Sodium pick-up ion distribution during the first MESSENGER flyby: An event study

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Abstract

Observations by the Fast Imaging Plasma Spectrometer (FIPS) onboard MESSENGER, obtained during the first Mercury flyby on January 14, 2008, show that Mercury's magnetosphere is surrounded by an extended cloud of ions originating from the planetary exosphere [1]. The most abundant of these species was shown to be sodium, whose spatial distribution peaked at closest approach and exhibited secondary maxima in the magnetosheath. MESSENGER Magnetometer measurements demonstrated a diamagnetic decrease of the magnetic field magnitude at the outbound flank [2,3]. These findings suggest the possible formation of a plasma boundary layer. This layer could be associated with either enhanced plasma pressure due to sunward-convecting plasma sheet ions, solar wind ions entering the magnetosphere along open flux tubes, or heavy planetary ions with large gyro-radii entering from the magnetosheath [2,3]. Here we investigate this last possibility.

In order to understand the origin and spatial-temporal evolution of planetary ions, we have constructed maps of the energy, flux, and density of sodium pick-up ions during the flyby using single-particle tracing. The magnetosphere of Mercury is described by a magnetohydrodynamics simulation [4]. Measurements by MESSENGER upstream of the magnetosphere provide the input to the magnetospheric model. The modeled magnetic and electric fields and the magnetosheath velocity distributions provide the grid into which magnetosheath sodium ions are launched. The particles are followed until they escape to the solar wind or encounter the magnetopause.

The initial distribution of these ions is obtained from a Monte Carlo model of Mercury's exosphere [5]. The source processes considered by the model are photon-stimulated desorption (PSD), micrometeoroid impact vaporization, and sputtering caused by the solar wind. Ejecta from these processes have different energy spectra resulting in different height dependences. Additionally, each process has a different azimuthal profile: impact vaporization is likely isotropic, ion sputtering reduces as the cosine of the azimuth from the sub-solar point, and higher powers of cosine (azimuth) are possible for PSD due to adsorption or ion-enhanced diffusion [6]. These properties of exospheric neutrals critically affect the resulting pickup distribution and determine whether the ion flux can effectively alter the large-scale topology of the magnetosphere.

Our simulations thus provide a means to test the hypothesis of sodium-ion boundary layer formation, as well as to assess the distribution of sodium neutrals during the flyby. Note that the Mercury Atmospheric and Surface Composition Spectrometer [7] onboard MESSENGER observed neutral sodium in the anti-sunward tail and on the night side [8] but not the day-side distribution.

References