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Magnetosphere

Recent Revelations in Magnetospheric Studies at Mercury

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Since the launch of BepiColombo, a number of new studies have emerged with high expectations of what BepiColombo can bring in the near future. MESSENGER observations have been revisited, new simulations and models have been developed, and BepiColombo has conducted flybys of Mercury. In this talk, I will revisit those recent studies relevant to Mercury's magnetosphere and summarize the capabilities of BepiColombo instruments. In this talk, I will revisit those recent studies relevant to Mercury's magnetosphere and summarize what we can do with BepiColombo instruments.

Surface

Mercury in a box - the DLR high temperature spectroscopy laboratory

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At the Planetary Spectroscopy Laboratory (PSL) of the German Aerospace Center (DLR) in Berlin we are working on providing an extensive spectral library for the interpretation of the MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS, ESA/JAXA BepiColombo mission) instrument data.

MERTIS covers the spectral range of 7- 14 and 7-40 μm and the main objectives are to map the surface composition of Mercury, to identify rock forming minerals, and study surface temperature.

PSL is the only infrastructure in the world that allows measuring spectra of solid and powdered materials, in air/vacuum, from low to very high T (-200° to 1000°C), over an extended spectral range (0.3 to > 100 μm) and in a climate-controlled room. PSL operates three Fourier Transform Infrared Spectrometers (FTIR), equipped with internal and external chambers, to measure emissivity, biconical and hemispherical reflectance and transmittance. Micro-FTIR reflectance measurements can be performed with one of our spectrometers coupled with an Hyperion2000 microscope.

A high-temperature emissivity setup coupled with one spectrometer allows measuring MIR emissivity spectra of analog material at relevant Mercury's surface temperatures in vacuum. A list of Mercury analogs has been compiled: our collection contains olivine, enstatite, labradorite, augite, komatiite, tektite, anorthoclase, bytownite, L-chondrite, albite, hypersthene, diopside, quartz, nepheline, graphite, lunar simulants, and many sulfides. Samples are prepared in the rock preparation laboratory of our department, fully equipped with tools for sample processing, including sieving systems, grinders, mortars, and ovens for sample treatments. A high vacuum oven allows samples treatment at temperatures up to 1600 °C.

Understanding Mercurian Spectral Alteration through Simulation of Nanophase Weathering Agents

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The importance of the analysis of spectral changes on planetary surfaces has continued to increase. With the upcoming data from the Bepicolombo mission, new insights into the formation and composition of Mercury will be gained. Mercury shares some similarities with the Moon, for example, the lack of an atmosphere, but there are more differences, particularly the scarcity of data compared to the lunar surface. Extracting as much information from the obtained data as possible is even more important. It is particularly difficult to understand the effects on the spectra observed by remote sensing, as we do not have returned samples that may provide specific information about soil composition. That is why we are attempting to enable the simulation of the observed effects by adding agents to familiar lab mixtures. This approach has already seen promising results in simulating the effects of space-weathering on the lunar regolith. The same effects can be obtained by incorporating a cluster of nano-phase particles that could also be generated by a small number of larger particle. These effects extend even to the TIR spectral range, where a spectral shift can be observed and coincides with artificially weathered materials in a laboratory. This simulation-based approach can also be transferred to the Mercurian surface, where we will attempt to understand specific spectral effects without having to create different mixtures meticulously and laboriously in laboratories and measure the resulting spectra. In our research, we selected the mineral enstatite's spectrum for a comparable simulation. We aim to explore the impact of the incorporation of various substances, such as iron (II) sulfide, calcium, and magnesium, which are considered potential agents in the weathering process of the mercurian surface.

Spectral curvature of Mercury: implications for composition and space-weathering

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Spectral reflectance is a key tool for investigating the composition and space-weathering processes of airless planetary bodies. MESSENGER spectroscopic observations lack absorption features of mafic minerals such as pyroxene or olivine. Mercury's spectral units are then defined by their overall reflectance and spectral slope. As observed on the Moon, Mercury's fresh materials exhibit a higher spectral reflectance and less red continuum slope (increasing reflectance with increasing wavelength). Among the freshest material are the hollows. These meters- to kilometers-size depressions surrounding by bright halo feature a strong concave curvature in the visible domain between 300 and 600 nm. Here I present recent studies of hollows and this spectral characteristic: "curvature" using observations from the MASCS/MESSENGER (Mercury Atmospheric and Surface Composition Spectrometer) instrument. Hollows spectra are first compared with laboratory measurements of Mercury's analogs. Spectral modelling shows that the best analogs to reproduce the high spectral curvature of hollows are sulfides and/or chlorides. Spectral curvature of the entire Mercury's surface is then investigated in order to identify if other geological units exhibit the same spectral feature. High spectral curvatures mainly map the youngest terrains: hollows, bright spots and very bright craters. This result demonstrates that freshly exposed materials on Mercury are spectrally similar to hollows-forming material such as sulfides. In addition, longitudinal variations of curvature correlate with Mercury's hot and cold poles which suggest that high surface temperature alters this spectral feature. These studies of MESSENGER spectral observations provide observation targets for the BepiColombo mission.

Other

BepiColombo Status and first Results

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The joint project project between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) for exploration of Mercury, BepiColombo, has been launched on 20 October 2018 from the European spaceport Kourou in French Guyana. Following the launch it has successfully performed several flybys (one at Earth, two at Venus and three of Mercury). After another three flybys at Mercury in late 2024 and early 2025 BepiColombo with its state of the art and very comprehensive payload will orbit the planet and perform measurements to increase our knowledge on the fundamental questions about Mercury's evolution, composition, interior, magnetosphere, and exosphere [1]. BepiColombo consists of two orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (Mio).

A status of the mission and its instruments, and results from science operations during cruise and during the flybys will be given.

Chemistry of collisions of meteoroids with Mercury

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A realistic model of physico-chemical processes during collisions between meteoroids (CI chondrites) and Mercury considering condensation of refractory elements and variable adiabatic index during expansion of impact-produced clouds was developed. Equilibrium chemical composition of impact-produced cloud containing species of 20 elements (O, H, S, C, Cl, Si, Mg, Al, Ca, Na, Fe, Mn, Ni, N, Zn, K, Co, Ti, P, and Cr) was calculated. Dependence of the equilibrium chemical composition of impact-produced clouds on velocity of collisions and initial pressure was studied. Quenched chemical composition of impact-produced cloud is estimated. In accordance with this model relative fraction of atoms of Na, K, Ca, and Mg delivered to the Hermean exosphere by impacts of meteoroids is significantly higher than that previously estimated with usage of the model with constant adiabatic index and without considering condensation as a factor affecting on pressure in impact-produced clouds.

Mercury analogues and laboratory measurements to prepare BepiColombo

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Mercury's surface studies are difficult from ground-based observations and from the limited number of missions that have explored the Hermean environment. Characterising further Mercury's properties from laboratory measurements is a great and timely opportunity given BepiColombo's arrival in late 2025.

Through spectral measurements of Mercury analogues, our goal is to explore the mineralogical properties of Mercury's surface and its dependency on orbital measurements and Mercury's environment. Through dedicated measurements, we have explored the variability of spectral properties as a function of observation conditions (i.e., incidence and emission angles) and irradiation level (i.e., fluency up to 5x10^17 He+/cm2 with an energy of 20 KeV). Our analysis shows that the variability of spectral properties with varying illumination conditions can be correlated to specific compositions and particularly the magnesium content. We notice that spectral slopes increase with higher magnesium content and higher phase angle. Similarly, we noticed that the spectral slopes increase with irradiations of samples and reach a plateau. This puts important constraints on the capability of orbital measurements to observe spectral variabilities that are linked to recent geological phenomena and specific mineralogical and elemental compositions.

These analyses were done with increasing complexity of the analogues with improved matching mineralogy and composition with the known properties of Mercury. Starting from komatiite and boninite terrestrial analogues, we later used the mixing of adequate meteorites and minerals to match the expected composition of Mercury. The following improvement are in the preparation of synthetic samples that better match the composition and crystalline structures, an activity currently ongoing and expected to provide samples for the Mercury community.

Surface

Modeling of Mercury's regolith using MESSENGER spectrophotometry

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Mercury is covered by a regolith that affects how light is scattered from the planet's surface. To deduce physical properties of Mercury's regolith, we use spectrophotometry from the MDIS (Mercury Dual Imaging System) instrument of NASA's MESSENGER (MErcury Surface, Space ENvironment, GEochemistry and Ranging) mission. The data comes in eight colors [1] between the wavelengths of 433.2 nm and 996.2 nm, with phase angles from 20 to 130 degrees and incidence and emergence angles constrained to below 70 degrees. A theoretical particulate-medium model is used to interpret the observed reflectance. The model includes a shadowing correction that depends on three geometry parameters of the regolith. The first parameter is the packing density v, while the other two parameters describe the regolith's roughness as a fractional Brownian motion (fBm) surface: the Hurst exponent H in the horizontal and the amplitude σ in the vertical direction. The numerical implementation of the model includes a set of discrete parameter values [2]. Trilinear interpolation is used to extend the parameters to have arbitrary values within the ranges of 0.15–0.55 for v, 0.20–0.80 for H, and 0.00–0.10 for σ. We optimize the model parameters in least-squares sense using the Nelder–Mead simplex method [3], followed by Markov chain Monte Carlo (MCMC) sampling that uses proposed parameter values drawn from Gaussian distributions. Our results indicate that Mercury's regolith is densely packed ($v = 0.541 \pm 0.010$) with moderate horizontal variations ($H = 0.529 \pm 0.009$) and large height variations ($\sigma = 0.098 \pm 0.002$). The MCMC solution allows us to predict the spectrophotometry for differing viewing geometries. Future work includes improving the implementation of the model by increasing the range of the parameter values, especially for the packing density.

[1] Domingue et al., Icarus 257, 477 (2015)

[2] Wilkman et al., Planet. Space Sci. 118, 250 (2015)

[3] Nelder and Mead, Comput. J. 7[4], 308 (1965)

Surface

Investgating the Origin of Flows Around Craters on Mercury

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Craters on Mercury are typically surrounded by ballistically emplaced ejecta deposits, which thin gradually away from their rim. However, flow features have been identified around some craters on Mercury, whose layered morphologies, steep margins, and lobate shapes contrast with ballistic deposits. Flow features around craters occur elsewhere in the Solar System, e.g. on Mars, where many are interpreted as ground-hugging flows of ejecta during an impact event, where volatiles may fluidise ejecta material. In contrast, some examples may be landslides, especially on bodies with minimal volatiles like the Moon. Mercury provides an interesting point of comparison: an intermediary step between volatile abundant Mars and volatile depleted Moon. We globally surveyed Mercury for mass movement features around craters, encompassing flows and landslides, and surveyed the Moon for comparison. We find both bodies have a similar number of features (Mercury 97, Moon 92). Mercury is larger, but the Moon has a higher crater density, so abundances per crater are comparable. Most features identified extend downslope into adjacent craters, with the majority having failure scarps at their source. Morphological evidence indicates syn-impact formation, collapse of proximal ejecta or the transient crater rim into the adjacent crater being a likely origin. The similar frequency of these features around craters on Mercury and the Moon indicates they are a fundamental feature of impact cratering on uneven topography, with volatiles not required to explain their existence. However, Mercury, unlike the Moon, does have two examples of crater-related flows on flat ground, interpreted here as ejecta flows. Additionally, Mercury has more flows that lack a source failure scarp and seem to emanate directly from a crater rim.

Simulation of Micrometeoroid Bombardment of Sulfur-Rich Mercury Analogs in the Laboratory

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We synthesized three powdered samples of forsteritic olivine with FeO contents consistent with compositions observed at the surface of Mercury (0.53, 0.1 and 0.05 wt.% FeO) and mixed each sample with 4 wt.% sulfur. The mixtures were pressed into pellets and were irradiated with a Nd-YAG pulsed laser under ultra-high vacuum to simulate progressive exposure to micrometeoroid impacts. Ex-situ UV-visible (0.25-0.9 µm) and in-situ near-infrared (0.75-2.5 µm) reflectance spectra were acquired to identify spectral changes in the samples. The surface morphology was analyzed by scanning electron microscopy (SEM), and electron-transparent thin sections of each sample were prepared with a focused ion beam (FIB) for microstructural and chemical analysis in the transmission electron microscope (TEM).

We observe a global reddening with progressive irradiation for all samples. We also note brightening after irradiation in particular for the 0.05 wt.% FeO sample. The 1 µm absorption band is still present after irradiation, even for the sample with the lowest FeO content. We identified melt deposits on forsterite grains and a few sulfur-rich deposits across the irradiated pellets. No elemental S particles are found at the surface of the samples after irradiation, which might suggest their vaporization by laser irradiation. We prepared FIB sections for both melt-rich and S-rich regions of our samples for analysis in the TEM and analyses are ongoing. We expect to observe melt layers with similar thicknesses (50-100 nm) to those seen in our previous samples mixed with graphite, as well as S-rich deposits superimposing the crystalline phase.

Fundamental Physics

Investigating Mercury’s present and past tidal stresses

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A planet's orbital eccentricity can undergo significant variations over time due to planetary secular perturbations. Mercury's proximity to the Sun, its distinctive 3:2 spin-orbit resonance, and its substantial orbital eccentricity make it a fascinating case for studying tidal forces and the stresses they cause. In the past, Mercury may have experienced a state of heightened eccentricity and spin rates. In the study presented here, we explore the present and past tidal stresses through three possible evolutions for the spin and eccentricity of Mercury, in particular the previous spin/orbit configurations of 5/2, 2/1 and 3/2 before final capture, and their progressions through the past 2 Ga based on Correia and Laskar (2009). We find that Mercury currently experiences tidal stress values of up to ~ +/- 15 kPa with a tidal bulge that can radially displace the surface by a maximum of ~ 2.20 m. In the past, Mercury could have experienced tidal stresses of ~ +/- 40 kPa with strong local variations throughout the cycle prompted by higher spin rates. We can hypothesize that Mercury might have experienced surface alterations induced by these orbital dynamics. Advanced instruments such as the BepiColombo Laser Altimeter (BELA), set to arrive at Mercury in December 2025 as part of the European Space Agency's BepiColombo mission, are expected to deliver unparalleled data and will play a crucial role in precisely mapping Mercury's global topography, enhancing our understanding of the planet's surface variations.

Surface

Smooth and Intercrater Plains Morphology at the Lander Scale

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Some of the most compelling scientific questions we have for Mercury require the acquisition of data from the planet surface, including the sampling of surface materials, the use of seismic signals to probe the interior, and even to sample water ice and organic lag deposits in permanently shadowed regions. In addition to the tremendous difficulty in safely landing a payload on the surface of Mercury, future in-situ missions would considerably benefit from knowledge of local surface roughness, slope, and the size distribution of hazards (e.g., rocks) in relation to the clearance and stability configuration of the spacecraft. Unfortunately, the resolution of existing orbital image datasets for Mercury precludes landing site assessments analogous to the proven methods developed for Mars landing site analysis. Yet the high-resolution images of Mercury's surface that were acquired during the MESSENGER mission's low-altitude campaign offer a basis to compare at the meter scale via crater size–frequency distributions the morphological difference—or similarity—between the two major terrain types on the planet, intercrater plains and smooth plains. In this presentation, we reports results of our study to test the hypothesis that crater statistics for smooth and intercrater plains terrains are, at the largest map scales, functionally indistinguishable—such that targeting a landing site on a smooth plains deposit, which might seem at face value to be a more forgiven terrain type on which to land, might not constitute any inherent safety advantage than landing at an intercrater plains site. If this hypothesis is supported, then the scientific return of a Mercury landed mission need not be limited to a particular terrain type.

Surface

Effects of ion irradiation on Mercury terrestrial analogues in the visible to mid-infrared

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As an airless body, Mercury is subject to space weathering, including solar wind ion irradiation, which complicates remote sensing data analyses by modifying the spectral properties of the surface. We present an experimental study performed on Mercury's volcanic surface analogues to provide a better constraint on spectral alterations induced by solar wind. We used 20 keV He+ with fluences up to 5E17 ions/cm2 to simulate ion irradiation reaching the surface. Terrestrial ultramafic lava already identified as good analogues for Mercury were used: a boninite, a basaltic komatiite and a komatiite. Spectra were acquired in the visible to mid-infrared (VMIR) wavelength range, between 0.4 and 16 µm. In the visible to near-infrared samples show an exponential darkening, a reddening and a flattening of spectra. Above 1E17 ions/cm^2, the exponential darkening reaches a plateau while the reddening and flattening do not show any definable trend. In the mid-infrared, we observe a red-shift of Reststrahlen bands. The Christiansen feature is red or blue-shifted according to the irradiation dose. The spectral alteration is closely influenced by the composition. As Mercury's surface is compositionally heterogeneous, the degree of spectral alteration varies on the planet and putatively participates in the heterogeneous spectral properties of the surface. This work provides ground-truth data for future ESA-JAXA BepiColombo observations. The alteration of VMIR spectral features induced by ion irradiation simulated in the laboratory will be used for future SIMBIO-SYS and MERTIS data analyses.

