# MARS-ReCO: Multiangle Approach for Retrieval of Surface Reflectance from CRISM/MRO Observations.

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**Introduction:** The CRISM instrument aboard the MRO spacecraft is the first imaging spectrometer to operate systematically in multi-angle mode at high spatial resolution around Mars [1]. Each CRISM targeted observation is composed of eleven hyperspectral images (0.36-3.92 µm) acquired at different emergence angles from the same site of Mars. The nadir image is acquired at full spatial resolution (~18 m/pix) while the bracketing images, the so-called Emission Phase Function (EPF), are acquired at ~180 m/pix. This angular coverage provides unprecedented information that can be used to improve the atmospheric correction of CRISM observations and therefore to retrieve spectrophotometric curves in units of reflectance of the materials at the surface. These products may be crucial to characterize surface materials and to discriminate between different types of terrains.

A novel approach to retrieve surface reflectance from CRISM targeted observations in units of top-of-atmosphere (TOA) radiance is put forward. First, the aerosol content in the atmosphere is estimated. Second, data are compensated from the absorption coming from atmospheric gases. Third, surface reflectance is derived after correction for aerosol effects. The retrieved surface reflectance curves may be fitted to classical photometric models such as Hapke's in order to derive physical properties of the observed terrains.

**Preprocessing:** The eleven hyperspectral images forming a single CRISM observation are initially processed to build an integrated multi-angle product (hereafter referred to as SPC cube). First, all images are projected onto a common geographical space using the associated auxiliary data which contain the latitude and longitude of each pixel. This is done after degrading the spatial resolution of the nadir image by a factor ten. Second, the SPC cube is built by arranging all TOA radiance values corresponding to a single observation (i) along the *x* axis according to the corresponding emergence angle (up to 11), (ii) along the *y* axis according to the spatial location (each *x* position corresponds to a so-called *superpixel*, that is, a terrain unit observed by one or more geometries), and (iii) along the *z* axis according to the spectral wavelength. Approximatively only 30% of *superpixels* are sensed by four or more geometries due to the non-optimal overlap among the footprints of the eleven images of a targeted observation.

**Estimation of the dust content:** Recently an algorithm has been developed to retrieve the aerosol optical thickness (AOT) from CRISM targeted observations [2]. This original method is based on the correlation between the intensity of the $CO_2$ gas absorption band at 2 µm and the amount of aerosols. The strength of the radiative coupling between these two atmospheric constituents is expressed by the definition of a new parameter $\beta$ that can be used to retrieve the AOT in addition to the level of radiance. After the factor $\beta$ is calculated according to geometry for a given CRISM observation, the AOT is estimated by fitting the resulting curves using a DISORT based model. The main requisite of this method is an optical path length that is large enough so that the aerosol/gas coupling is significant. CRISM observations are suitable for the method in [2] because of their large angular coverage.

**Correction for atmospheric gases:** The effects of atmospheric gases on each spectrum of a CRISM observation are characterized by the spectral transmission of the atmosphere along the vertical dimension. This atmospheric quantity is calculated using a radiative transfer (RT) model and using the vertical compositional and thermal profiles of the actual date, location and altitude. More details in the calculation of the vertical transmission can be found in [3]. Due to the radiative coupling between aerosols and gases the resulting vertical transmission must be altered by the estimated AOT (see [2] for more details). After this step CRISM spectra are shaped only by the signal coming from the surface and the signal coming from the aerosols.

**Correction for aerosol contribution and retrieval of surface reflectance:** The separation between the signal coming from the surface and the signal coming from the aerosols is not straightforward due to the anisotropic scattering properties of both elements. Currently adopted atmospheric correction approaches are based on the hypothesis that the surface is isotropic or lambertian [4]. Although this assumption largely simplifies the inverse problem it critically corrupts the angular shape of the retrieved photometric curve or the BRDF model as solid surfaces are hardly isotropic.

An algorithm referred to as MARS-ReCO (Multiangle Approach for Retrieval of Surface Reflectance from CRISM Observations) has been recently proposed to compensate for aerosol effects and to retrieve surface reflectance [5]. This method is inspired by the work done in terrestrial remote sensing in [6]. MARS-

