POTENTIAL DETECTION OF EXPOSED MARTIAN WATER ICE WITH MULTISPECTRAL IMAGES FROM THE EXOMARS COLOUR AND STEREO SURFACE IMAGING SYSTEM. L. L. Tornabene[1], P. Becerra[2], C. Cesar[2], S. Conway[3], G. Cremonese[4], A. Lucchetti[4], G. Munaretto[4], A. McEwen[5], M. Pajola[4], M. Patel[6], J. Perry[5], A. Pommerol[2], V. Rangarajan[1], F. Seelos[7], N. Thomas[2], J. Wray[8], [1]Inst. for Space & Earth Exploration, Western University, London, Canada (ltornabe@uwo.ca), [2]Physikalisches Inst., Univ. Bern, Bern, Switzerland, [3]CNRS, Université de Nantes, France, [4]INAF, Osservatorio Astronomico di Padova, Padova, Italy, [5]LPL, Univ. of Arizona, Tucson, AZ, [6]STEM, Open University, Milton Keynes, UK, [7]JHU/APL, Laurel MD, [8]Earth & Atmos. Sci., GIT, Atlanta, GA.

Introduction: The characterisation of Martian ice deposits is a critical Mars science objective [1]. Ice holds important clues about the current and past history of Mars from both a climate and habitability perspective; in addition, access to H_2O ice is essential for in-situ resource utilization (ISRU). While ice can be qualitatively distinctive in visible and near-infrared images, being amongst the brightest surface materials observed [e.g., 2-3], its appearance may not be sufficient to unambiguously quantify the coverage and extent of these deposits on the Martian surface [e.g., 4]. The most common approach for identifying H_2O ice on the Martian surface relies on hyperspectral data (e.g., OMEGA and CRISM) [5-6] that resolves diagnostic absorption bands in the visible near-infrared (VNIR). However, multispectral approaches to mapping H_2O ice on planetary surfaces are theoretically feasible and currently the focus of upcoming missions [7-8]. The ultimate goal of this work is to determine if the VNIR spectral characteristics of H_2O ice are sufficiently diagnostic at the multiband-level to enable its identification with the Colour and Stereo surface Imaging System (CaSSIS).

Background: CaSSIS is a VNIR bi-directional push-frame stereo camera on the ExoMars 2016 Trace Gas Orbiter (TGO). Its image swath is up to 9.4 x 60 km, with as many as four broadband colours spanning a sensitivity range from ~400 to 1100 and centered at 497.5 (**BLU**), 677.4 (**PAN**), 835.4 (**RED**) and 940.2 nm (**NIR**); images are ~4.6 m/px (resampled to 4 m) [9].

While the orbit of TGO prevents CaSSIS from observing water ice on the surface of north polar cap, Mars presents other opportunities at lower latitudes [6,10-13]; these include perennial ice mounds within Louth and Korolev Craters [6,10,11], which have been heavily observed by CaSSIS.

General Methods: Prior to multispectral analysis, CaSSIS images of Louth and Korolev were calibrated to I/F using standard procedures [9, 14-15]. A dark subtraction correction (DS-Corr) method [16] was applied to minimize the dominant contributions to spectra in the VNIR range from atmospheric scatter (e.g., ferric dust aerosols) [e.g., 17, 18]. Spectral parameters that highlight ferric and ferrous contributions, including the possible presence of ice [4], were calculated to aid spectral extraction and analysis. CaSSIS spectra were then compared to lab-measured, modeled and observed spectra of water-ice from CRISM.

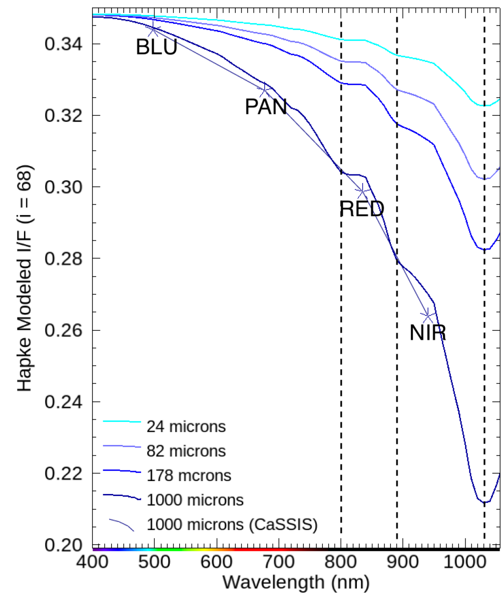

Fig. 1. Hapke-modeled spectra of H_2O ice of different average grain sizes, viewed at an incidence angle of 68º [20]. A spectrum convolved to the 4-bands of CaSSIS is also included for the 1000 μm model (thin line w/stars). Characteristic absorption bands observed at 800, 890 and 1030 nm (dashed-lines).

