MARS VOLATILE MISSION CONCEPT: MARS ICE CONDENSATION AND DENSITY ORBITER. T. N. Titus¹, A.J. Brown², S. Byrne³, A. Colaprete⁴, T. H. Prettyman⁵, ¹USGS Astrogeology Science Center, 2255 North Gemini Dr., Flagstaff, AZ 86001 (titus@usgs.gov), ²Plancius Research, Severna Park, MD 21146. ³University of Arizona, Tucson, AZ 85721 ⁴NASA Ames Research Center, ⁵Planetary Science Institute.

Introduction: Over the last two decades, our understanding of Mars has changed. Missions such as Mars Global Surveyor (MGS), Mars 2001 Odyssey (M01), Mars Express (MEx) and Mars Reconnaissance Orbiter (MRO) have shown modern Mars to have an active and dynamic surface, dominated by surface-atmosphere interactions. The Phoenix lander has provided ground truth for the presence of extensive subsurface deposits of water ice at high latitudes [1]; however, no other landed mission has probed the Martian high latitudes and polar regions.

This abstract focuses on polar processes and describes a set of investigations that are crucial to fully illuminate the exchange of volatiles between the surface and the atmosphere.

The Mars Polar Night: Much of Mars polar processes occur during dark periods (seasonal and diurnal). The majority of the seasonal polar cap forms in darkness through direct condensation and snowfall. Thermal instruments, such as MGS Thermal Emission Spectrometer (TES), M01 Thermal Emission Imaging System (THEMIS), and MRO Mars Climate Sounder (MCS), observed surface temperatures and spectral features, which enabled values for CO₂ ice grain size and H₂O ice and dust contamination to be constrained. Although some surface compositional data have been gleaned from visible, near infrared, and short-wave infrared imaging and spectroscopy, these instruments measure reflected solar light and are accordingly ineffective during periods of darkness. MGS Mars Observer Laser Altimeter (MOLA) was the only instrument to view the polar cap in the polar night at 1-µm. The primary mission was to map elevation, not measure the reflectance of the polar ice. Most of the polar night reflectance data were therefore saturated.

The annual mass exchange of polar ice from one pole to the other is sufficient to affect the gravity field of Mars. These shifts in the gravity field, when combined with MOLA altimetry, are useful to constrain the seasonal cap bulk density, but not local variations related to accumulation modes or temporal changes in density, porosity and grain size [2-4]. Additionally, neutron and gamma-ray observations provide another method to determine the cap mass and distribution of CO₂ on broad spatial scales (of a few hundred square kilometers) [5].

Composition, Density, & Condensation Modes: The CO₂ ice that forms in the polar night is mostly CO₂ ice with small amounts of dust and H₂O. It is possible that a layer of H₂O ice exists as a bottom layer, because the surface will reach the freezing temperature of H₂O before it reaches that of CO₂. The seasonal CO₂ may also have density gradient because the two accumulation modes, direct condensation and snowfall, are superimposed. Additionally, sintering may cause surface ice-grain sizes to increase [6] on time scales of five-to-eight sols [7, 8].

<table>
<thead>
<tr>
<th>Suggested Instrumentation</th>
<th>Wave length</th>
<th>Science Focus</th>
<th>Legacy Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging LiDAR (with Tunable LASER)</td>
<td>~1.2-1.6 µm</td>
<td>Volatile Composition and grain size; Altitude of ice particles</td>
<td>MOLA</td>
</tr>
<tr>
<td>Interferometric synthetic aperture radar</td>
<td>~1-10 cm</td>
<td>Monitor Ice Depth</td>
<td>Magellan</td>
</tr>
<tr>
<td>Thermal Neutron Imager</td>
<td>Thermal Neutrons</td>
<td>Monitor Column Abundance</td>
<td>MONS</td>
</tr>
<tr>
<td>Thermal Emission Imager</td>
<td>6-100 µm</td>
<td>Monitor energy balance</td>
<td>TES, THEMIS, MCS</td>
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</table>

CO₂ Accumulation Modes: What is the nature of CO₂ deposition (e.g., snow or direct frosting, continuous or sporadic) in space and time?

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

Investigation: Measure and monitor surface ice composition and grain size.

