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Refining the boundary between the Phobos Blue/Red spectral units with the ExoMars-CaSSIS imagery

M. Pajola (1,2), E. Simioni (3,2), A. Lucchetti (2), C. Re (2), G. Cremonese (2), N. Thomas (4), A. Pommerol (4), L. Tornabene (5) and the CaSSIS Team
(1) NASA Ames Research Center, Moffett Field, CA 94035, USA (maurizio.pajola@nasa.gov, maurizio.pajola@gmail.com) (2) INAF Osservatorio Astronomico di Padova, 35122 Padova, Italy, (3) CNR-IFN UOS Padova LUXOR, Padova, Italy (4) Physikalisches Institut der Universität Bern, 3012 Bern, Switzerland, (5) Centre for Planetary Science and Exploration, Department of Earth Sciences, University of Western Ontario, London, Ontario N6A 5B7, Canada

Abstract

The Martian satellite Phobos has been the subject of several photometric and spectroscopic studies ranging from the Visible to the Infrared wavelength range over the past 40 years [1]. In particular, disc-resolved observations of the leading and trailing parts of the anti-Mars hemisphere of the satellite and part of the sub-Mars hemisphere were obtained with the Videospectrometric Camera (VSK), the Combined Radiometer and Photometer for Mars (KRFM), and the Imaging Spectrometer for Mars (ISM) on 1989 USSR Phobos 2 mission. By means of these observations the spectral characteristics of specific areas were investigated, and it was determined that Phobos could be divided into two main spectral units, i.e. the so-called "bluer" and "redder" unit [2]. High-resolution colour imaging by the HiRISE instrument on Mars Reconnaissance Orbiter shows that the bluer unit appears to drape over the rim of Stickney. Bluer material can be seen both inside and outside the crater rim [3]. Over the following years multiple works have attempted to understand whether this spectral dichotomy is due to different mineralogical compositions, surficial grain sizes or the extent of space weathering. However, this aspect remains a matter of debate [4-8], and thus requires additional data analysis. Furthermore, sample return missions targeting Phobos are being proposed to improve our understanding of these spectral characteristics. An example is the JAXA Mars Moon eXploration (MMX) mission, which has been accepted as the next Japanese flagship mission. The intention is to return samples taken from both the bluer and the redder units by 2029 (http://mmx.isas.jaxa.jp/en/index.html).

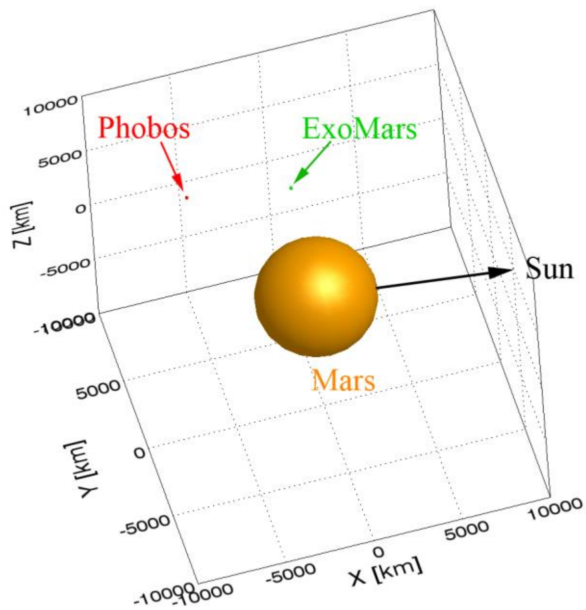

Fig. 1: The geometry of ExoMars-Phobos observation. The black arrow points towards the Sun.

On 26 November 2016, the ESA ExoMars Trace Gas Orbiter performed a close approach to Phobos at a distance of ~7600 km. The geometry of the observation (Fig. 1) allowed the Colour and Stereo Surface Imaging System (CaSSIS, [9]) instrument to capture a stereo pair centred on the boundary of the two spectral units in the direction of the sub-Mars point. This study focuses on this image pair in order to refine the distribution and spatial extent of the two units, and to provide detailed colour maps that can be used by the future MMX mission in order to select the Phobos sampling sites.

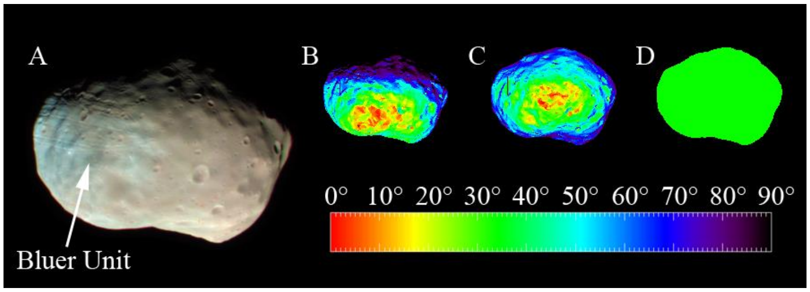

Fig. 2: A) RGB image prepared using filters at 0.937 µm for Red, 0.675 µm for Green and 0.499 µm for Blue. The Bluer unit is indicated as well. B, C and D are the incidence map, the emission map and the mean phase angle (35°) map, respectively.

CaSSIS images in four different filters: BLU – 0.499, PAN – 0.675, RED – 0.836 and NIR – 0.937 µm, [9]. The CaSSIS image was obtained when Phobos was on the dark side of Mars, so there is little or no Mars shine affecting the dataset. The spatial resolution is ~ 85 m (Fig. 2). The images were mosaicked with a recursive process using the Speeded Up Robust Features (SURF). The photometric incidence (*i*), emission (*e*) and mean phase angle (α) maps related to the CaSSIS observation were calculated from the 3D shape model of [10] by using the SPICE kernels ExoMars-Phobos geometric information [11]. We then computed the Lommel-Seeliger disk function ($D(i,e)$) for each CaSSIS Phobos pixel and corrected the datacube by dividing the I/F of each pixel by these values. In the photometrically corrected cube, the regions with angles larger than 80° are excluded.

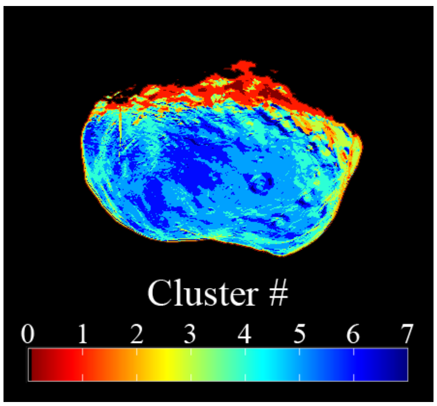

Fig. 3: The clusters identified on the CaSSIS dataset.

In order to refine the boundary between the spectral bluer and the redder unit we applied on the 4-filters dataset a statistical clustering based on a K-means partitioning algorithm [12]. It was developed and evaluated by [12,13] and makes use of the Calinski and Harabasz criterion [14] to find the intrinsically natural number of clusters, making the process unsupervised. A natural number of eight clusters was identified within the CaSSIS cube, see Fig. 3. Each resulting cluster is characterized by an average spectrum and its associated variability: Cluster #6 is the one with the flatter spectral trend and represents the bluer unit observed in Fig. 2A. All other clusters have spectra with distinct redder slopes. The geographical location of the bluer unit we obtained has then been reprojected on Phobos 3D shape model, and 3D maps available for the MMX mission are eventually prepared.

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