APPLICATION OF AN EMPIRICAL DARK [SHADOW] SUBTRACTION METHOD TO CRISM VNIR+IR DATA AS A SUPPLEMENTAL METHOD FOR SPECTRAL ANALYSIS OF THE SURFACE.

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Introduction: Determining the mineral and phase composition of the Martian surface is key to understanding the geologic history and evolution of the planet. VNIR multi- and hyperspectral datasets from orbit (e.g., OMEGA, THEMIS VIS, CRISM. HiRISE, CaSSIS) [1-5] are often used to provide quantitative constraints on the composition of the surface but must be corrected for all atmospheric and photometric effects [7-9] prior to analysis. In addition to atmospheric CO_2 absorptions, VNIR radiative transfer from Mars is also dominated by scattering due to aerosols in the atmosphere, which has a significant impact on interpreting remotely sensed VNIR surface spectral characteristics [10-11]; this is especially true over the wavelength range shortward of 1000 nm where the contributions of a ferric iron oxide aerosol (i.e., airborne Martian dust) have the most impact on orbital spectra [11]. As a result, all calibrated orbital VNIR datasets of Mars are considered "Top Of the Atmosphere" (TOA) [e.g., 10-11] until they have been appropriately corrected for. Importantly, this is till the case even for the "atmospherically corrected" cubes (e.g., CRISM joined VNIR+IR data, i.e., MTRDRs [11]), that are only corrected for effects of the CO_2-dominated gas absorption (i.e., by applying the division of elevation-scaled volcano-scan spectra for all pixels in the scene [12-14]). While atmospheric CO_2 has been scaled out, the aerosol scattering contribution remains, which contributes to a reduction of the spectral contrast from the surface. This is one of several reasons why spectral ratioing is often adopted to enhance the spectral characteristics of a Region Of Interest (ROI) on the surface and to determine its composition.

Tornabene et al. [15] has recently demonstrated that a simple empirical dark subtraction (DS-correction), when applied to both CRISM and CaSSIS, may be able to provide remarkable results in isolating surface spectral components and permitting direct comparisons with reference spectra. This can prove to be significantly helpful over the ratioing method commonly employed for CRISM analysis, especially in cases where a spectrally bland region needed to ratio against may not be present in the scene or sufficiently spectrally neutral. This work presents results from the application of a DS-correction method to CRISM cubes to gauge its usefulness as a supplement for spectral validation, and perhaps uncovering additional endmembers present in the data where standard methods fail.

Methods: We applied a standard minimum value DS correction in ENVI, commonly used to minimize scatter in terrestrial datasets [15], to atmospherically CO_2-corrected MTRDR cubes. Because higher Aerosol Optical Depths (AOD) for common scatterers cause further reduction in surface spectral contrasts, we only use (and recommend) CRISM cubes with lower estimated dust and water-ice AOD (not much greater than ~1.0 and 0.2, respectively). We begin our analysis with 31 observations: 29 covering the CRISM type-localities summarized by Viviano-Beck et al. [16], 1 covering the compositionally diverse and well-characterized uplift of Alga Crater [17] (**Fig. 1**) and 1 covering the ExoMars 2022 rover landing site in Oxia Planum (**Fig. 2**).

Validation of the DS correction: We note that the DS correction may be prone to over-correction as it can sometimes extract values from surfaces not in shadow (e.g., a deeply absorbing and wavelength-dependant dark surface). Furthermore, there may be cases where shadowed pixels, while being dominated by scatter, also contain reflections off the surface, including any nearby bright materials (illuminated slopes and/or surface frost/ice). Hence, minimization of DS overcorrection results is key to pivotal to provide robust results and thereby, gives impetus for a validation approach. Based on our previous work [15], this approach includes: (a) visually inspecting the minimum spectrum from the scene (this should generally approximate a Martian dust spectrum as it is always present in the atmosphere (dust AOD is generally > 0.0 [9]) (b) ensuring that the minimum values come from shadows; and (c) ensuring that any component of interest is not present in a shadowed area, especially frost and/or ice. In cases where minima pixels do not lie in shadow, a modified DS correction approach may be used, but is not always be successful [18].

Results: *Alga Crater*: **Fig. 1** shows the DS-corrected spectra extracted from known locations for olivine- and low-Ca pyroxene (LCP)-bearing materials after [17]. DS correction was able to help isolate a previously undocumented unit (grey spectrum in **Fig. 1A)** that is most consistent with a plagioclase-rich endmember. Notably, these results were obtained without using the standard ratioing technique.

Detection of an LCP-bearing component in Oxia Planum: **Fig. 2** highlights the matching of averaged DS corrected spectra with an LCP spectrum provided by