Using Permanently Shadowed Regions to Constrain the Origin of Mercury's Volatile Polar Deposits

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Multiple lines of evidence show that Mercury's permanently shadowed regions (PSR) near both poles host deposits of water ice and volatile compounds. The presence of both water ice as well as low-reflectance volatile compounds stable to higher temperatures than water ice in the PSRs has provided strong support for the origin of the volatiles being exogenic, delivered to Mercury via impacts of asteroids, comets, and/or micrometeorites. Observations of the volatile deposits have shown that they preserve distinct surface reflectance values and have sharp boundaries, indicating that the deposits are geologically young or continually refreshed. In this presentation, we investigate two categories of PSR-bearing craters in Mercury's north polar region in order to gain new insights into the origin of Mercury's polar deposits. The first crater category includes those that are predicted by thermal models to have temperatures low enough to sustain water ice at their surface but that lack extensive radar-bright deposits. The second crater category includes the lowest latitude craters to host radar-bright deposits. We will show examples and models of both of these crater categories and discuss the implications for the origin and age of Mercury's polar volatiles inventory.

Carbon speciation on Mercury and diamond formation at the core-mantle boundary

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The carbon budgets of terrestrial planets result from the volatile contents of their building blocks, element speciation and storage in different reservoirs, potential volatile losses to space, and the evolution of these processes over time. In MESSENGER data, abundant carbon was identified on Mercury's surface, which is interpreted as the remnant of a primordial graphite flotation crust, in turn suggesting that Mercury's highly reduced magma ocean and core were saturated in carbon. Here, we re-evaluate carbon speciation in Mercury's deep interior in light of the most recent geophysical models of the planet's internal structure. We used high-pressure, high-temperature experiments in a multi-anvil cubic press combined with thermodynamic models to calculate the liquidus at the base of Mercury's magma ocean. Although a sulfur-free magma ocean would have been in the stability field of graphite, sulfur dissolution in the silicate melt under the unique reduced Mercurian conditions depresses the sulfur-rich liquidus to temperatures spanning the graphite-diamond transition. We show it is possible, though statistically unlikely, that diamond was stable in the silicate magma ocean. However, the formation of a solid inner core containing a FeSi phase would have caused diamond to crystallize from the cooling molten residual core, rose to the CMB and transformed to graphite. Secular cooling to the current CMB temperature would promote the retrograde transformation of graphite to diamond and the formation of a diamond layer that will become even thicker with time.

On the origin of the thermal hydrogen and helium in the exosphere of Mercury

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During the 1st flyby of Mercury by BepiColombo, The UV spectrograph Probing the Hermean Exosphere by Ultraviolet Spectroscopy (PHEBUS) measured the brightness of the exospheric emissions of helium (58.3 nm) and hydrogen (121.6 nm). Such emissions were also detected before by Mariner 10 during its Mercury flybys with a density scale height in agreement with a population partly or fully accommodated with the surface. The main source of this thermal population could be the solar wind protons and alpha particles impacting the surface in the magnetospheric cusps of Mercury and reflected as thermal atoms. Other sources for both species could come from impact of the interplanetary neutral atoms, while for helium, internal radioactivity and for hydrogen water dissociation are also additional sources. In this presentation, using Mariner 10 and the more recent BepiColombo/PHEBUS observations, we study the solar wind source and the relative efficiency to produce a thermal population of H and He around Mercury and discuss these results.

Surface

Statistical analysis on the new catalog of impact craters of Mercury

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The distribution of impact craters on a Solar System body is important as it may provide important information on the flux of impactors and its asymmetry, on the age of the processes that occurred on the surface, and the main characteristics of the surface itself. Mercury has been explored by Mariner 10 in 1974 and by MESSENGER in 2011-2015, which allowed the developed of catalogs with up to about 16.000 impact features.

We generated a new catalog of craters using an automatic approach based on the last YOLOv8 version of the Deep Learning models. The basemap used to detect impact craters is based on the images of MESSENGER, with a spatial resolution of 166 m/px, but we applied an own Super Resolution algorithm to increase the resolution by a factor 2. The resulting catalog is composed by more than 9 millions of craters across the entire surface of Mercury. This new catalog will be used to derive a more accurate age of geological units and specific features, and for the planning of SIMBIO-SYS observations.

In this work, we present the preliminary statistical analysis of the automatically-detected craters. This was done by firstly subdividing the Mercury surface in 15 quadrangles, then the different geological units smooth and intercrater plains, cratered terrains, and/or other surface structure, in each of them. We computed and compared the Size Frequency Distribution (SFD) of craters at both the quadrangle and unit levels. We obtained minor differences of crater density between quadrangles.

Magnetosphere

A fully kinetic perspective on the solar wind interaction with planet Mercury

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The planet Mercury hosts a weak intrinsic, shifted magnetic field that in combination with a tenuous exosphere gives rise to a small but highly dynamic magnetosphere. Both ion and electron acceleration processes, and their mutual coupling, determine the overall shape of the local plasma environment and the solar wind access to the surface.

Based on global three-dimensional fully kinetic particle-in-cell simulations, we provide a detailed overview of (1) the relevance of local acceleration processes on the global circulation patterns for purely northward and purely southward interplanetary magnetic field directions, (2) how solar-wind electron precipitation drives efficient ionization of multiple neutral exosphere species and emission of X-rays from the surface of the planet, and [3] how Mercury's magnetic field is able to shield the surface from up to 90% of the incoming solar wind flux.

These results will help interpret the observations of the ongoing ESA/JAXA BepiColombo mission.

Surface

Analyzing Hollow Degradation States Across Mercury Using Deep-Learning Detections

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Hollows are some of the most interesting features on Mercury. These small, shallow depressions likely formed via volatile loss and appear to be very geologically young, possibly even forming and evolving today [1–6]. To date, three major classes of hollows have been proposed [4,5], showing a range of reflectance and morphologic characteristics. These three classes may be linked to the developmental sequence of hollows, such that young, active hollows have high visible reflectance and distinct morphologies (rounded, irregular outlines and flat, shallow floors), older hollows have muted reflectance signatures, and expired hollows have softened morphologies.

Important questions remain regarding when, why, and how quickly hollows evolve through these stages. Understanding their distribution and degradation states can help address these questions. We trained a convolutional neural network - the Mercury HOllows Retrieval NETwork (HORNET) - using a Yolov5x instance segmentation architecture (PyTorch 1.7) to automatically detect hollows in MESSENGER Narrow Angle Camera (NAC) images and we are manually classifying their degradation states. Here we report our global results, which include numerous new discoveries of individual hollows and the first global database of hollow degradation states. We are using this database to improve our understanding of hollow evolutionary sequences by analyzing the environments and growth patterns of hollows in various degradation states.

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Magnetosphere

Energy dispersions in Mercury's northern magnetospheric cusp

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Dispersions in proton energy in Mercury's northern magnetospheric cusp are common. These features were recorded by MESSENGER/FIPS as changes in average proton energy as the spacecraft passed latitudinally through the region, and were observed under a range of solar wind conditions and interplanetary field orientations. We find that these signatures are spatial rather than temporal in nature, and that they correspond to ions on newly-opened field lines streaming away from the reconnection site. The duration of these signatures and their common occurrence indicate that dayside reconnection often remains steady for longer than a Dungey timescale. We demonstrate how these dispersions can be used to estimate the local convective electric field strength and the dayside open-closed field boundary latitude, both of which provide new estimates of magnetospheric forcing and constraints for modeling comparison.

Surface

Photometric Properties of Glacial-Like Flows Observed in Raditladi Basin

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There is increasing evidence of a multi-kilometer thick volatile rich layer (VRL) within Mercury's crust, associated with chaotic terrain formation [1], and locally evidenced at the surface by hollow formation. Recent identification of glacial-like deposits connects the VRL to the genesis of hollows, explaining their conspicuous association to impact craters [2]. Other presentations at this meeting (Galiano et al., Buoninfante et al.) also provide evidence for this layer exposed within Praxiteles basin's peak ring complex. Here, we present an initial photometric study of Raditladi glacier-like features, documenting the variation in regolith structure and assessing how their morphologic evolution might reflect variations in the stability of volatile evacuation pathways from the subsurface. Subtle differences are observed between the basin floor and the flow units, with the flows being slightly higher in albedo, smoother in roughness, and slightly less opaque and irregular texturally than the basin floor.

References:

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Determining the Influence of the IMF and Planetary Magnetic Field Models on Mercury's Magnetosphere Along Spacecraft Trajectories of MESSENGER, BepiColombo and MPO

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Mercury's planetary magnetic field models (PMFMs) agree on a majorly dipolar field structure with a northward shift of the magnetic equator. However, due to the northerly biased orbit coverage of past spacecraft missions and different data analyzing methods, the available PMFMs differ in the determined multipole magnitudes for the dipole, quadrupole and octupole moments. While the PMFMs agree well with northern observations, we find that the predicted magnetic field values differ in the unexplored equatorial and southern regions. In the forward modeling approach of this study, we apply three different PMFM representatives, differing in their values of the dipole, quadrupole and octupole moments, and model the resulting solar wind interaction via a global hybrid model with sets of the 4 most common interplanetary magnetic field (IMF) directions under otherwise average solar wind conditions. Extracting our modeled fields along the flybys of MESSENGER and BepiColombo, as well as along four representative orbits of the Mercury Planetary Orbiter (MPO), allows us to estimate local field variations due to IMF and PMFM influence. Our modeled magnetic field components separate significantly by up to 60 nT between the PMFMs in low-altitude southern regions, leading to displacements of magnetopause, cusps and current sheet locations. We find that MESSENGER flyby observations agree best with modeled field ranges resulting from a quadrupolar PMFM and that certain nightside regions are useful to estimate upstream IMF polarity. We also demonstrate how comparing BepiColombo swingby and MPO orbit phase observations with modeled results can help determine the correct PMFM for Mercury.

Magnetosphere

Solar wind precipitation onto the Mercury surface measured by the ENA instrument on BepiColombo/MMO spacecraft

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Quantitative measurement and characterization of solar wind protons (and magnetospheric ions) precipitating onto Mercury's surface are essential to understanding a variety of phenomena, including space weathering of Mercury's surface regolith, production of surface hydration and following water molecules, and secondary particles (ions and neutrals) released into the exosphere and magnetosphere.

In situ measurements of precipitating particles from orbiting spacecraft make it challenging to accurately characterize particle fluxes at the surface. Landers can be used to determine the precipitating fluxes, but the measurement is limited to a local region; thus, their global distribution cannot be determined. On the other hand, observations of reflected neutral hydrogen atoms from the surface (originating from the precipitating protons) can provide a quantitative, global identification of solar wind flux precipitating at the surface of Mercury using an orbiting platform. The benefit of this experiment was recently demonstrated by similar observations on the Moon. In this study, we discuss the precipitating protons at the surface of Mercury from the energetic neutral atom data obtained by the ENA instrument onboard BepiColombo/MMO spacecraft during its Mercury flybys.

Energetic Electrons Observed During BebiColumbo Mercury Flybys

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We report on BepiColumbo SIXS observations of Energetic populations in the Mercury Magnetosphere. Whilst on the first flyby we observed no such populatios, on both bthe second and third flybies we opserved strong energetic particle signatures. We will compare these with the measurements made by Messenger (Lawrence et al. 2015, Lindsay et al. 2016) The data was consistent with two separate populations, characterised by different pulsation frequencies, observed on the nightside, and cuting out sharply at the magnetopause exit. These are interpreated in the context of the Lawrence et al. observations.

Plasma environment of Mercury's magnetosphere as seen by BepiColombo during its third flyby

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On June 19th 2023, BepiColombo performed its third (MFB3) gravity assist maneuver at Mercury. During this flyby, the spacecraft approached the planet from dusk-nightside toward dawn-dayside and traveled down to close distances ~ 235 km altitudes above the planet's surface. Even though BepiColombo is in a so-called "stacked configuration" during cruise (meaning that most of the instruments cannot be fully operated yet), a number of instruments can still make interesting observations. Particularly, despite their limited field-of-view, the particle sensors allow us to get a hint on the plasma composition and dynamics along a unique path across the magnetosphere and very close to the planet over a wide range of energies, from few eV/e up to 40 keV/e. In this presentation, we will show an overview of the plasma environment from the Mercury Ion Analyzer (MIA) and the Mercury Electron Analyzer (MEA). Moreover we will present the first ion composition observations of the Mass Spectrum Analyzer (MSA). MIA, MSA and MEA are part of the Mercury Plasma Particle Experiment (MPPE, PI: Y. Saito) consortium that is a comprehensive instrumental suite for plasma, high-energy particle and energetic neutral atom measurements onboard Mio (Saito et al. 2021). During this flyby, MSA and MIA revealed the presence of energetic (> 10 keV/e) and cold (< 50 eV/e) heavy ions inside the magnetosphere around closest approach. Moreover, we will show major features of the Mercury magnetosphere highlighting different regions: 1) Low Latitude Boundary Layer, 2) central plasma sheet and 3) evidence of a ring current [Hadid et al., Nature Communications, under review].

Magmatic diversity inferred from geochemical end-members around the Caloris basin

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MESSENGER observations revealed that a large part of Mercury's surface was formed by multi-stage volcanism, so surface heterogeneity in elemental composition is a key to understanding interior evolution. Elemental composition maps have been produced from MESSENGER X-Ray Spectrometer (XRS) data and suggested a compositional difference between the interior and exterior of the Caloris basin, but their lower spatial resolutions compared with spectral and geological data make a comprehensive interpretation difficult. This study aims to determine the geochemical end-members around the Caloris basin, using a mixing model that represents elemental composition measurements by XRS as mixing of different end-member compositions. We defined end-member units based on geological contexts using spectral and geological units. The end-member compositions that best reproduced our model were determined by least-square fitting.

We obtained 5 end-member units: Caloris Interior Plain, non-Caloris HRP, Caloris Exterior Plain, Intercrater Plain (IcP) and Caloris Group. The derived end-member compositions constitute the observed surface compositions. The Caloris interior and exterior plains showed a compositional variation consistent with a fractional crystallization from a single magma source. On the other hand, the composition of Intercrater plain does not lie on the same trend, suggesting the existence of another magma source with a different composition. The two different magma sources could have originated from a common mantle source with different temperature-pressure conditions or from different mantle sources.

Magnetosphere

Magnetosheath modeling around Mercury using boundary-fitted grids

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Mercury's magnetosheath is possibly one of the most frequently encountered plasma domains for the BepiColombo-Mio spacecraft due to its highly elliptical orbit extending up to about 6 planetary radii. Here we present our construction of the steady-state magnetosheath model of the plasma flow velocity and the magnetic field by mapping the magnetosheath harmonic function (the solution of the Laplace equation) onto the user-defined shape of the magnetosheath based on the boundary-fitted orthogonal (or nearly orthogonal) grids. The advantages with the harmonic function model are: (1)the method is numerically by far inexpensive and can easily be set to compare with the spacecraft data or simulation results, and moreover, (2) the method can be used in a reversed way to determine the upstream condition (flow velocity and magnetic field) for a given set of data and shape in the magnetosheath. Different ways of implementation of the mapping are possible. We present the magnetopause-normal mapping as an example (providing a nearly orthogonal mapping for the equatorial magnetosheath region) and compare with the hybrid simulation results. We also extend the method to a more refined and versatile style and introduce the numerical conformal mapping for the magnetosheath as an open-boundary grid generation problem.

Interior and evolution

Formation of Mercury: A review

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Mercury is a mystery as to its origin. Mercury has about 6% of the mass of the Earth. Mercury's core makes up about 70% of its mass, which implies a significant enrichment of iron relative to silicates, while its mantle is severely depleted in oxidised iron. Although Mercury is the innermost planet and orbits close to the Sun, the presence of volatile elements, organic matter and water has been reported on Mercury's surface. Various models of giant impact(s), accretion processes and/or selective condensation within the protoplanetary disk have recently been proposed for the formation of Mercury. In this talk I will try to review these recent updates on Mercury's formation.

MHD parametric study on Kelvin Helmholtz and tearing mode instabilities on the Mercury magnetopause with MESSENGER data.

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Understanding Kelvin-Helmholtz (KH) waves and their dynamics at the Mercury magnetopause will shed light on mechnisms like plasma trasnfer of momentum and magnetic reconnection in the comlex near environment of our innermost planet. In this study, we investigate KH instability phenomena MESSENGER data to achieve two key objectives. Firstly, we identify KH waves occurring at the Mercury magnetopause, using the magnetometer (MAG) and Energetic Particle and Plasma Spectrometer (EPPS) onboard the MESSENGER spacecraft. Secondly, we employ a 2D+t flexible magnetohydrodynamic (MHD) model to simulate the development of KH vortices and tearing mode instability, focusing on four distinct events that occurred between 2011 and 2013, characterised by the presence of large-amplitude wave trains within the magnetopause. The model explores the parameter space by varying the plasma solar wind, the Alfvénic Mach number and the Reynolds and magnetic Reynolds numbers. The results obtained from our combined observational data and modelling approach contributes to a comprehensive understanding of the spatial and temporal dynamics of KH waves at Mercury's magnetopause and helps to constrain the main dimensionless parameters which describes the interaction of the solar wind and the magnetospheric boundary of Mercury.

