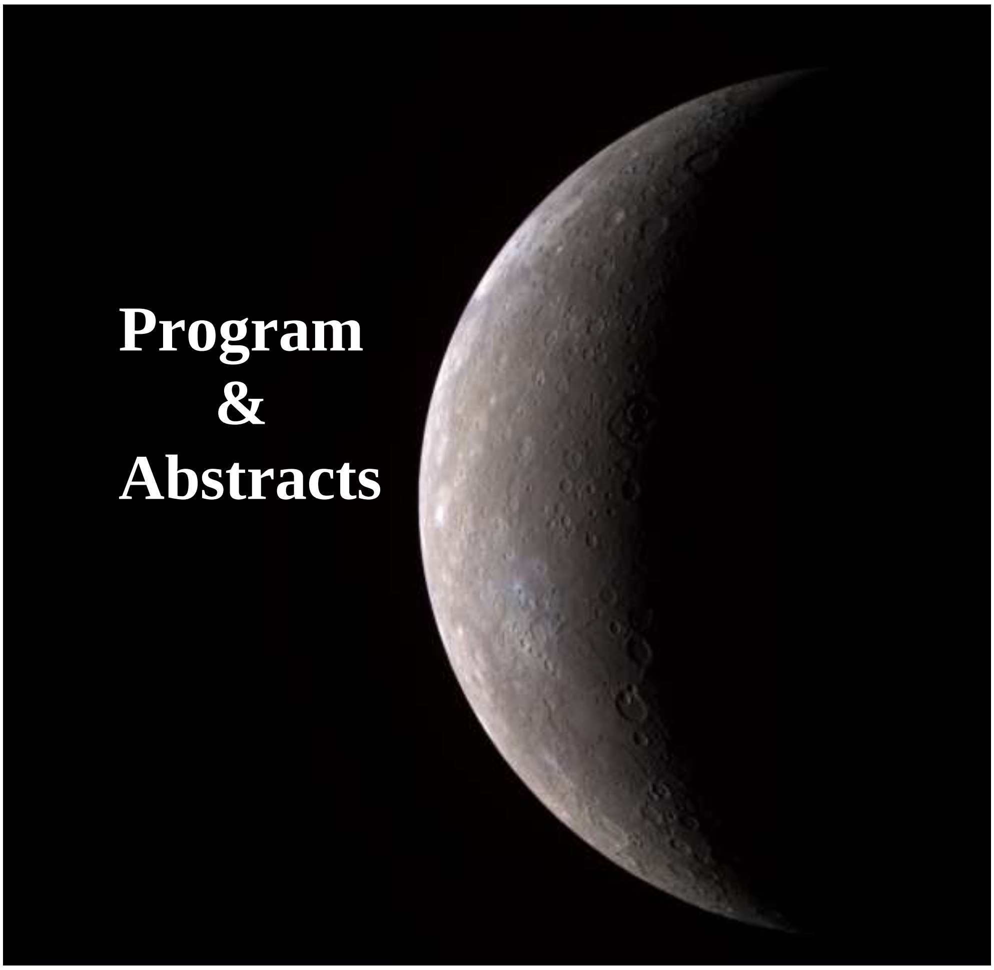
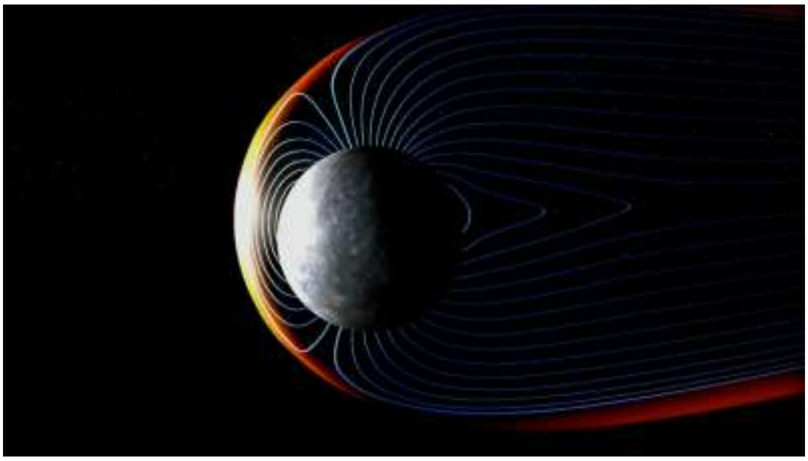
From MESSENGER to BepiColombo ……

DLR Berlin, Germany, 16-18 June 2015



Day 1 - Tuesday 16 June



Credit NASA

09:15 Introduction — Helbert;Benkhoff

Magnetosphere Block

Invited

09:30	Mercury's magnetic field: MESSENGER observations and BepiColombo opportunities	Johnson et al.
10:15	Mercury's magnetosphere - Bepi Colombo science possibilities	Delcourt
11:00	***Coffee break***	

Contributed

11:15	Induction balance at the magnetopause of Mercury	Hayner
11:25	A Study of the Low-Latitude Boundary layer on Mercury	Liljeblad et al.
11:35	Dynamo model explanation for Mercury's unusual magenetic field	Takahashi
11:45	MESSENGER's plasma observations in Mercury's northern magnetospheric cusp	Raines et al.
11:55	Modelling Mercury's magnetospheric magnetic field: Past, present and future	Korth et al.
12:05	Localized electron induced X-ray flourescence on the nightside surface of Mercury and its implications for magnetospheric structure	Lindsay et al.
12:15	Discussion	All
13:00	***Lunch***	

Posters

Mercury's disappearing dayside magnetosphere events (MESSENGER): Evidence for severe dayside erosion and/or compression?	Middleton et al.
Magnetospheric flux transport at Mercury	Imber et al.

Credit NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Surface Block

Invited

14:00	Geochemistry of Mercury's surface: Results from MESSENGER	Shoshana Weider
14:40	The Global Cessation of Effusive Volcanism on Mercury	Byrne et al.
15:05	The tectonics of Mercury: Infromation from MESSENGER imaging and topography	Klimczak et al.
15:30	Studying the surface of Mercury with BepiColombo	Joern Helbert
16:10	***Coffee break***	

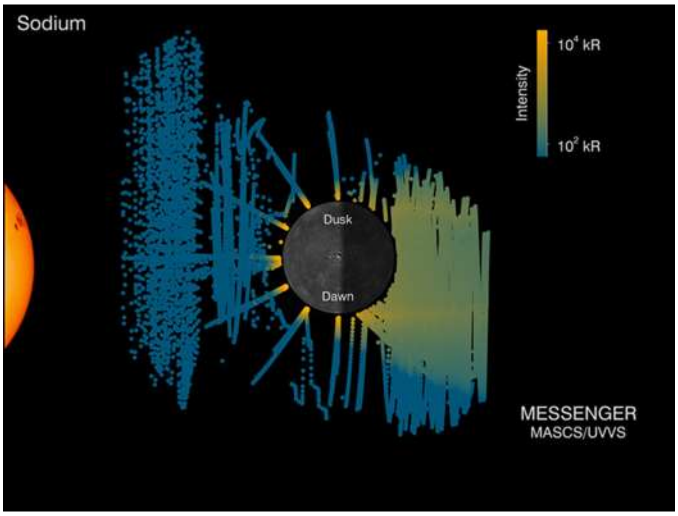
Contributed

16:30	Water Ice on Mercury: Exploring the South Polar Regions	Chabot et al.
16:40	High-resolution measurements of Mercury's surface composition with the MESSENGER X-ray spectrometer	Frank et al.
16:50	Mercury's Hollows: Morphology and Spectral and Elemental Variations	Izenberg et al.
17:00	Measurements of surface reflectance and roughness on Mercury with the Mercury Laser Altimeter	Neumann et al.
17:10	The Mercury Global Mapping Project	Prockter et al.
17:20	Geological mapping of Mercury in preparation for BepiColombo	Rothery & Massironi
17:30	Photometric Properties of Mercury's Surface at Visible to Near-Infrared Wavelengths	Domingue et al.
17:40	Can MESSENGER Visible to Near-Infrared Photometric and Spectral Data Inform Predictions about BepiColombo Mid-Infrared Spectral Findings?	Vilas et al.
17:50	Future observations of Mercury with BepiColombo's Mercury Imaging X-ray Spectrometer (MIXS)	Martindale et al.
18:00	Discussion	All
19:00	End of day	

Posters

Characterizing explosive volcanism on Mercury (withdrawn)	Besse et al.
Mantle sources and melting conditions for basalts on Mercury	Charlier & Namur
MERTIS calibration campaign for performance characterization.	Amore et al.
Geologically supervised classification of Rembrandt basin and Caloris basin on Mercury: from MESSENGER to BepiColombo.	D'Incecco et al.
A Study of Thermal Expansion on the Predicted Mercury Surface Minerals: Preparing for MERTIS on BepiColombo	Ferrari et al.
Polar volatiles on Moon and Mercury: similarity and difference (withdrawn)	Mitrofanov et al.
Mercury Surface in the Planetary Emissivity Laboratory (PEL): Preparing for MERTIS on BepiColombo	Maturilli et al.
Gamma-ray spectroscopy of Mercury surface by the Mercury Gamma-ray and Neutron Spectrometer (MGNS): from MESSENGER to BepiColombo. (withdrawn)	Kozyrev et al.
MESSENGER-based targets for high-resolution compositional analysis by BepiColombo	Thomas et al.
Simulation of the performance of the BepiColombo Laser Altimeter instrument based on MESSENGER data	Gouman et al.

Day 2 - Wednesday 17 June



Exosphere Block

Invited

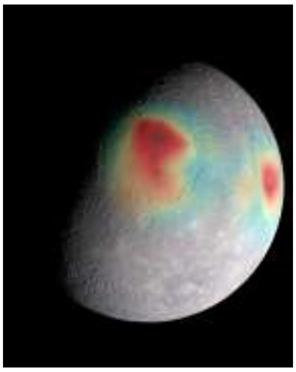
09:30	Exploring Mercury's Surface-bound Exosphere from Orbit: Observations by the Mercury Atmospheric and Surface Composition Spectrometer aboard the MESSSENGER Spacecraft	McClintock et al.
10:15	Mercury's exosphere: from MESSENGER to Bepi-Colombo	Leblanc et al.
11:00	***Coffee break***	

Contributed

11:15	Mercury's Calcium Exosphere in the MESSENGER Era	Burger et al.
11:25	Direct measurement of interplanetary dust influx on Mercury - An origin of sodium exosphere and space weathering of Mercury	Hirai
11:35	Seasonal variability of Mercury's sodium and interplanetary dust distribution	Kameda et al.
11:45	Impact Vaporization as a Source of Mercury's Calcium Exosphere with Evidence for a Meteor Shower	Killen et al.
11:55	Mercury Sodium Atmosphere Spectral Imager (MSASI) onboard BepiColombo/MMO	Murakami et al.
12:05	MESSENGER Observations of Mercury's Sodium Exosphere	Cassidy et al.
12:15	Discussion	All
13:00	***Lunch***	

Posters

A long-term all-sky imager observation of lunar sodium tail.	Nishino et al.



Interior Block

Invited

14:00	Mercury's interior: New views from MESSENGER	Hauck et al.
14:45	Title TBC	Westrenen
15:30	***Coffee break***	

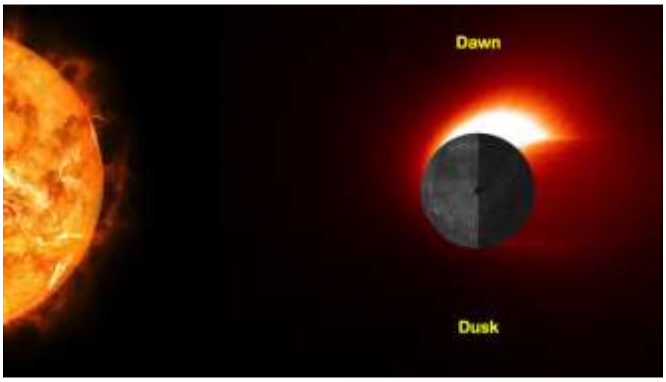
Contributed

16:00	The gravity field of Mercury after the MESSENGER mission	Genova
16:10	Insights from MESSENGER into the crustal structure of Mercury's geochemical terranes	James et al.
16:20	The impact of near-zero obliquity on the evolution of Mercury	Kamata et Kuramoto
16:30	Mercury Orbiter Radio Science Experiment (MORE): global full-cycle numerical simulation	Milani
16:40	Topography and Shape of Mercury from the Mercury Laser Altimeter	Smith
16:50	Density and sound velocity of liquid Fe-alloys under high pressure: Implications for Mercury core	Terasaki
17:00	Discussion	All
17:30	End of day	
19:30	*Social event/dinner* **-** Zur letzten Instanz - warm buffet at the oldest continuously operating restaurant in Berlin.	

Posters

Orbit simulations for BepiColombo using MESSENGER- based high-order Mercury gravity field data	Lüdicke et al.
Constraining Mercury's interior structure with geodesy data and its present thermal state	Rivoldini et al.
First MESSENGER ORBITAL Observations of Mercury's Librations	Stark et al.
MEASURING MERCURY'S TIDAL DEFORMATION BY LASER ALTIMETRY PERSPECTIVES FOR BELA ONBOARD THE BEPICOLOMBO SPACECRAFT	Steinbrügge et al.
Mercury's low-degree geoid and topography from insolation-driven elastic deformation	Tosi et al.
Thickness of the crust of Mercury	Padovan et al.
Mercury Gravity Field and Rotational State from the BepiColombo Radio Science Experiment	Mariani et al.

Day 3 - Thursday 18 June



The Big Picture Block

General topics

09:00	Open discussion on Lessons Learned for science operations and science planning	All
Contributed		
10:00	Mercury Orbiter Radio Science Experiment (MORE): benefits from an extended mission	Imperi et al.
10:10	MERCURY REFERENCE FRAME and TOPOGRAPHIC BASE MAP from Combined MESSENGER Stereo Photogrammetry AND Laser Altimetry	Oberst et al.
10:20	Mercury's Exosphere: Lessons Learned from MESSENGER and Follow-On Possibilities for BepiColombo	Killen et al.
10:30	Discussion	All
11:00	***Coffee break***	

Invited

11:30	The “Big Picture” as seen by MESSENGER	Solomon
12:15	The “Big Picture”: expected contributions from BepiColombo	Spohn
13:00	Final discussion	All
13:30	End of meeting	

MESSENGER – BepiColombo
Joint Science Meeting

DLR Berlin, Germany, 16-18 June 2015

On the following pages all abstracts are listed in no particular order.

If one searches for a special abstract, it is recommended to click on the titles of the abstracts, in the agenda pages above, to easily access it.

