MARTIAN SURFACE PHOTOMETRIC PROPERTIES FROM ORBIT BY CRISM/MRO AT GUSEV CRATER AND MERIDIANI PLANUM.

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Introduction: Our objective is to derive the physical properties of the martian surface using photometry in order to study geologic processes. For that purpose we aim at estimating the surface bidirectional reflectance distribution function (BRDF) from space multi-angle imagery. However that requires a correction of the atmospheric photometric effects. This challenging procedure can be addressed by the Multiangle Approach for Retrieval of Surface Reflectance for CRISM Observations (MARS-ReCO) [1,11] taking the advantage of the multiangle capabilities of the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [2] on board the Mars Reconnaissance Orbiter (MRO). In order to validate the MARS-ReCO procedure, we compared derived photometric curves to ground truth measurements acquired with the Panoramic Camera (Pancam) at the top of both Mars Exploration Rovers at Gusev Crater and Meridiani Planum [3,4].

Dataset and methodology:

Selection of CRISM observations. The Emission Phase Function (EPF) acquisition associated to each Full Resolution Targeted (FRT) observations is composed of 11 hyperspectral images at different emission angles (11 geometries) of the same target [2]. In order to estimate the physical parameters of the materials at the surface, the photometric range within a single EPF acquisition can be improved by combining several overlapping strips. In this way, the sampling of the BRDF is more complete [5]. Consequently, 3 observations with varied geometry conditions have been selected from the Spirit landing site and 4 on the Opportunity landing site with phase angles between 40 and 120° in both sites. The 11 images of each CRISM EPF observation are combined and binned at about 300 m per pixel.

Retrieval of surface BRDF. The signal from the surface is contaminated by the scattering and absorption of photons due to the dust aerosols in the martian atmosphere. The MARS-ReCO procedure [1,11] is used to retrieve the surface BRDF by using a fully non-lambertian hypothesis considering the anisotropy of the aerosols and the martian surface, including the optical depth values provided by Michael Wolff [6].

Retrieval of physical properties. Retrieved reflectance values at the considered geometries are analyzed using a Hapke's photometric model [7] with 6 parameters: single scattering albedo ω, macroscopic roughness θ, particle phase function described by a 2-term Henyey-Greenstein function that includes the parameters b (asymmetric parameter) and c (backscattering fraction), and opposition effect described by its width h and magnitude $B0$ (here, since the phase angles are greater than 40° and therefore h and $B0$ are not constrained). Those parameters were derived from the retrieved reflectance at 750 nm by means of inverting the Hapke model using a genetic algorithm [8,9].

Results: In both MER's traverse paths, Johnson et al. derived the physical parameters of the same a Hapke photometric model [7] for each defined geologic units from measured BRDF values by using diffuse sky illumination and local facet orientations [3,4]. A direct comparison between CRISM and Pancam measurements is not straightforward as Pancam provides local measurements (rocks and soils) whereas CRISM measures extended area (landscape) dominated by unconsolidated materials called soils.

Gusev Crater. Four regions of interest (ROIs) are used for the CRISM photometric study, located close to the MER path. Our results were compared to 3 photometric sequences taken by Pancam in the Gusev plain: Landing site, Bonneville Rim and NW of Missoula. Table 1 reports the Pancam and CRISM results at Gusev Plain. Parameter ω from CRISM is consistent with their Pancam counterpart for the soil unit and the dark wind streak region in which Spirit is located. The couple b and c from CRISM are generally consistent with Pancam results and they agree especially well with the soil unit for each of the 3 studied Spirit sites. That confirms our assumption that soil dominates surface photometry derived from orbit. The surface exhibits more broadly backscattering properties (low value of b and high value of c). Parameter θ from CRISM is consistent with the Landing Site soil and show rougher soil than at Bonneville rim and NW of Missoula (cf. table 1). Indeed, the main geological unit near Bonneville and Missoula craters is the ejecta deposits dominated by relatively large and randomly-dispersed clasts. Contrary to the ejecta deposits, the intercrater plains, like at the Landing site and in our CRISM ROIs, are dominated by finely-grained and well-distributed clasts increasing the surface roughness [10].

Meridiani Planum. One ROI is selected for our CRISM photometric study which results were compared to 2 photometric sequences taken by Pancam at Meridiani Planum: South of Voyager and Purgatory region. Table 1 reports the Pancam and CRISM results at Meridiani Planum. Parameter ω from CRISM is consistent with the Pancam retrievals for soil units. The couple b and c from CRISM observations are more consistent with the Spherule soil category which exhibits more broadly backscattering properties than the Striped soil unit. Parameter θ from CRISM is consistent with the South of Voyager soils and show rougher soil than at Purgatory region (cf. table 1).

All the retrieved physical parameters from orbital measurements are consistent with in situ measurements at Spirit and Opportunity landing sites.

