics
  (Lead: Rumi Nakamura)
- On-Board Computers
  (Lead: Gabriel Giono)
- Space Magnetometers
  (Lead: Werner Magnes)
- Satellite Laser Ranging
  (Lead: Michael Steindorfer)

The IWF is mainly financed by the OeAW and to a lesser extent through competitive grants from the Austrian Research Promotion Agency (FFG), the Austrian Science Fund (FWF), the European Union, ESA, and NASA.



Career stages, gender, and nationalities of the IWF members in 2025 (© icons: AdobeStock).

SOLAR WIND & GEOSPACE

The solar wind is a stream of magnetized plasma produced in the solar atmosphere, which interacts with planets and bodies throughout the solar system. Among the different planetary systems, geospace is a natural plasma laboratory with different types of boundaries and regions that are created through the interaction between the solar wind and the Earth's intrinsic magnetic field and plasmas. Near-Earth space is therefore a suitable place to study fundamental physical processes such as plasma acceleration or heating as it is the most easily accessible region, with multiple spacecraft equipped with advanced instrumentations. The study of the near-Earth's plasma environment is essential for understanding how our planet as well as other planets work or have developed. How the Sun and solar wind affect the plasma environment of the Earth or other planets is called, in a more general term, space weather.

The IWF has been participating in a number of missions in geospace and solar wind from the planning and proposal phase, to the development and building of new hardware and finally the operation and calibration of the instruments. Data from these missions have been extensively analyzed at the IWF by applying different methods and theoretical models to compare with the observations. The research topics cover therefore both.

Combining *MMS* multi-point data with low-Earth orbit spacecraft as well as ground-based data, comprehensive analysis of plasma and magnetic field disturbances associated with kinetic ballooning-interchange instability activity in the magnetotail are performed and their effects on auroral activity are determined. These results are relevant to interpret the data from the upcoming *SMILE* mission, where the magnetospheric activity will be deduced from global auroral images. Studies combining in-situ measurements at different altitudes (distance from Earth surface) are essential to understand the magnetosphere-ionosphere coupling, i.e., energy/moment/mass exchange between the plasmas originating from the planet and the solar wind.

THEMIS/ARTEMIS

NASA's five-spacecraft mission *THEMIS (Time History of Events and Macroscale Interactions during Substorms)*, was launched in 2007. In 2010, the two outer spacecraft were sent to an orbit around the Moon and renamed *ARTEMIS (Acceleration, Reconnection, Turbulence and Electrodynamics MISsion)*. The inner three probes remained in their near-Earth orbits. As Co-I of the magnetometer, the IWF team is using *THEMIS* data to study dynamical processes in the magnetosphere as well as the dayside magnetosphere boundaries.

MMS

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

The IWF leads the *Active Spacecraft POtential Control (ASPOC)* of the satellites and participates in the *Electron Drift Instrument (EDI)* and the *Digital FluxGate magnetometer (DFG)*. In addition to the operation of these instruments and the scientific data analysis, the IWF is contributing to inflight calibration activities as well as deriving a new data product such as the density determined from the controlled spacecraft potential.

Since mid 2024, the spacecraft configuration has been changed to new configurations including larger separation. This change enables new multi-scale observations with unprecedented high temporal resolution. The schemes for selecting the burst-mode data for downloads have been modified accordingly.

CLUSTER

ESA's *Cluster* mission was designed to study different plasma processes due to the interaction between the solar wind and the Earth's magnetosphere. *Cluster*, launched in July and August 2000, was the first four-spacecraft mission that can differentiate between temporal and spatial changes of the different plasma processes. The IWF was Principal and/or Co-Investigator (PI/Co-I) on five instruments and contributed to data archiving activities at the *Cluster Science Archives (CSA)* in addition to the science data analysis.

After 24 years of successful observation, the first of the four *Cluster* space science satellites, *Salsa*, successfully deorbited on 8 September 2024 over the South Pacific and *Cluster* ended its science operation. The second satellite, *Rumba*, reentered the atmosphere on 22 October 2025 at a remote corner of the South Pacific Ocean. The last two *Cluster* satellites, *Samba* and *Tango*, will reenter about 24 hours apart in August 2026.

VIGIL

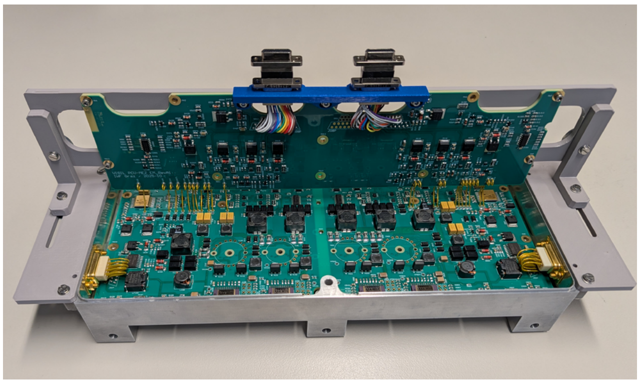
In the early 2030s, the *Vigil* mission of ESA shall position a satellite at the fifth Sun-Earth Lagrange point, which trails the Earth in its orbit by 60 degrees. The mission aims to perform continuous 'side' view observations of the Sun and particularly the space between the Earth and the Sun, thereby providing measurement data for operational space weather services.

Space weather refers to the environmental conditions in space as influenced by the Sun and the solar wind. These conditions can have various effects on technological systems in space and on Earth. Space weather includes phenomena such as solar flares, coronal mass ejections (CMEs), solar wind variations, and geomagnetic storms. These events can impact satellite operations, GPS navigation, power grids and radio communications, among other things. Understanding and monitoring space weather is important for safeguarding both space-based and ground-based technology and infrastructure.

The *Vigil*-based monitoring system is foreseen to substantially increase the accuracy of space weather forecasting and improve the reliability of event-based warnings when solar events take place.

The payload contains instruments which remotely observe the Sun and the direct path between the Sun and the Earth as well as sensors which monitor the magnetic field and the plasma configuration at the position of the spacecraft.

The IWF, as partner of Imperial College London, provides the fluxgate magnetometer measuring the magnetic field from very low frequencies up to about 60 Hz for solar wind monitoring as well as the detection and characterization of high-speed solar wind streams. IWF's main responsibility lies in the manufacturing and test of the Power Control Unit (PCU) as well as the on-ground calibration. The focus in 2025 was on the assembly and test of two precursor models of the PCU in preparation for the development of the later Qualification and Flight Models.



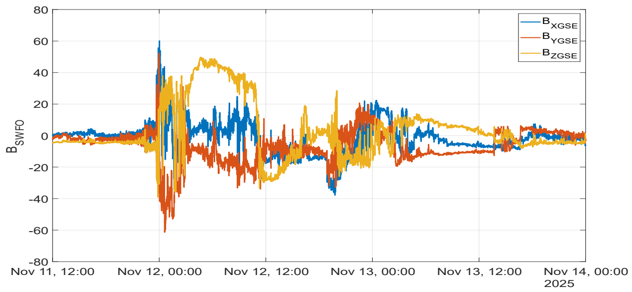
Electrical and Functional Model (EFM) of the Power Control Unit (PCU) mounted to the test frame for functional and performance verification before delivery to Imperial College London for instrument integration.

SPACE WEATHER FOLLOW-ON

The *Space Weather Follow On (SWFO)* mission is a joint undertaking by NASA and the National Oceanic and Atmospheric Administration (NOAA). The satellite will collect solar wind data and coronal imagery to support NOAA's mission to monitor and forecast space weather events. Its launch took place on 24 September 2025. The *SWFO-L1* satellite will orbit the Sun at approximately 1.5 million kilometers from Earth in Lagrange point L1. At this point the gravitational and centrifugal forces of Sun and Earth balance each other, which makes it an ideal place for observing the Sun.

The Southwest Research Institute together with two sub-contractors at the University of New Hampshire (UNH), Durham, and the IWF designed, developed, integrated, and calibrated the magnetometer instrument *SWFO-MAG*. It includes two three-axis magnetometers and associated electronics to measure the vector of the interplanetary magnetic field. The IWF has the lead for the Sensor Controller Board, which hosts the front-end electronics for the two fluxgate sensors. A microchip, which has originally been developed for the *Magnetospheric Multi-Scale* mission, is the central component of the front-end electronics.

IWF's main activities in 2025 included remote support of the pre-launch phase and the commissioning of *SWFO-MAG* during the transition phase between launch and arrival at Lagrange point L1. However, 2025 also saw the start of the development phase for two follow-up missions, which are scheduled for launch in 2028 and 2032 to ensure seamless and reliable space weather forecasting from L1. The magnetometer for these two missions will again be built by the *SWFO-MAG* team.



The *SWFO* magnetometer measured the magnetic field at the spacecraft location on its way to L1 during the solar event, which reached the spacecraft just before midnight on 12 November 2025 (preliminary data). Magnetic field amplitude and variation are increased by more than a factor of five.

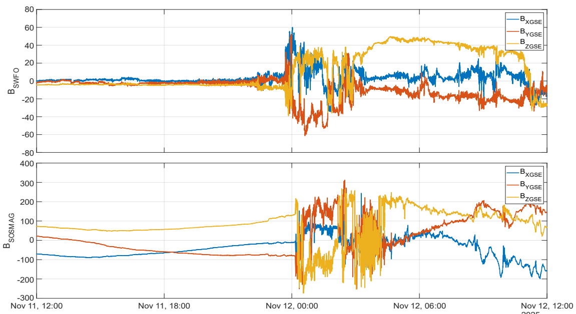
GEO-KOMPSAT-2A

GEO-KOMPSAT-2A (GEOstationary KOrea Multi-Purpose SATellite-2A, GK-2A) is a South Korean meteorological and environmental satellite in geostationary orbit at 128.2° East, which also hosts a space weather environment monitoring system. The Korean Meteorological Administration managed the implementation of the satellite, launched in 2018, and the necessary ground segment. The space weather observations aboard *GK-2A* are performed by the Korean Space Environment Monitor (KSEM), which was developed under the lead of the Kyung Hee University. It consists of a set of particle detectors, a charging monitor and a four-sensor *Service Oriented Spacecraft MAGnetometer (SOSMAG)*.

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

Flight data verification, in-flight calibration and operation support were continued also in 2025, the seventh year of operation. A fault-free operation is particularly important now, as the Sun is still in its most active phase, resulting in regular strong interactions with the Earth's magnetosphere.

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



SOSMAG (lower panel) measured the magnetic field in geostationary orbit during the 12 November 2025 geomagnetic storm, which was the strongest storm of 2025, ranked third in strength within Solar Cycle 25 so far. This space weather event, e.g., resulted in impacts such as loss of altitude on commercial satellites, disruptions in telecommunications, and rerouting of dozens of flights on near-polar routes. The same event was measured by *SWFO* on the Sun-Earth line earlier (preliminary data in upper panel) demonstrating the mission's space weather forecasting capability.

CSES

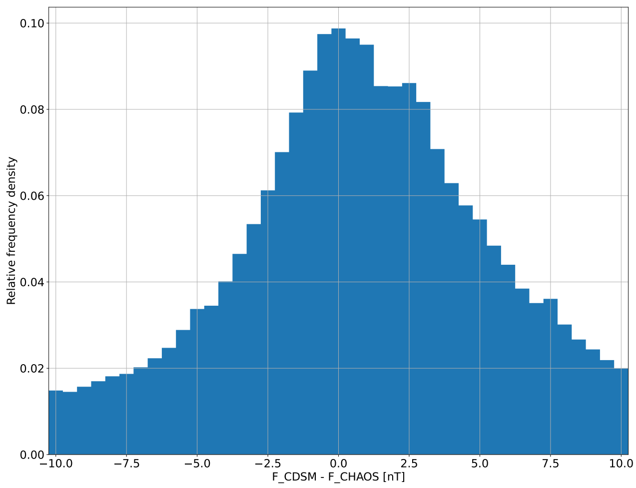
The *China Seismo-Electromagnetic Satellites (CSES)* are scientific missions dedicated to investigate and monitor varying electromagnetic fields and waves as well as plasma parameters and particle fluxes in near-Earth space, which are induced by natural sources on ground like seismic and volcanic events.

After the successful launch of the first satellite *CSES-1* in February 2018, *CSES-2* followed in June 2025. It is now in the same Sun-synchronous circular low Earth orbit as *CSES-1*, with a local time of the descending node at 2 pm, but with a phase difference of 180 degrees. The combined observations of both satellites double the detection probability of natural hazard-related events and will help to separate seismic from non-seismic events.

The *CSES* magnetometers, which are nearly identical on both spacecraft, have been developed in cooperation between the Chinese National Space Science Center (NSSC), the Institute of Experimental Physics of Graz University of Technology (TUG), and the IWF. NSSC is responsible for the dual sensor fluxgate magnetometer, the instrument processor and the power supply unit, while the IWF and TUG participate with the jointly developed absolute scalar magnetometer, called *Coupled Dark State Magnetometer (CDSM)*.

The magnetometer sensors of *CSES-1* have completed the seventh year of flawless operation in low Earth orbit with the first version of the *CDSM*, which was originally designed for a five-year operational lifetime.

The *CDSM* sensor aboard *CSES-2* was successfully commissioned together with the Chinese fluxgate sensors during the second half of 2025.



This histogram shows the difference between the magnetic field measured by the *CDSM* and the predicted field from the CHAOS model. The difference is well centered around zero, proving the accuracy of the in-flight measurements.

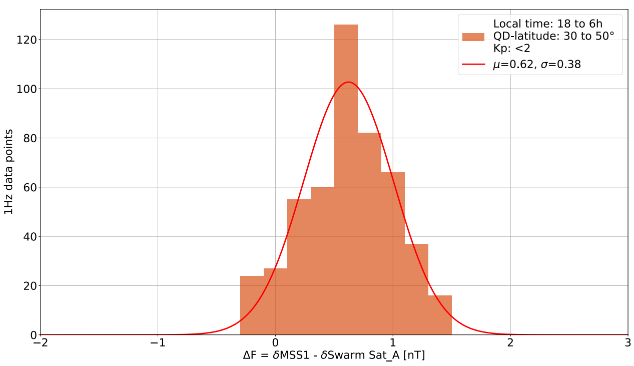
MACAU SCIENCE SATELLITE

Macau Science Satellite 1 was initiated by the Institute of Space Technology and Application at the Macau University of Science and Technology and has been implemented with support from the China National Space Administration and the local government of Macau. It consists of two satellites *(1A* and *1B)*, which were placed in a near-equatorial orbit with an inclination of 41° in May 2023 to study the geomagnetic field and specifically the South Atlantic Anomaly, from space.

The South Atlantic Anomaly is a region with a significantly weakened geomagnetic field and associated increased radiation impact on Earth. Its center lies over Brazil and its eastern coast. The inner of the two Van Allen radiation belts extends to about 700 kilometers from the Earth at the equator. In the region of the South Atlantic Anomaly, it comes much closer to Earth. Currently, this magnetic anomaly is increasing its spatial extension and the field strength is further decreasing, showing the dynamics of the Earth's dynamo. Together with ESA's *Swarm* mission, launched in 2013, it is explored and measured in greater detail than ever before.

The scientific payload aboard satellite *1A* consists of a high-energy particle detector, a star tracker, a fluxgate magnetometer, and a scalar magnetometer. The sensor and sensor-related electronics of the scalar magnetometer are contributed by the IWF in cooperation with the Institute of Experimental Physics of Graz University of Technology. The flight instrument is a replica of the instrument for the *CSES-2* satellite. The development of the processor and power supply electronics for the scalar magnetometer as well as its overall integration and testing were carried out by the Harbin Institute of Technology, Shenzhen in cooperation with the National Space Science Center of the Chinese Academy of Sciences.

2025 was the second full year of the mission's science phase. All instruments, including the Austrian *CDSM*, operated absolutely nominally, confirming a successful continuation of the science phase of the mission.



Histogram of the difference between the magnetic field strengths measured by the *CDSM* and the magnetometer of ESA's *Swarm A* satellite. Both satellites approach each other at regular intervals to within 250 km. The fitted normal distribution function shows a perfectly low mean difference of μ = 0.62 nT with a standard deviation of σ = 0.38 nT during 15 close approaches.

SMILE

The *Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)* is a joint mission of ESA and the Chinese Academy of Sciences (CAS), scheduled for launch in 2026. It aims to complete our understanding of the Sun-Earth connection by measuring the solar wind and its dynamic interaction with the magnetosphere. The IWF participates in two instruments: the *Soft X-ray Imager (SXI)*, led by the University of Leicester, and the magnetometer *(MAG)*, led by CAS.

The IWF, in cooperation with international partners, contributed the instrument's control and power unit *EBox* for *SXI*. It coordinated the development and design of the Digital Processing Unit (DPU) and was responsible for the mechanical design and the tests at *EBox* level. The IWF is also participating in the preparation of the science working group activities of *SMILE* including the modeling working group and is working on magnetic storm science topics relevant to the mission.

The *SMILE* team takes a quick break from testing the instruments to smile for a group photo in front of the spacecraft (© ESA & CAS).

SOLAR ORBITER

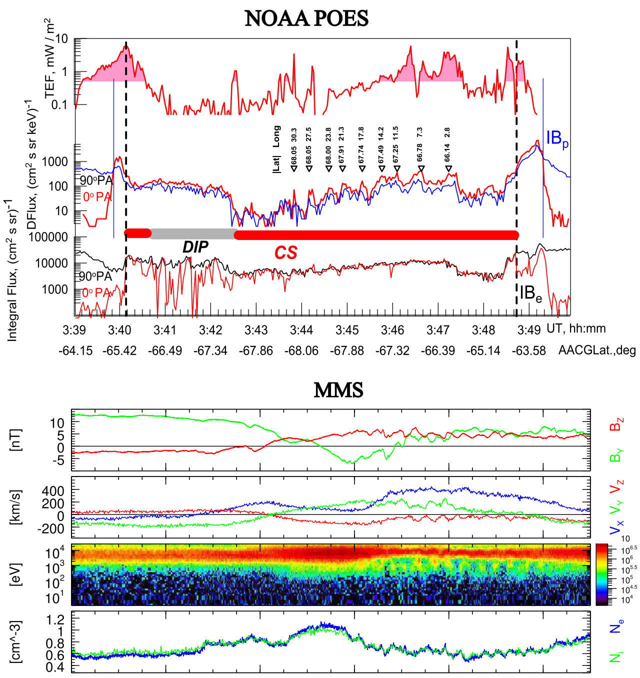
Solar Orbiter is an ESA-led space mission with NASA participation to investigate the Sun. Flying a novel trajectory, with partial Sun-spacecraft corotation, the mission investigates in-situ plasma properties of the inner solar heliosphere and observes the Sun's magnetized atmosphere and polar regions. Gravity assist from Venus and Earth will be used to reach the operational orbit, a highly elliptical orbit with perihelion at 0.28 au.

The IWF built the Digital Processing Unit (DPU) for the *Radio and Plasma Waves (RPW)* instrument and calibrated the *RPW* antennas, using numerical analysis and anechoic chamber measurements. Furthermore, the institute contributed to the fluxgate magnetometer *(MAG)*. *RPW* measures the magnetic and electric fields at high time resolution and determines the characteristics of magnetic and electrostatic waves in the solar wind from almost DC to 20 MHz. The instrument has been operating nominally since the launch in 2020.

ARE THERE BALLOONING-INTERCHANGE HEADS IN THE MIDTAIL?

The *Magnetospheric Multi-Scale* mission *(MMS)* observed a series of isolated dipolarization fronts (DFs) embedded in fast bursty bulk flows (BBFs) near 18 Earth's radii down the magnetotail, during a weak steady convection event. A number of distinctive signatures in the *MMS* data manifest kinetic ballooning-interchange instability (BICI) activity in the midtail, whose signatures were recently identified in near-Earth *THEMIS* observations. For the first time strong electromagnetic waves near the proton-cyclotron frequency were identified in the magnetometer data, which also showed a signature in the high-resolution plasma data (top image). The predicted azimuthal wave propagation was confirmed from four-point observations and compared with the plasma flows' and DFs' motion. An adapted magnetospheric model to identify the ionospheric and ground footprints of the magnetic field lines was used. Inspecting energetic particles from conjugate low-altitude spacecraft azimuthal passages, for the first time the azimuthal structuring of energetic proton fluxes is found, suggesting multiple sheets of field-aligned currents (top image). Auroral observations indicate the presence of a structured poleward azimuthal auroral arc and injection points. *MMS* midtail observations are compared with previous near-Earth observations and the peculiarities of possible BICI generation during steady convection events is discussed. The midtail BICI activity could be associated with greater temporal and spatial scales as compared to those of the near-Earth BICI activity.

Panov et al., Earth Planets Space, 77, 152, 2025.



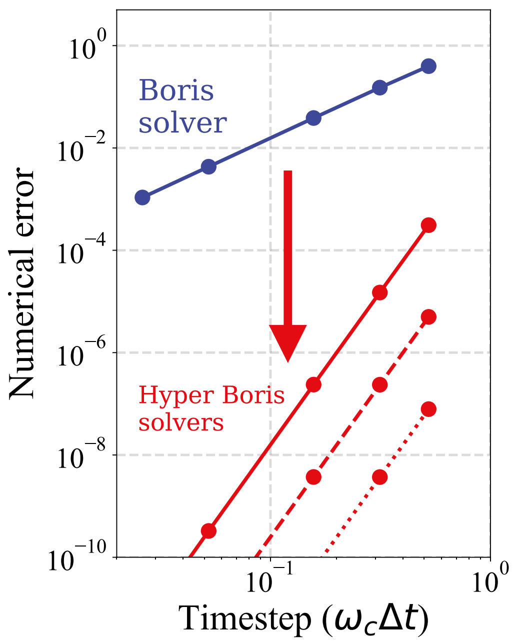
Conjugate low-altitude *NOAA POES* and in-situ *MMS* observations of magnetotail activity.

HYPER BORIS SOLVERS: HIGH-ACCURACY PARTICLE INTEGRATORS FOR PARTICLE-IN-CELL SIMULATION

Theoretical space physicists extensively use particle-in-cell (PIC) simulations. In the core part of PIC simulations, the (Buneman-)Boris method has been standard integrating the equation of motion for more than 50 years. It is second-order accurate in time and its numerical error is proportional to the square of the timestep, $\sim(\Delta t)^2$.

