CONTRIBUTION OF THE OPPOSITION EFFECT TO THE PHOTOMETRIC VARIABILITY SEEN ACROSS GUSEV CRATER FROM ORBIT BY HRSC / MARS-EXPRESS. P. C. Pinet[1], A. Jehl[1], Y.D. Daydou[1], S.D. Chevrel[1], D. Baratoux[1], F. Heuripeau[1], N. Manaud[1,2], A. Cord[1,2], G. Neukum[3], the Mars Express HRSC Co-Investigator Team. [1]UMR 5562 / CNRS / GRGS, Observatoire Midi-Pyrénées, Toulouse, France, Patrick.Pinet@dtp.obs-mip.fr, [2]European Space Agency (ESA), European Space & Technology Centre (ESTEC), P.O.Box 299, 2200 AG Noordwijk, The Netherlands, [3]Freie Universitaet Berlin, Department of Earth Sciences, Malteserstr. 74-100 Building D, D-12249 Berlin Germany.

Introduction and context: So far, in situ reflectance measurements of selected rocks and soils over a wide range of illumination geometries have been obtained by the Viking Lander, Mars Pathfinder and MER multispectral imaging facilities. As a result of the exploration carried out by the rover Spirit, the surface states and their variations within Gusev crater are well-documented [1, 2, 3].

One of the new investigations from orbit that can be addressed with the multi-angular HRSC dataset generated with the nadir-looking, stereo and photometric channels, is to derive the surface photometric characteristics for mapping the variation of the soil / bedrock physical properties of Mars, and to relate them to the spectroscopic and thermal observations produced by OMEGA, TES and THEMIS instruments [e.g., 4]. The HRSC camera is a push-broom imaging system with 9 detectors, 5 of them having the same panchromatic filters. They are usually referenced as nadir channel (nominally directed toward nadir), two photometric channels (directed 12.9° in both directions from nadir), and two stereo channels (directed 18.9° from nadir) [5]. Since they have different emission and phase angles, this set of five overlapping images can potentially be used to extract photometric information [6]. However, this possibility presents some limitations due to the narrow range of photometric angles and the potential atmospheric influence. As a matter of fact, a single orbit HRSC image set does not contain enough information for describing the whole photometric function [6]. In order to compensate for the limited number of observational geometries associated with one HRSC acquisition, observations from several overlapping strips acquired at different times along the mission must be combined in order to span as much as possible the phase angle domain [6]. Ten overlapping strips have been obtained over Gusev crater and south flank of Apollinaris Patera by Mars Express in 2 years orbiting around Mars, with 2 orbits (24 and 72) at low phase angle (g<50°;i~30°), 2 orbits (637 and 648) at high phase angle (g>60°; associated with dawn illumination conditions i~80°) and 6 additional orbits (987, 1879, 2249, 2271, 2685, 2729) with varied geometry conditions). In the following, HRSC data are binned at 1.6 km / pixel and orthorectified with the HRSC DTM October 2005 version [7] to correct for mis-registration and minimize compression effects.

Photometric results and interpretation: Minnaert and two-term phase function Hapke models [8] demonstrate that HRSC multi-angular observations acquired over Gusev crater and Apollinaris southern flank along the ongoing Mars-Express mission can be pieced together to derive integrated phase functions over a wide range of phase angles (5-95°) at moderate spatial resolution on the order of 400 m - 1.6 km.