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

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

Investigation: Measure the column mass abundance of the CO₂ ice in the seasonal polar caps with accuracy of 50 kg/m² sampled at approximately every 10° of Lₐ.
Non-Polar Ice: Over the last decade, H2O and CO2 ices have been discovered at mid-to-low latitudes. Some of this ice is diurnal in nature, condensing at night and subliming in the early morning. Other deposits appear to be at least semi-permanent where the ice is located in permanently shadowed regions (PSR).

Investigation: Determine condensation mode, composition, and amount of ice that forms during the night.

Investigation: Determine the composition and amount of ice that exists in PSRs.

Mission Concept: We suggest four types of instruments for this mission concept.

Tunable Laser Imaging LiDAR system: The key instrument to these investigations, which has yet to fly to Mars, is a tunable-laser imaging LiDAR system that is sensitive to (and can differentiate between) CO2 and H2O ice [9]. This instrument could determine accumulation modes and monitor changes in compositions and grain sizes of surface ices within the polar night. This instrument could also monitor changes in ice thickness.

Radar: Interferometric synthetic-aperture radar could also monitor seasonal ice thickness and possible changes in ice properties. Wavelength and bandwidth parameters will be engineered to measure changes of a few centimeters.

Thermal Neutron Imager: A thermal neutron imaging system could directly monitor the changing CO2 ice column abundances (kg/m2).

Thermal Emission Array: A thermal emission spectrometer or bolometer could indirectly derive CO2 ice column abundance and grain sizes.

Final Thought: The key to further understanding Mars polar processes is to peel back the veil of darkness from the polar night!

Table 2: Science Traceability Matrix.

<table>
<thead>
<tr>
<th>Science Questions</th>
<th>Investigation</th>
<th>Measurement(s)</th>
<th>Possible Instruments</th>
<th>MEPAG Goal(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>What fraction of seasonal CO2 ice deposits are from snow vs direct deposition?</td>
<td>Determine surface ice grain size and composition.</td>
<td>Composition; Grain size</td>
<td>Imaging LiDAR</td>
<td>IIA4</td>
</tr>
<tr>
<td>What altitude does the CO2 snow form?</td>
<td>Determine altitude of snow formation.</td>
<td>Altitude</td>
<td>Imaging LiDAR</td>
<td>IIA1; IIA4</td>
</tr>
<tr>
<td>What is the role of H2O ice in CO2 condensation?</td>
<td>Determine when, where, and how H2O ice is incorporated into the seasonal cap.</td>
<td>Composition; Grain size</td>
<td>Imaging LiDAR</td>
<td>IIA1; IIA4; IIIA1</td>
</tr>
<tr>
<td>What is the role of dust in CO2 condensation?</td>
<td>Determine when, where, and how dust is incorporated into the seasonal cap.</td>
<td>Composition; Grain size</td>
<td>Imaging LiDAR</td>
<td>IIA1; IIA4; IIIA1</td>
</tr>
<tr>
<td>What happens to the snow/ice deposits after they are deposited on the surface?</td>
<td>Monitor surface ice changes in composition and grain size. Monitor changes in local ice density.</td>
<td>Composition; Grain size; Ice Depth; Ice Column Abundance</td>
<td>Imaging LiDAR; InSAR; Thermal Neutron Imager</td>
<td>IIIA1</td>
</tr>
<tr>
<td>What is the net effect of basal sublimation of seasonal CO2?</td>
<td>Measure the heat budget and compare to ice column abundance.</td>
<td>Thermal Emission; Ice Column Abundance</td>
<td>Thermal Emission Imager; Thermal Neutron Imager</td>
<td>IIIA1</td>
</tr>
<tr>
<td>What is the extent and composition of diurnal ice deposition?</td>
<td>Determine condensation mode, composition, and amount of ice that forms during the night.</td>
<td>Composition; Grain size</td>
<td>Imaging LiDAR</td>
<td>IIA1; IIA4; IVB3</td>
</tr>
<tr>
<td>What is the extent &amp; composition of ice deposits in PSRs?</td>
<td>Determine the composition and amount of ice that exists in PSRs.</td>
<td>Composition; Grain size</td>
<td>Imaging LiDAR</td>
<td>IB1; IIA 4; IVB3; IVB3</td>
</tr>
</tbody>
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