

NEUTRON SPECTROSCOPY CAN CONSTRAIN THE COMPOSITION AND PROVENANCE OF PHOBOS AND DEIMOS. R. C. Elphic¹, P. Lee², M. E. Zolensky, D. W. Mittlefehldt, L. Lim, A. Colaprete¹,
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Introduction: The origin of the martian moons Phobos and Deimos is obscure and enigmatic. Hypotheses include the capture of asteroids 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 dark, 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 to 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.

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 primitive composition; 2) co-accretion with Mars, suggesting a dominantly ordinary chondrite 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 some constraints on their nature, though they lack strong 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. Figure 1 shows CRISM spectra that evidence 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 and CM chondrites are considered spectral analogs, and can have several wt% or more in carbonates.

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

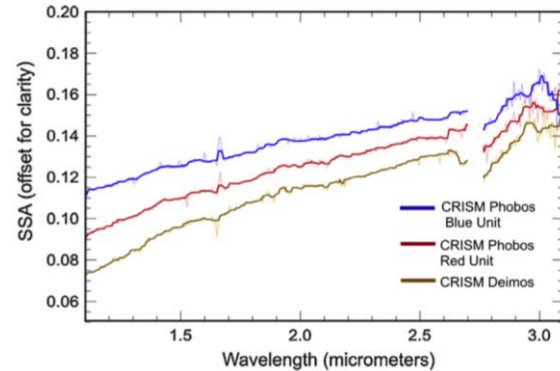


Fig. 1. MRO/CRISM spectra of Phobos (red and blue units) and Deimos. The feature at 2.8 μm is attributed to phyllosilicates. From [2].

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 their bulk composition and identify potential meteoritic analogs.

An eccentric Mars orbit permits periodic re-encounters with Phobos (near periaapsis) with a minimum of required propulsion. We have simulated the results of 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 neutron transport code was used to calculate the composition-dependent neutron leakage flux.

Figure 2 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, ordinary chondrites group very distinctly from carbonaceous chondrites, particularly the hydrous Tagish Lake, Kaidun, CI and CM compositions. Mars crustal compositions (from SNC meteorites) overlap with HEDs but both are distinct from the more primitive meteorites. Also shown are several examples of ureilites, aubrites and a lunar ferroan anorthosite. Thus, the thermal-vs-epithermal results should distinguish between primitive and differentiated compositions, pointing to one or the other formation scenarios.

Figure 3 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.

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.

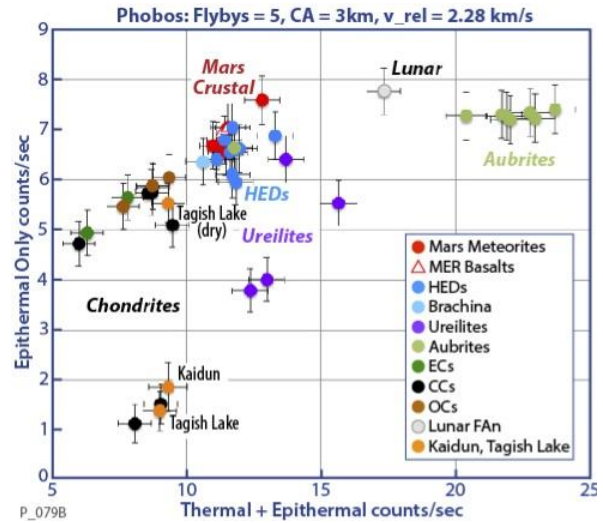


Fig. 2. Results from 5 simulated flybys of Phobos, at a closest-approach distance of 3 km, and relative velocity of 2.28 km/sec.

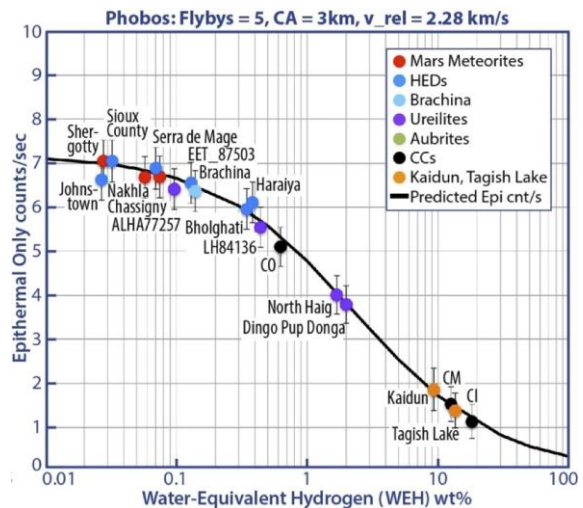


Fig. 3. Epithermal-only neutron count rate versus water-equivalent hydrogen in the bulk meteorite.