MULTISPECTRAL IDENTIFICATION OF WATER-ICE ON MARS FROM HIRISE IMAGES. V.G. Rangarajan[1,2], L.L. Tornabene[1,2], G.R. Osinski[2], R. Beyer[3,4], R. Heyd[5], F.P. Seelos[6], K.E. Herkenhoff[7], V.T. Bickel[8], A. Dapremont[6], G. Munaretto[9] [1]Institute for Earth and Space Exploration, University of Western Ontario, London, ON, Canada. [2]Dept. of Earth Sciences, University of Western Ontario, London, ON, Canada. (vrangara@uwo.ca), [3]SETI Institute, Mountain View, CA, USA. [4]NASA Ames Research Center, Mountain View, CA, USA. [5]Lunar and Planetary Laboratory, University of Arizona, AZ, USA. [6]Applied Physics Laboratory, John Hopkins University, Laurel, MD, USA. [7]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ, USA. [8]Center for Space and Habitability, University of Bern, Switzerland. [9]INAF-Osservatorio Astronomico di Padova, Padova, Italy.

Introduction: Reliable detection and characterization of water-ice on the surface of Mars is of critical importance, not only to inform us on the present and past climate of the planet, but also to provide us valuable information on its in-situ resource availability and distribution, for future human exploration missions [1,2]. Remote sensing datasets have been very useful in this regard, with visible/near-IR (VNIR) and thermal IR data serving as the preferred tools to study frost [e.g., 3,4]. Frost-related deposits and icy exposures have also been identified through the VNIR, based on their higher surface albedo values. This is because ice/frost deposits are highly reflective in the blue part of the electromagnetic spectrum [5-8] and possess diagnostic VNIR and IR absorptions positioned at 1500, 2000 and 1260 nm (from strongest to weakest) [9,10]. Furthermore, [11,12] also show that while the spectral characteristics of water-ice short-ward of 1050 nm are weaker, they may be used detect water-ice. These features include (i) a relatively higher overall reflectance in blue wavelengths with a local peak near ~490nm, (ii) weak asymmetric overtone absorptions at ~800, 890 and 1030 nm [9], and (iii) a steep downward slope in reflectance from 490 to 1000nm.

Most of these characteristics have been shown to be resolved with CRISM data of water-ice deposits shortward of 1050 nm (see SOM of [13]) and more recently with the Colour and Stereo Surface Imaging System (CaSSIS) [11], provided scattering effects of the atmosphere over the VNIR range are minimized. The aim of this work is to apply these methods to HiRISE to determine if surface water-ice may be quantitatively distinguished from other bright materials.

Methods: Publicly available HiRISE RDR JP2 products are stretched from a digital number (DN) of 3 to 1021, with DN=3 assigned to the minimum brightness of a 9 x 9 pixel down sampled image during radiometric processing [14]. While these products may be confidently used to characterize surface features in spectral ratio-space through calculations of relative albedo [14,15], they often mask out the true surface response of both the darkest (e.g., shadow), and brightest (e.g., ice) pixels in the image. Not only altering the spectral character of potential ice, this cosmetic processing step often impacts the ability to apply a Dark Object Subtraction (DS) correction to minimize atmospheric scattering contributions and better isolate surface signatures. Hence, for a more accurate spectral characterization, versions of the HiRISE radiometrically calibrated product prior to application of the cosmetic radiometric improvement must be used to make more confident interpretations. These products can be generated by feeding HiRISE EDRs in ISIS [16] through (in order) HiCal, HiStitch, HiccdStitch, HiColorInit, HiJitReg, HiSlither and Hicolornorm processing pipelines [17].