VNIR Spectral Characteristics of H_2O ice:

Lab-measured and Hapke-Modeled Spectra: Here we compare and describe hyperspectral lab (218 bands) [19] and Hapke-modeled spectra (700 bands) [20] of H_2O ice (grain sizes from 10- to 1000-μm) with their CaSSIS band-pass-resampled equivalents. Full lab and modeled spectra of pure H_2O ice over the sensitivity range of CaSSIS show three key spectral characteristics (**Fig. 1**): **1**) relatively high reflectance with a peak near blue (~490 nm); **2**) asymmetric overtone absorption bands observed at ~ 800, 890 and 1030 nm (from weakest to strongest); and **3**) A rapid downward slope in reflectance from blue to 1000 nm.

When these spectra are convolved to the CaSSIS band-passes (spectrum marked by stars in **Fig. 1**), these three spectral characteristics are generally resolved, with the exception of the specific absorptions around 800, 890 and 1030 nm. The CaSSIS BLU band is higher than the NIR and spectra slope from BLU to NIR with a steep drop off from PAN to NIR. These attributes are especially apparent for H_2O ice with larger grain-sizes, which tend to deepen the three absorptions and increase the slope and curvature towards the NIR.

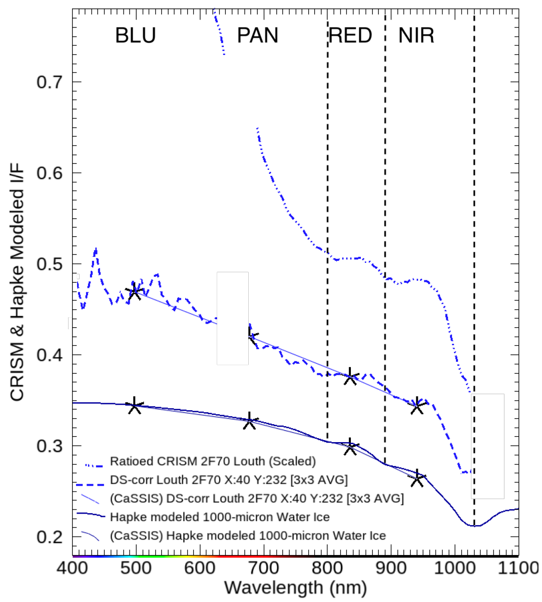

Fig. 2 CRISM I/F spectra (dashed) for the Louth Crater ice mound (**FRT00002F70),** taken at 59º incidence and Ls ~134º, vs. both the full (solid line) Hapke-modeled spectra and its resampled CaSSIS-convolved spectral equivalent (thin lines w/stars). Characteristic absorption bands observed at 800, 890 and 1030 nm (dashed-lines). Spectral gaps are due to the standard removal of bad CRISM bands.

CRISM observations: H_2O ice detection with CRISM has been typically reported based on spectra derived from its longer wavelength IR (L) detector [e.g., 5-6]; this is due to the presence of a stronger H_2O ice absorption band centered around 1500 nm. However, after the loss of the L-detector in 2018, it has become necessary to look to the CRISM VNIR S-detector data for H_2O ice detection. Dundas et al. [14] showed that CRISM I/F spectra of two mid-latitude scarps exposing subsurface H_2O ice resolve the aforementioned absorptions for H_2O ice in the VNIR (see Fig S6 included in the supplementary materials for [14]). These results prompted us to explore CRISM of the Louth Crater mound to see if these features are resolvable which in turn would suggest that a detection with CaSSIS might be possible.

