MERCURY'S EMISSION PHASE FUNCTION (EPF) AS OBSERVED BY BEPICOLOMBO MERTIS AND MARINER 10 IRR. T. M. Powell[1] (tyler.powell@jhuapl.edu), B. T. Greenhagen[1], S. Adeli[2], J. Helbert[2], N. Verma[2], O. Barraud[2], K. Wohlfarth[3], M. Tenthoff[3], E. Jhoti[4], and H. Hiesinger[5], [1]Johns Hopkins University Applied Physics Laboratory, [2]German Aerospace Center (DLR) – Institute of Planetary Research, [3]Image Analysis Group, TU Dortmund University, [4]University of California, Los Angeles, [5]Institut für Planetologie (IfP), Universität Münster.

Introduction: Rough planetary surfaces do not emit uniformly in all directions. Small-scale roughness results in a diverse range of surface temperatures, driven primarily by the orientation of slopes to the sun, and secondarily by scattering and re-emission between opposing slopes [1,2]. To a distant IR instrument, this unresolved, sub-pixel roughness expresses in two basic ways: 1) the relative proportions of warm and cool surfaces within the measurement's field-of-view changes with viewing angle, leading to differences in apparent brightness temperature (T_B); and 2) the mixture of sub-pixel temperatures results in an emission spectrum that deviates from that of a blackbody [2,5,7]. Understanding the Emission Phase Function (EPF) is critical to interpreting measured T_B and emission spectra. While the EPF of the Moon has been well studied due to a wealth of telescopic [3] and spacecraft data sets [2,4,5,6,7], the EPF of Mercury has yet to be characterized in detail. However, new data acquired by the Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) [8,9,10] instrument onboard BepiColombo [11] provide a new opportunity to study Mercury's EPF.

In this work, we leverage two complementary data sets: 1) Newly-acquired low phase angle data collected by BepiColombo MERTIS; and 2) high phase angle data collected by the Mariner 10 Infrared Radiometer (IRR). We compare these results using a global thermal model [12] that simulates EPF effects using lunar-like surface roughness [4,5].

BepiColombo MERTIS: MERTIS consists of an IR grating spectrometer (TIS) spanning 7 to 14 µm, and a radiometer (TIR) with two channels at 7-14 µm and 7-40 µm [8]. During BepiColombo's 5th flyby of Mercury on December 1st, 2024, MERTIS observed Mercury for the first time through its deep space calibration viewport [9,10]. The observed region was a ~2000 km wide north-south swath of the day-side with excellent incidence angle coverage. Due to the flyby geometry, with the sun almost directly behind the spacecraft, the MERTIS observations are at low phase angle (4-6˚). This unique data set will be complementary to future MERTIS data, which will nominally observe with near-nadir geometry when BepiColombo enters orbit in 2026.

Mariner 10 IRR: The Mariner 10 mission was equipped with an Infrared Radiometer (IRR) with two spectral channels at 8.5-14 µm and 34-55 µm [13]. During its March 29, 1974 flyby, the IRR observed the brightness temperature of Mercury along a roughly equatorial transect. While most of the transect covered the night-side, some observations were made of Mercury's illuminated day-side at high phase angles (~120˚). The combination of Mariner 10 IRR and MERTIS data allows us to investigate the low-phase and high-phase end-members of Mercury's EPF.

Global Thermal Model: To simulate Mercury's surface temperatures for the MERTIS and Mariner 10 flybys, we develop an 8 pixel-per-degree (ppd) global thermal model [12] that includes solar illumination, topographic scattering and emission, and subsurface heat conduction assuming lunar-like regolith properties [14,15]. Surface albedo is set by the MESSENGER Mercury Dual Imaging System (MDIS) reflectance map [16] which has a typical value of ~0.075. We account for EPF effects using a semi-analytical roughness model that treats the surface as a series of bowl-shaped craters in radiative equilibrium [5], which has been shown to closely match EPF data of the Moon collected by the Diviner instrument on LRO [4]. This approach is similar to [17], who instead use a fully numeric, fractal roughness model [7] to investigate the MERTIS data. To determine the T_B that would have been detected by MERTIS and Mariner 10, we integrate the EPF-corrected directional emission from each model pixel across the ground-projected field-of-view of each MERTIS and Mariner 10 data record, accounting for the incidence, emission, and azimuth angles.

Preliminary Results: Figure 1A-C shows modeled surface temperature, modeled EPF-corrected T_B, and MERTIS data for the BepiColombo flyby. Both the modeled and MERTIS T_B are strongly influenced by roughness, showing a more gradual drop-off in T_B towards the planet's limb when compared to the modeled surface temperatures. This behavior can be understood as MERTIS preferentially observing sub-pixel warm, sun-facing slopes due to the low phase angle geometry.

Figure 2A shows the drop-off in temperature with incidence angle. We note that MERTIS T_B values are systematically higher than our model predicts, and higher than an ideal blackbody at the same solar distance and incidence angle. This may be due to non-optimal viewing through the deep space calibration viewport, which was not designed for scientific measurements. This is currently under investigation [10]. However, apart from this offset, the drop-off in brightness temperature with incidence angle follows a similar behavior to the EPF-corrected model. Interestingly, small differences in viewing geometry during the incoming and outgoing legs of the flyby result in noticeable differences in the drop-off of T_B with incidence angle, a behavior exhibited in both the model and MERTIS data.

