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ABSTRACT BOOKLET

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ORALS

Advancing Mercury's Geodesy with the MORE Experiment

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The Mercury Orbiter Radio-science Experiment (MORE), one of the scientific investigations of the BepiColombo mission, is designed to achieve scientific goals in Mercury's geodesy and fundamental physics. By leveraging precise radio tracking measurements, MORE will refine our understanding of Mercury's interior, expanding our knowledge based on the results of the MESSENGER mission. In this work, we assess the performance of the geodesy investigation conducted by MORE, focusing on the orbital phase, starting in early 2027. In particular, this study evaluates how BepiColombo's refined gravity data can reduce the uncertainty in the estimate of the Love Number k2, rotational state and crustal thickness of Mercury. We report the results of the numerical simulation based on the up-to-date mission scenario, which consists of a two-year orbital phase. We simulate synthetic radio observables and estimate the model parameters through a precise orbit determination of the spacecraft. We use the covariance matrix coming from this analysis to perform a Monte Carlo simulation to obtain a set of gravity fields statistically compatible with a reference field (HgM009, derived from a recent reanalysis of the MESSENGER dataset). By combining these gravity fields with available topographic data, we produce a distribution of Mercury's crustal thickness maps, from which we infer the corresponding estimation uncertainty. Our results show that MORE will significantly enhance the resolution and accuracy of Mercury's gravity field, tidal and rotational parameters, enabling a more reliable association of gravity anomalies with surface features, such as impact craters, lobate scarps, and rift zones. By reducing uncertainties in Mercury's geophysical properties, the MORE experiment will advance planetary science, providing critical data for interpreting the planet's geological history and internal structure.

The Effect of Different Internal Structure Models on Mercury's Rotational State

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The rotational motion of a celestial body is influenced by its internal structure, shape, and the gravitational torque exerted by the external, massive bodies. Mercury is the target of the European Space Agency (ESA) BepiColombo mission, and, during the scientific phase around the planet, the spacecraft's instruments will collect a wealth of data, including gravity and altimetric measurements, surface images, and measurements of its magnetic field. Combining these data sets will provide critical insights into Mercury's orientation. This analysis relies on a coupled numerical integration of both the orbital dynamics of the Solar system and Mercury's rotational dynamics. The integration involves tracking a set of Euler angles for each layer of Mercury and their variations over time. The model of Mercury's orientation accounts for not only the gravitational torques exerted by external bodies, but also the internal coupling torques between the different layers of the moon: viscoelastic torque, gravitational torque, and inertial torque. This work examines how different internal structure models of Mercury affect its orientation. The current model assumes a three-layer structure: a solid inner core, an outer molten core (fluid layer), and solid silicate crust and mantle. By varying the physical properties, shape, and dimensions of these layers, we assess their impact on Mercury's libration. The analysis reveals the sensitivity of Mercury's orientation to its internal structure model. The forthcoming BepiColombo mission will provide real data on the amplitude of Mercury's libration. Any effects that produce libration amplitudes smaller than the mission's detection threshold will not be detectable by the probe. Therefore, the sensitivity analysis presented here is valuable for predicting the performance of BepiColombo data analysis and understanding what features may or may not be measurable.

Simulated Micrometeorite Bombardment of Iron-Free Silicate Mixtures: New Insights into the Role Carbon May Play in Mercurian Space Weathering

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Carbon is hypothesized to be present as a darkening agent on the surface of Mercury from excavations of a theorized graphite floatation crust or from exogenic material introduced by impactors (Vander Kaaden and McCubbin 2015, Klima et al. 2018, Bruck Syal et al. 2015). Additionally, graphite has recently been shown to be a possible component in Mercurian space weathering products (Bott et al. 2024). Using the Washington University Laser Space Weathering Laboratory (Gillis-Davis 2022), we have simulated the effects of micrometeorite bombardment on mixtures of powdered silicates (< 80 μm) with little to no iron (San Carlos olivine, forsterite, and enstatite) and various C-bearing opaques (graphite, carbon black, and anthracite). We present visible, near-infrared, intermediate-infrared, and mid-infrared reflectance spectra of these mixtures to prepare the BepiColombo team for interpretation of SIMBIO-SYS and MERTIS data. Transmission electron microscopy and energy-dispersive X-ray spectroscopy will be performed on select samples to identify any nano-/microphase opaques that may have formed.

Experimental Investigation of Silicate Sulfidation Kinetics

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Observations by NASA's MESSENGER mission confirmed that Mercury's surface is enriched in sulfur (up to 4 wt.%). The nature of this enrichment has been debated ever since. One theory is that it represents the composition of the interior, where S has been released through volcanic degassing. The gaseous S could then react with the surface rocks, leading to the formation of sulfides such as niningerite (MgS) and oldhamite (CaS). Additionally, the formation and decomposition of these sulfides are possibly related to the formation of hollows – rimless, flat-floored depressions encircled by bright haloes – on the surface of Mercury. However, the behavior of S and the kinetics of sulfidation reactions under Mercury's highly reducing conditions remain enigmatic. We are performing a series of high-temperature experiments to investigate the kinetics and mineralogy of the reactions between gaseous S and silicate minerals expected on Mercury's surface.