Mercury's Magnetosphere: Structure, Dynamics, and Its Role in Cross-Disciplinary Science

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Mercury, the innermost planet in the solar system, possesses a mini-magnetosphere arising from the interaction of its relatively weak internal field with the solar wind. Mercury's magnetosphere consists of many familiar structures commonly found in other planetary magnetospheres, such as the bow shock, magnetopause, magnetotail and various large-scale current systems. However, the unique external and internal conditions at Mercury result in many distinctive features in its space environment. In particular, the proximity of Mercury's core - where its internal field originates - to the planet's surface and magnetospheric boundaries suggests that the planetary interior has a significant influence on how the magnetosphere responds to the external forcing by the solar wind. Moreover, the ambient solar wind in the inner heliosphere that interacts with Mercury has a low Alfvénic Mach number, implying that magnetic reconnection at Mercury is very efficient and consequently the global dynamics is dominated by effects of reconnection. Unlike other planets, Mercury's lack of an appreciable ionosphere and the presence of a tenuous exosphere not only lead to more direct space weathering of its surface but also allow for direct electrodynamic coupling between the magnetosphere and the planet's interior. As such, Mercury's magnetosphere is intimately connected to the solar wind, the planetary exosphere, surface, and interior, forming a highly coupled system. This presentation aims to provide a tutorial on Mercury's magnetosphere, focusing on the fundamental elements that govern its structure and dynamics and key aspects that are relevant to cross-disciplinary science concerning the planet's interior, surface and exosphere.

Surface

Evidence for a Complex Explosive Volcanic History at Nathair Facula

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Ongoing studies of the explosive volcanic vents on Mercury, and their associated pyroclastic deposits, have revealed evidence for a complex volcanic history. We have produced a case study of the intricate Nathair Facula volcanic complex using integrated geomorphological and photometric studies of the vent and surrounding region. Outside the physical vent structures, the observable surface textures, crater morphologies, and eventual presence of dark halo craters all support the presence of a contiguous, meters-thick pyroclastic deposit which gradually thins and mixes with the background regolith. This gradual thinning is also consistent with the photometric modeling. Meanwhile, at the physical vent structure itself, our analysis reveals evidence of at least three topographically distinct vent structures. While one of these structures is morphologically muted, the other two structures preserve significant amounts of fine-scale structure and detail on their floors and walls. This suggests at least two distinct eruption events at the site, with the morphologically fresh vents forming after the initial vent structure, and these latter two structures forming synchronously, or near-synchronously. Perhaps most intriguingly, the photometric modeling of the near-vent region shows evidence for multiple regions with significant variations in particle texture and opacity. This is consistent with a dynamic, dense eruption plume. Given the spatial scale, morphologies present, and properties of the pyroclastic deposit, we suggest Nathair Facula may be more analogous to features such as Kilauea Iki in Hawaii than the pyroclastic vents and deposits on the Moon.

Tides on Mercury with a solid-liquid mixed layer

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Tidal response provides insights on the deep interior structure of planetary bodies. Recent estimates on the tidal Love number of Mercury including the MESSENGER Extended mission are higher than previous estimates, suggesting a softer interior structure. One of intriguing idea is a partially molten layer at the base of the mantle, as is also proposed for the Moon and Mars. We calculate tidal responses of Mercury with a solid-liquid mixed layer using a dynamical poro-visco-elastic gravitational theory we recently developed. We find that a conventional treatment for partial melting invoking an exponentially reduced viscosity may lead to an overestimation of the degree of melting. We also present a pattern of tidal deformation. Future analyses using our approach would be beneficial for BepiColombo as well as other planetary exploration missions.

Deep Neural Networks for Surface Composition Reconstruction from Simulated In Situ Exospheric Measurements at Mercury

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Exospheric measurements at airless bodies have the potential to improve and complement the surface composition mapping by dedicated imagers. These measurements are crucial for understanding surface release processes, the dynamics of interactions within the planetary environment, and the impacts of erosion and space weathering on planetary evolution. Our research introduces a tentative proxy method for estimating Mercury's regolith composition using in-situ measurements from its neutral exosphere, employing deep neural networks (DNNs). We utilize a supervised, feed-forward DNN model known as a multilayer perceptron (MLP). This model, consisting of fully-connected neural layers, processes as inputs exospheric densities and proton precipitation fluxes from a simulated orbital scenario around Mercury and predicts the elemental composition of the surface regolith below.

The DNNs can estimate the exospheric generation mechanisms, acting as a representation tool of surface-exosphere interactions and enlightening the processes that contribute to the formation of the exosphere, including micrometeoroid impact vaporization, ion sputtering, photon-stimulated desorption, and thermal desorption. Although the present study is a prototype, we show that through rigorous training and testing, the MLP DNN has the potential to accurately predict and map surface compositions from exospheric data. These findings confirm the model's robustness and its sophisticated capability to handle complex data, offering promising directions for improving the analysis of intricate surface-exosphere relationships and refining models that simulate planetary exospheres.

This study sets the stage for analyzing data from the SERENA instrument package on the Mercury Planetary Orbiter of the BepiColombo mission to Mercury, which is set to begin its primary phase in 2026.

Other

He+-ions around Mercury observed by Messenger FIPS and first measurements of MPPE/MSA onboard BepiColombo

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The Messenger spacecraft was in orbit around Mercury from 2011 to 2015 after a 7-year cruise phase. The FIPS instrument onboard measured the ion composition in the vicinity of Mercury and in the inner solar system. Gershman et al., JGR, 2013 evaluated the observations by FIPS during cruise phase of He+-ions of interstellar origin. In this presentation we continue this work to the in-orbit phase and discuss the He+-ion energy spectra and ratios of He+/ He++- ion measurements. We consider two possible sources of He+: (1) the interstellar neutral He ionized close to Mercury and (2) solar He++-ions converted close to or at the surface of Mercury. Remarkable is the similar high mean ratio of He+/ He++- ions in the upstream solar wind and in the inner magnetosphere, while the ratio is reduced in the magnetosheath. We conclude that outside the magnetosphere the source is interstellar while inside the magnetosheath and magnetosphere both sources may be of similar magnitude. FIPS data show a continuous evolution of He+- spectra from solar wind towards Mercury. This could mean that interstellar He+ is concentrating at Mercury by increased electron impact ionization close to the planet.

In addition, measurements of He+-ions of the Mass Spectrum Analyzer (MSA), part of the Mercury Plasma Particle Experiment (MPPE) of BepiColombo obtained in the solar wind in June 2022 and during the third Mercury flyby (MFB3) on June 19th 2023 have been analyzed. Significant amount of He+ could be observed on the nightside of Mercury in agreement with Messenger observations.

Combined morpho-spectral analysis highlights recent explosive volcanic eruptions

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Explosive volcanic activity on Mercury extended after the end of the widespread effusive volcanism era (Jozwiak et al., 2018). The specific eruption timing for individual pyroclastic deposits remains largely debated and holds significant implications for the planet's volatile content and thermal evolution. This work explores the relative timing of explosive eruptions by analyzing the relationship between the morphological degradation of the vents and the spectral changes in the associated deposits. We find that the pyroclastic deposits exhibit a wide range of spectral properties, typically characterized by increased brightness, a red spectral slope, and a curved spectrum compared to the average surface. The study shows a correlation between the deposit spectra and the vent degradation, characterized by a rapid initial darkening and spectral flattening over time, followed by stabilization. The deposits with heavily degraded vents reach the properties of the local background terrain, rendering old deposits spectrally undetectable. To explain these temporal variations in spectral properties, we propose three potential processes: space weathering, mixing with the underlying terrain, and changes in erupted pyroclast size. Space weathering acts “fast”: spectral changes induced by nanophase iron accumulation produced by space weathering on the Moon saturate after ~1 Ga (Tai Udovicic et al., 2021). If a similar mechanism is responsible for most of the spectral modifications observed over time, then a large part of explosive eruptions on Mercury could be significantly younger than previously expected. This research provides further insight into Mercury’s volcanic history and the processes that have shaped its surface over time.

Exosphere

Linewidth Measurements of Mercury’s Alkali Exosphere

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Precision radial velocity spectrometers are common tools in the exoplanet community that can offer resolved linewidth measurements in Mercury’s exosphere. Here we present observations of the sodium and potassium exosphere from such instruments at the Keck I and Lowell Discovery Telescopes, sampling from Mercury’s dayside up to 5 planetary radii down the comet-like tail. While the collisionless exosphere is not inherently thermal, effective temperatures are nonetheless a useful energy metric that we derive by convolving the instrumental line spread functions with a forward model of the Doppler-broadened hyperfine structure. Resulting sodium above the low-latitude dayside limb is approximately ~1200K, consistent with MESSENGER's scale heights, while gas at high latitudes is 100-200K more energetic. Despite bright enhancements near the magnetic cusps, linewidths here show no evidence for an ion-sputtered component with energies predicted by theory or laboratory time of flight experiments. The potassium exosphere is less extended than sodium at only ~700K, but both species exhibit significant escape during peak radiation pressure. Line profiles show steep growth with down-tail distance until their effective temperatures level off near 10,000K at 3 planetary radii. We interpret this to be the furthest extent of gravitationally bound gas, where atomic trajectories reach apex and return toward the surface. Beyond 3 radii, the escaping gas populations show a constant effective temperature with distance.

First results of BepiColombo SERENA ion sensors observations during the first Mercury flybys

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The ESA-JAXA BepiColombo mission to Mercury is along its journey to Mercury. It has already performed three Mercury Flybys and other three flybys are scheduled before January 2025. Once in the nominal mission, starting in 2026, the two spacecraft will observe Mercury's environment from two vantage points, and many instruments will be operated. In particular, the Search for Exospheric Refilling and Emitted Natural Abundances (SERENA) experiment is devoted to the detection of neutral and ionized particles in the inner environment of Mercury for the study of the interaction between the Sun and the planetary surface, exosphere and magnetosphere. While during the cruise the two SERENA neutral detectors, STROFIO and ELENA, are hidden inside the BepiColombo composite spacecraft, the two ion analyzers, MIPA and PICAM, are located outside and already collect scientific data. BepiColombo crossed magnetospheric regions never observed by the MESSENGER mission. Interesting and unexpected ion measurements have been collected during the first three Mercury's flybys. While the observations confirmed that Mercury has a dynamic magnetosphere, new populations have been also identified. In this presentation some first results are presented.

Modelling of the seasonal variation and altitude profile of Ca and Ca-bearing molecules observed in Mercury's exosphere

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Observations of Calcium column densities in Mercury's exosphere exhibit a scale height consistent with a temperature > 50,000 K, and with a source located mainly on the dawn-side of the planet. It was suggested that the originating process is due to MMIV (Micro-Meteoroids Impact Vaporization), but previous estimations were not able to justify the observed intensity and energy. We use an exospheric Monte Carlo model to simulate the 3D spatial distribution of the Ca-bearing molecule and atomic Ca generated by the MMIV process. The exospheric energetic Ca component derives from the shock-induced non-equilibrium dissociative ionization and neutralization of Ca+ during the vapor cloud expansion, while a low energy Ca component is generated later by the photo-dissociation of the Ca-bearing molecules released by MMIV.

Since the exact temperature, the photolysis lifetimes of the produced molecules and the excess energy during photolysis processes are still not well constrained values, we investigate different model assumptions. We simulate the seasonal variation of Ca distribution and altitude profile of Ca and Ca-bearing molecules comparing the theoretical calculations with data observations. This study permits to find the set of model input parameters able to reproduce the observed Ca content.

The work is a meant to be a step forward in the understanding of the MMIV process at Mercury; furthermore, the model is a strong and useful tool to the scientific community for the interpretation for data as well a for observational strategies of the ESA/JAXA BepiColombo mission, that will start its nominal mission phase in 2026

Spectrophotometric modelling of MESSENGER/MDIS multiangular observations reveals physical properties of Mercury’s pyroclastic deposits.

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Modelling the photometric properties of a reflecting surface can give insights into its physical properties at the microscopic (i.e, radiative transfer) scale [1]. We apply a methodology validated on hollows [2] to four locations showing signatures of explosive volcanism, i.e. Praxiteles, Tyagaraja, Picasso craters and Agwo faculae. We analyze Hapke parameter maps for these sites and compare them with geologic maps to infer the physical properties of the reflecting regolith. In particular, the pyroclastic deposits surrounding the explosive vents at these locations are characterized by increasingly backscattering particles with respect to their surroundings, i.e. material formed through the cooling of molten rocks (impact melt, smooth plain material). Such behavior is attributed to the presence of pyroclastic vesicular particles originating from volatile exsolution during magma ascent phase as is the case of pyroclastic deposits on Earth.

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Exosphere

The Yearly Variability of the Sodium Exosphere of Mercury: an Analytical Approac

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Observations of the sodium exosphere of Mercury show a peculiar yearly variability, with two intensity maxima at aphelion and perihelion. Here we present an analytical model for the total Na exosphere content, and we compare our results with ground-based observations. The model is able to reproduce the observed data, both in magnitude and in the seasonal variability. The combined effect of the planetary rotation with the modulation of sources and losses magnitude along the orbit, is able to produce a source of Na at dawn, which is needed to explain the observed maximum at aphelion. Also, we demonstrate that a process producing a consistent Na supply rate at the nightside, which can either be plasma or micrometeoroid precipitation, is needed as well. Finally, we propose a possible explanation for the dusk enhancement of Na that was seen in the MESSENGER data during the inbound leg of Mercury's orbit, and we show, with the help of the model, how this is linked to the observation of yearly variability.

Magnetosphere

Overview of the initial results from BepiColombo Mercury flybys

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The ESA-JAXA joint mission BepiColombo is now on the track to Mercury. After the successful launch of the two spacecraft for BepiColombo, Mio (Mercury Magnetospheric Orbiter: MMO) and Mercury Planetary Orbiter (MPO), commissioning operations of the spacecraft and their science payloads were completed. BepiColombo will arrive at Mercury in the end of 2025, and it has 7-years cruise with the heliocentric distance range of 0.3-1.2 AU. The long cruise phase also includes 9 planetary flybys: once at the Earth, twice at Venus, and 6 times at Mercury. Even before arrival, we already obtained fruitful science data from Mercury during three Mercury flybys completed on 1 October 2021, 23 June 2022, and 19 June 2023. We performed science observations with almost all the instruments onboard Mio and successfully obtained comprehensive data of Mercury's magnetosphere such as magnetic fields, plasma particles, and waves. During the three Mercury flybys, BepiColombo passed through similar trajectories, but the Mercury magnetospheric observations showed very different from each other. Here we present the updated status of BepiColombo/Mio, initial results of the science observations during the Mercury flybys, and the upcoming Mercury flyby plans.

Mercury's mantle as constrained by high-pressure experiments

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Primitive melts provide information on the thermo-chemical state of the mantle of terrestrial planets. On Earth, several billion years of plate tectonics has cycled surface material into the deep mantle, erasing information on the earliest conditions and producing a new fabric of lithological and chemical heterogeneity. On stagnant-lid planets, where cycling of surface material into the mantle is less efficient, we may have a chance to see further back to their formation. In this case, mantle heterogeneity may originate from magma ocean fractional crystallization.

Mercury, as the smallest planet of the solar system, offers the chance to see such a primitive mantle structure. Mercury is characterized by a large core (70 vol.%), a thin (400 km) mantle, and a thick (20-70 km) volcanic crust. It is believed that the volcanic crust was dominantly produced from 4.2 to 3.5 Ga, with minor explosive magmatic activity that may have lasted until as recently as < 1 Ga. Mercury's surface composition was mapped by the MESSENGER spacecraft and reveals various geochemical provinces ranging in compositions from Mg-rich magmas to Al-enriched lavas. In this contribution, we provide constraints on the temperature conditions of mantle melting needed to produce Mercury's volcanic crust, based on low- to high-pressure, high-temperature, experiments. These novel experiments shed light on the likely mineralogy and composition of Mercury's mantle sources. Mercury's mantle is currently dominated by forsterite and enstatite and perhaps some large amounts of sulfide minerals. In contrast, during the main episode of crust formation, Mercury's mantle was likely enriched in olivine-, garnet-, clinopyroxene/orthopyroxene- and perhaps plagioclase-bearing lithologies. Based on partial melting experiments of such sources, we will describe the role of mantle lithology, degree of partial melting, volatiles and Mercury's reducing oxygen fugacity in controlling the major element composition of its erupted lavas. In particular, we will show how high-degree melting of fertile sources results in highly-refractory mantle residues that cause large-scale magmatic activity to rapidly decline.

Magnetosphere

Statistical analysis of the characteristic magnetic field structure in Mercury's nightside magnetosphere

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Focusing on the magnetic field observation of MESSENGER, we find a characteristic depression structure in the nightside magnetosphere. Even in a series of orbits where the satellites pass over almost the same region, this depression structure may or may not be observed. This observational feature suggests that this structure changes on a time scale of a few hours. The structure is observed over a wide region in the nightside magnetosphere. Several previous studies have concluded that this structure is due to the tail current sheet crossing, and no in-depth studies have been conducted. However, when we focus on the magnetic field components that create this depression structure, we find that the main components are different between those observed near Mercury and those observed in the magnetotail side of the magnetosphere. This suggests that the depression structure observed, especially near Mercury, is caused by some magnetospheric structure other than the tail current sheet. We call this structure observed near Mercury a "dip."

This study statistically analyzes where dips occur spatially and under what conditions and then discusses the physical mechanism responsible for the dip. The presentation reports on the current status of our research.

Dynamical effects of whistler-mode chorus emission waves in Mercury's magnetosphere

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Whistler-mode chorus waves can play important roles in the kinetic electron dynamics in planetary magnetospheres. Chorus waves in the dawn side of Mercury were detected by PWI during the BepiColombo/Mio flybys in 2021 and 2022. Based on theoretical analyses and simulations successfully reconstructing Earth's chorus wave properties, we report on possible generation regions of chorus waves in Mercury's magnetosphere. The theoretical analysis for low-temperature-anisotropy electrons shows a clear asymmetric day–night spatial distribution of the possible chorus generation region because of the difference in the nonlinear convective wave growth along the magnetic field lines. Simulation results show a rapid enhancement of the ring electron current belt by resonant interactions with repetitive chorus waves. In this presentation, we will discuss on the energetic electron dynamics in Mercury's magnetosphere locally enhanced by nonlinear chorus wave–particle interactions.

