THE PSYCHE GAMMA-RAY AND NEUTRON SPECTROMETER: CHARACTERIZING THE COMPOSITION OF A METAL-RICH BODY USING NUCLEAR SPECTROSCOPY.

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Introduction: The asteroid 16 Psyche is the largest of the metal asteroids, and is thought to be the exposed core of a larger differentiated body, or may possibly be composed of primordial material having accreted from highly reduced metal-rich material [1]. In the latest round of NASA Discovery mission proposals, an orbital mission to 16 Psyche was selected for a Phase A study with possible launch in late 2020 [2]. The science goals of the Psyche mission include understanding planetary iron cores, examining the interior of a differentiated body, and exploring a new type of world, namely a metal planet. A key part of answering the science goals and objectives of the Psyche mission is to measure its surface elemental composition. Specific diagnostic measurements include elemental abundances of Ni, Fe, Si, K, S, Al, Ca, Th, and U, as well as the spatial distribution of 16 Psyche's metal-to-silicate fraction (or metal fraction).

Planetary nuclear spectroscopy (measurements of gamma-ray and neutron emissions from a planetary surface) is ideal for measuring the composition 16 Psyche, which likely has high concentrations of FeNi metal, and possibly spatially varying amounts of metals and silicates. Nuclear spectroscopy is well suited for such measurements because Fe and Ni produce a large flux of gamma rays and neutrons, and both measurables are highly sensitive to varying amounts of metals and silicates that may be distributed across the surface of 16 Psyche. Here, we describe the Psyche Gamma-Ray and Neutron Spectrometer (GRNS) and discuss the range of possible neutron measurements at 16 Psyche. A companion report describes expected gamma-ray measurements at 16 Psyche [3].

The Psyche Gamma-Ray and Neutron Spectrometer (GRNS): The Psyche GRNS consists of gamma-ray and neutron sensors that will make comprehensive measurements of 16 Psyche's surface elemental composition. These sensors measure gamma rays and neutrons created when energetic galactic cosmic ray (GCR) protons impact the asteroid's surface. Gamma-ray and neutron spectroscopy has become a standard technique for measuring planetary surface compositions, having successfully made composition measurements of the Moon, Mars, Mercury, and the asteroids Eros, Vesta, and now Ceres [4–12]. The Psyche GRNS is a high-heritage design based on the successful MESSENGER GRNS [13] and the Lunar Prospector Neutron Spectrometer (LP-NS)[14]. Specifically, gamma rays are measured with a cryocooled high-purity Ge (HPGe) sensor surrounded by a borated-plastic anticoincidence shield (ACS). The ACS serves to both reduce the charged-particle background in the Ge sensor, and to measure epithermal (neutron energy, E_n between 0.4 eV and 500 keV) and fast neutrons ($0.5<E_n<10$) as was done on the Lunar Prospector [14], Mars Odyssey [15], Dawn [16], and MESSENGER [13] missions. Slow neutrons ($E_n>0.01$ eV) are measured with a ^{3}He gas proportional counter as was done on Lunar Prospector [14].

Planetary Neutron Measurements: GCR-produced neutrons have proven to be highly diagnostic of planetary surface compositions and are best used in conjunction with planetary gamma-ray measurements. Gamma-ray measurements provide element-specific information, but with generally poorer statistical precision. In contrast, neutron measurements are not as element specific, but have higher statistical precision and can provide high-fidelity maps of quantitative composition parameters (including weighted elemental sums) that can be directly linked to surface elemental compositions. Specifically, thermal neutrons are sensi-

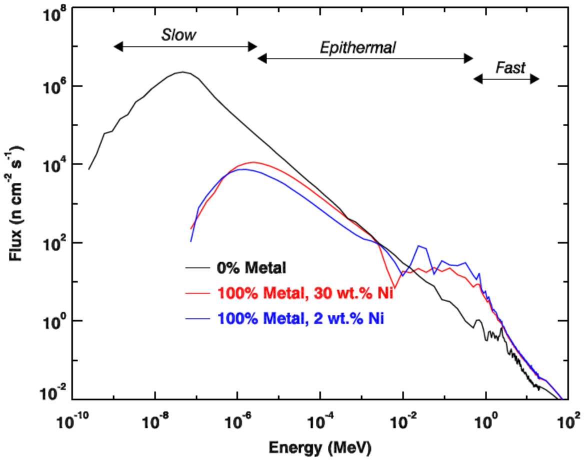

Fig. 1. Modeled neutron flux spectra for possible Psyche surface compositions, ranging from provinces containing no metal (black) to 100% metal (red and blue). High (30 wt.%, red) and low (2 wt.%, blue) Ni concentrations within the high-metal case are shown.

tive to the distribution of neutron absorbing elements (e.g. Fe, Ti, Gd, Sm) across a planetary surface [17-19], epithermal neutrons are highly sensitive to hydrogen concentration [4,6,9,11], and fast neutrons provide a measure of average atomic mass (<A>) and, together with thermal neutron data, are useful for identifying and mapping compositional terranes [19, 20].

Neutron Measurements at 16 Psyche: Planetary neutron measurements are ideally suited for quantifying and mapping 16 Psyche's compositional variability, and will serve as a robust complement to the element-specific gamma-ray measurements [3]. This suitability derives from the large epithermal and fast-neutron count rates resulting from metal-rich compositions expected for 16 Psyche's surface, and from the high sensitivity of all neutron energy ranges to 16 Psyche's metal fraction. Figure 1 shows modeled neutron spectra for elemental abundances at 16 Psyche, ranging from provinces comprised of 100% silicates (0% metal) to 100% metal, and Ni concentrations within the metal fraction ranging from 2 wt.% to 30 wt.%. It has been suggested that the IVA iron meteorites might be a possible analog for expected materials on Psyche [21]. Thus, IVA iron meteorite phyoxene (bronzite) and metal (trace elements) were combined (e.g. via methods of [22]) to produce bulk compositions presented here. Neutron energy "band-pass filters" (analogous to visible spectral band-pass filters) for the three neutron energy ranges are shown in Figure 1. The modeled fluxes show that slow neutrons are highly diagnostic of the presence (or absence) of silicate materials. Epithermal and fast neutrons have large count rates at higher energies (E_n>1 keV), and provide independent diagnostic information about the metal fraction and Ni abundance in the metal.

