Observing the Moon and Venus with the MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) during the flybys of the ESA-JAXA BepiColombo spacecraft. J. Helbert[1], A. Maturilli[1], M. D'Amore[1], Y-J. Lee[2], B.T. Greenhagen[3], G. Arnold[1], H. Hiesinger[4] [1]Institute for Planetary Research, DLR, Rutherfordstrasse 2, 12489 Berlin, Germany (joern.helbert@dlr.de), [2]Zentrum für Astronomie und Astrophysik, TU Berlin, Germany, [3]Johns Hopkins Applied Physics Laboratory, USA [4]Institute for Planetology, Wilhelms University, Münster, Germany

Introduction: BepiColombo [1] is a dual spacecraft mission to Mercury launched in October 2018 and carried out jointly between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). BepiColombo uses a solar electric propulsion system. The trajectory is a combination of low-thrust arcs and flybys at Earth (1), Venus (2), and Mercury (5) and will be used to reach Mercury with low relative velocity. Before arriving at Mercury, BepiColombo will perform an Earth-Moon fly on April, 10 2020 and Venus flybys in October 2020 and 2021.

The MERTIS instrument: MERTIS (Figure 1) combines a push-broom IR grating spectrometer (TIS) with a radiometer (TIR). TIS operates between 7 and 14 µm and will record the day-side emissivity spectra from Mercury, whereas TIR is going to measure the surface temperature at day- and night side in spectral range from 7-40 µm corresponding to temperatures from 80-700 K. TIR is implemented by an in-plane separation arrangement. TIS is an imaging spectrometer with an uncooled micro-bolometer array. The optical design of MERTIS combines a three mirror anastigmat (TMA) with a modified Offner grating spectrometer. A pointing device allows viewing the planet (planet-baffle), deep space (space-baffle), and two black bodies at 300 K and 700 K temperature, respectively. During the Venus flybys we will use the deep space view for Venus observations and obtain deep space observations before and after the flybys.

Observational constraints: BepiColombo was launched on October 20, 2018 by an Ariane 5 from the ESA launch facility in Kourou (French Guyana). The ESA Mercury Planetary Orbiter (MPO) and the JAXA Mercury Magnetospheric orbiter were launched in a composite with a propulsion element - the Mercury Transfer Module (MTM) and a sunshade cone (MOSIF) to protect the MMO (see Figure 2).

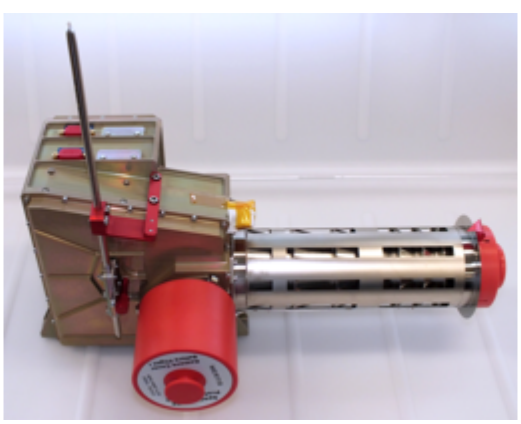

Figure 1 MERTIS flight model with spaceport in front and planet baffle to the right

In this configuration the nadir (z-axis) of the spacecraft points towards the MTM. Therefore, most instruments cannot operate during cruise. While the planet-viewing port of the MERTIS instrument is also blocked by the MTM, the instrument has a second viewport through the radiator which in nominal operations at Mercury is used for deep space calibration.

MERTIS Observing strategy and constraints during the flybys During the flybys MERTIS will use the second viewport – the so-called "spaceport" for observations of Moon and Venus and potentially Earth. This requires that the radiator of the MPO is pointing at the target. Due to attitude constraints for the BepiColombo stack in general and the MPO specifically this limits the observing periods and geometries. MERTIS is a pushbroom instrument, therefore it requires the spacecraft motion to build up an image.

In the nominal calibration sequence MERTIS observes for 70% of the time through the planet viewing baffle and for 30% of the time the two internal black bodies and deep space. This sequence is built into the nominal operation mode of the instrument. The two black bodies within MERTIS are required for radiometric calibration and to correct drifts in the instrument temperature. During the flybys we expect significant drifts in the instrument temperature. Therefore, a special flyby operation mode was created in which MERTIS observes the target through the spaceport and obtains every 60 seconds calibration frames from both black bodies. MERTIS has been successfully operated in flyby mode during a cruise checkout end of August 2019.

Earth-Moon flyby: During the Earth-Moon flyby the MERTIS instrument [2,3,4] will primarily obtain observations of the Moon in the spectral range from 7-14µm as well as temperature maps with the integrated radiometer covering the 7-40µm range. This will be the first hyperspectral observations of the Moon in this spectral range from space.