In this work, the non-relativistic Boris solver has been substantially extended. First, n-times subcycling has been introduced repeating the numerical procedure n-times, with an n-times smaller timestep, $\Delta t/n$. This allows for solving the equation with better second-order accuracy, $\sim(\Delta t/n)^2$. Second, higher-order modification to the standard method has been added. This achieves fully higher-order accuracy, $\sim(\Delta t)^N$ ($N = 2,4,6\ldots^{th}$ order). Third, these two methods were combined to amplify their benefits. This new method is called the hyper Boris solver, because it has two hyper parameters of the subcycling, number n, and the order of accuracy, N. The n-cycle N^{th}-order solver has an ultrahigh accuracy of $\sim(\Delta t/n)^N$, as shown in the figure below. The computational cost of the new solver is still affordable. As it achieves higher accuracy than before, larger timesteps can be used in the simulation. This in turn allows for performing more, or more complex, PIC simulations with the same amount of computing time.

Zenitani et al., Comput. Phys. Commun. 315, 109695, 2025.

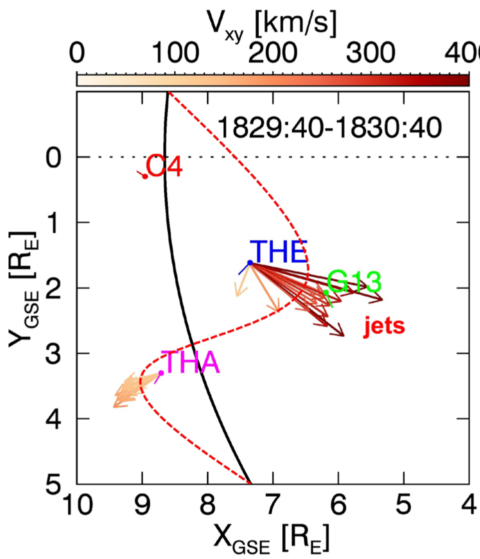


A scaling relation of numerical errors (vertical axis) as a function of the normalized timestep Δt (horizontal axis). Numerical errors by the standard Boris solver are shown in blue and significantly smaller errors by the new solvers (three variants of the 6^{th}-order hyper-Boris solvers) are shown in red.

MAGNETOPAUSE DEFORMATION INDUCED BY HIGH-SPEED JET FROM FORESHOCK TRANSIENT

The Earth's magnetic environment is constantly influenced by the solar wind. One pathway for energy transfer from the solar wind into the magnetosphere is through high-speed jets (HSJs), which are intense, fast streams of plasma generated by disturbances upstream of the bow shock. Using a combination of satellite observations *(Cluster*, *THEMIS*, and *GOES)* and ground-based measurements (SuperDARN, GPS-TEC, and magnetometers), a strong HSJ sequence, initiated by a foreshock transient, was tracked. These jets significantly deformed the magnetopause, sometimes depressing it toward the Earth, even closer than geosynchronous orbit. They also enhanced ionospheric convection and current systems. Overall, the results demonstrated how upstream solar wind disturbances can efficiently inject energy into near-Earth space, with clear impacts on the geospace system.

Kim et al., Geophys. Res. Lett., 52, 20, e2025GL117683. 2025.



Deformation of the magnetopause due to high-speed jets. Satellite locations (C4, THE, THA, G13), ion flow vectors, nominal (black), and reconstructed (red) magnetopause shape, based on the spacecraft observations.

MULTI-TERMINATOR METHOD TO REVEAL IONOSPHERIC DISTURBANCES BEFORE AN EARTHQUAKE

A multi-terminator method to investigate the ionospheric disturbances recorded before an earthquake (EQ) occurrence was applied to an EQ in Turkey on 6 February 2023. Those disturbances affected the amplitude and the phase of the VLF signal emitted by the TBB transmitter (27.31°E, 37.40°N, Turkey) and detected by the Graz facility (15.43°E, 47.06°N, Austria) at the IWF. The TBB transmitter ray-path crossed the preseismic sensitive region estimated from the Dobrovolsky relationship and the Fresnel zone.

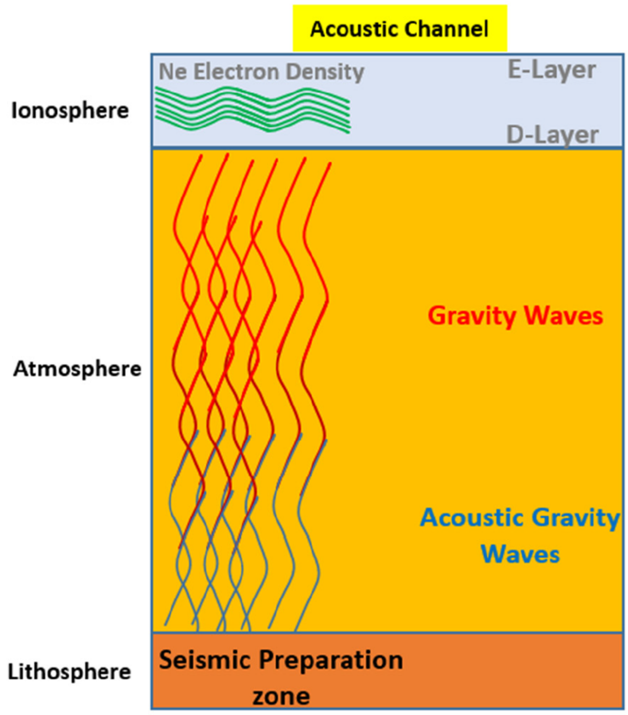


Illustration of the acoustic gravity waves channel based on the lithospheric atmospheric ionospheric coupling above the EQ preparation zone.

The spectral feature anomalies are linked to the perturbed ionospheric electron density above the EQ preparation zone. The following physical steps are considered in the acoustic channel as shown in the figure: In the lithosphere, micro-fracturing engenders free electron charges at the Earth's surface. Those charges modify the atmospheric conductivity and lead to the generation of weak acoustic gravity waves (AGWs), which strongly amplify with altitude. AGWs generate gravity waves (GWs) in the boundary between the higher atmosphere and the lower ionosphere. The anomalies in the transmitter signal (amplitude and phase) are related to the drop/growth of the ionospheric electron density created by GWs, mainly in the D-layer.

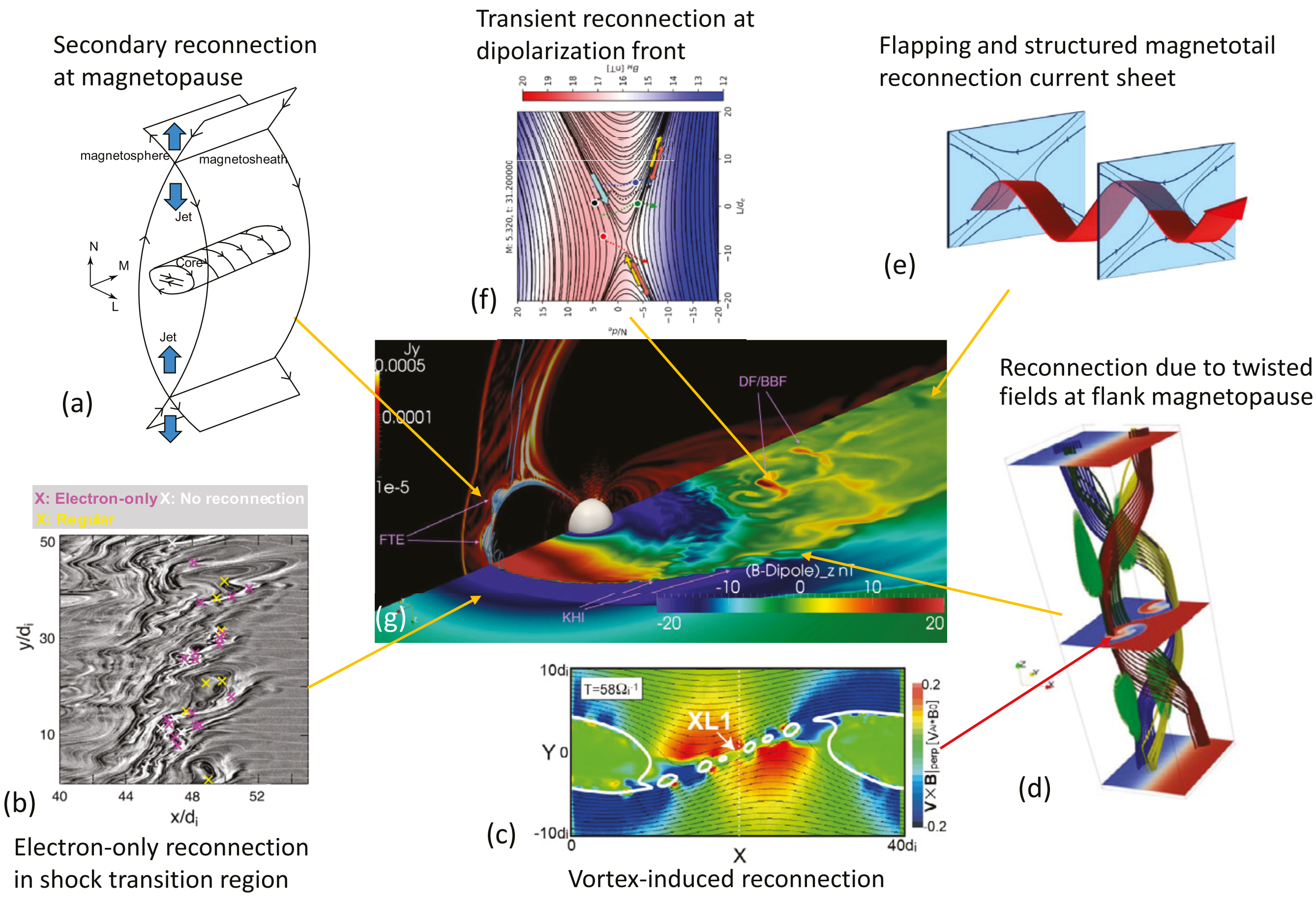
Boudjada et al., Geosciences, 15, 245, 2025.

WHAT ARE THE OUTSTANDING PROBLEMS OF MAGNETIC RECONNECTION?

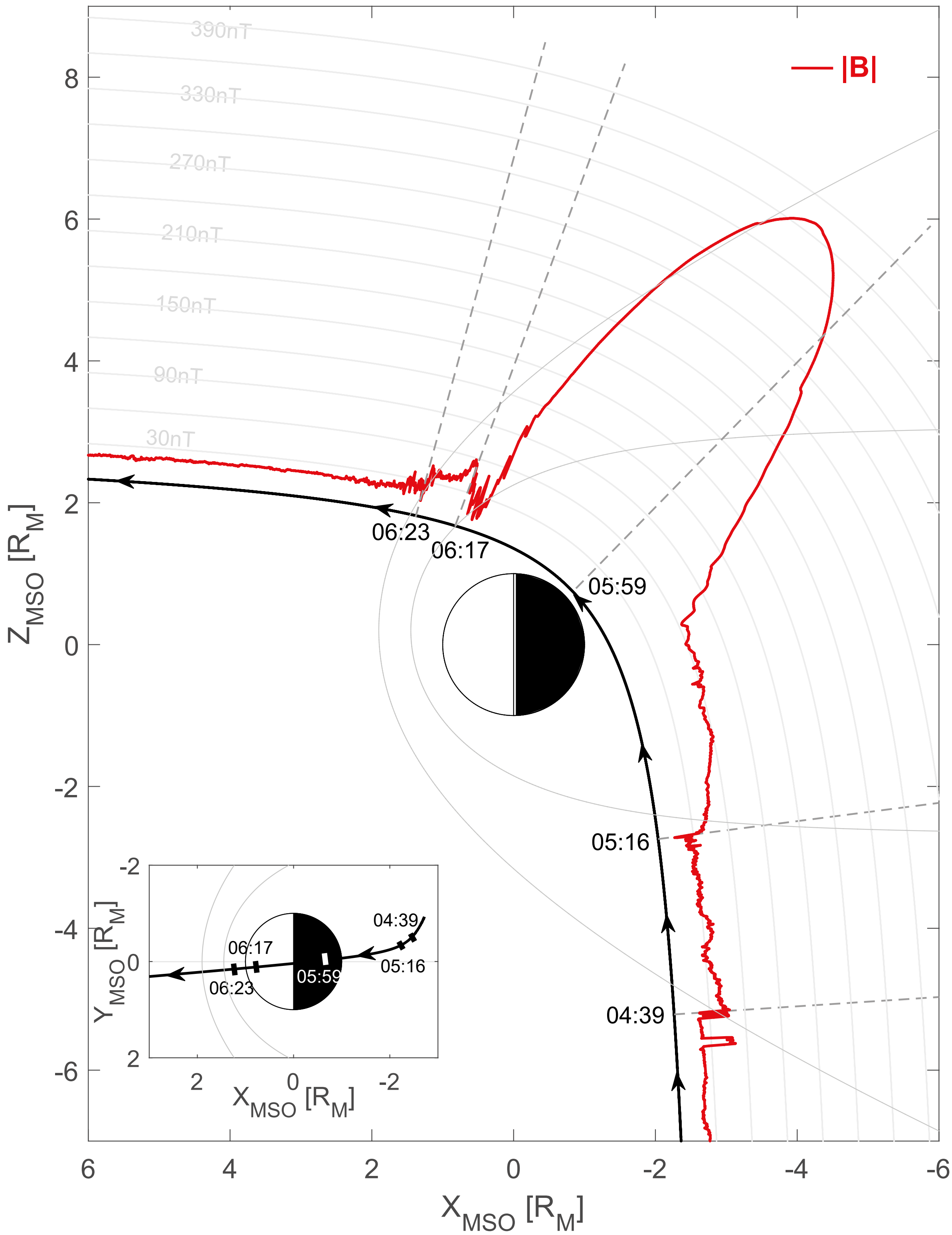
Magnetic reconnection is a fundamental energy conversion process in plasmas that drives transport and leads to explosive large-scale magnetic energy releases. Advanced in-situ plasma measurements from *MMS* and numerical simulations confirmed some theoretical predictions and led to several new discoveries on the dynamics of reconnection. *MMS*, combined with other spacecraft and empirical and/or theoretical modeling, has allowed to gain new insights into reconnection at different types of current sheets throughout the magnetosphere (see figure). While the overall solar wind-magnetosphere coupling has been conventionally explained by magnetic reconnection at the dayside magnetopause and in the nightside large-scale current sheet, transient reconnection in small-scale current sheets have been reported in the magnetosheath, flank magnetopause, and nightside near-Earth magnetosphere as shown in the figure.

Based on reviewing observational and theoretical studies of magnetic reconnection in geospace, at different planets, at the Sun and in the solar wind, in astrophysical and laboratory plasmas, outstanding problems are highlighted. These questions include the complex dynamics and structures in the diffusion region, cross-scale and regional couplings, the onset of magnetic reconnection, and the details of particle energization. These questions led also to possible future directions for magnetic reconnection research. That is, new observations which cover multi-scale capabilities and new simulations, enabling simultaneously kinetic and global scales, and more interdisciplinary approaches among magnetic reconnection studies for different plasmas, i.e. space, astro and laboratory.

Nakamura et al., Space Science Reviews, 221, 17, 2025.



Reconnection in geospace. Recent in-situ measurements and simulations have revealed 3D, complex, and localized reconnection features throughout geospace.



BepiColombo's trajectory and magnetic field observations during the sixth Mercury flyby. The black line shows the spacecraft's trajectory (meridional cut XZ_{MSO} Mercury Solar Orbital coordinates) and in the equatorial plane (XY_{MSO} plane illustrated in the inset panel). Positive X_{MSO} points toward the Sun, while positive Y_{MSO} and Z_{MSO} point opposite Mercury's orbital motion and northward to the ecliptic plane, respectively. The red line displays magnetic-field amplitude measurements recorded during the flyby. After the bow shock crossing, *BepiColombo* entered the magnetosheath around 04:39 on 8 January 2025. At 05:16 it crossed the magnetopause, moving into Mercury's magnetosphere from the southern nightside. The closest approach occurred at 05:59 at roughly 250 km altitude, where the magnetic field reached about 290 nT, increasing to nearly 350 nT over the north polar region. The spacecraft exited the magnetosphere at 06:17, re-entering the dayside magnetosheath, and finally crossed the bow shock at 06:23, returning to the pristine solar wind.

SOLAR SYSTEM

The IWF is involved in several international space missions and experiments that address solar system phenomena, planetary environments and related data analysis. The interaction of the solar wind with the magnetospheres, upper atmospheres or surfaces of solar system planets and bodies are studied. Moreover, theoretical studies related to comparative planetology, habitability and space plasma physics between solar system planets and exoplanets are also carried out for understanding the early and later evolution of Venus, Earth, and Mars.

Two highlights marked the year 2025. ESA's *JUICE* mission performed its Venus flyby and the ESA/JAXA *BepiColombo* spacecraft had its final flyby at Mercury.

MERCURY

Mercury has garnered significant attention due to the ESA/JAXA *BepiColombo* mission, which focuses on the planet's weak intrinsic magnetic field and its interaction with the solar wind. The sixth Mercury flyby of BepiColombo marks the last milestone on the road to orbit.

BEPICOLOMBO

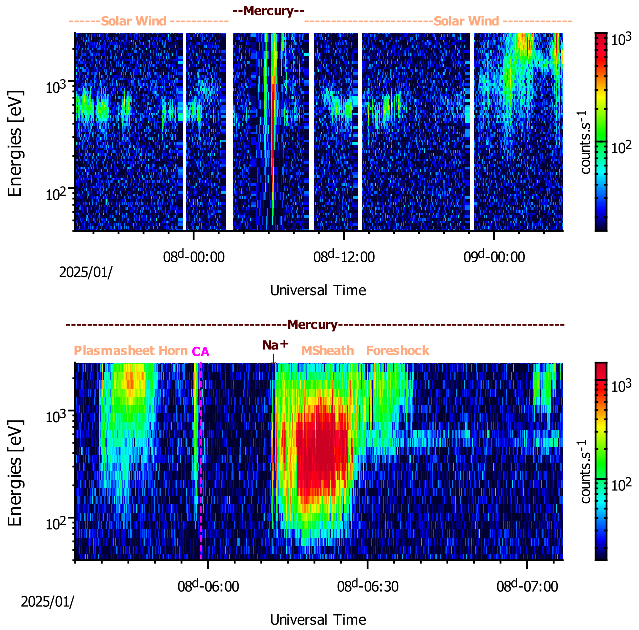
On 8 January 2025, the ESA/JAXA *BepiColombo* mission achieved another major milestone as it skimmed just 300 km above Mercury's surface, reaching closest approach at 05:59 UTC. During this passage, the spacecraft captured fresh images of the planet, carried out targeted measurements of Mercury's complex environment, and continued fine-tuning its science instruments ahead of the mission's main operational phase.

Since its launch in 2018, *BepiColombo* has been steadily making its way toward the innermost planet. This sixth and final gravity-assist maneuver slowed and redirected the spacecraft, setting it on course for orbital insertion around Mercury in late 2026. Throughout the cruise phase, the mission's two scientific orbiters - ESA's *Mercury Planetary Orbiter (MPO)* and JAXA's *Mercury Magnetospheric Orbiter (Mio) - h*ave travelled stacked on ESA's *Mercury Transfer Module (MTM)*. Upon arrival, the orbiters will separate from the transfer module and begin their dedicated science missions.

This final flyby offered a particularly valuable opportunity to explore the interesting regions of Mercury's inner nightside magnetosphere. The trajectory carried *BepiColombo* across the nightside equator and over the north pole, passing through areas where charged particles stream from Mercury's magnetotail toward the surface. The spacecraft also crossed the northern magnetic cusp, where the planet's magnetic field channels solar particles downward.

As with previous flybys, most of *BepiColombo's* instruments were active, including the three payloads contributed by the IWF on both *MPO* and *Mio*. The magnetometers *MPO-MAG* (under IWF technical management) and *Mio-MGF* (under IWF lead) operated throughout the encounter, delivering detailed measurements of Mercury's magnetic field, while the *PICAM (Planetary Ion Camera*, under IWF lead) onboard *MPO* captured the diverse particle populations present in these rarely accessible regions.

The data collected during this flyby enrich the growing body of measurements from *BepiColombo's* earlier encounters and build on the heritage of NASA's *MESSENGER* mission. Together, they offer fresh insight into the dynamic and still mysterious space environment surrounding the innermost planet of our solar system.

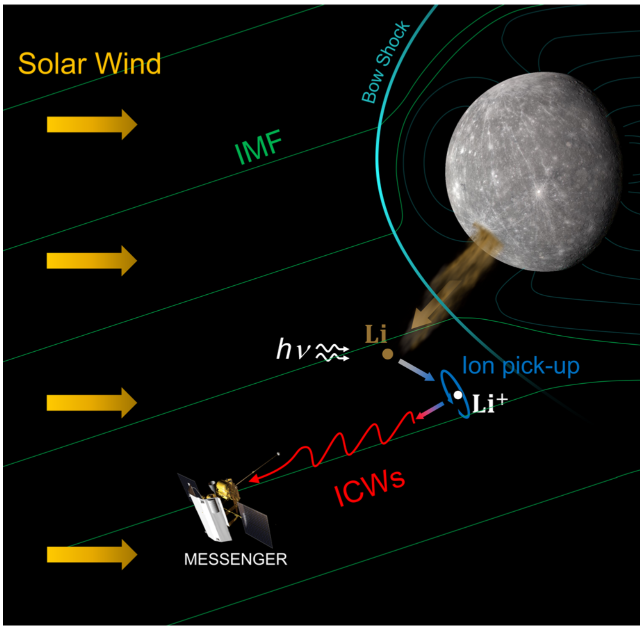


The top panel shows the overview of the *PICAM* observations, from 8 and 9 January 2025. The bottom panel shows the zoomed-in *PICAM* observations near the planet, where *BepiColombo* reached it closest approach (CA) at ~2025-01-08 05:58 UTC.

LITHIUM AT MERCURY

For the first time, lithium was detected, using an advanced magnetic-wave analysis technique. Mercury's exosphere is extremely thin, and although past missions like *Mariner 10* and *MESSENGER* revealed elements such as hydrogen, helium, sodium, potassium, magnesium and iron, lithium had remained elusive - likely because it exists in very low concentrations, which are difficult to detect with particle instruments directly.

