HYDROGEN AT MERCURY'S NORTH POLE? UPDATE ON MESSENGER NEUTRON MEASUREMENTS.

David J. Lawrence[1], William C. Feldman[2], Larry G. Evans[3], John O. Goldsten[1], Ralph L. McNutt Jr.[1], Larry R. Nittler[4], Patrick N. Peplowski[1], Thomas H Prettyman[2] and Sean C. Solomon[4]. [1]The Johns Hopkins University Applied Physics Laboratory (11100 Johns Hopkins Drive, Laurel, MD, 20723; David.J.Lawrence@jhuapl.edu); [2]Planetary Science Institute, Tucson, AZ 85719; [3]Computer Sciences Corporation, Lanham-Seabrook, MD 20706; [4]Carnegie Institution of Washington, Washington, DC 20015.

Introduction: One of the primary goals of the MESSENGER mission is to understand the nature of the radar-bright deposits at the poles of Mercury [1]. The leading explanation is that these deposits, located inside permanently shadowed craters near both poles, contain large amounts of frozen water ice. Orbital neutron spectroscopy has become a standard technique for making measurements of planetary surface hydrogen concentrations, having been used to make such measurements at the Moon and Mars [2,3]. A Neutron Spectrometer (NS) was included on the MESSENGER spacecraft to measure any hydrogen concentrations near Mercury's north pole so as to determine if large amounts of hydrogen, and by inference water ice, can be correlated with the radar-bright signatures.

The MESSENGER spacecraft has been in orbit about Mercury since 18 March 2011. The NS has been successfully operating and collecting data throughout most of the primary orbital mission. Here we provide an update on the expected neutron signals, the operation of the NS, and the status of the NS data analysis.

Expected NS Signals: An analysis carried out prior to Mercury orbit insertion (MOI) predicted the neutron signals expected for several possible models of water ice in the radar-bright craters at Mercury's north pole [4]. It was concluded that NS measurements of epithermal neutrons would confirm the presence of hydrogen concentrations in excess of 50 wt.% water-equivalent hydrogen (WEH) distributed in the radar-bright regions. Specifically, if there are concentrations of water ice near Mercury's north pole that cause large reductions in epithermal neutrons at the surface, the NS would detect epithermal neutron counting-rate reductions in orbit of up to ~4% relative to dry materials with a statistical significance of >9 standard deviations after correcting for all systematic variations.

We have since investigated how measurements of fast neutrons can provide independent confirmation of the presence of water ice. From fast neutron efficiency calculations similar to those used for the Dawn GRaND instrument [5], we have calculated the signal change in fast neutrons from the MESSENGER NS as a function of WEH (Fig. 1). Whereas fast neutrons show a smaller signal change than epithermal neutrons, sufficiently large amounts of water ice can nevertheless reduce the fast neutron signal at the surface by over an order of magnitude. When translated to orbital altitudes, 100 wt.% water ice at the surface would provide a comparable signal to that from epithermal neutrons. If water ice is buried by tens of centimeters of dry soil, as has been suggested [1], then fast neutrons would show a smaller reduction in flux than calculated here [6]. Separate measurements of epithermal and fast neutrons may therefore provide a measure of the thickness of any dry soil covering.

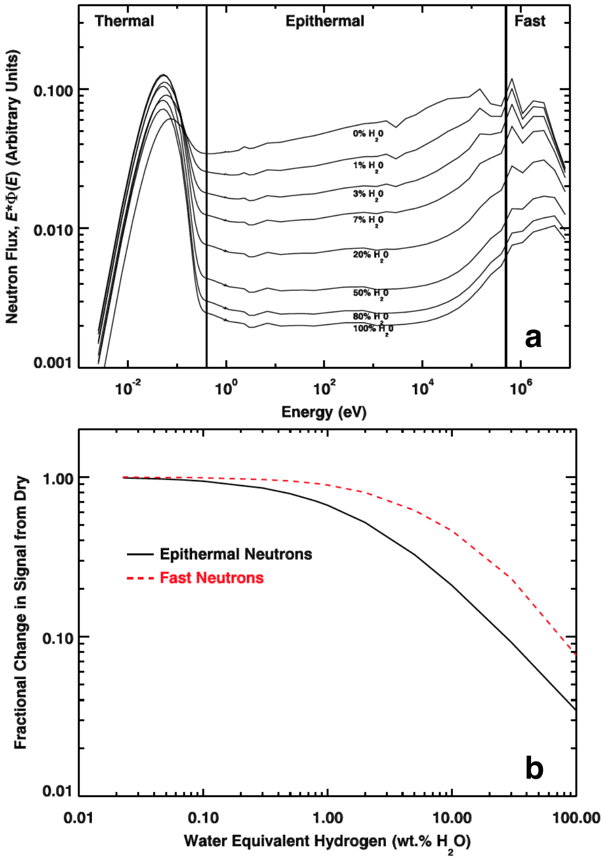

Fig. 1. (a) Neutron lethargy (flux times energy) versus energy for various amounts of water ice ranging from 0 wt.% H_2O to 100 wt.% H_2O. Energy ranges for epithermal and fast neutrons labeled. (b) Fractional change in neutron signal from a dry soil for epithermal (black solid) and fast (red dash) neutrons versus WEH concentration.

