THE PSYCHE GAMMA-RAY AND NEUTRON SPECTROMETER: CALIBRATED, DELIVERED, AND READY FOR LAUNCH. Patrick N. Peplowski[1*], John O. Goldsten[1], Morgan T. Burks[2], David J. Lawrence[1], Paige A. Arthur[3], Eric Cheng[1], Cody N. Colley[3], Michael J. Cully[1], Jordan M. Effron[1], Joan Ervin[3], Samuel G. Fix[1], Erin M. Hoffer[1], Evan M. Livingstone[1], Kathryn M. Marcotte[1], Maria de Soria-Santacruz Pich[3], Meena Sreekantamurthy[1], Noah Z. Warner[3], and Zachary W. Yokley[1], [1] Johns Hopkins Applied Physics Laboratory, Laurel MD USA ([*]Patrick.Peplowski@jhuapl.edu); [2] Lawrence Livermore National Laboratory, Livermore, CA USA; [3] NASA Jet Propulsion Laboratory, Pasadena, CA USA.

Introduction: The Psyche spacecraft, which has a launch window that opens in August 2022, will explore the largest M-type asteroid, 16 Psyche. Originally thought to be the exposed core of a now-disrupted protoplanet, recent observations allow for a wider variety of possible origins for this enigmatic object [1]. The Psyche Gamma-Ray and Neutron Spectrometer (GRNS), one of three science instruments on the Psyche spacecraft, will measure the major-element composition of 16 Psyche's surface, providing valuable data to resolve the origin of the asteroid. The GRNS consists of two complementary sensors: a Gamma-ray Spectrometer (GRS) and a Neutron Spectrometer (NS), each with its own dedicated Data Processing Unit (DPU).

In late 2020 through 2021, in the middle of a global pandemic, the flight model GRNS was assembled and underwent full environmental testing and science calibration at the Johns Hopkins Applied Physics Laboratory. In August 2021, GRNS was shipped to the Jet Propulsion Laboratory for integration and testing on the Psyche spacecraft. In September 2021, the now-integrated GRNS was tested and the instrument demonstrated laboratory-quality performance.

Gamma-Ray Spectrometer: GRS (Figure 1) uses a 5 cm x 5 cm high-purity germanium (HPGe) crystal, surrounded by a boron-loaded plastic scintillator anti-coincidence (AC) shield. The HPGe sensor, which is cooled by a Lockheed Martin pulse-tube cryocooler, provides gamma-ray measurements. The AC Shield provides cosmic-ray background rejection, low-energy and fast neutron detection, gamma-ray burst detection, and cosmic-ray monitoring.

Neutron Spectrometer: The NS (Figure 2) has three ^{3}He gas-proportional-counter-based neutron sensors. The bare, Cd-wrapped, and polyethylene-wrapped neutron sensors are each sensitive to a different neutron energy range, analogous to multispectral imaging using different bandpass filters. Bare and Cd-wrapped neutron sensors are common in planetary science; the polyethylene-wrapped sensor provides sensitivity to higher-energy neutrons [2] in a range tuned to discriminate between metal-rich compositions like those originally expected for 16 Psyche.

Instrument Performance: The GRNS was installed on a dedicated spacecraft boom (Figure 3), and in late September, 2021, it was powered by the spacecraft for a comprehensive test of its science performance. Highlights from this test include:

- 1.92 keV energy resolution at 1332 keV for the HPGe gamma-ray measurements (Figure 4A),
- 3.5% energy resolution for neutron measurements with all three sensors, and clear resolution of all spectra features (wall-effect events, no-gain and full gain peaks; Figure 4B),
- Clean, unambiguous identification of cosmic ray events in the AC shield via the "low-gain" channel (Figure 4C).

