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THEMIS Na exosphere observations of Mercury and their correlation with in-situ magnetic field measurements by MESSENGER

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ABSTRACT

The Na exosphere of Mercury is being studied since its discovery in mid '80s from Earth-based telescopes, and it has revealed a high dynamics and variability. Although the processes and their relationships characterising the Hermean exosphere generation and dynamics are still not exhaustively understood, there are no doubts on a tight interconnection among the planet's surface, exosphere, intrinsic magnetic field, the solar wind and the Interplanetary Magnetic Field (IMF). In this paper we analyze an extended dataset of images of the exospheric Na emission, collected from 2009 to 2013, by means of the THEMIS ground-based telescope, in order to perform a comprehensive statistical study of the recurrent Na emission patterns, and also their potential relationship with the IMF variability. For this purpose, we take advantage of a subset (years 2011–2013) of contemporary in-situ measurements of the IMF obtained by the MAG instrument on-board the MESSENGER spacecraft. We found that the high latitude double peak is the most common Na emission pattern, supporting the view that the solar wind ion precipitation through the polar cusps has an important role in the generation of the observed Na exospheric configuration. Moreover, the lack of a statistically significant North–South asymmetry seems to disfavor the existence of an asymmetric and/or shifted intrinsic magnetic dipole. By analyzing a subset of *quasi-full disk* images, we found that the double peak Na emission is typically aligned along the meridian, mostly occurring in the pre-noon sector (53%), about 1/3 close to the noon meridian (36%), whereas only 11% takes place in the post-noon sector. Finally, the comparison with the IMF data seems to indicate that the contribution of the IMF B_X component to the magnetic reconnection is generally weak, even if we found a noticeable correlation between positive IMF B_X and symmetric double peak pattern. Negative IMF B_Z values are usually connected to double peak emission, whereas positive IMF B_Z values are more frequently associated to single peaked equatorial Na emission.

1. Introduction

The sodium bright doublet emission at 5890–5896 Å, thanks to its good visibility also obtained from ground-based observations, is broadly used to study the exosphere of Mercury (e.g. Potter and Morgan, 1997; Sprague et al., 1997; Killen et al., 2001; Leblanc et al., 2008, 2009, 2010, 2013). Earth-based observations were performed for 30 years, since the discovery of Na component in 1985 (Potter and Morgan, 1985) and provided a large dataset of images in which recurrent patterns are observed, as well as a variable intensity. Earth-based observations of Mercury often take advantage of solar telescopes that allow observations during daytime. Hence, valuable series of data for many hours per day are now collected and can be used to study the variability of the exosphere of Mercury through its sodium component.

The study of the exosphere of Mercury and its dynamics is important to understand the processes that generates the planet's tenuous (collisionless) atmosphere given strong bombardment of the surface by solar wind plasma and micrometeoroids, as well as the relatively strong IMF at such a close distance from the Sun. A proper understanding of the exosphere relates with the interrelations among all the parts of Mercury's environment (for a review, see Milillo et al., 2005). Earth-based observations of the Na exosphere often exhibit a two-peak pattern. These peaks are usually located at mid/high latitudes in both hemispheres of Mercury and they can often differ in intensity and extent, e.g. one peak is more intense or wider than the other. Asymmetries

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between dawn and dusk have also been hypothesized (Sprague et al., 1997; Potter et al., 2006; Schleicher et al., 2004). Moreover, the major overall variability observed from ground is seasonal, meaning that it is linked to the True Anomaly Angle (TAA) (e.g. Schmidt et al. 2010; Leblanc and Johnson, 2010; Cassidy et al., 2014) and is interpreted as a composite effect of the planet's distance from the Sun, radiation pressure, Doppler shift on resonant scattering efficiency and Na deposition and migration over the surface (day/night anisotropies). More recently, in-situ measurements from MASCS on-board MESSENGER spacecraft, proved that Na exhibits a clear year to year recurrence (Cassidy et al., 2014); nevertheless, no other variability could be distinguished. It should be noted, however, that the MASCS observations are restricted to the dayside equatorial region and that the global exosphere configuration can be observed only by ground based telescopes. In fact, when removing the known yearly variations from the images of Na emission obtained by THEMIS, a solar telescope with good spatial resolution, variability in intensity and different emission features becomes evident also on shorter time-scales, i.e. 1 h (Leblanc et al., 2009; Mangano et al., 2013).

The morphology of the two-peaks of Na intensity is believed to be related to the interaction of the solar wind particles with the intrinsic magnetic field that drives them into preferred regions of the surface (i.e., the footprints of the magnetic cusps). Some debate exists about the processes acting to produce such peculiar features. In fact, the ion-sputtering process alone is not expected to be able to release enough Na to account for the intensity of the observed peaks at mid- to high-latitude position (Mura et al., 2009). Leblanc and Johnson (2003) modeled the efficiency of the various release processes during different orbital phases, suggesting that the exosphere generation is the result of the complex relationship between surface and external environment. Also Mura et al. (2009) suggested a synergy of more than a single process to account for observational evidence of the two peaks features: the plasma ions impacting the surface at the cusp footprints loosen the Na atoms in the crystalline structure of rocks and regolith; the subsequent desorption (induced both from the action of temperature and photons) results in the final release of Na into the exosphere.