Figures 2 and 3 show modeled count rates [9] for a range of metal fractions and Ni concentrations within the FeNi metal, as would be measured during the Psyche mission's lowest-altitude mapping orbit. Slow neutrons (Figure 2) provide a highly sensitive measure of metal fraction such that low count rates indicate a metal-rich surface and high count rates indicate a metal-poor surface. When slow neutrons are combined with epithermal and fast neutrons, both the metal fraction and Ni compositions can be constrained. An example composition of 8 wt.% Ni and 80 vol.% metal fraction is shown in Fig. 2. The high count rates and possible compositional contrast will provide statistically robust maps of neutron compositional parameters with a spatial resolution comparable to that obtained with the neutron measurements at Vesta [11,18]. Neutron measurements combined with gamma-ray elemental measurements will enable Psyche's elemental composition to be comprehensively understood thus allowing the Psyche mission goals to be met with robust margin.

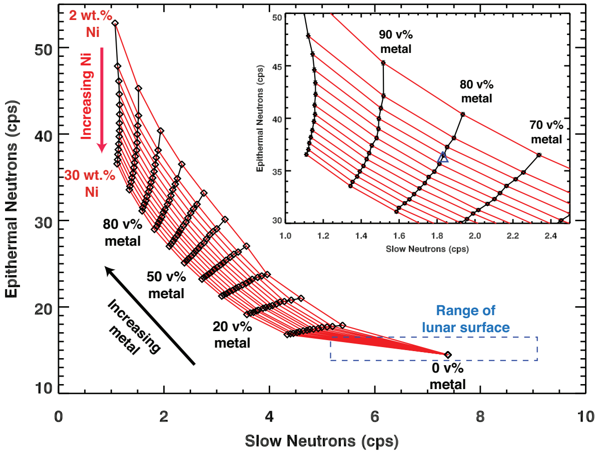

Fig. 2. Modeled count rates for slow and epithermal neutrons for a range of metal to pyroxene fractions (vol.%, black) and concentration of Ni in the metal (wt.%, red). The dynamic range of neutron measurements at the Moon is shown by the dashed blue box. Count rates for 8 wt.% Ni and 80 vol.% metal shown as blue triangle in inset; statistical errors for mapping are the size of the black data symbols.

References: [1] L. T. Elkins-Tanton et al., *LPSC*, Abstract #1632, 2015; [2] L. T. Elkins-Tanton et al., this *LPSC*, 2016; [3] P. N. Peplowski et al., this *LPSC*, 2016; [4] W. C. Feldman et al., *Science*, 281, 1496, 1998; [5] T. H. Prettyman et al., *JGR*, 111, 10.1029/2005JE002656, 2006; [6] W. C. Feldman et al., *Science*, 297, 75, 2002; [7] W. V. Boynton et al., *Science*, 297, 78, 2002; [8] P. N. Peplowski et al., *Science*, 333, 1850, 2011; [9] D. J. Lawrence et al., *Science*, 339, 292, 2013; [10] P. N. Peplowski et al., *Met. & Planet. Sci*., 50, 353, 2015; [11] T. H. Prettyman et al., *Science*, 338, 242, 2012; [12] T. H. Prettyman et al., this *LPSC*, 2016; [13] J. O. Goldsten et al., *Space Sci. Rev*., 131, 339, 2007; [14] W. C. Feldman et al., *JGR*, 109, 10.1029/2003JE002207, 2004; [15] W. V. Boynton et al., *Space Sci. Rev*., 110, 37, 2004; [16] T. H. Prettyman et al., *Space Sci. Rev*., 163, 371, 2011; [17] R. C. Elphic et al., *JGR*, 105, 20333, 2000. [18] T. H. Prettyman et al., *Met. & Planet. Sci*., 48, 2211, 2013; [19] P.N. Peplowski et al., *Icarus*, 253, 346, 2015; [20] D. J. Lawrence et al., this *LPSC*, 2016; [21] J. Yang et al., *Nature*, 446, 888, 2007; [22] J. Berlin et al., *Mic. Microa*, 14, 110, 2008.

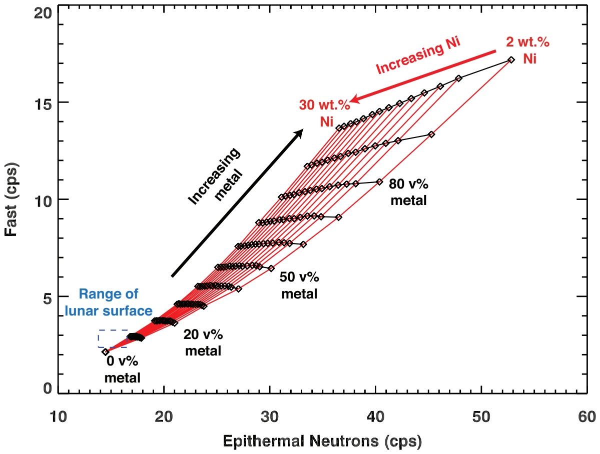

Fig. 3. Modeled count rates similar to Figure 2, but for epithermal versus fast neutrons.