Spectral Properties of Hermean Central Peaks

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Studying the central peaks of impact craters provides insight into the composition of a planet's subsurface, as these materials likely originate from great depth, depending on factors such as crater size, target properties, and impact conditions. This study aims to enhance our understanding of Mercury's crustal stratigraphy, in preparation for the upcoming MERTIS measurements of the BepiColombo mission, by analyzing the spectral characteristics of central peaks across a range of crater sizes. Using data from the MESSENGER mission, we investigated 38 impact craters on Mercury's surface. Applying the Mercury Dual Imaging System (MDIS, Hawkins et al., 2007) mosaic, we identified and mapped central peaks of impact craters within a diameter range of approximately 28 to 158 kilometers. Most of these craters (34) are located at the southern hemisphere due to limited data coverage in the northern hemisphere. Spectral features like curvature and UV downturn were extracted from Visible and Infrared Spectrograph (VIRS) spectra using the Mercury Surface Spectroscopy (MeSS) database (Barraud et al., 2020; Besse et al., 2020). Comparisons were made between these spectral characteristics and the measured crater diameters. While some central peaks exhibited considerable variation in spectral characteristics, others were consistent across multiple spectra. A correlation between spectral features and the crater diameter could not be determined. However, distinct groups of central peaks with unique spectral signatures were identified for further investigation.

Magnetosphere

Cusp Plasma Filaments in Mercury's Cusp: A Review and Comparison with Earth

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MESSENGER, while in orbit about Mercury, observed highly localized, ~3-s-long reductions in the dayside magnetospheric cusp termed as cusp filaments. These filament flux tubes decrease up to 90% of the ambient magnetic field intensity and were observed from just poleward of the magnetospheric cusp to midlatitudes. Analysis of cusp filaments observed by MESSENGER indicates that cusp filaments are likely caused by plasma being injected down the magnetospheric extensions of the flux transfer events that form at the magnetopause as a result of localized magnetic reconnection. These particles within the cusp filaments are also observed in the low-altitude cusp and are thought to be able to precipitate onto Mercury's surface. This has particularly important implications to surface sputtering and surface weathering in Mercury polar region as a major contributor of particle precipitation due to the high occurrence of FTEs at Mercury (i.e. FTE showers) during extreme solar wind conditions. Here, we will review our current understanding of cusp plasma filaments at Mercury, their integrated total precipitation rate and relationship to occurrence of FTE showers in the dayside magnetosphere. We will discuss how the arrival of Bepi-Colombo at Mercury can help advance our knowledge on the nature of these cusp plasma structures and better estimation of their particle precipitation contribution. We will also present initial analysis of cusp filaments in the Earth's cusp observed by Cluster and compare differences in properties with their hermean counterparts.

Surface

Thermal Modeling of Mercury with Roughness and Topography: Comparison with Mariner 10 IRR and Predictions for BepiColombo MERTIS

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The MERTIS instrument on BepiColombo will map Mercury's thermal emission at high resolution. In preparation, we develop a thermal model that accounts for topographic scattering and emission, and the effects of roughness on non-nadir viewing. Our model agrees with brightness temperatures recorded by the Mariner 10 Infrared Radiometer (IRR).

Thermal model: We produce a global map of modeled surface temperature at 8 pixel-per-degree resolution. We determine direct solar illumination using an ephemeris and account for slope using the MESSENGER Global DEM. Each facet receives indirect scattering and emission from the surrounding terrain. Temperatures are determined using a 1D conduction model with lunar-like properties.

Mariner 10 IRR: The IRR recorded brightness temperatures using two spectral channels (11 and 45 μm). The flyby's forward- and aft- viewing geometry led to observations at high emission angle. Rough surfaces do not emit uniformly in all directions, and sub-pixel temperature variations cause measured brightness temperatures to shift with wavelength. We use a roughness model that treats the surface as a series of bowl-shaped craters to correct the IRR data.

Results: The corrected IRR daytime temperatures agree with a thermal model with ~0.08 albedo. IRR nighttime temperatures require thermophysical properties that vary with depth, with an H-parameter of ~12 cm. However, we note that the best-fit H-parameter is sensitive to the model of temperature-dependent conductivity that is used. Future observations will help to constrain these properties. We also use this model to highlight interesting surface temperature phenomena which we expect to observe in future MERTIS data.

Influence of the IMF strength and direction on the Hermean Magnetosphere

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Through the interaction with the strong solar wind, Mercury's weak magnetic field leads to a comparatively small and dynamic magnetosphere. The internal field is dipole-dominated, very axisymmetric and significantly offset towards north.

To first order the magnetopause completely separates the magnetosphere from the magnetosheath and thus no magnetic field may penetrate this boundary. In reality, the magnetosheath magnetic field may diffuse across the very thin boundary within a finite time. We first investigate how the magnetosheath magnetic field changes under different IMF conditions and directions. Second, we can investigate the penetration of the magnetic field from the magnetosheath through the magnetopause inside the magnetosphere and obtain the dependency of the IMF strength and direction.

Magnetosphere

Proton precipitation in Mercury's northern hemisphere

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A key component of space weathering at Mercury is impact of solar wind protons onto its surface regolith. These precipitating protons, with typical energies in the ~1-10 keV range, often cause the release of neutral atoms and ions through sputtering. Besides acting as a source of Mercury's exosphere, this process can change the composition of regolith grains over time, as well as their spectral properties, and therefore has broad implications for the study of Mercury and other airless bodies. Using plasma and magnetic field data from the MESSENGER spacecraft, which orbited Mercury 2011-2015, we have examined two areas in the northern hemisphere where precipitation of solar wind source protons is significant, the magnetospheric cusp and plasma sheet horn. For the cusp, we have estimated the flux of precipitating protons throughout the over 4100 orbit mission, finding an average 10^7 cm^{-2} s^{-1} and substantial variability. On the nightside, we have identified the plasma sheet horns, the high-latitude extension of the central plasma sheet, in over 800 orbits. Estimated precipitation fluxes through representative horns show a similar flux to the cusp, 3-5 x 10^7 cm^{-2} s^{-1}. We discuss the implications of these precipitating fluxes, the variability of the cusp and horn locations, and the manner in which MESSENGER traversed the horns in the context of sputtering-driven space weathering and magnetospheric convection.

Structure and dynamics of the hermean magnetosphere revealed by electron observations after the first three Mercury flybys of BepiColombo, 50 years after Mariner 10.

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The Mercury Electron Analyzer (MEA) obtained new electron observations during the first three Mercury flybys (MFBs) by BepiColombo on 01 October 2021 (MFB1), 19 June 2022 (MFB2), and 23 June 2023 (MFB3). We identify the magnetospheric boundaries and describe the structure and dynamics of the electron populations observed in the various regions explored along the flyby trajectories. We compare and contrast our new BepiColombo electron observations with those obtained from the Mariner 10 Scanning Electron Spectrometer (SES) 50 years ago.

A comparison to the averaged magnetospheric boundary crossings by MESSENGER indicates that the magnetosphere of Mercury was compressed during MFB1, close to its average state during MFB2, and highly compressed during MFB3. Our new MEA observations revealed a significant dusk-dawn asymmetry in electron fluxes on the nightside magnetosphere, and of strongly fluctuating electrons with energies above 100s eV on the dawnside magnetosphere. Magnetospheric electron densities and temperatures were in the range of 10-30 cm^{-3} and above a few 100s eV in the pre-midnight-sector, and in the range of 1-100 cm^{-3} and well below 100 eV in the post-midnight sector, respectively.

MEA electron observations of different solar wind properties encountered during the first three MFBs revealed the highly dynamic response of the solar wind-magnetosphere interactions at Mercury. A good match is found between the electron plasma parameters derived by MEA in the various regions of the Hermean environment with similar ones derived for a few cases from other instruments on board BepiColombo.

Magnetosphere

High frequency waves and electron dynamics in the Hermian environment: Mio PWI and MEA observations

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High frequency (HF) waves (e.g., whistlers) play a leading role in energizing electrons in planetary magnetospheres. The Plasma Wave Instrument (PWI) onboard BepiColombo/Mio spacecraft is designed specifically to measure those HF waves. During the first two flybys of Mercury, the search-coil magnetometers (part of the PWI instrument), albeit not yet deployed, allowed detecting the first whistler waves in the Hermean environment. Theoretical and numerical analysis showed the potential impact of those waves on electrons (cf. Ozaki et al. talk). Here, we expand that study to include the data from the 3rd Mercury flyby and from the MEA (electron analyser) instrument onboard Mio. In particular, we discuss the correlation between the evidenced wave activity during the three flybys and the energization of electrons across different energy ranges. We discuss the impact of the study on understanding electron energization and transport in the Mercury's magnetosphere, along with some instrumental caveats related to the current stowed configuration of the spacecraft and the limited field-of-view of the MEA instrument.

Exosphere

From Mercury's surface to its atmosphere

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Many bodies in the solar system are surrounded by collision-free atmospheres. The tenuous atmosphere for each species comes from many sources, such as diffusion from the interior, meteoroid impact vaporization, and ion sputtering. For example, the Moon intercepts a continuous rain of 1.4 tons of sub-millimeter sized meteoroids per day , while Mercury collects ~12 tons/day. Vaporization of regolith by these high-speed particles is sufficient to account for a good part of the gas densities surrounding these bodies. The different sources impart to gas unique velocity distributions and variations with time of day and season, thus helping us determine the relative importance of each source, findings which can inform us about physical processes that take place throughout the solar system. This tutorial presentation will review recent observations, calculations of expected gas production rates, and models of microphysical processes to summarize our present understanding of these atmospheres, with emphasis on Mercury.

Magnetosphere, Exosphere

Evidence for Atomic Li in Mercury's Exosphere

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The planet Mercury has an extended exosphere containing various neutral species, which have been detected in situ or from groundbased telescopes. To date, H, He, Na, K, Ca, Mg, Al, Fe and Mn are identified in the space environment around Mercury. Based on the solar system abundances of the elements, the existence of lithium (Li) has also been predicted. As of now, there has been no observation of Li, suggesting that the column density should be less than the instrument detection limit of $\lesssim 8.4\times10^{7}$ cm^{-2}. We report the first evidence of the existence of atomic Li in the exosphere of Mercury and its altitude density profile, derived from in-situ magnetic field observations by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft. The obtained surface column density is $\approx 7.5 \times 10^{6}$ cm^{-2} and, thus, about one order of magnitude smaller than the upper limits. Our analysis suggests that the major source of Li in Mercury's exosphere is meteoritic ablation at the surface. The derived Li/Na ratio of $\approx 4.5 \times 10^{-4}$ is consistent with the ratio associated with ordinary chondrites. This discovery implies that the (micro-)meteorites serve as the main contributor to the presence of the heavy elements in the exosphere of Mercury.

INHERITED AND POST-INFILL TECTONIC STRUCTURES IN CALORIS PLANITIA, MERCURY

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Caloris Planitia has a complex geological history thought to have begun with a large impact event, followed by lava infilling and tectonic deformation. The basin (1500 km diameter) is characterized by a sharp, asymmetrical, rim which has been retained in many places. The approx. 3.5 km thick infill covers the entire basin and has a highly irregular topography. Across the surface of the infill are various fault scarps which have been previously interpreted as both compressional and extensional faults. Here we present a new analysis which identifies several dozen new faults and helps constrain many relationships between the deformational history, shared and unique to, the infill and plateau.

The Messenger Global DEM (665 m/px) combined with seven local DEMS (avg. 185 m/px) were used to compare the results of a topographical analysis at various pixel resolutions. We highlighted topographic trends observed in the DEMs by implementing a three step process: 1. “Least Squares Regression”, 2. “Nearest Neighbor Differences”, and 3. “Convolution Filtering”. Pixels are then given a color based on dip direction. The results of this process highlights the slope of all surface features so that the dip direction of linear features in the topography can be easily visualized. This aids the identification of fault scarps. Comparisons between the lower resolution global DEM to the seven higher resolution local DEMS provides the opportunity to visualize structures both regionally and locally. Together these filtered DEMs provide a new appreciation for the structural geology of Caloris Planitia.

How Carbon May Affect Space Weathering Products on Mercury: An Experimental Approach

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Mercury's surface has been observed to have very low abundances of iron (e.g., Warell et al. 2006, Murchie et al. 2015, Nittler and Weider 2018), yet its surface is 1.6 times darker than that of similarly low-iron surfaces like the lunar highlands (Braden et al. 2011). Traditional lunar and S-type space weathering is then an unlikely explanation for the darkening of Mercury's surface over time, so what could be causing the observed darkening (Pieters and Noble 2016)? Carbon is hypothesized to be present as a darkening agent on the surface of Mercury today from excavations of a theorized graphite floatation crust and this carbon may exist in concentrations of up to 5 wt. % within Mercury's low-reflectance material (Vander Kaaden and McCubbin 2015, Klima et al. 2018). Could this carbon also be a component in nanophase and/or microphase space weathering products?

To answer this question, we aim to simulate the effects of space weathering on Mercurian regolith analogs that contain little to no iron. The silicates we have chosen are mixed with various C-bearing opaques to understand and characterize how different forms of carbon impact the results of simulated space weathering experiments. The simulated environment system at Washington University's laser space-weathering laboratory allows for uniform irradiation of a sample at 10^{-7} torr, and uses two Continuum Surelite I-20 Nd:YAG lasers of different pulse widths to recreate the thermal conditions of a micrometeorite impact (Gillis-Davis 2022).

Spectra and TEM analyses of our mixtures will be analyzed in the context of existing telescopic and remote-sensing data to prepare the BepiColombo team for spectral interpretation of SIMBIO-SYS and MERTIS data.

X-ray emission from Mercury's nightside and its dependence on magnetospheric activity

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X-ray emission from the nightside of Mercury has previously been detected and catalogued using data from the X-ray Spectrometer onboard the MESSENGER spacecraft. Unlike on the dayside where this is caused by solar coronal X-rays, nightside emission is likely the result of precipitating energetic electrons. We have reanalysed MESSENGER-derived datasets of Si and Ca emission in the northern hemisphere, using a new map projection and a field-of-view centroiding method to plot event locations. We then filtered them against a series of parameters which may influence activity in Mercury's magnetosphere. Of these parameters, we have found a positive correlation between the frequency of emission and disturbance index, a measure of the activity level of the magnetosphere scaled from 0 to 100. 48% of all Si X-ray emission events occurred on orbits with a disturbance index of >70, and 21% with a disturbance index of >90.

This suggests that there is a higher likelihood of observing X-ray emission when Mercury's magnetosphere is more disturbed, either due to an increased frequency of particle precipitation, an increase in the energy of the precipitating particles, or a combination of both. This correlation with DI is stronger in events on the dawn side of the planet, with the frequency of dusk side events showing weak or no correlation. This is consistent with previous nightside X-ray emission studies which show that the frequency of emission is significantly lower on the dusk side, and with many other studies of Mercury's magnetosphere which have observed similar dawn-dusk asymmetries.

Surface

Enhanced UV/visible reflectance of mercurian low reflectance material in MDIS-controlled Mariner 10 mosaics

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The mercurian crust is anomalously dark for its measured composition, perhaps due to the excavation and mixing of a buried, primary flotation crust enriched in graphite. The combined spectral ranges of the Mariner 10 vidicon cameras and the MESSENGER MDIS instrument accommodate characteristic reflectance features of graphite and can test for its presence in low reflectance material in the crust. We geometrically controlled Mariner 10 images using MDIS products as ground and radius sources, achieving sub-pixel registration between the image sets. Enhanced UV/visible reflectance of low reflectance material relative to surrounding color units observed in the controlled image mosaics is consistent with increased reflectance shortward of 400 nm - below the MDIS detection limit, and consistent with the presence of carbon. Future analyses with higher spectral resolution in the UV could better discriminate between carbon-bearing phases, elucidating the physical and chemical properties of low reflectance material and the evolution of the mercurian crust. Ongoing work will utilize the newly controlled Mariner 10 images for temporal change detection on the surface over forty- and fifty-year baselines, further highlighting the utility of multi-mission analyses.

Present-Day Endogenic and Exogenic Activity on Mercury

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Exogenic and endogenic processes play critical roles in shaping the surfaces of planets, but quantifying their current rates on Mercury remains challenging. Using images from the Mercury Dual Imaging System taken between 2011 and 2015, we observed notable surface modifications. Our temporal study revealed twenty reflectance changes using before and after images, including one notable example featuring bright ray-like features extending from an impact site, indicative of a recent collision. If all observed changes are due to impacts, this would imply a current impact flux rate a thousand times greater than existing models suggest. Additionally, we observed alterations on slopes in regions rich in tectonic features and identified several changes near or on hollows, suggesting active endogenic processes. These findings highlight the ongoing interplay of endogenic and exogenic forces in altering Mercury's surface. Looking ahead, the BepiColombo spacecraft, equipped with the SIMBIO-SYS suite of high-resolution imagers, will enter Mercury's orbit in just over a year. This mission is expected to enrich our understanding by offering more detailed imagery and enabling extended temporal comparisons with earlier MDIS data from the MESSENGER and Mariner 10 image sets, thus providing a much longer baseline between observations and greater overall temporal coverage.