Thanks to the relevant dataset collected over decades of observations, statistical studies on the Na exosphere configurations are possible. Such a statistical analysis was performed by Potter et al. (2006) using a dataset of 7 years (1997–2003); they analyzed the Na exospheric asymmetries observed on the disk of Mercury in both longitudinal and latitudinal directions. They found a dawn/dusk asymmetry with statistically higher terminator-to-limb ratios when dawn is in view. Their analysis suggests that the south peak is more frequent when dawn hemisphere is observed. They did not find any correlation between peaks and TAA and no clear predominance of one hemisphere to the other.

Similarly, Leblanc and Johnson (2010) using the global intensity data collected by a huge set of ground-based observations and the Mercury Exosphere Global Circulation Model (MEGCMS), investigated the processes responsible for the Na exosphere modulation along the Mercury orbit. They concluded that the dominant active process varies during Mercury's year but it is mainly consistent with the Photon Stimulated Desorption process, apart from the portion of the orbit when TAA is 25–40°, where the Thermal Desorption prevails. The temperatures observed by MESSENGER/MASCS are in agreement with a PSD distribution (Cassidy et al., 2014).

Nevertheless the role of the solar wind entry inside Mercury's magnetosphere after the reconnections between the IMF and the internal magnetic field is evidently linked to the spatial distribution of Na exosphere (Killen et al., 2001). So that, a detailed study of Na emission pattern correlated to the IMF configurations is the way to solve the Na puzzling case. Thanks to the MESSENGER spacecraft (Solomon et al., 2007), we now have the possibility to directly compare ground-based data to in-situ IMF measurements.

In the present paper we use a dataset of 5 years (2009–2013) of observations obtained at the THEMIS solar telescope in Tenerife to make a statistical analysis of recurrent patterns. In addition, we cross-check a subset of data (years 2011–2013) with the magnetic data of IMF coming from in-situ measurements of the MAG sensor on-board MESSENGER spacecraft to try to give new insights in the connection between recurrent Na exospheric patterns and the IMF configuration. In Section 2 the sodium exospheric observations and the magnetic field dataset are described and analyzed. In Section 3 we discuss the statistical analysis, and in Section 4 we draw our conclusions.

2. Datasets

Two different sets of data are used: Earth-based spectroscopic images of Na D2 emission of the exosphere (5890 Å), and in-situ measurements of the IMF as obtained from MAG, the magnetometer on-board MESSENGER spacecraft (Solomon et al., 2007).

Earth-based data are obtained by using the THEMIS solar telescope (López Ariste et al., 2000) located in Tenerife (Canaries, Spain). THEMIS telescope has a 0.9 m primary mirror and a 15.04 m focal length and it can be used during the daylight to image Mercury Na exosphere above the disk for several hours per day.

A long campaign of Na exospheric observations is performed since 2007 with noticeable results (Leblanc et al., 2008, 2009, 2013; Leblanc and Johnson, 2010; Mangano et al., 2013) and a wide database is now available. Since 2009, THEMIS was used together with the MTR spectrograph in multiline mode, with two different cameras observing both the Na D1 and D2 lines at the same time. The spectral dispersion was of 11 mÅ per pixel and the spectral resolution 27 mÅ, about 220,000 resolving power. For further details on the observation setup and procedure refer to the papers cited above. In the present paper, we used the measurements achieved along five consecutive years, between 2009 and 2013 (see Table 1). In fact, in this time period we have both D2 and D1 emission data to cross-check for a more precise determination of exospheric Na emission, and a more robust data reduction protocol. After the data reduction, a dataset comprising a total of 644 images of Mercury's exospheric Na emission is obtained.

The MESSENGER spacecraft is orbiting around Mercury since March 2011. The MAG sensor is mounted on a 3.6-m boom and may collect magnetic field samples from 50-ms to one-second intervals (Anderson et al., 2007). Depending on the spacecraft position along the orbit, it may collect data from either the IMF or the intrinsic magnetic field of the planet Mercury. In our analysis we used the calibrated MAG magnetic field data (Korth et al., 2011–2013), obtained via the Planetary Data System (PDS) and Planetary Plasma Interactions Node (PPI), by selecting the time periods when the MESSENGER was in the unperturbed Solar Wind (SW), that is outside the Hermean magnetosphere (see details in Section 2.2).

2.1. Exospheric emission patterns analysis

To perform an unbiased statistical analysis of the Na emission in Mercury's exosphere, we started by identifying the recurrent Na emission patterns without any aprioristic assumptions connected to the volatile elements release mechanisms, to the Hermean magnetospheric structure or to its relationship to the IMF. In the following we just hypothesized that the observed Na emission patterns is a proxy of the surface emission region.

To minimize the risk of a wrong classification, we carefully examined the whole dataset of 644 images and rejected all the images affected by acquisition problems (spatial shifts during the