The problem was approached differently. Instead of searching for lithium atoms directly, *MESSENGER's* magnetic field data were examined for pick-up ion cyclotron waves (ICWs), a signature produced by freshly ionized lithium. These waves were detected, indicating lithium's presence. These ICWs arise when neutral lithium atoms escape from Mercury's surface and are ionized by strong solar ultraviolet radiation. Once ionized, the lithium ions are swept up by the solar wind, generating plasma instabilities. These instabilities produce electromagnetic waves that oscillate at the lithium ion cyclotron frequency - an unmistakable magnetic "fingerprint" tied to lithium's mass-to-charge ratio. This magnetic signature finally reveals lithiums presence, something neither spacecraft particle detectors nor ground-based observations had been able to confirm despite longstanding expectations.



Four years of *MESSENGER* magnetic field data were examined and 12 distinct ICW events were found. Each one lasted only minutes, offering short but clear glimpses of lithium being released into Mercury's extremely thin exosphere. The brief, sporadic lithium signals helped pinpoint their source. Slow processes like surface heating or steady solar wind sputtering were ruled out, leaving short, explosive events - specifically meteoroid impacts - as the most likely cause. Meteoroids striking Mercury at ~110 km/s generate vapor clouds heated to several thousand Kelvin, easily lifting lithium into the exosphere. This link strongly supports the idea that impacts both deliver new material and vaporize existing surface deposits, continually supplying volatiles.

The results challenge long standing ideas that Mercury lost most of its volatile elements early in its history due to solar heating or a giant impact. Although Mercury's high density and oversized iron core once supported that view, *MESSENGER's* measurements show significant amounts of volatile elements, such as lithium. Thus, the new study suggests Mercury has been steadily replenished over billions of years by meteoroid impacts, reshaping how scientists think rocky planets evolve under continuous bombardment. This mechanism may also apply to other airless bodies like the Moon, Mars, and asteroids, helping explain how they acquire and maintain volatile materials despite lacking substantial atmospheres.

Schmid et al., Nat. Comm., 16, 6205, 2025.

Generation mechanism of ICWs in Mercury's space environment. Lithium (Li) released through (micro-)meteoroid evaporation at the surface can ascend beyond Mercury's planetary magnetic field (blue lines) and the bow shock (light blue arc), reaching the solar wind region where it becomes photoionized by the Sun's extreme UV radiation, characterized by the light frequency, ν times Planck's constant, h. The freshly ionized Li^+ starts to gyrate in the presence of the interplanetary magnetic field (IMF, green lines) and gets picked up by the background solar wind. The solar wind plasma becomes unstable, which excites the ICWs (red line) that are subsequently detected by the *MESSENGER* spacecraft. The display elements are not to scale.

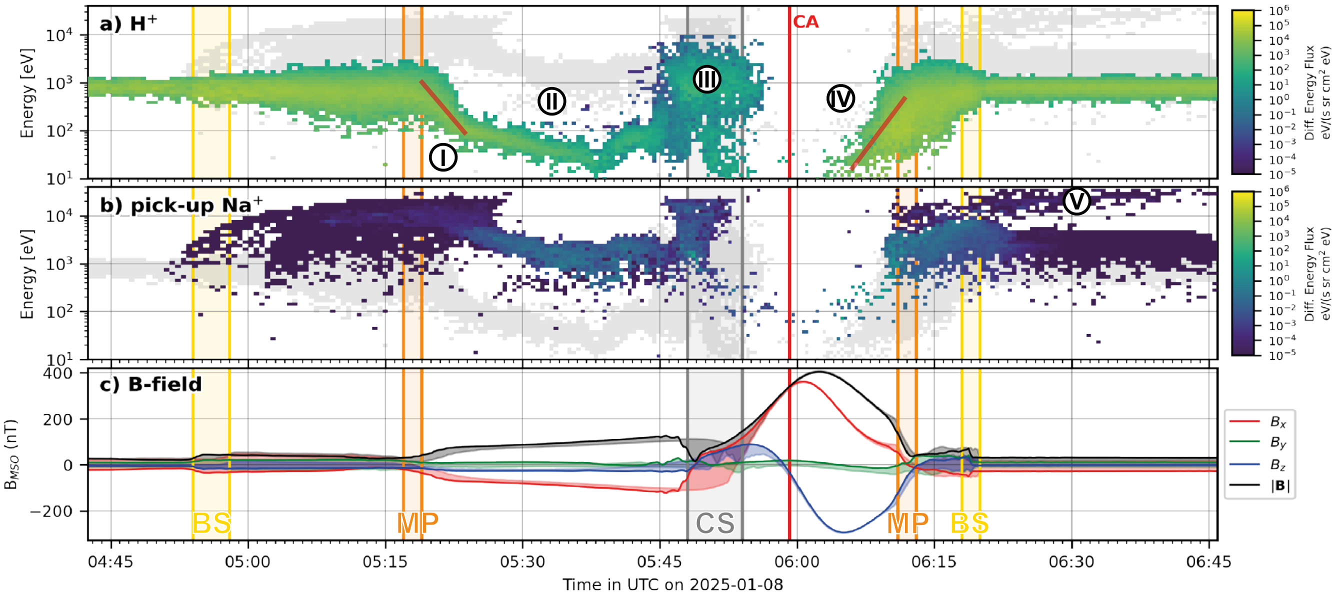
ION-KINETIC MODELING AND FLYBY REFERENCES FOR BEPICOLOMBO AT MERCURY

Mercury's magnetospheric plasma environment was interpreted using global hybrid plasma simulations in support of *BepiColombo* observations. The global three-dimensional hybrid model AIKEF was used to establish a methodology for deriving ion energy distributions from kinetic simulation data in a form directly comparable to particle instrument measurements.

Three particle-counting approaches were evaluated, ranging from simple volume-based sampling to omnidirectional differential flux calculations and a field-of-view–constrained technique that accounts for realistic instrument viewing geometries. Statistical confidence intervals were introduced to quantify stochastic variability within quasi-stationary simulations. Application to earlier *BepiColombo* flybys shows that measured ion energy spectra are consistent with modeled confidence ranges, while systematic effects related to solar wind input parameters and phase-space resolution dominate over stochastic variations.

Based on this framework, a model-based reference was established for *BepiColombo's* sixth Mercury flyby on 8 January 2025 using twelve hybrid simulations covering a broad range of solar wind dynamic pressures and interplanetary magnetic field configurations, including a self-consistent sodium exosphere. Ion energy spectra and magnetic field signatures extracted along the high-latitude nightside trajectory reveal five characteristic plasma regions: the magnetosheath, a high-latitude plasma mantle, the southern and northern lobes, the central tail current sheet, and upstream solar wind regions with pick-up ions. A clear energy-dispersion-like signature is identified in the plasma mantle, marking the transition from magnetosheath to lobe plasma. The thickness and energy gradient of this region are strongly influenced by the solar wind's dynamic pressure, providing a physically grounded reference for interpreting *BepiColombo* observations and diagnosing upstream solar wind conditions from in-situ measurements.

Teubenbacher et al., A&A, 698, A12, 2025.
Teubenbacher et al., Earth, Planets and Space, 77, 109, 2025.

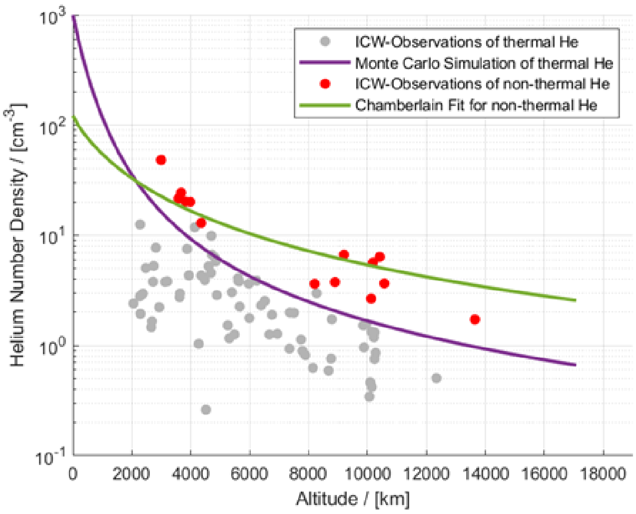


Simulation results for *BepiColombo's* sixth Mercury flyby under average solar wind and planetward-southward IMF conditions. Panels show ion energy spectra for (a) protons and (b) sodium ions, and (c) the magnetic field, with shaded areas indicating variability across all IMF scenarios. Vertical lines mark boundary crossings and closest approach (CA), and regions I-V denote key plasma regions as described in the publication.

MERCURY'S HELIUM EXOSPHERE

The presence of a Helium (He) exosphere at Mercury was first established by *Mariner 10* through remote spectrometric measurements obtained during its 1974-1975 flybys. More recently, exospheric He was also detected by the *PHEBUS* instrument aboard *BepiColombo*, although with lower number densities than those inferred from the *Mariner 10* observations. An in situ He density profile was subsequently inferred using magnetic field and plasma data from the *MESSENGER* mission. These measurements were used to identify ion cyclotron waves (ICWs) produced by pick-up He ions originating from the exosphere. The observations reveal two distinct He populations surrounding Mercury: a dominant thermal component released from the surface and a more energetic, intermittent component that is likely associated with meteoroid impact–induced surface vaporization. ICW-based estimates further suggest that the He content of Mercury's extended exosphere varies with the frequency and energy of impacting (micro-)meteoroids.

Weichbold et al., J. Geophys. Res., 130, e2024JE008679, 2025.



Altitude-dependent He density profile in Mercury's exosphere. The dots indicate the neutral He number densities reconstructed from the He^{+} ICW observations. The violet line represents the result of a Monte Carlo simulation for thermal He. Therefore, all gray dots represent He-observation released in thermal processes, while the red dots show non-thermal He-observations. A least square fit of the red dots yielded the green Chamberlain profile.

VENUS & MARS

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

The IWF is engaged in astrochemical models for the atmospheres of Earth and Venus, including cloud formation, and is member of the Atmospheric Modeling Working Group of ESA's *Envision* mission to Venus.

TIANWEN-1

Tianwen-1 ("questions to heaven") is China's first Mars mission, consisting of an orbiter and a rover named *Zhurong*. The mission is designed to conduct a comprehensive remote sensing of the Red Planet, as well as surface investigations. The IWF contributed to a magnetometer aboard the orbiter.

Since the switch-on of the *Mars Orbiter MAGnetometer (MOMAG)* on 13 November 2021, it has been in continuous operation with two operational modes: 32 Hz for 120 min around periapsis and for 60 min around apoapsis, and 1 Hz for the rest of the 8-hour orbit. *MOMAG* demonstrated good performance, nevertheless all measurements indicated various spacecraft magnetic effects due to the lack of a magnetic cleanliness program and the rather short 3.2 m boom. The two-sensor gradiometer formation, where the outboard sensor is located at the end of the boom and the inboard sensor at 0.9 m from the outboard, is used to remove the spacecraft magnetic effects. The zero offset has been successfully calibrated using the magnetic field data in the solar wind or in the Martian magnetosheath. The cleaned scientific data have been publicly released and several dozens of research papers have been published.

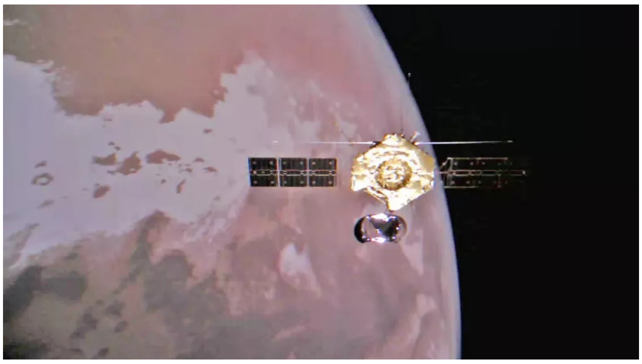
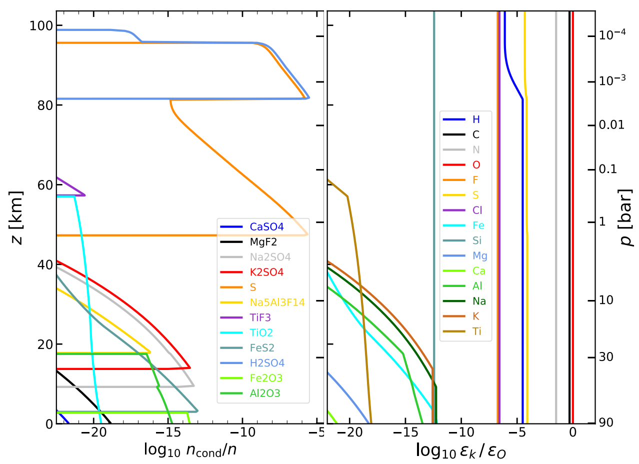


Image of *Tianwen-1* above Mars, taken by a small camera that was jettisoned to photograph the spacecraft in orbit above the Martian north pole (© CNSA/PEC).

PREDICTION OF SULFATE HAZES IN THE LOWER VENUS ATMOSPHERE

In the frame of the FWF-funded VeReDo project, the DiffuDrift code, originally developed to simulate cloud formation in exoplanet atmospheres, was substantially improved to become applicable to the vertical structure of clouds and hazes in the Venus atmosphere. These improvements include the modelling of cloud formation at arbitrary Knudsen numbers, the inclusion of passive aerosol particles, coagulation and particle charges, and cloud opacities. The model finds several metal chloride and metal fluoride molecules to be present in trace concentrations ($<10^{-12}$) over the Venus surface, in particular $FeCl_2$, NaCl, and KCl. These trace concentrations are sufficient to stabilize a number of solid materials in the lower Venus atmosphere (<40 km). In particular, three so far unreported haze layers of solid potassium sulfate, sodium sulfate, and pyrite were found above about 15.5, 9.5, and 2.4 km, respectively (see figure). At a height of 45 km, particle radii of about 0.15-0.25 µm and particle densities of about 10-100 cm^{-3} are reached, depending on the assumptions about the near-surface aerosol particle concentration and the efficiency of coagulation connected to the particle charges. All particles in the lower Venus atmosphere are found to be strongly negatively charged; otherwise coagulation would be very efficient to grow and rain them out. The model can roughly reproduce previously published opacity and discharge current data.

Woitke et al., Planet. Sci. J. 6, 225, 2025.

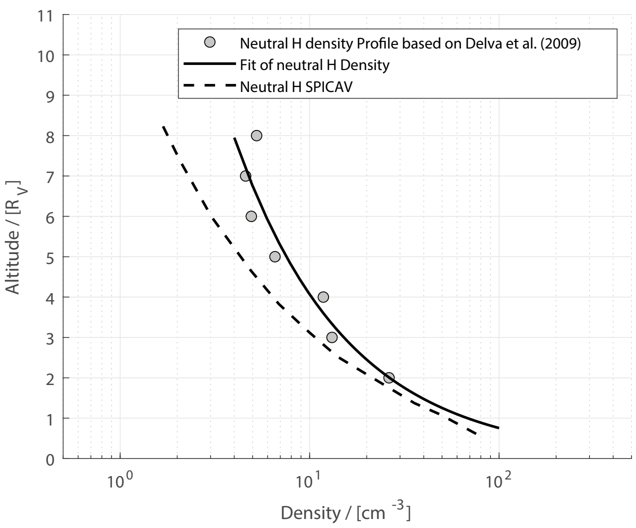


Simulation of the vertical structure of the Venus clouds and hazes, n_{cond} is the volume density of condensed units, and n the total gas particle density. Left: the lower Venus atmosphere is featured by layers of solid potassium sulfate K_2SO_4 at 15.5 km, sodium sulfate Na_2SO_4 at 9.5 km, and pyrite FeS_2 at 2.4 km. Right: element abundances with respect to oxygen remaining in the gas phase.

ICWs: A TOOL FOR EXOSPHERE CHARACTERIZATION

The exospheres of planetary bodies are usually observed by spectroscopic methods, low-orbit space telescopes, or neutral and ion particle detectors, and flight mass spectrometers. Recently, a complementary method for the characterization of exospheres, especially the extended regions, has been reviewed. This technique is based on the analysis of ion cyclotron waves (ICWs), which are detected by spacecraft with magnetometers and plasma instruments. ICWs are generated through the pick-up of exospheric ions that originate from exospheric neutral atoms over a large distance upstream of planetary bodies. The newly ionized exospheric particles generate an unstable secondary ion population in the external solar wind plasma, where their interaction can produce plasma waves arising from various instabilities. The observed and detected wave power can be used to derive the corresponding pick-up ion density and hence its related neutral particle density (i.e., H, H_2, D, He, Li, etc.). Exospheric particles can be identified by analyzing precisely their masses via their different but certain gyrofrequencies, even when they are very close, like H or D, to each other. For the explanation of the extended H exosphere at Venus shown in the figure below, charge exchange and photochemical processes are responsible for the production of suprathermal atomic hydrogen. Deuterium isotopes will also undergo the same photochemical reactions in the thermosphere and it can be expected that D isotopes should also be present in Venus's extended exosphere. Different than in Mars's exosphere, Venus's extended exosphere does not contain H_2 molecules.

Lammer et al., Front. Astron. Space Sci., 11, 1499346, 2025.

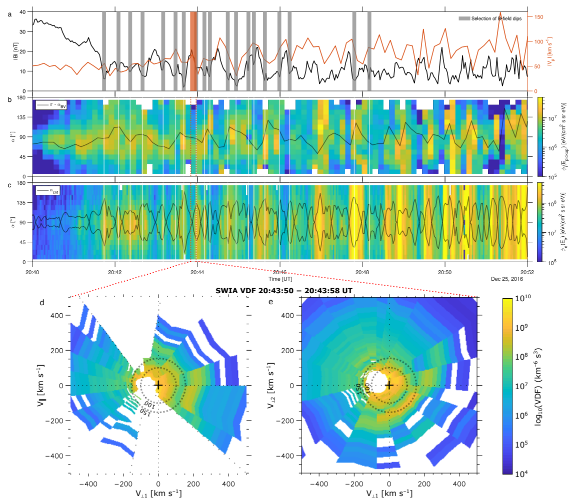


Venus's exospheric H profile (solid line and dots) inferred from ICWs based on H+ pick-up ions, compared to the average Lyman-α based neutral density derived from *SPICAV* onboard *Venus Express*.

LOCAL GENERATION OF MIRROR MODES BY PICKUP PROTONS AT MARS

Mirror mode structures are born from a plasma instability driven by a large temperature anisotropy and appear downstream of planetary and interplanetary shocks, in their magnetosheaths. As so-called "magnetic bottles" imprisoning dense and hot plasma, they are usually observed downstream of their region of formation, where the anisotropy is large and free energy is available, implying that they are advected with the plasma flow to the detection region. At Earth and other planets, the quasi-perpendicular shock provides the plasma with the necessary heating along the perpendicular direction to the local magnetic field. At Mars, which boasts an extended exosphere, an additional source of temperature anisotropy exists, through unstable ring-beam velocity distributions, that is, through ions locally ionized and subsequently picked up by the local electric fields. For the first time an example of near locally-generated mirror mode structures due to pickup protons at Mars is presented, using the full plasma instrument suite on board the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission. Events with mirror modes in quasi-perpendicular and quasi-parallel shock conditions are presented, and the locality of their generation is discussed and it is shown that, in addition to the classic quasi-perpendicular source of anisotropy, another source exists, that is, unstable pickup protons. The existence at Mars of this extra ion anisotropy-generating mechanism is reminiscent of comets.

Simon Wedlund et al., JGR 130, e2024JA033275, 2025.



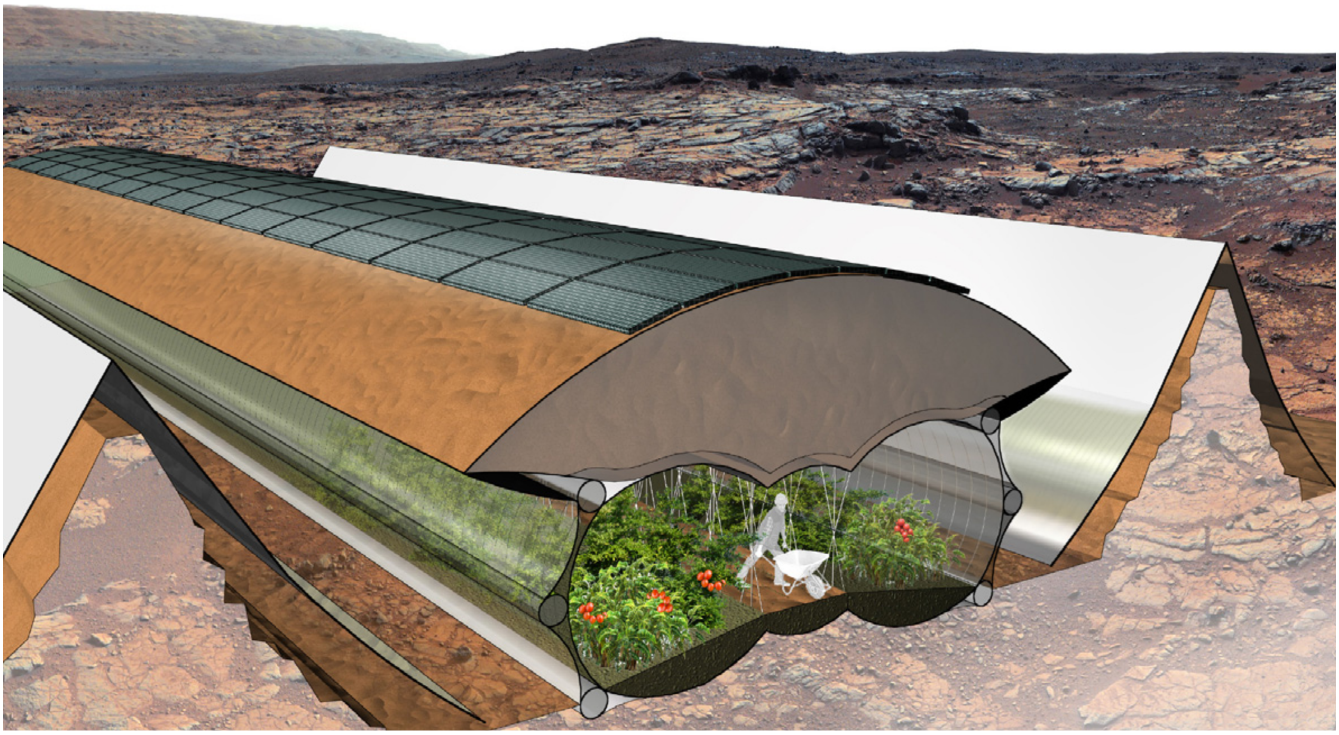
Ion and electron pitch-angle distributions (PADs) for a mirror mode event in the magnetosheath plasma rest frame. (a) Total magnetic field and bulk plasma velocity. (b) SWIA ion energy differential fluxes versus time and PAD at the local newly injected pickup proton energy in the E_{pickup} = 40-100 eV range in the plasma rest frame. (c) SWEA electron energy differential fluxes versus time and PAD for an energy of E_e = 100 eV. (d, e) SWIA ion velocity distribution functions measured in the plasma rest frame between 20:43:50 UT and 20:43:58 UT, in the $V_{\perp 1}$-$V_{\parallel}$ and $V_{\perp 1}$-$V_{\perp 2}$ planes, with superimposed contours of equal velocities at 100 and 150 km s^{-1}. In panel (a), a selection of the most prominent B-field dips is highlighted in gray.

