NEUTRON SPECTROSCOPY ON A METAL WORLD: TAILORING THE PSYCHE NEUTRON SPECTROMETER. Z. W. Yokley[1], P. N. Peplowski[1], J. O. Goldsten[1], D. J. Lawrence[1], I. Jun[2], T. H. Prettyman[3], L. T. Elkins-Tanton[4], and the Psyche Mission Team. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (Zachary.Yokley@jhuapl.edu); [2]NASA Jet Propulsion Laboratory, Pasadena, CA, 91109; [3]Planetary Science Institute, Tucson, AZ 85719; [4]Arizona State University, Tempe, AZ 85287.

Introduction: The Discovery-class Psyche mission to the M-class asteroid (16) Psyche will be the first exploration of a metal-rich body and will further our understanding of the cores of igneous bodies [1]. The payload includes a neutron spectrometer (NS) composed of several sensors, each targeted to a different energy range of Psyche's neutron emission spectrum.

Neutron spectrometers have been successfully used to measure compositional parameters at rocky and icy worlds [2, 3]; however, important differences in the neutron spectrum are expected at Psyche. Compared to previously explored bodies, there will be an enhanced fast and a suppressed thermal neutron flux. Additionally, the flux and spectral shape of the epithermal neutrons carry important compositional information. These differences raise the question: Are the baseline sensors of the Psyche NS, which are based on heritage instruments, optimized for Psyche's unique neutron environment? This question motivated an evolution of the Psyche NS from a two-sensor to a three-sensor design that can best exploit the unique properties of Psyche's neutron spectrum [4].

Planetary Neutron Spectroscopy: For planetary bodies with little to no atmosphere, spallation reactions induced by galactic cosmic rays (GCRs) in the subsurface produce copious high-energy free neutrons. These neutrons then undergo nuclear interactions before escaping the body or being absorbed in the surrounding material.

Neutrons that escape with few interaction are termed fast neutrons and have energies >0.5 MeV. Other neutrons will scatter many times and come into thermal equilibrium with the surface before escaping. These are thermal neutrons, which have energies <0.5 eV.

Between fast and thermal neutrons are the epithermal neutrons whose overall flux and spectral shape contain compositional information. The epithermal neutrons can be divided into low-energy epithermals (henceforth denoted as epithermals) and high-energy epithermals (HEE) with the division around 500 eV. Figure 1 shows several neutron spectra with varying metal fractions. Clearly the amplitude and shape of the spectral features vary with composition.

Baseline Psyche NS Sensors: At the start of Psyche's Phase B, the NS consisted of two low-energy neutron sensors for measuring thermal and epithermal neutrons. Fast neutron measurements are made with the gamma-ray spectrometer (GRS) anti-coincidence (AC) shield. The AC shield also gives a crude measurement of HEE from uncorrelated neutron captures. This measurement is termed the "AC shield singles."

For the lowest energy neutrons, ^3He gas proportional counters (GPCs) were chosen based on heritage from the Lunar Prospector NS [5]. Because GPCs have sensitivity to both thermal and epithermal neutrons, one sensor is covered with a thermal-neutron-absorbing Cd wrap leaving it sensitive only to epithermal neutrons. The other sensor has no wrap, and the thermal neutron measurement is derived from the difference in the count rates of the two sensors.

The AC shield is a cup-shaped volume of boron-loaded plastic scintillator, whose primary purpose is to veto GCR events from the GRS-measured gamma-ray spectrum. The AC shield's fast neutron mode looks for

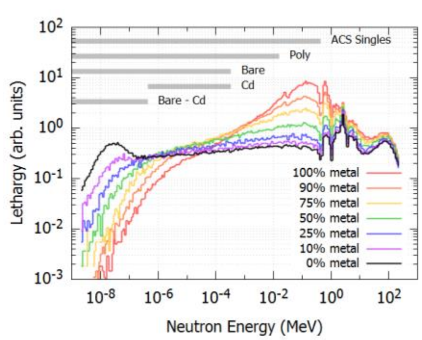

Fig. 1. Neutron spectral variations (displayed as lethargy, or flux times energy) for various metal fractions. The energy sensitivity bars of some neutron sensors are also shown. See Fig. 2 for their definition.

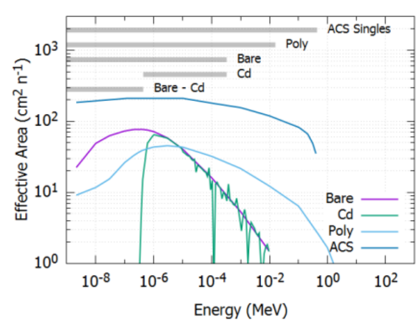

Fig. 2. Sensor effective areas for three GPCs and the AC shield singles measurement. The singles curve was taken from [6] and scaled to the size of Psyche's AC shield. The sensitivity bars correspond to the range where the effective area is >10 cm^2.

time correlated events within a set coincidence window. The first event comes from a fast neutron scattering off a proton in the scintillator, and the second comes from a neutron capture on ^{10}B. This is the same approach used for fast neutron measurements by Lunar Prospector [5] and MESSENGER [7].