The dataset will help to validate the calibration of the MERTIS instrument and will allow a direct comparison of the spectral characteristics of the Moon and Mercury. A coordinated observation campaign with the Diviner instrument on the NASA Lunar Reconnaissance Orbiter (LRO) is planned.

Within the attitude constraints for BepiColombo the time allocated for MERTIS pointing during the Earth-Moon flyby is 4 hours long and starts 1 day before closest approach. The moon is nearly fully illuminated during this time. The angle between Moon and Earth (from limb to limb) is 8.5 in the beginning and increases up to 10.64 degrees. It moves 1.6 degrees in these four hours. The apparent size of the Moon starts at 0.268 degrees and increases up to 0.2927 degrees. Given the field of view (FoV) of 4° MERTIS will have approximately 7 pixels across the Moon, resulting in a resolution of roughly 500km/px.

The 4 hours will be divided in 4 segments of approximately 1 hours connected by short slews. The attitude in each segment will be quasi inertial (this means no tracking, just keeping the Sun within illumination constraints) with the Moon slowly drifting in the FoV such that it is aligned with the boresight right in the middle of the segment.

Venus flyby: The spacecraft approaches the planet from the solar direction, over the dayside. The closest approach (CA) occurs above the evening terminator of the planet, and then the spacecraft moves away from the planet to the anti-solar direction, over the night side. During ~50 min before CA, MERTIS performs close-up dayside observations from late morning to late afternoon via noon time on Venus at low latitudes of the southern hemisphere. Due to the 100% cloud cover on the planet, most of thermal emissions are corresponding to temperatures at the upper cloud level atmosphere (60-70 km) [5]. The shorter wavelength edge of the 15-µm CO_2 band covered by TIS/MERTIS will be used to test approaches to retrieve temperature profiles from the cloud tops to slightly above using the inversion methods of radiative transfer. Simultaneous cloud top structures and SO_2 gas abundances above the clouds can be estimated from the observed spectra over the 7-14 µm range of TIS/MERTIS. It will be the first time after Venera since 1980 that spaceborne spectral observations close to Venus can be obtained within this wavelength range [8].

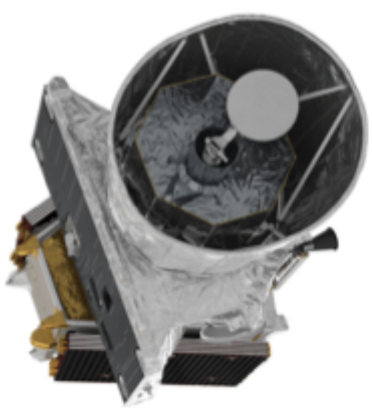

Figure 2 Rendering of the BepiColombo stack seen from top with MMO in the MOSIF, below that the MPO and the MTM

Space- and Ground-based coordinated observations: The Venus atmosphere observation opportunities of BepiColombo will become more comprehensive with coordinated observations with another spacecraft, Venus orbiter Akatsuki, and Earth-based telescopes. These will provide similar or different viewing geometries simultaneously with BepiColombo from the two more observing locations (Akatsuki and Earth), so day and night sides of Venus can be captured simultaneously. The coordinated observations at overlapped spectral ranges will offer unique chances of cross validation of measured data, and will extend spectral ranges of BepiColombo. Also, these will monitor Venus for longer periods, from before CA to after, so temporal variations of Venusian atmosphere will be well monitored. The coordinated observations will assist instantaneous observations by BepiColombo to make better understanding on its observations. For more details and to participate see http://bit.ly/BepiVenus

MERTIS observing Venus (and Earth) as an exoplanet: During the cruise phase up to five opportunities have been identified where Venus will pass through the field of view of the MERTIS instrument and the solar electrical propulsion is not operating. During these opportunities MERTIS will obtain timeseries of Venus consisting of up to 60 blocks of 5 minutes of observations with 30 minutes spacing. This dataset is comparable to typical observations of exoplanets and will provide a blind-test for retrieval algorithms for rotation rate and cloud structure.

References: [1] Benkhoff, J., et al. (2010) Planetary and Space Science 58(1-2): 2-20. [2] Hiesinger, H. and J. Helbert (2010). Planetary and Space Science **58**(1-2): 144-165. [3] Helbert, J., et al. (2010). SPIE **7808**: 78080J. [4] Hiesinger, H. et al (2020) this meeting. [5] Moroz, V.I., et al., (1990) Adv. Space Res., vol. 10, no. 5, p. 77. [6] Oertel, D. and V. I. Moroz (1984). Pisma v Astronomicheskii Zhurnal **10**: 243-252. [7] http://s.dlr.de/5l53