Modeling Thermal Profiles of Mercury's Surface: Insights from BepiColombo's MERTIS 5th Flyby

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1. Introduction -

The Mercury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) working in the range of 7-14 µm with a spectral resolution of 90 nm for spectrometer and 7-40 µm radiometer with two bands (Hiesinger et al., 2008) had the first opportunity to observe Mercury on the 1st of December, 2024 during the 5th flyby for BepiColombo. With the closest approach of around 37,000 kms, MERTIS observed the planet from the North Pole to the South Pole during its 37 minutes of observation time spanning between the latitudes of 140° to 230°. The flyby had a spatial resolution of around 27 km for the spectrometer and around a 100 km for the radiometer covering parts of the Caloris basin in the north and the Bashō crater in the south.

2. Thermal modelling of the Region of Interest –

As part of the preparation for the Flyby, the MERTIS team prepared to characterize the spectral emission and map the surface minerology along with the temperature variation. The thermal model is developed as part of the preparation. The thermal model considers a 1-directional thermal conduction scheme (Yan, et al. 2005). The surface temperature of Mercury is mainly dependent on three parameters – the radiation received from the sun, the radiative loss of heat and the thermal conduction of the surface and sub-surface (Bauch et al., 2021; Yan et al., 2005). Aubrite is one of the materials considered for the calculation of the thermal conductivity due to its characteristic proximity to Mercury (Keil, 2010). The results generated from these calculations will be used to develop a temperature map for the ROI. This map will be used along with the emissivity spectral measurement from Planetary Spectroscopy Laboratories (PSL) of the German Aerospace Center (DLR), to better understand the temperature ranges and characterize the surface mineralogy.

Investigating the Thermophysical Properties of Mercury's Regolith Using Mariner 10 IRR Nighttime Observations in Preparation for Bepicolombo MERTIS

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The MERTIS instrument [1] onboard BepiColombo will be the first to map Mercury's thermal emission at high resolution. To prepare for nighttime data, we developed a thermal model accounting for topographic scattering and emission, and surface roughness effects on non-nadir viewing. We compare our results with Mariner 10 Infrared Radiometer (IRR) [2] nighttime data and evaluate several regolith conductivity models.

Mariner 10 IRR: In 1974, the IRR measured brightness temperatures on Mercury using two spectral channels (11 and 45 μm). The flyby's forward- and aft- pointing geometry led to observations at high emission angle. Rough surfaces do not emit uniformly in all directions, and sub-pixel temperature variations cause shifts in brightness temperature with wavelength. Using a roughness model [3] and lunar Emission Phase Function data [4], we correct the IRR data for viewing geometry. Mariner 10 mostly observed Mercury's nightside, which is ideal for studying surface thermophysical properties.

Thermal Model: We produce an 8 pixel-per-degree model of global surface temperatures. IRR nighttime temperatures require thermophysical properties that vary with depth and temperature, similar to the Moon. We explored multiple regolith conductivity models which are based on lunar and laboratory data [e.g. 5, 6, 7, 8]. Importantly, most models require extrapolation from lunar temperatures to the higher temperatures achieved on Mercury, and the thermophysical properties derived using Mariner 10 data are sensitive to this extrapolation. Future MERTIS nighttime temperature mapping will refine regolith thermophysical property constraints.

References: [1] Hiesinger et al. (2010) PSS, 58, 144-165. [2] Chase et al. (1976) Icarus, 28, 565-578. [3] Jhoti et al. (2023) LPSC, 54, 2806. [4] Bennett et al. (2024) LPSC, 55, 2311. [5] Hayne et al. (2017) JGRP, 122, 2371-2400. [6] Martinez & Siegler (2021) JGRP, 126, e2021JE006829. [7] Vasavada et al. (1999) Icarus, 141, 179-193. [8] Keihm et al. (1973) EPSL, 19, 337-351.

Quantitative Evaluation of Thermal Redistribution: Updated Estimate of Surface K And Th Abundances

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MESSENGER's Gamma-Ray Spectrometer (GRS) measured the surface abundances of radioactive elements. Measurements showed spatial variations of K abundances, but the low spatial resolutions of GRS data made a detailed comparison with geological data difficult.

To understand the origin of the spatial variation in K/Th ratios, this study aims to quantify the correlation with the surface temperatures. We updated a gamma-ray propagation model and applied it for GRS data analysis. The estimated end-member K/Th ratios negatively correlated with the surface temperatures, supporting the thermal redistribution of volatile elements. Considering that the redistribution does not change the total amount of K and Th, we estimated Mercury's representative K/Th ratio of ~4800 according to the hemispherical average, which approximately agrees with those of terrestrial planets.

Space Weathering Investigation through Neural Networks Applied to Impact Craters

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Space weathering (SpWe), the physical and chemical alteration of the planetary surface by micrometeorites and the solar wind, is the only process currently affecting the surface of Mercury. Although observational data and laboratory experiments have provided information on how SpWe affects surface reflectance spectra, our present knowledge does not allow us to satisfactorily quantify the degree of SpWe experienced by different regions of the planet, preventing us from using SpWe as a more effective indicator of surface age or from establishing a link between its spatial distribution and those of particle precipitation and micrometeoroid impacts.