Spectral analysis of a CRISM FRT00002F70 (**Fig. 2**) shows that both ratioed and DS-Corr spectra derived from the mound reveal all three of the spectral characteristics described above. Despite the level of noise in the CRISM DS-corr spectrum, it generally provides a better match with lab and modeled spectra of H_2O ice than the ratioed CRISM spectrum, particularly over the lower wavelength range. The ratioed CRISM spectrum plots off the chart at shorter wavelengths, as it has very high relative I/F values (>1), which is due to ice being much brighter than the ice-free and ferric-bering surface that was divided out in the denominator (i.e., broad/deep absorption band centered around ~500 nm).

CaSSIS Observations: Averaged spectra derived from CaSSIS images of Louth and Korolev are generally consistent with H_2O ice exhibiting high BLU values, a slope from PAN to NIR and a deflection from RED to NIR (**Fig. 3**). While spectra of some ice-free surfaces may exhibit a NIR-deflection due to the presence of ferrous materials [e.g., 4], these spectra do not bear all three of these H_2O ice spectral characteristics. Contributions from CO_2 frost are deemed to be minimal to non-existent, as these CaSSIS observations were taken at a solar longitude (Ls) when H_2O is expected to dominate [21].

Conclusions: Based on this preliminary analysis, there appears to be sufficient spectral distinction over the sensitivity range and at the 4-band spectral resolution provided by CaSSIS to quantitatively identify and characterize H_2O ice. However, further work is required to 1) determine how unique CaSSIS H_2O ice spectra are when compared to other common minerals and phases known to exist on Mars; 2) understand and address complications from illumination effects and surface and atmospheric ferric dust contamination; 3) determine how the scene-dependant dark subtraction correction method affects the I/F of individual bands.

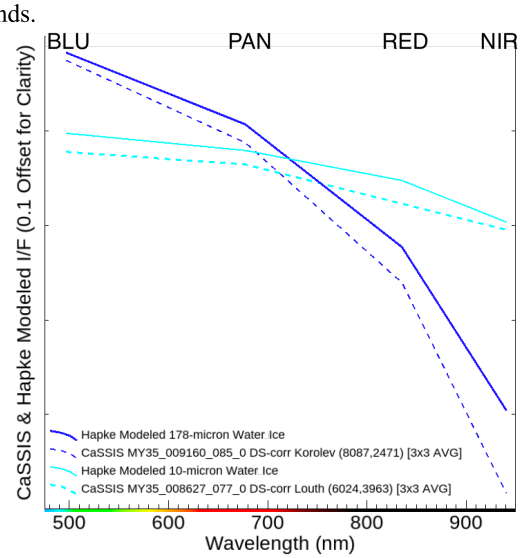

Fig. 3 DS-corr I/F spectra (dashed) derived from observations of H_2O ice deposits in Louth Crater (**MY35_008627_077_0**; i = 77º; Ls ~100º) and Korolev Crater (**MY35_009160_085_0**; i = 59º; Ls ~120º) compared with CaSSIS-convolved Hapke-modeled spectra (solid lines) of 10-µm and 178-µm H_2O ice (i = 68º). **NOTE**: CaSSIS Louth image lacks the "RED" band.

References: [1] Perry et al. (2020) *LPS 51*, 2645. [2] James et al. (1994). *Icarus*, 109. [3] Bell et al. (1997) *JGR*, 102. [4] Tornabene et al. (2018) *SSR*, 214. [5] Langevin et al. (2007) *JGR*, 112. [6] Brown et al. (2008) *Icarus*, 196. [7] Cohen et al. (2020) *IEEE*, 35. [8] Kruzelecky et al. (2019) *IAC 70*, 19-A3.2B.6x50377. [9] Thomas et al. (2017) *SSR*, 212. [10] Conway et al. (2012) *Icarus*, 220. [11] Bapst et al. (2018) *Icarus*, 308. [12] Sori et al. (2019) *JGR*, 124. [13] Dundas et al. (2018) *Science*, 359. [14] Roloff et al. (2017) *SSR*, 212. [15] Pommerol et al. (in prep) *PSS*. [16] Chavez et al. (1988) *Rem. Sens. Env.* 24. [17] Wolff et al. (2009) *JGR*, 114. [18] Fernando (2017), *LPS* 48, 1635. [19] Baldridge et al. [20] Becerra et al. (2015) *Icarus* 251. [21] Brown et al. (2017), *LPS* 48, 2672.

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