EPSC Abstracts
Vol. 5, EPSC2010-408, 2010
European Planetary Science Congress 2010

Mercury's exospheric magnesium: Constraints from MESSENGER second and third flyby data

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1. Introduction

In 2008 – 2009 the surface-bounded, collisionless exosphere of Mercury was probed with Ultraviolet and Visible Spectrometer (UVVS) measurements that were obtained during three planetary flybys by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft [*1*,*2*]. The measurements detailed the distribution of two previously known metallic constituents of Mercury's exosphere, Na and Ca, and indicated the presence in the gas phase of yet another metallic species, Mg. This paper presents a comparison of the observed magnesium abundances in the tail, polar regions, and the pre-dawn sector, to a number of exospheric models with the purpose of constraining the source and loss processes for this neutral species.

2. Findings from second flyby data

Chamberlain models of Mercury's neutral magnesium exosphere reveal that the tail is populated by hot ejecta having an equivalent Maxwellian temperature T of 20,000 K or higher as the atoms leave the surface [*3*]. In contrast, given the insignificant losses of magnesium neutrals to photoionization during their transport from the surface to the tail, the observations near the surface can be reproduced only if an additional source having temperatures of 3,000 – 5,000 K is assumed.

The cooler, near-surface component is consistent with the production of atomic Mg by micrometeoroid impact vaporization (T = 3,000 – 5,000 K) at rates $\leq 10^6$ Mg atoms cm^{-2} s^{-1}. This near-symmetric source contributes mainly to the column abundance measured near the dawn terminator (Fig. 1).

An obvious candidate process for energetic ejecta is sputtering by the solar wind precipitation along open field lines in Mercury's magnetosphere. However, magnesium in the regions of the polar tail sampled by MESSENGER was on average a factor of 3–5 higher than what can be explained by sputtering alone for a mean influx of 2×10^8 protons cm^{-2} s^{-1} poleward of ±50° and a sputter yield of 0.1 per ion.

This result suggests that, in analogy to what has been proposed for Mercury's exospheric calcium [*4*], the magnesium tail is likely supplemented by a population of dissociating molecules such as MgO at the rate of $(1 - 3) \times 10^6$ Mg atoms cm^{-2} s^{-1} and a "temperature" of 20,000 K or higher (Fig. 1).

3. Questions addressable with third flyby data

Results from a single pass provide limited information regarding neutral source processes because of uncertainties in the inferred exospheric temperature as well as the limited information on the amount and distribution of the sputtered flux. Consequently, the magnesium density and its distribution cannot be determined uniquely from the data obtained during the second flyby. Model comparisons to the measurements by MESSENGER obtained during its third flyby promise to further constrain these results given the substantially improved coverage of the near-surface region that was achieved during this encounter. Features of the modelled second flyby fits that can be validated or refuted with the newer observations include:

- If magnesium is primarily impact-driven, what is the cause of its non-uniform distribution? Given the geometry of Mg observations during the second flyby, there could be large enhancements, by up to a factor of 6, in the impact vapor production at dawn as a result of a meteoroid stream without an effect on the tail data but in clear agreement with the near-terminator measurements.
- Because the sputtering component is likely a substantial fraction of the total column abundance in the tail, could the exospheric Mg be "patchy" due to temporal effects related to the rapidly changing magnetospheric conditions during these observations [*7*]?
- Could the distribution of Mg at low altitudes be attributed to a source of dayside magnesium that is colder than impacts?

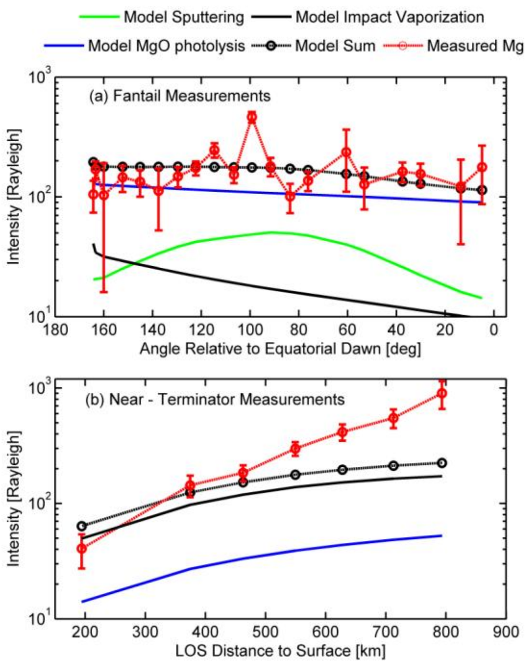

Figure 1. A possible model of Mercury’s magnesium exosphere consisting of three source processes: sputtering (green), impact vaporization of atomic Mg (black), and photolysis of MgO molecules (blue).

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