MESSENGER OBSERVATIONS OF MERCURY'S EXOSPHERE: WHERE DO WE STAND AFTER THREE FLYBYS? Ronald J. Vervack, Jr.[1], William E. McClintock[2], E. Todd Bradley[3], Matthew H. Burger[4,5], Rosemary M. Killen[5], Ann L. Sprague[6], Nelly Mouawad[4], Noam R. Izenberg[1], Mark C. Kochte[1], and Mark R. Lankton[2], [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (Ron.Vervack@jhuapl.edu); [2]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303; [3]Dept. of Physics, University of Central Florida, Orlando, FL 32816; [4]Dept. of Astronomy, University of Maryland, College Park, MD 20742; [5]NASA Goddard Space Flight Center, Greenbelt, MD 20771, [6]Lunar and Planetary Laboratory, The University of Arizona, Tucson, AZ 85721.

Introduction: The MESSENGER spacecraft [1] has completed its third and final flyby of Mercury before orbit insertion in March 2011. During each of the three flybys, the Ultraviolet and Visible Spectrometer (UVVS) channel of the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) [2] conducted numerous observations of Mercury's exosphere. Because of the high spatial resolution possible with MASCS, the first flyby revealed detailed structure in the sodium (Na) and calcium (Ca) distributions, including an unexpected dawn-dusk asymmetry in Ca [3]. Observations during the second flyby not only confirmed the structure in the Na and Ca distributions but also resulted in the first detection of neutral magnesium (Mg), a species long predicted to be a significant component of the surface [4]. Continuing this trend of discoveries, the third flyby provided a dataset that includes the first MASCS observations over the polar regions of the planet and the first detection of emission from an ionized species, in this case Ca^+. These nearly simultaneous, high-spatial-resolution measurements of several geochemically important species obtained by MASCS during the MESSENGER flybys of Mercury have provided an unprecedented glimpse into the structure of the exosphere and the processes that control it.

MESSENGER Observations: The workhorse on MESSENGER for measuring emission from both neutral and ionized species in Mercury's exosphere is the UVVS component of the MASCS instrument. It is a scanning grating monochromator with three spectral channels — far-ultraviolet (FUV: 115-190 nm), mid-ultraviolet (MUV: 160-320 nm), and visible (VIS: 250-600 nm) — that provide a spectral resolution varying from 0.2 nm at UV wavelengths to 0.5 nm at visible wavelengths [2]. The instrument is equipped with a two-position aperture that subtends a field of view of either 0.04°×1° or 0.04°× 0.05°. The combination of the field of view and spectral resolution enables excellent observations of Mercury's exospheric emissions on both spatial and spectral scales, from which the distribution of a given species can be inferred.

The MESSENGER trajectories during the three Mercury flybys and the UVVS observations in each case are illustrated in Figure 1. Observations occurred in five more or less distinct regions, which are color-

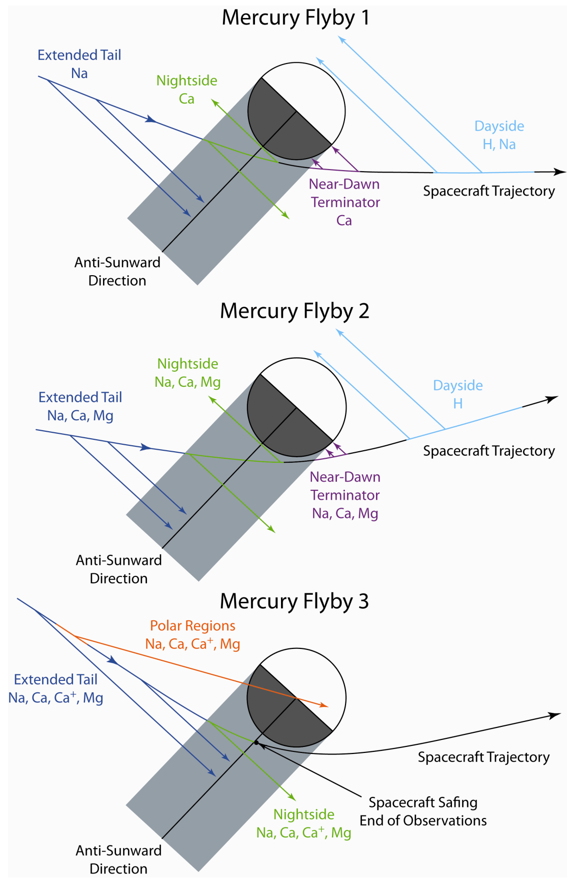

Figure 1. Schematic illustration of the MASCS observations during MESSENGER's three Mercury flybys. The spacecraft moved from left to right in all flybys; the view is looking down from the north. Five observation regions are color-coded: extended tail (blue), polar regions (red), nightside (green), near-dawn terminator (purple), and dayside (cyan). The species observed in each region during each flyby are shown. Arrows indicate the line-of-sight direction for the observations. The angle off the trajectory for the polar observations is not to scale; the observations occurred farther out than can be shown on this diagram. During the nightside observations, the look direction rotated from dawn to dusk through north during the first two flybys and from south to north through dawn during the third flyby. Black portions of the spacecraft trajectory are regions of no exospheric observations.