Orbital Operation of MESSENGER NS: The MESSENGER NS has operated near-continuously since MOI except for a 10-day interval in June during a MESSENGER long-eclipse period. Between 26 March 2011 and 31 December 2011, the NS has collected 271.6 days of data with an effective 30.5 days of collection time at less than 4000 km altitude. Of the total collection time, 33.7 days have been eliminated due to solar particle events, Mercury magnetospheric energetic electron events, and spacecraft thrust maneuvers. The remaining 237.9 days of valid data represent an 87.5% duty cycle, which is comparable to that for previous orbital neutron measurements [7]. All of the NS sensors are operating well and within specification established from calibration data [8].

Initial Analysis of MESSENGER NS Data: Characteristics of the MESSENGER mission present data reduction challenges not experienced previously [e.g., 2,3]. First, due to mission operational requirements, the MESSENGER spacecraft is in a highly eccentric orbit about Mercury with a periapsis altitude of a few hundred km in the northern hemisphere and an apoapsis altitude of ~15,200 km. This is in contrast to the near-circular orbits of previous planetary neutron measurements. As a consequence, mapping coverage is obtained only for Mercury's northern hemisphere, and substantial corrections must be made to the data to compensate for the constantly changing spacecraft altitude (Fig. 2). The expected signature of water ice deposits also will be relatively small because of the spacecraft's high altitude above the deposits. Second, when close to the planet, the NS acquires data at a variety of spacecraft attitude orientations relative to nadir, a situation that requires the development of corrections not needed for previous measurements acquired at constant nadir-pointing orientations. All these corrections require a complex data analysis procedure that is currently in process and is summarized below.

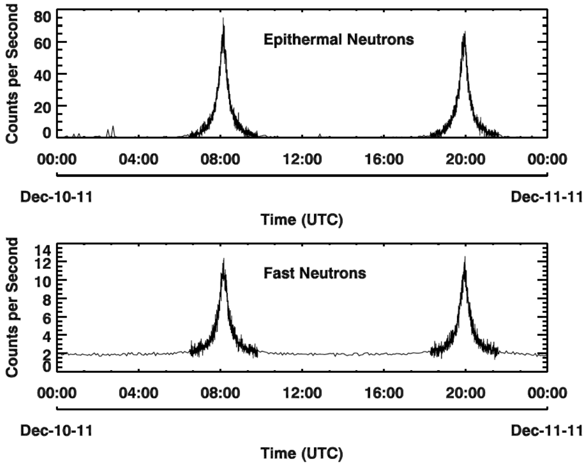

Fig. 2. Epithermal (top) and fast (bottom) neutron count rate data taken from a single day (10 December 2011) of orbital operation. The dominant variation in the data is due to the changing spacecraft altitude. The count rate peaks occur at the two spacecraft periapsis locations for each 12-hour orbit.

The analysis is being carried out with independent processing of epithermal neutrons and fast neutrons. Additional analysis of simulated data using a full instrument/spacecraft particle transport model [9] is being conducted in parallel to guide the direction of the data processing. Important parameters that affect the neutron data with variations on the order of 4% or greater are the following.

Altitude Variations: The largest effect that drives the measured neutron signals are variations in the solid angle subtended by Mercury within the omnidirectional NS field of view because of variable spacecraft altitude (Fig. 2). A simple solid-angle correction is understood [e.g., 7], but altitude-dependent spacecraft obscuration effects must also be taken into account.

Spacecraft Orientation: The spacecraft orientation can affect the measured neutrons during each orbit as well as during different orbital seasons. From a detailed survey of the data, the most important orientation angle is the spacecraft y-axis angle, which is defined as the angle between the spacecraft y-axis (Magnetometer boom) and the local nadir. Separate y-axis angle corrections must be made for epithermal and fast neutrons to account for the energy-dependent attenuation of neutrons through spacecraft material.

Vertical Doppler Effect: A neutron Doppler enhancement occurs when the speed of the spacecraft is faster than the neutron speed. For previous neutron measurements, the Doppler effect was important only for along-track velocities. For the MESSENGER NS, a vertical Doppler effect (i.e., along the local nadir vector) is also important. This effect shows an asymmetry between incoming and outgoing portions of the orbit and is being corrected through a combination of data and simulations.

Summary: Throughout the MESSENGER's primary mission, the orbital inclination continues to increase towards a maximum near 85ºN. Thus, the best neutron data for identifying polar hydrogen will be collected during the last quarter of the yearlong primary mission. As the NS analysis proceeds, we are continuing to gain quantitative understanding of the many effects that influence the measured neutrons, now approaching the needed 4% level.

References: [1] J.K. Harmon et al., *Icarus*, 211, 37, 2011; [2] W.C. Feldman et al., *JGR*, *107*, 23231, 2001; [3] W.C. Feldman et al., *Science*, 297, 75, 2002; [4] D.J. Lawrence et al., *Planet. Space Sci*., 59, 1665, 2011; [5] T.H. Prettyman et al., *Space Sci. Rev.*, 162, 10.1007/s11214-011-9862-0, 2011 [6] W.C. Feldman et al., *JGR*, 116, 10.1029/2011JE003806, 2011; [7] S. Maurice et al., *JGR*, *109*, 10.1029/ 2003JE002208, 2004; [8] J.O. Goldsten et al., *Space Sci. Rev*., 131, 339, 2007; [9] D.J. Lawrence et al., *Icarus*, *209*, 195, 2010.