There are, however, easily distinguishable surfaces on Mercury that have experienced less SpWe than the rest of the planet: young impact craters and their ejecta. I have therefore retrieved data on impact crater spectra from MESSENGER MASCS/VIRS data and trained a neural network to distinguish between craters belonging to different geologic eras. The neural network should be sensitive primarily to the weathering of the surface and will make it possible to develop better SpWe indicators, which may eventually be adapted to data from BepiColombo's SYMBIO-SIS/VIHI instrument.

Modelling of Ca Mercury's Exosphere Observed by PHEBUS during the First Three Flybys

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INAF/IAPS

Meteoroid bombardment of Mercury's surface causes seasonal variability in its Ca exosphere, as observed by the MESSENGER mission. The observed high-energy Ca component exhibits a dawn enhancement and a pronounced dawn–dusk asymmetry, consistent to the directionality of meteoroid impacts. In this study, we use the exosphere generation model in IAPS (Institute for Space Astrophysics and Planetology) to simulate the 3D spatial distribution of Ca-bearing molecules and atomic Ca produced by the meteoroid impact vaporization (MIV) process. In the model, the energetic Ca component originates from shock-induced, non-equilibrium dissociative ionization and neutralization of Ca+ during the vapor cloud expansion, while a low-energy Ca component is generated later through the photo-dissociation of Ca-bearing molecules released by MIV.

The Ca uncondensed fraction in the vapor cloud and the relative abundance of atomic and molecular Ca component involved in the different processes are unconstrained parameters in the model, that play a crucial role in determining the distribution of Ca atoms and Ca-bearing molecules in the exosphere.

We use the Ca observations of PHEBUS (Probing of Hermean Exosphere By Ultraviolet Spectroscopy) spectrometer onboard the Bepicolombo spacecraft during the first three Mercury's flybys to constraint these parameters.

Based on the geometry of the observations during the flybys, we simulate the exosphere and reconstruct the Ca profiles along the instrument's line of sight. Preliminary results suggest that a high-energy Ca component with a temperature of approximately 50,000 K is consistent with the observed intensities, while the contribution from a low-energy component seem to be negligible.

This work advances our understanding of the MIV process on Mercury and provides a valuable tool for interpreting data and guiding observational strategies for the ESA/JAXA BepiColombo mission.

Sodium and Potassium Linewidths as an Atmospheric Escape Diagnostic at Mercury

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We present observations of Mercury's sodium and potassium exospheres from precision radial velocity spectrometers, sampling regions on Mercury's dayside and up to 5 planetary radii down the comet-like tail. While the collisionless exosphere is not inherently thermal, effective temperatures are a useful energy metric that we derive by convolving the instrumental line spread functions with a forward model of the Doppler-broadened hyperfine structure.

The weighted average of sodium gas effective temperatures at low and mid-latitudes is 1233 ± 14 K along the noon meridian, in good agreement with MESSENGER-based scale heights here. At the dawnside terminator and poles, this average increases to 1404 ± 14 K, which we attribute to gas transport toward the terminator induced by strong radiation pressure, and the loss of the least energetic atoms to Mercury's surface during this transport.

Effective temperatures of alkali gases increase dramatically between Mercury's dayside and tail. From the dayside to 4.3 RM downtail sodium increases from 1228 K to 7464 K, and potassium increases from 758 K to 8451 K. Line profiles of Na D in the exotail appear distinctly non-Maxwellian, changing shape from Gaussian to boxcar with increasing distance.

These results are interpreted as an effect of gravitational filtering of the velocity distribution function, in which low energy atoms fall to Mercury's surface and high energy atoms escape. The observations at a given altitude reflect what velocity distribution remains after Mercury's gravity removes the least energetic population component. The sodium effective gas temperature becomes invariant between 3.5 and 4.3 RM down the exotail, indicating the ballistic apex of bound particle trajectories is < 3.5 RM at this point in Mercury's season and all farther gas is escaping. Mercury's environment provides a textbook example of how Doppler broadening can be used as a diagnostic for atmospheric escape in planetary exospheres.

Investigation of the Low Latitude Boundary Layer (LLBL) in Mercury's Magnetosphere Using MESSENGER data

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LPP

The MESSENGER spacecraft, which orbited Mercury from 2011 to early 2015, revealed key features about the structure and dynamics of Mercury's magnetosphere, such as the Low Latitude Boundary Layer (LLBL). A statistical study [Liljablad et al., 2015] have surveyed the properties of the LLBL over the first orbital year of MESSENGER. More recently, during its third Mercury flyby (MFB3) in 2023, the BepiColombo spacecraft has crossed the LLBL in Mercury's duskside magnetosphere. Utilizing the ion analyzer (MIA) and mass spectrum analyzer (MSA) from the Mercury Plasma Particle Experiment (MPPE), a clear energy dispersion of ions ranging from a few eV/e to 40 keV/e was observed [Harada et al., 2024; Hadid et al., 2024]. The goal of this work is to extend those studies by performing a comprehensive analysis of the LLBL using all the MESSENGER data acquired over its lifetime. Analysis of magnetic field and ion data identified 351 LLBL cases, including 38 with decreasing and 88 with increasing H^+ energy dispersion. Most He^{2+} ions exhibited decreasing energy dispersion. LLBL cases showed a strong dawn-dusk asymmetry: 85% of H+ decreasing cases occurred on the duskside, while 89% of H+ increasing cases were on the dawnside. Events with opposing H^+ and He^{2+} dispersions resembled H^+ increasing cases. The average H^+ temperature is higher for increrasing cases compares with decreasing and no-dispersion cases. In increasing cases, the a pitch angle of the proton flux peak is near 90°, perpendicular to magnetic field lines.

