The Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) at the Moon – First Results and Status Report. H. Hiesinger[1], J. Helbert[2]. K. Bauch[1], M. D'Amore[2], M. Maturilli[2], A. Morlok[1], M. Reitze[1], A. N. Stojic[1], I. Varatharajan[2], I. Weber[1], K. Wohlfarth[3], C. Wöhler[3], [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (hiesinger@uni-muenster.de), [2]DLR – Institut für Planetenerkundung, Berlin, [3]Technische Universität Dortmund.

Introduction: Launched onboard the BepiColombo Mercury Planetary Orbiter (MPO) in October 2018, the Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS) is on its way to planet Mercury [e.g., 1]. MERTIS consists of a push-broom IR-spectrometer (TIS) and a radiometer (TIR), which operate in the wavelength regions of 7-14 µm and 7-40 µm, respectively [e.g., 2]. This wavelength region is characterized by several diagnostic spectral signatures: the Christiansen feature (CF), Reststrahlen bands (RB), and the Transparency feature (TF), which will allow us to identify and map rock-forming silicates, sulfides as well as other minerals. Thus, the instrument is particularly well suited to study the mineralogy and composition of the hermean surface at a spatial resolution of about 500 m globally and better than 500 m for approximately 5-10% of the surface. The instrument is fully functional onboard the BepiColombo spacecraft and exceeds all requirements (e.g., mass, power, performance). On its way to Mercury, BepiColombo is performing several flyby maneuvers at the Earth/Moon, Venus (2x), and Mercury (6x) [e.g., 3]. These fly-bys are excellent opportunities to further test and adapt our software and operational procedures. Here, we report on operational procedures and preliminary results of the flyby at the Moon on April 10th, 2020. MERTIS is the first instrument to observe the Moon in this thermal infrared wavelength region.

BepiColombo's Moon Flyby Operations: The BepiColombo mission consists of two spacecraft, the Japanese Mercury Magnetospheric Orbiter (MMO) and the European Mercury Planetary Orbiter (MPO). The MMO is protected by a sun shield and during cruise, is stacked on top of the MPO. Below, the Mercury Transfer Module (MTM) uses an ion propulsion system to propel the spacecraft stack to Mercury where it will separate. During cruise, the MTM blocks the view of most instruments and only a few instruments are capable of making scientific observations. MERTIS is among the few instruments that could see the Moon during the flyby. However, as the planet baffle, which will be used to observe Mercury is blocked by the MTM, we had to adopt our operational procedure to use the space baffle for the observations of the Moon as well as for the other planets that we will encounter in our flybys, i.e., Venus and Mercury. During the mapping phase at Mercury, the space baffle will be used to observe cold space as a calibration target together with the two internal black bodies at 300 K and 700 K. During the flyby, MERTIS could observe the Moon for about 4 hours divided into four 1-hour long segments with intermittent slews. We did not track the Moon, rather it was drifting through the MERTIS field of view. At the time of observation, the spacecraft-facing side of the Moon was almost completely illuminated and the approach geometry resulted in a view of the lunar surface that is very similar to the one from Earth. Thus, MERTIS covered mostly the lunar nearside. The pixel scale of the MERTIS observations was on the order of 500 km. Thus, large geologic provinces, i.e., mare or highlands, can be identified but detailed studies, for example of landing sites, are impossible. In addition, the rather low signal-to-noise ratio of the lunar observations further complicates the data interpretation. Hence, it must be emphasized that MERTIS was never intended to perform measurements under such conditions. More details on the MERTIS operations during the Moon flyby are provided by [3].

Geometry Correction: Receiving the data, we recognized a misalignment of the observations with respect to the information retrieved from the spacecraft SPICE kernels. We developed a procedure to minimize this offset [4]. In particular, for each frame that shows a signal, we determined the center of the signal by a Gaussian fit and calculated the expected center of signal based on SPICE-kernel data. We found that the offset varies among the individual lunar observations. Thus, the misalignment is not a simple offset along the spatial dimension of the sensor (x-direction) but a function of both x- and y-direction.

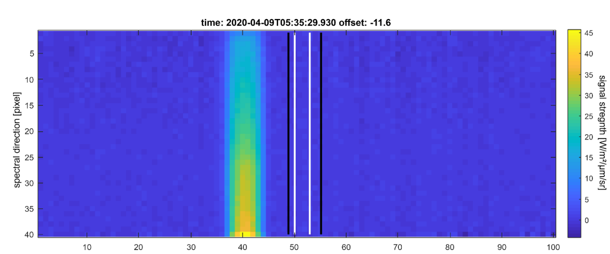

Fig. 1: MERTIS observation of the Moon with spatial dimension shown along the x-axis and spectral information on the y-axis. Cold space is shown in dark blue, the position of the Moon is given by the warmer colors. Black lines indicate the SPICE position of the lunar limb, white lines show pixels completely located on the lunar disk [4]

Of all MERTIS observations, 4929 show a clear signal. For these observations, we calculated the offset between the observed and predicted signal position, summed up its absolute value in each frame, and compared it to the result with different values for x and y. Applying an optimization procedure [5], we found a local minimum at x=8.1071375 mrad and y=0.613725 mrad offsets, which corresponds to about 11.6 pixels offset in x-direction and 0.9 pixels offset in y-direction. More details on the MERTIS operations are provided in a companion abstract [4].

