Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 41 (2008) 1386–1391
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Mercury's sodium exosphere explored by the BepiColombo mission

K. Yoshioka [a,*], K. Hikosaka [a], S. Kameda [b], H. Nozawa [c], A. Yamazaki [b], I. Yoshikawa [a]

[a] *The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[b] *Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1, Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan*
[c] *Kagoshima National College of Technology, 1460-1, Shinko Hayato-cho, Kirishima-city, Kgoshima 859-5193, Japan*

Received 6 December 2006; received in revised form 23 November 2007; accepted 23 November 2007

Abstract

The Mercury's Sodium Atmosphere Spectral Imager (MSASI) on BepiColombo will address fundamental scientific questions pertaining to the Mercury's sodium exosphere. Together, our measurements on the overall scale will provide ample new information on regolith–exosphere–magnetosphere coupling as well as new understanding of the dynamics governing the surface-bounded exosphere. We will compare the four different source mechanisms in preparation for modeling MSASI data and show the feasibility of identifying a process.

Keywords: Mercury; BepiColombo; Sodium; Exosphere

1. Introduction

Mariner 10 made the first measurement of Mercury's atmosphere during the 2 flybys in 1974 and 1975. The ultraviolet spectrometer discovered three constituents: H, He, and O (Broadfoot et al., 1974). On the other hand, ground-based observations found the exospheric constituents of Na (Potter and Morgan, 1985), K (Potter and Morgan, 1986), and Ca (Bida et al., 2000). Among already known species, sodium is the most detectable and has been most intensively studied. Later observations revealed significant changes of brightness with time and space. Time variations related to solar activity (Shemansky and Morgan, 1991), Mercury's heliocentric position (Leblanc and Johnson, 2003), magnetospheric ion precipitation (Potter and Morgan, 1997a), and solar particles (Potter et al., 1999) were reported. As for the spatial asymmetry, Sprague et al. (1997) found that average column density of Na atoms in the morning is higher than that in the afternoon by a factor of 3, and Kameda et al. (2007) observed that the rate of change in the sodium density at low latitudes was quite different from that at high latitudes. Sprague et al. (1998a) suggested that ejection of Na atoms from the surface by the sunlight is the cause of the asymmetry. In the morning, there are larger amount of Na atoms, which were implanted on cold surface during the night. Most of Na atoms start to eject from the surface at the terminator of the morning. On the contrary, in the afternoon most of Na atoms on the surface have already been exhausted except at rough terrain areas in high latitudes regions.

2. Mercury's atmosphere

Sodium atoms in the exosphere may possess multiple velocity distributions that reflect the release mechanisms from the surface rock, e.g., (1) photon-stimulated desorption (McGrath et al., 1986; Yakshinskiy and Madey, 1999; Madey et al., 2002), (2) charged-particle sputtering (Potter and Morgan, 1990, 1997b; Potter et al., 1999; Killen et al., 2001), (3) micro-meteoroid impact/vaporization (Morgan et al., 1988; Killen et al., 2001), or (4) thermal desorption (Hunten and Sprague, 1997, 2002; Sprague et al., 1997; Leblanc and Johnson, 2003). Each process seems to be a source for the vapor Na in the Mercury's

* Corresponding author.
E-mail address: yoshioka@eps.s.u-tokyo.ac.jp (K. Yoshioka).

0273-1177/$34 © 2007 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2007.11.024

exosphere. The spatial distribution in the exosphere is different, depending on the initial speed.

We first provide insights on the sodium density distribution in Mercury's surface, on the morphology of Mercury's exosphere with respect to heliocentric position and phase angle, and then perform 3D Monte Carlo simulation in each mechanism.

2.1. Thermal-stimulated desorption (TSD)

Thermal desorption is also quoted as an important mechanism of production for Mercury's Na exosphere (Hunten and Sprague, 1997, 2002; Sprague et al., 1997; Leblanc and Johnson, 2003). They suggested that this mechanism could dominate the production of Na into the exosphere. This conclusion has been partly demonstrated by solar occultation observations (Schleicher et al., 2004), showing the strong morning/evening asymmetry that is associated with hot to cold migration and therefore the potential importance of thermal desorption. The identification of the morning/evening asymmetry is essential to discern this process.