Exosphere

MESSENGER observations of Mercury's seasonal planetary ions and escape

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Mercury is the planet closest to the Sun and does not have a significant atmosphere. Instead, it has a surface-bounded exosphere. Mercury also has a global intrinsic magnetic field that interacts with the solar wind to form a small magnetosphere. In this presentation, we introduce our investigations of Mercury's planetary ions, i.e., Na^+-group ions, based on the measurements from the MESSENGER mission. We show that the densities and escape rates of the Na^+-group ions are dependent on Mercury's orbital phase around the Sun, exhibiting a seasonal variations with rates from 0.2 to 1×10^{25} atoms/s. This rate is comparable to the ion's escape rates at other inner planets, which is surprising given that Mercury only has a tenuous exosphere. We propose that this can be attributed to several processes such as efficient photoionization, solar wind sputtering, and solar wind momentum exchange at Mercury, and the Na^+-group ions include several ion species such as Na^+, Al^+, Si^+ and Mg^+ etc. We aim to enhance our understanding of Mercury's exosphere and contribute to the broader field of planetary magnetospheric and atmospheric researches.

Mg Exosphere of Mercury Obtained by PHEBUS onboard BepiColombo during its second and third Swing-bys

Yudai SUZUKI[1]

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The exosphere of Mercury is an important target for understanding the dynamics of the coupled system of space environments, planetary tenuous atmospheres, and planetary surfaces. Mg is especially crucial species to establish general methods for estimating the surface chemical composition distribution through observations of exospheres as their distributions in the exosphere and the surface are strongly correlated. However, due to their low radiances, Hermean Mg exosphere has been detected only by MESSENGER/MASCS and thus their spatiotemporal variations have been poorly understood.

In this study, we constructed a calibration method and revealed the distribution of Hermean Mg exosphere using MPO/PHEBUS of the BepiColombo mission during its second and third Mercury swing-bys. After the background noise subtraction by fitting and sensitivity calibration by stellar observations, Mg light curves and seasonal variations were obtained that were well consistent with both an analytical model and a three-dimensional numerical calculation. Comparing the Mg and Ca radiances obtained by PHEBUS during the Mercury swing-bys, the Mg exosphere has lower energy than Ca. This is consistent with a lower energy for Mg to be required for photodissociation from molecules than for Ca.

Multi-View Shape from Shading for High-Resolution DEM Construction and Albedo Retrieval

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Shape from Shading (SfS) is a surface reconstruction method that improves photogrammetrically obtained Digital Elevation Models (DEMs) to create highly accurate DEMs close to image resolution. In the past, we have used our SfS framework [1], to generate and validate local DEMs of Mercury with less than ten m/pixel effective resolution [2]. We also demonstrated the algorithm's robustness when we created DEMs from BepiColombo flyby MCAM images [3]. Mercury's surface hosts many features of high scientific interest with substantial albedo variations, such as hollows, young craters, and volcanic vents. These features make it challenging for the algorithm to distinguish between albedo and illumination from a single image and can lower the quality of the surface slope estimates. Furthermore, compared to the Moon or Mars, the image data available for Mercury are sparse and often exhibit unfavorable illumination and viewing conditions. Previously, we employed an iterative albedo initialization scheme to successfully address these challenges [2]. Now, we further update our SfS algorithm to include several co-registered MDIS images simultaneously. This multi-view SfS approach enables a more precise reconstruction of the albedo map and, thus, the surface heights by better distinguishing the effects of the albedo and the illumination. We use this improved method to update some of our original DEMs. Several local high-resolution stereo DEMs of Mercury's surface have been released in recent years. In preparation of the BepiColombo mission, we use parts of these datasets to create refined high-resolution DEMs and albedo maps.

[1] Grumpe, A., Wöhler, C., 2014. Recovery of elevation from estimated gradient fields constrained by digital elevation maps of lower lateral resolution. ISPRS Journal of Photogrammetry and Remote Sensing, 94, 37 - 54.

[2] Tenthoff, M.; Wohlfarth, K.; Wöhler, C. High Resolution Digital Terrain Models of Mercury. Remote Sens. 2020, 12, 3989.

[3] K. Wohlfarth, M. Tenthoff, J. Wright, V. Galluzzi, C. Wöhler, H. Hiesinger, J. Helbert, J. Zender, J. Benkhoff. Computational Models for Mercury Surface Analysis, Mercury Exploration Assessment Group (MExAG) Annual Meeting, February 2023, https://www.hou.usra.edu/meetings/mexag2023/eposter/6034.pdf

Other

Characterization, Modeling, and Population Analysis of Super-Mercuries

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Mercury is distinctively different from other terrestrial planets in the solar system because of its high core mass fraction. The formation of mercury is thought to be caused by giant impacts but the theory is still debated because of the existence of volatile elements on the surface, which would have been eliminated during the giant impact event. For super-Mercury exoplanets, too, giant impact is only among many plausible theories, including tidal stripping, preferred iron concentration over silicates due to photophoresis, surface tension, and/or magnetic field. To understand which mechanism plays a role and to what extent, a sample of confirmed and well-characterized super-Mercuries is needed. I will present detailed characterization of super-Meruries at individual system level using state-of-the-art astronomical observation and interior modeling, as well as population level using advanced hierarchical Bayesian analysis. The study of super-Mercuries at these levels will shed light on the formation origin and potential dichotomy between super-Earths and super-Mercuries.

A whirlwind tour of Mercury's surface

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In this invited tutorial talk, I will introduce Mercury's surface for a general planetary science audience. The objective is to give non-surface specialists some fundamental knowledge to help them formulate interdisciplinary research questions at the intersection of surface science and their own specialisms.

POSTER

P-01

Surface

SwingBy #5 - MERTIS first science observation at Mercury

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The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) is a push-broom IR-spectrometer (-TIS) and a radiometer (-TIR), operating at 7-14 and 7-40 μm, respectively, on-board the ESA/JAXA BepiColombo science payload and is currently on its way to Mercury. On December 2nd, 2024, BepiColombo will swing by Mercury for the 5th time. This swing-by provides MERTIS the unique opportunity to observe for the first time the surface of Mercury using its space view, following the same approach used for Venus and the Moon. The MERTIS operation and science team is preparing to perform the first thermal infrared surface mapping of Mercury. This will begin addressing the main goals of the MERITS instrument which are investigating the surface composition, globally mapping of the mineralogy, understanding the temperature variations and thermal properties of Mercury's surface. In order to support this observation: 1) a series of laboratory experiments on analogue materials to the composition of the surface of Mercury are being currently undertaken at the Planetary Spectroscopy Laboratory (PSL) of DLR in Berlin and the IRIS lab in Münster; 2) a preliminary temperature map of the target area is being generated; 3) and the MERTIS data of the Moon flyby on April 10th, 2020 is being analyzed. These preparation studies in addition to the MERTIS data collected during the swing-by #5 will pave the path for the MERTIS surface mapping and data interpretations during the BepiColombo orbital mission.

P-02

Surface

Observations of the particle - surface interaction at the Moon: Lessons for Mercury

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The Moon and Mercury are covered by regolith formed by micrometeoroid bombardment. Their surfaces experienced similar maturity processes (space weathering) but with different rates. Space-weathering efficiency of the micrometeoroid bombardment is 5-7 times higher at Mercury. The low energy (keV –range) ion flux is 10 times more intense. However, the Moon and Mercury demonstrate very similar IR-spectra (Sprague et al., 2007) that indicates the physics of the particle – surface interaction is same. We review the relevant observations from the lunar orbiters (Chandrayaan-1 and IBEX) and rover (Yutu-2 on Chang'e-4) revealing the solar wind ion interaction with the lunar regolith. We will discuss hydrogen and proton backscattering processes and place them in the comparative planetology perspective. We will also review the most recent results on heavy ion sputtering and possible applications to the extended coronae. We briefly mention the possibility for such exotic components as negative ions originating from the particle – surface interaction at Mercury and the Moon. The main message of this talk is the Moon is the key for understanding Mercury.

P-03

Surface

Updates on MASCS geometric calculation & Unsupervised observation clustering for photometric correction

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The MASCS instrument was an essential part of the NASA MESSENGER mission that orbited the planet Mercury between 2011 and 2015. The Visible-Infrared Spectrograph (VIRS) channels cover the visible (300–1050 nm) and near-infrared (850–1450 nm) ranges. We recomputed MASCS geometries using the NAIF SPICE toolkit's Python implementation spiceypy. While the MASCS PDS calibrated data records (CDR) contained some geometrical information, certain key parameters (such as local time) were missing. Local time serves as a useful proxy for surface temperature due to Mercury's slow rotation. A detailed digital elevation model (DTM) of the entire planet was not available, so Mercury shape was approximated as an ellipsoid. We updated this approximation with the DTM from MESSENGER/Mercury Laser Altimeter (MLA). Leveraging the updated measurements, we developed a machine learning method to automatically select similar observations for photometric correction. We extracted MDIS mosaic and DTM pixel data under each individual MASCS field of view (FOV) as proxies for geomorphological units and sub-pixel roughness. To cluster similar observations, we applied HDBSCAN, an algorithm that extends DBSCAN by creating a hierarchical clustering structure and extracting a flat clustering based on cluster stability.

P-04

Surface

MERTIS/BepiColombo and the Moon - how to push an instrument to its limits and beyond

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The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) is part of the ESA-JAXA BepiColombo science payload on its way to Mercury. MERTIS consists of a push-broom IR-spectrometer (-TIS) and a radiometer (-TIR) which operate at 7 to 14 μm and 7 to 40 μm, respectively. The main objectives of MERTIS are to provide the surface composition, global map of the mineralogy, temperature variations and thermal properties of Mercury's surface. The target spatial resolution of MERTIS-TIS is lower than 300 m at 400 km apoherm and 500 m for the global mapping. The signal-to-noise ratio (S/N) at the Christiansen feature (7.5 μm) is higher than 200 at the day-side temperature of Mercury (450 K - 700 K). During its cruise, BepiColombo completed an Earth/Moon flyby in 2020. MERTIS was able to acquire data through its space baffle and had the opportunity to observe the Moon during the flyby. The closest approach occurred on April 10th 2020 at a distance of around 700 000 km from the Moon. The spatial resolution of MERTIS-TIS observations is about 500 km/pixel at this distance to the Moon, which is far away from the targeted spatial resolution at Mercury. The day-side temperature of the Moon's surface (up to 400 K) is lower than that of Mercury, which considerably decreases the S/N. Here we show how MERTIS data successfully point to the two major lunar terrains: highlands and mare despite the low spatial resolution and S/N. This flyby considerably helps us for the preparation of Mercury's observations.

P-05

Surface

Detection of the 830 nm spectral feature in Praxiteles basin: hints of hollows' formation

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10. University of Helsinki, Finland

MASCS/MESSENGER [1] reflectance spectra and MDIS/MESSENGER [2] multicolor images of the Mercury surface [e.g. 3] are featureless, except for hollows in Dominici, Hopper, Canova, Velazquez craters and Raditladi basin [4-8], where a 630 nm absorption band was detected in photometrically corrected MDIS spectra.

We analysed the 198 km in diameter Praxiteles basin (27.11°N, -60.28°E) in the Victoria quadrangle [9]. The analysis of the basin was performed using MDIS data photometrically corrected and removing potential residual effects due to topographical relief. A reflectance minimum at 828.4 nm occurs in several MDIS spectra in the basin, suggesting the existence of a potential absorption band. This MDIS reflectance minima is spatially correlated with strong spectral curvature of MASCS reflectance spectra between 300 and 600 nm. The 830 nm feature was observed in the youngest craters of the basin where fresh material was exposed through mass wasting and hollows, as well as in some hollows placed on the floor of the basin. The in-depth investigation of the 830 nm band suggests that the feature is indicative of a phase preceding that hollows' formation and could represent the most recent process on Mercury.

[1] McClintok and Lankton (2007) SSR 131. [2] Hawkins et al. (2007) SSR 131. [3]Robinson et al. (2008) Science 321. [4] Vilas et al. (2016) GRL 43. [5] Lucchetti et al. (2018) JGR:Planets 123. [6] Blewett et al. (2011) Science 333. [7] Vaughan et al. (2012) LPSC 1187. [8] Thomas et al. (2016) Icarus 276. [9] Galluzzi et al. (2016) MemSAIt 87.

P-06

Surface

X-ray fluorescence emission simulations for Mercury surface regolith

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The BepiColombo mission to Mercury is equipped with two X-ray instruments, the Mercury Imaging X-ray Spectrometer (MIXS) and the Solar Intensity X-ray and particle Spectrometer (SIXS). SIXS will monitor the incident flux from the Sun, while MIXS detects the X-ray fluorescence (XRF) emission signal from the surface of Mercury induced by the solar flux. The science goal of the MIXS measurements is to produce global element abundance maps. The observations will be done in varying geometries with respect to the incidence and emergence angles from the local surface normal.

The rough particulate surface will affect the strength of the XRF signal in different observing geometries. Similarly to photometry, the effect of the observation geometry must be modeled for a uniform analysis of the abundances. We are using our XRF simulation suite to study the effect. The suite consists of a packing code to create the rough particulate surface and an XRF simulation code to trace the observed signal in a given geometry [1]. We can track either the strengths of the XRF lines of a single element or ratios of XRF line strengths from multiple elements, as a function of illumination and emergence angles. We show a comparison with simulations to experimental data presented by McKee et al. in this conference [2].

[1] Parviainen H, Näränen J, and Muinonen K. (2011). Soft X-ray fluorescence from particulate media: Numerical simulations. JQSRT 112, 1907–1918.

[2] McKee M. et al. Investigating the Impact of Planetary Regolith on MIXS X-ray Fluorescence Observations. Mercury 2024 conference, Kyoto, Japan, June 4–7.

P-07

Surface

Do we need a heterogeneous mantle to explain the spectral properties of Mercury's volcanic basin infills?

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The study of geological processes such as impact cratering and volcanism provides information on Mercury’s evolution. Volcanism has shaped Mercury's surface and considerably modified impact basins after their formation by the emplacement of younger volcanic infills. Caminiti et al. (2023) clarified the volcanic history of the Caloris basin by classifying MESSENGER MASCS footprints according to spectral units (Murchie et al., 2015). We applied this same spectral classification to the Rembrandt basin, improved the classification and characterized a new younger volcanic spectral unit (Helbert et al., 2013; Semenzato et al., 2020). These improvements allow us to distinguish low-reflectance material, high-reflectance red plains, low-reflectance blue plains and intermediate plains as well as to define the younger high-reflectance red plains. We investigated and compared major impact basins on Mercury: Caloris, Rembrandt, Tolstoj, Beethoven, and Rachmaninoff. A detailed analysis of each basin allows us to clarify their geological histories including the number of volcanic infillings as well as to confirm that volcanic smooth plains are spectrally heterogeneous (Helbert et al., 2013). Similarities between spatially distributed basins highlight that spectral units associated with basin infills have no spatial and compositional dependence showing no lateral heterogeneity in the mantle. However, it depends on the size of the basin. This could be linked to vertical heterogeneities or different intensities of deep perturbations by impacts leading to different melt production and evolution through time. BepiColombo data are eagerly awaited to investigate the compositional variability of volcanic smooth plains and precise the definition of spectral and morphological units.

P-08

Magnetosphere

Electron properties at Mercury: when global 3D-PIC simulations meet the PWI/AM2P and PWI/SORBET experiments of BepiColombo

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6. LAPLACE, Univ. Toulouse, France

Mercury is the only telluric planet of the solar system, apart from Earth, possessing an intrinsic magnetic field. This magnetic field influences the dynamics of the solar wind plasma impinging on the planet, forming a magnetosphere. Mercury's magnetosphere has only been investigated in the past, by the NASA Mariner10 and MESSENGER missions, and is today the target of the joint ESA-JAXA BepiColombo mission. BepiColombo plasma instruments will observe for the first time the electron kinetic physics at Mercury. In order to interpret and plan BepiColombo's in-situ observations, an interplay is needed between global models of Mercury's magnetosphere and instrumental modeling. In this work, we present a study of the expected instrumental response of the PWI/AM2P and PWI/SORBET electric experiments onboard BepiColombo, that will both provide electron density and temperature measurements, based on a two-step, fully-kinetic numerical approach. First, we run fully-kinetic, three-dimensional, global simulations of the interaction between Mercury's magnetosphere and the solar wind using the implicit particle-in-cell code iPIC3D. Second, we use the electron distribution function derived from the previous step as input for a numerical model of the electric antennas used by both the AM2P and SORBET experiments onboard the JAXA Mio spacecraft of BepiColombo. Our 3D full-PIC simulations show bi-Maxwellian (hot and cold population) electron distribution functions in the nightside of Mercury. We investigate the possibility of detecting these two Maxwellian populations using the AM2P and SORBET experiments. We also explore regions where in flight calibration the AM2P experiment should be performed.

We show that for part of the Mio orbit, Mercury's magnetic field will alter significantly the PWI/AM2P and PWI/SORBET measurements. We provide a new instrumental model for each of the two experiments that are, for the first time, able to take into account the effects of the external magnetic field. This makes it possible to obtain a plasma diagnostic from the PWI/AM2P and PWI/SORBET measurements. We also investigate the possibility of measuring electron properties previously not accessible to the instrument equivalent to PWI/AM2P and PWI/SORBET, such as the electron temperature anisotropy.