Ion-kinetic modeling of Mercury's magnetosphere: A reference for BepiColombo's sixth flyby

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BepiColombo's sixth Mercury flyby (MSB6) on January 8, 2025, offers a high-latitude trajectory through key magnetospheric regions, providing an opportunity to study Mercury's plasma dynamics. This study uses the global 3D hybrid plasma code AIKEF to model Mercury's magnetosphere under twelve solar wind and IMF scenarios, incorporating kinetic ion treatment and a self-consistent sodium exosphere. Ion differential energy spectra are computed for solar wind protons and exospheric sodium ions along the MSB6 trajectory. Results highlight significant variations in magnetospheric boundaries and particle populations, with bow shock crossings shifting by up to 12 minutes and ion energies reaching up to 10 keV for protons and 30 keV for sodium ions. These findings offer a reference for interpreting BepiColombo observations and advancing our understanding of Mercury's magnetosphere.

Kinetic simulations of Helium in the Hermean plasma environment

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Helium was first detected in the Hermean exosphere together with hydrogen and oxygen by the airglow spectrometer on the Mariner 10 spacecraft. Sources of the Hermean helium population include outgassing after radioactive decay of heavy atoms, capture of solar wind He2+, and interstellar pick-up He+. Several processes can lead to a change in ionization of helium, including photoionization by solar radiation, and electron ionization and capture. Ionized helium can be convected and lost from the plasma environment due to the interaction of the Hermean magnetic field with the solar wind. The abundances of the different helium species in different regions of the Hermean environment are an indicator of the respective dominant helium sources and losses.

The aim of this study is to model the different helium species in the Hermean magnetosphere in preparation for the arrival of the ESA spacecraft Bepi Colombo. Simple MHD simulations of Mercury's magnetosphere are combined with kinetic simulations of helium atoms. The kinetic simulations include ionization and loss processes in order to investigate the evolution of the different helium species. Furthermore, a statistical analysis of the helium atoms is used to study the ratios of the helium species in the different regions of the Hermean environment in comparison to observations by the MESSENGER mission.

Solar wind context during the third flyby of Mercury by BepiColombo

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IRAP

On June 19, 2023, before and after the third Mercury flyby (MFB3) by the probe BepiColombo, the solar wind (SW) exhibits unusual properties like a very slow solar wind and a very dense plasma. During MFB3, the Mercury Electron Analyzer (MEA) measured a continuous high energy flux of electron in the nightside dawn sector of the magnetosphere. In order to constrain further studies related to the electron precipitation on the surface, or magnetic reconnection at Mercury, we aim to characterize the SW properties during the whole MFB3, using the conjunction of Parker Solar Probe (PSP) and Mercury.

We monitor the Sun activity using SOHO coronagraphs and use a Potential-Field Source-Surface (PFSS) model to identify the location of magnetic footpoints of PSP and BepiColombo on the surface of the Sun. We perform a ballistic propagation of the plasma parameters and the magnetic field measured by Parker Solar Probe at BepiColombo, we verify if the plasma seen at PSP is the one impacting Mercury.

We find that PSP and BepiColombo share the same magnetic footpoints during a time interval that covers the entire MFB3. A slow perturbation is observed at PSP and propagate until Mercury, thus also measured by BepiColombo. We find a good agreement between the density measured at PSP and BepiColombo. All those elements tends to confirm that the MFB3 occurred during the crossing of a slow SW perturbation.

We also demonstrate that the IMF orientation was oriented southward during the whole MFB3, wich is a strong interplanetary magnetic field (IMF) driver for SW-magnetosphere-surface interactions. This result is a strong constraint to take into account for the further study on the MFB3.

Impact of Solar-Wind Turbulence on a Planetary Bow Shock

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Small magnetospheres, such as Mercury's, are subject to be significantly impacted by the solar wind dynamics. Using the newly developed hybrid particle-in-cell (PIC) code Menura, we investigate - for the first time - the impact of the turbulent nature of the solar wind dynamics on the 3D structure and dynamics of an Mercury-like magnetosphere [Behar et al, A&A, 2024]. Two global simulations, differing only in the solar wind's nature—laminar in one case and turbulent in the other—are performed to highlight how solar wind turbulence significantly alters key regions. Compared to the laminar case, we find that the solar wind turbulence introduces larger fluctuations in the bow shock's position and disrupts the coherence of the magnetosheath structures. Additionally, this study shows how turbulent solar wind conditions affect the ion foreshock upstream of the quasi parallel bow shock.

We discuss these results in the context of the forthcoming multi-spacecraft BepiColombo mission.

Reports on the workshop at ISEE about observational plans of the Mio spacecraft and integrated research of the heliospheric system science

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BepiColombo has just performed all nine swingbys as scheduled on January 8, 2025, and succeeded in obtaining the scientific observational data during swingbys. Data analyses for the obtained data are undergoing. In particular, BepiColombo has found new perspectives on the Mercury magnetosphere, and observations during the nominal period will likely yield further results. Although the mercury orbit insertion (MOI) has been postponed one year due to the MTM module, the BepiColombo mission has surely moved forward in preparation for a new MOI in 2026. This one-year extension is also a valuable opportunity to reconsider the science topic with BepiColombo.

