

Insights into the Nature of Mercury's Exosphere: Early Results from the MESSENGER Orbital Mission Phase

William E. McClintock (1), Matthew H. Burger (2,3), Rosemary M. Killen (2), Aimee W. Merkel (1), Menelaos Sarantos (2,3), Ann L. Sprague (4), Sean C. Solomon (5), Ronald J. Vervack, Jr. (6)

(1) Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303, USA; (2) Planetary Magnetospheres Laboratory, Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA; (3) Goddard Earth Sciences Technology and Research, Morgan State University, Baltimore, MD 21251, USA; (4) Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA; (5) Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; (6) The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA (william.mcclintock@lasp.colorado.edu).

Abstract

The Ultraviolet and Visible Spectrometer aboard the MESSENGER spacecraft has been making routine observations of Mercury's exosphere since March 29, 2011. Correlations of the spatial distributions of Ca, Mg, and Na with MESSENGER magnetic field and energetic particle distribution data provide insight into the processes that populate the neutral exosphere.

1. Introduction

Mercury is surrounded by a surface-bounded exosphere that is the interface between its surface and the space environment. Before the Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) mission, Mercury's exosphere was known to contain hydrogen (H), helium (He), sodium (Na), potassium (K) and calcium (Ca). The Mariner 10 Ultraviolet Spectrometer detected H and He [1], and ground-based observers discovered Na, K, and Ca [2-4]. While H and He are thought to originate from the solar wind, Na, K, and Ca are likely produced by the interaction of the space environment with the planet's surface. Sources that have been identified include photon-stimulated desorption (PSD), solar wind sputtering, thermal vaporization, electron-stimulated desorption, and meteoroid impact [e.g., 5]. Once released, neutral constituents travel on collisionless trajectories under the influence of gravity and solar wind pressure until they return to the surface, escape from the planet, or are ionized. Ground-based observations have shown that Na, and K are highly variable, exhibiting both seasonal and episodic components [6]. Seasonal variations arise primarily from changes the planet's orbital distance from the Sun and heliocentric radial velocity. Episodic variations can result from spatial and temporal variations in solar wind precipitation patterns that are controlled by the interplanetary magnetic field.

2. MESSENGER Observations

MESSENGER's route to Mercury included three flybys of the planet. During each of the flybys the Ultraviolet and Visible Spectrometer (UVVS) channel of MESSENGER's Mercury Atmospheric and Surface Composition Spectrometer (MASCS) observed the anti-sunward hemisphere starting at a distance of ~ 25,000 km behind the planet's midnight surface and ending as the spacecraft crossed the plane of the terminator. The Na distributions seen during these encounters displayed enhanced concentrations above the planet's poles and seasonal density variations [7-9]. These were consistent with the picture developed from ground-based observations in which solar wind plasma sputters Na or enables enhanced PSD, and the ejected atoms are accelerated antisunward into the tail by seasonally dependent solar radiation pressure [5]. Observations of Ca revealed unexpected enhancements in the dawn-side hemisphere. Mg was also observed during the second and third flyby. Its distribution is more uniform than that of Ca, suggesting that the source, transport, and loss processes for these two chemically similar species are different. Furthermore, the significant concentrations of Ca and Mg in the tail region of Mercury are difficult to reconcile with a dayside sputtering source and solar-radiation-pressure transport to the tail [8]. Altitude profiles above both the north and south poles, obtained during the third flyby, revealed distinct distributions for all three species. Both Na profiles displayed two-component distributions, suggesting multiple source processes. The southern scans for Ca and Mg exhibited similar single-component profiles; but the northern Mg scan exhibited a complex structure, which is inconsistent with a single source, even though the northern Ca scan matched its southern counterpart. The UVVS also detected Ca⁺ approximately 2.5 Mercury radii behind the terminator. This pattern is consistent with

photoionization of Ca on the dayside followed by transport by magnetic field convection [9].