SIMULATION OF MARS HABITATS

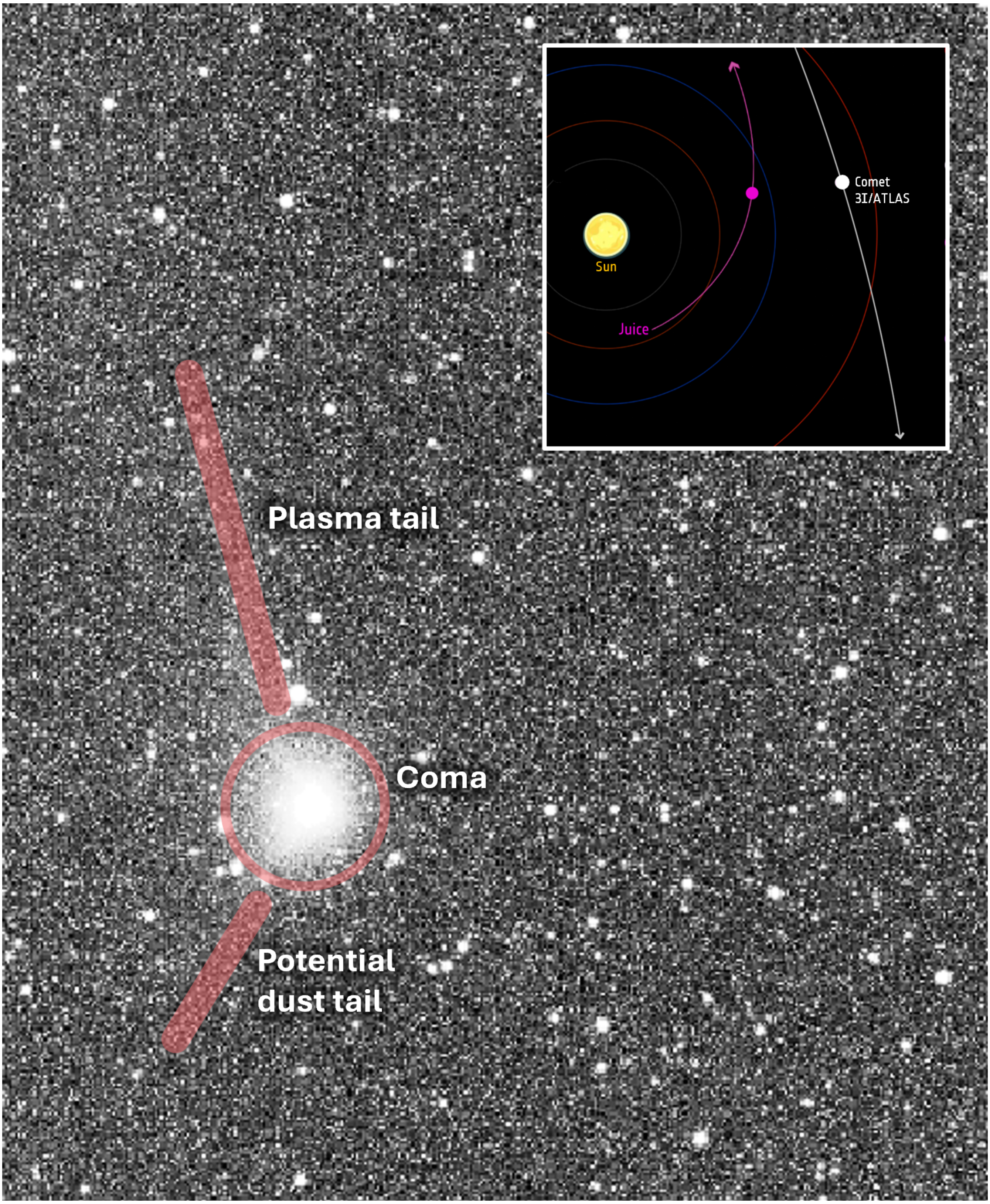
After having successfully studied suitable sites and building blocks of habitats, including life support systems for housing human residents on the Moon, at the IWF similar investigations were performed for habitats on Mars. Here, the focus was on solar irradiation and heat transfer modelling for the habitat. It was inferred that the Valles Marineris region is a suitable location for establishing the first human outpost on Mars. During clear sky conditions, sufficient solar illumination power is available to operate greenhouses and a photovoltaic electrical power station. A design for Mars habitats (including greenhouses) was described, built of flexible inflatable tiles and protected against harmful cosmic radiation by Mars surface regolith as shielding material, following a design proposed by the Austrian architect Thomas Herzig.

A flexible mirror system redirects solar light through windows into the habitat, so that greenhouse food production and comfortable living conditions are guaranteed, at least in the absence of dust storms. However, during global dust storms, some additional heat supply (or larger mirror systems) may be needed, and safety measures (protection of windows and mirrors) are foreseen. Temperature conditions inside the habitat are adapted by (partially) covering the windows with isolating roller blinds, which are closed during the night. Numerical simulations showed that, with a suitable setup, the interior air temperature does not exceed about 30 °C in daytime or fall below 15 °C in the night during clear atmospheric conditions. Thus, most of the time no additional cooling or heating system is necessary, which makes the design extremely energy saving and sustainable.

Kömle et al., Planet. Space Sci., 269, 106216, 2025.



Impression of the studied inflatable Mars habitat (© T. Herzig).



During November 2025, ESA's *Jupiter Icy Moons Explorer (JUICE)* used five of its science instruments to observe comet 3I/ATLAS. The instruments collected information about how the comet is behaving and what it is made of. In addition, *JUICE* snapped the comet with its onboard *Navigation Camera (NavCam)*, designed not as a high-resolution science camera, but to help *JUICE* navigate Jupiter's icy moons following arrival in 2031. The image was taken on 2 November 2025, during *JUICE's* first slot for observing 3I/ATLAS. It was two days before *JUICE's* closest approach to the comet, which occurred on 4 November at a distance of about 66 million km (© ESA/Juice/NavCam).

JUPITER

Jupiter, together with Saturn one of the two gas giants, is the largest planet in our solar system, located at 5.2 au from the Sun. One Jupiter year is 11.86 Earth years and one Jupiter day varies between 9h50′ around the equator, 9h55′40.6″ for latitudes greater than 10° and 9h55′29.71″ for the magnetic field. Jupiter also has the most satellites of any planet in our solar system, with the four large Galilean satellites as the best known. Three of these, Europa, Ganymede and Callisto will be the targets of the recently launched ESA mission *JUICE*.

The *JUICE* mission highlights in 2025 were the successful Venus gravity assist on 31 August, which also marked the closest approach to the Sun during the entire journey to Jupiter. *JUICE* also observed the interstellar comet 3I/ATLAS with five scientific instruments as it passed through the spacecraft's vicinity. By the end of 2025, *JUICE* has completed about one third of the entire cruise phase until arrival at the gas giant.

JUNO

NASA's *Juno* mission to Jupiter arrived in July 2016, to study the gravitational field, the magnetosphere and the atmosphere. After 9 years orbiting Jupiter, the spacecraft continues its investigation of the Jovian system until its end of life. The orbit has been adjusted and *Juno* is moving more and more into the inner magnetosphere, encountering the volcanic moon Io.

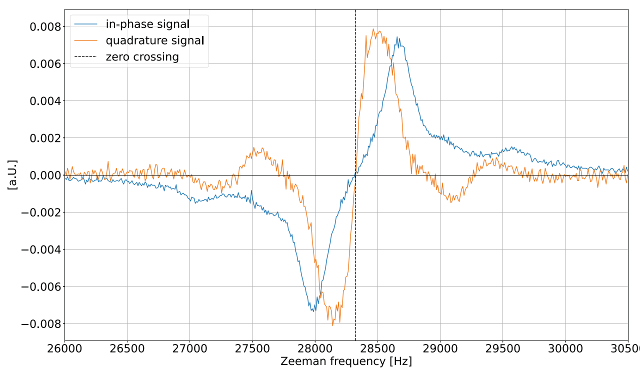
JUICE

The JUpiter ICy moons Explorer (JUICE) is an ESA L(arge)-class interplanetary mission to the Jupiter system that was launched on 14 April 2023 from Kourou, French Guiana. Its powerful instrument package will make in-situ and remote sensing measurements of Jupiter and the Galilean moons during a three-year science operation phase starting in July 2031. The tour in the Jupiter system will include a high-latitude phase, fly-bys of Callisto, Ganymede and Europa culminating in elliptical and circular orbits around Ganymede down to an altitude of 200 km in 2035. Detection and characterization of potential sub-surface oceans on Europa and Ganymede are a key science goal of the mission as is the interaction between Ganymede's internal field with the Jovian magnetic field.

The IWF participates on Co-Investigator basis in two of the ten scientific instruments aboard *JUICE*. The *Particle Environment Package (PEP)* is led by the Swedish Institute of Space Physics and the IWF participates in the *PEP* consortium with scientific studies related to the plasma interaction and exosphere formation of the Jovian satellites.

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

In accordance with the operating and test specifications of the *JUICE* space probe, one functional check of *J-MAG* was carried out from 31 March until 6 April 2025. It was based on measuring the interplanetary magnetic field, which is only a few nanotesla in magnitude. These tests are used to verify instrument health, update software and calibrate systems as needed during the long cruise to Jupiter. In 2025, only one such test took place because the satellite was within the Earth's orbit at a relatively close distance from the Sun. Consequently, a second test campaign was not possible for thermal reasons. The Graz scalar sensor showed nominal behavior during the test, and all important parameters, such as the optical performance of the light path and the quantum interference signal, which is essential for the precise magnetic field measurement, are stable since the beginning of the mission.



Quantum interference signal measured during the third checkout phase end of March 2025. It is essential for the precise measurement of the magnetic field which is marked with zero crossing of the resonance. Signal quality is stable on an excellent performance level since the beginning of the cruise phase.

MOONS & COMETS

The study of moons and comets can give answers to some important questions in the areas of solar system and planetary formation, habitability, and exoplanets. Comets are assumed to be the remainders of the building blocks of the solar system. Recent missions as *Rosetta* and *OSIRIS-Rex* have studied 'old' comets (i.e. comets that have performed already multiple orbits around the Sun) in-situ and even brought some material back to Earth. A new mission, *Comet Interceptor*, will focus its attention to a dynamically new comet or an interstellar object.

Moons, which might harbor an ocean below their kilometers-thick icy surfaces, can give information on potential habitability. Missions like *Galileo* (discovered the oceans under the icy surface of Europa and Ganymede) and *Juno* have studied the icy moons and Io (a volcanic moon) with flybys. The recently launched missions *JUICE* (ESA) and *Europa Clipper* (NASA) will use their high-quality instruments during encounters with the Jovian icy moons Callisto, Ganymede and Europa to obtain further detailed information. One important objective of these missions is to find indications whether these moons can have a habitable shell inside of them, and thereby enlarge the so-called habitable zone around stars, if sub-surface habitats can exist.

COMET INTERCEPTOR

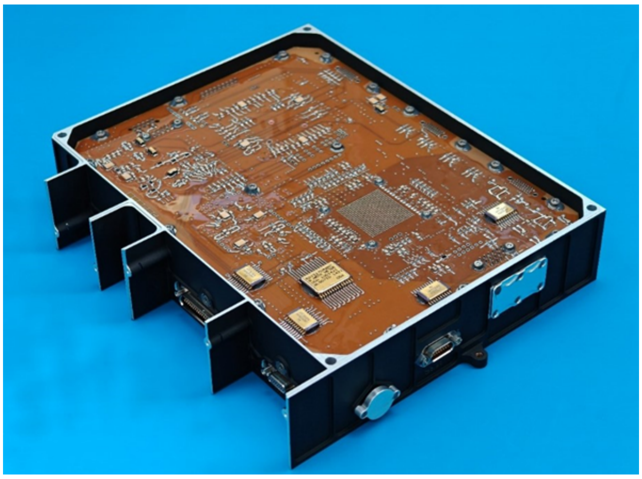
The ESA/JAXA *Comet Interceptor* mission will be the first to visit a comet coming directly from the outer region of the solar system, carrying material untouched since the dawn of the solar system. The spacecraft will be 'parked' in space before moving to intercept a suitable pristine comet. When the comet is near, the main spacecraft will release two probes to observe the comet from multiple directions at the same time.

The mission will consist of three spacecraft: mother spacecraft A and daughter spacecraft B2 under the responsibility of ESA and daughter spacecraft B1 under the responsibility of JAXA. The European prime contractors that will build the spacecraft are OHB for spacecraft A and Sener for spacecraft B2. Spacecraft B1 will be built in Japan. *Comet Interceptor* is planned to be launched in the last quarter of 2028 or the first quarter of 2029 with an Ariane 6-4 from Kourou, French Guiana.

The IWF contributes hardware to two instruments on *Comet Interceptor*. On spacecraft *A* the Data Processing Unit (DPU) for the *Mass Analyzer for Neutrals in a Coma (MANiaC*, led by University of Bern) is being developed and built. On spacecraft *B2* the electronics for the *Flux Gate magnetometer (BFG*, led by Imperial College London) is being developed and built, which is part of the *Dust, Fields and Plasma suite (DFP*, led by the Space Research Center of the Polish Academy of Sciences, CBK).

In 2025, the two flight models (PFM) of the *BFG* electronics and sensors were successfully integrated into the common flight electronics box at CBK. Together with the spacecraft A magnetometers, the instruments undergo an intensive calibration and inter-instrument time synchronization campaign, conducted in the mountains of Austria in the Geomagnetic Conrad Observatory of Geosphere Austria, utilizing the Merritt coil system test facility. Furthermore, the entire *DFP-B2* suit, from which the magnetometers are a part of, was subject to comprehensive EMC and Thermal-Vacuum tests lead by CBK at ESA's test facilities in The Netherlands and Warsaw, Poland, respectively. With the upcoming delivery of the *DFP* suite to Sener (Spain) in spring 2026, the responsibility of the *BFG* instrument will be laid into the hands of the capable spacecraft prime contractor. A final magnetic check-out of the entire *B2* spacecraft at INTA (Instituto Nacional de Técnica Aeroespacial, Spain) magnetic facilities in summer 2027 will finalize the qualification of the *Comet Interceptor B2* spacecraft and makes it ready for the journey to L2, waiting to chase down a yet to be discovered 'dynamically new' comet.

The Electrical Functional Model (EFM) and the ProtoFlight Model (PFM) of the *MANiaC* DPU were delivered to the University of Bern, in June and December 2025, respectively. The EFM DPU has been integrated with the instrument and is used by the University of Bern for testing of the performances. The PFM DPU was the first flight board delivered by international partners to Switzerland and will be integrated in the instrument flight model in 2026. Finally, the Preliminary Design Review for the Application Software was closed-out in the summer of 2025 and its development and validation is progressing.



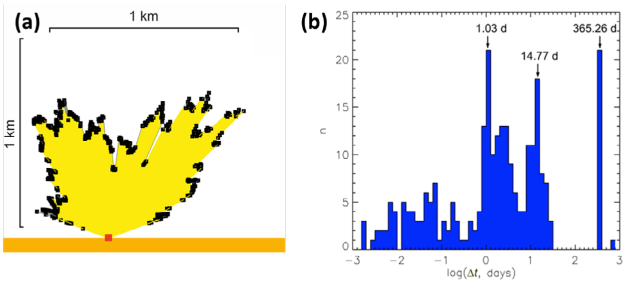
MANiaC PFM DPU integrated in its flight mechanical frame (© OeAW/IWF).

DETECTION OF COMPACT CLOUDS OF LUNAR DUST POTENTIALLY HAZARDOUS TO SPACECRAFT

The high rate of accidents involving space probes approaching and/or landing on the lunar surface is currently a very curious fact. Probing of lunar dust clouds, either remotely, by scattering of sunlight, or in-situ, by spacecraft detectors, reveals a variety of their altitudes, lifetimes, and physical parameters. On the other hand, dense low-altitude dust clouds result in gradual fading and emerging stars occulted by the lunar limb, instead of their diffraction-controlled "quick" disappearance and appearance.

Statistical analysis of spatial and temporal features of the long-lasting anomalous stellar occultations reveals an average shape of the related obscuring dust clouds, looking like an impact plume of about 1 km size (see figure). The probability of anomalous occultations peaks during the Perseid meteor shower in August (figure a), confirming the impact-related nature of most of the dust clouds. However, additionally a semi-monthly periodicity was discovered (figure b), which points to a complementary mechanism of dust lifting related to the solar tidal effects, which trigger dust ejection phenomena, such as outgassing of the lunar interior and/or slumping of crater rims, and generate a certain portion of low-altitude dust clouds which can cause contamination of the onboard equipment and mechanical systems, resulting in their malfunctions.

Khodachenko et al., Geophys. Res. Lett., 52, e2024GL111606, 2025.



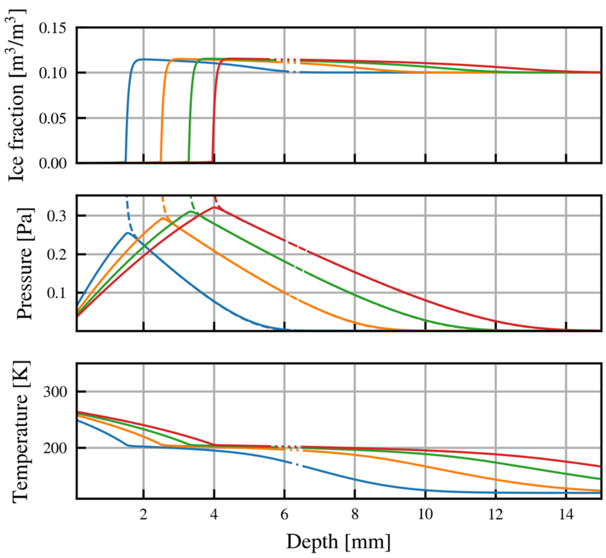
a) Average silhouette of the obscuring dust clouds above the lunar limb, obtained for the western parts of the lunar limb as the angular distributions of average extent of the obscuring clouds versus incidence angle. Red square marks an occultation point at the edge of lunar limb. b) Periodogram, i.e., the distribution of long-lasting stellar occultations versus logarithm of the time intervals between successive occultation events log(Δt). The annual (365.26 days), daily (1.03 day), and half of the synodic lunar month (14.77 days) periodicities are arrowed.

SIMULATION OF COMETARY SURFACES

The outgassing behavior of cometary surfaces is not sufficiently understood. This is especially true when considering the uppermost layers of the porous regolith and how it behaves and is active under solar irradiation. To derive a clearer picture of that process, we carry out 1D transient simulations on the heat and mass transfer in an icy cometary subsurface. Using the commercial simulation software COMSOL, the heat equation, the diffusion equation, and the ice-gas phase change are solved. As a novelty, the equations are solved fully coupled and account for dynamically changing properties such as particle size due to the redeposition of ice.

The results show that sublimated gas not only escapes the comet's surface to form the gas tail but also flows downward, where it deposits as ice and decreases porosity. This produces a so-called sinter layer that is stronger than the overlying loose regolith. The upper panel of the figure below shows how the surface desiccates over time. Deposited ice has accumulated where the ice fraction exceeds the initial 10 %, which shows this so-called sinter layer. In this work, also different models for the ice distribution were looked at. It was found that after some thermal processing, the ice is more likely to deposit outside of porous agglomerates rather than inside the agglomerates. Therefore, ice starts to clog up the pore space, which dampens further downward flow.

Zivithal et al., MNRAS, p.staf1091, 2025.



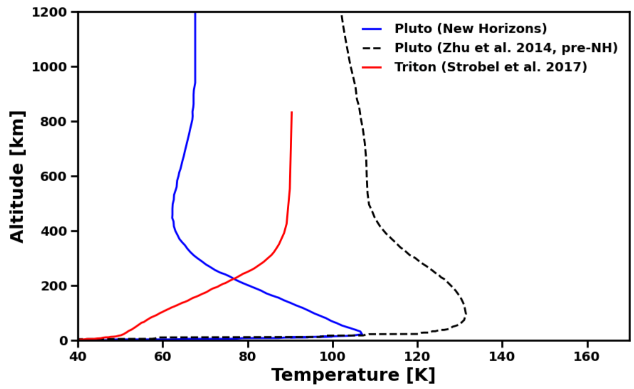
These simulation results show the depth-dependent evolution of a desiccating cometary surface. It was found that due to recondensating downward gas-flow, a sinter layer builds up beneath the surface (ice fraction exceeding the initial 10%). This layer is much harder than the loose cometary dust above and below. This is in agreement with findings by the *Philae* lander, which detected such a hard layer while deploying the *MUPUS* instrument. Colors show the time of insulation (blue 1, orange 2, green 3, red 4 hours). The sinter layer is also visible in the temperature profile as a region with a small temperature gradient.

FUTURE MEASUREMENT NEEDS FOR THE ATMOSPHERES OF PLUTO, TRITON, AND ICY BODIES IN GENERAL

Pluto's and Triton's tenuous N_2-atmospheres share important similarities since both likely originated in the Kuiper belt. However, some key differences, such as their thermospheric structures, stand out. As shown in the figure below Pluto's thermosphere is much colder than expected, whereas Triton's is warmer and fits better with atmospheric models. The reason for this difference is poorly understood, as are other important parameters, such as the origin of their icy building blocks, the evolution of their atmospheres, and important modeling parameters, including their eddy diffusion profiles and haze and aerosol characteristics. Important atmospheric unknowns are suggested and future measurement needs to resolve them, thereby gaining a better understanding of their atmospheres and icy bodies in general. These include ongoing and continuous monitoring of their atmospheres, spectrally mapping their surface volatile ices, and measuring important isotopic and elemental ratios (e.g., $^{14}N/^{15}N$) within their atmospheres and surfaces.