P-09

Surface

Modeling Cold Spots on Mercury: Opportunities for BepiColombo Observations

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Thermal measurements of the lunar surface by Diviner revealed the widespread presence of "cold spots," which have anomalously low nighttime temperatures and are associated with very young impact craters, often extending 10–100 crater radii from fresh impacts [1-3]. Lunar cold spots cool rapidly after local sunset until they are at least 2 K colder than the surrounding terrain [1-3]. They have low thermal inertia within the uppermost ~10 cm and appear to be composed of decompacted regolith materials that have been "fluffed-up" by impacts [2].

Cold spots should also occur on Mercury (or any airless body with regolith and significant gravity [2]), but they have never been observed due to an absence of temperature measurements. Excitingly, the ESA/JAXA BepiColombo spacecraft will enter orbit around Mercury in late 2025 [4] and will have the opportunity to observe cold spots, enabling new studies of impact processes and regolith properties of Mercury, as well as comparisons to the Moon.

Here we model the temperature of cold spots on Mercury [5] for the time period of the BepiColombo mission. We discuss when, where, and how cold spots should be identifiable with MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS). We present a case study about the possibility of a small cold spot associated with the impact site of NASA's MESSENGER spacecraft. We then conclude with a discussion of key science questions and predictions related to cold spots on Mercury.

[1] Bandfield+ 2011. [2] Bandfield+ 2014. [3] Williams+ 2018. [4] Hiesinger+ 2020. [5] Hayne+ 2017.

P-10

Magnetosphere

Evolution of Mercury’s magnetotail structure with magnetospheric activity

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Mercury’s magnetosphere experiences dynamic magnetic reconnection. In the magnetotail, this reconnection drives Mercury’s substorm process and unloads the magnetotail lobes to produce fast plasma flows, dipolarizations, flux ropes, and energetic electrons. Previous studies have constructed statistical descriptions of Mercury's magnetotail from MESSENGER observations, but by combining observations from many intervals have blurred the description across different magnetospheric activity levels. To understand the dependence of large-scale magnetotail structure and characteristics on magnetic activity, we characterize the magnetotail during magnetospherically quiet versus active intervals from MESSENGER observations. Using the presence of dipolarizations in the plasma sheet as a proxy for activity, we find that the active magnetotail possesses a depleted plasma sheet, substantially reduced dawn-dusk asymmetries, and a significantly smaller nightside dipolar region. These active versus quiet descriptions indicate the role of magnetic reconnection in shaping Mercury’s magnetotail and serve as a reference for data-model comparison as well as context to BepiColombo measurements.

P-11

Surface

Why we should target only Explosive volcanism and hollows!

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BepiColombo's arrival at Mercury is a fantastic opportunity to further unravel the mysteries of the innermost planet. While orbiting Mercury’s surface, BepiColombo will make scientific observations of higher spatial and temporal resolutions with quasi uniform latitudinal distribution. We propose to dedicate a significant time of the observations to hollows and explosive volcanism to improve our understanding of Mercury’s geochemical evolution. Pyroclastic vents and their associated faculae are puzzling features that of the most recent volcanic activity of Mercury. Dedicated observations of these features will not only help in characterising Mercury's surface, but it will also provide crucial constraints in understanding its internal structure. Previous studies have helped characterise the composition and physical properties of these features, although a deeper characterisation of the timing and eruption modes is fundamental in deriving properties of Mercury’s interior and evolution. Hollows are one of the highlight discoveries of MESSENGER, while at the same time, they are poorly understood. These geological features are young features associated with the possible degassing of the sub-surface and sulfur-rich crust of Mercury. New observations from BepiColombo will help further constrain their formation mechanism and composition. This will provide fundamental inputs in understanding Mercury’s magma ocean evolution, its crustal composition and layering. Investigating hollows with BepiColombo will also help to understand the composition and variations of the current exosphere and the contribution of the sub-surface outgassing process. For all of these exciting scientific questions, properly targeting hollows and explosive volcanism with BepiColombo is of paramount importance for the planetary community.

P-12

Magnetosphere

What Mio could teach us about Mercury's deep magnetotail

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We investigate what magnetic field topologies depending on different IMF directions BepiColombo would be able to observe along its magnetotail passages based on recent modeling results. It turns out that the magnetotail topology is strongly dependent on the upstream magnetic field direction of the solar wind, similar to that of Earth. In contrast to Earth, however, Mercury's magnetospheric plasma exerts an additional, surprising influence. We will then investigate if accepted ways to identify the tail topology based on previous spacecraft missions can be safely applied to BepiColombo.

Short answer: it depends.

Preparations for the Mercury Imaging X-ray Spectrometer's observations of Mercury's Low Reflectance Material

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3. KU Leuven, Belgium

The Mercury Imaging X-ray Spectrometer (MIXS) onboard BepiColombo MPO will make spatially resolved measurements of elemental abundances in Mercury's upper surface. MIXS observes fluorescent X-rays generated following interactions with impinging solar coronal X-rays and ultimately yields abundance maps of the major rock-forming elements from sodium through nickel.

The source of Mercury's low reflectance material has been identified as a key science question. Many proposed darkening agents produce hypotheses that can be tested through spatially resolved fluorescence observations with MIXS, others have already been challenged by MESSENGER's XRS. However, the leading candidate, graphite (carbon), cannot be sensed by MIXS through XRF. Carbon fluorescence at 277 eV is theoretically within MIXS' calibrated energy range at launch; however, nominally MIXS will not telemeter events below the Oxygen K line (525 eV) and the solar monitor, SIXS-X, will not provide data below 1 keV. Furthermore, fluorescence is extremely limited by carbon's low photoelectric attenuation coefficient and fluorescence yield.

The background observed in XRF spectra is dominated by scattered incident X-rays. Low atomic number materials such as carbon have large scattering coefficients, however, small interaction cross-sections make this increase difficult to detect. In a laboratory environment, we observed a catalogue of terrestrial reference materials and graphite-spiked samples with the MIXS QM detector and successfully compared their relative scatter intensities to modelled intensities. We detail how differing solar conditions will affect MIXS' observations and predicts its effect on the ability of two scatter-based methods to provide indirect, supporting evidence of carbon enrichments associated with LRM.

P-14

Surface

Extracting Potassium Abundances on Mercury from MESSENGER X-ray Spectrometer Data

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1. Arizona State University

Potassium (K) is a moderately volatile element that can be used to trace refractory/volatile fractionation processes in the early solar system and early planetary crusts. The MESSENGER mission's gamma-ray spectrometer (GRS) detected decays of 40K from Mercury's near-subsurface. A GRS-derived K map of northern latitudes revealed spatial heterogeneity, but the low spatial resolution (1000 km) only allowed crude correlation with surface geological units. Moreover, the instrument's failure after one year precluded the accumulation of additional K GRS data to improve statistics. K also emits fluorescent x-rays that are in principle detectable by MESSENGER's X-Ray Spectrometer (XRS), which collected data for the full 4 years of the mission duration. The x-ray fluorescence line for K (3.3 keV) is not resolved from that of Ca in the XRS spectra, but simulations show that its presence affects the shape of the Ca peak and that with careful fitting, K abundances likely can be inferred from spectra that were acquired during large solar flares, where the signal-to-noise ratio is highest. We aim to produce an accurate map of K abundance across Mercury's surface with enhanced spatial coverage and resolution (compared to GRS) using XRS data. Comparison of the XRS results (which derive from the top tens of micrometers) with GRS data (from 10s of cm) and with other geochemical and geomorphic maps will aid in deconvoluting thermal and geological effects on the surface distribution of K.

P-15

Surface

Update on the Quadrangle Geological Map Series of Mercury

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A series of geological maps is being developed at a regional scale for each quadrangle of Mercury in anticipation of the ESA/JAXA BepiColombo mission. These maps serve to assist in identifying scientific targets and providing context for interpreting new data. They are created at an average mapping scale of 1:600,000 through photogeologic interpretation of MESSENGER/MDIS end-of-mission basemap mosaics. Following USGS planetary mapping guidelines and the Horizon 2020 Planmap project standards, the maps are then published at an output scale of 1:3,000,000. By 2022, eight out of fifteen quadrangles (H-02, H-03, H-04, H-05, H-06, H-10, H-13, H-14) had been completed and published. To ensure consistency, boundaries of published maps were reviewed and updated to create a continuous digital geological map now accessible on the Mercury Quickmap website. The current merged quadrangle maps provide a coherent and uninterrupted view of Mercury's geological framework, covering over 50% of the planet. The remaining seven quadrangle maps are scheduled for completion by the end of 2024 (H-07, H-08, H-09, H-11, H-12, H-15), with only H-01 expected to be finalized in 2025.

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P-16

Exosphere

Investigating the helium exosphere of Mercury with multiple BepiColombo instruments: insights into the response to the solar wind variations, thermal accommodation, and internal outgassing

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We discuss plans for a comprehensive investigation of Mercury's helium (4He) exosphere exploiting the multi-instrument capabilities of BepiColombo. The main source of helium is the flux of solar wind alpha particles (He++), thus 4He is key to understand the response of Mercury's exosphere to solar wind variations. Moreover, helium can also be endogenous, i.e. outgassing from the interior of the planet. On the Moon, the airless body most similar to Mercury in terms of exospheric source and loss processes, this endogenous source is a few tens of % of the solar wind source. Since 4He is the product of the radioactive decay of 232Th, 238U, and 235U within the crust, its outgassing rate constrains the abundance of such elements in the interior. The arrival of BepiColombo at Mercury provides the opportunity to perform these investigations with unprecedented spatial and temporal coverage and resolution. On the one hand, SERENA-Strofio and PHEBUS measure the abundance of neutral exospheric helium for complete coverage of local time and location. On the other hand, SERENA-MIPA and MPPE-MSA measure the flux of helium pickup ions and solar wind alpha particles, to determine the exospheric loss rate due to ionization and charge exchange and the exospheric source rate due to solar wind. These observations will shed light on the response of Mercury's exosphere to variations in solar wind He++, on the source rate of endogenous helium (outgassing from the Mercurian interior), and even on the thermal accommodation of helium with the Mercurian surface (from altitude profiles).

P-17

Magnetosphere

Low-energy Ions in Mercury's Magnetosphere Observed by MIA during Mio's third Mercury flyby

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During the third Mercury flyby, MIA onboard Bepicolombo Mio observed multiple ion populations: (i) energy-dispersed ions in the dusk-to-midnight magnetotail with the low-energy (<~100 eV/q) ions reaching the deep midnight magnetosphere with estimated densities of tens of cm^{-3}, (ii) ~keV ions with densities of ~10 cm^{-3} around the midnight region, and (iii) ~10 keV ions with densities of several cm^{-3} in the dipolar field region. We conduct test particle simulations with background magnetic fields from the KT17 model and electric fields from Volland-Stern potentials without corotation, thereby inferring the origins and fate of the detected ions. The data-model comparison suggests that the <~100 eV/q ions originate from the duskside tail magnetopause and are transported by magnetospheric convection in an energy-selective manner. Also, most of the detected ions on the nightside are predicted to precipitate onto the low-latitude surface of Mercury if a typical cross-polar cap potential is assumed. These results suggest a critical role of magnetospheric convection in shaping the plasma structure of Mercury's magnetosphere. In-orbit observations of BepiColombo will provide excellent tools to investigate this still-unclear important process of Mercury's magnetosphere.

P-18

Surface

Exploring Mercury with the MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS)

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The MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) is part of the payload of the Mercury Planetary Orbiter spacecraft of the ESA-JAXA BepiColombo mission. MERTIS combines an imaging spectrometer covering the wavelength range of 7-14 µm with a radiometer covering the wavelength range of 7-40 µm. The instrument will map the whole surface of Mercury with a spatial resolution of 500 m for the spectrometer channel and 2 km for the radiometer channel. The compositional map of Mercury provided by MERTIS will allow unique insights into the evolution of the least explored terrestrial planet and will directly address questions raised by the NASA MESSENGER mission. For example, MERTIS will be able to provide spatially resolved compositional information on the hollows and pyroclastic deposits and answer the question whether hollows are actually predominately composed of sulfide. MERTIS will also provide spatially resolved temperature maps inside the permanently shadowed craters, thereby potentially constraining the stability of water ice deposits in those craters.

BepiColombo is currently in the final part of its 7-year journey to Mercury. The interplanetary cruise includes in total nine flybys for gravitational assists: one at Earth, two at Venus and six at Mercury. MERTIS could obtain so far observations during the Earth flyby in April 2020, the first Venus flyby (FB1) in October 2020 and the second Venus flyby (FB2) on August 10, 2021. The recently published results for FB2 show that MERTIS performed well beyond requirements and provided new insights into the long-term stability of the Venusian atmosphere.

P-19

Magnetosphere

Spectral Modelling the Induction Effect of a Strong CME Hitting Planet Mercury

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Planet Mercury, with its weak internal magnetic field, is continuously exposed to an intense solar wind. This interaction becomes particularly dynamic during coronal mass ejections, resulting in a strong compression of the magnetosphere. Such events drive electrical currents within the planet, which, depending on the planetary conductivity structure, lead to secondary magnetic fields detectable outside. Analysis of these induced fields provides insights into Mercury's interior structure.

Here, we utilized data from the Helios-1 probe, recorded during a CME at 0.31 AU, to evaluate changes in solar wind conditions and their impact on Mercury's magnetosphere. We applied a semi-empirical model to estimate the external field variations and employed end-members of radial symmetric conductivity models to calculate the range of induced magnetic fields. Our analysis highlights the influence of these variations on Mercury's upper mantle layers, taking into account both dipolar and quadrupolar components of the magnetic field. Eventually, we predict the potential induced magnetic fields at the future location of the BepiColombo spacecraft, currently en route to Mercury.

P-20

Interior and evolution

Electrical Conductivity of Mercury's Interior

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Determining the electrical conductivity-depth profile of Mercury is one science objective of the ESA-JAXA BepiColombo mission, because conductivity can be used to provide insights about the composition and thermal state of the planet. Conductivity data also inform about the state of the core, its chemistry, and the intrinsically generated magnetic field. We developed electrical conductivity-depth profiles of Mercury, using electrical laboratory measurements on crust, mantle, and core analogs, an estimated thermal profile across the planet, and petrological constraints. The conductivity of the silicate portion of the planet considers a crust with varying amounts of graphite and nine different mantle mineralogies. Varying the amount and degree of connectivity of alkaline earth sulfide in the mantle using mixing models results in increasing bulk conductivity by a factor of up to 6. The core-mantle boundary region spans a large range of conductivity values (up to a factor of ~1000), depending on bulk composition and the distribution of silicate and sulfide materials. The large metallic core is the most conductive component of the planet (>10^5 S/m), assuming an Fe-Si(-S) composition. Our results can be tested with future induction data about the interior of the planet from the BepiColombo mission.

P-21

Surface

Reconstruction of the Strindberg Crater from filtered MLA data

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The imminent arrival of the joint ESA-JAXA BepiColombo mission at Mercury in 2025 will usher in a new era of exploration of our Solar System's innermost planet. With the BELA laser altimeter on board, the mission aims to comprehensively map Mercury's surface and study its tidal dynamics by measuring surface deformation.

Filtering algorithms have been developed and tested using data from NASA's MESSENGER laser altimeter MLA in preparation for BepiColombo's arrival. Several filtering techniques, including median, a neural network, RANSAC, have been evaluated for their ability to produce accurate digital elevation models (DEMs) of regional features on Mercury. This talk will present the culmination of these efforts.

P-22

Surface

Searching for Evidence of Ancient Explosive Volcanism on Mercury

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Explosive volcanism on Mercury appears to have operated in the relatively recent geologic past, as recently as the last ~1 Ga, despite the major phase of effusive volcanism ceasing by ~3.5 Ga. To date, no pyroclastic vents or deposits have been identified in the (likely effusively erupted) smooth plains deposits, and nearly all identified pyroclastic vents are significantly younger than previously supposed. How common was explosive volcanic activity in the earlier geologic history of Mercury? What can this missing piece of Mercury's volcanic history reveal about the fraction and distribution of volatiles in the interior? To address these questions, we are searching for morphologic and spectroscopic evidence of ancient explosive vents and pyroclastic deposits on Mercury. Our morphologic analysis includes investigating the interiors of craters >40 km within a buffered region ±100 km along the boundaries of the mapped smooth plains deposits. Any irregular depression that is morphologically distinct from an impact crater is marked as a candidate vent, and is further investigated using high-resolution images and topography (where available). This search is ongoing and has already identified over 20 candidate vent features. Once mapping is completed and all candidate vents have been confirmed or rejected as volcanic vents, we will investigate how their spatial distribution relates to other geologic features including previously mapped volcanic vents, smooth plains deposits, and other large-scale geology. Our results will probe the relationship between effusive and explosive volcanism, as well as the role of explosive volcanism during and after the onset of global contraction.

P-23

Magnetosphere

Investigation of the Ultralow Frequency (ULF) foreshock boundary at Mercury

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Ultralow frequency (ULF) waves are found in certain parts of the upstream region of planetary bow shocks. These waves are believed to be driven by the interaction of ions reflected from the bow shock with the original solar wind ions. The region where ULF waves can possibly be observed is then determined by the regions accessible to the reflected ions within the foreshock (defined as the region magnetically connected to the bow shock). The boundary of the region where ULF waves are observed at Earth is known to also depend on the growth rate of the waves and on the direction of the interplanetary magnetic field (IMF). As a first step in identifying the ULF foreshock boundary at Mercury, we use MESSENGER observations to investigate the presence or absence of clear ULF wave activity close to the bow shock. The boundary of regions where ULF waves are present, as parametrized by the angle Bn between the IMF and the bow shock normal, are identified and their dependence on the IMF is studied. The results are compared to results from other planets.