To discuss these topics in the Japanese community, a domestic workshop on scientific results obtained from BepiColombo and the operational plan of the Mio spacecraft is being held at the Institute for Space-Earth Environmental Research (ISEE), Nagoya University, from February 5 to 6, 2025. Furthermore, an early career session and an interdisciplinary research session on heliospheric, planetary, and magnetospheric topics are also planned.

In this presentation, we will summarize the discussion during the domestic workshop, which will be held at ISEE on February 5–6.

POSTERS

Model of the Mercury's mantle evolution

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Mercury presents a high bulk density (5430 kg m^-3) and an internal structure with a large core of about 2000 km and a relatively small mantle of about 300–500 km depth (Smith et al., 2012). The Mercury mantle could have experienced the cessation of mantle convection during its evolution or, alternatively, convection could be still active in the mantle at present. We aim to model the evolution of the Mercury mantle since the formation time of calcium–aluminium–rich inclusions (CAIs), including the magma ocean stage, and its interaction with the planetary core.

We solve the equation of conservation of mass, momentum, and energy to describe the mantle convection dynamics in a two-dimensional Cartesian geometry. In addition, we model the mineralogy of the Mercury mantle using modelled mineral assemblages from Perple_X software, predicted to be stable at thermodynamic equilibrium as a function of temperature and pressure, following a similar approach as Cioria et al. (2024). The model results will be constrained using radio science experiment data returned by the BepiColombo mission.

Can Crustal Magnetic Field Signals Be Detected during the Bepicolombo Flybys?

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While previous satellite missions were able to investigate the global magnetic field of Mercury’s northern magnetosphere, only little is known about the magnetic fields of Mercury's crust. Only a small latitudinal band of 40 degrees in Mercury's northern hemisphere was characterized during MESSENGER's low-altitude campaign. The ESA/JAXA BepiColombo mission is currently in the cruise phase towards Mercury. During this phase, BepiColombo will perform 6 flybys of Mercury with closest approach altitudes as low as 200 km, giving the limited opportunity to explore magnetic fields that can potentially be superimposed by crustal magnetic fields. In particular, large craters are expected to be associated with magnetized material producing crustal signals as previously seen by MESSENGER spacecraft. However, the total planetary magnetic field strength observed at these low altitudes is still about one order of magnitude larger than previously observed crustal fields, leading to the challenge of disentangling the magnetic field observations into external, core and crustal fields. In this study, we want to address the feasibility of measuring crustal fields during the flybys of BepiColombo. In particular, we focus on the first flyby of Mercury (October 2021), where the closest approach was colocated over a relatively large basin in the southern hemisphere (Beethoven basin). We began by producing a geological map of the distribution of iron-rich, and thus likely magnetized, region in the vicinity of the closest approach. This distribution is then used to produce a theoretical Equivalent Source Dipoles (ESD) model to derive the theoretical crustal fields at the spacecraft's altitude. Given Mercury's very dynamic magnetosphere, the calculated theoretical signals from the crustal field cannot be directly compared with the measurements, since they are a sum of signals from different sources (external, core and crustal fields). To estimate the internal and external fields along the flyby, we employ the global hybrid model AIKEF and produce a magnetosphere as a result of the observed upstream solar wind conditions. Those modeled fields are being subtracted from BepiColombo’s observed magnetic field, resulting in the residual field. Comparisons between the results of the ESD theoretical model and the residuals from the simulated magnetosphere model will allow us to understand the detectability of the crustal fields during the BepiColombo flybys, and at least give an upper limit for the magnetization in the flybys regions.

Planetary Interior Modeling by Synthetic Gravity Data Generation

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Gravity inversion techniques are essential for characterizing the internal mass distribution of planetary bodies by integrating data on shape, gravity, and rotation. However, the ambiguity inherent in scalar gravity signals, particularly regarding mass-depth trade-offs, complicates structural inference. To address this, we present a novel approach based on the spherical harmonics framework of Wieczorek et al. (2015). Layers gravitational coefficients [Cnm, Snm], directly tied to the internal mass distribution, are computed for specified interior models (homogeneous layers). Interior parameters include layer count, thickness, density, and interface topography (if present). For bodies with known Bouguer anomalies, interface topography can be derived using a filtering approach as proposed in Wieczorek and Phillips, 1998, which doesn't assume any isostatic compensation model. Spherical harmonics coefficients for each layer are then summed globally to compute gravitational potential, acceleration, and Bouguer anomaly maps.

The best-fit internal structure consistent with observations is found varying randomly the parameters within realistic bounds and comparing the synthetic results to observed data. The best parameter configuration is identified by the best RMSE.

This methodology can adapt to diverse planetary shapes, configurations, and datasets thanks to its mathematical framework, despite simplifying assumptions, such as homogeneous layers. Successful benchmarking on Mercury demonstrates its accuracy, identifying a crust-mantle boundary at ~27 km depth and a mantle density of 3240 kg/m^3, aligning with prior studies (see Buoninfante et al, 2023).