The temperature of the surface T_S depends both on the solar zenith angle and on the solar photon flux intensity. On the dayside

$$T_S = \left[T_0 + T_1 \times (\cos(\text{longitude}) \times \cos(\text{latitude}))^{\frac{1}{4}}\right] \times (0.306/R_{obs})^2$$

with $T_1 = 125$ K and $T_1 = 600$ K. On the nightside; $T_S = 125$ K. This formula is used in Killen et al. (2004). The subsolar point is placed at latitude and longitude equal to zero. The initial Na concentration in Mercury's surface (Fig. 1) is set to 3.975×10^{12} atoms/cm^2 (Killen et al., 2001). A grid of 72×36 cells with equal surface area is defined to describe Mercury's surface density distribution. At each time step and for each cell, a spatial position in the cell and the probabilities of a test-particle to be ejected at the position by thermal desorption are chosen randomly.

The motion of a test-particle in the environment of Mercury is driven by the gravity of Mercury and the Sun and by the solar radiation pressure that depends on the instantaneous heliocentric radial velocity of each atom. Since Na atoms are ejected from Mercury's surface mainly as neutrals, magnetic and electric effects are not considered. Collisions with other particles are also neglected.

The region of thermal desorption domination is inconclusive. There are analogies between lunar and Mercurian atmosphere. Based on the observations of Na and K in the lunar atmosphere, Sprague et al. (1992) concluded that the atmosphere only in the subsolar region is dominated by thermal desorption, and in all other areas, the photo-desorption is dominant process. On the other hand, Hunten and Sprague (1997) mentioned that, at Mercury, day-side temperatures are so high that the region of thermal desorption domination is larger than that of the moon.

3. 3D Monte Carlo simulation

The distribution of the neutral atmosphere is strongly affected by solar radiation. The shape and size of the exosphere could change depending on true anomaly angle (TAA). Here we show the results of 3D Monte Carlo simulations in each mechanism at TAA = 0° where the effect of solar radiation becomes small and at TAA = 60° where the effect becomes large. A photo-ionization determines neutral Na lifetime in the exosphere. It changes from 4.5 h at perihelion to 19.4 h at aphelion in the case of theoretical estimation at low solar activity.

3.1. Photon-stimulated desorption (PSD)

It is known that physical processes and ejection threshold for Na atoms as the photon-stimulated desorption (PSD) are very similar to those as the electron-stimulated desorption (Killen and Ip, 1999). A laboratory experiment of the electron-stimulated desorption simulating ejection of

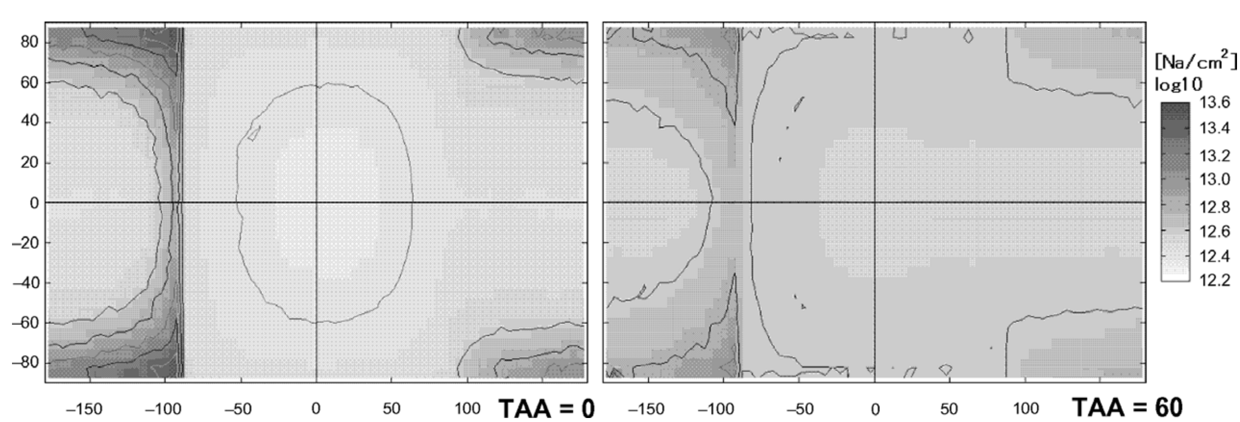

Fig. 1. The Na density distribution in Mercury's surface at TAA = 0° (left panel) and TAA = 60° (right panel). The centers of each picture mean subsolar point, horizontal axes do local time and vertical axes do latitude.