TROPICAL FROST ON MARTIAN VOLCANOES. A. Valantinas[1], N. Thomas[1], A. Pommerol[1], E. Hauber[2], V. Bickel[3], N. Schorghofer[4], A.S. McEwen[5], M. Almeida[1], M. Read[1], V.G. Rangarajan[6], G. Munaretto[7], M. Pajola[7], C. Re[7] and G. Cremonese[7]. [1]Physikalisches Institut, Universität Bern, [2]Institut für Planetenforschung, DLR, [3]Center for Space and Habitability, University of Bern, [4]Planetary Science Institute, [5]LPL, University of Arizona, [6]Inst. Space & Earth Exploration, Western University, [7]INAF-Astronomical Observatory Padova.

Introduction: The sublimation and condensation of frost is an important driver of several active geomorphological processes on Mars [1]. It is estimated [2] that there are hundreds of thousands of slope streaks in the equatorial regions - latitudes that are devoid of H_2O frost from 13°S to 32°N [3]. CO_2 frost on the other hand, based on the analysis of surface nighttime temperatures and thermal modeling, was suggested to condense at night in the dusty equatorial regions [4] and on the tallest Tharsis volcanoes [5]. It was proposed that the diurnal sublimation and condensation cycle of CO_2 frost may destabilize dusty slopes and trigger slope streaks [4]. Recent studies [6] attempted to detect the putative equatorial frost using early morning observations of the Thermal Emission Imaging System (THEMIS) [7] but were not successful. Using novel observations of the Colour and Stereo Surface Imaging System (CaSSIS) [8] onboard the ESA's Trace Gas Orbiter (TGO) we discover vast tropical frost deposits on the Arsia (AM), Ascraeus (ASM) and Olympus Montes (OM) calderas. We confirm the detections in OM using a supporting observation from the High Resolution Stereo Camera (HRSC) [9] onboard the ESA's Mars Express orbiter. Although our observations indicate that frost is present atop the tallest Tharsis volcanoes, slope streaks are absent in these regions. This suggests that the sublimation and condensation of frost may not be the primary cause of slope streak formation.

To determine the composition of the observed frost deposits we have recently made joint observations with the Nadir and Occultation for MArs Discovery (NOMAD/TGO) team [10], which will be presented at the conference.

Methods: We surveyed ~4,200 CaSSIS images (acquired up to 2022-02-05) with illumination geometries of 50–90° incidence within dusty, low thermal inertia (<100 TIU) regions (60° N to 30° S). The CaSSIS images acquired at extremely high solar incidence angles (85–90°) were observed to contain color and calibration artifacts due to the decrease in signal-to-noise ratio (SNR) and/or an increase in aerosol contribution from the atmosphere [11]. All images with color artifacts were labeled as ambiguous and were not used for further analysis. Frost identification relied upon the following three criteria: 1) correlation with topography (e.g. frost is absent on well-illuminated, warm slopes), 2) bluish or whitish coloration in the

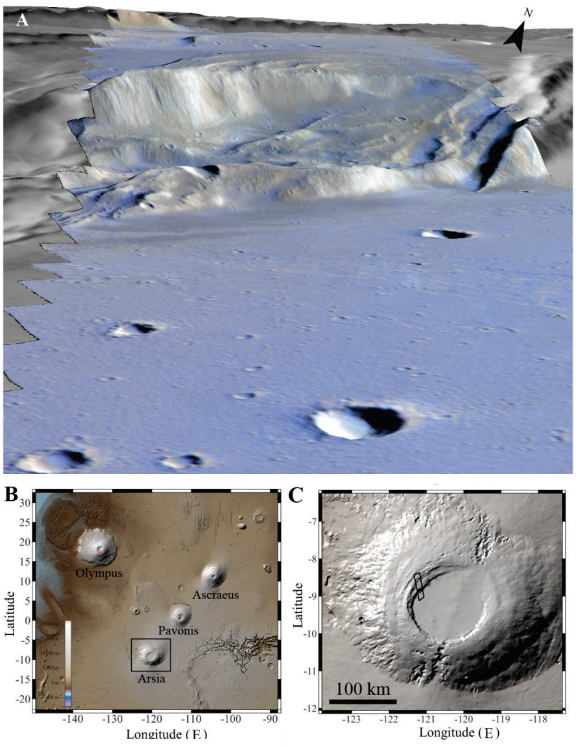

Figure 1. Early morning frost in the Arsia Mons caldera (LST = 8:03AM, Ls = 93.9º). Frost (blue) is observed on the caldera plains, small crater floors and in shadowed areas, but is absent on well-illuminated steep slopes (A). Spatial context of Tharsis volcanoes (B) and a close up of Arsia Mons (C). The CaSSIS image footprint is shown in black in (C) and it was orthorectified and draped over the CTX DEM (A). Vertical exaggeration is x10. The spatial resolution is ~4.6 m/px. The topographic map is MOLA color hillshade 64 ppd (B-C). CaSSIS image ID: MY35_008465_192_0_NPB. Image dimensions ~40 x 8 km.