New in-situ measurements of Mercury's Helium exosphere through Ion Cyclotron Waves: Challenges and Chances

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Recently, the first in-situ helium abundance measurements around Mercury were derived from the signature of Ion Cyclotron Wave (ICW) events in the MESSENGER MAG data [1]. The data is scarce and limited to high-altitude dayside positions. Nonetheless, the interpretation of these measurements is interesting from two aspects. Firstly, these measurements relate to the Helium abundance results of the PHEBUS team, which during BepiColombo's first Mercury flyby inferred a Helium column density from their UV spectroscopy measurements [2]. Their flyby-science results indicate a much smaller exospheric Helium abundance than prior experiments of similar kind (UVS during Mariner 10) [3]. Simulated UVS observables based on the new ICW abundance measurements are consistent with the observations of PHEBUS and support the hypothesis of an erroneous observation model in earlier publications [1]. Secondly, an adequate explanation of the ICW abundance measurements demands a process which can explain significant local (and likely transient) abundance enhancements at high altitudes [4]. Such processes could involve strong local surface erosion events, such as the impact of (deci)meter-sized meteorites [4,5]. Coordinated observations from the BepiColombo mission could validate the ICW measurement technique and capture cross-disciplinary evidence of such surface erosion events [4,6].

[1] Weichbold et al. (2024), 'Helium in Mercury's Extended Exosphere Determined by Pick-up Generated Ion Cyclotron Waves' (submitted)

[2] Quémerais et al. (2023), 'Observation of Helium in Mercury's Exosphere by PHEBUS on BepiColombo'

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[5] Mangano et al. (2007), 'The Contribution of Impulsive Meteoritic Impact Vapourization to the Hermean Exosphere'

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Mg Exosphere of Mercury Observed by PHEBUS onboard BepiColombo during Its Mercury Swing-bys

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Mercury's exosphere is an important target for understanding the dynamics of coupled systems in space environments, tenuous planetary atmospheres, and planetary surfaces. Magnesium (Mg) is especially crucial for establishing methods for estimating the surface chemical composition distribution through observations of the exosphere because its distribution in the exosphere and on the surface are strongly correlated. However, owing to its low radiance, the Hermean Mg exosphere has only been detected by the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) onboard the Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) spacecraft. Thus, we have few observation data for areas other than low latitude regions in addition to few detection cases of short-term or sporadic fluctuations, resulting in a poor understanding of ejection and transportation mechanisms of the Mg exosphere.

Here, we analyzed the distribution of the Hermean Mg exosphere by BepiColombo MPO/PHEBUS during its Mercury swing-bys. After establishing calibration and background subtraction methods, Mg light curves were obtained, which were in agreement with Chamberlain model and a three-dimensional numerical calculation. Temperature of exospheric Mg atoms was about 5,000 K, much lower than that of Ca (>50,000 K) obtained by PHEBUS during the swing-bys. Mg may mainly be generated through photo-dissociation of Mg-bearing molecules such as MgO, and high energy Ca may be generated by neutralization of Ca+ ions.

Geological mapping and structural analysis of the western half of the Eminescu quadrangle (H09), Mercury

Mayssa EL YAZIDI

INAF/IRA

We present the results of the geologic mapping for the western half of the Eminescu quadrangle (H09) on Mercury. We used different data from NASA MESSENGER MDIS to produce a geological map that covers 72°- 108°E and 22.5°N - 22.5°S. The map was delivered at 1:300,000 output scale for mapping and linework digitalisation at 1:400K. We distinguish three morphological plains units: Smooth, intermediate, and intercrater Plains. We mapped craters with diameter greater to 5 km and we used 3-class crater system (C1-C3) appropriate to their degradation degree. A large group of lobate scarps and wrinkle ridges have been mapped. Frequent surface interconnection has been observed between crater and lobate scarps. Craters with 5 to 20 km of diameter are largely distributed compared to craters with diameter over 20 km or buried and degraded craters. Our observations show that compressive tectonic and cratering are the main driving processes for the surface geomorphology and the diversity of the plains units. The geologic map that we produced will help studying the western half of the Eminescu quadrangle (H09). This map is the first geological map for the selected area with such output scale. In this work we are proposing a list of 38 geologic sites as potential science targets to support the ESA-JAXA BepiColombo space mission for the exploration of Mercury.

MERTIS saw Mercury for the First Time! Insights from Laboratory Studies on FeO-free Analog Materials in Comparison to Mercury Flyby 5 Data.

Aurelie VAN DEN NEUCKER

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The MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS) on board of the BepiColombo spacecraft achieved a significant milestone on the 1st of December 2024, by successfully acquiring its first surface measurements in the MIR spectral range over a duration of ~30 mins and closest approach of ~37000km, during the spacecraft's MSB#5 along Mercury. The main objective of MERTIS is to characterize Mercury's surface mineralogy, by measuring its spectral emissivity and probing insights on the planet's geochemical composition and thermal properties.

