PHOBOS MRO/CRISM VISIBLE AND INFRARED (0.4-2.5 µm) SPECTRAL CLUSTERING.
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Context: Whether Phobos is a captured asteroid or it formed in situ around Mars, remains an open and debated scientific question within the scientific community. JAXA's proposed Mars Moon eXploration (MMX) sample return mission will address this question by reaching Phobos in early 2020s and returning Phobos samples to Earth few years later.

Dataset: We use the CRISM Visible (0.5 – 0.9 µm, VIS) and Infrared (1.0 – 2.5 µm, IR) dataset obtained on 10/23/2007 when Phobos was on the dark side of Mars. Such data were obtained with a phase angle of 40° and a scale of 356 m/px (Fig. 1). The photometric incidence (*i*) and emission (*e*) were calculated from the 3D shape model of [1] and the resulting maps are shown in Fig. 1. We computed the Lommel-Seeliger disk function for each CRISM Phobos pixel:

$$D(i,e) = 2cos(i)/cos(i)+cos(e).$$

The CRISM corrected datacube is then obtained by dividing the I/F images by D. In the photometrically corrected, the regions with angles larger than 80° are excluded.

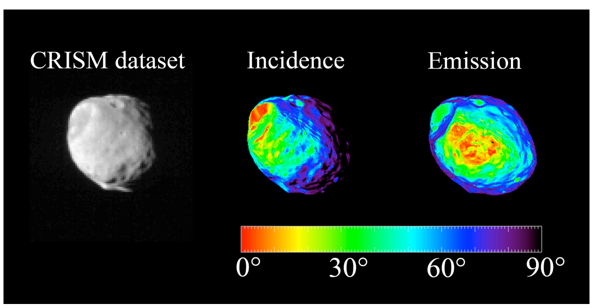

Fig. 1: The MRO/CRISM original dataset with the corresponding Incidence and Emission maps.

Analytical Approach: On the photometrically corrected CRISM data we applied a statistical clustering [2] independently to the VIS and IR ranges. A maximum number of eight and ten clusters were identified for the VIS and IR ranges, respectively (Fig. 2). Each resulting cluster is characterized by an average, and its associated variability (Fig. 3). This approach has been previously applied for compositional interpretation of different Solar System objects, e.g. asteroids, Mars, and Iapetus [2-4]. The algorithm is agnostic of the physical meaning of the resulting clusters, and scientific interpretation is required for their subsequent evaluation.

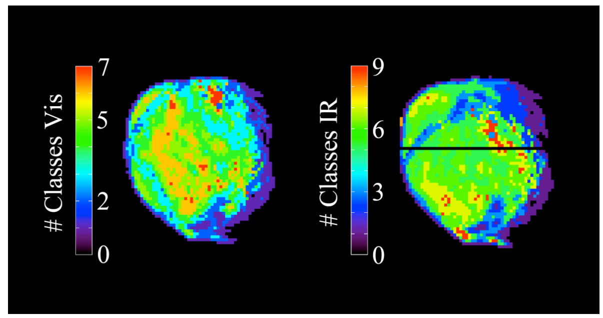

Fig. 2: The clustering technique applied on the VIS and IR CRISM dataset.

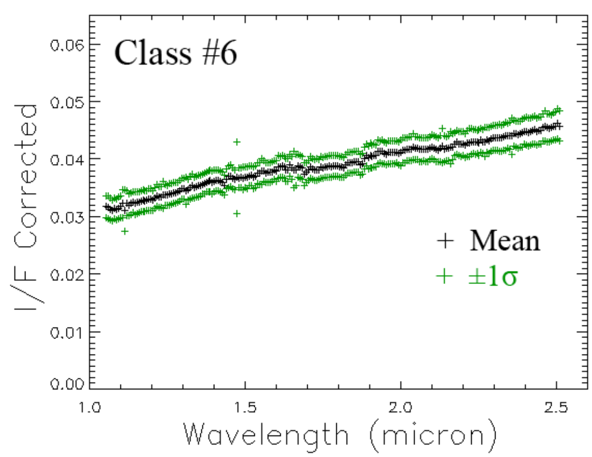

Fig. 3: An example showing the mean I/F and its associated ± 1σ for class #6 of the CRISM IR dataset.

Spectral Modeling: We used Shkuratov's model [5] for compositional interpretation of Phobos' surface. The model calculates the albedo of a powdered surface from the optical constants of candidate materials. We used the materials preferred by [6] that include Tagish Lake meteorite [TL, 7] and Mg-rich pyroxene glass [PM80, 8]. The Shkuratov model is used in a Downhill Simplex algorithm [9], aka amoeba, that iteratively, and simultaneously changes the relative abundance and grain sizes of these two components to minimize the differences between the model and observations using a chi-squared criterion. The best-fitting models were achieved with a simple intimate mixture. Since the clusters of Fig. 2 refer to distinct areas on Phobos, we treated the VIS and the IR spectra separately.

Independently from the class, the best fitting models for the VIS dataset have a grain size of 13.5 μm for TL and 22.0 μm for PM80, while the relative percentages of TL and PM80 vary between 80-20% and 92-8%, respectively. For the IR dataset the best fitting models have an almost constant TL grain size of 12.0 μm, while the PM80 grain size varies from 17.5 to 20. In this case study, the mutual percentages of TL-PM80 range from 89-11% to 95-5%.

Conclusions: Spectral models of the CRISM VIS and IR datasets are consistent with the intimate mixture of Tagish Lake meteorite and Pyroxene glass suggested by [6] based upon another instrument and mission, but with slightly different relative abundances and grain sizes. Since Tagish Lake is commonly used as a spectral analog for D-type asteroids [10], these results with the CRISM data provide additional support for compositional similarities between Phobos and D-type asteroids.

References: [1] Gaskell, R.W. (2013) NASA Planetary Data System, 155. [2] Marzo, G. et al. (2009), *JGR*, 114, E08001. [3] Pinilla-Alonso, N. et al. (2011), *Icarus*, 215, 1, 75. [4] Dalle Ore, C. et al. (2012), *Icarus*, 221, 2, 735. [5] Shkuratov, Y. et al. (1999), *Icarus*, 137, 235. [6] Pajola, M. et al. (2013), *ApJ*, 777, 127. [7] Roush, T. L. (2003), *Met. & Planetary Science*, 38, 419. [8] Dorschner, J. et al. (1995), *A&A*, 300, 503. [9] Press, W. H. et al. (1992), Cambridge Univ. Press, New York. [10] Hiroi, T. et al. (2001), *Science*, 293, 2234.

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