NEUTRON SPECTROSCOPY CAN CONSTRAIN THE COMPOSITION AND PROVENANCE OF PHOBOS AND DEIMOS. R. C. Elphic[1], P. Lee[2], M. E. Zolensky[3], D. W. Mittlefehldt[3], L. F. Lim[4], A. Colaprete[1], [1]NASA Ames Research Center, Moffett Field, CA 94035 USA [2]SETI Institute, Mountain View, CA 94043 USA, [3]NASA Johnson Space Center, Houston, TX 77058 USA, [4]NASA Goddard Space Flight Center, Code 691, Greenbelt, MD 20771 USA

Introduction: The origin of the martian moons Phobos and Deimos is obscure and enigmatic. Hypotheses include the capture of small bodies originally from the outer main belt or beyond, residual material left over from Mars' formation, and accreted ejecta from a large impact on Mars, among others. Measurements of reflectance spectra indicate a similarity to low-albedo, red D-type asteroids, but could indicate a highly space-weathered veneer. Here we suggest a way of constraining the near-surface composition of the two moons, for comparison with known meteoritic compositions. Neutron spectroscopy, particularly the thermal and epithermal neutron flux, distinguishes clearly between various classes of meteorites and varying hydrogen (water) abundances. Perhaps most surprising of all, a rendezvous with Phobos or Deimos is not necessary to achieve this. Multiple flybys suffice.

Possible Origins and Composition: Of the various possible origins of Phobos and Deimos, three are usually discussed: 1) capture of objects from the outer solar system, and so having a volatile-rich primitive composition; 2) co-accretion with Mars, suggesting a dominantly volatile-poor chondritic composition; 3) re-accretion of giant impact ejecta, having a basaltic/ultramafic composition similar to the martian surface and upper mantle.

Spectroscopic Evidence of Phobos/Deimos Composition. Near infrared spectra of Phobos and Deimos provide few constraints on their nature, as they lack unambiguous features diagnostic of minerals. In particular both bodies are dark and red in the visible-to-NIR, resembling D- or T-type asteroids. Using visible and NIR data from MEx/OMEGA and MRO/CRISM, Fraeman et al [1,2] argued for an intrinsic composition similar to primitive meteorites. CRISM spectra show evidence for a 2.8 μm metal-OH phyllosilicate feature. Glotch et al. [3] re-examined MGS/TES thermal IR observations of the moons and identified features indicating the presence of water (6 μm), as well as evidence for a fine admixture of carbonates at a few wt%. Tagish Lake, CM and CI chondrites are considered spectral analogs, and can have several wt% or more in carbonates.

An important caveat is that the "Redder Unit" on Phobos might be a quasi-global accumulation of material derived from Deimos. This veneer may exceed 1 m in many locations on Phobos. With sufficient flybys, however, a neutron spectrometer would be able to constrain the composition of the "Bluer Unit", which might represent surface exposures of true Phobos subsurface composition.

Using Neutrons for Composition: When galactic cosmic rays impinge on the surfaces of airless bodies, a population of subatomic particles is produced, including relatively long-lived neutrons. The energy distribution of these neutrons is strongly affected by the composition of the surface material. Applied to the problem of Phobos and Deimos, the neutron leakage flux in the epithermal range can provide information about hydrogen (or water, OH) content in the topmost 1 meter of the moon's surface. Thermal neutrons leaking out of the surface are mainly influenced by the presence of elements with large capture cross sections, for example iron and chlorine. So neutron measurements provide a means of differentiating hydrous from anhydrous, and iron-rich from iron-poor compositions. Such measurements have been successfully made from orbit at the Moon, Mars, Mercury, Vesta and Ceres.

Phobos/Deimos Flybys. To acquire these measurements, a rendezvous with, or landing on, Phobos or Deimos is not necessary. A lower risk, less expensive alternative is to perform multiple flybys of the moons in a Mars-centric orbit. With a limited number of close passes by the moons, it is possible to constrain the bulk surface composition in the top ~1 meter and identify potential meteoritic analogs.

An eccentric Mars orbit permits periodic re-encounters with Phobos (near periapsis) with a minimum of required propulsion. We have simulated the results of only 5 flybys of Phobos with a close approach distance of 3 km and a relative speed of 2.28 km/sec. We have used a wide variety of assumed Phobos compositions, in order to demonstrate the measurement space. The instrument model is that of the Lunar Prospector neutron spectrometer. The MCNP6 monte carlo n-particle transport code was used to calculate the composition-dependent neutron leakage flux.