1) Characterizing explosive volcanism on Mercury

S. Besse (1), A. Doressoundiram (2), J. Benkhoff (1), L. Griton (2) (1) European Space Agency, ESTEC, 2200 AG Noordwijk, Netherlands, (sbesse@cosmos.esa.int) (2) LESIA, Observatoire de Paris, F-92195 Meudon

Abstract Volcanism on Mercury has been indisputably identi- fied at various locations on the surface, whether it is by means of both effusive and explosive volcanism [1, 2, 3]. Its characterization is crucial to understand the evolution of the planet, in particular the thermal evolution of the mantle, and the volatile content of the planet. This analysis presents a detailed view of the pyroclastic deposits of the Caloris basin, and the Hesiod region to properly describe their spectroscopic properties. Observations from the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [4] are used to understand the spectral characteristics of the pyroclastic deposits, both in the visible and near-infrared. Additional calibration steps are proposed to reconcile the difference of absolute re- flectance between the visible (VIS) and near-infrared (NIR) detectors. These calibration steps allow the use of the full spectral range of the MASCS instrument. Pyroclastic deposits exhibit a redder spectral slope in the VIS and NIR. This is a confirmation of earlier observations using either MASCS [5] or the Mercury Dual Imaging System (MDIS) [3]. This spectral slope diminishes towards the edge of the deposits to match that of Mercury's average surface. Spectral properties in the ultra-violet (UV) have been previously described [5], a change of these properties as a function of distance to the vent is however systematically observed. This spectral variations could be consistent with a lower iron content of the pyroclastic deposits with respect to the average surface of Mercury. This detailed analysis of the volcanic deposits, with a very large sample of the MASCS observations from the MESSENGER mission, have also highlighted the limitations of such an analysis. The limitations are of different natures, and could be significantly improved with the upcoming BepiColombo mission of the European Space Agency [6]. The separation of the VIS and NIR signals in two detectors have created an offset in reflectance that is very difficult to correct without assumptions. The VIHI hyperspectral imager of the Symbio-Sys instrument suite [7] onboard the BepiColombo mission will cover the range 400 to 2000 nm with one single detector. It is thus expected that the re- flectance between the VIS and NIR will be more consistent. The other difficulties of the MASCS dataset are related to the coverage and illumination conditions of the observations. Given that the MASCS instrument is also used to characterize the properties of the exosphere, the coverage of the surface is not done with optimal geometries with respect to what Symbio-Sys will be capable of achieving given its constant nadir pointing to the surface. Additionally, the illumination conditions are also not optimal for the MASCS instrument. The phase angle is generally above 45 degrees, which is not optimal for spectroscopic observations of the surface. With its nadir pointing, observations from the VIHI instrument will be done under illumination conditions more favorable to extract spectroscopic information from the volcanic deposits, and it will also extend the investigations to the southern hemisphere given BepiColombo's different orbit [6] with respect to MESSENGER [8]. This work was submitted in March 2015 to JGR for publication.

References [1] Head, J. W., and 10 colleagues 2008. Volcanism on Mercury: Evidence from the First MESSENGER Flyby. Science 321, 69. [2] Prockter, L. M., and 12 colleagues 2010. Evidence for Young Volcanism on Mercury from the Third MESSENGER Flyby. Science 329, 668. [3] Kerber, L., Head, J. W., Blewett, D. T., Solomon, S. C., Wilson, L., Murchie, S. L., Robinson, M. S., Denevi, B. W., Domingue, D. L. 2011. The global distribution of pyroclastic deposits on Mercury: The view from MES- SENGER flybys 1-3. Planetary and Space Science 59, 1895-1909. [4] McClintock, W. E., Lankton, M. R. 2007. The Mercury Atmospheric and Surface Composition Spectrometer for the MESSENGER Mission. Space Science Reviews 131, 481-521. [5] Goudge, T. A., and 19 colleagues 2014. Global inventory and characterization of pyroclastic deposits on Mercury: New insights into pyroclastic activity from MESSENGER orbital data. Journal of Geophysical Research (Planets) 119, 635-658. [6] Benkhoff, J., van Casteren, J., Hayakawa, H., Fujimoto, M., Laakso, H., Novara, M., Ferri, P., Middleton, H. R., Ziethe, R. 2010. BepiColombo Comprehensive exploration of Mercury: Mission overview and science goals. Planetary and Space Science 58, 2-20. [7] Flamini, E., and 37 colleagues 2010. SIMBIO-SYS: The spectrometer and imagers integrated observatory system for the BepiColombo planetary orbiter. Planetary and Space Science 58, 125-143. [8] Solomon, S. C., McNutt, R. L., Gold, R. E., Domingue, D. L. 2007. MESSENGER Mission Overview. Space Science Reviews 131, 3-39.

2) Mercury's Calcium Exosphere in the MESSENGER Era

Matthew H. Burger, Rosemary M. Killen, William E. McClintock, Aimee W. Merkel, Ronald J. Vervack, Jr., Timothy A. Cassidy, Menelaos Sarantos

The Ultraviolet and Visible Spectrometer (UVVS) on MESSENGER made near-daily observations of calcium in Mercury's exosphere. These observations revealed a persistent, energetic source of calcium located on the dawn hemisphere. The source shows a strong seasonal variation with little year-to-year variability, with the peak source rate occurring shortly after perihelion. Killen and Hahn (2015) showed that the Ca source rate is consistent with Mercury's passage through the interplanetary dust disk assuming the presence of a cometary dust stream (possibly associated with Comet Encke) intersecting Mercury's orbit near a true anomaly of 25º. The source mechanism may therefore be the dissociation of Ca-bearing molecules produced in impact vaporization plumes. We have also found times when our nominal dawn-centered model fails to fit some of the data suggesting the presence of additional sporadic sources of exospheric calcium.

3) The Global Cessation of Effusive Volcanism on Mercury

Paul K. Byrne, Lillian R. Ostrach, Brett W. Denevi, Clark R. Chapman, Caleb I. Fassett, Jennifer L. Whitten, Christian Klimczak, Erwan Mazarico, Steven A. Hauck, II, James W. Head, and Sean C. Solomon.

The MESSENGER spacecraft has returned a variety of observations of Mercury’s smooth plains, the majority of which are volcanic in origin. The largest such deposits are located in the northern hemisphere and include the extensive northern plains (NP) and the Caloris basin interior and exterior plains (with the latter likely including basin ejecta material). Crater size–frequency analyses have shown both the NP and the Caloris interior deposits to have been emplaced, within statistical error, around 3.8 Ga, on the basis of any of the published crater production models for Mercury. The areal density of impact craters (for a given range of crater diameters) for other smooth plains deposits on Mercury (e.g., the volcanic deposits within the Rembrandt basin) are comparable to that for the NP and Caloris plains, implying that these additional deposits are of a similar age.

To test whether this age marked the end of a period of globally distributed volcanic resurfacing on Mercury, we determined crater size–frequency distributions for six additional volcanic smooth plains units, primarily in the planet’s southern hemisphere. We calculated crater density for each site in terms of $N(10)$, the number of craters $\geq$10 km in diameter per 10^6 km^2. This approach has the benefit of allowing direct comparison of disparate sites without the use of a particular model chronology or production function. The collective range of $N(10)$ values we found for these six sites ($N(10) = 39$–161) is within the span of previously reported values for other volcanic smooth plains on Mercury, and substantially lower than the range found for several intercrater plains units. Importantly, although a small deposit in Rachmaninoff basin may be as young as 1 Ga, we have yet to identify widespread (e.g., $>1 \times 10^5$ km^2) effusive volcanic deposits anywhere on Mercury with resolvably lower $N(10)$ values than those we determined.

The Caloris, Rembrandt, Beethoven, and Tolstoj interior plains are clearly hosted by antecedent impact structures, as are many smaller deposits across the planet, at least some of which are volcanic. This collocation of many of the youngest effusive volcanic units on Mercury with impact structures is consistent with predictions for a planet undergoing contraction from secular cooling of the interior. Global contraction induced a state of net horizontal compression in Mercury’s lithosphere, inhibiting the vertical ascent and eruption of magma. However, the impact process would not only have deposited impact heat at depth, but would have removed overburden, heavily fractured the lithosphere, and relieved accumulated compressive stresses locally—making impact structures prime sites for late-stage eruptions in a tectonic regime otherwise generally unfavorable to extrusive activity. If the rate of magma production after the onset of global contraction remained unchanged, the ratio of intrusive to extrusive material may be greater for the innermost planet than for bodies with longer histories of effusive volcanism. Future observations returned by the BepiColombo mission may help determine the extent to which Mercury’s crust is composed of igneous intrusions, especially in the southern hemisphere.

4) Water Ice on Mercury: Exploring the South Polar Region

Nancy L. Chabot, John K. Harmon, Carolyn M. Ernst, Brett W. Denevi, David T. Blewett, Scott L. Murchie, and James W. Head

More than two decades ago, Earth-based radar observations first revealed that portions of Mercury's polar regions have high radar backscatter and circular polarization ratios, characteristics interpreted to be indicative of water ice deposits located within areas of permanent shadow [1-4]. Since insertion into orbit about Mercury in 2011, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has acquired abundant additional evidence that Mercury's north polar region hosts water ice and other frozen volatiles. MESSENGER's visible imaging campaigns [5] and illumination modeling [6] identified regions of permanent shadow near Mercury's north pole, thermal models indicated that temperatures could sustain surface and near-surface water ice [7], and neutron spectrometry measurements detected enhanced hydrogen in Mercury's north polar region at levels appropriate for water ice as the primary constituent of polar deposits [8]. Additionally, passive visible and active near-infrared measurements revealed high- and low-reflectance surfaces on the polar deposits [9, 10]. The high-reflectance values are consistent with the presence of surficial water ice, whereas the low-reflectance surfaces have been interpreted to be lag deposits of organic-rich volatile material several tens of centimeters thick that cover and insulate the water ice. MESSENGER's highly eccentric orbit had a minimum altitude of ~200–500 km over Mercury's north polar region for most of the mission, enabling measurements by the Mercury Laser Altimeter (MLA) [9] and the Neutron Spectrometer (NS) [8], as well as imaging by the Mercury Dual Imaging System (MDIS) of the surfaces within permanently shadowed craters [10]. In contrast, MESSENGER's initial orbit had a maximum altitude of ~15,200 km over
Mercury's south polar region for the first year of the mission, and the maximum altitude was lowered to ~10,000 km in April 2012. This high altitude did not enable similar measurements by MESSENGER for Mercury's south polar region. Earth-based radar observations [4] nonetheless show evidence consistent with water ice in Mercury's south polar region, and MDIS imaging has identified extensive regions of permanent shadow [11], including within the 180-km-diameter crater Chao Meng-Fu, the largest crater on the planet to host extensive radar-bright deposits.

In this presentation, we will review MESSENGER's measurements of Mercury's north polar region and present MDIS imaging and Earth-based radar results obtained for Mercury's south polar region, all of which provide valuable data to guide BepiColombo in the first in-depth exploration of Mercury's south polar deposits.

[1] Slade M. A. et al. (1992) *Science, 258*, 635–640.
[2] Harmon J. K. and Slade M. A. (1992) *Science, 258*, 640–643.
[3] Butler B. J. et al. (1993) *JGR, 98*, 15003–15023.
[4] Harmon J. K. et al. (2011) *Icarus, 211*, 37–50.
[5] Chabot N. L. et al. (2013) *JGR, 118*, 26–36.
[6] Mazarico E. et al. (2014) *LPS, 45*, abstract 1867.
[7] Paige D. A. et al. (2013) *Science, 339*, 300–303.
[8] Lawrence D. J. et al. (2013) *Science, 339*, 292–296.
[9] Neumann G. A. et al. (2013) *Science, 339*, 296–300.
[10] Chabot N. L. et al. (2014) *Geology, 42*, 1051–1054.
[11] Chabot N. L. et al. (2012) *GRL, 39*, L09204, doi:10.1029/2012GL051526.

5) Mantle sources and melting conditions for basalts on Mercury

B. Charlier[1,2], O. Namur[2]

[1]Department of Geology, University of Liege, Belgium
[2]Institute für Mineralogie, Leibniz Universität Hannover, Germany

Chemical measurements of Mercury's surface by MESSENGER have been used to distinguish several geochemical provinces[1]. Here we present intermediate- to high-pressure and high-temperature phase equilibria obtained experimentally on two compositions relevant to Mercury's surface: (1) the Northern Volcanic Plains (NVP; Mg/Si=0.25) and (2) the Intercrater Plains and Heavily Cratered Terrains (IcP-HCT; Mg/Si = 0.70). We use high-temperature, medium- to high-pressure experimental data to infer the multiple saturation point (MSP) of surface lavas, i.e. the pressure and temperature of melt generation in the mantle based on the co-saturation of forsterite (*Fo*) and enstatite (*Ens*) as liquidus phases. Considering the relatively high sulfur concentration in Mercury's lavas, we performed experiments on sulfur-free and sulfur-saturated starting compositions. We ran experiments for 4-8 hours at 1310-1650°C in piston-cylinder (> 0.7 GPa) and in internally-heated pressure vessel (< 0.7 GPa). For the sulfur-free NVP composition, experiments constrain the position of the MSP at ca. 1.2 GPa and 1430°C. For the IcP-HCT composition, the MSP is located at 1.8 GPa and 1550°C. The presence of sulfur in starting compositions changes significantly the conditions of the MSP (NVP: 0.75 GPa, 1370°C; IcP-HCT: 0.75 GPa, 1450°C) due to the depression of the liquidus in the presence of volatiles and complexing of Mg and S in the silicate melt[2]. Experimental results together with published data in the CMAS system are also used to calibrate predictions by the pMELTS algorithm in order to infer melting conditions necessary to produce any composition at the surface of Mercury, that range from 0.5 GPa at 1300°C to 2.2GPa at 1550°C. Probability histograms show that in most cases, melting occurred at 1-1.25 GPa. Although surface lavas have most probably been produced by melting of contrasted mantle sources, the present-day residual mantle is made up of forsterite and enstatite.

References: [1]Weider et al. (2015) EPSL 416: 109-120; [2]Parman et al. (2015) LPSC: 2345.

6) MERTIS calibration campaign for performance characterization.

Mario D'Amore[1], Alessandro Maturilli[1], Jorn Helbert[1],
Ferrari Sabrina[1], Harald Hiesinger[2]

1 Institute for Planetary Research, DLR, Rutherfordstrasse 2, Berlin, Germany;
2 Westfälische Wilhelms-Universität, Institut für Planetologie, Münster, Germany.

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. The mission is scheduled for launch in 2017 with arrival at Mercury in 2024. MERTIS combines a push-broom grating thermal infrared spectrometer with a thermal infrared radiometer that share the same optics, instrument electronics, and in-flight calibration components and span wavelength ranges of 7–14 and 7–40 μm, respectively. Among its scientific goals, MERTIS will infer rock-forming minerals, map surface composition, and study surface temperature variations on Mercury with an uncooled microbolometer detector. To achieve these goals the instrument maps the surface of Mercury with a spatial resolution of 500m for the spectrometer channel and 2km for the radiometer channel.
To exploit the full potential of the unique MERTIS dataset, an extensive calibration campaign has been performed at the DLR. This includes radiometric, spectral, and geometrical calibrations. In addition we have performed in the Planetary Emissivity Laboratory (PEL) of DLR measurement of analog and reference materials at temperatures from room temperature up to 500°C – slightly higher than the peak daytime temperature expected at Mercury. Measurements have been performed with both the MERTIS Qualification (QM) and Flight (FM) Model. The QM will be upgraded to be a spare of the FM and will stay in the PEL for future reference and characterization.
These measurements obtained at PEL allow evaluating the MERTIS performance in direct comparison with the laboratory spectrometer. The samples comprises: chondrites, bytownite, komatiite, olivines, quartz, tektites, iron blast furnace slag (our inert reference material) and a mixture of bytownite, anorthite and tektite. Our samples span the grain size range from < 20 to 1000 micron in size, to assess the instrument performance over the whole range of expected surface granularity. The instrument was tested on each sample using all observation modes planned for Mercury. The goal was simulating real observations at Mercury in different phases of Bepi Colombo mission at Mercury.

7) Geologically supervised classification of Rembrandt basin and Caloris basin on Mercury: from MESSENGER to BepiColombo.