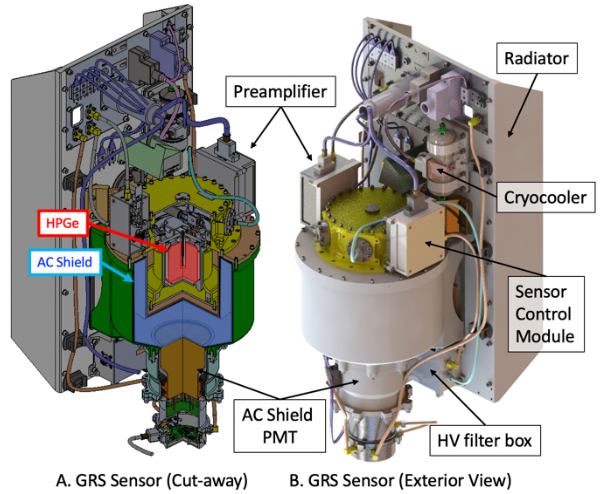

Figure 1. *Major components of the Psyche GRS.*

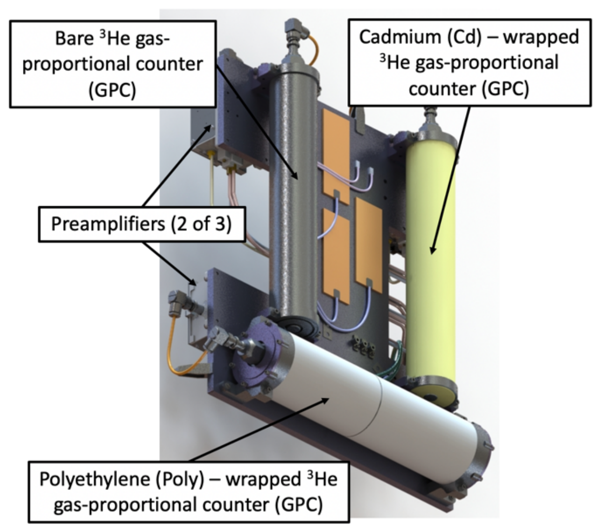

Figure 2. *Major components of the Psyche NS.*

Each of these metrics and new capabilities established a new standard in performance for a planetary nuclear spectroscopy instrument. In addition to these highlights, the AC Shield provides clean measurements of fast (>0.1 MeV) neutrons via double pulse neutron triggering algorithms (e.g. [2]; Figure 4D), low-energy neutron measurements, and detection of gamma-ray bursts as demonstrated with a mobile gamma-ray source.

Summary: The Psyche GRNS meets or exceeds the performance of all prior planetary nuclear spectroscopy instruments. In addition, its placement on a boom, ability for high-temperature annealing [4], use of a long-life cryocooler, and planned orbital profile (<1 body radius altitude, 75+ days for operation) directly address lessons learned from all prior nuclear spectroscopy investigations. The Psyche GRNS is ready to produce a best-in-class dataset that will resolve our questions regarding the formation and evolution of 16 Psyche and, by extension, the mysterious M-type asteroids.

References: [1] Elkins-Tanton, L.T.,et al. 2020, *J. Geophys. Res. Planets*, *125*(3), p.e2019JE006296. [2] Yokley, Z. W. et al., *50th LPSC*, #1295, 2019; [3] Feldman, W.C., et al. 1991, *Nucl. Inst. Methods in Phys. Res. A, 306*(1-2), pp.350-365. [4] Peplowski, P.N., et al. 2019, *Nucl. Instr. Methods in Phys. Res. A, 942*, 162409. [5] Peplowski, P.N., et al. 2020, *Nucl. Instr. Methods in Phys. Res. A, 982*, 164574.

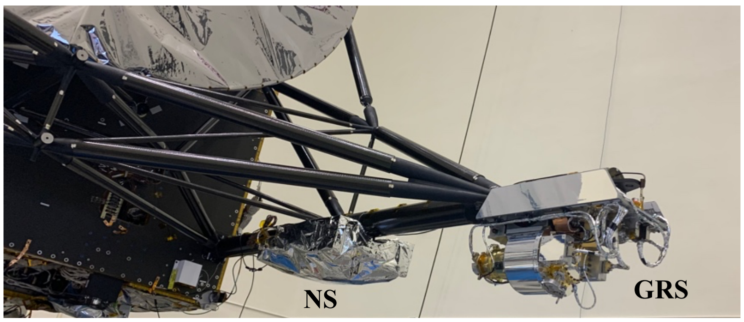

Figure 3. *Photograph of the GRS and NS on the Psyche spacecraft, taken just after installation on the 2-m boom. The GRS sensor is located at the end of the boom, the NS is located at the midway point. The data shown in Figure 4 were taken with the sensors in this configuration. Note that the NS (sensor lower down on the boom) is covered in its thermal blanket. In this photograph, the GRS thermal blanketing has not yet been installed.*