Conclusion: The multiangle CRISM observations combined with the retrieval of the surface BRDF by MARS-ReCO by taking into account a non-lambertian surface and by using an inversion procedure developed for the Hapke photometric model allows us to estimate accurate surface photometric properties from space. The consistency of the presented results with in situ photometric results by Pancam demonstrates that MARS-ReCO provides meaningful surface BRDF and our inversion procedure, realistic surface photometric properties. Now, we investigate the possibility to map BRDF. This methodology will be applied to study surface processes on Mars, by combining several overlapping CRISM EPF acquisitions, acquired under varied geometric conditions, enables the retrieval of surface photometric properties from space, clearly improved over previous results with High Resolution Stereo Camera (HRSC) [5].

References: [1] Ceamanos X. et al. (2011) *EPSC-DPS,* Abstract 1252. [2] Murchie S. et al. (2007) *JGR*, 112, E05S03. [3] Johnson J. R. et al. (2006) *JGR*, 111, E02S14. [4] Johnson J. R. et al. (2006) *JGR*, 111, E02S16. [5] Jehl A. et al. (2006) *LPS XXXVII*, Abstracts 1219. [6] Wolff M. et al. (2009) *JGR*, 114, E00D04. [7] Hapke B. (1993) *Cambridge University Press.* [8] Cord A. et al. (2003) *Icarus*, 165, 414-427. [9] Souchon A. et al. (2011) *Icarus*, 215, 313-331. [10] Ward J. G. et al. (2005) *GRL*, 32, L11, 203. [11] Ceamanos et al. (2011) *IEEE IGARSS.*

		Site	Unit	ω	$\bar{\theta}$ (deg.)	b	c
Gusev Crater	MER Spirit	Landing site (Sol 013)	Gray Rock	0.83 (+0.01,-0.01)	7 (+3,-4)	0.931 (+0.045,-0.044)	0.065 (+0.058,-0.058)
			Red Rock	0.79 (+0.03,-0.02)	20 (+3,-3)	0.187 (+0.026,-0.031)	0.876 (+,-)
			Soil	0.76 (+0.01,-0.01)	15 (+2,-1)	0.262 (+0.010,-0.010)	0.715 (+0.029,- 0.032)
		Bonneville Rim (Sol 087-088)	Gray rock	0.72 (+0.04,-0.04)	23 (+3,-4)	0.434 (+0.035,-0.037)	0.359 (+0.048,-0.050)
			Red rock	0.70 (+0.01,-0.01)	15 (+3,-3)	0.219 (+0.017,-0.020)	1.000 (+,-)
			Soil	0.66 (+0.00,-0.00)	7 (+1,-1)	0.170 (+0.008,-0.008)	0.823 (+0.025,-0.024)
		NW of Missoula (Sol 102-103)	Gray rock	0.70 (+0.02,-0.02)	13 (+2,-3)	0.406 (+0.018,-0.032)	0.206 (+0.019,-0.025)
			Red rock	0.83 (+0.02,-0.02)	19 (+1,-2)	0.450 (+0.023,-0.064)	0.255 (+0.032,-0.072)
			Soil	0.69 (+0.01,-0.00)	11 (+1,-1)	0.241 (+0.011,-0.009)	0.478 (+0.036,-0.022)
	CRISM	ROI I		0.70±0.02	17.81±0.54	0.22±0.02	0.49±0.04
		ROI II		0.69±0.02	16.95±0.33	0.20±0.02	0.54±0.03
		ROI III		0.74±0.01	17.71±0.32	0.33±0.02	0.43±0.02
		ROI IV		0.68±0.02	15.04±0.61	0.17±0.02	0.66±0.07
Meridiani Planum	MER Opportunity	South of Voyager (Sol 437-439)	Spherule soil	0.53 (+0.02,-0.07)	14 (+1,-2)	0.249 (+0.022,-0.031)	0.491 (+0.058,-0.057)
			Striped soil	0.56 (+0.01,-0.01)	15 (+1,-1)	0.305 (+0.010,-0.022)	0.353 (+0.033,-0.032)
		Purgatory region (Sol 449-473)	Spherule soil	0.51 (+0.00,-0.01)	10 (+0,-1)	0.230 (+0.006,-0.007)	0.761 (+0.023,-0.013)
			Striped soil	0.52 (+0.24,-0.00)	11 (+0,-1)	0.117 (+0.011,-0.012)	1.000 (+,-)
	CRISM	ROI I		0.53±0.03	15.35±0.95	0.17±0.03	0.66±0.10

Table 1: Retrieved Hapke parameters and their standard deviation from Pancam respectively on board Spirit and Opportunity at Gusev Crater (for Sol 13, 87-88 and 102-103 units) [3] and at Meridiani Planum (for Sol 437-439 and 449-473 units) [4] at 753 nm (the underconstrained parameters are indicated by "(+,-)") and from CRISM by combining several CRISM observations and by applying the MARS-ReCO procedure and the genetic algorithm.