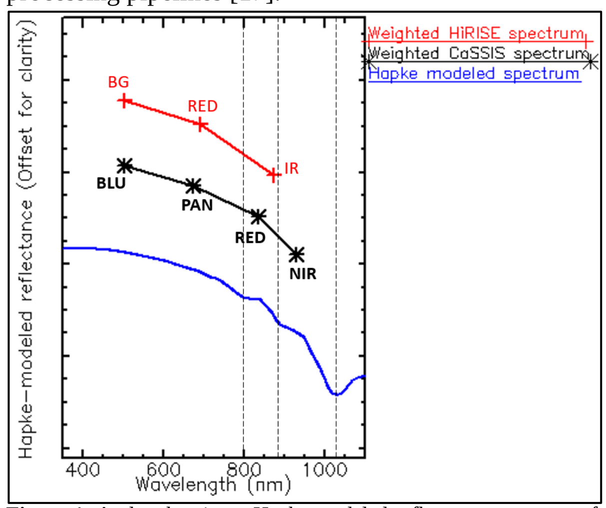

Figure 1. A plot showing a Hapke modeled reflectance spectrum of 1000 µm water-ice particles at 45° incidence (blue) and corresponding weighted CaSSIS (black) and HiRISE (red) spectra generated by spectrally resampling the blue spectrum to CaSSIS and HiRISE instrument response functions respectively. Dashed lines show the position of the three weak absorptions of water-ice in the VNIR centered at ~800, 890 and 1030 nm. Black asterisks (*) represent the four CaSSIS band centers and red plus symbols (+) mark the three HiRISE colour band centers.

A DS correction, a technique commonly used for minimizing smog and haze in terrestrial datasets [18] and shown to improve spectral analysis of Martian surface when using VNIR datasets [6,8], is carefully applied and validated. Spectral band ratios like BG/RED, BG/IR and parameters, including ICE-ATM and WATER-ICE parameters adapted from CaSSIS to HiRISE [6], may be used to delineate icy signatures and are computed here for further validation.

These methods are tested on a time series set of images of bright materials associated with recent mid- to high latitude impact craters and that are confirmed to be water-ice based on CRISM [19,20]. A variety of non-icy targets are also used to fully understand the capabilities and limits of these methods.

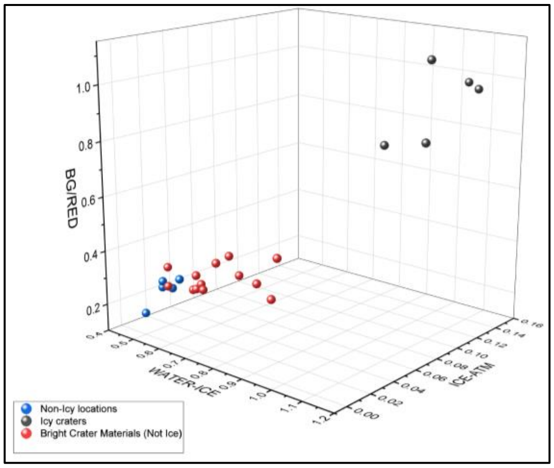

Figure 3. A three-dimensional spectral parameter plot of 23 DS-corrected and processed HiRISE images targeting a variety of features including ice-excavating impacts, non-icy locations and bright non-icy crater materials, predominantly sedimentary in origin. The plot indicates water-ice rich areas uniquely show very high BG/RED, ICE-ATM and WATER-ICE ratios, and can hence be discriminated from non-icy locations.

Results: Fig. 2 shows a series of three HiRISE images of a recent ice-excavating impact, acquired between 2010 and 2013. DS-corrected I/F spectra acquired from the blue and red ROIs in Fig. 2a show a distinct spectral difference between the icy and non-icy (dusty) region in the crater (Fig. 2d); Spectra for the icy region is characterized by a high BG I/F value, along with a spectral deflection towards the IR, indicative of the ~1030nm water-ice absorption. The image sequence in Fig. 2 also shows that the ice deposits spectrally change over time. A distinct spectral drop from RED to BG is observed in subsequent ice spectra. Such a drop is consistent with the characteristic ~550 nm absorption feature of ferric iron oxide dust [6] and exhibited by all three red spectra. When this is coupled with a dramatic increase from RED to IR in the third blue spectrum (Fig 2f), we interpret this to signify the almost complete removal of ice through sublimation and increased concentration of a dust lag. Differences between the final blue and red spectra (relatively higher blue and lower IR) further indicates that the ice has not yet been completely removed from the scene which is consistent with the visual provided in Fig 2c.