RELAB [19]. These spectra were extracted from CRISM FRT 9A16, particularly from pixels over exposures in the walls of two craters SE from the center of the 3-sigma landing ellipse. This LCP-bearing material has not been previously reported for this FRT, nor elsewhere over the landing ellipse [e.g., 20], but this is likely due to poor coverage of the landing site with targeted CRISM observations. LCP bearing materials appear to dominate the primary materials that crystallized early in the history of Mars [e.g., 21], and therefore represents an important target for future investigation by the ExoMars Rosalind Franklin rover. While it appears that LCP has only been identified in this one CRISM targeted observation to date, an LCP component could be more widespread at local/in situ scales and accessible to the rover.
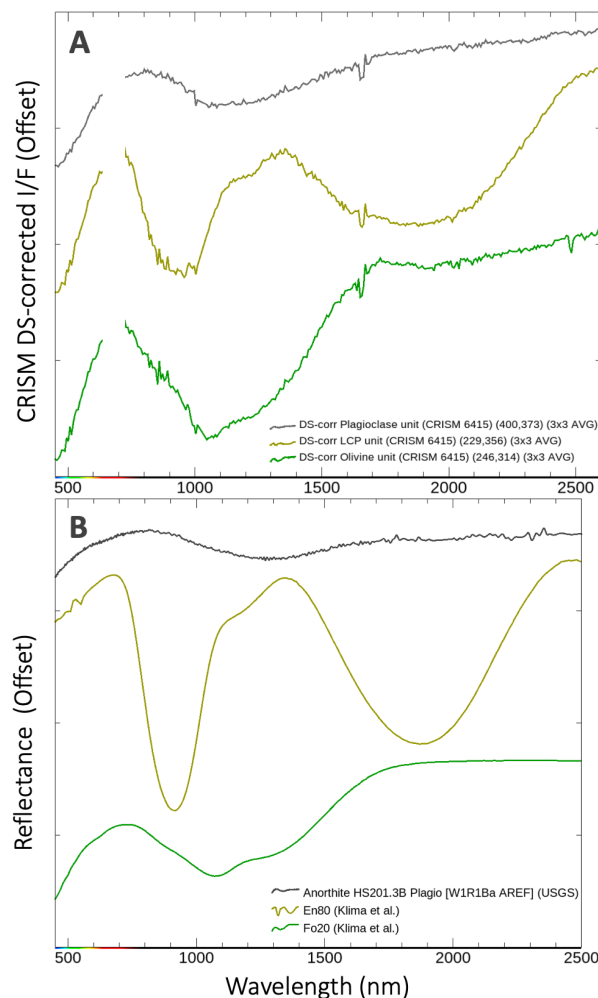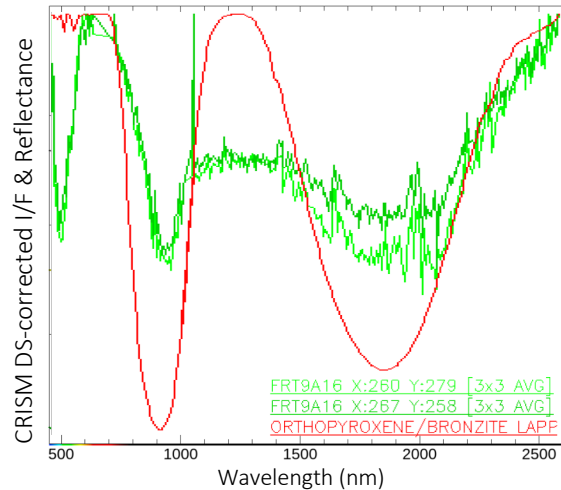

Fig. 2 Continuum-removed spectra extracted from CRISM FRT 9A16 over Oxia Planum (unratioed 3x3 averaged DS-corrected I/F spectra; green) and a scaled RELAB reference reflectance spectrum for Orthopyroxene (LCP; red).

Conclusions: Preliminary spectral results indicate that the DS correction serves as a useful, less time-intensive approach to compositional analysis from remote sensing VNIR observations. While such a correction is acquisition geometry and scene dependent (i.e., must be based on pixels completely in shadow) and may be prone to over-correction, the results obtained from well-corrected CRISM cubes permits direct comparisons with reference spectra without the need for spectral ratioing with a spectrally bland or neutral component in the scene. Since there are several caveats to consider, this correction method should be used to augment and complement, not replace, the results obtained from the standard CRISM ratioing and other photometric correction methods.

References: [1] Bibring J. P. et al. (2004) ESA Spec. Pub., 37-50 [2] Christensen P.R. et al. (2004) SSR, 110, 85-130. [3] Murchie S. et al. (2007) JGR, 112. [4] McEwen A.S. et al. (2007) JGR, 112. [5] Thomas N. et al. (2017) SSR 212, 1897-1944. [6] McGuire P.C. et al. (2008) IEEE Trans. Geosc., 46(12), 4020-4040. [7] Ceamanos X. et al. (2019), JGR, 118. [8] Itoh and Parente (2021) Icarus, 114024. [9] Wolff M.J. et al. (2017) Cambridge Univ. Press, Chapter 6, 106-171. [10] Fernando J. et al. (2017) LPSC XLVIII, p.1635. [11] Seelos F. et al. (2016) *LPSC*, 1783.[12] Pelkey S.M. et al. (2007), JGR 112. [13] McGuire P.C. et al. (2009) PSS, 57, 809-815. [14] Morgan et al. (2011) LPSC, 2453. [15] Tornabnene et al. (2021), LPSC, 2459. [15] Chavez P. (1988) RSE, 24, 459-479. [16] Viviano C.E. et al. (2014), JGR, 1403-1431. [17] Skok et al. (2012), JGR 117. [18] Quantin-Nataf et al. (2021) Astrobio. [18] Tornabene et al. (in prep). [19] Pieters (1983), JGR, 9534-9544. [20] Quantin-Nataf et al. (2021), Astrobiology, 345-366. [21] Baratoux et al. (2013) JGR, 59-64.[22] Clark et al. (2007) USGS #231.[23] Klima et al. (2007) MAPS, 235-253.

Fig. 1. CRISM DS-corrected spectra vs. reference reflectance spectra. A) Unratioed 3x3 averaged DS-corrected I/F spectra extracted from CRISM FRT 6415 covering the uplift of Alga Crater. B) Library reflectance spectra from USGS [22] (Anorthite) and Klima et al. [23] spectral libraries (LCP – EN80 and Olivine – Fo20).