**PREPARING TO MEASURE (16) PSYCHE'S ELEMENTAL COMPOSITION: INTERPRETATION OF PSYCHE NEUTRON MEASUREMENTS.** David J. Lawrence[1], John O. Goldsten[1], Patrick N. Peplowski[1], Thomas H. Prettyman[2], Zachary W. Yokley[1], L. T. Elkins-Tanton[3]; [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD; [2]Planetary Science Institute, Tucson, AZ; [3]Arizona State University, Tempe, AZ (David.J.Lawrence@jhuapl.edu).

**Introduction:** The Psyche Gamma-Ray and Neutron Spectrometer (GRNS) will use planetary nuclear spectroscopy to measure the elemental composition of the M-class asteroid (16) Psyche. The GRNS is part of the NASA Psyche mission that will orbit the main-belt asteroid of the same name; the overall goal of the mission is to determine if the Psyche asteroid is the exposed core of a proto-planetary body. Recent Earth-based measurements and new interpretations of existing measurements have revised our understanding of the nature of (16) Psyche [1]. The currently accepted density of Psyche is bounded to be 3.4–4.1 g/cm$^3$, which is lower than previously thought (as high as 7 g/cm$^3$). As a consequence, it is now understood that Psyche can have a broader range of possible compositions. Psyche's Fe abundances could plausibly range from 25 wt.% to upwards of 90 wt.%; by consequence, the silicate fraction could range from less than 0.1 to greater than 0.7. Thus, instead of assuming iron meteorites are representative of Psyche, a wider range of possible compositions can be considered, including analogs such as CB and enstatite chondrites, pallasites, and mesosiderites [1,2].

Here, we focus on the neutron measurements at Psyche. The Psyche mission is the first time that four neutron energy bands are purposely being used to measure the composition of a planetary body [3]; planetary neutron measurements typically use two or three energy bands. An extra energy band was added to the Psyche GRNS to more effectively characterize the expected metal-rich content of Psyche [4].

**Psyche Neutron Measurements:** The four neutron energy bands measured by the Psyche GRNS are: thermal (neutron energy, $E_n$<0.4 eV), low-energy epithermal (0.4<$E_n$<10 keV), high-energy epithermal ($E_n$<100 keV), and fast (0.5 MeV<$E_n$<5 MeV). The lowest energy bands are measured with three $^3$He gas proportional counters, the first of which is bare, the second is covered in Cd, and the third is covered in polyethylene. The highest energy fast neutrons are measured with the borated plastic scintillator anticoincidence shield on the gamma-ray spectrometer.

To gain understanding of the Psyche neutron measurements, we carried out a set of particle transport simulations. The outputs of these simulations are count rates from each of the sensors for various assumed surface compositions. To ensure these simulated count rates encompass a range of possible Psyche surface compositions, we completed 840 separate simulations with variable metal-to-silicate fraction (0 to 90 vol.%), Ni concentration in the metal (0 to 30 wt.%), and hydrogen (H) concentration (0 to 500 ppm). The variable metal-to-silicate fraction (or silicate fraction) is meant to be broader than the full range of actual Psyche abundance. We define silicate fraction as the total amount of non-Fe and non-Ni abundances (in all phases) to the total Fe+Ni abundance. A range of H is used to account for expected non-zero and possibly variable H concentrations from exogenous sources [5] that can measurably affect the neutron measurements.

**Results of Count-Rate Simulations:** Fig. 1 shows count-rate scatter plots (or feather plots) for two of the six different permutations of the four neutron measurements. Each sensor combination provides different information about the three composition measurables of metal-to-silicate fraction (or silicate fraction), Ni abundances, and H abundances. For example, the combination of thermal versus fast neutrons (Fig. 1A) provides a good measure of silicate fraction. However, with variable and/or uncertain H abundances, the thermal versus fast neutron count-rate combination would do a poor job of constraining Ni concentrations, as there is significant overlap for count rates with variable H abundances.