The need for future in situ measurements is specifically highlighted, including a lander on at least one of these bodies, to emphasize the importance of comparative planetology (e.g., by related missions to pristine comets, Titan, and Enceladus), and point out the necessity to improve various model constraints. ESA's planned L4 mission to Enceladus with its potential to observe crucial isotopic ratios will hence be an important cornerstone for better understanding the origin and evolution of icy bodies in general, including Pluto and Triton.

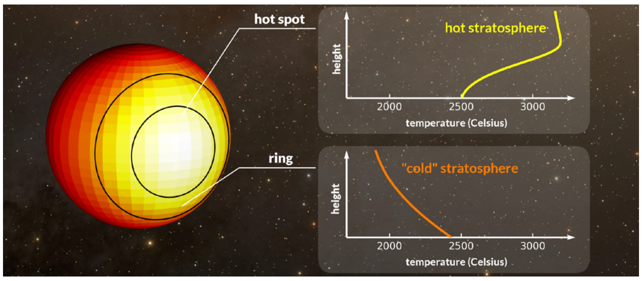
Scherf et al., in Triton and Pluto, Eds. Luspay-Kuti and Mandt, Ch. 10, 2025.



A comparison of the atmospheres of Pluto and Triton. For Pluto, pre-New Horizons models (dashed line) substantially overestimated Pluto's thermospheric temperature. The reason for its low temperature is still not understood, but this conundrum can be resolved by specific measurements as suggested in this chapter.

DIVERSITY OF EXOPLANETS

The field of exoplanet research - i.e., the investigation of planets orbiting stars other than the Sun - has developed strongly in the past decades. The first exoplanet orbiting a Sun-like star, 51 Peg b, was detected in 1995. More than 6000 exoplanets, most in planetary systems, are now known. Improved instrumentation and analysis techniques have led to the detection of smaller and lighter planets, particularly orbiting bright, nearby stars, which therefore enable in-depth structure and atmospheric characterization. Although hot Neptunes and (ultra-) hot Jupiters are still prime targets for atmospheric characterization, smaller planets are entering the realm of the planets for which the atmosphere can be directly probed. This is particularly thanks to the advent of the *James Webb Space Telescope (JWST)*. With its large collecting area and broad suite of instruments, *JWST* is driving a revolutionary view of exoplanetary atmospheres and of the cosmos at large. The IWF has been involved in a number of studies based on *JWST* observations.



3D temperature map of exoplanet WASP-18 b.

The main exoplanet missions in which the IWF is involved with hardware and/or science are *CHEOPS, CUTE, PLATO, ARIEL, ARRAKIHS,* and *NewATHENA*.

The European consortium in charge of the majority of *CHEOPS* observing time in 2025 made use of *CHEOPS* observations to publish about 20 articles in refereed journals. *CUTE* is still delivering scientifically valuable data four years after launch. However, the orbit is decaying rapidly and reentry in the Earth's atmosphere is expected to occur in 2026.

The IWF focuses on the study and characterization of planetary atmospheres and of star-planet interaction phenomena using both theory and observations, in particular on the analysis of planet formation, weather and climate phenomena, evolution, and mass-loss processes. The research is based on collecting and analyzing ground- and space-based observations to constrain the models, as well as on modeling of planetary atmospheres and of planet formation from first principles.

Furthermore, the IWF has significantly deepened its direct involvement in the development of future exoplanet missions. In reply to a call issued by ESA, in spring 2025 the IWF submitted as Principal Investigator (PI) a proposal for a mini-F(ast)-class mission called *Wide-band Atmospheric Laboratory for Transiting Exoplanet Research (WALTzER)*. The proposal was upgraded to the F(ast)-class and passed the first down-selection. The final proposal will be submitted in spring 2026 with the announcement of the result later in the year.

The IWF also took up leadership roles at European level in the development of NASA's next astronomy flagship mission called the *Habitable Worlds Observatory (HWO)* and its instrumentation.

CHEOPS

CHEOPS (CHaracterising ExOPlanet Satellite), successfully launched in December 2019, started regular science operations in April 2020. The mission studies exoplanets by means of ultra-high precision photometry. The primary science goals are to precisely measure the radii of Neptune- to Earth-sized planets to constrain the internal composition and atmospheric evolution, study the atmospheric properties of transiting giant planets, and look for new planets particularly in already known systems.

In 2025, *CHEOPS* continued operations as part of the first extended mission, which will last until the end of 2026, and the *CHEOPS* science team prepared and submitted the request for the second extended mission. The possible second extension until the end of 2029 would enable overlaps with *PLATO* and possibly *ARIEL*. Furthermore, in 2025 the *CHEOPS* team decreased the satellite Sun-exclusion angle from 120° to 115°, which enabled a significant increase in the portion of the visible sky.

The IWF contributed the *Back-End-Electronics*, one of the two onboard computer, which is responsible for controlling the data flow and the thermal stability of the telescope structure. The institute also developed and is maintaining the mission's signal-to-noise calculator. Within the Guaranteed Time Observations of the *CHEOPS* consortium, the IWF chairs the task force coordinating the effort towards obtaining ground-based radial velocity observations for planetary mass measurements, coordinates the re-analysis of archival observations from other facilities to better constrain planetary transit ephemerides prior to *CHEOPS* observations and the efforts towards modeling eclipse and phase curves observations. The institute hosts two members of the *CHEOPS* board and two of the *CHEOPS* science team.

CUTE

CUTE (Colorado Ultraviolet Transit Experiment) is a NASA-funded 6U-form SmallSat led by the University of Colorado, that was launched in 2021. *CUTE* performs low-resolution transmission spectroscopy of transiting exoplanets at near-ultraviolet wavelengths. It studies the upper atmosphere of short-period exoplanets with the aim of observationally constraining atmospheric escape processes, which are key to understand planetary evolution, and detect heavy metals, which constrain the presence and composition of aerosols in the lower atmosphere.

The IWF is the only technological contributor to the mission outside of the University of Colorado (Boulder, USA), where *CUTE* was developed. The institute is responsible for the data simulator, the data signal-to-noise calculator, the ground data reduction software, the data analysis procedures and the algorithms defining the onboard data reduction software, and for preparing the data for archival storage on the NASA Exoplanet Archive. In 2025, the IWF supported the scientific exploitation of *CUTE* exoplanet transit observations.

ARIEL

ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) is ESA's fourth M(edium)-class mission, led by University College London, planned to be launched in 2031. It will investigate the atmospheres of several hundred exoplanets to address fundamental questions on how planetary systems form and evolve. During its four-year mission, *ARIEL* will observe 1000 exoplanets ranging from Jupiter- and Neptune- down to super-Earth-size in the visible and infrared with its meter-class telescope. The analysis of *ARIEL* spectra and photometric data will enable extracting the chemical fingerprints of gases and condensates in planetary atmospheres, including the elemental composition for the most favorable targets, with a particular focus on carbon and oxygen. Thermal and scattering properties of the atmospheres will also be studied.

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

PLATO

PLATO (PLAnetary Transits and Oscillations of stars) is ESA's third M(edium)-class mission, led by DLR. Its objective is to find and study a large number of exoplanetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. It will also detect and characterize at least 200 gas giant exoplanets. *PLATO* has also been designed to investigate seismic activity of stars, enabling the precise characterization of the host star, including its age. Launch is expected in early 2027.

The IWF co-leads the work package studying planetary habitability and leads the work packages studying cloud and gas chemistry, as well as multi-dimensional properties of planetary atmospheres. The institute takes part in two further work packages (on stellar characterization and on planetary evolution) aiming at gaining knowledge and preparing the tools necessary to best exploit the data. The IWF contributed to the development of the *Instrument Control Unit (ICU)* by delivering the *Router and Data Compression Unit (RDCU)*.

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

The two *RDCU* Flight Model boards (FM1 & FM2, delivered in 2024) were integrated into the *ICU* in 2025 and passed the environment tests at subsystem level. The *ICU* was integrated to the spacecraft platform and will undergo its own set of tests before launch. In 2025, the IWF has completed all the testing required for the flight spare (FM3), which will remain available at the IWF in case if there are issues on the FM1 or FM2. Furthermore, the IWF started an externally-funded project aiming at quantifying systematic uncertainties in stellar evolution modelling, and thus in the determination of stellar and exoplanetary masses and ages.

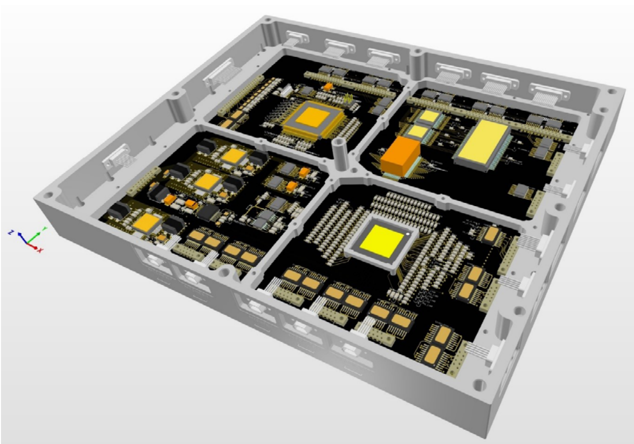
In September 2025, the sunshield and solar array module was mounted to *PLATO*, completing the spacecraft's construction in a dedicated cleanroom at ESTEC (© ESA - SJM Photography).

NEWATHENA

ATHENA (Advanced Telescope for High-ENergy Astrophysics) was ESA's second L(arge)-class mission in the Cosmic Vision 2015-2025 plan. It was reformulated in 2023 due to cost overrun. The now approved mission is called *NewATHENA*. Most of the scientific objectives of *ATHENA* remain, namely: (1) the study of hot gas in clusters and groups of galaxies and in the intergalactic medium to determine how ordinary matter assembles into large-scale structures and (2) the study of black holes growth and their impact on the universe. Thus, *NewATHENA* remains an observatory in the X-ray range of the electromagnetic spectrum with the aim of understanding the high energetic processes close to the event horizon of black holes and provide more details for the baryonic component locked in ultra-hot gas. The science redefinition team widened the scientific scope of *NewATHENA* and added stars hosting exoplanets to the mission's science drivers, addressing the contribution of stellar activity to exoplanet habitability.

The mission is now in the study phase; once the mission design and costing have been completed, it will be proposed for adoption into ESA's Science Program in mid-2027, after which construction can begin. Launch is planned in 2037 on an Ariane 6.4.

The IWF is part of the consortium for the *Wide Field Imager (WFI)* and will provide the Data Processing Module (DPM) as part of the *Instrument Control Unit (ICU)*. The design work for the DPM prototype was completed in 2025 and the required electrical components were received. Finalization of the layout, followed by assembly, testing, and delivery of the DPM prototype is expected to be completed by the end of 2026.



Rendering of the *NewATHENA WFI* DPM.

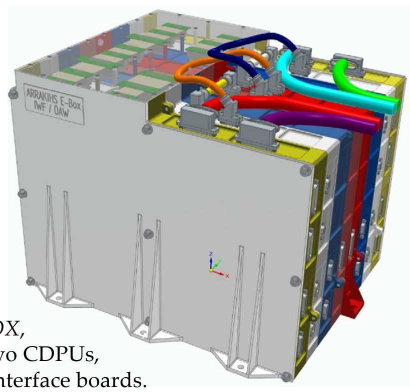
ARRAKIHS

ARRAKIHS (Analysis of Resolved Remnants of Accreted galaxies as a Key Instrument for Halo Surveys) is ESA's second F(ast)-class mission and was selected in 2022. The mission will explore the nature of dark matter, by observing the ultra-low surface brightness halo and stellar streams for a representative sample of Milky Way-type galaxies in the nearby universe. These observations will test the predictions of different dark matter models and baryon physics mechanisms on these large-scale structures, and assess with statistical significance whether the reported tensions are the result of selection effects and/or small number statistics. The mission scientific payload is a single instrument consisting of four identical two-mirror telescopes. Each telescope provides high-precision photometry of the same relatively large (1°) part of the sky, each in a different wavelength band, from visible to near-infrared.

The IWF is leading the development of the main electronics sub-system *(EBOX)*, which controls the instrument, communicates with the spacecraft, collects the scientific data from the four imaging sensors and maintains the telescopes at their optimal temperature. The institute will provide the Common Data Processing Unit (CDPU), as well as the *EBOX* housing, and is in charge of integrating the other *EBOX* units as well as conducting the required environmental tests (e.g., vibration, thermal-vacuum, etc.).

In 2025, the IWF has coordinated the design of the *EBOX* with international partners from Spain, Denmark, and Norway, and has completed an extensive data-package delivery for the instrument Preliminary Design Review in early 2026. Production of the CDPU prototype and engineering model is expected in 2026.

Similar to *NewATHENA*, the high sensitivity of the instruments may enable progress also in exoplanet research. IWF scientists are investigating secondary science goals for which the *ARRAKIHS* instrument would be suitable. Given the high-precision photometric capabilities of *ARRAKIHS*, the instrument can be used to collect multi-band photometric transit observations of already known transiting exoplanets, in a similar fashion to what is currently done by *CHEOPS*, and thus extending *CHEOPS'* legacy beyond the 2030s.

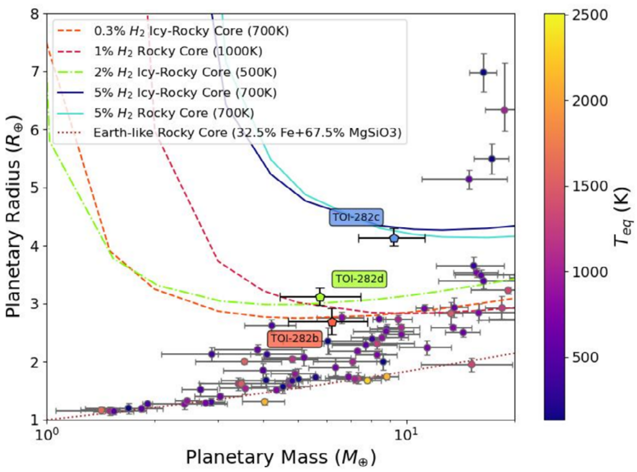


Rendering of the *ARRAKIHS EBOX*, composed of two Power Supply Units, two CDPUs, two Thermal Control Units, and two Near-Infrared Interface boards.

CHARACTERIZATION OF THE 3 LONG-PERIOD PLANETS TRANSITING TOI-282

TOI-282 is a bright (V = 9.38) F8 main-sequence star known to host three transiting long-period (P_b = 22.9 d, P_c = 56.0 d, and P_d = 84.3 d) small ($R_p \approx$ 2-4 $R_\oplus$) planets. The orbital period ratio of the two outermost planets, namely TOI-282 c and d, is close to the 3:2 commensurability, suggesting that the planets might be trapped in a mean motion resonance. *TESS* photometry has been combined with high-precision *HARPS* and *ESPRESSO* Doppler measurements to refine orbital parameters, measure the planetary masses, and investigate the architecture and evolution of the system. In particular, a Markov chain Monte Carlo joint analysis of the transit light curves and radial velocity time series has been performed followed by a dynamical analysis to model transit timing variations and Doppler measurements along with N-body integration. The analysis led to planetary radii of R_b = 2.69±0.23 $R_\oplus$, R_c = 4.13±0.15 $R_\oplus$, and R_d = 3.11±0.15 $R_\oplus$ and masses of M_b = 6.2±1.6 $M_\oplus$, M_c = 9.2±2.0 $M_\oplus$, and M_d = 5.8±1.0 $M_\oplus$, which imply mean densities of ϱ_b = 1.8±0.7 g cm^{-3}, ϱ_c = 0.7±0.2 g cm^{-3}, and ϱ_d = 1.1±0.3 g cm^{-3}, respectively. The three planets may be water worlds, making TOI-282 an interesting system for future atmospheric follow-up observations with *JWST* and the *ELT*.

Barone et al., A&A, 704, A41, 2025.

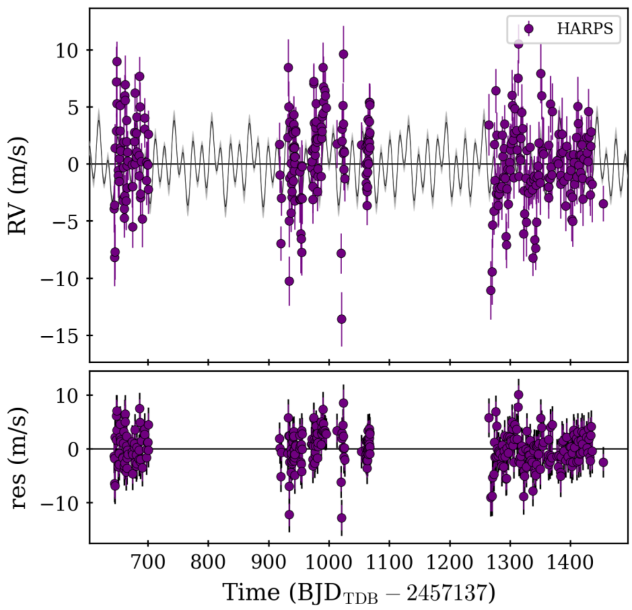


Mass-radius diagram showing the position of TOI-282 b (T_{eq} = 867±16 K), TOI-282 c (T_{eq} = 643±12 K), and TOI-282 d (T_{eq} = 561±11 K) with respect to the transiting planets whose masses and radii are known with a precision better than 30% and 10%, respectively (circles). The colored lines show theoretical planetary composition models.

CHEOPS AND TESS CONFIRM A NON-TRANSITING SIXTH PLANET IN THE SYSTEM HIP 41378

Gravitational interactions between exoplanets could lead to transit timing variations (TTVs), whose amplitude enhances when planets are in or near mean-motion resonances (MMRs). When both TTVs and radial velocity (RV) measurements are available, a combined analysis can break degeneracies and provide a robust system characterization. HIP 41378 hosts five confirmed transiting planets with periods ranging from 15 to over 542 days, providing a unique dynamical laboratory for investigating wide multi-planet systems analogous to the Solar System. An intensive space-based photometric follow-up of HIP 41378 with *CHEOPS*, *TESS*, *K2*, *Spitzer*, and *HST* alongside *HARPS* spectra has been presented. The TTVs and RV signals of the two inner sub-Neptunes have been dynamically modeled. HIP 41378 b (P_b = 15.57 d) and c (P_c = 31.71 d) are close to a 2:1 MMR. TTVs have been clearly detected with amplitudes of 20 minutes for planet b and greater than 3 hours for planet c. The planetary nature of HIP 41378 g has been dynamically confirmed. This is a non-transiting planet with a period of about 64 days and a mass of about 7 $M_\oplus$, close to a 2:1 commensurability with planet c, suggesting a possible mean-motion resonance chain in the inner system. The period of HIP 41378 d has been constrained to three possible aliases (P_d = 278, 371, and 1113 days) suggesting that the system could be placed in a double quasi resonant chain, highlighting its complex dynamical architecture.

Leonardi et al., A&A, 702, A211, 2025.

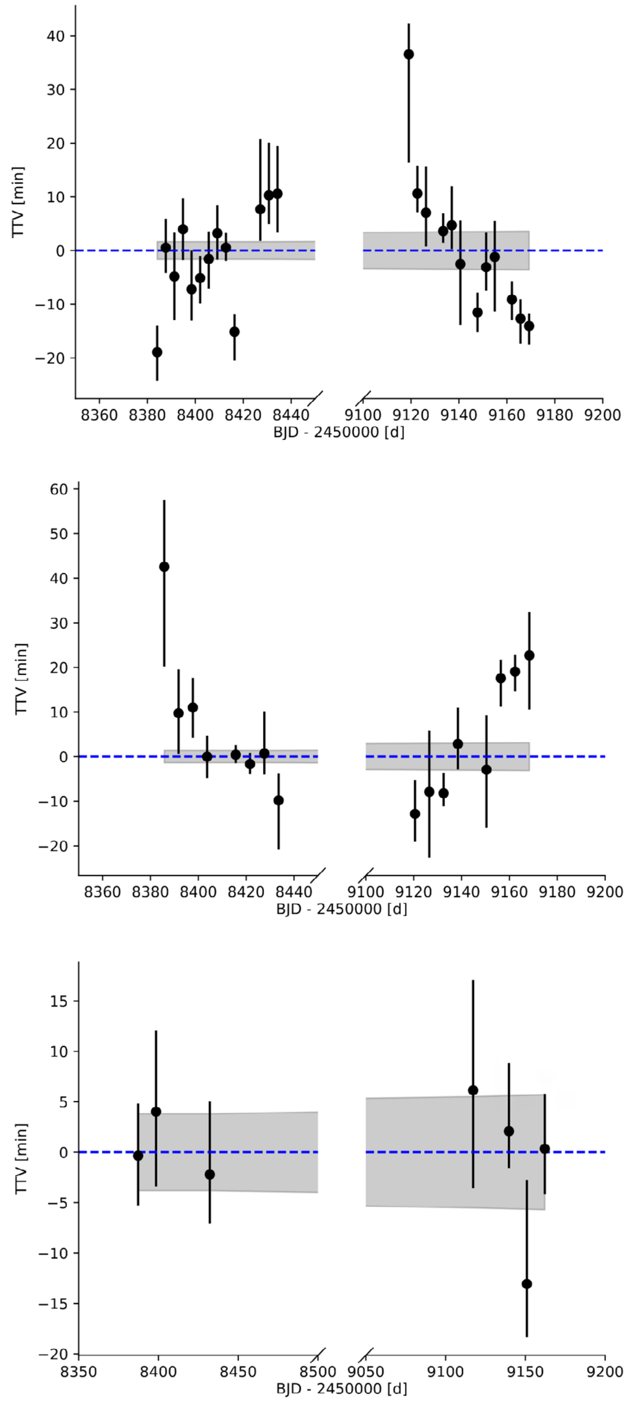


Radial velocities of HIP 41378 (top) and the residuals obtained after subtraction of the model (bottom).

