WAVELENGTH DEPENDENCE OF LIMB-DARKENING OF MARS FROM VISIBLE AND NEAR-IR TELESCOPIC SPECTRAL IMAGING

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We are investigating the photometric properties of Mars using Earth-based telescopic spectral imaging obtained during 1988 [1]. Each spatial pixel consists of 300 spectral channels from 0.44 to 1.02 μm, calibrated to radiance factor (r(p)) through a careful procedure involving standard star observations in 1988 and 1990 [2]. Calibrated data include 3 spectral images with solar phase angle (g) of 12° and 4 images with g of 4°. Pixels near the sub-Earth point have a spatial footprint of about 280x150 km. Preliminary work using Hapke photometric function [3,4,5] reveals a dependence of both single-scattering albedo and roughness parameter on wavelength. The former is in agreement with observed spectra of the martian surface, but the latter is unexpected.

Because of the instrumentation and observation method, individual slit exposures cannot simply be lined up to give an accurate spatial view of Mars. A photographic record of the slit position on Mars was made simultaneously with every CCD exposure at the telescope. Each slit position was then independently projected to a simple cylindrical map base and the data for that exposure resampled appropriately (Fig. 1). In addition to accurately determining latitude and longitude for each pixel, illumination (i) and emission (ε) angles are calculated and added to the data base during this processing step. The resultant data base for g, i, ε, and r(p) as a function of wavelength is used for subsequent photometric modeling. Our initial objective is to characterize the limb-darkening of Mars as a function of surface albedo and wavelength. These data allow this analysis to be performed at high spectral resolution for the first time. For initial modeling data were averaged over five wavelength bands: Blue (0.438-0.478 μm), Green (0.530-0.578 μm), Red (0.618-0.678 μm), NIR (0.700-0.74 μm), and MIR (0.93-1.00 μm). Fig. 2 represents a typical slit profile of Mars' surface, given by a combination of limb-darkening and surface material characterization for the various spectral bands. The difference in profile from Blue to MIR is evident. The Hapke photometric function has been fit to the data base for these spectral bands. The constant phase angle, 4°, for the first image under analysis allowed us to reduce the number of parameters to be searched for in Hapke photometric function to two, as a result of the constant phase function P(g) and the constant opposition-effect function B(g). Existing information about the opposition-effect for the martian surface [6] allowed us to consider null the contribution to Hapke photometric function from the opposition-effect term.

A typical slit profile across Mars disk and the best fit for Hapke photometric function is plotted in Fig. 3, together with the best fit for the Minnaert photometric function, drawn for comparison. The result of the fit of Hapke photometric function to the data for the various spectral bands is reported in Fig. 4 for the single-scattering albedo and the roughness parameter vs. wavelength. The increase in single-scattering albedo from Blue to IR is consistent with the observed spectra of high- and low-albedo units (e.g. [7]). On the other hand, the inverse dependence of the roughness parameter with wavelength is unexpected for a surface, since the roughness effect is based on modeling the surface as unresolved facets (>> λ), tilted at various angles and should affect every wavelength in the same way [8]. Such behavior of the roughness parameter with wavelength is, then, indicating the presence of other effects that a simple Hapke photometric function cannot account for; one of these is due to the presence of the atmosphere that affects shorter wavelengths (Blue) more than longer ones (IR). Another effect is due to the bimodal character of the martian surface (bright and dark material) that is not taken into account in the Hapke photometric function. This effect is being investigated by applying the Hapke photometric function to dark and bright regions separately, and might be dealt with by generating a photometric function that combines Hapke photometric functions for dark and bright regions together.

One drawback of the Hapke photometric function for the determination of macroscopic roughness from telescopic data is the limited range of phase angle. A study of the geological interpretation of photometric surface roughness by Helfestein [9] shows that "reliable determination of photometric roughness from disk-integrated data or from disk-resolved photometric observations of geological features requires observations which extend from small phase angles out to phase angles above 90°". In particular, observations at high phase angles seem to provide the most important constraints for determination of the roughness parameter. However, even given a high uncertainty in the estimated values of the roughness parameter for our data, we believe that the general trend of the roughness parameter with wavelength is real and can provide the starting point for a further elaboration of the photometric function for Mars in which atmospheric effects are included.

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Fig. 1: Simple cylindrical map projection of Mars telescopic data (9/26/88).

Fig. 2: Slit profile from same Mars data for: a) Blue, b) Green, c) Red, d) NIR, e) MIR.

Fig. 3: Slit profile from same Mars data and best fit Hapke and Minnaert photometric functions.

Fig. 4: Single-scattering albedo and roughness parameter vs. wavelength for Hapke fit.