Figure 2B shows a similar analysis for the Mariner 10 IRR data. The high phase angle viewing geometry results in T_B values that are significantly lower than the modeled surface temperature. The EPF-corrected model aligns well with the Mariner 10 IRR data, accurately reproducing the higher T_B measured in the 8.5-14 µm channel compared to the 34-55 µm channel. The agreement between our thermal model and both the low- and high- phase data sets for Mercury suggests that Mercury's EPF generally resembles that of the Moon.

Conclusions: BepiColombo MERTIS and Mariner 10 IRR brightness temperatures are strongly influenced by roughness-driven EPF effects. We demonstrate that this behavior can be reproduced using a thermal model which incorporates lunar-like surface roughness. These preliminary results indicate that, to first approximation, the thermal-scale roughness on Mercury is similar to that of the Moon. The low-phase MERTIS data set from BepiColombo's 5th flyby will be an invaluable complement to future nadir-pointing observations.

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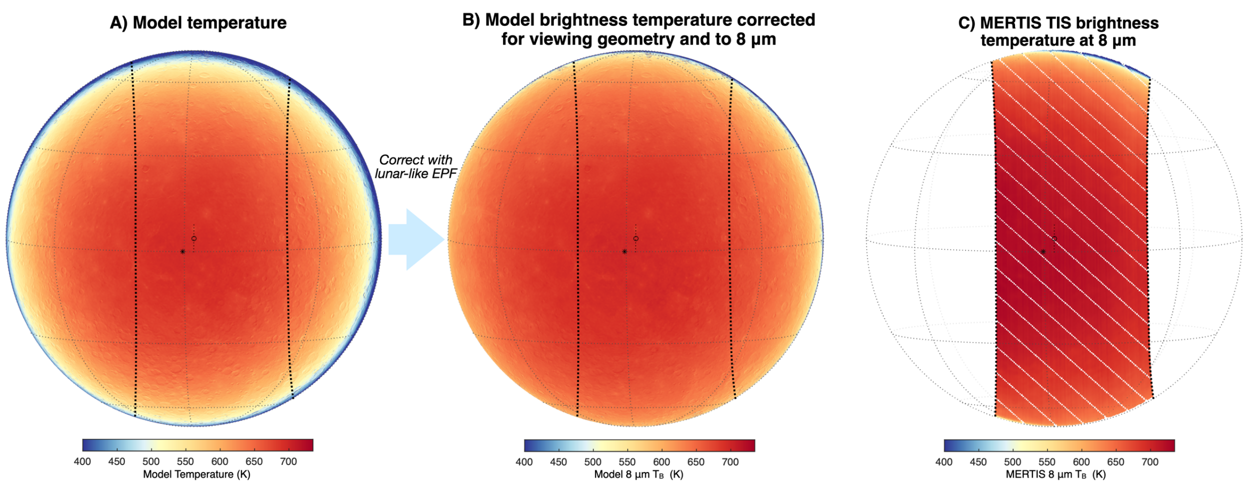

Figure 1. A) Modeled surface temperatures of Mercury on December 1st, 2024, and B) predicted T_B at 8 µm after applying a lunar-like EPF model [4,5]. C) Observed MERTIS TIS 8 µm T_B. Markers note the sub-spacecraft (circle) and sub-solar (asterisks) points.

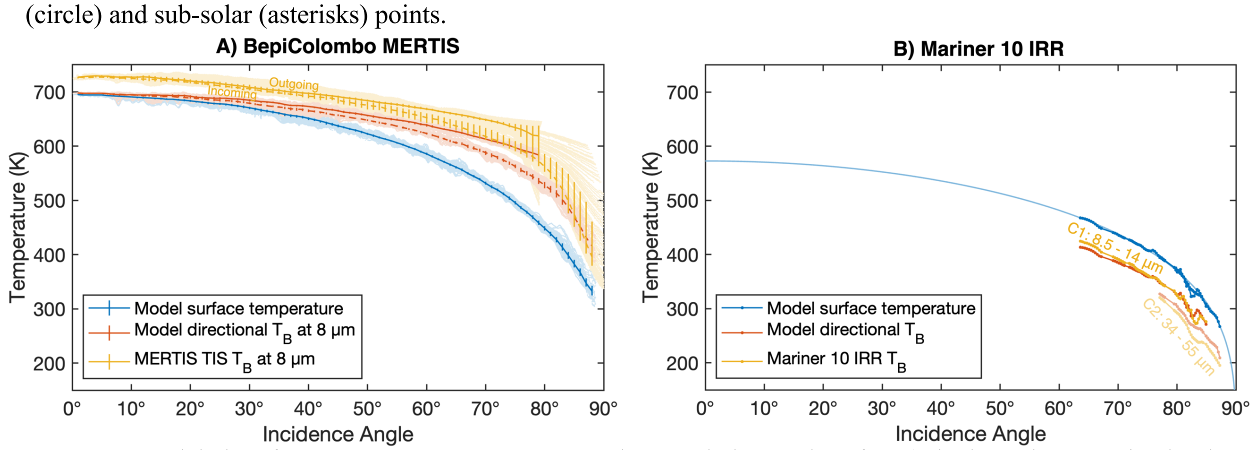

Figure 2. Modeled surface temperatures, EPF-corrected T_B, and observed T_B for A) the low-phase BepiColombo MERTIS flyby and B) the high-phase Mariner 10 IRR flyby. Differences in Mercury's solar distance lead to lower surface temperatures during the Mariner 10 flyby (~0.466 AU) than for the BepiColombo flyby (~0.315 AU).