Radiance - Emissivity Calculation: Emissivity is the ratio of the thermal radiation from a surface to the radiation from an ideal black body at the same temperature and is commonly calculated by dividing the measured radiance by the Planck function of a single temperature. However, although this procedure works well for smooth surfaces or for observations at small emission and incidence angles, such calculations are complicated by surface roughness, albedo, and the resulting temperature variations across planetary surfaces, particularly if the observation covers large areas. With MERTIS, we cover about 500 km/pixel and it is reasonable to assume that such a large footprint will not be characterized by a single temperature and, thus, a single Planck function. Rather, the radiation of such a surface will be characterized by a superposition of many Planck functions [6] resulting from small surface facets with different orientations to the Sun and albedo. Hence, we developed a thermal model, which takes these effects into account by utilizing fractal rough surfaces constrained with statistical properties of the Moon. Our radiance model successfully reproduces the measurements. Applying the radiance model to the lunar data, we identified a small offset with respect to the measured data and a blurring of the radiances by the instrument's point spread function. An iterative Bayesian optimization procedure allowed us to minimize the offset and to derive a new set of misalignment values of x=8.28795 and y=1.046445. A detailed description of the model, which is based on previous work of [7-9], is given in [6].

Preliminary Results: After the final thermal calibration, the resulting MERTIS emissivity spectra of mare and highlands are unexpected in that they are extremely similar. However, it has to be kept in mind that the large footprint of a MERTIS pixel almost always will include mare and highlands at various relative proportions and that there are only a few observations of "pure" mare or highlands regions. For both terrains, we observe a strong emissivity maximum around 9 µm and a local minimum around 8 µm. Thus, the spectra do not exhibit a strong CF around 8 µm visible in thermal infrared laboratory measurements of Apollo samples [10], terrestrial analog material, and telescopic measurements [11]. In particular, comparing MERTIS spectra to laboratory spectra of common lunar minerals, [12] observed significant differences. Preliminary work suggests that silicate mineral composition, grain size, temperature, or submicroscopic iron cannot account for the observed spectral differences. We are currently exploring the possibility that the uppermost regolith layer is dominated by a glassy layer resulting from intense space weathering [13]. Using the DIScrete Ordinates Radiative Transfer (DISORT) framework [14] to simulate the uppermost layer of the regolith, [13] reproduced (1) the local minimum around 8 µm, (2) the emissivity maximum around 9 µm, and (3) the decline in emissivity toward 10.5 µm. However, for wavelengths longer than 10.5 µm, the model spectrum and the MERTIS spectra disagree with each other. More studies are necessary to fully understand the MERTIS spectral information. For further interpretations of the MERTIS spectra, the reader is referred to [12-13, 15].

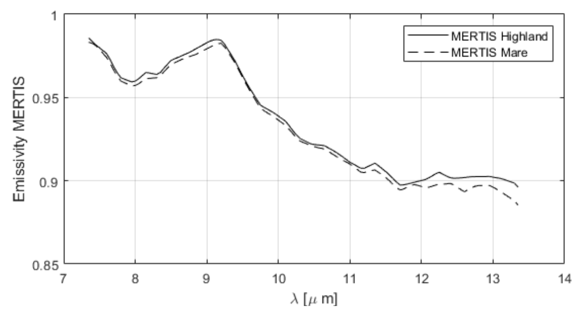

Fig. 2: MERTIS average emissivity spectra of lunar mare and highlands regions [13]

Conclusions: The BepiColombo flyby at the Moon offered the MERTIS team an opportunity to test operational procedures, gain experience with the instrument, and acquire data that can be scientifically interpreted in terms of the composition and mineralogy of the lunar surface. On the basis of the data gathered, we can conclude that the calibration and interpretation of MERTIS spectra is less straight forward than was expected from laboratory measurements. However, most of these complications are reasonably well understood and solutions are being developed in order to prepare for the first Mercury flyby in August 2021.

References: [1] Benkhoff et al. (2021), Space Sci. Rev., submitted; [2] Hiesinger et al. (2020), Space Sci. Rev. 216; [3] Maturilli et al. (2021a), LPSC [4] Schmedemann et al. (2021), LPSC [5] Lagarias et al. (1998), SIAM J. Optimization 9; [6] Wohlfarth et al. (2021), LPSC; [7] Rozitis and Green (2011), Month. Not. Roy. Astron. Soc. 415; [8] Davidsson et al. (2015) Icarus 252; [9] Grumpe et al. (2019), Icarus 321; [10] Donaldson-Hanna et al. (2012), JGR Planets 117; [11] Sprague et al. (1992), Icarus 100; [12] Morlok et al. (2021), LPSC; [13] Wohlfarth et al. (2021), LPSC; [14] Laszlo et al. (2016), Light Scattering Reviews 11, Springer; [15] Maturilli et al. (2021b), LPSC