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Mercury's Mg Exosphere from MESSENGER data

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1. Introduction

The discovery measurements of Mercury's exospheric magnesium, obtained by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) probe during its second Mercury flyby [1], revealed a distribution with altitude that could not be attributed to a single ejection process from the regolith [2, 3]. Rather, the observed mix of cooler and hot components implied that multiple source mechanisms were at play, none of which dominated [2, 3]. Source processes considered included micrometeoroid impact vaporization, molecular photo- dissociation, and solar wind sputtering.

MESSENGER entered orbit about Mercury on 18 March, 2011. Since then, the Ultraviolet and Visible Spectrometer (UVVS) channel of MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) has been observing Mercury's exosphere nearly continuously. We present measurements with the UVVS of the magnesium distribution, obtained during the first six months of the primary orbital mission, to better constrain the source processes for this species.

2. Data Analysis Methods

Daily measurements of Mg brightness were fit with non-uniform exospheric models. With Monte Carlo sampling we traced the trajectories of a representative number of test particles until photoionization or contact with the surface. Test particles were uniformly distributed within each of 2,000 surface patches. These particles represent the mapping of a “unit flux” leaving one surface element onto the three-dimensional (3D) volume. Once these model “profiles” were saved onto a 3D grid, we ran sightlines from MESSENGER to infinity and computed brightness integrals. A penalized least squares regression method was then used to estimate the best spatial release pattern that fitted the data each day under the assumption of a given velocity distribution function for released ejecta. Distributions tested had temperatures of 700–20,000 K. The uncertainty in retrieved parameters from our method can be quantified with standard statistical techniques such as cross-validation and bootstrap.

Note that only those particles that contribute to the measurement can be constrained with our method. Atoms and molecules produced on the nightside must escape the shadow in order to scatter light if the excitation process is resonant-light scattering, as assumed here.

3. Results and Implications

A statistical analysis of data from three Mercury years revealed that dayside Mg can be fitted by the combination of a 3,000 K and a 20,000 K exosphere, although a 5,000 K source fits equally well. Such initial fits of the Mg data imply that the temperature of this species is not well-constrained. A model of two temperatures is more likely on the basis of information obtained during the flybys [1, 2, 3], during which, unlike orbital measurements, we could observe ejecta farther from the planet and hence better constrain the most energetic sources.

The combined source fluxes inferred from orbital phase data approach locally 2 × 10^6 atoms cm^{-2} s^{-1}, consistent with the flyby results, and may be provided by impacts as previously surmised [2,3]. The portion of the signal at 3,000 K would be emitted directly as atoms, and the portion at 20,000 K could be attributed to the formation of Mg-bearing molecules as a precursor to fast atoms [4].

The source of exospheric Mg is asymmetric. As shown in Figure 1, we often infer with our models that Mg originates near dawn. The cooler (3,000 K) component does not always correlate spatially with the hot component. The hot Mg component is almost always correlated to the hot Ca source, which is also inferred to originate near dawn, suggesting that hot Ca and Mg atoms could be perhaps produced by the same physical process. In order for micrometeoroid impacts to be responsible for producing gaseous Mg and Ca around Mercury, models of micrometeoroid precipitation onto Mercury's surface must account for the production of molecules with a dawn-dusk asymmetry. No predictions of micrometeoroid precipitation as a function of planetocentric location are available at present.

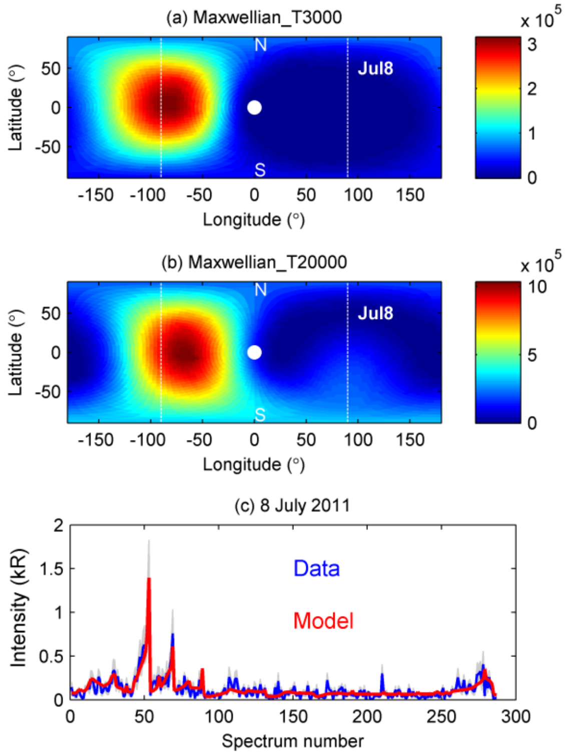

Figure 1: Mg flux (atoms cm^{-2} s^{-1}) from Mercury's surface under the assumption of a Maxwellian velocity distribution function for released ejecta. Both a cool and a hot component contribute to the measurements obtained on 8 July 2011: (a) efflux for the 3,000 K source, (b) efflux for the 20,000 K source, (c) comparison of model with measured brightness. The white dot denotes the subsolar point; dusk (evening) is on the right, and dawn (morning) is at left.

4. Limitations and Outlook

The finite dissociation lifetime of a molecule has not been modeled properly. Figure 1 shows a fit to the data if the molecules dissociated immediately after impact, a proxy for a more realistic dissociation source. This model of photo-dissociation of putative Mg-bearing molecules (e.g., MgO) can be improved by treating the unknown dissociation lifetime as a free model parameter (1- 1,000 s) [3]. The longer the assumed dissociation lifetime, the more localized the "footprint" of surface source flux will be, and the higher the rate necessary to explain the measurements.

We now know the distribution of surficial Mg to be highly non-uniform [5]. Therefore, inferring the properties of the source process(es) from MESSENGER measurements is complicated given that exospheric ejecta represent a convolution of surface content and source influx. As the mapping of Mercury's surface content improves, and as more exospheric measurements become available during MESSENGER's extended mission phase, the nature of source(s) of Mg gas will become clearer.

References

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