Figure 1 shows the results of the flyby simulations. The neutron spectrometer measures thermal+epithermal neutron flux (x-axis) and epithermal-only flux (y-axis). In this space, error bars denote 1-sigma counting rate uncertainties. Note that enstatite chondrites and ordinary chondrites overlap with CH, CV and CO examples, due to the lack of reported hydrogen in the published compositions used here. But the hydrous Tagish Lake, Kaidun, CI and CM compositions are very distinct from other chondrites. Mars crustal compositions (from SNC meteorites and Mars Exploration Rover (MER) basalts) overlap with HEDs but both are distinct from the more primitive chondritic meteorites, and from two other achondrite types, ureilites and aubrites. A lunar ferroan anorthosite is also included for reference. Thus, the thermal-vs-epithermal results should distinguish between primitive and differentiated compositions, pointing to one or the other formation scenarios. Similar results obtain for flybys of Deimos, where encounter speeds are lower and loiter times near the smaller moon are longer.

Figure 2 shows the epithermal-only count rate as a function of water-equivalent hydrogen in the bulk meteorite. It should be possible to establish the hydration state of the surface of both Phobos and Deimos, adding further constraints to the spectroscopic results. Here again, the distinction between relatively dry, crustal/mantle lithologies and wet, primitive outer main belt lithologies will help constrain provenance.

Resolving Surface Compositional Variations: The neutron spectrometer is an omnidirectional instrument; its footprint on Phobos or Deimos thus corresponds to whatever surface of the moon is in view at any given moment, and thus varies with distance from the object. With enough flybys that target, for example, the "Bluer" spectral unit on Phobos, it may be possible to distinguish this from the surrounding "Redder" unit materials. We will describe how this may be achievable, using a shape model of Phobos and the predicted neutron fluxes from an irregular, 3-dimensional object.

Summary: A mission scenario involving multiple close flybys of Phobos and Deimos can provide neutron measurements with sufficient robustness to constrain the composition and origin of the moons, at much lower cost and risk than rendezvous or landed missions.

References: [1] Fraeman, A. A. et al., *J. Geophys. Res., doi:10.1029/2012JE004137* (2012). [2] Fraeman, A.A. et al., *Icarus* 229 (2014) 196–205. [3] Glotch, T. D. et al., *LPSC (2014),* abstract #2587.

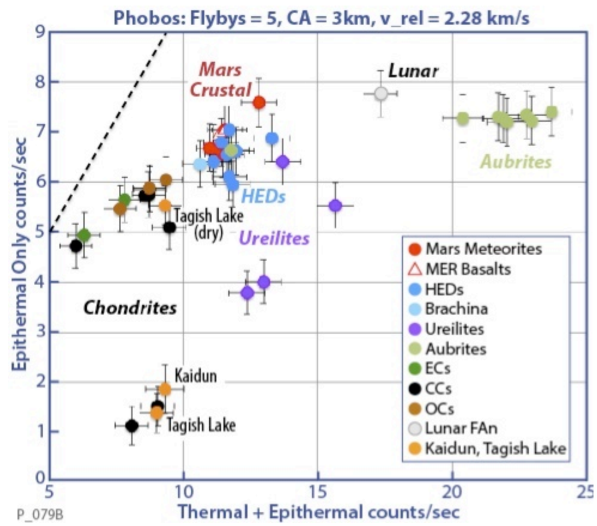

Fig. 1. Results from 5 simulated flybys of Phobos, at a closest-approach distance of 3 km, and relative velocity of 2.28 km/sec. Dashed line is 1:1, illustrating how the thermal neutron contribution varies.

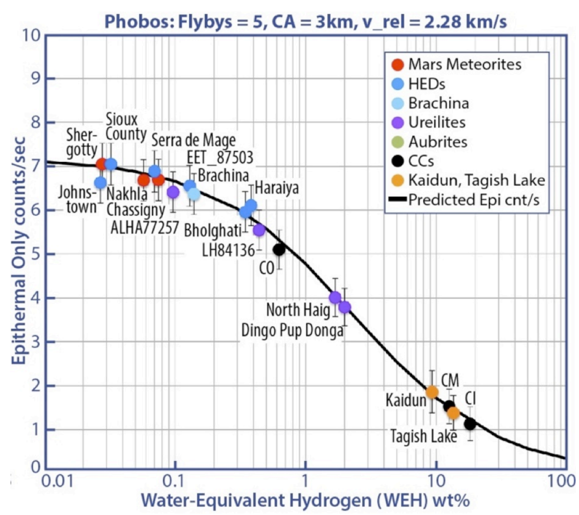

Fig. 2. Epithermal-only neutron count rate versus water-equivalent hydrogen in the bulk meteorite.