To simplify our understanding of this complex phase space (four neutron measurements and three compositional variables), we use an analysis technique known as Principal Component Analysis (PCA). PCA is a statistical technique where a set of partially correlated measurements – in this case the four neutron measurements – undergo a geometric-like transformation to generate a new set of variables that are formally uncorrelated. While one of the major benefits to PCA operations is to reduce the number of "important" variables, in this case PCA is used to maximize compositional information while minimizing ambiguous overlap of measured data. We define a measurement vector $\boldsymbol{x}=[C_{\mathrm{therm}}, C_{\mathrm{lowE}}, C_{\mathrm{highE}}, C_{\mathrm{fast}}]$, where $C$ represents the simulated count rates for each neutron sensor. Using these inputs, the PCA determines a 4 x 4 element matrix, $\boldsymbol{E}$, that transforms each input data vector into a new principal component (PC) vector, $\boldsymbol{u}$: $\boldsymbol{u}_m = \boldsymbol{E}_m\boldsymbol{x}_m$, where $m$ represents each of the 840 simulated compositions.

Fig. 2 shows three-dimensional scatter plots where each of the 840 x 4 element vectors have been transformed into PC space. The resulting data cloud is a stretched and curved parallelepiped-like volume. Most importantly, there are no overlapping data points as each is located in a unique position within the volume. To illustrate the compositional variability within this PC

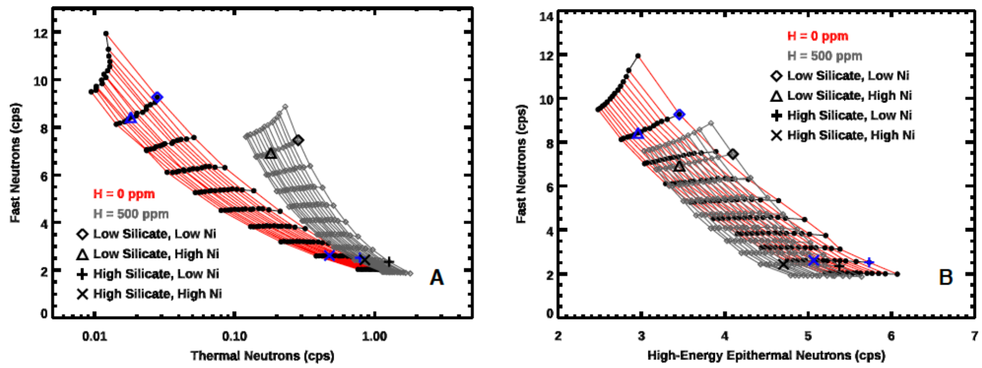


**Fig. 1.** Simulated neutron count rates. Contours of constant Ni and silicate content are shown by the red and black lines, respectively. Specific low silicate (20 vol. %), high silicate (80 vol.%), low Ni (2 wt.%) and high Ni (20 wt.%) values are given by the large symbols. Red/black lines use 0 ppm H, grey lines use 500 ppm H.

volume, each panel shows the data points color coded to represent the silicate fraction (Fig. 2A), the Ni abundance (Fig. 2B), and the H abundance (Fig. 2C). PC1 is dominantly correlated with silicate fraction, PC2 is dominantly correlated with Ni abundance, and PC3 is dominantly correlated with H abundance. Thus, with an appropriate calibration, each of the PCs can be directly linked to a specific composition parameter.

To test how well this simulation framework represents known compositions, we calculated the neutron fluxes for six different bulk meteoritic compositions identified by [1,2] as spanning the likely values that will be observed at Psyche. Fig. 2D shows these count rates transformed into PC space. The PC1 values for these meteoritic compositions correlate closely with silicate fraction, as do the PC2 with Ni and PC3 with H. We also simulated the expected count rate of bulk Mars material [6] with variable H content, which is relevant for the Psyche measurements because we expect to measure neutrons from Mars during a Mars gravity assist. The PC-transformed count rates are shown as dark-red symbols in Fig. 2D. While Mars compositions are quite different from the original compositions considered, they show consistency with this framework.

