FIRST ION PLASMA MEASUREMENTS IN THE MERCURY MAGNETOSPHERE. Thomas H. Zurbuchen[1], Jim M. Raines[1], George Gloeckler[1], James A. Slavin[2], Stamatios M. Krimigis[3,4], Rosemary M. Killen[5], Ann L. Sprague[6], Ralph L. McNutt, Jr.[3], and Sean C. Solomon[7], [1]Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, 2455 Hayward St., Ann Arbor, MI 48109-2143, USA, thomasz@umich.edu, jraines@umich.edu, gglo@umich.edu; [2]Code 670, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA, James.A.Slavin@nasa.gov; [3]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723, USA, tom.krimigis@jhuapl.edu, Ralph.McNutt@jhuapl.edu; [4]Academy of Athens, Office of Space Research and Technology, Soranou Efesiou 4, Athens 11527, Greece; [5]Department of Astronomy, University of Maryland, College Park, MD 20742, USA, rkillen@astro.umd.edu; [6]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, sprague@lpl.arizona.edu; [7]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, scs@dtm.ciw.edu.

Introduction: The MESSENGER mission to Mercury offers the first opportunity for direct measurements of low-energy ions in Mercury's magnetosphere. We present observations by the Fast Imaging Plasma Spectrometer (FIPS), which is part of the Energetic Particle and Plasma Spectrometer (EPPS) instrument [1,2]. These first observations characterized Mercury's heliospheric environment, its magnetosphere, and, potentially, pick-up ion components originating from surface sputtering and atmospheric processes [3]. We focus on the observations of the sputtered component, to analyze the processes responsible for the violent interaction of the heliospheric environment with Mercury. We then place these observations in the context of predictions of Mercury's exosphere from magnetohydrodynamic and other models [4,5].

Observations: During its two 2008 Mercury flybys, MESSENGER provided unique insights and numerous "firsts" that have already transformed our understanding of Mercury. Prior to these encounters, the planet Mercury was visited three times in 1974-75 by Mariner 10. The observations yielded irrefutable evidence for an internal magnetic field and for magnetospheric activity that was discovered using magnetic field and high-energy particle measurements [6], but no measurements of the ionized exosphere were available. Thus, the FIPS measurements on MESSENGER provided novel and unprecedented contributions to many of the scientific discussions that have been ongoing for over 30 years. FIPS measures ions from 100 eV/e to 14 keV/e with a time resolution of up to 8 s. During a measurement interval, FIPS detects individual ions within the mass range 1-60 amu that enter its unique, 1.4-π-sr field of view. These observations occur during the entire Mercury encounter, to a Mercury closest approach distance of 200 km.

Sources of the Ionized Exosphere: Because of the small size of Mercury's magnetosphere and Mercury's inner heliosphere location, heliospheric interactions with Mercury's surface are more violent than those of any other terrestrial planet [7]. These heliospheric interactions are depicted in Fig. 1. Because of insufficient shielding by Mercury's magnetic field, solar wind components can directly interact with Mercury's surface [4]. These collisional interactions result in ion sputtering and chemical sputtering. Chemical sputtering ensues when the sputtering agent, i.e., solar wind ions, undergo chemical interactions with the planetary surface. The reaction product is a molecule [8,9]. Typically, both interactions result in neutral products, which become part of the Mercury environment once they undergo ionization, most likely photo-ionization.

However, a minor fraction of these products can sputter directly from the planetary surface, leading to

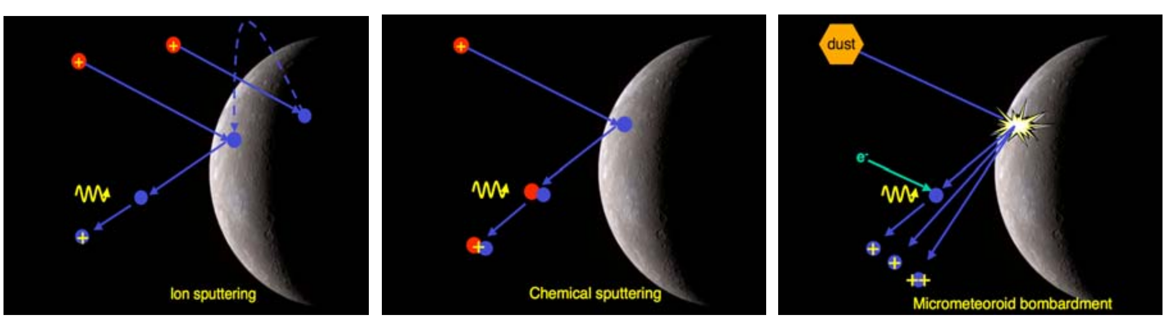

Fig. 1. Surface interaction processes leading to ionized exosphere. See text for details.

trajectories that are predictable, for a given configuration of the magnetospheric electric and magnetic fields. The third contribution to the ionized exosphere comes from surface interactions with micrometeoroids. Due to the comparatively large orbital velocity of Mercury, and the fact that, because of their electromagnetic interactions, small micrometeoroids are expected to be omnidirectional, these interactions are much more violent on Mercury than on the Moon or other planetary bodies in the outer solar system. Micrometeorioid impacts lead to small-scale evaporation and possibly ionization, in which both the micrometeoroid material and surface material are ejected from Mercury's surface. One of the core questions addressed by the MESSENGER data relates to the relative importance of these source processes, and particularly the unexpected importance of water-group ions and highly charged particles in Mercury's ionized exosphere.