RADII, MASSES, AND TRANSIT-TIMING VARIATIONS OF THE THREE-PLANET SYSTEM ORBITING TOI-396

TOI-396 is an F6V bright naked-eye star ($V \approx 6.4$) orbited by three small ($R_p \approx 2\ R_\oplus$) transiting planets, which were discovered through *TESS* space-based photometry. The orbital periods of the two innermost planets, namely TOI-396 b and c, are close to the 5:3 commensurability ($P_b \sim 3.6$ d and $P_c \sim 6.0$ d), suggesting that the planets might be trapped in a mean-motion resonance (MMR). Radial velocity (RV) observations of TOI-396 have been carried out and analyzed, in conjunction with photometry from four *TESS* sectors, to measure the masses of the three planets, refine their radii, and investigate whether planets b and c are in MMR. The RV measurements have been extracted via a skew-normal fit onto the *HARPS* cross-correlation functions and a Markov chain Monte Carlo joint analysis of the Doppler measurements and transit photometry has been performed, while the breakpoint method has been employed to remove stellar activity from the RV time series. A transit timing variation (TTV) dynamical analysis of the system has been performed, together with a simulation of the temporal evolution of the TTV amplitudes of the three planets following an N-body numerical integration. The analysis confirms that the three planets have similar sizes ($R_b = 2.004\pm0.046\ R_\oplus$; $R_c = 1.979\pm0.051\ R_\oplus$; $R_d = 2.001\pm0.064\ R_\oplus$), in agreement with previous findings. However, these measurements are ~1.4 times more precise thanks to the use of two additional *TESS* sectors. For the first time, the RV masses for TOI-396 b and d have been derived, finding them to be $M_b = 3.55\pm0.95\ M_\oplus$ and $M_d = 7.1\pm1.6\ M_\oplus$, which implies bulk densities of $\rho_b = 2.44\pm0.68$ g cm^{-3} and $\rho_d = 4.9\pm1.1$ g cm^{-3}, respectively. The results suggest a quite unusual system architecture, with the outermost planet being the densest. Based on a frequency analysis of the *HARPS* activity indicators and *TESS* light curves, the rotation period of the star is found to be $P_{rot,*} = 6.7\pm1.3$ d, in agreement with the value predicted from $\log R'_{HK}$-based empirical relations. The Doppler reflex motion induced by TOI-396 c remains undetected in the RV time series, likely due to the proximity of the planet's orbital period to the star's rotation period. The data also revealed that TOI-396 b and c display significant TTVs. While the TTV dynamical analysis returns a formally precise mass for TOI-396 c of $M_{c,dyn} = 2.24^{+0.13}_{-0.67}\ M_\oplus$, the result might not be accurate, owing to the poor sampling of the TTV phase. Furthermore, TOI-396 b and c are close to but out of the 5:3 MMR. A TTV dynamical analysis of additional transit photometry, e.g. collected with *CHEOPS*, evenly covering the TTV phase and super-period is likely the most effective approach for precisely and accurately determining the mass of TOI-396 c. Numerical simulation suggests TTV semi-amplitudes of up to five hours over a temporal baseline of ~5.2 years, which should be duly taken into account when scheduling future observations of TOI-396.

Bonfanit et al., A&A, 693, A90, 2025.

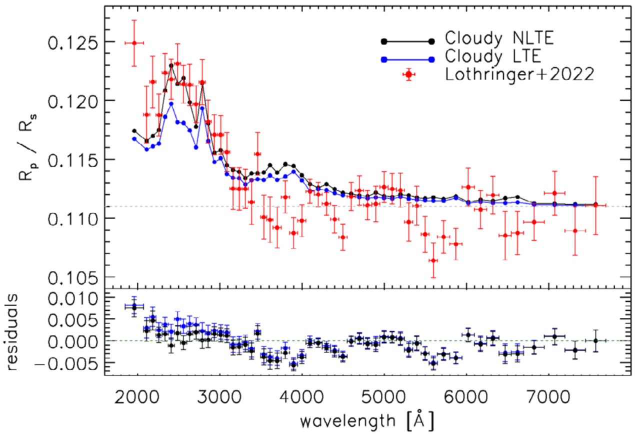


TTV amplitudes obtained for TOI-396 b (top panel), TOI-396 c (middle panel), and TOI-396 d (bottom panel). The gray shaded region highlights the 1σ uncertainty region as derived from error propagation of the linear ephemerides.

NLTE ATMOSPHERIC MODELLING OF WASP-178 b AND COMPARISON WITH UV AND OPTICAL OBSERVATIONS

The atmosphere of the ultra-hot Jupiter (UHJ) WASP-178 b has been modeled while accounting for non-local thermodynamical equilibrium (NLTE) effects. The model has been further compared to near-ultraviolet (NUV) and optical observations. The model returned an isothermal temperature-pressure profile for pressures varying between higher than 10 mbar and lower than 10^{-8} bar, with an almost linear increase from ~2200 K to ~8100 K in between. The temperature structure is driven by NLTE effects, particularly in the form of increased heating resulting from the overpopulation of long-lived FeII levels with strong transitions in the NUV band, where the stellar emission is strong, and of decreased cooling due to the underpopulation of MgI and MgII levels that dominate the cooling. The planetary atmosphere is hydrostatic up to pressures of ~10^{-9} bar, and thus accurately modeling spectral lines forming at lower pressures requires accounting for both hydrodynamics and NLTE effects. The NLTE synthetic transmission spectrum is an excellent match with the HST data, contrary to the LTE model. This contrasts with previous LTE results requiring SiO absorption to fit the observations. The accurate characterization of the atmosphere of UHJs is possible only when accounting for NLTE effects and particularly for the level population of Fe and Mg, which respectively dominate heating and cooling.

Fossati et al., A&A, 699, A186, 2025.

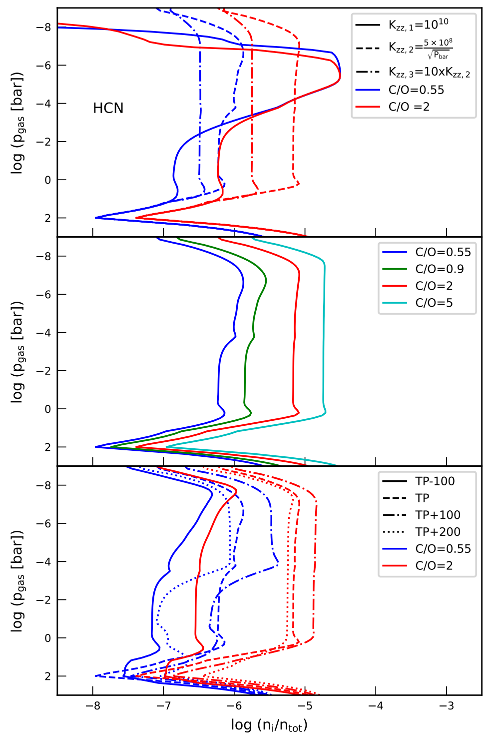


Comparison of the NLTE (black) and LTE (blue) theoretical transmission spectra with the *HST* observations (Lothringer et al. 2022, red). The horizontal error bars shown for the red points correspond to the size of the wavelength bins. The gray horizontal dashed line indicates the broad-band planet-to-star radius ratio obtained from optical transits. The bottom panel shows the residuals between the observation and each of the models, with a green dashed line at zero for reference.

KINETIC AND PHOTOCHEMICAL DISEQUILIBRIUM IN THE POTENTIALLY C-RICH ATMOSPHERE OF WASP-69 b

The atmospheric chemistry of the warm Jupiter WASP-69 b is investigated using high-resolution transmission spectroscopy combined with kinetic modeling. Observations revealed the presence of H_2O, CO, CH_4, NH_3, and C_2H_2, which prompted an analysis of disequilibrium processes - vertical mixing and photochemistry - of their abundances. A suite of 1D photochemistry diffusion models was computed to explore variations in the carbon-to-oxygen ratio (C/O), local gas temperature, and eddy diffusion strength. It was found that CH_4, NH_3, C_2H_2, and HCN are highly sensitive to these processes, while H_2O and CO remain near equilibrium, except at very low pressures. Carbon-rich atmospheres (C/O ≈ 2) favor enhanced CH_4 and C_2H_2, with NH_3 converting to HCN at high temperatures. Photochemistry amplifies C_2H_2 and HCN production in the upper atmosphere. Cross-correlation of synthetic spectra with observational data indicates that multiple models fit within statistical uncertainties, leaving C/O unconstrained. However, scenarios with C/O ≈ 2 provide the best match, consistent with the carbon-rich atmospheric interpretation based on chemical inconsistencies with equilibrium models. This underscores the importance of deep-atmosphere modeling, as NH_3 quenching occurs at pressures >100 bars, influencing HCN predictions. Future *JWST* observations are expected to confirm HCN signatures, offering critical insights into exoplanet formation and atmospheric dynamics.

Bangera et al., Astrophys. J., 980, 147, 2025.



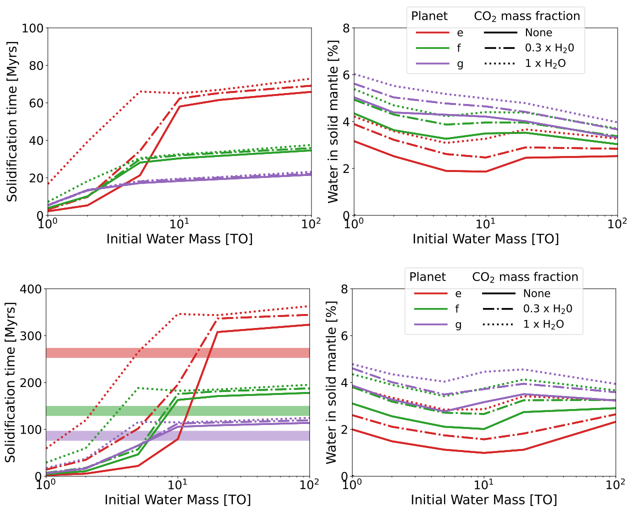
This figure highlights the degenerate way in which eddy mixing efficiency (Kzz), the atmospheric Carbon-to-Oxygen ratio (C/O), and temperature, effect the concentrations of chemicals (here HCN) in the atmosphere of gas-giants.

HOW MIXED OUTGASSING CHANGES VOLATILE DISTRIBUTIONS IN MAGMA OCEANS AROUND M DWARF STARS

The MagmOc2.0 module of the VPlanet model is an advanced tool for simulating the first 100 Myrs of rocky exoplanet evolution. MagmOc2.0 allows to investigate coupled outgassing of H_2O and CO_2 during the magma ocean stage, a critical phase that determines planetary habitability, with radiative transfer calculations in vertically extended atmospheres. The model was used to explore scenarios for the TRAPPIST-1 planets with varying initial water inventories (1 to 100 terrestrial oceans, TOs) and CO_2 ratios (0.1 to 1) under different albedo conditions (0 and 0.75).

It was found that CO_2 significantly influences volatile retention and magma ocean lifetimes. For water-poor planets (≤10 TOs), CO_2 diffusion-limited escape delays atmospheric desiccation by up to hundreds of Myr, allowing entry into the habitable zone with mixed H_2O-CO atmospheres. Conversely, volatile-rich planets always retain thick (>1000 bar) atmospheres. CO_2 increases for all cases the amount of initial water sequestered in the mantle by up to 6% which may be released into the atmosphere later in the evolution even with complete desiccation, which is relevant for TRAPPIST-1 e. Interior modeling, adjusted for TRAPPIST-1 metallicity, suggests dry compositions for inner planets and volatile-rich scenarios for TRAPPIST-1 f and g. A robust link between early atmospheric evolution, interior structure, and habitability is established, providing essential constraints for future missions such as *PLATO*, *HWO*, and *LIFE*.

Carone et al., A&A, 693, A303, 2025.



Solidification times (left) and mantle water retention (right) for TRAPPIST-1 e, f, and g under varying CO_2 levels and albedo assumptions (top: 0.75, bottom: 0). Scenarios compare pure H_2O atmospheres with mixed H_2O-CO_2 cases, highlighting the influence of CO_2 on magma ocean duration and volatile sequestration.

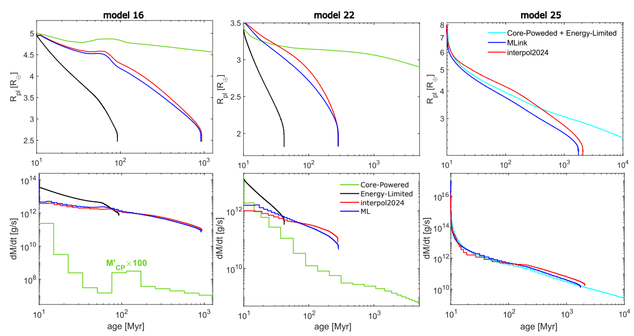
GRID-BASED EXOPLANET ATMOSPHERIC MASS-LOSS PREDICTIONS VIA NEURAL NETWORKS

The atmospheric Mass Loss INquiry frameworK (MLink) is a neural-network-based framework for predicting atmospheric mass-loss rates in exoplanets, addressing a critical challenge in planetary evolution modeling. Accurate estimations of mass-loss rates is essential for understanding the diversity of sub-Neptunes and super-Earths, where atmospheric escape significantly influences long-term evolution. Traditional approaches like hydrodynamic modeling and analytical approximations are computationally expensive or prone to inaccuracies, particularly near regime transition points between XUV-driven escape, core-powered mass loss, and Roche lobe overflow.

MLink uses a dense neural network trained on an extensive grid of over 11,000 hydrodynamic upper-atmosphere models, supplemented by a dedicated test set. Compared to classical interpolation schemes, MLink reduces maximum interpolation errors and improves robustness across parameter space, including regions near the radius gap where observational constraints are most stringent. Validation against 234 synthetic planets demonstrates that MLink achieves prediction accuracies within a factor of two for over 90% of cases, outperforming radial-basis-function regression and previous algorithms.

Application to evolutionary modeling confirms that improved interpolation accuracy mitigates systematic biases in planetary radius predictions, which can otherwise exceed observational uncertainties. This advancement enables rapid, precise atmospheric evolution simulations and paves the way for future integration of more complex physical processes in exoplanetary studies.

Reza et al., A&A, 694, A88, 2025.



Planetary radius (top) and mass-loss rate (bottom) evolutionary tracks for selected planets as predicted employing MLink (blue lines), interpol2024 (red lines), energy-limited approximation (black lines), and core-powered mass loss (green lines), or the combination of the latter two (cyan).

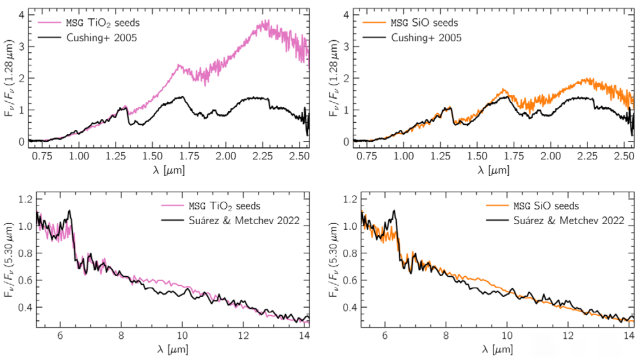
THE MSG MODEL FOR CLOUDY SUB-STELLAR ATMOSPHERES

The MSG model, a new grid of one-dimensional, disk-integrated self-consistent sub-stellar atmosphere models incorporates microphysical cloud formation. The MARCS radiative-convective equilibrium atmosphere model is coupled with a kinetic, stationary, non-equilibrium cloud formation model. The limitations in reproducing silicate absorption features observed in recent *JWST* and archived *Spitzer* spectra of brown dwarfs and planetary-mass companions are addressed. The grid spans effective temperatures from 1200 K to 2500 K at log(g) = 4.0 and includes updated opacities, equilibrium chemistry, and nucleation species (TiO_2 or SiO) beyond previous models.

It is shown that clouds exert significant radiative feedback, producing warmer pressure-temperature profiles and detached convective zones at $T_{eff} \leq 1600$ K. Synthetic spectra exhibit strong near-infrared reddening and diminished molecular absorption features, diverging from observations. Tests with alternative nucleation species (SiO vs. TiO_2) and reduced mixing efficiency yield to less red spectra but fail to reproduce the characteristic 10 µm silicate absorption feature. Analysis suggests this discrepancy arises from insufficient small-particle populations at observable altitudes, likely linked to underestimated nucleation rate or mixing efficiency.

The MSG framework represents an important step toward physically consistent modelling of cloudy sub-stellar atmospheres. Future work may incorporate convective motion, particle size distributions, and combined 1D model approaches to resolve current challenges and improve agreement with observational data.

Campos Estrada et al., A&A 694, A275, 2025.

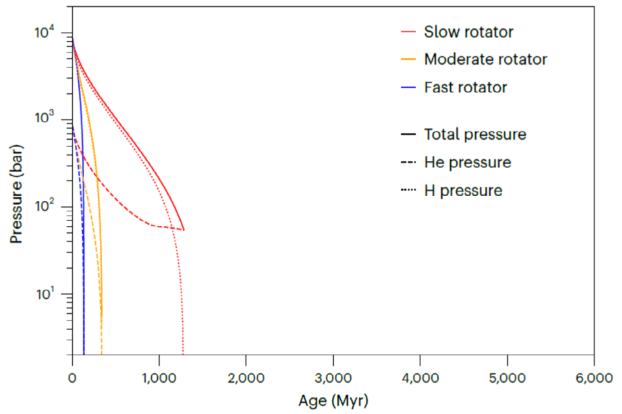


Comparison between observed spectra of 2MASS 15071627 (L5) and MSG cloudy models, nearIR and midIR data. The observed spectrum (black) is compared to MSG models at T_{eff} = 1600 K and log(g) = 4.0 using TiO_2 (pink) or SiO (orange) nucleation seeds. Flux is shown as F_{ν} to highlight the 10 µm silicate feature.

EARTH-LIKE PLANETS WITH He ATMOSPHERES

The discovery of low-mass exoplanets, including several within the habitable zone (HZ) of their host stars, has led to speculations about the kind of atmosphere that surrounds them. Recent detections of exoplanets revealed the existence of a large population of low-mass planets with less than three Earth-masses that are surrounded by H_2 atmospheres that were accreted from the protoplanetary disk. Gas disks usually have about 10 % fraction of He; because of this, one can expect planets between 0.75 and 3.0 Earth-masses that orbit in the classical habitable zone of solar-like stars, where their primordial atmospheres could be enriched with a primordial He-fraction. As shown in the figure below, depending on the mass of the planet, a possible accreted primordial gaseous envelope by the planet during the gas disk phase, and the host star's stellar high-energy X-ray and extreme UV flux between about 10 and 120 nm, it is found that Earth-like planets with masses between about 0.95 and about 1.25 Earth-masses inside the habitable zone of Sun-like stars can end up with He-dominated primordial atmosphere. The future discovery of such planets will not only enhance the understanding of the accretion speed of terrestrial exoplanets, but will also open questions related to the habitability of Earth-like planets because the low mixing ratio of O_2 expected for a He-dominated primordial atmosphere can hardly sustain complex aerobic life as we know it.

Lammer et al., Nat. Astron., 9, 1022, 2025.



Evolution of the total (solid lines) and surface partial pressures of hydrogen (dotted lines) and He (dashed lines) for a 0.97 Earth-mass HZ planet around a Sun-like star exposed to the EUV flux evolution of a slow (red), moderate (green), or fast (blue) rotating Sun-like host star.

PLANET-FORMING DISKS

All planets are believed to form in so-called protoplanetary disks as a byproduct of star formation. These disks have a lifetime of only about 3-10 Myrs. The IWF studies these systems both theoretically and observationally, to understand the physical and chemical processes in these disks that set the initial conditions for planet formation.

In 2025, one common theme was the modeling of dust dynamical processes in disks, such as gravitational settling, ring instabilities and the formation of vortices, which can initiate planet formation by concentrating the dust more and more. Different hydrodynamical codes were used to predict these spatial structures, followed by the simulation of the dust continuum radiative transfer to find out at which wavelengths and spatial resolutions such processes might be observable with future space missions such as the *Large Interferometer For Exoplanets (LIFE)*, aiming at the preparation of an auxiliary science case for it.

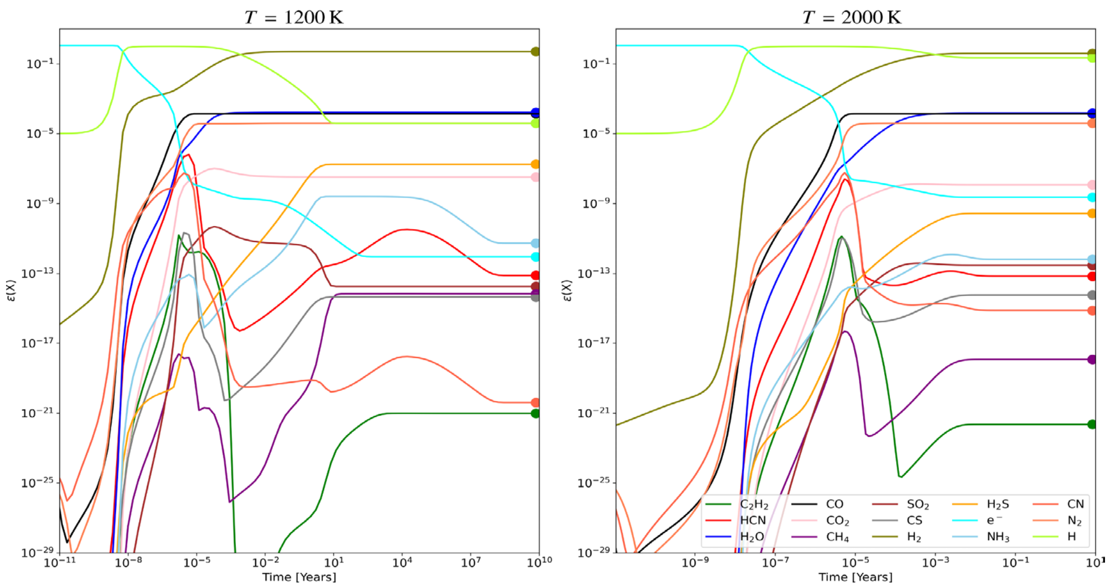
Another topic was to use the thermo-chemical disk modeling code ProDiMo to predict the chemical and temperature structure of the inner disk to interpret *James Webb Space Telescope (JWST)* observations. In addition, the impact of external irradiation and disk winds of different kinds (photoevaporation and magneto-thermal winds) on disk evolution, disk lifetime, and the appearance of the outer disk with instruments like the *Atacama Large Millimeter/submillimeter Array (ALMA)* was studied.

CAN THERMODYNAMIC EQUILIBRIUM BE ESTABLISHED IN PLANET-FORMING DISKS?

Astrochemical methods developed for planetary chemistry are combined with those developed for interstellar and disk chemistry. The resulting network is called ChaiTea. Termolecular (3-body) reactions have been included in the low- and high-pressure limits, and the concept of reversing all gas-phase reactions based on Gibbs free energies has been adopted. The resulting ChaiTea network is expected to relax towards thermochemical equilibrium, a behavior that previous networks did not exhibit. Indeed, when all causes of deviation from equilibrium are eliminated, such as cosmic ray, X-ray and UV photoreactions, all chemical concentrations are found to reach equilibrium, albeit only after very long timescales (see figure).