P-24

Surface

A consideration of an application of the lunar surface potential estimation to Mercury

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Both the Moon and Mercury are called 'airless bodies' because they do not possess dense atmospheres. The surface of airless bodies directly interacts with its ambient plasma and the interaction causes surface charging. The degree of surface charging is evaluated by the electrostatic potential of the surface. Estimating the surface potential is important for understanding the electrostatic environments near the surface. Kato et al. (2023) developed a numerical model of the energy spectrum of electrons ejected from the sunlit lunar surface, thereby suggesting that the comparison between the model and the electron observations above the lunar surface can infer the acceleration or deceleration of electrons and estimate the potential difference. In this study, we introduce the study of the lunar surface potential estimation and discuss its application to Mercury.

P-25

Other

Mercury Dust Monitor (MDM) Onboard the Mio Orbiter of the BepiColombo Mission

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The Mercury Dust Monitor (MDM) is an in-situ cosmic-dust instrument developed for the Mio stage of the joint ESA-JAXA Mercury exploration mission. The BepiColombo spacecraft, carrying MDM as part of its science payload, was launched by an Ariane 5 rocket on October 20, 2018. Commissioning tests were completed in near-Earth orbit before the spacecraft began its long journey to Mercury.

MDM features a sensor made of four piezoelectric lead zirconate titanate (PZT) plates, which convert mechanical stress from dust particle impacts into electrical signals. Once scientific operations begin, MDM will measure the impact momentum from dust particles orbiting the Sun as they collide with the sensor. It will also record the arrival direction of these particles.

This paper serves as a reference for understanding the MDM instrument and its expected scientific operations. It provides a basis for future scientific articles related to MDM's observational data.

P-26

Other

Capabilities for Long-Duration Landers On Mercury

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Missions to the surface of Mercury have had limited consideration in the past, at least partially due to the fact that Mercury experiences extreme temperatures on its surface. Temperatures on the surface can reach 430C for nearly 30 days and night temperatures can plumet to -180C. The recent Planetary Decadal Surview Report [OWL, 2023] and the studies leading up to it reflect the importance of Mercury targeted science. To enable this and other related science, NASA has been developing capabilities for a small lander that is designed to operate for months in the extreme temperatures such as found on Mercury. The capabilities being developed for Mercury and Venus promise to enable new missions not yet considered. This work summarizes technical advances that are preparing us for long-duration (months) operations on Mercury.

P-27

Interior and evolution

Possible origins for late explosive volcanism on Mercury

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Both effusive and explosive types of volcanism were identified on the surface of Mercury during the MESSENGER mission. Most of the preserved effusive deposits are dated from 4.1 to 3.5 Ga. Their parental magmas result from decompression melting associated with early mantle convection, when the mantle was still sufficiently hot. However, explosive activity formed pyroclastic deposits over a long time span, from 3.9 Ga until as recently as less than 1 Ga. Since convection melting likely ceased much earlier due to mantle cooling, the formation of some of these deposits, most of which occur within impact craters, suggests another process at play.

Partial melting of the mantle might have been locally prolonged by various mechanisms such as impacts, insolation, and local heterogeneity of mantle composition. The efficiency of these mechanisms and their potential combination is investigated here to determine a plausible scenario for late explosive volcanism on the planet.

We propose that the source of explosive magmas was located within the lower crust or the upper lithospheric mantle and composed of late-stage cumulates of the magma ocean. These lithologies remained fertile as they were never involved in mantle convection and primordial melting. Their composition could be rich in sulfur and heat-producing elements, promoting partial melting. Impacts could locally increase temperatures sufficiently to melt these rocks partially, creating magma reservoirs. Pyroclastic eruptions could then be triggered by the interaction of magma with the nearby hypothetical graphite layer formed as a floatation crust during the magma ocean stage of the planet.

P-28

Surface

Synthesis of Mercury surface analogues in evacuated silica tubes: implications for chlorides, sulfides, and phosphides formation

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Evacuated silica tube experiments are designed to investigate multi-phase interactions in a closed system, under low pressure (below 1 bar), high temperature (up to 1400°C), and controlled oxygen fugacity (IW+2 to IW-6). This experimental setup is particularly valuable for replicating natural systems involving gaseous components, fully or partially molten materials, and crystal phases. It is also suitable for reproducing the highly reducing magmatism found on Mercury and studying solubility or degassing processes related to moderately volatile elements (S, Cl..). In this study, we produced potential analogues of Mercury's surface, including glasses, chlorides, sulfides, and phosphides, with varying crystallinity, phase proportions, and sulfur content. We will discuss the feasibility and limitations of producing analogous materials in evacuated silica tube, as well as the advancements made in producing a wide range of chloride, sulfide, and phosphide compositions. Our samples will later contribute to the spectral database required by the MERTIS (MErcury Radiometer and Thermal Infrared Spectrometer) onboard the BepiColombo mission.

P-29

Surface

Numerical modelling of impact craters within the Hermean Permanent Shadowed Regions

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Hermean Permanently Shadowed Regions (PSRs) have been suggested to contain water ice deposit, based on radar and neutron observations, and they can be thermally stable environments for water ice on geologic timescales. Images and reflectance measurements highlighted the presence of bright and low-reflectance materials, suggesting that ice deposits can be both exposed at the surface and insulated by 10–30 cm of a carbon-rich material sublimation lag.

Water ice could have been delivered by (1) a continuous flux of water-bearing micrometeoroids, or (2) few individual and large impacts of comets and/or hydrated asteroids. Based on the relative purity of water-ice deposits and of the correlation between the polar crater age and the percentage extension of their PSRs, both sources could have contributed to the ice deposit formation.

A key point to determine which source is responsible of the water-ice delivery is the quantification of the projectile mass ratio that remains within the planet gravity.

Our goal is to numerical model a number of impacts by means of iSALE shock physics code. The projectiles have diameters ranging from small (1 to 1000 μm) to large (>1 m) sizes, and velocities of 20 and 40 km/, respectively in the two cases. The target is modelled as a basaltic sheet, with a water ice layer on top or within it. In this work, we present the preliminary results of such modelling and the analysis of the projectile fate.

P-30

Other

BepiColombo: Monitoring solar activity and scientific observations during Cruise with the Quick Look Analysis (QLA) tool

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The BepiColombo mission is a joint ESA/JAXA mission that launched in October 2018 and will enter Mercury orbit in December 2025. With a very short mission duration (one Earth year of nominal mission, with another year as possible extension) and a very harsh environment at Mercury, the science team will benefit from rapid and continuous access to the scientific measurements from all the instruments with relevant contextual information to better understand the operational environment. And this is the purpose of the quick-look analysis (QLA) tool provided by the ESA's Science Ground Segment. The QLA is an interactive web-interface to the data that assists the science team in identifying regions or periods of interest, manipulating and displaying data in various ways, performing trend analyses, notification of events and out-of-limit detection. This is also useful for comparing a given moment across multiple data sources as well as for analysing trends in the data over longer time periods.

Despite the limited science capabilities of the spacecraft in cruise configuration (as the boresight of many instruments is partially or fully blocked by the Mercury Transfer Module), several instruments perform calibration and scientific measurements during the flybys. This contribution will highlight how the quick-look analysis tool has been used to monitor the solar activity during Cruise and scientific observations during the flybys, and how this favours collaboration across the science team aiming at maximising the scientific return of the mission.

P-31

Surface

Investigating the Impact of Planetary Regolith on MIXS X-ray Fluorescence Observations

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Among the payload of instruments on board the upcoming BepiColombo mission is MIXS - the Mercury Imaging X-ray Spectrometer. The primary mission goal of MIXS is to produce global elemental abundance maps of Mercury's surface using X-ray fluorescence (XRF) spectroscopy. However, several studies have shown that planetary regolith causes deviations in XRF signal intensity compared to that predicted by the fundamental parameters model. If unaccounted for, these 'regolith effects' could lead to a mischaracterisation of the surface elemental abundances due to the energy-dependent nature of these effects.

Recent laboratory work has been undertaken using the MIXS Ground Reference Facility (GREF) to uncover the magnitude of these effects. A physical model was derived to account for the increased attenuation for X-rays in a regolith medium. This was incorporated into the fundamental parameters equation along with a 'surface roughness' free parameter in the model to curve-fit the equation to the GREF data. The accuracy of the fit between the model and data is remarkable and appears consistent at a range of viewing geometries and sample compositions for a particular grain size distribution.

Using the correction factors obtained from this study, a comprehensive and universally applicable correction technique is being developed for future planetary missions employing XRF. MIXS will be the first X-ray instrument to directly incorporate this correction technique into its data analysis routine which will result in more accurate elemental abundance mapping of the surface terrain of Mercury.

P-32

Surface

Mid-IR Study of Oxides for the BepiColombo Mission

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The MERTIS (MErcury Radiometer and Thermal Infrared Spectrometer) is a mid-infrared instrument (7 µm-14 µm) onboard of the BepiColombo ESA/JAXA mission to Mercury. After arrival in 2025, it will map the mineralogy of Mercury [1]. For the interpretation of the expected data, we have studied natural samples such as impact rocks and meteorites [e.g. 2]. A further focus are analogs based on compositions measured by MESSENGER [3].

Recent modeling of the oxidation state of the hermean surface indicate a much more reducing environment than assumed so far [4, 5]. In addition to the common minerals (pyroxene, plagioclase, sulphides...), significant amounts of oxides (corundum, spinel, periclase), metallic phases (Fe, Si ...), halides, but also exotic varieties of common minerals (e.g., Ca-olivine) occur in models based on these conditions.

In order to cover this type of phases, we will present first spectra of oxides. Given the differences in structure, oxides show fundamentally different features in the range of interest for the MERTIS instrument. Instead of characteristic bands in the 7 µm-14 µm region, oxides have a broad, trough-like low. Even low contents of oxides could have significant influence in the shape of the spectrum in mixtures with silicates.

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P-33

Surface

Multidisciplinary analysis of Praxiteles crater on Mercury: investigating the interplay of impact cratering, volcanism, and volatile sublimation on Mercury

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Praxiteles is a peak-ring basin (diameter ~ 180 km) centered at 27.1 °N/-60.3 °E, classified as a moderately degraded basin of early-Calorian age [1,2]. We updated the 1:3M geological map by [1], based on the photointerpretation of MESSENGER end-of-mission basemaps [3] and the USGS DEM. Using high-resolution NAC images (mostly 18-20 mpp) we produced new mosaics, mapping in detail the irregular pits and hollow fields within its floor. Pits (compound volcanic vents) developed along the peak ring, which was partly destroyed by explosive eruptions and covered by the smooth plains. Our mapping highlights the presence of hollows following the concentric, but asymmetrical and offset peak-ring structure. A novel absorption feature and geomorphologic expressions of volatile sublimation have been identified on fresh craters that impacted the remnant peak ring (see Galiano et al., this congress). Through the combination of impact simulations [4], spectral analysis, and stratigraphic interpretation, we modeled the formation and evolution of Praxiteles including the possible presence of a shallow 2.8 km thick volatile-rich layer (VRL). Results showed that VRL has been uplifted after the impact, preferentially along the peak-ring contributing to its disruption via devolatilization, and finally exposed by the younger craters via recent hollow formation.

P-34

Fundamental Physics

Orbital evolution of planetesimals in the inner solar system and mantle erosion of proto-Mercury by their impacts

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Mercury is a dense planet and is estimated to have a much higher core mass fraction than other rocky planets in the solar system. One possible explanation for this is a collisional scenario in which proto-Mercury has lost a large part of its mantle layer in violent impacts.

Studies using SPH simulations have investigated and found the impact conditions for a giant impact to form Mercury-like planets in mass and iron fraction (e.g., Asphaug & Reufer 2014; Chau et al. 2018). However, recent studies using N-body simulations have reported that giant impacts suggested by previous SPH studies are very rare in the context of planet formation (Clement et al. 2019; Franco et al. 2022).

Therefore, in this study, we investigate the possibility that mantle materials of proto-Mercury are gradually stripped away by a large number of planetesimal collisions that occur during the planet formation process, ultimately forming Mercury's high core mass fraction. We consider that the secular resonance near Mercury's orbit may play a role in causing the high-velocity planetesimal impacts enough for mantle erosion.

In this study, we calculate the orbital evolution of a large number of planetesimals distributed in the inner solar system using N-body simulations. We also estimate the erosion (or accretion) mass depending on the impact conditions of these collisions by using the scaling law derived by Hyodo & Genda (2020). In this presentation, we will present detailed results of the above calculations.

P-35

Magnetosphere

Characterization of the solar wind interaction with the lunar mini-magnetospheres : Implication for Mercury's magnetosphere

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Although the Moon does not have a global magnetic field like the Mercury, crustal remanent magnetizations (lunar magnetic anomalies, hereafter LMAs) are nonuniformly distributed over the lunar surface. The interaction between the solar wind and LMAs leads to the formation of mini-magnetospheres. Since the spatial scales of lunar mini-magnetospheres are very small, below several tens of kilometers, direct observations of the lunar mini-magnetospheres are challenging from a typical altitude of lunar orbiters (~100 km). As a result, the solar wind-LMAs interaction has not been fully understood.

Saito et al. (2012) first reported simultaneous observations of ions and electrons below 30 km altitude based on a single low-altitude path obtained by 'Kaguya'. In this study, we extensively analyze low-altitude data of ions, electrons and electromagnetic fields obtained by Kaguya. By analyzing multiple orbits over various LMAs, we comprehensively characterize the plasma environment and electromagnetic fields in the solar wind-LMA interaction region.

Comparing to relatively small and isolated LMAs, we observe the strongest solar wind ion reflection and whistler mode waves over the South Pole Aitken region, which has the largest horizontal scale among LMAs. This suggests that the nature of the solar wind-LMAs interaction varies greatly depending on the spatial scales of mini-magnetospheres.

The interaction between Mercury's weak dipole magnetic field with the intense solar wind gives rise to the formation of the small magnetosphere of Mercury. We discuss the potential implication of our results on lunar mini-magnetosphere for Mercury's small magnetosphere in terms of spatial scales of the magnetic obstacles.

P-36

Exosphere

Mercury's exosphere observed by PHEBUS visible channels during the first three BepiColombo flybys.

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Mercury possesses a tenuous atmosphere composed mainly of atoms rather than molecules. Atomic calcium (Ca) has been observed in Mercury's exosphere first from ground-based telescopes [1,2] and later with MESSENGER/MASCS [3,4,5]. The observations revealed a dawn enhancement in the Ca emission and seasonal variations, and indicated an energetic source of Ca.

PHEBUS visible channels detected the emission line of Ca at 422.8 nm during BepiColombo flybys of the innermost planet in October 2021, June 2022, and June 2023. The observations show that the Ca exosphere is enhanced in the dawn region and extended in the morning side (up to 10,000 km of altitude). Moreover, the observations imply a highly energetic source process for Ca.

PHEBUS visible channels also detected species at low altitudes on the morning side during the three flybys, potentially manganese (Mn) or potassium (K). Mn emission lines at 403 nm were detected by MESSENGER/MASCS [6] but only towards the end of the mission and over limited local times and true anomaly angles. However, the true anomaly angles of BepiColombo flybys of Mercury are different from those corresponding to Mn detection by MESSENGER/MASCS. As for K, its emission lines at 404 nm were not detected by MESSENGER/MASCS [6]. Only the strongest emission lines between 765 and 770 nm were detected from the ground [7].

[1] Bida et al., 2000
[2] Killen et al., 2005
[3] McClintock et al., 2008
[4] McClintock et al., 2009
[5] Vervack et al., 2010
[6] Vervack et al., 2016
[7] Potter and Morgan, 1986

P-37

Surface

A Possible Phase of Late Heavy bombardment-induced Salt Glaciation on Mercury: Implications for Surficial Elemental Compositions and Regolith Seismic Stability

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Our recent research [1,2] has significant implications for our understanding of Mercury's geological history. It suggests the planet possesses a buried volatile-rich crustal layer (VRL) with a thickness of ~2 km, which was partly brought up to the surface by the Raditladi and Eminescu impacts within uplifted peak rings ~ 1 Ga [2]. Glacier-like features, probably composed of halite, throughout these peaks suggest that the VRL became unstable upon exposure and, at some locations (e.g., Eminescu), mostly disappeared in less than ~1 Ga.

We have surveyed numerous crater interior floors, previously interpreted as solidified melt pools. However, this interpretation is inconsistent with our finding of widespread hollows within them, indicating a near-surface VRL composition. Hence, we propose the following new hypothesis - LHB impacts generated interior salt glaciers, which subsequently were reduced to form crater interior plains stabilized beneath refractory layers. This hypothesis is also consistent with previous chaotic terrain studies showing that plains can also form as a VRL end member through a sustained break-up and disintegration due to volatile losses [1,2].

The proposed glaciation phase implies that vast volumes of volatiles would have been accessible to the planet's surface volatile cyclicity, potentially forming a volatile source for the elemental volatile veneers that cover the heavily cratered terrains. In addition, the surficial nature of these elemental compositions implies that Mercury's upper regolith has experienced little to no seismically induced convection, in contrast to the Moon. These findings are crucial for understanding the interplay between impact craters and Mercury's volatile cyclicity.

