

MARS MISSION CONCEPT: MARS ICE CONDENSATION AND DENSITY ORBITER. T. N. Titus¹, T. H. Prettyman², A. Brown³, A. Colaprete⁴, S. Byrne⁵ ¹U.S.G.S. Astrogeology Science Center (2255 N. Gemini Dr., Flagstaff, AZ 86001, ttitus@usgs.gov), ²Planetary Science Institute, ³SETI Institute, ⁴NASA Ames Research Center, ⁵University of Arizona

Introduction: Knowledge of the deposition cycle of the Martian polar ice presents a gaping and dangerous hole for future Manned Mars missions that will seek to exploit the resources or access the historical record that the polar caps represent. The polar cap extends to roughly 45 deg. latitude each winter and presents a major source of water for human explorers, but the necessary understanding of its composition and deposition processes is scant at best. The MICADO instrument suite (Figure 1 and Table 1) has been designed in order to fill that gap. Many of the remaining questions in understanding Mars polar processes may have effects relevant to both human exploration and pre-cursor missions. For example, the coupling of the CO₂ and H₂O cycles may determine where near surface water ice is either currently present (and available for human use) or where past ice deposits may have been available for past life. The coupling of the CO₂ and dust cycles may determine in which years planet encircling dust storms occur and which years are quiescent. These dust storms are potentially dangerous to any *in situ* or human habitats that depend on solar energy, reduce visibility, and may be a potential hazard as an abrasive agent. A greater understanding of these three cycles are coupled will improve GCMs and other climate models ability to predict both future and past climatic conditions.

CO₂ Ice Density: What are the densities, column abundance and areal coverage of the CO₂ ice that compose the seasonal and residual polar caps?

Investigation: Measure the spatial and temporal evolution (thickness) of the seasonal polar caps with centimeter vertical resolution sampled at approximately every 10° of L_s.

Investigation: Measure the topography of the south polar residual cap at 20 meter (horizontal) and centimeter (vertical) resolutions.

Investigation: Measure the column mass abundance of the CO₂ ice in the seasonal and residual polar caps with accuracy of 50 kg/m² sampled at approximately every 10° of L_s.

Discussion: Surface CO₂ ice emplacement can occur either as direct deposition onto the surface or as precipitation (snow) from the atmosphere aloft. The time evolution of these two modes of ice emplacement and subsequent grain growth primarily determines the seasonal cap density. Spatial and temporal density variations of the seasonal CO₂ ice are expected, but cannot

be easily measured with present day observations. For example, an estimate of the volumetric density of seasonal CO₂ ice has been determined by combining MOLA altimetry (37.5 cm precision over ~170 m footprints) (e.g., [1]), gravity measurements (radio science) [2], and nuclear spectroscopy (e.g., [3-5]). Unexpectedly, the results are consistently much lower than the density of solid CO₂ ice, and may indicate either measurement bias in thickness measurements or the effects of physical processes that are currently not understood. Similar results were obtained for the density of the residual polar ice. To determine CO₂ ice density as a function of space and time, we recommend two specific measurements: vertical changes in the cap height (and thus depth, given the substrate topography) during the fall, winter, and spring seasons, and a simultaneous determination of the CO₂ ice column abundance. The changes in elevation could be monitored by either a laser altimeter or by interferometric synthetic aperture radar (InSAR). The second measurement could be accomplished with a collimated, thermal-neutron detector, designed to exploit the relative motion of the spacecraft and the neutrons to localize surface emission sites. Since CO₂ surface ice is a very bright source of thermal neutrons and thermal neutrons are readily absorbed by thin layers of material (e.g., Cd or Gd), it would be possible to build a compact CO₂ ice imaging system with high spatial resolution (e.g., able to resolve spatial variations in the cap on a scale of 50-100 km), close to an order of magnitude improvement over that presently achieved by Mars Odyssey instrumentation (600 km resolution) [6]. Absorption of thermal neutrons by atmospheric noncondensable gas (N₂ and Ar) would be corrected using microwave data (using CO as a proxy for Ar and N₂) or using measurements of epithermal neutrons. The column abundances would be determined to better than 50 kg/m², and coupled with thickness measurements accurate to 0.01 m, which would enable the determination of density to within 3.3% (for a 1 m thick solid slab). This level of precision allows for the testing of different theories on the physical form of the ice (e.g., snow vs. slab-ice vs. hoarfrost) and how ice properties change with time (e.g., compaction, dust loading). Determining the thickness of the residual CO₂ ice cap to the nearest centimeter will also assist in the assessment of long term climate change.