CaSSIS NPB (NIR = 940, PAN = 670, BLU = 497 nm) and synthetic RGB (PAN and BLU only) products, and 3) elevated I/F values in the BLU filter relative to frost-free terrains (within the CaSSIS absolute uncertainty of 3% [12]). To analyze cases where frost deposits correlate with topography, we used CaSSIS and Context camera (CTX) Digital Elevation Models (DEMs). CaSSIS DEMs were produced by a pipeline developed at INAF-OAPD [13,14]. CaSSIS images that did not have respective CaSSIS DEMs were rectified over CTX

DEMs using QGIS. CTX DEMs were produced using the NASA Ames stereo pipeline [15].

Results: We observed eight instances of frost in the equatorial regions atop AM, ASM and OM. Figure 1A shows one such case in AM where morning frost is ubiquitous on the caldera floor and rim. All CaSSIS detections fall within the local cold seasons and early morning hours. Since frost is not observed during the afternoon hours, the condensation and sublimation cycle is seasonal and diurnal. Furthermore, frost is not identified below 15 km in altitude. The latter point is clearly illustrated by a recent HRSC observation of the OM caldera acquired on 2022-11-30 (Fig. 2). In this wide-angle observation frost appears to have condensed on the caldera floor and the outer rim, but not on the volcano flanks.

On 2022-11-25 we have made a joint CaSSIS-NOMAD early morning observation of the OM caldera. The CaSSIS observation resulted in a positive detection of frost and the NOMAD observation is currently being analyzed. The NOMAD Limb, Nadir and Occultation channel (LNO) can be used in nadir mode to distinguish between water or carbon dioxide frost [e.g. 16].

Discussion: Due to the high elevation of the sites with early morning frost, far above the scale height of the Martian atmosphere (10.8 km), the downward sky irradiance is very small at night. Combined with the small thermal inertia of the surface, this suggests that the observed frost deposits may be composed of CO_2.

To test the hypothesis that the presence of frost on the volcano calderas may interact with the surface geomorphology, we acquired and reviewed several HiRISE/CTX observations. Slope streaks were not present on the calderas of AM, ASM and OM, even though meters thick layers of dust [17], strong winds [18] and steep slopes are available in these locations. On the other hand, a CaSSIS-led study did not find early morning frost in Arabia Terra, a region where slope streaks are abundant [19]. Both points suggest that the slope streak formation is independent of frost formation and therefore unlikely to be correlated with seasons.

In addition, the dust found on the caldera floors is indurated and forms meter-scale reticulate bedforms [20]. To investigate the idea that frost may be a contributing factor to soil induration we searched but were not able to find any correlation between the reticulate textures and frost deposits. This likely suggests that aeolian processes and cementation agents other than frost control the formation of these features or that the induration may have happened earlier during a recent but different Mars climate.

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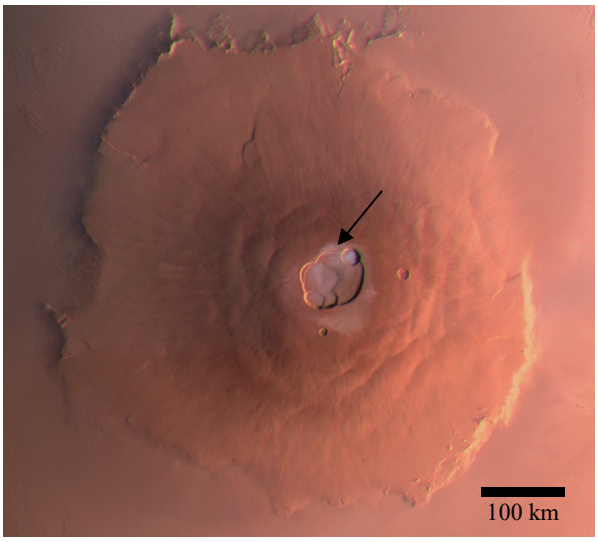

Figure 2. Early morning frost (marked by black arrow) on the Olympus Mons caldera (LST = 7:20AM, Ls = 346.7º). This image was acquired by HRSC on 2022-11-30. North is up and illumination is from the right.

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