D'Incecco, Helbert, D'Amore, Ferrari, Maturilli, Head, Hiesinger

[1]Institute for Planetary Research, DLR, Berlin Germany

The MESSENGER mission with its MDIS and MASCS instruments opened a new path of scientific observations of geologic and spectral properties of the shallow crust of Mercury. This path will be soon continued by BepiColombo, which will provide an even more detailed analysis with its SIMBIO-SYS and MERTIS instruments.

Using the same geologically supervised procedure already used for previous studies (1-3), we analyzed the spectral properties of Rembrandt and Caloris basins. On the basis of the new MDIS-based map of smooth plains (4), we defined the following units for Caloris and Rembrandt basin, respectively: a) internal smooth plains, within the rim of the two basins, b) external smooth plains, from the external smooth plains out to 1 R distance from the rim crest of the two basins, c) non-smooth plains deposits out to 1 R distance from the rim of the two basins. Moreover, we also analyzed the Odin Formation (4) and we finally compared the characteristics of these units with those of the External Reference Area (era) unit (1,2) which represents intercrater plains. From the DLR MASCS database (5), we selected all spectra covering these units, calculating: a) spectral slope in the 350-450 nm range and in the 450-650 nm range, from spectra normalized at 700 nm wavelength (5) and b) absolute average reflectance in the 700-750 nm range with a 40°-50° range of incidence angle.

Preliminary results show that the Caloris basin internal smooth plains are characterized by distinctive spectra. While all units display comparable values of absolute average 700-750 nm reflectance (with 40°-50° i.a.), the spectral slope of Caloris basin internal smooth plains is characterized by the lowest values of spectral slope in both the 350-450 nm and 450-650 nm ranges. All other units, in contrast, are spectrally closer to intercrater plains (era unit). These first results confirm the key role played by Caloris basin as a marker horizon for global stratigraphy.

The identification of the exact mineralogy behind the spectral heterogeneities observed by the MDIS and MASCS instruments will be the main target of MERTIS and SIMBIO-SYS. Besides the important results achieved by the MESSENGER mission, its dataset can be used a basis for planning and preparation for the BepiColombo mission. The Planetary Emissivity Laboratory (PEL) at DLR is currently testing Dataset Fusion Techniques (DFTs) in order optimize the use of the future BepiColombo dataset.

[1] D'Incecco, P., et al. 2015, Submitted to Planet. and Space Science.
[2] D'Incecco, P., et al. 2015, EGU 2014, abstract 51-45.
[3] Helbert, J., et al. 2013, Lun. Plan. Sci. Conf. 44, abstract 1496.
[4] Denevi, B. W., et al. 2013, J. Geophys. Res. Planets, 118, 891–907.
[5] D'Amore, M., et al. 2013, Lun. Plan. Sci. Conf., abstract 1900.

Sabrina Ferrari[1], Alessandro Maturilli[1], Mario D'Amore[1], Jörn Helbert[1]
Cristian Carli[2], Fabrizio Nestola[3], Harald Hiesinger[4]

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8) A Study of Thermal Expansion on the Predicted Mercury Surface Minerals: Preparing for MERTIS on BepiColombo

Sabrina Ferrari[1], Alessandro Maturilli[1], Mario D'Amore[1], Jörn Helbert[1]
Cristian Carli[2], Fabrizio Nestola[3], Harald Hiesinger[4]

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The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission unveiled that most of the detectable surface of Mercury is constituted by low-Fe and Mg-rich basalts [1,2], dismissing the previously assumed widespread presence of more felsic materials - as on the Moon's surface. In this background, the BepiColombo mission will be fundamental to reveal the residual igneous crust of the Mercury surface, in order to assess its petrogenesis.
The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) on BepiColombo will be able to provide thermal infrared (TIR) emissivity spectra from 7 to 14 μm. This wavelength range is very useful to identify the structural properties of several silicates, and the position of the emissivity bands provides hints on the solid solutions. In addition to space-weathering degradation and impact-induced structural modifications, the thermal expansion driven by the daily temperature variation of the surface of Mercury significantly affects the crystal structure and density of the present minerals and, consequently, their thermal infrared spectral signature. This behaviour has been recently demonstrated for several common terrestrial mineralogical phases [3,4,5], and could be even predicted for other silicates. A more difficult interpretation of the spectra arises, of course, from the simultaneous presence of different minerals, each one with its characteristic thermal expansion coefficient.
In addition to the temperature-dependent spectral variations of single constituents (e.g. plagioclases, olivine, pyroxenes), the DLR Planetary Emissivity Laboratory (PEL) is measuring emissivity spectra of linear mixtures that most likely could be present on the surface of Mercury. To this aim, spectra of binary compositions (e.g., anorthosite, gabbro) and their single-phase components are measured along the MERTIS wavelength range in vacuum from low to high-temperatures - up to 450°C.

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9) High-resolution measurements of Mercury’s surface composition with the MESSENGER X-Ray Spectrometer

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By measuring solar-induced X-ray fluorescence (XRF) from the top ~100 μm of Mercury’s surface, MESSENGER’s X-Ray Spectrometer (XRS) can record the abundances of the key rock-forming elements Mg, Al, Si, S, Ca, Ti, and Fe. Analysis of the first orbital XRS measurements revealed a surface that is rich in Mg and S but depleted in Al, Ca, and Fe relative to typical terrestrial and lunar crustal materials [1]. XRS maps constructed with several years of orbital data [2], together with maps of neutron absorption [3,4], revealed the presence of several distinct geochemical terranes, although their boundaries do not always correspond to those identified from geological mapping or spectral reflectance. The published XRS data record extends through December 2013 and includes global coverage of Mg/Si and Al/Si as well as partial maps of other major elements [2].

More recent observations include those from MESSENGER’s low-altitude campaign, which has allowed for measurements with cross-track footprints as small as a few kilometers. Our updated, higherresolution maps not only confirm the existence of the previously identified geochemical terranes but also reveal heterogeneities within them for the first time [5]. Additionally, the new data represent a ~40% increase in coverage of the S/Si, Ca/Si, and Fe/Si maps, including several Fe/Si measurements within the large (>5×106 km2) and enigmatic high-Mg region (HMR). The HMR has the highest Mg/Si, S/Si, and Ca/Si seen on Mercury; now, the new maps show that it also hosts the planet’s highest surface concentration of Fe, ~2–3 wt%. This elevated Fe is consistent with the high levels of fast neutron absorption also detected there [3]. The origin of the HMR is unclear, but one possible explanation is that it is the remnant of an extremely ancient, highly degraded impact basin that excavated Mg-rich mantle material [2].

Our updated maps have unveiled small-scale chemical heterogeneities within the geochemical terranes that were unresolved or poorly resolved with the previous data. For example, the HMR hosts a small area on its eastern side that is low in Mg and high in Al relative to the rest of the terrane. Comparison with geological maps shows that the anomaly coincides spatially with an unnamed crater that is ~150 km in diameter. The new maps also show chemical variations within Caloris basin. The interior smooth plains within the basin on average have low Mg/Si and high Al/Si relative to mean planet values, but there are areas within those plains higher in Mg and lower in Al that align with craters that excavated low-reflectance material (LRM) from the subsurface. Similarly, the previous XRS maps were unable to resolve substructure within the relatively young peak-ring Rachmaninoff basin, which has higher Mg/Si than its surroundings. Our new measurements show that its bright interior smooth plains are consistent with lower Mg/Si than the rest of the basin floor but that an area of high Mg/Si does not match the distribution of LRM along the basin edges.

The low-altitude campaign has allowed for the highest-resolution geochemical maps of Mercury to date, revealing features on geological scales that were previously too small to resolve with the XRS dataset. Although the MESSENGER mission will soon come to an end, much work remains to provide geological explanations for Mercury’s geochemical trends.

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10) The gravity field of Mercury after the MESSENGER mission

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April 2015 is the last month of the extraordinary journey of the MESSENGER mission to the planet Mercury. The primary mission started on 18 March 2011 from a 12-h near-polar orbit with its periapsis at 200 km altitude and 60°N latitude. The periapsis drifted north and increased up to 500 km because of the gravitational perturbation of the Sun. Several orbitcorrection maneuvers (OCM) were needed to lower the minimum altitude to 200 km. X-band tracking data collected by the NASA Deep Space Network (DSN) during the first year allowed the determination of the gravity field of Mercury up to degree and order 20 (HgM002). This gravity field led to refinements in the internal structure model of the planet (*Smith et al.,* 2012*; Genova et al..* 2013).
In March 2012, the mission orbital phase was extended for a second year (XM1), and the spacecraft transitioned to an ~8-h orbit period one month later. A second extended mission started in March 2013 (XM2) for a third year without any orbital corrections. The periapsis was allowed to decrease from 440 km to 250 km and drift from 83°N to 75°N. *Mazarico et al*. (2014) analyzed the additional data from XM1 and XM2, before the marked decrease of the periapsis altitude below 200 km, to determine the gravity field of Mercury up to degree and order 50 (HgM005), the tidal Love number $k2$, the orientation of the pole, and the ephemeris of the planet.
A low-altitude campaign began in March 2014 for the last 12 months of the mission. The spacecraft has collected radio tracking data at unprecedented low altitudes in Mercury's northern hemisphere. The remaining fuel onboard the spacecraft enabled the navigation team to keep the periapsis altitude in a range of 5–50 km for the last 40 days. The DSN tracked the spacecraft during periapsis passages from April to October 2014, when the spacecraft periapsis altitude was between 25 and 100 km. In the last six months of the mission, the closest approaches of MESSENGER were occulted by Mercury and were thus not visible from Earth. However, additional radio tracking data have been collected at altitudes (50–100 km) that are still substantially below the initial periapsis altitude.
The new low-altitude radio tracking data have enabled the determination of an updated model of the gravity field of Mercury to degree and order 100. With these data, the resolution of the field in the northern hemisphere has been improved, revealing features that were previously undetectable and that correlate well with topography. The zonal harmonics are in good agreement with those of previous models of the gravity field. We also included the determination of tides, orientation, and ephemeris of the planet in our analysis.

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11) INDUCTION BALANCE AT THE MAGNETOPAUSE OF MERCURY
D. Heyner

The location of the magnetopause separating the magnetosphere from interplanetary space is usually controlled by a pressure balance between the magnetic pressure inside and the thermal pressure of the shocked solar wind outside this boundary. As a result of magnetic reconnection some of the dayside magnetospheric flux is eroded to the nightside of the planet. In consequence, the magnetopause is moved towards the planet taking along the magnetopause currents. Thus, the external field from the magnetosphere that the planet experiences is intensified. Electromagnetic induction within the planetary interior acts against this external field amplification by increasing the effective planetary dipole moment. This pushes the magnetopause outwards again. Here, we estimate to which extent the induced magnetic fields compensate the flux erosion by reconnection.

12) Direct measurement of interplanetary dust influx on Mercury — An origin of sodium exosphere and space weathering of Mercury
Takayuki HIRAI, Ph.D.

"Block3 Exosphrere"

Abstract:
The dust environment around Mercury consists of various dust components; interplanetary dust originated from comets and asteroids, interstellar dust coming from out of the solar system, β(Beta)-meteoroids blown away from the sun, and ejected or levitated fragments from the Mercury's surface. Among these dust components, influx of interplanetary dust is thought to have significant effect on the Mercury's surface environment: 1) production of Na exosphere of Mercury and 2) promotion of space weathering on Mercury's surface. However, the lack of direct measurement of dust distribution around Mercury has restricted understanding of such dust influence on the Mercury's surface environment. The Mercury Dust Monitor onboard the Mercury Magnetospheric Orbiter of BepiColombo mission will provide the world's first information about the dust population around Mercury. In this presentation, we will review the effect of interplanetary dust influx on the Mercury's surface environment and how to distinguish it among the various dust components.

13) Mercury’s Hollows: Morphology and Spectral and Elemental Variations

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Mercury’s hollows are a class of unusual features with higher reflectance (“brighter”) and lower spectral slope from visible to near-infrared wavelengths (“bluer” in color) than planetary average. These features are usually small, rounded, rimless, irregularly shaped depressions with steep sides and flat floors, and are mostly found in and around impact craters. Many have bright interiors and halos. They are found across the planet singly, in small clusters, and coalesced in large numbers in some locales. Formation of hollows appears to involve loss of a volatile-bearing material, followed by collapse and enlargement by scarp retreat.

We have explored the spectral, morphological, and elemental characteristics of hollows formations across Mercury to determine whether observed differences in spectral reflectance at ultraviolet (UV) to near-infrared (NIR) wavelengths as measured by the Visible and Infrared Spectrograph (VIRS) on MESSENGER’s Mercury Atmospheric and Surface Composition Spectrometer are genetic or associative in nature. All hollows examined appear to have origins or close associations with the low-reflectance material (LRM) color unit on Mercury, and approximately half are near pyroclastic materials and vents. Areas of LRM have high (0.71 and higher) UV ratio (UVr, the ratio of reflectance at 310 nm to reflectance at 390 nm). Hollows proximate to LRM have similar UVr but usually substantially higher brightness and higher visible–near-infrared ratio (VISr, the ratio of reflectance at 415 nm to reflectance at 750 nm) than the nearby LRM. Conversely, pyroclastic materials have low UVr (0.65 and lower), and hollows proximate to pyroclastic materials tend to have similarly low or even lower UVr, while being brighter and higher in VISr than the nearby pyroclastic materials. The geographic associations and spectral differences between hollows near LRM and those near pyroclastic materials could suggest two distinct source materials for hollows.

Hollows locations correlate somewhat with regions of higher than average concentrations of Mg, S, and Ca, with one or two notable exceptions where MESSENGER‘s X-Ray Spectrometer has its highest spatial resolutions. The weak global correlation adds support for the hypothesis that hollows are the product of loss of a volatile compound if that compound involves sulfur.

In areas with both pyroclastic features and hollows, no hollows are seen where pyroclastic deposits are thickest. In regions with a pyroclastic deposit, hollows preferentially form on scarps at which the material underlying the pyroclastic deposit is likely to be exposed. Where pyroclastic deposits are thin, hollows display similar development and morphology to those in regions that lack pyroclastic deposits. The morphological evidence does not appear to support two different modes of hollow formation. Instead, the hypothesis that the background surface is dominating the signature of hollow-related deposits within the VIRS footprint at sites with an “LRM” or “pyroclastic” signature appears to better explain this evidence.

The UVr values of the freshest-appearing hollows tend to be slightly lower than those of their background materials in both LRM and pyroclastic regions. This result might indicate one or both of the following: (1) hollows expose fresher versions of the surrounding background material, or (2) the spectral character of the freshest hollows is dominated by material that remains after loss of the volatile-bearing phase, and this lag material has a low UVr value.

14) INSIGHTS FROM MESSENGER INTO THE CRUSTAL STRUCTURE OF MERCURY'S GEOCHEMICAL TERRANES

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We use topography returned by the Mercury Laser Altimeter and gravity recovered from the Radio Science (RS) experiment on the MESSENGER spacecraft to calculate ratios and correlations of gravity and topography in Mercury's northern hemisphere. These calculated quantities yield insights into the compensation mechanisms associated with topography on Mercury. We also use gravity and topography fields to solve for the distribution of crustal thickness via single-layered and two-layered inversions. On the basis of these several models of crustal thickness, at least two geochemical terranes are broadly correlated with thinner-than-average crust: the inner Caloris plains and the so-called "high Mg region." The former terrane is notable for its relatively low Mg and high Al content detected by MESSENGER's X-Ray Spectrometer whereas the latter terrane has anomalously high Fe in addition to high Mg and low Al, suggesting a mafic to ultra-mafic surface composition. Uncertainties in the low-degree shape and geoid of Mercury add uncertainty to these inferred crustal thicknesses, and we use clone fields to place bounds on relative crustal thickness in these two terranes.