The amount of cosmic rays required to permanently drive the chemical system away from equilibrium is also discussed. The answer is highly temperature-dependent. At temperatures below 750 K, even a tiny cosmic ray ionization rate of 10^{-40} s^{-1} significantly alters the neutral chemistry, favoring N_2, CO, CO_2, and H_2O over the more stable combination of NH_3, CH_4, and H_2O. Using the ChaiTea network on full disk models, it is found that thermochemical equilibrium is never reached in protoplanetary disks, at any time or location.

Kanwar et al., A&A, 689, A294, 2025.

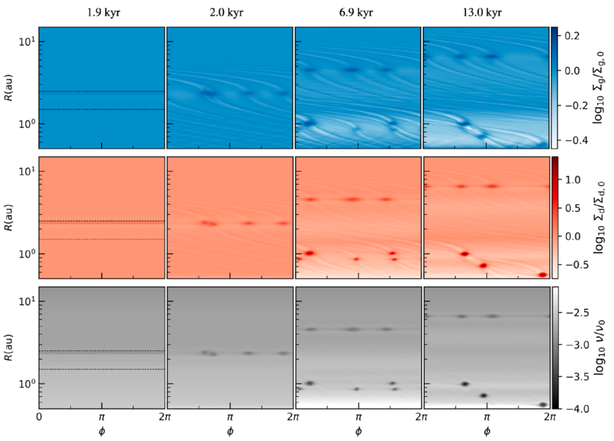


Astrochemical simulation of a gas at temperatures of 1200 K (left) and 2000 K (right) with density 10^{14} cm^{-3}, showing the molecular concentrations as a function of time. The large colored dots on the right show the independently computed concentrations in thermo-chemical equilibrium. The model starts from a fully ionized state and needs about 1 Gyr to reach thermochemical equilibrium.

HOW PROTOPLANETARY DISKS EVOLVE AND HOW THE DUST WITHIN THEM GROWS TO SEED PLANETS

During the process of low mass star formation, a centrifugally supported accretion disk inevitably forms due to the residual angular momentum in the parent molecular cloud core. The micron sized interstellar dust grows via various mechanisms, in the dynamic environment of this disk and eventually forms a planetary system, resulting in configurations that we observe in various exoplanetary systems. A global model of magnetic wind-driven accretion for the evolution of protoplanetary disks in the thin-disk limit is proposed, based on the insights gained from local shearing box simulations. Synthetic observations were obtained via detailed modeling with the radiation thermo-chemical code ProDiMo. The models that include disk winds satisfy the general expectations from both theory and observations, making this model a significant step forward in the direction of representing a more complete disk evolution, wherein the disk experiences concurrent torques from viscous, gravitational, and magnetic wind processes. With the same model, the phenomenon of the ejection of magnetic disk winds during episodic accretion was investigated, with a focus on the dust contained within these winds. Numerical experiments shed a light on the mechanism behind the production of dusty winds during outbursting events in young stellar objects. The sublimation of a volatile in these disks forms a radially extended "snow region" of constant temperature instead of a narrow "snow line". The possibility of Rossby vortex excitation and rapid planetesimal formation at temperature substructures associated with the snow regions was also investigated. It was found that the vortices form under favorable conditions and offer exceptionally favorable conditions for dust growth and the formation of planetesimals. This process is mediated by streaming instability and successive gravitational collapse, pointing towards a possible novel pathway for the rapid formation of planetary cores.

Kadam et al., A&A, 695, A516, 2025.
Kadam et al., A&A, 697, A43, 2025.
Kadam et al., A&A, 699, A57, 2025.

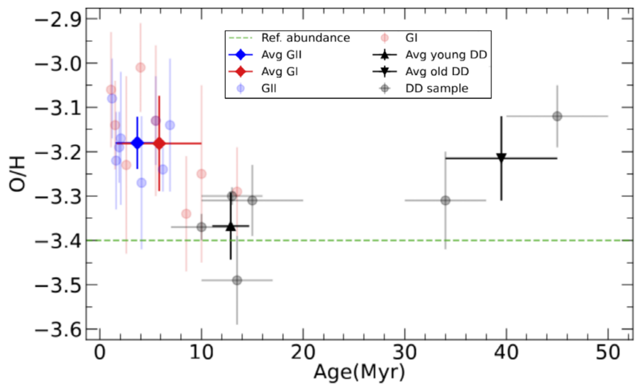


Simulations showing the formation of a positive feedback loop between gas, dust, and viscosity. The resulting gradient of gas surface density eventually becomes sharp enough to trigger Rossby wave instability, and vortices are formed. The progression of the vortex cascade in a standard protoplanetary disk model, shows the distribution of normalized dust, gas, and viscosity. The dashed lines show the region of the initial temperature plateau corresponding to the water snow region, which triggers such vortices.

ABUNDANCE ANALYSIS OF STARS HOSTING GAS-RICH DEBRIS DISCS

Accretion from protoplanetary or debris discs can contaminate the stellar photosphere, especially in stars that have radiative envelopes. Due to the relatively slower photospheric mixing, these stars can exhibit clear contamination signatures. The contaminated photosphere reflects ongoing disc processes, which are detectable through stellar spectroscopy. The composition of six gas-rich debris disc-hosting A-type stars has been investigated to understand possible links with their debris disc or earlier accretion stages. The oxygen abundance in intermediate-mass stars decreases with age until the debris disc stage (<20 Myr), after which it could end up rising. The downward trend could result from H_2O ice accumulating in dust traps or the formation of hydrated asteroids in the protoplanetary disc, locking oxygen in solids and reducing its accretion onto the star. All the stars share similar volatile abundances (C, O), but HD 110058 and HD 32297 exhibit refractory depleted abundances, which suggest residual or even chronic, accretion contamination from their earlier protoplanetary stages when the accretion rates were about five orders of magnitude higher. For HD 110058, with the highest refractory depletion, a lower limit on its earlier protoplanetary accretion rate of 9×10^{-8} M_S/yr has been estimated, similar to other Herbig stars and equal to the Herbig star HD 100546. This supports the hypothesis that refractory depletion in HD 110058 originates from a prior phase of higher accretion of dust-poor material.

Borthakur et al., A&A, 697, A59, 2025.



Stellar photospheric oxygen abundance vs age. GI and GII mean group I (i.e. stars with gaps) and group II (i.e. stars without gaps) protoplanetary disc-hosting stars, respectively. DD stands for debris disc-hosting stars.

SATELLITE LASER RANGING

IWF's Satellite Laser Ranging (SLR) station is continuously tracking more than 150 satellites equipped with retro-reflectors. Diffuse reflections of laser light from space debris are measured to perform Space Debris Laser Ranging (SDLR) measurements. In parallel, the reflected sunlight of space objects is recorded to gather Single Photon Light Curves (SPLC). The data of these three techniques form a unique catalog, which is utilized for different approaches to characterize satellites and space debris and as input for precise orbit determination. Machine learning (ML) is used to classify satellites or space debris based on single photon light curves. For the first time, a MHz laser ranging system was used to measure satellite and space debris with a single system at improved precision.

MACHINE LEARNING FOR SPACE DEBRIS CLASSIFICATION

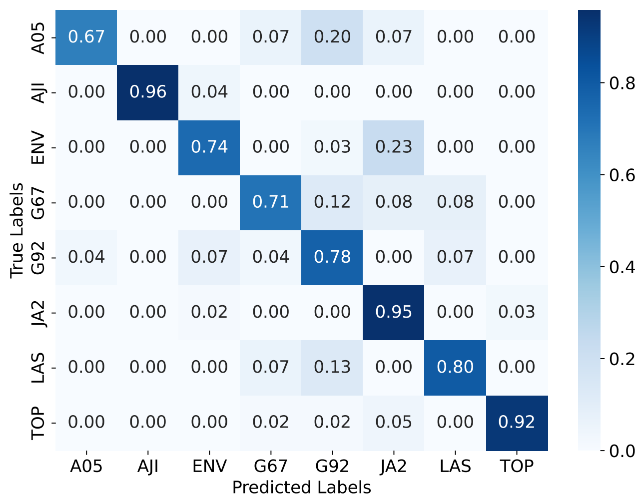
Ever since mankind's first advances into space, the population of non-functional, man-made debris in Earth's orbit has been continuously growing. Decommissioned satellites such as *TOPEX/Poseidon* or rockets left behind during launch processes are just two examples for so-called space debris. Uncontrollable objects like these can achieve high velocities up to 7 km/s, which renders them a threat to active space missions due to the risk of collision. Precise orbit predictions of debris can help to mitigate this threat; however, prediction quality depends on our knowledge of object properties such as shape, attitude, or rotational behavior. For the majority of today's debris population, these properties are unknown.

One possible way to learn more about a target is by ground-based optical telescope observations, but these are limited by factors such as small object sizes, large orbit heights, and atmospheric attenuation. Due to this, most visible space debris are optically non-resolvable, meaning that no information on the attitude can be drawn directly. Fortunately, unresolved observations still contain valuable information due to the variation in their brightness over time. Debris in orbit can start to rotate, and even non-rotating objects show varying illumination conditions due to the orbital geometry between satellite, station and sun. The resulting patterns hold information about e.g., surface properties, shape, and attitude behavior. Measurements that capture this temporal variation in object brightness are called light curves (LCs).

Since 2015, the SLR group of Lustbühel Observatory has been building a catalog, called IWF SPARC. It contains over 6500 LCs, which represent around 700 individual space objects. Usually, LCs are obtained by extracting the pixel brightness from CCD-based telescope images. IWF's data, however, are measured differently. Incoming photons are counted directly using a Single Photon Avalanche Diode (SPAD) detector. This type of detector allows to achieve a typical temporal resolution down to 10 ms, for bright targets down to the µs-level. File sizes are much smaller compared to CCD-based images and do not need image post-processing.

Traditional ML techniques (e.g., Random Decision Forest, RDF) as well as Neural Networks (NNs) were successfully utilized to characterize space debris using data from IWF SPARC. Models were trained to e.g., classify individual space objects (see figure). These models were able to differentiate between rocket bodies, spherical satellites, and active satellites. Having this information is especially interesting, since it allows to e.g., estimate an object's geometrical shape (cylinder, sphere or box), which in return can help interpret ambiguities in solutions related to spin and attitude determination. A key finding of the latest study is that a feature extraction step can significantly boost classifier performance. In this approach, features (e.g., mean or variance) are extracted from a LC first and then used as classifier input as opposed to using the raw LC directly. Using RDF in combination with Feature Extraction, accuracies as high as 90.7 % have been reported.

Trummer et al., Acta Astro., 226, 542, 2025.

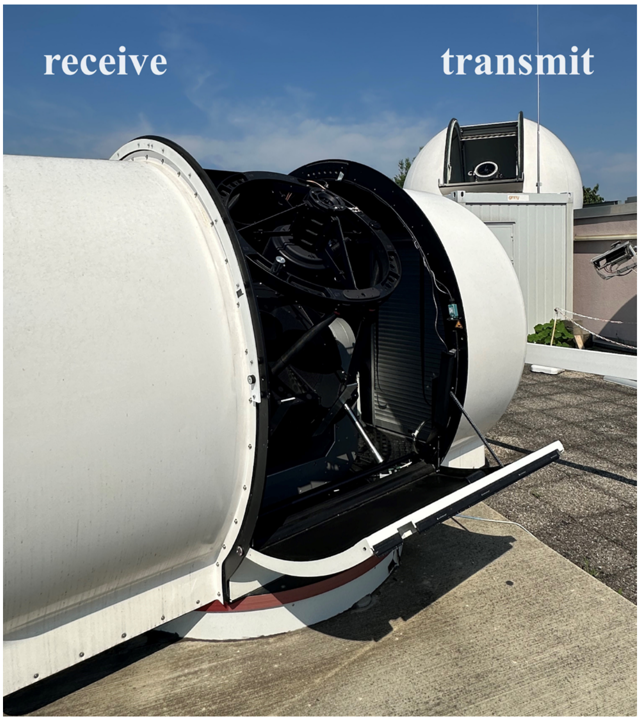


Confusion matrix achieved by a classifier type called XGBoost in combination with Feature Extraction. The 3-digit labels identify individual objects. Numbers within the matrix denote the average fraction of (mis)classified samples, the diagonals therefore indicate average fraction of correctly classified samples. 1 represents 100 % successful classification of LCs in a class.

MEGAHERTZ SPACE DEBRIS LASER RANGING

A laser ranging system based on a MHz-laser allowing for range measurements to satellites and space debris without changing the measurement setup was used to perform range measurements to satellites and space debris. Up to now separate systems have been used for the two different observation scenarios. Satellites equipped with retro reflectors are measured with lasers using 2 kHz repetition rate and a single shot precision down to 3 mm. The lower laser power however does not allow for measurement to space debris. A higher-powered laser used for space debris observations, yielding a precision of approx. 0.5 m, however, lacks the millimeter precision necessary for scientific missions.

The newly presented system relying on a MHz-laser is combining the strengths of both systems, while simultaneously increasing precision in both setups. To avoid atmospheric laser backscatter a bistatic measurement setup was established on the roof of Lustbühel observatory (see figure below) separating the transmit and receive system and thereby allowing to utilize the full laser power while operating the detector in free running mode. A narrow 0.19 nm filter was used to reduce the noise level while ensuring transmission of the laser wavelength. The central transmission wavelength was adjusted by fine-tuning the tilt of the filter angle in the detection package.

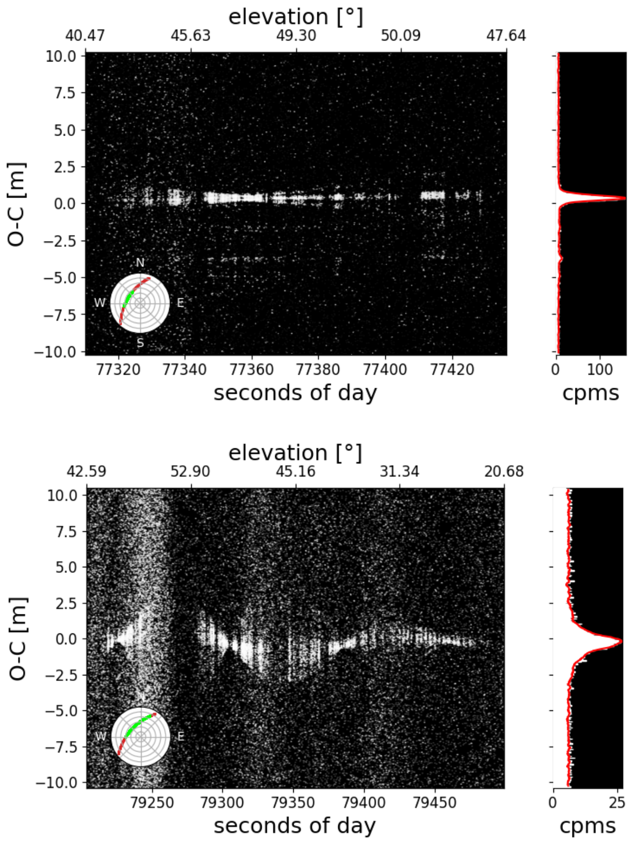


Bistatic MHz space debris laser ranging setup. The main SLR station (background) emits laser ranging pulses with MHz repetition rate. After being reflected by satellites or space debris, the signal is then received by the astronomical telescope visible in the front. The bistatic setup allows for avoiding atmospheric laser backscatter.

Satellites were measured up to a normal point precision (accumulated measurement precision in a timeframe of 15-300 seconds) down to a few micrometers. For the satellite *Jason-2*, up to 2.1 million successful range measurements were conducted within 15 seconds. The increased precision to space debris allows to distinguish between distinct surfaces of space debris objects. Measurements to *COSMOS 2082* (see figure below, upper graph) reveal reflections from different solar panels and show signs of a rotation. For *COSMOS 1867* (lower graph) a rotation period of approx. 170 seconds is found for the cylindrically shaped space debris object.

The MHz laser ranging system flexibly allows to adapt the repetition rate, even during ranging. Targets with stronger signal or lower noise allow for increasing the repetition rate to the maximum of 1 MHz, yielding optimal precision. For space debris targets typically, the signal is lower and it is hence beneficial to reduce the repetition rate to approx. 100 kHz. It was shown that besides atmospheric reflection, sunlight reflections from the body also contribute to the overall noise level.

Steindorfer et al., Nat. Comm., 16, 575, 2025.



Space debris laser ranging measurement with 100 kHz repetition rate to *COSMOS 2082*, NORAD ID #20624 (upper graph) and *COSMOS 1867*, NORAD ID: 18187 (lower graph). The Observed-Minus-Calculated Residuals reveal reflections from individual surfaces and show rotational behavior visible in the data from varying RMS, depending on the current attitude with respect to the observing station.

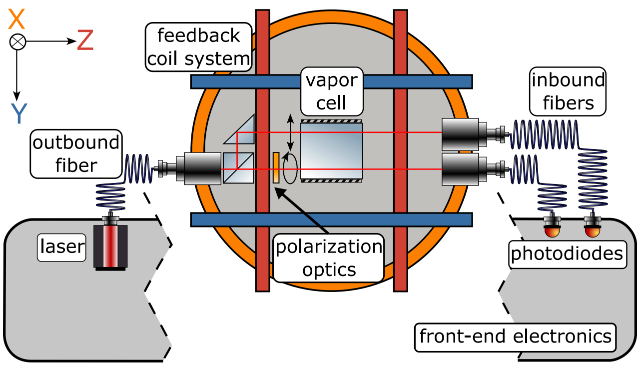
TECHNOLOGIES

NEW DEVELOPMENTS

One way of reducing the cost of space exploration, and thus enabling more frequent missions, is to reduce the spacecraft's size and launch mass. Consequently, scientific instruments also need to reduce their resource requirements in terms of volume, mass and power, while at the same time providing at least the same performance as traditional instruments. The development of new instrument technologies is therefore essential for competitive excellence in space research.

OPTICAL VECTOR MAGNETOMETER

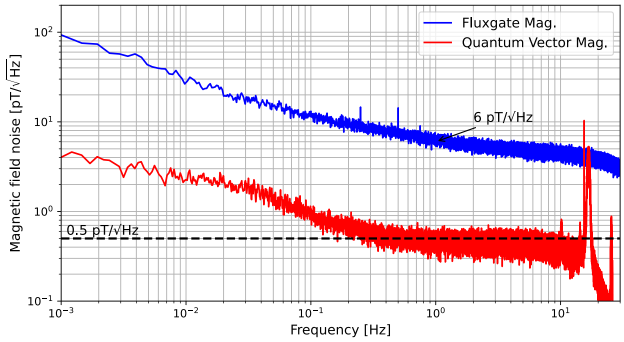
As fluxgate magnetometers - the most commonly used instruments to measure static and low frequency magnetic fields in space - suffer temperature and long-term drifts, they are in specific mission cases accompanied by optical magnetometers, which use atomic resonances to provide a reference point for calibration. A recent example is the *Coupled Dark State Magnetometer (CDSM)*, which measures the strength of the magnetic field with the help of a quantum-interference effect called Coherent Population Trapping (CPT). Thereby, the interference between quantum states of rubidium atoms excited by coherent light fields is read out optically.



Schematic drawing of the "dual parallel beam" concept. The linearly (upper beam) and circularly (lower beam) polarized beams contain information of the magnetic field components along the Z (lin.) and X/Y (cir.) axes.

The feasibility of utilizing CPT in the so-called Hanle configuration to realize an optical vector magnetometer (OVM), is being studied through a PhD project since 2022 (in the framework of IWF's Young Researcher Program in cooperation with the Institute of Experimental Physics of TU Graz). In 2024, this project gained synergetic support through an ESA-funded technology development project, with the aim of developing a laboratory model of the OVM for space application.

To find the optimal sensor design for achieving the primary goal of high sensor sensitivity, particularly in the bandwidth below 1 Hz, three concepts of varying mechanical and optical complexity were explored. Through a detailed analysis of the vast parameter space, the sensitivity of all concepts could be optimized to outperform a state-of-the-art fluxgate. In addition, all concepts have the potential to combine the absolute scalar measurement of the *CDSM* with the vector measurement of the OVM, enabling a single instrument fully capable of self-calibration during flight. While the choice of the sensor design depends on the mission specific trade-off, the "dual parallel beam" concept (see schematic left) offers a compromise between complexity and performance (see graph below).



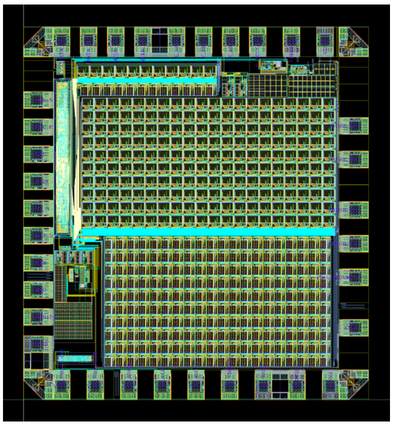
Sensitivity comparison between representative axes of a fluxgate magnetometer and the "dual parallel beam" sensor. The sensitivity is an order of magnitude better over the entire bandwidth from 0.001 to >10 Hz.

MAGNETOMETER FRONT-END ASIC

In the reporting year, the IWF and the Fraunhofer Institute for Integrated Circuits reactivated their collaboration on the development of a Magnetometer Front-end ASIC (MFA). The first generation was developed about 20 years ago. It is used in several magnetometers in space and three more flight models are currently made ready for flight. The next generation of the MFA should include an improved dynamic range and an advanced radiation hardness.

The first prototype contains a very low noise and high precision current-output sigma-delta Digital to Analog Converter (DAC) for stimulating the feedback coil of a magnetometer sensor. It is supposed to be the key element for a high-performance MFA microchip designed for a broad range of output currents from ±0.4 mA up to ±13 mA capable of driving a variety of different fluxgate sensors. The conversion quality targets a Signal to Noise Ratio (SNR) of 120 dB full scale with simultaneously maintaining a Total Harmonic Distortion (THD) of lower than -100 dB. A very specific topology based on a matrix of switched current (SI) elements was combined with a sophisticated control logic (delta sigma modulator) to fulfill the challenging requirements.

In 2025, the entire microchip design, verification and simulation took place, which finalized in the tape-out (delivering of the design files) of the project to the foundry. The microchip is produced on a 180 nm process known to be radiation tolerant to an ionization dose of up to 300 krad (with specific analog design measures) and a latch-up immunity up to 100 MeV cm^2 / mg as evaluated within a previous project.



