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Optical performance of PHEBUS/EUV detector onboard BepiColombo

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Abstract

BepiColombo, a mission of ESA (European Space Agency) in cooperation with JAXA (Japan Aerospace Exploration Agency), will explore Mercury, the planet closest to the Sun. BepiColombo will launch in 2014 on a journey lasting up to six and a half years; the data gathering phase should occupy a one year nominal mission, with a possible extension of another year. The data which will be brought back from the orbiters will tell us about the Hermean surface, atmospheric composition, and magnetospheric dynamics; it will also contribute to understanding the history and formation of terrestrial planets. The PHEBUS (Probing of Hermean Exosphere by Ultraviolet Spectroscopy) instrument will be flown on MPO: Mercury Planetary Orbiter, one of the two BepiColombo orbiters. The main purpose of the instrument is to reveal the composition and the distribution of the exosphere of Mercury through EUV (Extreme Ultraviolet: 55–155 nm) and FUV (Far Ultraviolet: 145–315 nm) measurements. A consortium composed of four main countries has been formed to build it. Japan provides the two detectors (EUV and FUV), Russia implements the scanning system, and France and Italy take charge of the overall design, assembly, test, integration, and also provide two small NUV (Near Ultraviolet) detectors (for the light from calcium and potassium molecules). An optical prototype of the EUV detector which is identical to the flight configuration has been manufactured and evaluated. In this paper, we show the first spectra results observed by the EUV channel optical prototype. We also describe the design of PHEBUS and discuss the possibility of detecting noble gases in Mercury's exosphere taking the experimental results so far into account.

Keywords: Mercury; EUV; BepiColombo; Exosphere; Noble gas

1. Introduction

PHEBUS (Probing of Hermean Exosphere by Ultraviolet Spectroscopy) is a double spectrometer for the Extreme Ultraviolet range (EUV: 55–155 nm) and the Far Ultraviolet range (FUV: 145–315 nm) dedicated to the characterization of the composition and dynamics of Mercury's exosphere, and the surface-exosphere relationships (Chassefière et al., 2010). It is a part of the ESA BepiColombo cornerstone mission payload devoted to the study of Mercury. The mission consists of two spacecraft: the Mercury Magnetospheric Orbiter (MMO) and the Mercury Planetary Orbiter (MPO) on which PHEBUS will be mounted. PHEBUS is a French-led instrument implemented in a cooperative scheme involving Japan (detectors), Russia (scanner) and Italy (ground calibration).

Mercury's exosphere was observed for the first time by the Mariner-10 spacecraft during its three flybys. Only three atomic species were clearly identified; two of which, the hydrogen and helium atomic species, most probably originate from solar wind (Broadfoot et al., 1974). The third, an oxygen atomic species, was observed at the limit

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of detection of the instrument (Broadfoot et al., 1976). Three other species have been later observed by Earth ground-based telescopes: atomic sodium (Potter and Morgan, 1985), potassium (Potter and Morgan, 1986) and calcium (Bida et al., 2000). In 2008 and 2009, the NASA MESSENGER spacecraft made observations during a flyby of Mercury before its orbital insertion in 2011. The UV spectrometer onboard that spacecraft detected atomic magnesium (McClintock et al., 2009). In addition, the third flyby revealed a distribution of magnesium, calcium, and sodium around the tail region of Mercury (Vervack and McClintock, 2010). All these species have been observed through resonant emission; the hydrogen, helium oxygen and magnesium in the UV, the calcium in the near UV, and the sodium and potassium in the visible spectral range. Since sodium D lines in visible are extremely strong, numerous studies have been done using ground based telescopes. The dynamics and distribution of sodium around Mercury are known to have dawn-to-dusk or north-to-south asymmetry (Yoshikawa et al., 2008a). A relation between the sodium distribution and the solar wind condition, or true anomaly angle has also been suggested (Kameda et al., 2007, 2008).

It is emphasized that PHEBUS has several advantages over the UV spectrometer of MESSENGER: the extension of the spectral range from 55 nm to 110 nm provides the capability of observing additional species like helium, argon, neon, etc., and using a scanning system allows greatly improving the coverage, vertical sampling rate, and trace species detection capability. PHEBUS observations in the spectral range of 55–110 nm allow us to take coordinated measurements of noble gases in conjunction with geochemical studies performed by MPO instruments, and ion species synergistically with ionospheric and magnetospheric studies performed by MMO instruments.

Ground based calibration is one of the most important steps in developing any space borne instrumentation. The spectral and spatial resolution, reflectivity, and quantum detection efficiencies are all values which must be evaluated carefully. After a short presentation of key science issues and objectives, a detailed description of the instrument and of its optical performance will be introduced.

2. Scientific objectives

The exosphere of Mercury is very tenuous, with pressures of only a fraction of a picobar. It results from a complex interplay of solar wind, the planetary magnetic field and its rocky surface. The generation and loss processes of exospheric components have been discussed in various studies (e.g. Killen et al., 2007; Yoshioka et al., 2008a). These processes include photon-stimulated desorption, impact vaporization, and venting from the interior. Some species like neon and helium originate from the solar wind. They are lost by photo-ionization or by direct escape from the surface. The origin and relationships between the exospheric components, magnetosphere and surface are well summarized by Leblanc et al. (2007).

The components of the Herman exosphere exist in a practically collision free regime. In addition, the exosphere is highly variable in time and space, typified by a global asymmetry between dayside and nightside, and has rapid temporal variations, possibly related to varying magnetospheric activity. The core scientific objectives of PHEBUS are oriented toward a better understanding of the coupled surface-exosphere-magnetosphere system. The main measurement objectives are the following:

- To detect any new species, including metallic species (Si, Fe, ...), atoms (C, N, S, ...), molecules and radicals (H_2O, H_2, OH, CO), noble gases (Ar, Ne), and ions (He^+, Na^+, ...), and in addition to measure previously detected species. (MESSENGER may have already detected some of these before this paper is published.)
- To measure an average exosphere (densities of constituents and their vertical structure), with as many species as possible monitored simultaneously, at different positions about the Mercury–Sun system.
- To measure sharp local and temporal variations of the exosphere content, at specific times and places of interest.
- To search for albedo variations of Mercury's nightside surface by observing the 121.6 nm line from the interplanetary Hydrogen Lyman alpha glow. This could allow finding possible signatures of surface ice layers (H_2O, SO_2, N_2, CO_2,) in high latitude polar craters. The albedo for water ice is around 2% (Hendrix and Hansen, 2008). On the other hand, the albedo for Mercury which is deduced from the Moon value is expected to be about 4%. Therefore, we can distinguish between areas by a difference in signal levels (10R for water ice and 20R for other areas). When in "Nightside H Ly-α mapping mode", BepiColombo/PHEBUS will also be able to look into permanently shadowed craters thanks to its movable entrance baffle (Chassefière et al., 2010).

3. Instrument design overview

PHEBUS is basically composed of two spectrophotometers and one scanning mirror with a single rotation axis. The movable off axis parabolic mirror collects the light coming from the exosphere above the limb onto the entrance slit of the spectrometer with a minimum number of reflections in order to maximize the UV count rate on the detectors. The mirror is protected from the stray light by an entrance baffle and collimator.

The mirror has a 170 mm effective focal length and a folding angle of 100°. The mirror determines the geometry of the instrument's Field of View (FOV) and the Line of Sight (LOS). The spectrometer component determines the spectral resolution of the instrument and is composed of an entrance slit, two holographic gratings and detectors. The