15) Mercury's Magnetic Field: MESSENGER observations and BepiColombo opportunities

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Mercury is the only inner solar system body other than Earth to possess an active core dynamo- driven magnetic field, and it hosts the smallest and most dynamic magnetosphere.
Measurements made by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft have provided a wealth of data on Mercury's magnetic field environment. Mercury's weak magnetic field was discovered 40 years ago by the Mariner 10 spacecraft, but the geometry, strength, and origin of the field could not be definitively established, in part because the large-scale structure of the magnetosphere was not well characterized. MESSENGER data have enabled the geometry of the magnetopause and magnetotail current sheets to be established, allowing the development of magnetospheric models, and have shown that the main contribution to the internal field is that generated by a core dynamo. The core field can be described as an offset axisymmetric dipole field; the magnetic equator lies ~0.2 *R*M (where *R*M is Mercury's radius, or 2440 km) north of the geographic equator and the dipole moment is 0.03% that of Earth's. This description of the core field, together with the average magnetopause and magnetotail fields, accounts for approximately 90% of the observed magnetic field inside the magnetosphere, and most of the remaining signal is attributable to sources of external origin. The largest external field sources include field-aligned currents that flow from high altitudes to the planetary surface and close within the planet, and diamagnetic depressions of the field due to local plasma pressures. These external sources cannot be represented using conventional potential solutions so analyses of the internal field structure even at the longest wavelengths (spherical harmonic degree and order 2 and above) must carefully discriminate against local plasmas and Birkeland currents. Re-analysis of the Mariner 10 observations has established that there has been no measurable secular variation in the internal field over 40 years. The power spectra for the core field and its secular variation versus spherical harmonic degree provide critical constraints for dynamo models. Induced core fields result from time-varying magnetopause fields, and their magnitude confirms the core radius estimated from the planet's mean density and moments of inertia. Night-side magnetic field measurements at altitudes below 100 km have revealed shorter wavelength fields, not seen at higher altitudes. These fields are inferred to result from magnetization of rocks at crustal or possibly upper mantle depths and suggest that a global magnetic field driven by dynamo processes in the fluid outer core operated early (at ~3.7–3.9 Ga) in Mercury's history. Ancient field strengths that range from those similar to Mercury's

present dipole field to Earth-like values are consistent with the magnetic field observations and with the low iron content of Mercury's crust inferred from MESSENGER elemental composition data.
BepiColombo observations will provide opportunities for advancing our understanding of Mercury's magnetic field in several ways. Southern hemisphere observations will provide information on the core field in a region not sampled by MESSENGER, and the more homogeneous data distribution will greatly facilitate global modeling of the long-wavelength internal field. Although the time interval between MESSENGER and BepiColombo observations is substantially less than that between MESSENGER and Mariner 10 data, the global mapping of the internal field afforded by BepiColombo will allow a more complete examination of upper bounds on secular variation in the dynamo field. The acquisition of simultaneous measurements of fields inside the magnetosphere and in the solar wind will be critical to future studies of induced fields, and in particular will allow the electrical conductivity structure of Mercury's mantle to be examined. Finally, improved characterization of lithospheric magnetic fields could be made if it is possible to acquire low-altitude observations at latitudes south of ~30°N.

16) The impact of a near-zero obliquity on the evolution of Mercury

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Abstract: The obliquity of Mercury is extremely small. As MESSENGER observations revealed, this would have an impact on current surface processes, such as preserving volatiles in permanently shadowed areas near poles [e.g., Lawrence et al., 2013]. The distribution of sodium may also be controlled by thermal conditions [Peplowski et al., 2014]. A smaller intensity of solar radiation near poles may also have impact on the evolution of the interior. Because the mantle of Mercury is very thin, temperature deep in the mantle may depend on latitude, leading to a latitudinal dependence of heat flux at the core-mantle boundary. Such a heat flux is an important ingredient for sustaining the north-south asymmetry of the magnetosphere [Hao et al., 2013]. Thus, investigations of north-south symmetry and asymmetry using MESSENGER and Bepi-Colombo data are crucial to understand the current state and evolution of the interior, surface, and environment of Mercury. In this presentation, we review MESSENGER results related to this topic and discuss future plans for studies combining data from these missions.

17) Seasonal variability of Mercury's sodium and interplanetary dust distribution

S. Kameda, T. Yasuda, and M. Kagitani –

Interplanetary dust distribution near Mercury remains unclear mainly because it is difficult to observe zodiacal light from inner solar system. Meanwhile, Mercury has a thin and unstable atmosphere and its source process is also unclear though many observations have been done for more than 20 years. In past studies, the observed atmospheric sodium density seems to have no correlation with the solar flux, heliocentric distance, etc. Mercury's atmospheric density is higher than averaged when Mercury is close to the ecliptic plane, and vice versa. Assuming that the interplanetary dust should be concentrated around the ecliptic plane, it is suggested that Mercury's atmosphere is thin when the dust and meteoroid flux is low. Therefore, we can know the distribution of the interplanetary dust by observing the emission from Mercury's atmosphere. We conducted ground-based observation in August and October 2008. In this presentation, we reported the results of our observat ions and discuss our hypothesis. In summary, from the result of our daytime observation, the variability in sodium density was less than 5%, which suggests that solar wind sputtering was not the dominant source process. Our result also shows a correlation between ecliptic altitude and the observed sodium density.

We are planning to observe Mercury's sodium exosphere before and after the MESSENGER's impact to Mercury. In this presentation, we will also show a preliminary result of the observation.

18) Mercury's Exosphere: Lessons Learned from MESSENGER and Follow-On Possibilities for BepiColombo

Rosemary Killen, MESSENGER MASCS Team

MESSENGER observations of Mercury's exosphere revealed a number of surprisingly persistent seasonal patterns in the exosphere. We discovered a large persistent dawn-centered Ca exosphere of extreme temperature, an enhanced Ca exosphere near 20° true anomaly angle (possibly related to the orbit of Comet 2P/Encke), a hot but much cooler Mg exosphere, and a warm Na exosphere with a seasonal pattern in the dawn/dusk ratio. We surmise that metal species in the exosphere may be correlated with the passage of dust from Comet Encke. A surprise is the lack of significant emission from atomic oxygen, most likely due in part to its very small g-value in the UV. We also found lower levels of atomic H emission than reported by the Mariner 10 UVVS. Because they were outside the wavelength range of the MASCS instrument, emission from the noble gases He, Ne, and Ar, all important cosmochemically, was not observed. Possibly due to the abnormally weak solar cycle, we observed little evidence for a solar wind influence on the exosphere. Important follow-on observations by Bepi-Colombo will be discussed.

19) The tectonics of Mercury: Information from MESSENGER imaging and topography

Christian Klimczak and the MESSENGER geology discipline group

Tectonics played a major role in Mercury’s geological history, and MESSENGER’s Mercury Dual Imaging System (MDIS) and Mercury Laser Altimeter (MLA) instruments have provided a multitude of observational constraints for understanding and reconstructing that history. Not only did tectonic processes markedly modify Mercury’s surface by forming thousands of major landforms, they also influenced the geologic settings in which volcanic resurfacing took place. Photogeologic and topographic observations show that the character of Mercury’s tectonics is dominated by brittle deformation on global, regional, and local scales, with a variety of landforms on Mercury’s surface pointing to faulting as the predominant style of deformation. Thrust-fault-related scarps are the most widespread tectonic landforms on the planet and range from a few to several hundred kilometers in length; some examples have accumulated relief of up to several kilometers. This widespread thrust faulting has been primarily the result of global contraction in response to cooling of the planet’s interior. Recent estimates of the strain accommodated by thrust faults globally are consistent with a decrease in planetary radius since the end of heavy bombardment of at least 5–7 km. In contrast, some volcanically flooded craters in the northern plains and plains within the Rembrandt and Caloris impact basins host normal-fault-related landforms, or graben. These graben display a progressive increase in geometric complexity with increasing crater size. Smaller volcanically infilled craters host graben populations with no preferred orientations, whereas the Caloris interior plains host discrete sets of graben with strongly basin-radial, -concentric, and mixed orientations. Yet another form of lithospheric deformation on Mercury seen with topographic data are long-wavelength topographic undulations. These undulations are marked by impact craters with flat floors that tilt away from the long-wavelength topographic highs. Such long-wavelength undulations are particularly well resolved in and around the Caloris basin. Here, systematic crater floor tilts define harmonic undulations with wavelengths up to 1200 km and amplitudes of 1–2 km. Cross-cutting relationships of tilted craters with fault-related landforms indicate that the undulations postdate the formation of many tectonic structures within and around Caloris. Future stereo imaging and laser altimeter measurements by the BepiColombo mission will improve our understanding of Mercury’s tectonic geomorphology and will help characterize the deformational history of the planet’s southern hemisphere as comprehensively as MESSENGER has done for the northern hemisphere.

20) Mercury's exosphere: from MESSENGER to Bepi-Colombo

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MESSENGER observations of Mercury's exosphere highlighted many features of its Na component that could not be identified from ground based observatories. In another way, ground based observations can provide direct much larger view of Mercury's exosphere and therefore should complete MASCS observations. Comparing simultaneous observations by both observatories might therefore lead to the most complete instantaneous view, ever obtained so far, of Mercury's Na exosphere. It might also provide an interesting view on the way ground based observations have been interpreted so far. In this presentation, we will present a first comparison between MESSENGER MASCS Na observations and THEMIS telescope observations.

21) A Study of the Low-Latitude Boundary Layer on Mercury

Elisabet Liljeblad, James Slavin, Jim Raines, Tomas Karlsson, Torbjörn Sundberg, Anita Kullen

The low-latitude boundary layer is a region where a constant transfer of mass and energy takes place. The layer has been studied extensively on Earth, but so far no comprehensive study on the layer on Mercury exists. This study aims for a systematic analysis on Mercury magnetopause crossings during year 2011 to identify and analyse the LLBL and its properties, including thickness, plasma parameters, interplanetary magnetic field (IMF) dependence and reconnection rates. The main goal is to determine plausible LLBL formation processes on Mercury, and to establish whether or not the Kelvin-Helmholtz instability (KHI) is involved in this process. Results so far show a clear dawn-dusk asymmetry in both occurrence and thickness, and indicate the KHI to be insignificant for the LLBL formation. Moreover, the LLBL appear to occur more often for low magnetic field shear and low reconnection rates, indicating also that local large scale reconnection near the subsolar point during southward IMF is an unimportant factor in the LLBL formation process.

22) Localized electron induced X-ray fluorescence on the nightside surface of Mercury and its implications for magnetospheric structure

S.T. Lindsay, E.J. Bunce and A. Martindale (Department of Physics & Astronomy, University of Leicester)

X-ray signals from the nightside surface of Mercury, have previously been described by Starr et al. (2012). We expand upon this data set to produce a catalogue which currently covers the first three years of the MESSENGER mission.
We find that the surface footprints of XRS during these events when mapped onto the surface of Mercury are closely clustered in local time, with the largest number of events observed at around 02:00 local time. The edges of the distribution of events do not extend past 00:00 and 06:00 local time, although the latter limit may be may be an artefact of our criteria for event selection, which precludes us from seeing partially lit events, and hence cannot extend past 06:00. Furthermore, we find that the events are separated into two clear latitudinal bands approximately symmetric about the magnetic equator, centred at ~50°N and ~20°S respectively.
We propose that these fluorescence events are caused by the interaction of particles, which are travelling along Mercury's magnetic field lines, with the surface. We postulate that these particles may be accelerated along the nightside magnetic field lines by reconnection events in the tail and thus precipitate to the surface of the planet. We frequently observe fluorescent events at the same geographic area during subsequent orbits (i.e. 12 or 8 hours apart depending on the phase of the mission), suggesting that the duration of the physical mechanism producing the precipitating fluxes can be many hours, which is long in relation to characteristic times of the Mercury magnetospheric environment (see, for example, the observation of magnetic substorms of 2-3 minutes duration by Slavin et al. (2010)). Our filter identifies these events by surface fluorescence in the Ca-Kα line, implying that the energy of at least some of these particles must exceed 4 keV.

23) Orbit simulations for BepiColombo using MESSENGER- based high-order Mercury gravity field data

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1. Introduction

We developed a tool to simulate the orbital motion of the BepiColombo spacecraft, scheduled for arrival at Mercury in 2023. The mission will consist of two spacecraft, the MPO (Mercury Planetary Orbiter, ESA) and the MMO (Mercury Magnetospheric Orbiter, JAXA). We simulate the orbital evolution of MPO, considering perturbing forces for a period of 2 years following arrival. This study was undertaken to support operational planning for the on-board mapping instruments, especially BELA (BepiColombo Laser Altimeter), currently being developed by DLR/UBE.
The knowledge of the evolution of the two orbits for the BepiColombo Mission is important, because active orbit- and attitude corrections are not possible after orbit insertion. Also due to the harsh thermal radiation from Mercury, which has implications on the thermal design of the spacecraft, the evolution of the periherm is of particular importance.
The results base on the ones represented at the EPSC 2012 with the following improvements:

- Usage of the actually Mercury Gravity Field (50 x 50, Messenger)
- New MPO Orbit Parameters
- Influence of reflected Sun-light
- New calculated coverage

1.1. Orbit Perturbations

Perturbing forces acting on the Keplerian MPO and MMO orbits include Mercury's non-spherical mass distribution, the gravitational force of other planets, and the Sun as well as radiation pressure from direct sunlight and sunlight reflected from Mercury (Fig. 1). Because of the perturbing accelerations, semi-major axis, eccentricity, inclination, ascending node, argument of pericenter, show complex variations. The program simulates the evolution of all these elements over a period of 2 years. The software was programmed using SPICE subroutines.

1.2. Numerical Integration

Starting from initial values for the state vector (i.e., position and velocity) or a set of orbital elements at time t0 given in [2], we obtain the spacecraft trajectory with an accuracy of the order of 1 m by choosing a step-size of 50 s [1]. The results of the numerical calculation were verified against the results of an independent BepiColombo orbit simulation by ESOC [2] and showed very good agreement.

1.3. Gravity Field Coefficients

With MESSENGER now being in science operations since April 2011, new Mercury gravity field parameters have become available [5]. In particular, coefficients are available for a spherical harmonics model of order and degree of 50. Previous orbit predictions had to be done using crude gravity field data obtained by MARINER 10 or during the early MESSENGER Mercury flybys [3], [5] assuming wide error margins for the gravity field coefficients.

1.4. Results (Examples)

Fig. 1 shows the accelerations in detail for the MPO. As expected, the gravity field terms of Mercury cause significant perturbing accelerations. Perturbations by other planets are small. The J3 term mainly influences the spacecraft altitude at pericenter. The altitude decreases from 400 km at the beginning of the science mission to about 250 km. This would be an advantage for BELA (lower altitude: higher signal levels) but a disadvantage for the MPO in terms of increased thermal radiation from the Mercury. J3 reflects an asymmetry between the northern an southern hemisphere in the gravity field of Mercury. Therefore, the longitude of pericenter is important because the effect of J3 decreases with increasing distance from Mercury. Shifting the argument of pericenter from the nominal initial value to lower values reduces the decrease of pericenter altitude significantly [Fig. 2].