Given the distinctive spectral characteristics of water-ice described earlier, band ratios may be helpful in separating areas rich in water-ice from those that are not. Fig. 3 shows a 3D plot between DS-corrected BG/RED, ICE-ATM and WATER-ICE spectral parameters for a set of ~23 HiRISE observations. Water-ice deposits typically have high BG/RED, ICE-ATM and WATER-ICE values, and therefore lie at the top right of the plot, while non-icy ferric surfaces typically lie at the bottom left of the plot.

Conclusions: Preliminary results from our work show that it may be possible to reliably identify water-ice exposures from DS-corrected HiRISE 3-point spectra and corresponding spectral parameters. This can prove to be extremely useful to help identify small-scale exposures that may be sub-resolution for CRISM and/or CaSSIS. Work is currently underway to expand and test the capability of these spectral parameters on a larger subset and variety of HiRISE images.

References: [1] Perry et al. (2020) *LPS 51*. [2] IMIM Report (2022). [3] Kieffer et al. (2000) JGR 105. [4] Brown et al. (2017), *LPS 48*. [5] Renno and Mehta (2010), *SPIE 78190*. [6] Tornabene et al. (2018) *SSR*, *214*. [7] Khuller & Christensen (2021), *JGR 126*. [8] Rangarajan et al. (2022), *LPS 53*. [9] Clark (1981) *JGR 86*. [10] Viviano et al. (2014), *JGR 119*. [11] Viviano et al. (2022) *LPS 53*. [12] Tornabene et al. (2021) *LPS 52*. [13] Dundas et al. (2018) *Science 359*. [14] Daubar et al. (2016) *Icarus 267*. [15] Schaefer et al. (2019) *Icarus 317* [16] Sucharski et al. (2020) *ISIS3.1* [17] Becker et al. (2022) *USGS* [18] Chavez (1988) *RSE 24*. [19] Byrne et al. (2009), *Science 325*. [20] Dundas et al. (2021). *JGR 126*.

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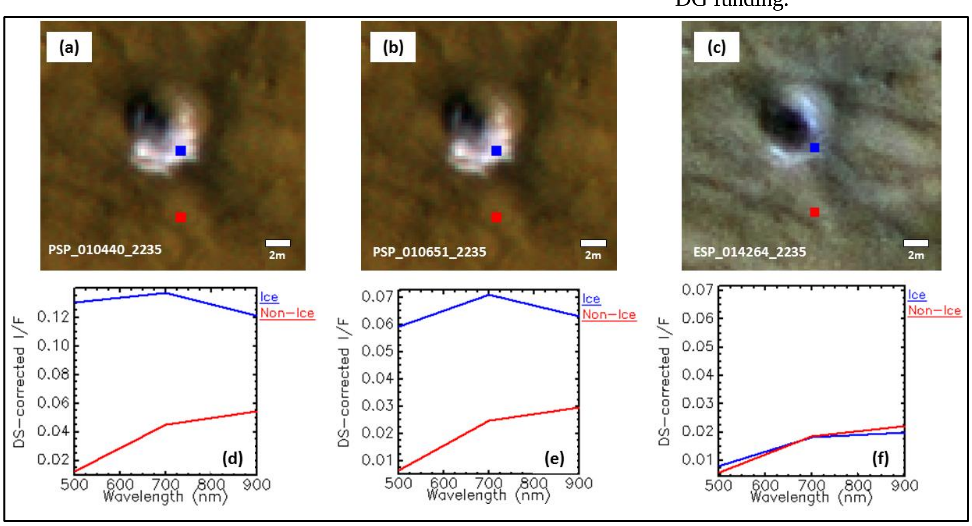

Figure 2. A series of three HiRISE IR-RED-BG colour composite images (Figs. a-c) showing gradual sublimation of ice excavated from an impact near Arcadia Planitia. Note that the images here are relatively stretched. Figs. (d)-(f) show spectra extracted from the blue and red ROIs shown in Figs. (a)-(c), that denote icy and non-icy regions in the image respectively. The plots show a distinct difference in spectral shape between the icy and non-icy spectra and that BG I/F reduces as the exposed ice continues to sublimate and/or gets covered by dust.