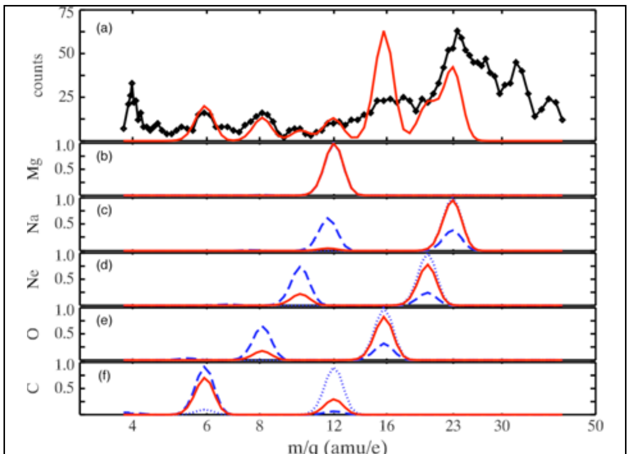

Fig. 2. MESSENGER observations of doubly charged ions, compared with equilibrium models for 30,000 K (blue dashed), 50,000 K (red) and 75,000 K (blue dotted).

MESSENGER Data: The data obtained by the first MESSENGER flyby is documented in Zurbuchen et al. [10]. With respect to the composition of the ionized exosphere, the second flyby yielded a qualitatively consistent picture. The top panel of Fig. 2 reproduces the mass spectrum of the first flyby. First, FIPS observed ionized Mg and Na, possibly Al, as well as Si, and Fe (not shown in Fig. 2). Ionized He and O were also found and are indicative of surface sputtering. Ionized carbon is detected but is unlikely to be from the Mercury surface. Second, FIPS observed molecular components, such as water-group ions and other molecules. The fluxes of these molecular species were as much as ~20% of the flux of ionized Mg and Na measured during the two flybys. This suggests that chemical sputtering may be a very important source process of the ionized exosphere. Third, we have observations of doubly charged ions (Fig. 2), which are indicative of a hot source. In order to determine an approximate temperature of the source for these particles, we performed ionization equilibrium calculations, effectively solving for a time-stationary Saha equation, using a set of consistent ionization and recombination rates [11]. Three equilibrium temperatures are assumed in Fig. 2, and equilibrium distributions are calculated for a series of five atomic species. The best consistency with the data is obtained at an electron temperature of approximately 50,000 K. The model over-predicts O^+, since it does not include the water-group ions that would be a source of O^+ as well and were therefore not included as a constraint in the fit. It is possible that magnetospheric plasmas are heated to that temperature, but the ionization equilibration lifetime is expected to exceed many years, by far exceeding the transport time of ions in Mercury's exosphere. The source process for these doubly charged particles remains under investigation, as 50,000 K appears to be too large to be associated with micrometeoroid-impact-generated plasmas.

Summary: The 2008 MESSENGER flybys have provided novel data on Mercury's exosphere. These data indicate that surface sputtering, chemical sputtering, and micrometeoroid impact are all important to Mercury's ionized exosphere. All three components are comparable in flux, inconsistent with some predictions that have favored ion sputtering as the dominant source. The heliospheric environment interacting with Mercury, however, has never before been observed with the composition resolution that FIPS is providing. It is therefore possible that interactions of solar wind with the near-dust environment can affect the composition of the heliospheric plasma, which would also affect exospheric composition.

References: [1] Andrews G. B. et al. (2007) *Space Sci. Rev., 131*, 523-556. [2] Zurbuchen T. H. et al. (1998) *Missions to the Sun., SPIE 3442*, 217. [3] Slavin J. A. et al. (2007) *Space Sci. Rev., 131*, 133-160. [4] Kabin K. et al. (2000) *Icarus, 143*, 397-406. [5] Domingue D. L. et al. (2007) *Space Sci. Rev., 131*, 161-186. [6] Russell C. T. et al. (1988) in *Mercury* (eds. F. Vilas, C. R. Chapman, and M. S. Matthews), Univ. Arizona Press, Tucson, 514-561. [7] Zurbuchen T. H. et al. (2004) *Adv. Space Res., 33*, 1884-1889. [8] Gibson, E. K., Jr., (1977) *Phys. Earth Planet. Inter., 15*, 303-312. [9] Potter, A. E. (1995) *GRL, 22*, 3289-3293. [10] Zurbuchen, T. H. et al. (2008) *Science, 321*, 90-93. [11] Mazzotta, P. et al. (1998) *Astron Astrophys. Suppl. Ser. 133*, 403-409.