2 Figures

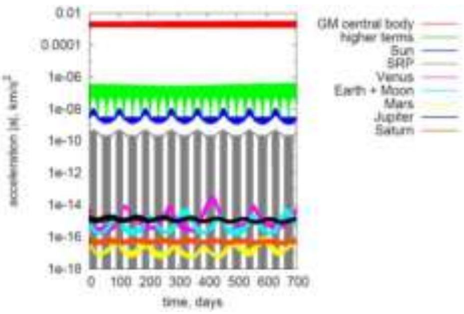

Figure 1: Accelerations acting on the MPO.

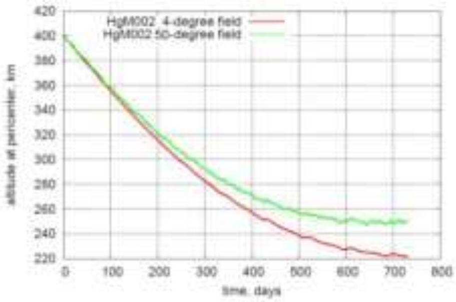

Figure 2: Pericenter altitudes of MPO.

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24) Mercury Surface in the Planetary Emissivity Laboratory (PEL): Preparing for MERTIS on BepiColombo

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MERTIS (MErcury Radiometer and Thermal Infrared Spectrometer) is one of the scientific payloads of the ESA deep space mission BepiColombo. MERTIS is an imaging spectrometer obtaining hyper-spectral data in the thermal IR (TIR) wavelength range (7-14 µm) with a medium spatial resolution to determine the mineralogical composition of the Mercury’s surface. Sharing the same optical path a pushbroom micro-radiometer is integrated allowing measurements of the Mercury surface temperature and obtaining the thermal inertia of the regolith.
MERTIS will measure the thermal radiation emitted from the hot Mercury surface, and by means of internal calibration target measurements, those data will be calibrated to surface emissivity spectra. The interpretation of surface emissivity spectra can be successfully carried out only with the support of a wide database of emissivity measurements on analogue materials. At the Planetary Emission Laboratory (PEL) of DLR we measure emissivity of powdered or bulk materials in vacuum, at typical Mercury diurnal temperature [1, 2]. The Bruker VERTEX 80V Fourier Transform Infrared-Spectrometer (FTIR) can be operated under vacuum to remove atmospheric features from the spectra. An external evacuable chamber is used to measure emissivity: it contains a motor-driven carousel

for up to 12 samples in the same working session, thermal sensors for each sample and a webcam for monitoring the activities inside the chamber. Induction heating system allows heating up the samples (in stainless steel cups) from 50°C to higher than 800°C. Bruker A513 accessory is used to obtain bi-conical reflectance with variable incidence angle i and emission angle e between 13° and 85° at room temperature, under purge or vacuum conditions, in the 1 to 100 µm spectral range [3]. A Bruker IFS 88 FTIR spectrometer is operated with a Harrick SeagullTM variable-angle reflection accessory to measure bi-conical reflectance at room temperature, under purging conditions in the extended spectral range from 0.4 to 55 µm, for incidence=emission angles from 5° to 85° [3].
Reflectance measurements in the TIR wavelength range are used for comparison (mostly on band positions) with emissivity spectra under Mercury conditions. Reflectance spectra of thermally processed Mercury analogues in the visible and near infrared region [3] have been used for the interpretation of spectra collected from MASCS spectrometer on NASA MESSENGER mission [4].

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25) Exploring Mercury's Surface-bound Exosphere from Orbit: Observations by the Mercury Atmospheric and Surface Composition Spectrometer aboard the MESSENGER Spacecraft

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The Mercury Atmospheric and Surface Composition Spectrometer (MASCS), aboard the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, began routine orbital observations of Mercury's dayside and nightside exosphere on March 29, 2011. Over slightly more than four Earth-years, MASCS measured exospheric emission from calcium (Ca), sodium (Na), and magnesium (Mg) at a daily cadence. These species exhibit different spatial distributions, suggesting distinct source processes. Ca dayside observations generally exhibit a single high-temperature component (>50,000 K) with a strong equatorial, dawn enhancement. Mg has a weaker dawn–dusk asymmetry and a somewhat lower temperature (4000–5000 K). Na exhibits two temperature components, one in the range 1200–1500 K and a second, more energetic component with an unconstrained temperature. MASCS observations show no evidence for thermal accommodation of these species to Mercury's surface temperature. MASCS observed seasonal variations in all three species that are remarkably repeatable from one Mercury year to the next, and did so consistently during the entire 17-Mercury-year duration of the orbital phase of the mission. Whereas MASCS has characterized the seasonal variation of the exosphere, it has provided, at best, only weak evidence for episodic behavior, which is observed in ground-based studies of Na and is widely attributed to plasma precipitation onto the surface. So far, attempts to correlate intensity fluctuations in MASCS data with changes in precipitation patterns inferred from observations by the Magnetometer, X-Ray Spectrometer, and Fast Imaging Plasma Spectrometer aboard MESSENGER have not yielded satisfactory results. This lack of correlation may be due in part to the MASCS observational geometries, which limit its view of the magnetic field cusp regions. MASCS has conducted a number of searches for other, weakly emitting species. Hydrogen data from the orbital phase are consistent with profiles observed during MESSENGER's flybys of Mercury. Oxygen detections have proved elusive, and the previously reported observation with a brightness of 4 R may only be an upper limit. The analysis of weak species data is ongoing and suggests that additional species are present.

26) Mercury's disappearing dayside magnetosphere events (MESSENGER): Evidence for severe dayside erosion and/or compression?

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During northward passes over Mercury's dayside hemisphere, the MESSENGER spacecraft normally enters the dayside magnetosphere before it descends to below ~ 500 km altitude. However, for some of these dayside passes the dayside magnetosphere is completely absent in the magnetometer (MAG) and Fast Imaging Plasma Spectrometer (FIPS) observations. During these "disappearing" dayside magnetosphere passes the MESSENGER measurements indicate that the spacecraft passed directly from the magnetosheath into the northern magnetospheric cusp and, finally, the high latitude nightside magnetosphere. Likely causes of these unusual events are severe reconnection-driven erosion and/or solar wind compression of the dayside magnetosphere, to the point where the closed field line dayside magnetosphere lies equatorward and/or below the orbit of MESSENGER. Case studies of such events in the MESSENGER data are presented. The hypothesis that these events are produced by extreme dayside magnetosphere reconnection and/or solar wind compression is tested using ENLIL predictions of solar wind conditions at Mercury's orbit and analysis of the MESSENGER measurements in the cusp and magnetotail.

27) Mercury Orbiter Radio Science Experiment (MORE):global full-cycle numerical simulation

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The Mercury Orbiter Radio science Experiment (MORE) is one of the ESA BepiColombo mission experiments, devised to improve our understanding of both planetary geophysics and fundamental physics. The Mercury Planetary Orbiter (MPO) spacecraft will be equipped with full instrumentation able to perform very precise range and range-rate tracking from the Earth, on-board accelerometry and accurate angular observations by an optical on-board camera. This will give the chance to determine with very high accuracy the spacecraft orbit around Mercury, allowing to achieve the following scienti_c goals: (1) to measure the global gravity _eld of Mercury and its temporal variations due to tides (gravimetry experiment), (2) to measure the rotation state of the planet, in particular the obliquity and the librations in longitude with respect to the 3:2 spin orbit resonance (rotation experiment), (3) to measure the orbit of Mercury and the propagation of radio waves between Earth and Mercury to test the theory of General Relativity, constraining possible alternative theories of gravitation and providing an improved dynamical model for the Solar System (relativity experiment).
The Celestial Mechanics Group of the University of Pisa developed a MORE dedicated software, orbit14, under an Italian Space Agency contract. The software is composed by two parts: a simulator, which creates observations and preliminary orbital elements, and the corrector, which determines the parameters of interest for the radio science experiment by a global least squares _t.
We present, for the _rst time, a full-cycle numerical simulation of the three experiments of MORE together, solving for all the parameters of interest in a global least squares _t. A
constrained multi-arc strategy is applied, and the list of solve for parameters in the gravimetry and rotation experiments includes: the harmonic coe_cients of Mercury gravity _eld up to degree 25, the Love number k2, the obliquity and the amplitude of the libration in longitude. With the global gravity _eld and the rotation state it is possible to constrain the internal structure of the planet, determining if the core is decoupled from the solid mantle or not.
As regards the test of General Relativity, we adopt a Parametrized Post Newtonian (PPN) formalism, solving for the well known PPN parameters , _, _, _1, _2 and for some other physical parameters as _, J2_, GM_, assuming a metric theory of gravitation. In this context, considering that the post Newtonian parameter appears both in the equations of motion of Mercury and the Earth, and in the equations for radio waves propagation through the Shapiro e_ect, we

can devise a superior conjunction experiment (SCE) during cruise phase. Such an experiment has been simulated with a recently developed JPL code: we present the results, showing that an accuracy in signi_cantly better than the state-of-the-art can be achieved. This result has been introduced in the orbit14 simulations as an a priori constraint on , useful to improve the determination of the other Post Newtonian parameters.
To perform a realistic scenario for the simulations, we include the detrimental e_ects in the parameters estimation due to accelerometer measurement errors, adopting the updated error model provided by the Italian Spring Accelerometer (ISA) team, the desaturation maneuvers and systematic errors in the range measurements. Finally, we include in simulations also the optical observables, as they will be performed by the on-board High Resolution Imaging Camera (HRIC, part of the on-board instrument SYMBIO-SYS) and we discuss the possibility of improving the knowledge of the rotation state and the orbit determination combining tracking data with optical observations.

28) Mercury Sodium Atmosphere Spectral Imager (MSASI) onboard BepiColombo/MMO

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Abstract:
Mercury's exospheric sodium has been most investigated in exospheric species to understand the dynamics and source process of surface-bounded exosphere because its emission is enough bright to be detected by a ground-based telescope. Since its discovery, a lot of ground-based observations have been done for more than two decades, and MESSENGER succeeded in its orbit insertion in 2011. However, the source process of sodium is yet to be clarified.
The Mercury Sodium Atmosphere Spectral Imager (MSASI) on the Mercury Magnetosphere Orbiter (MMO) of the BepiColombo mission is a high-dispersion visible spectrometer working in the spectral region near the sodium D2 emission (589 nm), a major constituent of the Mercury exosphere. A single high-resolution Fabry–Perot etalon is used in combination with a narrow-band interference filter to achieve a compact and efficient instrument design. The spectral resolution is 7 pm and it enables us to distinguish the sodium emission line from bright surface reflection of Mercury and to observe dayside exosphere. Full-disk images of the planet are obtained by means of a single-axis scanning mirror in combination with the spin of the MMO spacecraft. The temporal resolution is 2 msec, which enables to achieve the spatial resolution of 1.25 km. To achieve high temporal resolution, a high speed CMOS image sensor and an image intensifier are used in the detector unit.
We have already finished all the performance and environmental tests. In this presentation, we report the overview, the science objectives, the instrumentations, and final status of the development of MSASI.

29) Measurements of surface reflectance and roughnesss on Mercury with the Mercury Laser Altimeter

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In the course of the extraordinary 50 months that the MESSENGER spacecraft has been in orbit around the planet Mercury, the Mercury Laser Altimeter (MLA) (*Cavanaugh et al.*, 2007) collected more than 30 million range measurements from altitudes of more than 1500 km to less than 10 km above the surface. These ranges have provided an accurate topographic map of the northern hemisphere and especially detailed topography of polar craters suggested by Earth-based radar images to host frozen volatiles. During the Mercury orbit years 2–3 (March

2012–March 2014), the periapsis altitude of MESSENGER's orbit was sufficiently high for a campaign of off-nadir passes through the north polar region, during which multiple profiles ranged through 42 permanently shadowed craters greater than 8 km in diameter and poleward of 84°N latitude. Topography of these hidden regions enabled thermal models (*Paige et al.,* 2013) and illumination studies (*Mazarico et al.,* 2014). The targeted craters were suggested by radar to contain frozen volatiles. Where range and incidence angle permitted, a dual-threshold measurement of the return pulse waveform was obtained, and direct measurements were made of the zero-phase surface reflectance at 1064-nm wavelength (*Sun and Neumann,* 2015). The MLA reflectance measurements revealed areas of anomalously high reflectance within some crater interiors (*Neumann et al.,* 2013), interpreted to be surface exposures of water ice deposits. A dark, insulating blanket of unknown but volatile material was observed where modeled temperatures preclude long-lived ice at the surface. These measurements were corroborated by scattered-light imaging at visible wavelengths by the Mercury Dual Imaging System (*Chabot et al.,* 2014). The BepiColombo laser altimeter will provide further clues as to the origin and age of these formations.

The MLA timing information allows modeling of the pulse centroid time and the area and spread of the returned waveforms. The standard deviation of the pulse arises from the convolution of the laser pulse, the system impulse response, and the effect of terrain dispersion due to incidence and surface roughness (e.g., Neumann et al., 2003) at the 10–100 m scale of the laser footprint, finer than obtainable from the along-track roughness (e.g., *Kreslavsky et al.,* 2014).

During the last 9 months of the mission a series of low-altitude campaigns was conducted, during which MLA performed at 20 times closer than its design range. The MLA was able to cope with extremely low altitudes through the use of programmable detector amplifier gain and threshold settings, providing further insight into instrument calibration and measurement of surface properties. Maintaining smooth operation has been important for navigation and orbit determination during the final descent of MESSENGER.

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30) A long-term all-sky imager observation of lunar sodium tail

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The Moon possesses long tail of neutral sodium atoms that are emitted from the lunar surface and transported anti-sunward by the solar radiation pressure. Since the earth crosses the lunar sodium tail for a few days around the new moon, the resonant light emission from sodium atoms can be detected from the ground. Although it has been reported that bright emissions from sodium atoms of the tail is observed during the Leonids meteor shower, only few events without meteor shower have been investigated so far. Here we show a long-term (over 15 years) observation of the lunar sodium tail using all-sky imager at Shigaraki Observatory (35N, 136E), Japan. We have surveyed our database of all-sky sodium images at a wavelength of 589.3 nm to find that a bright spot emerges around the anti-lunar point for a few days around the new moon. Although the sodium spot is the brightest during the Leonids meteor shower, a weaker sodium spot is detected in the period without meteor shower as well. The

sodium spot gradually moves eastward (roughly, 0.2 hours a day), which shows that the sodium tail is strongly affected by the earth's gravity. We will present the latest results of our data analysis to discuss signatures of the lunar sodium tail as well as the origin of the lunar sodium exosphere.

31) MERCURY REFERENCE FRAME and TOPOGRAPHIC BASE MAP from Combined MESSENGER Stereo Photogrammetry AND Laser Altimetry

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We have computed digital terrain models (DTMs) for Mercury from MESSENGER stereo images following previously established procedures that involve image correlation and least-squares block adjustment techniques. We produced 165 individual small-area models (222 m grid spacing), which in total cover approximately 50% of the planet's northern hemisphere. To correct for offsets and tilts with respect to the Mercury reference frame, we co-registered the DTMs to laser altimeter profiles. However, because the individual laser altimeter profiles were taken at different times, we have carried out a joint inversion in which we solved simultaneously for Mercury rotation parameters as well as the static transformation parameters for each of the 165 DTMs. The corrected DTMs in the northern hemisphere, tied to the laser altimeter data, and the new rotation model represent a valuable realization of the reference grid for mapping applications at Mercury.

