EPSC Abstracts
Vol. 13, EPSC-DPS2019-2018-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Spectral detection of ices in permanent shadowed regions at Mercury poles: simulations for SIMBIOSYS-VIHI on BepiColombo mission

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Abstract

We report about a preparatory study aiming to verify the detection of ices hosted in Permanent Shadowed Regions (PSR) at Mercury polar regions by VIHI spectrometer [1], one of the three optical channels of the SIMBIO-SYS instrument [2]. As a consequence of the limited Mercury's obliquity (about 2 arcmin), many polar craters and depressions are permanently un-illuminated [3]. The total surface of PSR is estimated in 43.000 km^2 south of latitude -73° [3]. Many of those areas show clear evidences of the presence of ices deposits as demonstrated by Radar observations from Earth [4] and by Messenger Laser Altimeter data [5]. The PSR will be mapped by VIHI in the 0.4-2.0 µm spectral range with a spectral sampling of 6.25 nm/band and spatial resolution better than 200 m/px thus offering unprecedented possibilities to detect ice species in the areas of transient illumination conditions (penumbra). Spectral simulations on mixtures of anorthite and water ice in intimate and areal mixing with different grain sizes and abundances are performed to evaluate the detection of water ice and VIHI signal-to-noise during the different observation phases of the BepiColombo mission.

1. Introduction

From Mercury's orbit the solar disk has an apparent angular size ranging between 1.15° at aphelion to 1.76° at perihelion. This means that the illumination conditions are not those of a point source at infinite distance (parallel rays) but of an extended source at finite distance (diverging beams). As a consequence of this effect, the projected shadow line is not a sharp edge but rather a blurred transition area whose dimension depends from the Sun apparent size. The length of the penumbra on Mercury is not negligible reaching a length of 2.46 km at perihelion and 1.5 km at aphelion for the shadow casted by a crater's rim of 2 km height placed at latitude ±80°. Areas in penumbra conditions therefore could maintain surficial water ice due to the limited solar insolation while allowing to perform reflectance spectroscopy thanks to the fraction of light reaching the surface.

2. Spectral simulations

Photometric modelling in the proximity of shadows and through penumbra areas is a challenging task: apart illumination gradients we will expect multiple scattered light coming from nearby illuminated areas. For a similar analysis it will be necessary to simulate illumination on a Digital Elevation Model of the area of interest. However, the detection of water ice in PSR will be facilitated by the presence of diagnostic absorption features at 1.25, 1.5, 1.65, 2.0 µm within the VIHI spectral range. Those features in general are well-contrasted with respect to the average Mercury terrain reflectance (Fig 1 orange plot lines). Spectral modeling [6,7] is applied to different mixtures of anorthite and water ice, changing the abundances of the two endmembers, water ice grain size, mixing modality (areal and intimate) and incidence angle (here at 80° as typical for PSR). Since VIHI will observe mainly at nadir, we keep emission angle null. The trends of simulated reflectance for intimate and areal mixings of anorthite with 100 µm water ice grains from 0 to 20% are shown in Fig. 1.

3. VIHI signal to noise ratio

Simulated reflectance is used to compute VIHI theoretical SNR for the changing observation conditions occurring along BepiColombo orbit. We use the instrument responsivity and dark current measured during pre-launch calibration campaign [8] to compute instrument SNR. The computation is repeated at different viewing geometries according to

Mercury's true anomaly TA (from 0° at perihelion to 180° at aphelion), local illumination geometry (solar zenith angle) and planned VIHI integration time [9]. The resulting SNR values are shown in Fig. 2 for the areal mixing case for TA=0° and 180°.

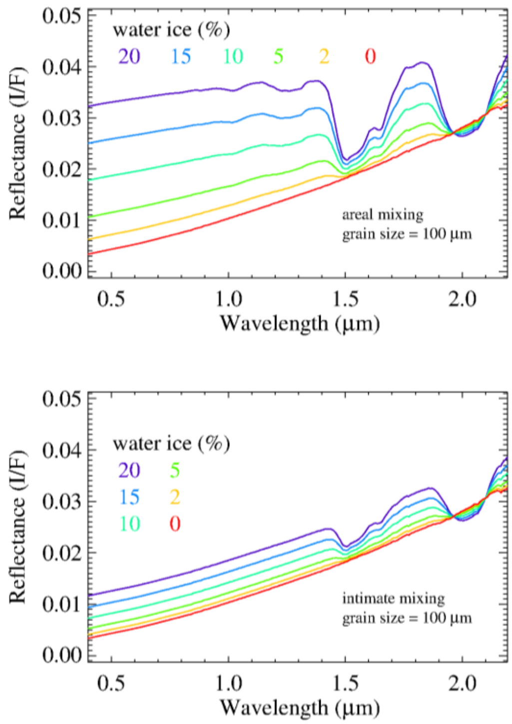

Figure 1: simulated reflectance of water ice-anorthite mixtures (areal mix top panel, intimate mix bottom).

4. Summary and Conclusions

The excellent responsivity of the VIHI spectrometer (up to 2000 DN m^2 sr µm W^{-1} s^{-1} at 1.2 µm) and the high radiance levels expected from Mercury's surface (up to about 500 W m^{-2} $µm^{-1}$ sr^{-1} at 1 µm for TA=0°, lat=0°) allow to reach good SNR values for the simulated reflectances across the full 0-4-2.0 µm range. In particular, for the worst case scenario (2% water ice abundance) we measure a SNR >300 at 1.5 µm (water ice diagnostic band) for both the areal and intimate mix cases at TA=0° and SNR>150 for TA=180° (Fig. 2). These simulations indicate the full capabilities of the VIHI instrument to detect water ice presence in partially-illuminated PSR up to few percent abundances allowing to better constrain the total mass of ices hosted at Mercury's poles.

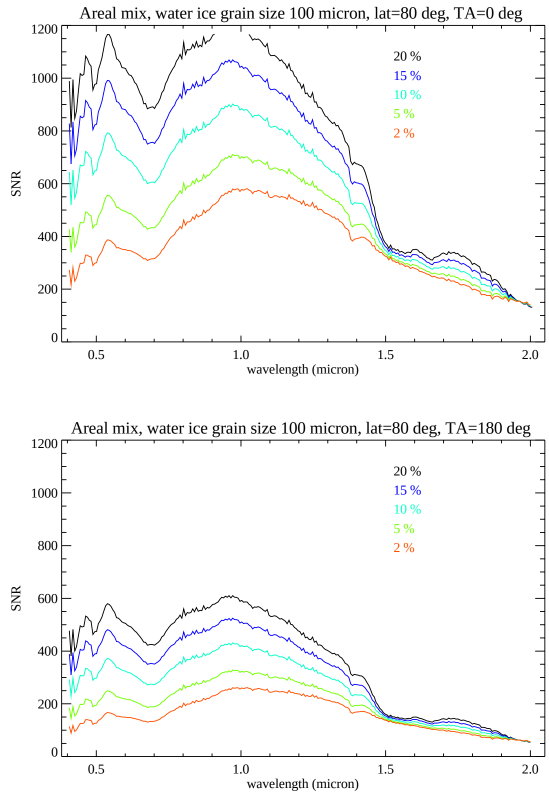

Figure 2: VIHI theoretical SNR at perihelion (true anomaly TA=0°) and aphelion (TA=180°) for the areal mixing case.

Acknowledgements

This research is supported by an Agenzia Spaziale Italiana (ASI) grant to the Istituto Nazionale di Astrofisica (No. INAF I/022/10/0). This research has made use of NASA's Astrophysics Data System.

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