MESSENGER entered orbit around Mercury on March 18, 2011, and the UVVS began routine observations of both the dayside and night side exosphere on March 29. Whereas the flybys enabled extensive observations of the neutral tail, operational constraints limit coverage during orbit to ~ 5000 km behind the terminator. UVVS operational scenarios during the first Mercury year of MESSENGER's nominal mission include observations of previously measured species (Ca, Mg, Na, K, and H). With the exception of K, altitude profiles for all of these species are routinely measured because they have strong emission lines that lie within the UVVS wavelength range (115 – 600 nm). Early orbital UVVS operations also include wavelength scans for neutral species with weaker emissions that are known or are predicted to be present in the surface materials (K, Si, Al, S, Mn, Fe, OH). Emissions from these species are not sufficiently bright for routine observation using the current operational scenarios. Targeted observing sequences, scheduled for MESSENGER's third and fourth Mercury years, will measure average exosphere content for those species that are detected and substantially reduce the detection limits for the rest. Scans for Mg⁺ and Ca⁺, which both have strong emission lines in the UVVS wavelength range, are also periodically conducted, but those ions have not yet been detected from orbit.

3. Discussion

During early orbital observations Mg has been detected at high altitudes, up to 4000 km above the surface, on both the dayside and night side and has a relatively uniform dawn-dusk distribution. Ca is patchier than Mg and is usually observed at lower altitudes (~ 2000 km). It exhibits the equatorial, dawn enhancements observed during the flybys. E-folding heights for Na on the dayside are ~ 200 km, consistent with the low-energy components observed in the polar altitude profiles during the third flyby. Distributions of all three species on the night side are variable and do not correlate with each other, consistent with flyby observations.

Correlations of Mercury's neutral exosphere composition and structure with direct measurements of the space environment from MESSENGER's Magnetometer and Energetic Particle and Plasma Spectrometer (EPPS) provide insight into source processes. Flyby observations showed that the location and area of the surface exposed to solar wind

plasma is highly variable. In addition early-orbit EPPS observations reveal episodic populations of energetic electrons in the night side magnetosphere. These impact the surface and have been observed to produce X-rays from the surface materials as observed by the MESSENGER X-Ray Spectrometer.

Acknowledgements

This work was supported by the National Aeronautics and Space Administration's Discovery Program through a contract to the University of Colorado from the Carnegie Institution of Washington.

References

- [1] Broadfoot, L.A., Kumar, S., Belton, M.J.S., McElroy, M.B.: Mercury's atmosphere from Mariner 10, *Science*, 185, 166-169, 1974.
- [2] Potter, A.E. and Morgan, T.H.: Discovery of sodium in the atmosphere of Mercury, *Science*, 229, 651-653, 1985.
- [3] Potter, A.E. and Morgan, T.H.: Potassium in the atmosphere of Mercury, *Icarus*, 67, 336-340, 1986.
- [4] Bida, T.A., Killen, R.M., and Morgan, T.H.: Discovery of calcium in Mercury's atmosphere, *Nature*, 404, 159-161, 2000.
- [5] Killen, R.M., et al.: Processes that promote and deplete the exosphere of Mercury, *Space Sci. Rev.*, 132, 433-509, 2007.
- [6] Killen, R.M., et al: Source rates and ion recycling rates for Na and K in Mercury's atmosphere, *Icarus*, 171, 1-19, 2004.
- [7] McClintock, W.E., et al.: Mercury's exosphere: Observations during MESSENGER's first Mercury flyby, *Science*, 321, 92-94, 2008.
- [8] McClintock, W.E., et al.: MESSENGER observations of Mercury's exosphere: Detection of magnesium and distribution of constituents, *Science*, 324, 610-613, 2009.
- [9] Vervack, R.J., Jr., et al.: Mercury's complex exosphere: Results from MESSENGER's third flyby, *Science*, 329, 672-675, 2010.