32) The Mercury Global Mapping Project

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Caleb I. Fassett, Jennifer L. Whitten, Rebecca J. Thomas,
and the MESSENGER Mapping Group

Geological mapping is an established tool for understanding the global and regional history of planetary bodies. We are undertaking the geological mapping of Mercury from MESSENGER image data, at the 1:10 million scale.

Regional and landform-specific global geological mapping of Mercury from MESSENGER images has already yielded valuable science results, elucidating the history and distribution of several major feature types and units. Such maps include those of regional plains (e.g., Denevi et al., 2009, 2013; Whitten et al., 2014), impact structures (e.g., Fassett et al., 2012), tectonic structures (e.g., Byrne et al., 2014), and pyroclastic vents (e.g., Goudge et al., 2014). On the regional scale, mapping of the Victoria quadrangle on Mercury has been completed (Galuzzi et al., 2014), and additional quadrangles will be mapped by BepiColombo team members over the next few years (D. Rothery, personal communication, 2014).

Despite, or perhaps because of, these multiple regional mapping efforts, there are compelling reasons to produce a single geological map of the entire surface of Mercury in the near term. One major rationale for this effort is to establish a set of standardized unit descriptions and nomenclature, so that future higher-resolution efforts by different mappers will be consistent and broadly interpretable by the scientific community. In addition, a global map will ensure that spatial and temporal relations among different surface units, and between geological units and tectonic structures, for example, can be made both regionally and across the planet, helping to address several basic questions about Mercury's geological history. Moreover, a global stratigraphic system for Mercury, incorporating

MESSENGER and Mariner 10 observations, can be developed for the first time. Finally, a global map will be a valuable tool for BepiColombo mission planning.

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33) Constraining Mercury's interior structure with geodesy data and its present thermal state

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Recent measurements of Mercury's spin state and gravitational field supplemented by the assumption that the planet's core is made of iron and sulfur give strong constraints on its interior structure. In particular, they allow a precise determination of Mercury's core size and average mantle density. Present geodesy data do, however, almost not constrain the size of the inner core. Interior structure models with a fully molten liquid core as well as models with an inner core almost as large as the core agree with the observations. Additionally, the observed internally generated magnetic field of Mercury does not preclude the absence of an inner core, since remelting of iron snow inside the core could produce a sufficient buoyancy flux to drive magnetic field generation by compositional convection.

Although sulfur is ubiquitously invoked as being the principal candidate light element in terrestrial planet's cores its abundance in the core depends on the redox conditions during planetary formation. Remote sensing data of Mercury's surface by MESSENGER indicate that Mercury formed under reducing conditions. As a consequence, substantial amounts of other light elements like for example silicon and carbon could be present together with sulfur inside Mercury's core. Compared to sulfur, which does almost not partition into solid iron at Mercury's core conditions, silicon partitions almost equally well between solid and liquid iron. Therefore, compared to a pure iron-sulfur core, if silicon is present in the core the density jump at the inner-core outer-core boundary could be smaller and induce a large enough change in the inner-core flattening to alter Mercury's libration amplitude. Moreover, the presence of silicon together with sulfur further reduces the core solidus temperature, potentially delaying the onset of inner core formation. Finally, if both silicon and sulfur are present in sufficient quantities a thin layer much enriched in sulfur and depleted in silicon could form at the top of the core as a consequence of a large immiscibility region in liquid Fe-S-Si at Mercury's core conditions.

The present radius of an inner core depends mainly on Mercury's thermal state and concentration of light elements inside the core. Because of the secular cooling of the planet, at a time in Mercury's evolution the temperature inside the core drops below the core liquidus temperature somewhere in the core, which can lead to the formation of an inner core and to the global contraction of the planet. The amount of contraction depends mainly on the temperature decrease, on the thermal expansion of the materials inside the planet, on the volume of crystallized iron-rich core liquid, and on the volume of crystallized crust.

In this study we use geodesy data (88 day libration amplitude, polar moment of inertia, and tidal Love number), the recent estimate about the radial contraction of Mercury, and thermo-chemical evolution calculations taking into account the formation of the crust, plausible past and present silicate-shell mineralogies, a growing inner core, and modeling the formation of iron-rich snow in the core in order to improve our knowledge about Mercury's inner core radius and thermal state. Since data from remote sensing of Mercury's surface indicate that Mercury formed under reducing conditions we consider models that have sulfur and silicon as light elements inside their core.

34) Topography and Shape of Mercury from the Mercury Laser Altimeter

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After 4 years of acquiring altimeter data over the northern hemisphere of Mercury, our knowledge and interpretation of the shape and topography of the planet has helped our understanding of its basic features and its evolution. Although confined to observations over the northern hemisphere because of the eccentricity of the spacecraft's orbit, the location of its periapsis, and the range limit of the Mercury Laser Altimeter (MLA) of <1800 km, the instrument acquired the first half of a global dataset that will be completed by the laser altimeter on the BepiColombo Mercury Planetary Orbiter. A major contribution of any laser altimeter is an accurate framework of radius measurements that at the longest wavelengths describes the shape of the planet, important to geophysics, and on the smaller scale a grid for the accurate registration of other datasets, including images that can provide detailed structural information often not obtainable with a profiling instrument.

MLA had a nominal range measurement accuracy of about a decimeter. Its measurement frequency of 8 Hz provided a measurement approximately every 400 to 500 m along track. However, the roughness of the surface of Mercury limited the effective radial accuracy of altimetry to about ~10 m, more than adequate for most global studies and for the estimation of surface slopes along track, and adequate for controlling and monitoring the orbital altitude of the spacecraft.

The initial observations, confirmed subsequently, showed a large depression centered near the north pole of about 3 km, considerably larger than expected on the basis of the planet's slow rotation. Occultation measurements suggest a similar, slightly smaller depression near the south pole, but because of the limited number and quality of the occultation measurements, confirmation by the BepiColombo laser altimeter is eagerly awaited. Overall, the dynamic range of topographic relief is nearly 10 km, but the long-wavelength shape variation is about 4 km.

In addition to altimetry, the MLA also measures the reflectance of the surface, a more difficult observation because it requires measurement of the outgoing and received pulse energies. These measurements, although part of the basic design, were very important because they provided confirmation of an increase in brightness of the surface in the permanently shadowed interiors of those polar craters suspected, on the basis of Earth-based radar measurements and thermal models, to host water ice at the surface of polar deposits. These observations often required the off-nadir pointing of the instrument (and spacecraft) and increased the altimetric range to the surface.

The altimeter data have also been successfully used in combination with imaging data to estimate the forced libration of the planet and confirm to first order the radar observations of Mercury's solid-body motions. Although limited to the northern hemisphere, the MLA observations have provided a grid that has been applied to the images so as to increase the global accuracy and resolution of surface features necessary to measure the variation in rotation of Mercury.

Present solutions for the shape, topography, and dynamics of Mercury by MESSENGER are based on the current orbital reconstruction that will be improved when the most recent gravity models and altimetry cross-over data are included. These definitive MESSENGER results will then be available for incorporation into a joint solution with the final BepiColombo data that will provide the best overall global geodetic description of Mercury for the foreseeable future.

35) First MESSENGER ORBITAL Observations of Mercury's Librations

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We have co-registered laser altimeter tracks from three years of near-continuous MESSENGER observations with geometrically rigid stereo terrain models to study rotation parameters for the planet Mercury. In particular, we provide the first observations of Mercury's librations from orbit. Our results are in agreement with those from earlier Earth-based radar measurements. In addition, we refine available estimates and error bounds for the orientation of the spin axis and the mean rotation rate of the planet. We find a libration amplitude, which confirms that Mercury possesses a liquid outer core. The mean rotation rate is observed to be significantly higher than the expected resonant rotation rate. We suggest that Mercury is undergoing long-period librational motion, forced by planetary perturbations of its orbit. On the basis of our new estimates of rotation parameters, we provide updates of interior structural parameters for Mercury.

36) MEASURING MERCURY'S TIDAL DEFORMATION BY LASER ALTIMETRY PERSPECTIVES FOR BELA ONBOARD THE BEPICOLOMBO SPACECRAFT

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We have performed numerical simulations to assess the uncertainty of the h_2 measurement by the BepiColombo Laser Altimeter (BELA). Based on the current orbit scenarios, we determined the number of crossovers available for differential altimetry measurements. The precision of the h_2 measurement is inferred from the expected mean range measurement error and the number of possible crossovers. Our model for the range measurement includes a detailed analysis of the instrument performance by taking into account Mercury's small-scale topography. The model is combined with the current BepiColombo mission scenarios and spacecraft performance design. We will show up to what accuracy BELA will be able to determine h_2 based on different operation scenarios. Implications on Mercury's interior structure, especially on the mantle, will be discussed.

37) Dynamo model explanation for Mercury's unusual magnetic field

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Observations by the MESSENGER spacecraft have shown that Mercury's magnetic field is remarkably different from Earth's with respect to magnitude and morphology. Although it is evident that the global magnetic field is generated by convective motions within the liquid core of Mercury via dynamo mechanisms, the observed magnetic field is extremely unusual to those who are familiar with Earth-type dynamo. Along with the weakness, another peculiar feature of Mercury's field detected by MESSENGER is a large north-south offset of the axial dipole from the planet's center. Now it is a challenge for dynamo modelers whether or not such peculiar features could be reproduced by dynamo modeling. In this presentation, we briefly summarize such efforts and show some new results obtained from our Mercury's dynamo model incorporating thermochemical core convection with core-crystallization scenario.

38) Density and sound velocity of liquid Fe-alloys under high pressure: Implication for Mercury core

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Density and sound velocity of liquid Fe-alloys under high pressure are important physical properties to give constraints on the sizes and compositions of molten outer cores of terrestrial planets, including Mercury. In this study, we have developed simultaneous measurement system of density and compressional wave velocity using multi-anvil apparatus to investigate the effect of light elements on these properties.

High-pressure experiments were performed using 180-ton cubic type press at BL22XU beamline, SPring-8 synchrotron facility. We have installed ultrasonic and imaging systems at this beamline. Used energy of monochromatized X-ray was 35 keV. Density was measured using X-ray absorption method. In this method, X-ray absorption profile from the sample was measured by using two ion chambers. Then, density was deduced by fitting the obtained X-ray absorption profile combined with Beer-Lambert law. Compressional wave velocity (V_P) was measured using pulse-echo over-lapping method. Travel time of the elastic wave in the sample was obtained from a time interval of detected echo signals derived from two sample edges. Sample length was directly obtained from the radiography image. Samples used were Fe-Ni-Si, Fe-Ni-C and Fe-Ni. Graphite cylindrical resistive heater was used to generate temperature. The measurements were performed up to 6 GPa and 2000 K.

Obtained V_P of liquid Fe-Ni is located slightly lower and aligned almost parallel to the V_P curve of liquid Fe as a function of pressure. This suggests that alloying 10 wt% of Ni into liquid Fe slightly decrease the V_P but little influence on the compressibility. On the other hand, it is found that alloying Si slightly increases the V_P of liquid Fe but decreases slightly the compressibility. The effect of light element on elastic properties of liquid Fe depends strongly on the alloying element species, especially at the conditions of small planet interiors. We will provide a clue to constrain the composition of Mercury core based on obtained density-V_P relation.
Keywords: Density, Sound velocity, Fe-alloy, Core, Liquid

39) Mercury's magnetosphere - Bepi Colombo science possibilities

D. Delcourt et al.

Operations of the MESSENGER spacecraft (NASA) that was inserted in orbit around Mercury in March 2011 terminated in April 2015. During this 4 year period, MESSENGER provided us with unprecedented observations of the small-scale hermean magnetosphere, concerning for instance the highly dynamical nature of this environment, the characteristics of the planetary magnetic field or the composition of the magnetospheric plasma. In contrast to the MESSENGER payload that had a limited set of plasma instruments, the forthcoming Bepi Colombo mission (ESA-JAXA) features a comprehensive suite of instruments dedicated to analysis Mercury's ionized environment. We will review a variety of magnetospheric science possibilities offered by Bepi Colombo and how they can extend the knowledge that we acquired from MESSENGER observations.

40) Mercury's low-degree geoid and topography from insolation-driven elastic deformation

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Mercury experiences an uneven insolation that leads to significant latitudinal and longitudinal variations of its

surface temperature. Such variations, which can be expressed in terms of degree-2 and 4 spherical harmonics, propagate at depth imposing a long-wavelength thermal perturbation throughout the mantle. We computed the accompanying density distribution and used it to calculate the mechanical and gravitational response of a 3-D spherical elastic shell. We then compared the resulting surface deformation and geoid at degree 2 and 4 against Mercury's topography and geoid derived from MESSENGER data. For an elastic thickness between 110 and 180 km - mainly dependent on the mantle thermal expansivity and representative of the time at which the pattern of surface temperature developed through the mantle - we obtain a variance reduction of more than 95% for the joint prediction of topography and geoid. The insolation pattern is thus responsible for Mercury's low-degree shape and geoid.

41) Thickness of the crust of Mercury

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The major igneous events that form and shape the crust of a rocky body, such as magma ocean solidification and volcanism, affect the interior thermo-chemical evolution through control on the bulk volatile content, partitioning of heat- producing elements, and heat loss. Therefore, characterizing the crust of a body provides information on that object's origin, differentiation, and subsequent geologic evolution. For Mercury, the crust may hold clues in particular to the still poorly understood processes of formation of this planet. Analysis of geoid-to- topography ratios (GTRs) has been previously applied to infer the thickness of the crust of the Moon, Mars, and Venus. We performed a similar analysis for Mercury with the gravity and altimetry data acquired by the MESSENGER spacecraft. We considered only the northern hemisphere, where the gravity field and topography are well constrained. We assumed that Airy isostasy is the principal mechanism of support of variations in topography, and we therefore excluded from the analysis regions that might not be compatible with this assumption, such as large expanses of smooth plains and large impact basins. For a conservative range of densities of the crust, we inferred a crustal thickness of 35±18 km (one standard deviation). This new mean value is substantially less than earlier estimates that were based on viscous relaxation of topography, on the relation between the low-degree gravity field and equatorial ellipticity, and on the depth of the brittle-ductile transition as constrained by models of thrust faulting and thermal evolution.

We explored three implications of this new inferred value of the crustal thickness. First, this relatively thin crust allows for the possibility of excavation of mantle material during the formation of large impact basins (such as Caloris). Second, the volume of silicate materials present in the crust of Mercury represents about 10% of the total silicate materials in the planet, the largest value among the terrestrial planets. This implies that Mercury had the highest efficiency of crustal production. Finally, by combining the estimate of the crustal thickness with the measured abundances of heat-producing elements on the surface of Mercury, a lower bound can be placed on the amount of heat production in the mantle at a time following the accretion and differentiation of the planet, approximately 4.45 Ga.

The upcoming Bepicolombo mission is expected to provide better gravity, altimetry, and spectrometry data. With these improvements it will be possible to better constrain the crustal thickness, to perform accurate spectral analyses (and infer parameters like crust and mantle densities, and elastic thickness), and to continue the search for mantle material exposed on the surface.

42) Gamma-ray spectroscopy of Mercury surface by the Mercury Gamma-ray and Neutron Spectrometer (MGNS): from MESSENGER to BepiColombo.