**Summary:** Planetary neutron data have provided essential composition information at all planetary bodies where such measurements have been made, e.g., the Moon, Mars, Mercury, Vesta, and Ceres, which collectively span a wide range of iron, silicate, and H abundances. Given that so little is currently known about Psyche, it is important to have multiple, independent ways to constrain its composition. The GRNS neutron measurements will provide such compositional constraints, namely a robust measure of the silicate fraction, as well as constraints on the Ni fraction and surface H content.

**References:** [1] L. T. Elkins-Tanton et al., *J. Geophys. Res.: Planets*, in review, 2020; [2] P. N. Peplowski et al., *50th LPSC*, Abstract #1731, 2019; [3] D. J. Lawrence et al., *50th LPSC*, Abstract #1544, 2019; [4] Z. W. Yokley et al., *50th LPSC*, Abstract #1295, 2019; [5] V. Reddy et al., *49th LPSC*, Abstract #1344, 2018; [6] Agee, C. B. et al., *Science*, 339, 780, 2013.

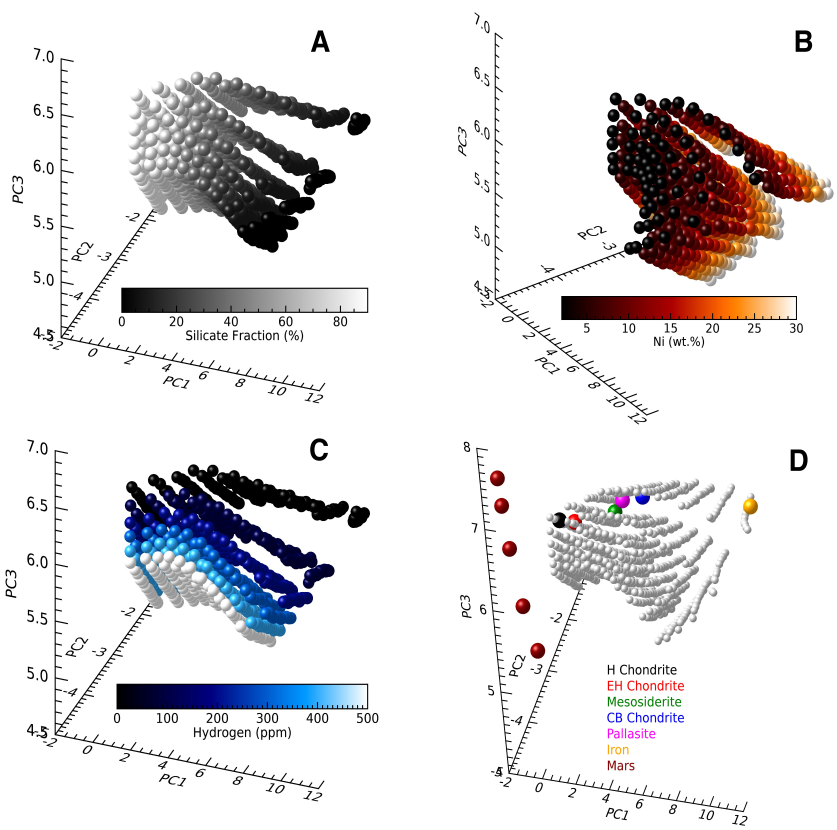


**Fig. 2** Three-dimensional scatterplot of the three principal components for the 840 neutron simulations for the range of silicate fraction, Ni concentrations, and hydrogen concentrations. Data points are in same locations for all panels. Data points are color coded based on silicate fraction (A), Ni concentration (B), and H concentration (C). Panel (D) shows the principal components for six different meteorite compositions along with six versions of Mars compositions with H concentrations of 0.5 wt.%, 0.9 wt.%, 1.8 wt.%, 4.5 wt.%, and 9 wt.% water equivalent H (WEH). Increasing values of WEH range from high to low PC3 values.