CO₂ Condensation Modes: What is the nature of CO₂ deposition (e.g., snow or direct frosting, continuous or sporadic) and sublimation (e.g., at some depth or at the ice surface, contribution of contaminant load) in space and time?

Investigation: Determine the mixing ratios of non-condensable gases within the polar night and during the polar sublimation phase.

Discussion: Mars Odyssey Gamma Ray Spectrometer (GRS) and Neutron Spectrometer (NS) data have shown that the wintertime atmosphere in the polar regions can become strongly enhanced with noncondensable gases (and are depleted in the springtime). This affects CO₂ condensation on the ground and in the atmosphere by changing the frost point, thus affecting the basic thermal structure of the atmosphere (and thereby affecting atmospheric circulation on a global scale). Because non-condensable gases are passive tracers, their time-dependent distribution can provide a great deal of information about the large-scale atmospheric circulation. It is thus very important that improved measurements of the enhancement/depletion of these non-condensable gases be made by future spacecraft. The GRS and NS Argon data have very low resolution in both space and time. Observation of trace gases other than N₂ and Ar may be feasible with spatial resolution higher than can be achieved by GRS or NS. Carbon monoxide is an obvious candidate because it can be measured very accurately at microwave wavelengths, enabling full coverage of the high latitude atmosphere, including regions in the polar night.

Investigation: Measure and monitor clouds in the polar night, ground fogs, and CO₂ precipitation (snow).

Discussion: Many of the physical expressions of the atmospheric portion of the polar energy balance on Mars occur on relatively small scales and are effectively unobservable by current passive spacecraft imagers (due largely to a lack of illumination or contrast, e.g., during the polar night). However, an active imaging instrument on an orbiting platform would enable a pioneering survey of these phenomena. An imaging LIDAR instrument, with lasers tuned to the continuum and spectral features of H₂O and CO₂ ices would allow observations of changes in H₂O and CO₂ discrimination in the snow pack and in the atmospheric clouds. Grain sizes, shapes, and cloud thicknesses would also be accessible. Nocturnal cloud surveys elsewhere on the planet (also poorly observable at the present time) would also be accessible to such an instrument.

Implementation: The following orbital instrument combinations are suggested payloads that would be synergistically capable of answering questions about the nature of Martian CO₂ ice processes. These packages are meant to be relatively inexpensive and lightweight to facilitate their inclusion as an add-on to an

existing mission concept or as a stand-alone discovery-class mission. Conceptually, these two packages could be combined into a single polar science orbiter.

CO₂ Density Instrument Package - laser altimeter or InSAR, high-resolution thermal neutron imager, microwave atmospheric sounder, and high-precision radio science (ultra-stable oscillator required).

CO₂ Phase Change and Polar Night Instrument Package - Microwave atmospheric sounder, imaging LIDAR, and high-precision radio science (ultra-stable oscillator required). The new instrument in this package is an imaging LIDAR. This instrument would be a high-power pulsed LIDAR with multiple-wavelength near infrared (NIR) capability to measure the spectral intensity and polarization characteristics of backscattered radiation from the Martian surface (particularly the polar caps) and atmosphere (particularly CO₂ and H₂O ice clouds). The proposed instrument is ideally suited for a mission to Mars to investigate the nature and seasonal abundance of icy volatiles, provide insight into surface and cloud grain sizes and shapes, evaluate cloud-particle microphysics and potentially provide atmospheric column content constituent chemistry.

Table 1: MICADO instrument package capabilities.

Instrument	Capability
ASPEN	Imaging LIDAR
InSAR	Interferometric Synthetic Radar
HRTNS	High resolution thermal neutron imager
MAS	Microwave atmospheric sounder
RS	Radio Science

MICADO – Mars Ice Condensation And Density Orbiter: By combining these two packages, one creates a powerful polar and atmospheric observing orbiter. Most of the instruments would benefit from legacy technologies that have already been flown to Mars (e.g., MGS MOLA and Mars Odyssey Neutron Spectrometer). The only “new” instrument is the imaging LIDAR. The MICADO satellite would have the ability to characterize and monitor the density of the seasonal ice caps, determine condensation modes, and determine composition and grain sizes of ices that compose both polar and non-polar clouds. Interannual changes in both residual polar caps could also be monitored if the mission extended to at least three Mars years..

References: [1] Aharonson et al. (2004) JGR 109, CiteID E05004 [2] Smith et al. (2001) Sci. 294 2141-2146 [3] Feldman et al. (2003) JGR, 108, CiteID 5103 [4] Litvak et al. (2007) JGR 112, CiteID E03S13 [5] Prettyman et al. (2009) JGR 114, CiteID E08005 [6] Boynton et al. (2002) Sci 297, 81.