Layout of the microchip, which is 4.3 mm^2 in size. The inner part mainly contains the matrix of the switched current elements and the outer ring shows the pads for the electrical connection of the microchip.

Parallel to the microchip production, which typically takes about six months, the functional and performance test environment has been set-up so that the evaluation of this first proto-type can start right away after the delivery of the microchip in early 2026.

MACHINE LEARNING

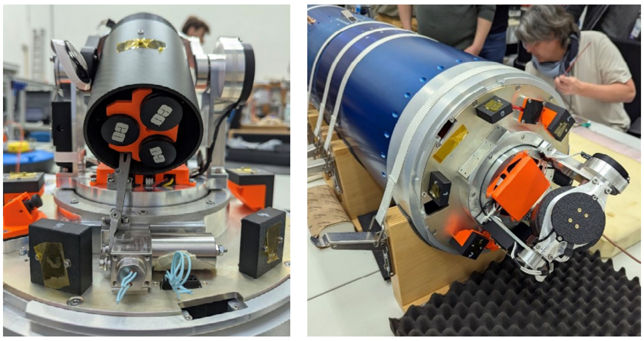
Over the last couple of years, the institute has focused on utilizing machine learning (ML) methods across its core research areas, including exoplanet climate and weather, exoplanet characterization and evolution, and satellite laser ranging. The institute has successfully created a pathway to integrate ML methods in addressing cutting-edge scientific and technological challenges in these domains. The exoplanet climate and weather group has developed ML surrogate models based on dense neural networks and gradient-boosting techniques that are capable of predicting three-dimensional gas temperatures and wind structures of arbitrary tidally locked gaseous exoplanets in near real-time, enabling rapid data interpretation pipeline development for future missions. Recent work from the exoplanet characterization and evolution group demonstrated that a neural network model predicts exoplanet atmospheric mass-loss rates with higher accuracy than classical approaches. Furthermore, the satellite laser ranging group developed an ML framework for classifying space debris using single-photon light curves, which can serve as a potential foundation for a real-time ML-driven data analysis pipeline to enhance space debris monitoring.

In addition to these focused applications, the institute is also actively researching three key pillars of ML techniques: adaptability, explainability, and interpretability. While recent work on Graph Neural Networks is not directly focused on space research, understanding such a model offers the possibility of applying it as a tool to predict molecular cluster formations within exoplanetary atmospheres, offering an ML-driven alternative to traditional Density Functional Theory. Similarly, the recent work on developing a Natural Language Processing-driven knowledge extraction framework from a large database can be extended to the development of a local, large language model-based information retrieval system.

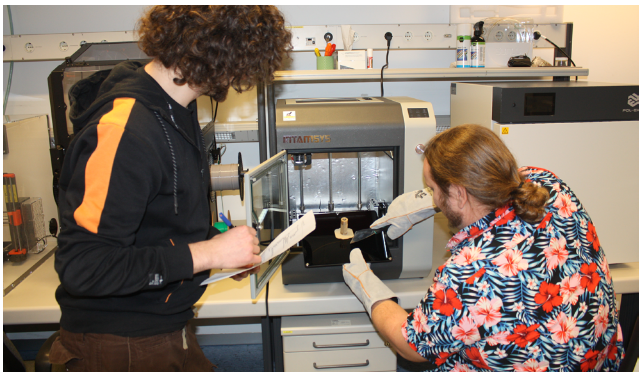
Reza et al., A&A, 694, A88, 2025.
Trummer et al., Acta Astronaut., 226, 542, 2025.

APEX

The *Auroral Polarization EXplorer (APEX)* is an instrument designed to measure the linear polarization of the auroral red and green emission lines. Ground-based measurements have reported few percent of linear polarization from these lines, but atmospheric contamination by scattering could not be ruled-out. *APEX* is a rocket-borne instrument, with the aim to provide the first measurements from above the atmosphere. *APEX* is developed by a team of students from the AeroSpace Team Graz (ASTG) and supervised by the IWF. It consists of three cameras, two equipped with bandpass filter (red and green) and on-chip mosaic linear polarization filters to capture the polarization of the emission lines. The third camera is a classical RGB camera, used for context reference and outreach. The camera head is installed on a three-axis motorized gimble which provides image stabilization during the exposure time of each observation. The pointing of the gimble is achieved with a combination of magnetometers and sun sensors, and sensors fusion using a Kalman filter. Gyroscopes provide the fine-feedback required for the image stabilization. *APEX* was accepted in December 2024 for a sub-orbital flight onboard a sub-orbital sounding rocket from the DLR/SNSA/ESA *Rocket EXperiment for University Students (REXUS)* program. In 2025, the team developed, manufactured and tested the instrument, under the supervision and financial support from the IWF. The instrument is now in its final preparation phase, with launch scheduled for 2026.



APEX, integrated on the *REXUS* rocket nose-cone module.



INFRASTRUCTURE

Space-born instruments are exposed to harsh environments, e.g., vacuum, large temperature ranges, radiation, and high mechanical loads during launch. They are expected to be highly reliable, providing full functionality over the entire mission duration, which could last for more than a decade.

The IWF operates several test and calibration facilities as well as special infrastructure for the production of flight hardware. A high-performance computer helps the scientists to cope with the enormous data, which have to be analyzed for space missions. For manufacturing and assembly of the electronics, in particular the flight units, very often specific mechanical tools and jigs are necessary.

In 2025, new 3D printers were purchased to make the prototyping of mechanical parts significantly more efficient and, above all, much faster.

For further information on the IWF infrastructure refer to oeaw.ac.at/en/iwf/institute/infrastructure.

3D PRINTING

In recent years, affordable 3D printing has entered the market. Many standard polymer materials are widely available for fast and easy prototyping. Thus, for many basic applications in the IWF laboratories, 3D printed parts have replaced custom manufactured parts from a conventional mechanical workshop. This saves a lot of time and money, while increasing the flexibility in engineering. However, these materials are not suitable for more demanding applications in terms of strength, high temperature environments and wear resistance. For this, more robust materials such as PolyEther-Ether-Keton (PEEK) are needed where a printer with higher performance is required. PEEK is especially interesting, because it is the go-to polymer for space applications due to its durability.

End of 2025 a new 3D printer was installed at the IWF. Now, material with a required nozzle temperature of up to 450 °C can be printed. The build plate can be heated up to 160 °C while maintaining a chamber temperature of 90 °C. This enables printing of the aforementioned high-performance materials. In order to reduce the moisture contained within the filaments, an additional drying oven was purchased for pre-heating and drying of the filaments. With this new setup the IWF is on its way to manufacture 3D printed space-ready parts in-house, which will be integrated in the next hardware projects.

Removal of a 3D printed PEEK part from the build plate. This 3D printed part will be used as a nozzle for dispersing gaseous nitrogen with temperatures down to -196 °C for performance testing of fluxgate magnetometers in very low temperature environments.

From above left to bottom right: Horst Bischof, Rector of TU Graz, Nobel laureate Didier Queloz, Christiane Helling and Luca Fossati at the public talk at TU Graz; Gaiatee Hussain and Christiane Helling at the opening of the Alpbach Summer School 2025 (© FFG); Paul Sihorsch, Christiane Helling, Dieter Grebner, Josef Aschbacher, and Birgit Dalheimer at the Ö1 Space Day; children making paper rockets during the ERN 2025; Günter Kargl and Georg Blüthner interviewed by the Radio Steiermark Kinderreporter Emilia, Noemi and Matis; Peter Falkner talking about 50 years of ESA during Graz in Space 2025.

IMPACT BEYOND SCIENCE

PUBLIC OUTREACH

The IWF was invited to participate in several outreach and networking events.

On 29 January 2025, with a lecture on physico-chemical processes in protoplanetary disks as studied by *JWST*, Peter Woitke proceeded the new year of the EAI Academy, which is an international educational program focusing on astrobiological topics co-organized by Ruth-Sophie Taubner.

On 27 February 2025, the IWF presented its Young Researcher Program at the MINT Kongress held at the Technical University of Leoben - a networking platform for the STEM community.

On 22 May 2025, the Austrian radio station Ö1 celebrated 50 years of the European Space Agency ESA. Together with Josef Aschbacher, Director General of ESA, and Dieter Grebner, CEO of Peak Technology and President of Astrospace, IWF Director Christiane Helling participated in a panel discussion on Austria's role in international space exploration.

On 27 May 2025, the visitors of the Science Garden Fair learned about IWF's active and future space missions.

In the first week of the summer holidays, the IWF participated in the "Kinderstadt Bibongo", teaching children between 6 and 12 years, how to become a "rocket engineer".

The biennial public lecture series "Graz in Space", organized by the IWF on 4 and 5 September 2025, celebrated 50 years of both ESA and the Alpbach Summer School. 16 scientists from ESA, the IWF, TU Graz, University of Graz, and Joanneum Research gave an overview of past, current, and future ESA missions with contributions from Graz. Guided tours at the IWF and the Lustbühel Observatory provided additional insights into space research made in Graz.

Under the theme "Life is Science in a world turned upside down", the European Researchers' Night (ERN) took place on 26 September 2025 in the city center of Graz. At IWF's interactive station "10, 9, 8 ... Lift-Off! From Earth to Space" children built paper rockets and then launch them, whilst their accompanying adults could find out all about IWF's upcoming space missions.

From 30 September to 2 October 2025, Nobel laureate Didier Queloz visited the IWF for the *CHEOPS* Science Team Meeting and gave a public talk at TU Graz on "The Exoplanet Revolution and Life in the Universe", which was attended by 500 people, mostly students.

Throughout the year, the IWF was invited to give talks or participate in discussion rounds inside and outside Austria. At the Wissensturm Linz, the Ars Electronica Center, and the Kepler Sternwarte Linz, Günter Kargl explained how to design and plan a space mission. During Yuri's Night at the Natural History Museum Vienna, Martin Volwerk talked about IWF's contributions to the *JUICE* mission and presented the newly developed scalar magnetometer. Ruth-Sophie Taubner talked about climate change on Mars, Venus and exoplanets in the frame of "KidSCH: Kultur in der Schule" at BRG Petersgasse and the search for life in the solar system at the "Kepler Teleskop Treffen" in Trahütten, Styria, and at "Kinderuni Wien". Together with Harald Ottacher, she participated in the autumn program of URANIA Steiermark, talking about life in the universe and how to prove its evidence. Helmut Lammer and Manuel Scherf also talked about Earth 2.0 at SETI Live, concluding that intelligent life might be far rarer than we thought.

Christiane Helling participated in the podcasts "oeco? logisch!" and "SciLUX", talking about climate protection and a possible planet B among the exoplanets. In the podcast "Fake Busters" of the Austrian newspaper Kurier, Manuel Scherf explained why it is so difficult to return to the Moon.

The Radio Steiermark-Kinderreporter:innen visited the IWF again in 2025, talking to Günter Kargl and Georg Blüthner about space weather phenomena and the upcoming *SMILE* mission.

In "Hallo, was machst du?", produced for the ORF Kids platform, Luca Fossati explained what it means to be an astrophysicist.

Stephan Zivithal contributed to the space blog in the Austrian newspaper Der Standard with an article on how researchers at the IWF are using space probes, simulations and laboratory experiments to unravel the mysteries of comets, and Ruth-Sophie Taubner and Fabian Weichbold wrote about how the IWF inspires children, students, and early-career researchers, offering workshops, summer internships and public events, which should help them take their first steps in space research.

In the IWF colloquium and seminar series, 21 international and 8 local speakers informed about current research topics and scientific results.

More information and pictures of the events are found at oeaw.ac.at/en/iwf/latest/events and a selection of reports in print, radio and TV is summarized in our media review at oeaw.ac.at/en/iwf/latest/iwf-in-the-media.

YOUNG RESEARCHER PROGRAM

The Young Researcher Program in interdisciplinary space science and planetary research (YRP@Graz) is a close collaboration between the IWF, the Graz University of Technology (TU Graz) and the University of Graz, which helps future researchers to gain first experiences in science.

In the fourth year of YRP@Graz four PhD positions were funded by the IWF and the FWF:

- Next generation exoplanet cloud formation model
  PhD student: Andrei Hünemeyer Dullius
  Supervisors: Christiane Helling and Peter Woitke (IWF/TU Graz)
- Towards an all-sky ion composition detector for the Saturnian system
  PhD student: Gabriel Maynard
  Supervisors: Gabriel Giono, Helmut Lammer, and Ali Varsani (all IWF)
- Coronal dimmings as signatures for CMEs
  PhD student: Thierry Fox
  Supervisor: Astrid Veronig (University of Graz)
- Rossby waves in stars
  PhD student: Zhengzhan Shang
  Supervisors: Astrid Veronig & Teimuraz Zaqarashvili (both University of Graz)

To foster collaboration within YRP@Graz, a network meeting was organized in April, the students were invited to a lunch with Nobel laureate Didier Queloz in September, and the traditional YRP Jamboree took place end of November 2025.

Nobel laureat Didier Queloz and the YRP@Graz PhD students.

The IWF offers a wide range of pre-scientific job opportunities and therefore actively engages with the Styrian high-school and university landscape. In summer 2025, twelve interns joined the IWF for periods ranging from one to six months. They were funded by the City of Graz and FFG. To foster connections, a networking event was held in August 2025.

IWF's 2025 summer interns with their supervisors.

Ruth-Sophie Taubner served as jury member of the German federal contest "Jugend forscht" for Geo- and Space Sciences, which took place in Hamburg, Germany, from 29 May to 1 June 2025. Last year's winner has joined the IWF as a summer student in 2025.

Following the OeAW young science initiative "Akademie im Klassenzimmer" Luca Fossati visited VS Vasoldsberg, VS Feldkirchen bei Graz, VS Klara Fietz in Graz, and VS/ASO Weiz, telling the kids all about planets inside and outside the solar system. Günter Kargl spoke at MS St. Ruprecht/Raab, HLW Weiz, and MS Hartberg about how to plan a space mission. Michael Steindorfer was invited by VS Hönigtal to chat about the danger of space debris. Ruth-Sophie Taubner talked about astrobiology at BG/BRG Diefenbach, BG/BRG Rahlgasse, and BG/BRG Erlgasse in Vienna. Last but not least, Martin Volwerk and Daniel Schmid held a workshop on northern lights at HLW Weiz.

MEETINGS

On 12 May 2025, the *PLATO* Follow-Up Meeting (3) was held online, discussing projects for the atmosphere characterization of gas planets with *PLATO*.

The Graz-Vienna Exoplanet Scientist Meeting (GVESM) is a series of meetings, focused on strengthening connections between researchers working in Austria in the field of exoplanet science. The meetings take place twice a year, alternating between Graz and Vienna. GVESM VI was held on 23 May 2025 at the IWF.

On 1 July 2025, the IWF hosted the inaugural meeting of the European *HWO* Program Coordination Group. The group's objective is to manage the European contribution to the planned NASA *Habitable Worlds Observatory (HWO)* flagship mission.

The Alpbach Summer School celebrated its 50th anniversary this year and was dedicated to "Small Bodies in the Solar System". 60 early career scientists from 22 different nations designed missions to the main asteroid belt, to the outer solar system's Centaurs, and to Saturn's ring system. Christiane Helling served as chair of the Program Committee and several IWF members acted again as group and roving tutors, as well as lecturers during this ten days event.

From 30 September to 2 October 2025, the *CHEOPS* Science Team Meeting was organized at the IWF. About 50 scientists participated in person, while another 15 joined online. The team met to discuss the status of the mission, the progress made on the analysis and publication of the data, and plan for the next mission extension request. The meeting was followed by the *CHEOPS/PLATO* Synergy Meeting, held from 2-3 October 2025, to streamline/kickstart synergy activities of the two missions.

N. Bangera, B. Besser, A. Blöcker, M. Boudjada,L. Carone, L. Fossati, K. Goodis Gordon, Ch. Helling, K. Kadam, R. Nakamura, M. Scherf, D. Schmid, V. Soni, R.-S. Taubner, M. Volwerk, P. Woitke, S. Zenitani, and S. Zivithal were members of scientific program and/or organizing committees at 4 national and 13 international meetings.

RECOGNITION

In recognition of his services to Styria as a centre of science, the Styrian Provincial Government has awarded Wolfgang Baumjohann, former Director of the IWF and President of the Division of Mathematics and Natural Sciences of OeAW since 2022, the Styrian Medal of Honour for Science, Research and the Arts, First Class.

Styrian Governor Mario Kunasek, Wolfgang Baumjohann, and Deputy Governor Manuela Khom during the award ceremony (© Land Steiermark/Robert Frankl).

Sohom Roy, postdoc in IWF's Space Plasma Physics Group, was awarded the Theodore Wolf Doctoral Dissertation Prize from the Department of Physics and Astronomy of the University of Delaware, USA.

In July 2025, Adriana Settino was named "Physicist of the Month" by the Austrian Physical Society ÖPG.

LECTURING

In summer 2025 and in winter term 2025/2026 IWF members gave lectures at the University of Graz, Graz University of Technology, FH Wiener Neustadt, University of Bologna, and Kyushu University.

THESES

Besides lecturing, IWF members are supervising Bachelor, Diploma, Master, and Doctoral Theses. In 2025, the following supervised theses have been completed:

Blasl, K.A.: Multi-Scale Kelvin-Helmholtz Instability at the Earth's Magnetopause, Doctoral Thesis, University of Graz, 96 pages, 2025. Supervisor: R. Nakamura

Gol, E.: Effects of MHD Disk Winds on Planetary Migration, Master Thesis, University of Graz, 75 pages, 2025. Supervisor: P. Woitke

Krenn, A.F.: Discovery and Characterisation of Transiting Rocky Exoplanets Using Current and Future Space Missions, Doctoral Thesis, University of Graz, 171 pages, 2025. Supervisor: L. Fossati

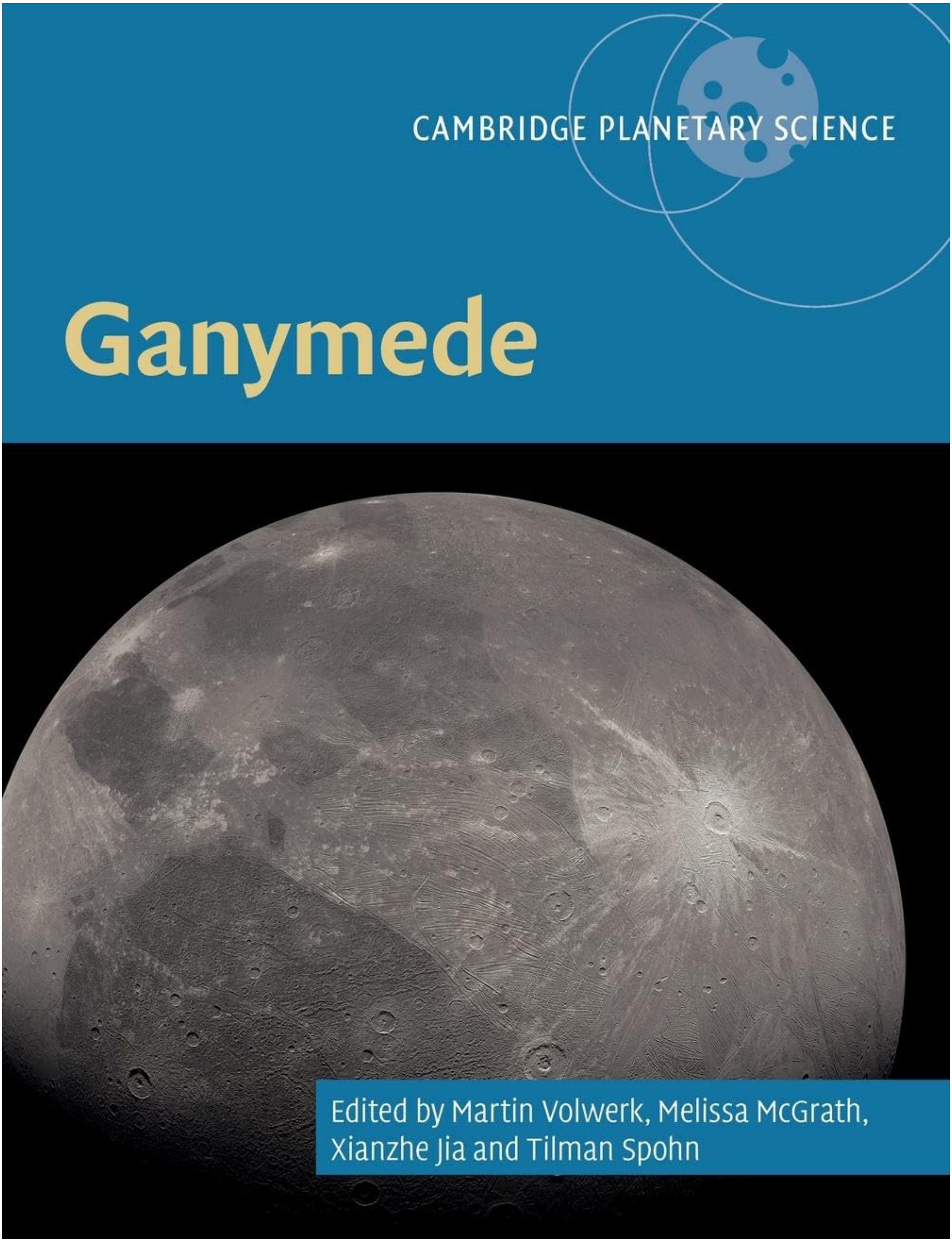
Lecoq Molinos, H.: Microphysics of Cloud Formation: The Path to Heterogeneous Nucleation, Doctoral Thesis, KU Leuven and TU Graz, 187 pages, 2025. Supervisor: Ch. Helling

Teubenbacher, D.: Numerical Modeling of Mercury's Magnetosphere in Preparation for *BepiColombo*: Hybrid Plasma Simulations and Ion Flux Diagnostics, Doctoral Thesis, University of Graz, 199 pages, 2025. Supervisor: Y. Narita

NEW PROJECTS

In 2025, the following third party projects with a budget greater than 100,000 EUR were acquired:

Project	Lead
FWF - Energy budget in the turbulent terrestrial magnetosheath	Z. Vörös
SWRI - Space Weather Observations at Lagrange 1	W. Magnes
DiGOS - DLR	M. Steindorfer



Cover of the book about Jupiter's moon "Ganymede", edited by Martin Volwerk et al., 2025.

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