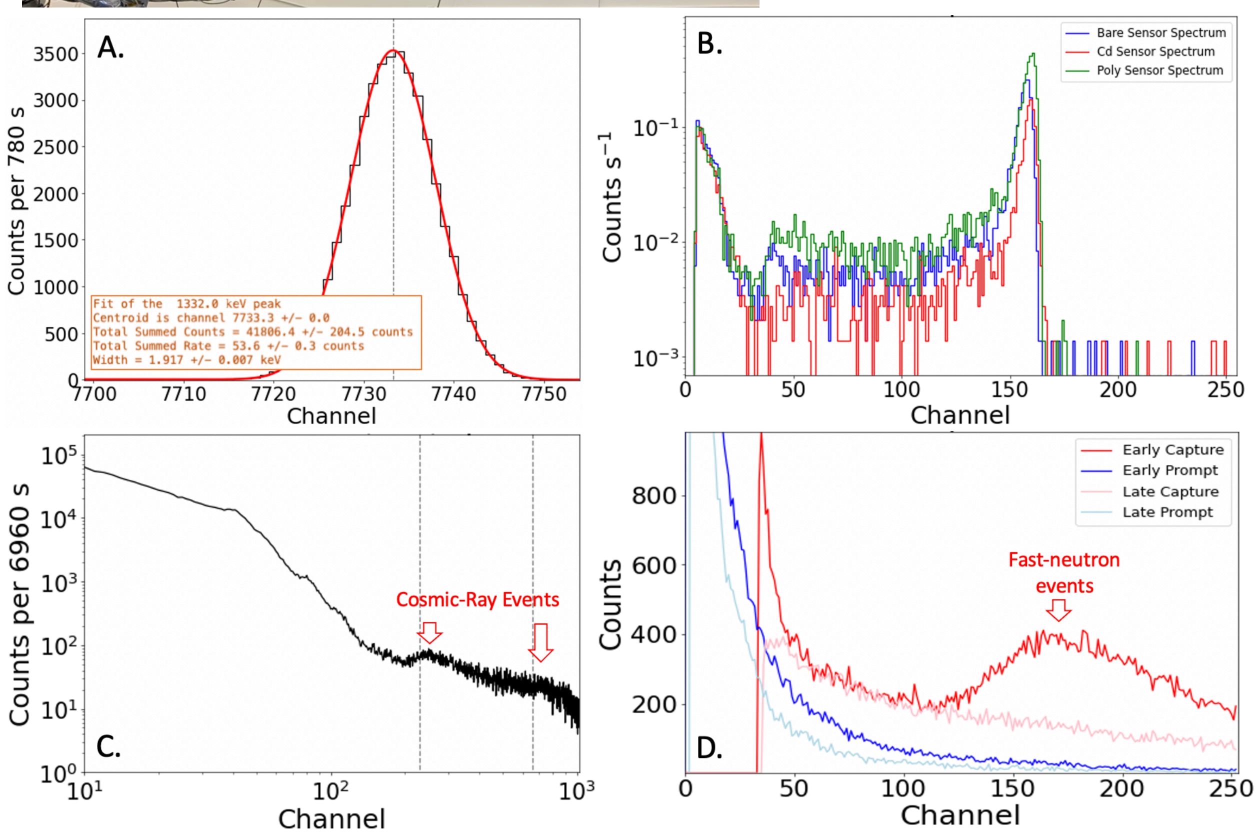

Figure 4. *A). A portion of the high-purity germanium gamma-ray spectrum showing the 1332-keV peak from ^{60}Co. A fit to the measurement (red) yields a full-width at half-maximum energy resolution of 1.92 keV.* ***B)*** *Neutron pulse height spectra from the three neutron sensors following irradiation with a ^{252}Cf neutron source. Note the clean, 3.5% energy resolution neutron capture peaks (channel ~150) and the wall-effect events (~40 < channel < 150; e.g. [5]).* ***C)*** *The "low-gain" spectrum from the AC Shield, which extends to energies of ~30 MeV. At high energies, two bumps correspond to direction detection of cosmic ray events.* ***D)*** *Fast neutron events, extracted from double-pulse events in the high-gain AC Shield measurements.*