A. Kozyrev and MGNS team.

Abstract:
The MGNS instrument was developed in Space Research Institute for detection the fluxes of neutrons and gamma-rays from the Mercury subsurface on-board the Mercury Polar Orbiter of ESA BepiColombo mission. The instrument contains the ^{3}He proportional counters and organic scintillator for detection of neutrons and also gamma-spectrometer with the scintillation crystal for detection of gamma-rays. For the gamma-ray spectroscopy, MGNS will use the innovation $CeBr_3$ crystal, which has been developed for the MGNS instrument at the latest stage of its development. The First Flight unit of MGNS with $LaBr_3$ for gamma-rays detection was replaced recently by the Second Flight unit with new $CeBr_3$ crystal.

Gamma-ray spectroscopy of the Mercury has already been performed by the Gamma-Ray Spectrometer (GRS) with HP Germanium detector onboard the MESSENGER spacecraft. The HP Ge detector is known to have much better energy resolution than any scintillation detector, including the $CeBr_3$ scintillation crystal, but on the other hand Ge needs cooling and it is not such a reliable one, as an $CeBr_3$ scintillation crystal. The GRS on Messenger collected the energy spectra of gamma-rays from the Mercury surface during about an Earth year, the northern hemisphere has been mapped mainly.

We present the results of gamma-ray calibrations measurements of MGNS with $CeBr_3$ crystal, and also comparison between gamma-ray performances of MGNS on BepiColombo and GRS on MESSENGER missions. Finally, we compare the sets of gamma-ray lines for the different models of the Mercury elementary composition, and consider the possibility to test these models based on the MGNS data.

43) Polar volatiles on Moon and Mercury: similarity and difference

I.G.Mitrofanov

Recent data from Messenger together with the earlier Arecibo radar measurements shown that practically all polar shadowed craters on Mercury should contain the valuable masses of water ice deposits. On the hand, data from LEND instrument onboard LRO detected no signatures of water ice for the majority of lunar polar craters with the permanent shadow, except for three southern craters Shoemaker, Cabeus and Haworth.

Possible physical reasons are considered to explain the difference of volatiles distribution at poles of Mercury and Moon. Scientific goals for BeppiColombo MGNS instrument are considered to explain the difference between polar regions of Mercury and Moon.

44) Mercury's interior: New views from MESSENGER

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Mercury, the smallest and densest of the terrestrial planets, has presented a host of mysteries regarding its internal constitution and evolution for more than half a century. MESSENGER observations of the planet's surface chemistry, volcanic and tectonic history, gravity field and rotation state, and magnetic field structure have led to substantial improvements in our understanding of the planet's history and internal structure. Determination of Mercury's low-degree gravity field in combination with the planet's rotation state has provided estimates of the planet's normalized polar moment of inertia as well as the fraction of the polar moment of inertia contributed by the outermost solid layer of the planet. These results indicate that the depth to top of the liquid outer core is only about 400 km, far less than once thought. Observations by MESSENGER's Gamma-Ray Spectrometer have constrained the heat production generated by the radioactive decay of potassium, uranium, and thorium within Mercury, which was one of the largest unknowns in understanding the planet's thermal history. X-Ray Spectrometer results have confirmed the extraordinarily low abundance of iron in surface materials and also revealed large abundances of sulfur. Together these results indicate strongly reducing conditions in Mercury's interior. A consequence of these reducing conditions is that Mercury's core likely hosts silicon, and perhaps sulfur, as its primary alloying elements

with iron. A further constraint on the nature and history of Mercury's interior is derived from the pervasive contractional tectonic features on the planet's surface. Global mapping with MESSENGER images and topography indicates that as much as ~7 km of radial contraction occurred since the late heavy bombardment. This global contraction is the consequence of the integrated internal cooling, including any partial solidification of Mercury's metallic core, over that time interval. MESSENGER observations of Mercury have led to a picture of Mercury's interior that is dominated by an even larger metallic core (and thinner mantle) than once thought, with a highly reduced composition that strongly influences how the planet has cooled, contracted, and generated its magnetic field. A synthesis of observations by the MESSENGER spacecraft not only constrains our knowledge of the internal structure of Mercury, it also yields important implications for the evolution of the planet's interior.

45) Mercury Gravity Field and Rotational State from the BepiColombo Radio Science Experiment

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The Mercury Orbiter Radio science Experiment (MORE) is one of the main instruments on board the BepiColombo Mercury Planetary Orbiter (MPO), designed to provide an accurate estimation of Mercury's gravity field by means of highly stable, multi-frequency radio links in X and Ka band, provided by the Ka band transponder (KaT) and the deep space transponder (DST) on-board the MPO. The state-of-the-art microwave equipment enables simultaneous two-way links in X/X (7.2 GHz uplink/8.4 GHz downlink), X/Ka (7.2/32.5 GHz) and Ka/Ka band (34/32.5 GHz), providing range rate accuracies of 3 micron/s (at 1000 s integration time) at nearly all elongation angles. Range observables accurate to 20 cm (two-way) will be attained using a novel, wideband (24 Mcps) ranging system, based upon a pseudo-noise modulation scheme. The multi-frequency link allows a nearly complete cancellation of the plasma noise both in Doppler and range measurements and hence an accurate determination of Mercury's gravity field and ephemerides with unprecedented accuracy.
The estimation of gravity field coefficients and planetary tidal deformation with the radio science experiment will provide enhanced information for modelling the planet's interior, starting from Messenger achievements. Additional analysis can be carried out in order to verify whether radio science can give a significant contribution in the study of other physical phenomena thanks to its complementarity due to a different orbital geometry with respect to Messenger. Since the strict connection existing between core and rotational state, one of the main purposes of the experiment is the measurement of Mercury's obliquity and libration though the MORE rotation experiment at an accuracy level adequate to derive useful geophysical information.
The orbit determination of deep space spacecraft is generally carried out by means of batch filters, for recovering the trajectory and the model parameters, i.e. gravity field coefficients. The complexity of Mercury's environment strongly penalizes the accuracy of the orbit determination because of the non- gravitational perturbations, such as the solar radiation pressure. For this reason the non-gravitational accelerations of the MPO will be measured by the highly sensitive Italian Spring Accelerometer (ISA).
High resolution images provided by HRIC camera can be used to constrain the orbit determination and therefore the gravity field and the rotational state reconstruction are advantaged: the correlation of surface landmarks extrapolated by two images of the same area taken at different epochs provides their displacement in time and hence represents an observable to be fed into an estimation process.
Crossovers maps generated in the frame of these simulations are also provided as inputs to the analyses employing optical observables.
A full numerical simulation of the radio science experiment was carried out in order to test if the attainable accuracies in the gravity field estimation are compatible with the scientific goals of the mission. This work reports on the results of those numerical simulations, taking into account the new mission profile, the ISA measurements error model and its calibration in the precise orbit determination process. An important outcome has been the identification of the most favorable observational strategy and location of surface landmarks in order to attain accuracies below 1 arcsec in the obliquity and libration amplitude.
The simulations reported in this work provide updated estimate of the uncertainties in the determination of the Mercury's gravity field up to degree and order 25 (with estimation accuracies from 10-11 for un- normalized quadrupole coefficients to 5×10-10 for higher order degrees and terms considered), the tidal Love number k2 (with

an estimation accuracy close to 10-4), the polar moment of inertia of the planet, and also Mercury's obliquity and longitudinal libration.

46) MESSENGER's plasma observations in Mercury's northern magnetospheric cusp

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Abstract
The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft has passed through Mercury's northern magnetospheric cusp on most of the more than 4000 orbits completed since 2011. Plasma and magnetic field observations have shown the cusp to be a key region of coupling among the solar wind, the exosphere, and the surface regolith: (1) Protons have been observed flowing into the cusp and forming a persistent, well-defined loss cone, strengthening predictions that these ions are precipitating onto Mercury's surface. (2) Estimates of the proton precipitation flux have been made with a simple adiabatic model and over a large range of altitudes, latitudes, and Mercury seasons. Spanning more than four orders of magnitude, these fluxes indicate that incident solar wind conditions are the dominant contributor to variations in cusp precipitation. (3) Upwelling low-energy (100–300 eV) Na+-group ions (mass per charge 21-30) are observed within the cusp. These ions appear to be locally energized from surface-sputtered ions or photo-ionized exospheric neutrals. (4) High-energy (>1 keV) Na+-group ions have been shown to be the dominant planetary ion in the cusp, exceeding at times the abundance of even solar wind alpha particles (He2+). In contrast to their low-energy counterparts, these ions appear to have been swept into the cusp from the dayside magnetosphere on newly reconnected field lines. (5) Deep, short-duration depressions in the magnetic field magnitude, called cusp filaments, have been commonly observed within the cusp and contain plasma of magnetosheath energies. These signatures are a measure of the access of plasma through the cusp to the surface and its response to forcing by the solar wind.

47) Mercury Orbiter Radio Science Experiment (MORE): benefits from an extended mission

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The Mercury Orbiter Radio science Experiment (MORE) of the ESA-JAXA BepiColombo mission to Mercury uses state-of-the-art ground and onboard instrumentation enabling a highly stable, multi- frequency radio link at X and Ka band (8.4 and 32.5 GHz). The advanced radio link configuration, based upon the simultaneous transmission and reception of X and Ka band signals, will provide two-way range and range-rate measurements free from plasma noise, with accuracies of 20 cm and 3 micron/s (at 1000 seconds integration time). In addition to the cancellation of the plasma noise, MORE will also greatly benefit from a direct measurement of the vectorial non-gravitational accelerations, carried out by the Italian Spring Accelerometer (ISA).

MORE aims at improving the already outstanding MESSENGER results on the determination of the gravity field of Mercury. In addition, a test of general relativity will be carried out by estimating several Post-Newtonian (PN) parameters.

The nominal duration of the mission around Mercury is one year. The main purpose of this work is to assess the improvements that can be attained from an extended mission of one or two years. We present a new set of simulations, assuming an optimal configuration and solving simultaneously for gravity harmonic coefficients, rotational state elements and relativistic PN parameters.

The main benefits come from the evolution of the orbit. Given the gravity field estimated by MESSENGER, the pericenter of BepiColombo’s planetary orbiter is expected to drift from the initial 15 degree N to 13, 41, 70 degree S respectively in one, two and three years. Simultaneously, the pericenter altitude is expected to decrease from 480 to 250 km in three years. This geometry allows a more detailed reconstruction of the gravity field, mainly in the southern hemisphere of the planet. We also show the benefits of the extended mission for the relativity experiment.

48) MESSENGER Observations of Mercury’s Sodium Exosphere

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The Mercury Atmospheric and Surface Composition Spectrometer (MASCS) UVVS (UltraViolet and Visible Spectrometer) on the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft observed Mercury's sodium exosphere during three flybys and from orbit for 17 Mercury years. What we found, in light of pre-MESSENGER understanding, was both expected and unexpected. Expected results included the dominance of the photon-stimulated desorption source process and the modulation of gravitational escape by photon pressure. Unexpectedly our observations do not seem to capture the episodic changes reported by ground-based observers. We have also not seen evidence of sodium thermalized to Mercury’s surface temperature as predicted by many pre-MESSENGER exospheric models. In my talk I will give an overview of our ongoing analysis of the UVVS sodium observations and our preliminary efforts to reconcile these results with ground-based work.

49) Future observations of Mercury with BepiColombo's Mercury Imaging X-ray Spectrometer (MIXS).

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MIXS will be the first imaging X-ray spectrometer deployed on a planetary science mission when it flies to Mercury on the upcoming ESA/JAXA BepiColombo mission, due for launch in 2016. It will measure the planetary X-ray flux, stimulated by solar X-rays and charged particle interactions with the surface. Its imaging capability and hence, low background make it ideally suited to following up measurements made by the XRS instrument on MESSENGER, which has confirmed the apparent paucity of iron at the surface on global scales and shown Mercury to be a diverse and interesting planet with significant chemical heterogeneity. Intriguingly for MIXS, some of these compositional differences do not seem to correlate with surface morphological units.

MIXS will build on MESSENGER observations by providing both a global view of Mercury's surface composition in both hemispheres and add high spatial resolution measurements, enabling the determination of the composition of small-scale surface features during periods of high solar activity. We will show how this dual focus is inherent in the

MIXS design and will answer fundamental questions about the nature of Mercury's surface and its evolution, as well as allow more detailed characterisation of small-scale features revealed by MESSENGER but not yet understood.

One example of this will be using MIXS-T's high resolution to investigate whether elemental abundances change local to the small-scale geological features which have been observed by MESSENGER's visible imager. For instance, the unexpected 2-5% sulphur abundance revealed by XRS on large scales may be expected to change significantly in certain geological units revealing the underlying processes involved in surface evolution. Specific geologically important targets for MIXS include: identifying the volatile species responsible for the formation of hollows and the spatially associated 'bright crater floor deposits'; the elemental composition of the diffuse 'red' spots centred on explosive volcanic vents; and spatially resolving the edges of the perplexing 'high magnesium region'.

Clearly, MIXS has an important surface-science focus, but the dataset that evolves from MIXS will also allow the study of complex interactions between Mercury's surface, its local environment and the solar wind, via remote sensing of the energetic electrons which precipitate to the surface and cause X-ray emission. These secondary science goals will be described in the context of MESSENGER results.

The instrument development will be described with specific reference to the final performance measured during the on-ground calibration of the flight model and its components. A specific focus will be given to how the characterisation of the instrument effective area, spectral resolution and background will be used to optimise the performance relative to the scientific goals.

MIXS is being developed by a consortium of Institutes and companies in the UK (University of Leicester, The Open University, RAL, Magna Parva), Finland (University of Helsinki, FMI, Patria, SSF, Oxford Instruments, Beneq), Spain (INTA, CAB, Lidax, Crisa), Germany (MPS, MPG-HLL, MPE, PNSensor) and France (PHOTONIS).

50) Photometric Properties of Mercury's Surface at Visible to Near-Infrared Wavelengths

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MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) acquired photometric observations of Mercury at 14 distinct sites across the planet's surface for the purpose of characterizing photometric behavior from visible to near-infrared wavelengths. The objective of these observations was to provide a dataset for photometric standardization, i.e., to derive a photometric correction that could reduce the observations to a standard illumination and viewing geometry. Photometric standardization allows for comparisons across the surface in addition to comparisons with laboratory measurements of candidate mineral components of the surface regolith. Modeling of the photometric data, in addition to providing a method for photometrically standardizing the data set, also allows for comparisons of textural properties (such as roughness and compaction) across Mercury.

The 14 MASCS photometric regions were divided into five distinct geologic units. Each geologic unit was modeled separately. In a first step, spectra from the exposures of a given geologic unit in all photometric regions were grouped together. Each spectrum provided a measure of reflectance at different incidence, emission, and phase angles for that particular geologic unit. In a second step, the spectra from a given geologic unit were compared across photometric regions. The modeling results from the two steps provided a basis for examining the range of variability in photometric properties among geologic units and from photometric region to photometric region.

Each data set is being modeled with two distinct methods that follow similar modeling efforts applied to images from MESSENGER's Mercury Dual Imaging System [1]. The first method invokes the Hapke model [2-8], which is based on geometric optics and the equations of radiative transfer. The second method uses the equations described by Kaasalainen et al. [9] and Shkuratov et al. [10], which have been successfully applied to observations of Vesta [11], the Moon [10], and Mercury's global color mosaic [1].

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51) Can MESSENGER Visible to Near-Infrared Photometric and Spectral Data Inform Predictions about BepiColombo Mid-Infrared Spectral Findings?

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As MESSENGER reaches the completion of its mission at Mercury, BepiColombo is preparing to launch, equipped with a suite of instruments that will expand our knowledge of Mercury's surface composition in several ways. The BepiColombo experiments will benefit from an anticipation of potential results in order to sharpen preparation for the interpretation of surface elemental composition measurements and the identification of candidate surface minerals from spectroscopic observations. This study focuses on predictions for the thermal infrared properties that will be observed by the Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) instrument on the BepiColombo Mercury Planetary Orbiter spacecraft.