References:

[1] Rodriguez, J. A. P., et al., (2019). Scientific Reports, Volume 10, article id. 4737

[2] Rodriguez, J. Alexis P., et al., (2023). Planetary Science Journal, Volume 4, Issue 11, id.219, 29 pp. doi: 10.3847/PSJ/acf219

P-38

Magnetosphere

Space Weather monitoring with BepiColombo at Mercury's orbit in preparation for orbit insertion

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BepiColombo has a large suite of instruments dedicated to plasma and solar physics, most of them operating on regular basis during the cruise phase, such as the Solar Intensity X-Ray and Particle Spectrometer (SIXS), the BepiColombo Environmental Radiation Monitor (BERM), the Solar Particle Monitor (SPM), the Mercury Gamma and Neutron Spectrometer (MGNS), and the BepiColombo Planetary Magnetometer (MPO-MAG). Some other instruments are operated on specific solar wind campaigns. The long cruise of BepiColombo (October 2018-December 2025) is constituting an exceptional opportunity for cross-calibration of instrumentation, but also for unique science opportunities and collaborations with other solar missions, such as Parker Solar Probe and Solar Orbiter that are helping to characterise the plasma environment within Mercury orbit distance.

Monitoring planetary space weather at Mercury is important in order to characterise the distribution of energy entering and dissipating within the planetary system. However, our knowledge of the solar wind within 0.3 au is quite limited, but large efforts are currently happening to combine observations from BepiColombo and other solar missions. In this work, we present an overview of the Space Weather environment encountered by BepiColombo so far and focus on a major solar event that took place in February 2022, which is used as example for solar wind variability encountered at such distances and for what to expect after orbit insertion. We are working towards gathering the needed synergies between the BepiColombo teams and other missions to characterise how the solar wind and solar energetic particles directly interact with the highly active Hermean magnetosphere and be of help to other teams within the mission to interpret the external context of their observations.

P-39

Exosphere

Strofio: A Status Update

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Strofio is a neutral mass spectrometer that utilizes a time-of-flight (TOF) technique to determine the mass-per-charge (m/q) of neutral species. Immediately following launch, one of the system's electrodes (D5) was shorted to ground. While this does not affect system resolution or sensitivity, it has significant implications for the TOF of each particle thereby affecting the mass range. We will present the latest advances we have made in optimizing the instrument in its current state.

P-40

Surface

Structural Investigation of reactivated multi-ring faults on Mercury: the case of Andal-Coleridge basin

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Mercury’s Discovery Quadrangle hosts a probable pre-Tolstojan multiring impact basin named Andal-Coleridge. Our objective is to validate its existence and understand its influence on the tectonic evolution of the quadrangle through detailed structural mapping and analysis. Examination of the structural map shows around 500 segments of contractional features, mainly arranged concentrically around a topographic low and a mascon detected in the Bouguer anomaly map. The uniform distribution of bins in the rose diagrams suggests an impact-related origin for most of them, with beta-analysis indicating the presence of two distinct impact basins. Discovery Rupes aligns concentrically with the primary distribution (Andal-Coleridge basin), while Adventure and Resolution Rupes surround a second basin (informally named b78), smaller and probably older than the Andal-Coleridge basin. The throw analysis reveals that Adventure and Resolution Rupes are the morphological expression of the same fault. Additionally, Discovery Rupes exhibits signs of reactivation within the Rameau crater, indicating fault erosion and its subsequent re-emergence due to Mercury's global contraction. Our preliminary findings, highlight the role of the Andal-Coleridge impact event in generating concentric faults, the impact of the Rameau-forming event on fault erosion and the role of Mercury’s global contraction in reactivating these structures as growth-fault systems. The study suggests a peak in throw-rate during the Tolstojan period, a declining activity towards the Mansurian period, which is possibly continuing to the present. This study may also represent a contribution for evaluating the rate of global contraction and its magnitude throughout Mercury’s evolution.

P-41

Magnetosphere

Can we compare 3D global hybrid plasma simulation outputs directly to particle instrument measurements?

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Understanding Mercury's magnetosphere is one of the primary goals of the BepiColombo mission. In addition to spacecraft observations, numerical modeling efforts have shown to add invaluable insight to the Hermean magnetic field topology, current systems and plasma distributions. However, existing comparisons between observed and modeled data are predominantly qualitative, lacking quantitative agreement due to diverse mathematical approaches. Notably, quantitative inconsistencies of observed and modeled ion densities and energies are particularly affected. Hence, this study addresses systematic and stochastic deviations, focusing on establishing confidence intervals for "ion counting" within the hybrid AIKEF (Adaptive Ion Kinetic Electron Fluid) model. The kinetic treatment of the ions enables to directly compare model results with observations of the Planetary Ion Camera (PICAM), which is a part of the SERENA suite onboard the BepiColombo mission. Multiple ion counting methods are introduced to find velocity distributions and evaluate differential particle fluxes. Our findings demonstrate that applying these methods to the modeled data, within the derived confidence interval, yield ion velocity distributions consistent with PICAM observations of Mercury's magnetosheath. The AIKEF model and the developed analysis tools serve as a powerful and convenient method of reproducing the ion and electro-magnetic field profile around Mercury for the BepiColombo mission, both in flyby and in-orbit measurements.

P-42

Surface

The 1:3M geologic map of H9-Eminescu quadrangle on Mercury

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The H9-Eminescu quadrangle on Mercury is located in the equatorial region between 22.5°N-22.5°S and 72°E-144°E. Data collected by the Mariner10 mission did not cover the longitudes of the Eminescu quadrangle and thus prevented the production of a first regional geologic map of the area. Imaged only during the MESSENGER mission, the quadrangle was firstly mapped in the 1:15M global geologic map of Mercury (Kinczyk et al., 2019). Nevertheless, since 2016 is going on a coordinated global mapping project for the production of a series of 1:3M regional geologic maps for Mercury (Galluzzi et al., 2024, this conference). Aiming at delivering all the regional maps in time for the BepiColombo mission, here we present the 1:3M geologic map for the H9-Eminescu quadrangle which provides a greater mapping detail than the 1:15M map together with a three-classes of craters classification and three terrain units. Geological contacts were mainly digitized from the ~166 m/px MESSENGER Mercury Dual Imaging System Basemap reduced Data Record monochrome basemap, with additional insights provided by auxiliary basemaps with different illumination conditions, color mosaics (Denevi et al., 2016) and elevation data (Becker et al., 2009). Overall, the northeastern portion of the quadrangle is largely morphologically and tectonically affected by the impact of the close Caloris basin. Extended thrust systems have been detected and they will help in better understanding the geomechanical evolution of the planet. Evidences of explosive volcanism have been detected but they are rarely associated with the bright yellow colors as from the enhanced color mosaics.

P-43

Magnetosphere

Hybrid particle simulation for ions dynamics in Mercury's inner Magnetosphere

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In preparation for the Mercury observation by the BepiColombo mission, which will start in December 2025, we began to study Mercury's magnetosphere by performing three-dimensional hybrid particle simulations. This study aims to clarify the structure of Mercury's magnetosphere, the entry process of the solar wind ions into the magnetosphere, and the ion dynamics in the magnetosphere by considering the ion kinetic effects. We particularly examined the ion dynamics near the Mercury's surface, including the drift and bouncing motions in the Mercury's magnetic fields, by analyzing particle trajectories, current structure, and the interactions between ions and the fields. We will show some of the results.

In Earth's magnetosphere, the drift motion of ions is well known as a significant source of the ring current. However, their existence and structural differences in Mercury's magnetosphere are still under debate. This study will also discuss the possibility of the ring current formation and its process in Mercury's magnetosphere.

P-44

Surface

Spectral and geochemical characteristics of Mercury analogs in preparation for the analysis of MERTIS FlyBy 5 measurements

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The MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS) of the BepiColombo mission has as main goal to characterize the Hermean surface mineralogy by measuring the spectral emissivity of Mercury's surface with a spatial resolution of at least 500 mpp. During the 5th Mercury FlyBy of BepiColombo on the 2nd of December 2024, MERTIS will operate and perform surface measurements on a large area of Mercury. This Region of Interest (ROI) that MERTIS will observe was studied for its spectral features and expected mineralogy, by subdividing the area in different spectral units. The main type of spectral units within our ROI were identified; Low Reflectance Material (LRM), Faculae and Hollows. To prepare for the upcoming remote sensing measurements of MERTIS, analogue materials to simulate the expected mineralogy within our ROI need to be selected and studied in laboratory. Microscopical analysis, as well as reflectance and emissivity spectral analysis of the analogous materials are needed for comparison to the remote sensing data once the BepiColombo spacecraft reaches Mercury and can operate. To simulate the Mercury surface, we selected the recently fallen Aubrite meteorite "Ribbeck", as this enstatite-rich material is highly reduced such as expected for the planet. This aubrite was also mixed with other minerals (e.g. graphite, sulfide) to simulate the different types of spectral units expected on Mercury. Here we present the laboratory analyses performed in our facilities at the German Aerospace Center (DLR) and the Museum für Naturkunde (MfN) in Berlin.

P-45

Surface

Surface and Environment Interactions Studies Group (SEIS): the best group ever

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The Surface and Environment Interactions Studies (SEIS) Group is a subgroup of the BepiColombo Young Scientist Study Group (BCYSSG). Its main goal is to bring early-career scientists from diverse backgrounds together to maximize the collective understanding of Mercury's surface and environment interactions. Another objective is to increase interdisciplinary collaborations in support of the ESA/JAXA BepiColombo mission. SEIS members come from different backgrounds ranging from geology, geophysics, geochemistry to atmospheric and plasma science and engineering. This allows for a unique understanding of various surface processes and their subsequent exosphere/magnetosphere interactions across different dimensional scales.

SEIS technical expertise currently includes spectroscopy (ultraviolet, visible, near-infrared, mid-infrared, x-ray, gamma ray, and neutron), geological mapping (tectonics, volcanism, geomorphology, stratigraphy, impact cratering…), modeling (3D surface reconstruction, molecular dynamics, magnetosphere-surface-exosphere coupling, magnetosphere-core coupling, polar deposits, particle dynamics and precipitation…), ground-based observations, and laboratory experiments (analogue studies, space-weathering, spectroscopy…). These techniques are applied to study Mercury's surface mineralogy, (thermo-)physical properties (temperature, roughness, porosity…), surface processes (geology, space-weathering…), planet formation, abundance of volatiles and surface-exosphere-magnetosphere interactions. SEIS members are involved in a wide variety of instruments onboard the BepiColombo spacecraft this includes cameras and spectrometers (e.g. MERTIS, SIMBIO-SYS, MIXS…), geophysics packages (e.g. MPO-MAG, MORE…) and exospheric instruments (e.g. SERENA, PHEBUS.). The group meets bi-monthly online and in-person during BepiColombo Science Working Team (SWT) meetings.

P-46

Exosphere

A subsurface reservoir as a potential explanation for the cold-pole enhancement in Mercury's sodium exosphere

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Since its discovery in Mercury's exosphere, sodium remains one of the most studied species in the Hermean environment. Observations have demonstrated that Mercury's sodium exosphere is evolving dynamically according to the orbital position of the planet while exhibiting an inter-annual variability. Some features of the sodium exosphere, such as the dawn-dusk asymmetry, have been partially explained through the introduction of the concept of a surface reservoir, replenished as atoms are adsorbed on the night side cold surface. Only considering such reservoir seems, however, insufficient in explaining the sodium enhancement measured over the cold longitudes by MErcury Surface, Space ENvironment, GEochemistry and Ranging (MESSENGER). Indeed, such surface reservoir ends up rapidly depleted after dawn so that the peak of the modeled sodium exospheric column density does not follow the observed orbital evolution. MESSENGER observations exhibit an increase of the sodium column density over the cold longitudes all along Mercury's orbit: from dawn to noon, when it reaches a maximum, and then a decreased column density following the cold longitudes until a True Anomaly Angle of 300°. By including a 1-D subsurface diffusion model to a 3-D Exosphere Global Model using a Monte Carlo test particles approach, we study the potential role of such subsurface reservoir on the sodium enhancement of the exosphere over the cold longitudes. We find that a significantly greater reservoir builds up at the cold longitudes which forms closer to the surface, and show that it reconciles global 3D modeling of the exosphere and the observed orbital evolution.

P-47

Surface

Preliminary temperature analysis of the Region of Interest using MERTIS onboard BepiColombo for the upcoming Mercury's 5th Flyby.

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BepiColombo will perform its 5th flyby of Mercury on the 2nd of December, 2024 during which MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS), part of the Mercury Planetary Orbiter spacecraft, will observe the Hermean surface to characterize its surface minerology and temperature variation. MERTIS-TIS has a spectral wavelength range of 7-14 µm and the Thermal Infrared (MERTIS-TIR) has a wavelength range of 7-40 µm. The currently planned Region of Interest (ROI) encompasses various types of terrain namely the Beethoven basin and several large craters such as Michelangelo, Durer & Vieira da Silva. The altitude difference in the region ranges from 2841 m to - 4453.5 m with a maximum slope of around 30°.

Due to proximity to the Sun, the surface of Mercury undergoes a large temperature variation while also showcasing difference in regional temperature identified as hot and cold regions. Various factors influence the temperature on Mercury's surface like the density of impact craters, topography, surface morphology, distance to the sun, density of the material etc. In preparation for the flyby, a preliminary temperature study is conducted using Python and the equations from the Vasavada model. The study takes several parameters into consideration namely Solar insolation, altitude, surface density, thermal conductivity etc. The results will be used to generate 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 in ROI and characterize the surface mineralogy for the upcoming BepiColombo flyby.

P-48

Surface

Refractive index of Mercury analog particles from light scattering measurements

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Silicate glass is a product of volcanism and impact cratering on planetary surfaces, and is a significant contributor to the scattering from planetary surfaces. Sample properties such as shape and size can be studied via light scattering, if the material complex refractive index is known. An inverse light scattering method for deriving the complex refractive index of a mm-sized single particle in a specific wavelength using laboratory measurements with the 4π scatterometer is presented. The measured samples were fragments of silicate glass, created as Mercury surface analogs. To obtain the complex refractive index of a glass sample, measurements were compared to simulations from a newly modified SIRIS4 Fixed Orientation (SIRIS4 FO) geometric optics code.

The 4π scatterometer is a unique instrument which measures the intensity of polarized light scattered from a particle using linear polarizers. Mueller matrix elements can be calculated for the particle from the measurements. The scatterometer uses an acoustic levitator as a sample holder, which provides nondestructive measurements and full orientation control of the sample.

The SIRIS4 FO code calculates the Mueller matrix elements over the full solid angle around the particle, as functions of the two scattering angles. A 3D model of the shape of the measured particle was constructed using X-ray microtomography and was transported to SIRIS4 FO.

The complex refractive index was obtained with a nonlinear least squares analysis by minimizing the sum of squared residuals between the Mueller matrix elements from measurements and simulations with varying refractive index values. The obtained real part of the refractive index was $n = 1.59$ and the imaginary part $k = 2.05 \times 10^{-5}$. Previous values of the refractive index derived by the manufacturers of the glass support our findings.

P-49

Magnetosphere

Investigating the properties of the Low Latitude Boundary Layer at Mercury using MESSENGER data

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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) [e.g., Wang et al., 2010]. A statistical study [Liljablad et al., 2015] has surveyed the properties of the LLBL over the first orbital year of MESSENGER (from 26 March 2011 to 31 December 2011). 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., in prep., 2024; Hadid et al., under review, 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. We have identified 807 LLBL crossings that we fully characterized using the magnetic field and particle data from the MAG and FIPS instruments, respectively, onboard MESSENGER, of which 104 cases showed a signature of the Kelvin-Helmholtz waves. We further investigate the ion properties within this region, in comparison with the BepiColombo data taken during MFB3.

P-50

Surface

Source of Mercury's Hollow-Forming Materials: Preliminary Results from Geological Mapping, Spectra, and Impact Simulations

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Mercury has a large core, but paradoxically the surface is also volatile rich. Most core-enlarging scenarios envisaged for Mercury would have heated the silicates and preferentially driven-off these volatiles. Mercury's hollows, flat floored, rimless depressions tens of meters deep and up to tens of kilometers across, appear to have formed by the loss of some volatile material to space upon its exposure at the surface, often by impact craters. Hollows lack superposing craters, indicating that they may be undergoing active formation today. The subsurface distribution of Mercury's hollow-forming material is not known. If confined to the upper few kilometers of Mercury's crust, sampled by the craters up to a few hundred kilometers in diameter in which most hollows are found, then perhaps it was accreted as a late veneer after the core-enlarging event. Alternatively, if the hollow-forming material is present throughout a greater thickness of Mercury's silicate portion then the timing of any high-temperature core-enlarging event must have taken place very early in the planet's history to allow time for a volatile-rich silicate fraction to reaccrete. Here, we study the Caloris basin: Mercury's largest, well-preserved impact structure. We employed a combination of geological mapping, reflectance spectroscopy, and numerical impact simulations to map the present-day distribution of the hollow-forming material in Caloris ejecta, preserved as hummocky plains hosting km-scale knobs, back to its pre-Caloris, subsurface distribution. Our results suggest that Mercury's hollow forming material comes from the whole thickness of the crust, a deeper constraint than previous studies.