Relevant Compositions for Psyche: Remote observations of Psyche indicate a predominately metal body (Fe and Ni) with some silicates [8]. The amount of silicates and the Ni fraction of the metal phase are important parameters for distinguishing between different formation hypotheses [1]. Remote sensing data also indicate the presence of water and/or hydrated minerals [9].

To determine the variety of neutron spectra that the NS might measure, we complied a set of compositions that envelope the possibilities indicated from remote sensing data. These compositions were input into a Geant4 [10] simulation and neutron spectra were produced by simulating GCR events. Figures 1 and 3 show spectra for variations in metal fraction, Ni, and H content. From the plots it is clear that there are large variations in the thermal, HEE, and fast neutrons regions. Furthermore, calculations of the expected count rates during orbital operations show that these regions have significant variability, while the epithermal measurement is nearly devoid of compositional variation. From these observations the Psyche NS should target the thermal, HEE, and fast neutron bands. Note however, that the epithermal channel is still required to derive the thermal measurement.

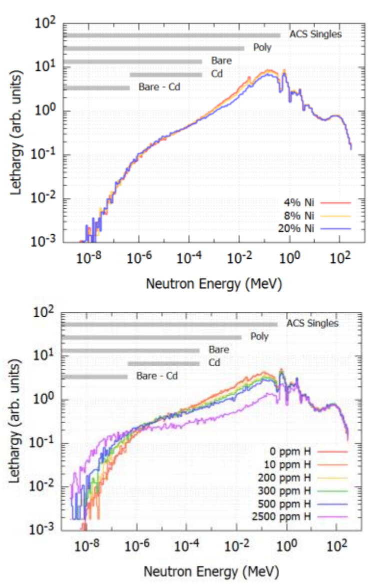

Fig. 3. (top) Neutron spectra for different Ni fractions in a 90% metal, 10% silicate reference Psyche. (bottom) Spectra for different H concentrations in 90% metal (8% Ni), 10% silicates.

Psyche NS Design Trades: The baseline Psyche NS, with the AC shield, was well suited to the measurement of thermal, epithermal, and fast neutrons. However, given the possibilities for the composition of Psyche, a measurement of the HEE neutrons would add important information to the NS investigation.

Two possibilities for a HEE sensor are the AC shield (using the singles measurement) and a polyethylene-wrapped GPC. The effective areas of these sensors are shown in Fig. 2.

As shown in Fig. 4, the AC shield singles events have poor resolution and a small signal-to-background ratio. The poor resolution is due to the complicated light transport in the AC shield [6], and the poor signal-to-background results from a large GCR and gamma-ray-produced continuum.

While GPCs have no sensitivity to HEE, by using a neutron moderating material, like polyethylene, around the GPC, the sensitivity to HEE can be raised. This provides an acceptable detection efficiency with superior signal-to-background. The better performance results from the relatively high resolution of the GPC and its insensitivity to other forms of radiation.

Based on the expected neutron environment and the superior performance of a GPC, the Psyche project decided to add to a polyethylene-wrapped GPC to the NS [4]. The three GPCs of the NS and AC shield are sensitive to the full energy range of neutrons which enables a robust measurement of the Psyche-originating neutron flux.

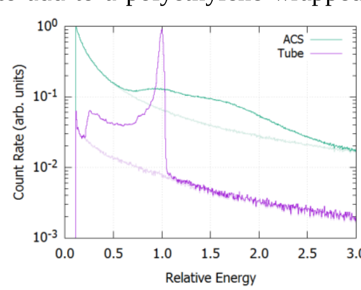

Fig. 4. The spectra for AC shield singles (green) and a GPC (purple). The background continuum is plotted with a lighter tint. These spectra have been scaled and shifted to place them on the same horizontal scale. Each spectra contains the same number of neutron captures.

References: [1] L. T. Elkins-Tanton et al., 48th LPSC, Abstract #1718, 2017; [2] T. H. Prettyman, Encyc. of Sol. Sys., 1161, 2014; [3] T. H. Prettyman et al., Sci. 355, 55, 2017; [4] D. J. Lawrence et al., 50th LPSC (this meeting), 2019; [5] W. C. Feldman et al., J. Geophys. Res. 109, E07S06, 2004; [6] P. N. Peplowski et al., Icarus, 253, 246, 2015; [7] J. O. Goldsten et al., Space Sci. Rev., 131, 339, 2007; [8] P. S, Hardersen et al., Icarus, 175, 141, 2005; [9] D. Takir et al., Astron. J., 153, 31, 2017; [10] S. Agostinelli et al., Nucl. Instrum. Methods Phys. Res. A, 506, 250, 2003.