To be able to interpret the measured remote sensing data within the observed region, analogue materials representative of the expected bulk mineralogy on Mercury were selected and were analyzed within the Planetary Spectroscopy Laboratory (PSL) of the German Aerospace Center (DLR), Berlin. Among the selected analog materials is the aubrite Ribbeck meteorite, chosen specifically for its enstatite-rich composition, abundance in exotic sulfides (e.g. alabandite, oldhamite) and depletion in FeO within its mafic minerals. The highly reduced nature of the aubrite aligns closely with the anticipated bulk mineralogy of Mercury, making it an ideal candidate for comparative analysis. Additionally, synthetic FeO-free mafic mineral end-members were prepared and are currently being studied as these are also hypothesized to be abundantly present on Mercury's surface.

The samples were incrementally heated up to 450 °C through induction within the vacuum (10-4 mbar) emissivity chamber of the PSL. The controlled heating allowed us to capture several spectra at 250-300-350-400 and 450 °C in the same spectral range as MERTIS (MIR, 7-14 microns). The collected spectra at the selected temperature range are comparable to Mercury's expected surface temperature within MERTIS MSB#5 observed region. By comparing the lab-measured emissivity spectra of the analogue materials with the data acquired during MSB#5, we aim to get a better understanding of Mercury's bulk surface mineralogy.

Exploring and Defining the rim of Caloris

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Determining where the rim of the Caloris Basin is, proves challenging. No previous study has ever paid close attention to defining this feature. Uncertainties in diameter and morphological factors ensures that answering key questions, like whether Caloris is a multi-ring basin, remains difficult. Potential defining characteristics: sharp elevation changes, distinct geological units (the Caloris Group) and sharp spectral changes, do not delineate a single continuous rim crest by themselves, instead presenting multiple candidates for the rim crest's location, and with gaps where the rim has likely been buried or destroyed. Unclear definitions within the Caloris Group further complicates attempts, resulting in uncertainties in unit identification. Finally, subsequent processes, such as lava infilling, tectonic activity and later impact events, have further obscured and degraded our potential defining characteristics. Thus, the question becomes not just "where is the rim?", but first "how do we define it?".

We present a preliminary assessment of criteria to define the rim of Caloris as the first step in conducting a systematic mapping study of the basin and wider units. We aim to examine the usable criteria, to identify the Caloris rim, with multiple objectives in mind: To develop a hierarchy of defining characteristics, emphasising properties and features related to primary basin forming processes over secondary modifications and to update and explore definitions of geological units. With this, using GIS software with data from the MESSENGER mission, we aim to produce maps of the Caloris Basin, using best efforts to define and determine the rims' location. Sites of particular interest will be highlighted as locations for potential observations in the upcoming BepiColombo mission.

Mercury's Altered Magnetosphere under Low Alfvénic Mach Number Conditions

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We investigate Mercury under low Alfvénic Mach number (MA) conditions using MESSENGER observations. These conditions are driven by ICMEs, that increase the upstream Alfvén speed and decrease MA. This study provides compelling evidence of Mercury's altered magnetospheric state under these extreme conditions, including observational evidence of Alfvén wing formation. We present a case study of a single ICME event in which the upstream conditions were sub- to trans-Alfvénic (MA < 1.5), generating Alfvén wings that are highly inclined to the upstream solar wind flow and point in the north/south direction. Compared with its nominal state, the dayside magnetosphere during the ICME exhibited a weaker, more expanded bow shock and significantly lower plasma density within the magnetosheath. During its traversal of the nightside magnetosphere, MESSENGER observed a highly inclined magnetic field relative to the typical magnetospheric magnetic field, populated with high-density plasma consistent with the formation of an Alfvén wing. We explore other candidate MESSENGER orbits in which Alfvén wings may be present and discuss how Alfvén wing formation depends on various upstream conditions such as IMF orientation. During a separate ICME event, the upstream IMF pointed eastward, generating Alfvén wings that are point dawnward/duskward.

This investigation of Mercury under extreme MA conditions provides insights into the nominal, sub-Alfvénic interactions between many outer planet moons and their host planet's magnetosphere and also informs our understanding of the many exoplanetary-stellar wind interactions occurring in low-MA environments.

The behavior of the magnetic cusp of Mercury

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The relationship between Mercury's magnetic cusp and variations in the solar wind has been examined in several prior studies. Building on this foundation, we combined two independent detection algorithms; one focused on identifying cusp signatures in magnetic field measurements, and another targeting particle data; to more comprehensively capture the cusp's characteristics. Utilizing this integrated approach, we performed a statistical analysis that reveals how the structure and occurrence of Mercury's magnetic cusp depend on solar wind conditions.

Detecting in-situ directional discontinuities in the solar wind at Mercury's Orbit

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Close to the first Mercury's flyby, at a heliocentric distance of about 0.34 au, BepiColombo observed several magnetic discontinuities in all components of the interplanetary magnetic field. The duration of these structures range from a few seconds up to tens of minutes. In this study, we use magnetic field measurements provided by MPO-MAG and the available SERENA/PICAM ion measurements to identify and characterise the properties of these magnetic structures, marked by rotations and reversals of magnetic field components, sometimes also leading to particle energization. We use the attitude gradient to detect discontinuities combined with minimum variance analysis to characterize their boundaries. The observed properties of these discontinuities are consistent with both the presence of in-situ magnetic switchbacks, during some radial reversals, and to the occurrence of small-scale flux ropes. The classification of the directional discontinuities reveals that the great majority belongs to the ED and RD type, with a lower fraction being classified as TD and ND type. The detection of directional discontinuities of different sizes and durations at Mercury's orbit has significant implications for both solar wind propagation and evolution studies. Our study underlines the importance of BepiColombo to offer a different point of view to carry out multi-spacecraft measurements to study simultaneously the origin and the evolution of the patch.