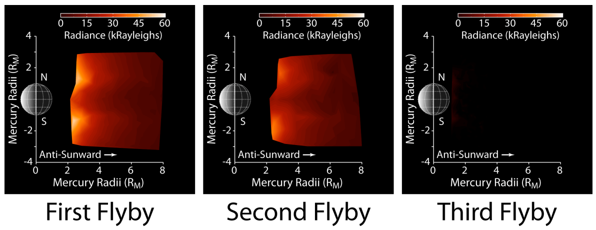

Figure 2. Comparison of Na emission in the extended tail during MESSENGER's three Mercury flybys.

coded in Figure 1: (1) extended tail, (2) polar regions, (3) nightside, (4) near-dawn terminator, and (5) dayside. We focus on the first three regions here.

The extended tail observations during the inbound leg of each trajectory provide an excellent illustration of MASCS observations of the various exospheric species, including both spatial and temporal differences that were observed. These measurements were obtained by rocking the UVVS line of sight back and forth about the Sun-Mercury line, sweeping out a region of space that is approximately three planet diameters tall when projected onto the plane formed by the Sun-Mercury line and Mercury's rotational pole (Figure 2). The motion of the line of sight across the shadow of the planet and the relatively long observational path lengths complicate the interpretation of the resulting "images," but such images provide a useful framework for comparison. During all flybys, successful observations in the extended tail were obtained of the Na doublet emission at 589.0/589.6 nm. Observations of emission by Mg at 285.2 nm and by Ca at 422.7 nm were obtained during both the second and third flybys, while emission from Ca^+ at 393.5 nm was observed during the third flyby.

Figure 2 compares the Na extended tail emission from the three flybys. These MASCS observations capture the changing distribution of neutral Na in the tail region that is a consequence of "seasonal" effects on the exosphere. Mercury's orbit is rather elliptical so the Doppler shift of Mercury relative to the Sun changes with time, as does the solar flux received by the planet. These two factors combine to provide a noticeable difference in the radiation acceleration experienced by exospheric species, a process that pushes atoms behind the planet to form the extended tail. During the third flyby, the magnitude of the radiation acceleration for Na was significantly reduced in comparison to what was seen during the first two flybys, and the extended tail became too weak to detect because few Na atoms were pushed behind the planet. In contrast, the population of Na atoms over the poles was relatively high, so we know a substantial amount of Na was actually released to the exosphere.

Observations of Ca and Mg obtained nearly simultaneously with the Na observations (small time — and thus pointing — differences owing to the scanning nature of the UVVS) in the tail region during the second and third flybys show that the spatial distributions differ for each of the three species. In contrast to Na, behind the planet Ca exhibited strong emission near the equatorial regions and less emission at higher latitudes during both of the flybys. Magnesium, on the other hand, had a distribution that may have been mostly isotropic during the second flyby, possibly a reflection of the observational sampling, but was potentially variable on moderate spatial scales during the third flyby. Observations of the Ca^+ distribution behind Mercury during the third flyby showed that it is concentrated near the equatorial regions like Ca. However, because Ca^+ is subject to forces exerted by the magnetosphere of Mercury (e.g., electric fields, reconnection events), the distribution in the dawn-dusk direction (out of the plane of the page in Figure 2) may be different than that of the neutral Ca. Calcium has a short photoionization lifetime, so nearly simultaneous observations of both Ca and Ca^+ may enable an accurate determination of the total exospheric Ca abundance to the extent that the magnetospheric influence on the Ca^+ can be understood.

Observations of the nightside and polar regions also showed different and varying distributions of Na, Ca, and Mg. The distributions observed in these regions, as well as in the extended tail, provide insights into the processes that generate and maintain the exosphere. For example, the Ca and Mg distributions require a high-energy source process because their distribution extends high above the surface [5,6], whereas Na is generally dominated by the photon-stimulated desorption source process that yields a distribution affected by the local solar zenith angle [7].

MESSENGER's flybys have provided important new details about the distribution of exospheric species, but the MASCS observations to date are only snapshots of the complicated Mercury exospheric system. A full understanding of the exosphere will require many observations spanning a variety of observing conditions, and we expect to obtain such a dataset during the orbital phase of the MESSENGER mission.

References: [1] Solomon, S. C., et al. (2007) *Space Sci. Rev.*, *131*, 3–39. [2] McClintock, W. E., and M. R. Lankton (2007) *Space Sci. Rev.*, *131*, 481–521. [3] McClintock, W. E., et al. (2008) *Science*, *321*, 92–94. [4] McClintock, W. E., et al. (2009) *Science*, *324*, 610–613. [5] Killen, R. M., et al. (2009), *Icarus*, submitted. [6] Bradley, E. T., et al. (2009), *EOS Trans. AGU*, *90*(53), Fall Mtg. suppl., P21A-1210. [7] Burger, M. H., et al. (2009), *Icarus*, submitted.