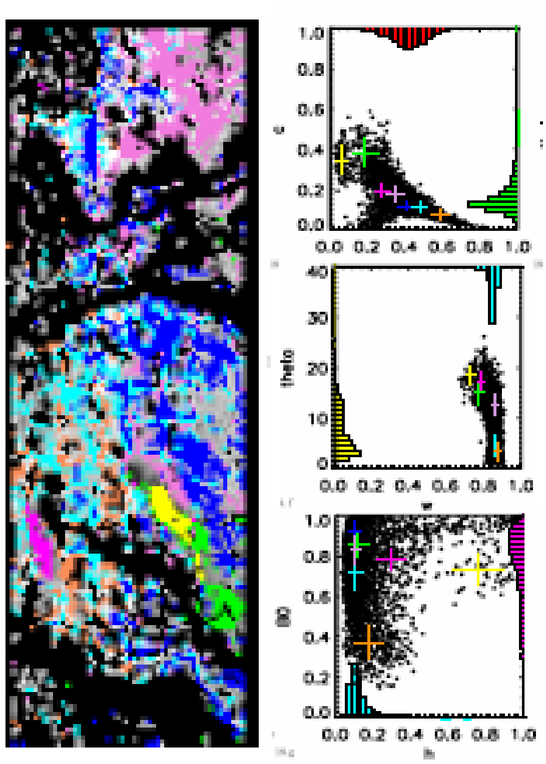

Figure 1. Photometric units across Gusev and Apollinaris derived from a Principal Component Analysis. Black areas, generally associated with local topography, are poorly modeled and thus discarded. Corresponding parameters values (mean, standard deviation) and their histogram distribution are shown in the adjacent graphs : b=f(c) , $\bar{\theta}$ =f(*w*), B0=f(h)

This work shows (see Figure 1 above) that one can document from orbit the photometric diversity of the martian surface properties.

Three units (Fig. 1) (Cyan, dark-blue and orchid) are present on both Apollinaris Patera flank and across Gusev crater floor. These three photometric units present the same high single scattering albedo *w* with rather forward scattering properties (high b, low c), low to intermediate macroscopic roughness ($\bar{\theta}$) and porous or not compacted powdered surface state as indicated by the opposition parameters (narrow width h, large amplitude B0 : 0.7-0.9). These units are widespread across the crater floor and Apollinaris.

Another unit (orange) has the highest single scattering albedo *w*, the smoothest surface in terms of $\bar{\theta}$, associated with an extremely forward scattering behavior. The opposition parameters are consistent with the presence of transparent particles in the surface powder layer. The distribution of this unit appears quite intermittent across the crater and does not seem to indicate any relationship with a given morphological structure. It may correspond to sparse areas where the structure of the surface dust layer is the most preserved.

The most pronounced photometric changes are observed in 3 units associated with the low-albedo features corresponding to dark streaks. These 3 units (yellow, green and magenta) have a low single scattering albedo, are the most backscattering surfaces across Gusev, have a high surface roughness $\bar{\theta}$ and present variable surface states as shown by the opposition parameters estimates, consistent with the occurrence of large basaltic sand grain sizes organized in more or less packed layers. The yellow and green units present a relatively more backscattering behavior, associated with rather high $\bar{\theta}$ estimates (14-18°). Clear differences are seen among these units in terms of opposition effect. While the green one exhibits typical characteristics (narrow width h, large amplitude B0), the magenta unit appears more unusual in terms of lobe width (h=0.30) and the yellow one is atypical with B0=0.73 and h= 0.75, suggesting the occurrence of a packed / compressed / narrow size distribution powder particulate surface. The photometric behavior reported for the magenta unit is consistent with the detection of a local photometric anomaly by [9].

Owing to the very different spatial resolution of this investigation versus the in situ analysis performed at Gusev with Pancam, and to the notion of multispectral classification of rocks and soils used to carry out the Pancam photometry studies on distinct units (e.g., gray rocks, red rocks, bright soils, dark soils, …) [2], a direct comparison between the present results and those from Pancam observations cannot be made in a straightforward manner. However, comparing our results obtained at 675 nm (HRSC visible channel) with the Pancam ones obtained at 753 nm show that the range of variation found here for each parameter is quite consistent with the estimates reached by [2]. It is particularly true for the single albedo *w* ranging between 0.69-0.87, the surface roughness $\bar{\theta}$ comprised between 0 and 20°, and the lobe width h generally ranging below 0.25.

Conclusions*: The opposition effect thus appears to play a significant role suggesting that the surface state optical properties across Gusev are strongly influenced by the porosity and packing characteristics or grain size distribution of the upper layer of the martian regolith.*

The mapping aspect of the present photometric investigation is quite useful to get a better sense of the meaning of the observed variations. Given the overall patterns derived from the photometric analysis, it is quite possible that the observed photometric variation at least for the western and central part of Gusev crater is partly driven by the prevailing wind regimes considered to be oriented north-northwest / south-southeast [10], continuously disturbing (sweeping, abrading, pressing, packing, dust removing) the very upper surface layer. The present photometric results agree with independent investigations based on thermal inertia, reflectance spectroscopy, in situ photometric and microscopic imaging and support the idea of a thin layer of fine-grained dust being stripped off in the low albedo units to reveal a dark basaltic substrate comprising coarse-grained materials.

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