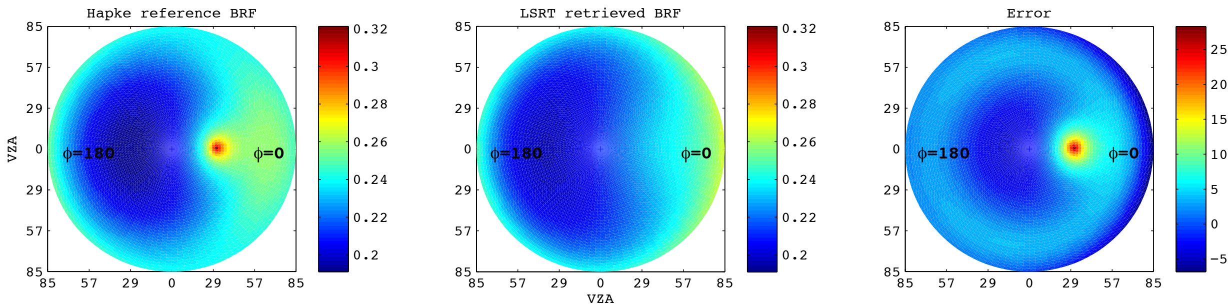


Figure 1: Surface reflectance corresponding to the material Soil generated using (left) the reference Hapke's model (see Table 6c in [8]) and (center) the RTLS model estimated by MARS-ReCO when AOT=1, incidence angle=30º and relative azimuth = {0º,180º}. (right) Relative difference in percentage. The reflectance is plotted in polar coordinates for a dense range of emergence angle and azimuthal angles and for the value of incidence angle that is used for generating the investigated photometric curve.

ReCO is based on the inversion of an accurate RT-based parametrization of the TOA radiance observed by CRISM. MARS-ReCO is a fast atmospheric correction approach since this parametrization is quasi-linear due to the adoption of a kernel-based model for the surface BRDF (a Ross-Thick Li-Sparse [RTLS] model) and a Green's function for the diffuse atmosphere (see [5] for details). The major novelty of MARS-ReCO in front other algorithms is the assumption of a non-Lambertian surface by means of the RTLS model. In addition, the look-up table (LUT) used in the inversion is relatively small as it only stores atmospheric quantities depending on geometric configuration. Indeed, the LUT does not depend on the surface thanks to the mathematical properties of the combination of the Green's function and the RTLS model. The LUT is computed for several realistic martian scenarios using DISORT and taking into account the radiative properties of mineral aerosols derived by Wolff et al. [7].

MARS-ReCO processes each *superpixel* of a SPC cube (formed by up to 11 angular measurements at a given wavelength) to retrieve the BRDF of the corresponding terrain unit. This is achieved by an efficient iterative algorithm aimed at minimizing the root mean square error between the angular measurements and the model. The reliability of MARS-ReCO is emphasized by discarding those *superpixels* whose radiance values are not good enough to be processed.

**Sensitivity study:** The capabilities of the proposed strategy have been tested on synthetic data that mimic the photometric properties of the planet Mars. This sensitivity study has been addressed to identify the acquisition configurations and the atmospheric conditions under which MARS-ReCO becomes less reliable. A realistic synthetic data set is simulated with DISORT considering the optical properties of martian aerosols [7] and the Hapke's BRDF of four mineral materials (two types of soils and two types of rocks) whose reflectances were measured by the Pan-Cam/MER instrument and fitted to a Hapke's model [8]. The synthetic CRISM-like photometric curve of each selected mineral material is simulated for multiple realistic geometric configurations (varying incidence angle and phase domain) and realistic martian atmospheric conditions (varying AOT). Results show that the retrieval of surface reflectance by MARS-ReCO is generally possible when the signal coming from the surface is significant in comparison with that of the atmosphere (i.e. moderate or high albedo, surface anisotropy different from that of the aerosols, low or moderate AOT, low or mild incidence angle, and significant phase domain). Fig. 1 shows the reference reflectance and the retrieved reflectance of a soil surface observed with a given geometry and atmosphere. MARS-ReCO retrieves a BRDF model which is very similar to the original BRDF used in the construction of the synthetic data using only eleven angular measurements. The absence of opposition effect comes from the lack of such a kernel in the RTLS model.

Retrieved surface reflectance may be analyzed using other photometric models such as Hapke's. Indeed CRISM targeted observations corresponding to the MER landing sites have been atmospherically corrected by the proposed approach and fitted to a Hapke's model in [9]. Satisfactory results shows the potential of MARS-ReCO in providing accurate surface photometric properties.

**References:** [1] Murchie S. et al. (2007) *JGR, 112, E05S03*. [2] Douté S. and Ceamanos X. (2010) *IEEE WHISPERS*. [3] Douté S. (2009) *IEEE WHISPERS*. [4] McGuire P. C. (2008) *IEEE Trans. Geosci. Remote Sens., vol. 46, no. 12, pp. 4020–4040*. [5] Ceamanos X. (2011) *IEEE IGARSS*. [6] Lyapustin A. et al. (2011) *JGR, 116, D03210*. [7] Wolff M. et al (2009) *JGR, 114, E00D4*. [8] Johnson J. R. et al. (2006) *JGR, 111, E02S14*. [9] Fernando J. (2012) LPSC #1960