Solar energetic electron events measured by MESSENGER

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We present a list of 61 solar energetic electron (SEE) events measured by the MESSENGER mission and the radial dependences of some parameters associated with these SEE events. The analysis covers the period from 2010 to 2015, when the heliocentric distance of MESSENGER varied between 0.31 and 0.47 au.

We compiled the list of SEE events measured by MESSENGER using hourly averages to find the prompt component of the near-relativistic (∼70–110 keV) electron peak intensities and to calculate the peak-intensity energy spectra. We also obtained the peak intensities and energy spectra for the same events as measured by the STEREO-A, -B, ACE, or Wind spacecraft when one of these spacecraft was in close nominal magnetic connection with MESSENGER to derive the radial dependences of these SEE parameters.

Results. (1) Because the background intensity level of the particle instrument on board MESSENGER is high, the SEE events measured by this mission are necessarily large and intense; most of them are accompanied by a shock driven by a coronal mass ejection and are widely spread in heliolongitude. The SEE events display relativistic (∼1 MeV) electron intensity enhancements. For this SEE sample, we found that (2) the SEE peak intensity shows a radial dependence that can be expressed as Rα, where the median value of the α index is αMed = −3.3±1.4 for a subsample of 28 events for which the nominal magnetic footpoints of the near 0.3 au and 1 au spacecraft were close in heliographic longitude. (3) The mean spectral index δ of a subset of 42 events for which the energy spectrum could be analysed is ⟨δ⟩ = −1.9±0.3, which is harder than the value found in previous studies using data from spacecraft near 1 au.

MESSENGER Observations of Self-Similar Flux Pileup Regions in Mercury's Low-Altitude Nightside Magnetosphere

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Mercury’s small magnetosphere is strongly driven by external solar wind conditions and exhibits short substorms on the timescale of minutes. During the expansion phase, as magnetic flux accumulated in the magnetotail lobes is released back towards the planet, a significant flux pileup region is formed in the low-altitude nightside magnetosphere. This flux pileup is supported by the substorm current wedge connecting the cross-tail current sheet to the planet's conductive core boundary through field-aligned currents, and characterized by a mesoscale enhancement of the magnetic field above the baseline intrinsic dipole magnetic field. The MESSENGER spacecraft explored this sector of the magnetosphere during its final orbits before impacting the planet, where it observed multiple such flux pileup regions throughout many local times at the nightside magnetic equator within 0.2 Mercury radii of the surface. Here, we organize and present these low-altitude observations into self-similar classes of events using MESSENGER magnetometer data. We demonstrate how these flux pileup regions correspond to a compressed, flattened magnetic geometry compared to the rarefied, kinked field typically observed in this region of the magnetosphere. These magnetic structures exhibit clear symmetry above and below the magnetic equator throughout the ~3 minute spacecraft crossing time, suggesting they are quasi-stationary structures that persist throughout the substorm. We also present a preliminary analysis of plasma wave signatures in the flux pileup region, as well as comparisons to coupled fluid-kinetic simulations to help contextualize the magnetospheric current systems associated with flux pileup. Future work aims to better account for the shape and distribution of these long-lived structures, and ultimately to connect them to the more dynamic dipolarization fronts observed in the nightside current sheet.

Sodium Ion Distribution in Mercury's Magnetosphere as seen from MSB12346

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Mercury's environment is populated with sodium ions that take peculiar paths through the magnetosphere.

Using hybrid modeling, we will investigate different sodium ion source regions and and their pathways through the magnetosphere.

The effect of the IMF direction on these pathways is investigated, revealing significantly different patterns for sodium ion behavior.

In particular, the sodium ion occurrence along the BepiColombo swingbys MSB12346 is being presented to allow for aided analysis with plasma instruments.

Solar wind velocity reconstruction at Mercury using MESSENGER bow shock and magnetopause crossings.

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The solar wind significantly shapes and influences planetary magnetospheres, driving their structure and dynamics. Mercury, with its weak intrinsic magnetic field and close proximity to the Sun, is particularly sensitive to solar wind variations and adapts quickly to solar wind changes. Understanding solar wind characteristics, such as flow speed, is essential for fine-tuning magnetospheric models and eventually for interpreting Mercury's magnetospheric response to solar wind changes. The solar wind speed affects both the aberration angle, which tilts the magnetosphere relative to the Mercury-Sun line, and the subsolar standoff distances from the internal dipole center of both the bow shock as well as the magnetopause.

This study reconstructs solar wind speeds from various bow shock and magnetopause crossings observed in-situ by MESSENGER's magnetometer. We fit empirical bow shock and magnetopause models to the aberration angle and treat the subsolar standoff distances as additional parameters. For single crossings, a strong correlation between the parameters emerges. Thus, they cannot be independently determined, resulting in an infinite set of possible solutions for solar wind speed. To alleviate this problem, we combine multiple crossings to find a common aberration angle. Here, we present and discuss the first statistical results from the analysis and compare them to average boundary shapes and positions.