The low-reflectance material (LRM) and high-reflectance red plains (HRP) spectral units are considered to be representative of end-member materials in wide abundance across Mercury's surface [1]. Intimate-mixture modeling of spectra obtained by MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) and filter photometry from the Mercury Dual Imaging System (MDIS) wide-angle camera (WAC) provide predictions for the mineral components that can be compared with the observed spectral attributes at visible to near-infrared wavelengths. The mineral assemblages inferred from spectral characteristics measured by MASCS and MDIS can be used to predict the thermal infrared properties that will be observed by MERTIS.

At the Planetary Emission Laboratory (PEL) at the Deutsches Zentrum für Luft- und Raumfahrt (DLR) the spectral properties of candidate materials are being measured as a function of temperature at visible to thermal infrared wavelengths [2, 3, 4]. These laboratory measurements are being used to inform the modeling of the MESSENGER observations and to predict the observations to be acquired by the MERTIS instrument [5].

We propose that the combinations of materials and their relative abundances identified by spectral mixing models matching the MESENGER MASCS and MDIS data could serve as guides to combinations of laboratory terrestrial materials to be studied in the PEL for predicting Mercury's surface properties in the thermal infrared. Beginning with the LRM and HRP, and progressing to such units as the hollows, the models can guide the combinations of minerals to be studied and measured, thus providing a sense of what could be observed by BepiColombo.

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52) Modeling Mercury's magnetospheric magnetic field: Past, present, and future

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Knowledge of Mercury's magnetospheric magnetic field is required to understand the sources of the planet's internal field and has evolved considerably since the first Mercury flyby by Mariner 10 in 1974. Because of the sparseness of the Mariner 10 observations, early models of Mercury's magnetospheric magnetic field were either Earth-like models scaled in size to account for Mercury's smaller planetary magnetic moment or developed specifically for the innermost planet with simplified assumptions for the geometry of the magnetospheric cavity. Detailed modeling of Mercury's magnetospheric magnetic field was enabled by the insertion of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft into orbit about the innermost planet on 18 March 2011. Between March 2011 and April 2015, nearly continuous magnetic field data have been acquired by MESSENGER's Magnetometer, and observations over multiple Mercury years have yielded repeated coverage in planetary longitude and local time. The new data set enabled the development of magnetospheric models with increased accuracy. The first such model featured an internal magnetic field represented by a dipole of magnitude 190 nT RM3 aligned with the planet's spin axis and offset by 479 km northward from the planet center, along with external fields resulting from currents flowing on the magnetopause boundary and in the cross-tail current sheet. The analytical formalism of this model confined the magnetospheric field within a magnetopause prescribed by a paraboloid of revolution. The increased spatial sampling of the magnetospheric cavity and its boundaries achieved over the course of the orbital phase of the MESSENGER mission allowed determination of the observed average magnetopause location. The most recent KT14 model uses this shape to confine the magnetospheric field and replaces the cross-tail current sheet of constant thickness by currents having a disk shape near the planet and extending into a Harris sheet at larger distances to ensure continuity of the field at the current sheet inner edge. The new model yields improvements over the previously developed paraboloid model in regions that are close to the magnetopause and the nightside magnetic equatorial plane. Magnetic-field residuals remain that are distributed systematically over large areas and vary monotonically with magnetic activity. The history and present state of knowledge of Mercury's magnetospheric magnetic field
provide a basis to consider future improvements enabled by additional current systems and future magnetic field observations from the BepiColombo mission. The anticipated primary advantage of the BepiColombo mission will be the ability to observe the magnetic field simultaneously in the solar wind and the magnetosphere to enable parameterization of the model by magnitude and direction of the interplanetary magnetic field. The additional spatial sampling in the magnetosphere and, especially, in the southern hemisphere near the planet are expected to further benefit future magnetic field modeling efforts.

53) Geologic mapping of Mercury in preparation for BepiColombo

David A Rothery (Open University) & Matteo Massironi (U Padova)

Planetary geological maps provide context for all kinds of data concerning surface characteristics and possible subsurface structure. Based on Mariner-10 imaging, 1:5M geological maps of 9 out of 15 Mercury quadrangles (or partial quadrangles) were published by the USGS. The whole planet has now been imaged by MESSENGER, which has also provided topographic and compositional data, especially for the northern hemisphere.
It is now possible and appropriate to make a new series of geological maps covering the whole planet. The Victoria quadrangle has already been remapped by Galluzzi et al., and the MESSENGER mapping group is proposing a 1:10M global geological map (Prockter et al., this meeting). Production of a comprehensive set of quadrangle maps to a uniform standard should now be begun by the community – meaning essentially the BepiColombo Surface & Composition Working Group and the MESSENGER mapping group.
It will be important to agree conventions. For example should we adhere to smooth plains and intercrater plains as before? How many age-classes of craters should be distinguished? Should we attempt to distinguish compositional and/or spectral differences among the plains units (high-reflectance red plains, low reflectance blue plains, etc)? How should we proceed with newly identified features such as hollows and pits (volcanic vents)? How should we record geochemical anomalies such as the high-Mg region, which bears no obvious relationship to any

photogeological unit? To what extent should we attempt to interpret tectonic features, rather than merely record them?
Many of these issues can be resolved by producing a mulitlayered digital map (in GIS), but nevertheless it makes sense to agree a common approach.

54) MESSENGER-based targets for high-resolution compositional analysis by BepiColombo

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During its orbital mission MESSENGER provided a wealth of image data that has greatly enhanced our understanding of the planet’s geology. However, limited spatial resolution, especially in the southern hemisphere, and limitations of the capabilities of its spectral instruments have made compositional analysis challenging. The issue of resolution was partially alleviated during MESSENGER’s terminal low-altitude campaign, which provided data hinting at a compositional complexity in some places surprisingly uncorrelated with the observed photogeological units [1]. These results, along with MESSENGER image data, provide a vital basis for selecting potentially fruitful targets for BepiColombo’s higher-resolution instruments.

A key goal of BepiColombo is to provide data with which we can better understand the discovery that Mercury has an unexpectedly high surface abundance of relatively volatile elements [2, 3]. The nature and source of these volatiles, and of magmas containing them, have important implications for models of Mercury’s formation and evolution, and for planet-formation models in general. Geologically, the presence of surface and subsurface volatiles is most clearly demonstrated by the formation of the rimless depressions known as ‘hollows’ and putative pyroclastic deposits. However, the resolution of MESSENGER X-Ray, ultra-violet and visible spectrometry has frustrated efforts to conduct meaningful compositional analyses of the deposits associated with these landforms and their variation over space and time [4, 5]. We use our comprehensive MESSENGER-derived global catalogues of hollows [6] and pyroclastic deposits [7] to identify sites and regions where the low-latitude periapsis (Fig. 1), higher spatial resolution, and unique capabilities of spectrographic instruments on BepiColombo can potentially answer important questions about the nature, distribution and temporal variability of volatiles and volatile-rich magmas within and on the surface of Mercury. These targets are a valuable input for planning the BepiColombo observation campaign.

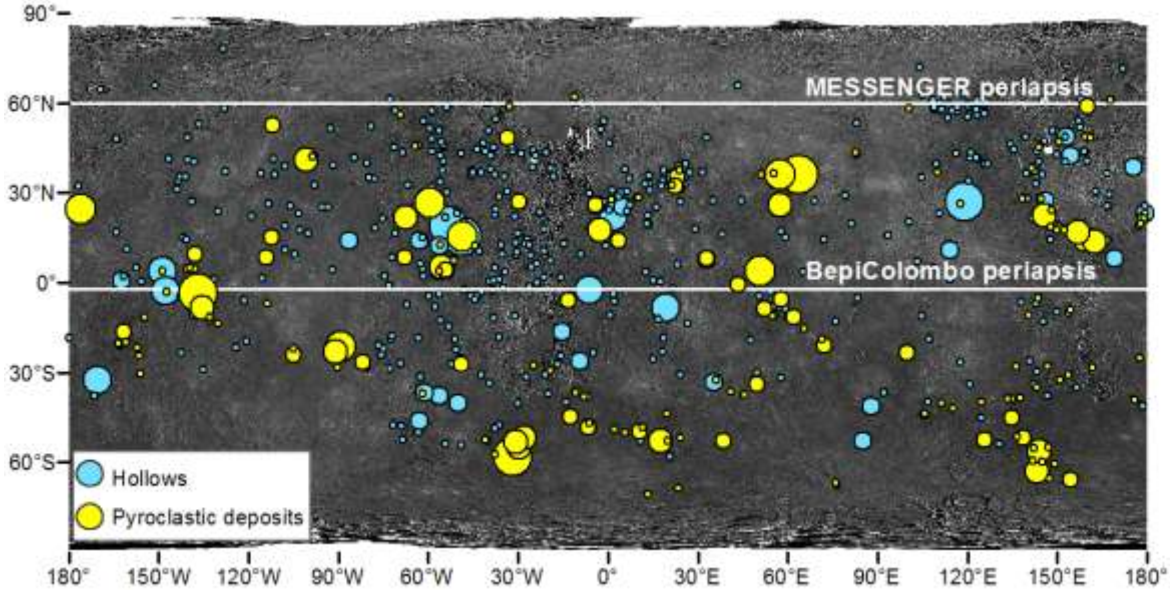

Figure 1. Global distribution of hollows and pyroclastic deposits in relation to spacecraft periapsis at the beginning of their orbital campaigns. Hollows and pyroclastic deposits: circles scaled by areal extent.

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55) Studying the surface of Mercury with BepiColombo

Jörn Helbert, DLR

The payload of the ESA-JAXA mission BepiColombo had been proposed long before the NASA MESSENGER mission provided us with new insights into the innermost of the terrestrial planets. The discoveries of the MESSENGER fundamentally changed our view of Mercury. It revealed a surface that has been reshaped by volcanism over large parts of geological history. Volatile elements like sulfur have been detected with unexpectedly high abundances of up to 4%. MESSENGER imagined structures that are most likely formed by pyroclastic eruptions in recent geologic history. Among the most exciting discoveries of MESSENGER are hollows – bright irregularly shaped depressions that show sign of ongoing loss of material.

BepiColombo will be building on what has been learned from the MESSENGER mission and extend the knowledge. Due to its more circular orbit BepiColombo will provide good spatial resolution for both hemispheres of Mercury. The mission will give us the first good look at the southern hemisphere of the planet.

All spectral instruments are imaging and cover a wider spectral range than the instruments on MESSENGER. Some instruments will provide us datasets that have not been obtained by MESSENGER in any form. MERTIS will for example provide the first temperature map of Mercury and will map the surface composition of the planet for the first time in the thermal infrared. The telescopic imaging channel of the XRS instrument will provide elemental composition at an unprecedented spatial resolution.

The MESSENGER results will be key to formulate the observation plan for the surface instruments on BepiColombo. They also have motivated a wide range of laboratory experiments that will help to better understand the results returned by the suite of instruments.

56) Impact Vaporization as a Source of Mercury's Calcium Exosphere with Evidence for a Meteor Shower

Rosemary Killen, Joseph Hahn and the MASCS TEAM

Abstract

Mercury's calcium exosphere varies in a periodic way with that planet's true anomaly. We show that this pattern can be explained by impact vaporization from interplanetary dust with excursions of Mercury through an interplanetary dust disk having an inclination within 5 degrees of the plane of Mercury's orbit and a heliocentric density variation as R^{-2}, where R is the heliocentric distance. However, an additional contribution besides the nominal dust disk is required near true anomaly 25° ±5°. This is close to but not coincident with Mercury's true anomaly (TAA=45°) when it crosses comet 2P/Encke's present day orbital plane. However, the meteor storms associated with Comet Encke (Taurids) encounter Earth at true anomaly angles ±20 degrees before and after the position where these two orbit planes cross. The lack of exact correspondence with the present day orbit of Encke is consistent with evolution of the comet dust over the past 10,000 years. The extreme energy of the escaping calcium, estimated to have a temperature >50000 K if the source is thermal, cannot be due to the impact process itself but must be imparted by an additional mechanism such as dissociation of a calcium-bearing molecule or ionization followed by recombination.

57) Magnetospheric flux transport at Mercury

S. M. Imber and J. A. Slavin

The large-scale dynamic behavior of Mercury's highly compressed magnetosphere is predominantly powered by magnetic reconnection. Energy and momentum are transferred from the solar wind to the magnetosphere, driving the large-scale circulation of magnetic flux through the system predominantly via the substorm, or loading-unloading cycle. We will present a statistical analysis of the average amplitude, duration and frequency of these loading-unloading events using magnetic field data acquired in orbit about Mercury by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft. The largest amplitude loading-unloading events cycle through ~50% of Mercury’s open flux content. We will analyse the combination of magnetotail and solar wind parameters leading to these extreme events.

58) Simulation of the performance of the BepiColombo Laser Altimeter instrument based on MESSENGER data

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The first European laser altimeter designed for interplanetary flight, BELA (BepiColombo Laser Altimeter on BepiColombo mission to Mercury), will be launched in January 2017. It is one of the eleven instruments onboard the MPO (Mercury Planetary Orbiter, one of the two spacecrafts of the BepiColombo mission) and will be nominally in a 400 km x 1500 km around Mercury (probable nominal orbit 480 km x 1500 km) with an orbital period of 2.3 h.

After descent into the nominal orbit, the MPO spacecraft will have only limited orbit correction capability. Hence, the orbit will evolve because of the Mercury gravity field, solar radiation pressure, and the albedo and infrared radiation from the planet itself. These effects can now be modelled providing predicts which can be fed back into a performance model of BELA. This allows us to update the predicted probability of false detection of the instrument, which is a strong function of altitude and background illumination, by simulation taking into account these updated parameters. The results of this simulation will be presented during this meeting.

59) Geochemistry of Mercury’s surface: Results from MESSENGER

Shoshana Z. Weider and the MESSENGER Geochemistry Discipline Group

Characterizing the chemistry of a planet is one of the most fundamental and insightful ways to learn about the body. As such, the results from the suite of geochemical instruments within MESSENGER’s payload have provided an invaluable resource for investigating several aspects of Mercury’s geology and history. A broad review of the most important geochemical results that have been obtained with MESSENGER’s X-Ray Spectrometer, Gamma-Ray Spectrometer, and Neutron Spectrometer during the four-year orbital mission will be given in this talk. Perhaps the most surprising of MESSENGER’s paradigm-shifting results are the multiple observations of abundant volatiles (e.g., sulfur, potassium, sodium, and chlorine) on the planet’s surface. This result has led to a (newly constrained) reexamination of the hypotheses for Mercury’s formation. In addition, global—or near global—mapping of MESSENGER’s geochemical data has revealed large-scale heterogeneities across the planet’s surface. Although there is remarkable agreement between the X-ray, gamma-ray, and neutron spectroscopy results, the boundaries of Mercury’s geochemical terranes do not always match those of its geological units. Smaller scale investigations of particular features of interest were possible during the latter stages of the MESSENGER mission. For instance, results from a targeted X-Ray Spectrometer observation of Mercury’s largest pyroclastic deposit reveal an uncommonly low abundance of sulfur in this region. This suggests that sulfur volatilization may be an important process during explosive volcanic activity on Mercury. Some of the remaining questions and topics of study in relation to Mercury’s geochemistry will also be covered in this presentation.

60) Title TBC

Westrenen