CLIMATE ORBITER FOR MARS POLAR ATMOSPHERIC AND SUBSURFACE SCIENCE (COMPASS): DECIPHERING THE MARTIAN CLIMATE RECORD

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Introduction: In many ways, Mars' icy climate record is recognizable to a terrestrial paleoclimatologist. Polar Layered Deposits (PLD) of water ice and dust at the north and south poles (NPLD & SPLD) are together similar in volume to the Greenland ice sheet and their stratified structure likely records climate over millions to tens of millions of years (Fig. 1) [1]. Surface water ice deposits that cover the NPLD interact with the current climate and may be the dominant source of water vapor in the annual global cycle [2]. Models suggest that depths to buried ice-sheets and pore-filling ice in the mid-latitudes should adjust with changing atmospheric conditions in a similar way to ice in the Antarctic Dry Valleys [3]. However, Mars has a host of unfamiliar ice deposits that also record climate: the geomorphology of a surficial CO_2 ice cap near the South Pole evolves by meters per year [4,5], and a buried CO_2 ice deposit at least equivalent in mass to the current atmosphere also resides in this area [6].

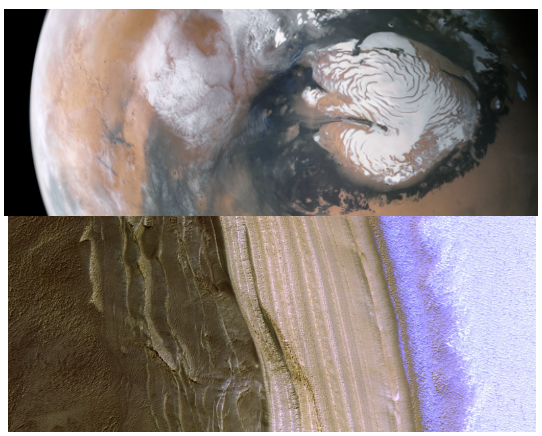

Fig. 1: COMPASS focuses on the interaction of the climate and ice deposits (top, HRSC image of the north polar region with clouds) and the climate record of the deposits themselves (bottom, HiRISE image of exposed bedding in the NPLD).

Despite decades of research based on remote sensing observations, key knowledge gaps prevent a full understanding of the martian climate and how it is recorded in icy deposits. Interaction of the atmosphere with surface and subsurface ice depends critically on atmospheric humidity near the surface, yet water vapor has only been quantified in column-integrated measurements or at specific landing sites. Winds have never been systematically measured on Mars – introducing large uncertainties into the modeling of atmospheric volatile transport. Buried ice sheets in the mid-latitudes have been detected by various means, but systematic measurements have not been made of their locations, depths, thicknesses and internal layering. PLD layers can only be viewed at heavily-mantled outcrops or in radar data that do not fully resolve them.

The Climate Orbiter for Mars Polar Atmospheric and Subsurface Science (COMPASS), is a Discovery-class mission that will provide the key missing datasets to leverage and apply our understanding of terrestrial climate records and meteorology to Mars. COMPASS will study Mars from the subsurface through the atmosphere using unprecedented measurements to definitively answer the question, "*How is the climate we observe today related to past climate variations recorded in Mars' ice deposits?*"

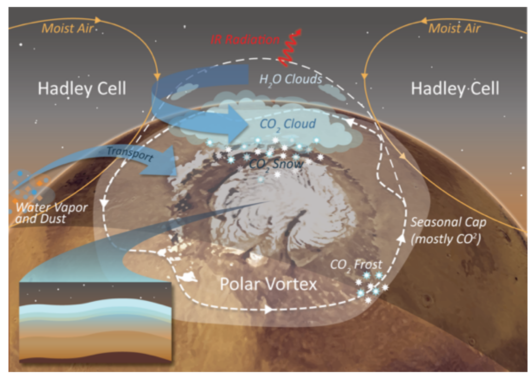

Fig. 2: COMPASS investigates interconnected processes in Mars' climate-ice system, including those illustrated here for the north polar winter. (Adapted from [9])

Science Objectives: Ice is the key to understanding past climate variations on Mars, because volatiles are sensitive tracers of atmospheric and surface temperatures through time [7]. Surface and subsurface ices interact with the atmosphere on different timescales, ranging from the seasonal CO_2 cycle to the multi-year advance and retreat of ground ice, to glacial/periglacial landforms and the polar layered deposits, which formed ~1 – 10 Myr ago [1,3,8]. The atmosphere acts as a conduit between these different ice reservoirs under changing conditions.

To fully understand past volatile exchange and the underlying climate forcings, COMPASS will observe present climate processes and volatile transport contemporaneously with measurements of icy reservoirs (Fig. 2) to achieve two science goals:

1. Understand interactions between the current climate and icy deposits
2. Map locations, quantify volumes and characterize layering of Amazonian-aged ice reservoirs globally

Proposed Mission Overview: The COMPASS mission accomplishes its science goals through atmospheric, surface and subsurface measurements taken with four instruments (Figs. 3,4):

CROME (COMPASS Radar Observer for Mars Exploration), a dual-mode L-band radar (Fig. 2) allows COMPASS to locate and resolve sub-meter scale layering within ice deposits on Mars. Buried ice will be detected and located by near-global Synthetic Aperture Radar (SAR) coverage. SAR data will also penetrate and characterize the dust that covers one third of the martian surface, and overlie subsurface ice deposits. Layers of ice and dust within the PLD and buried mid-latitude ice-sheets will be examined in a radar sounder mode. At an order of magnitude higher vertical-resolution than MRO's SHARAD, these sounder data allow the detailed correlation of stratigraphic beds with oscillations of orbital elements.

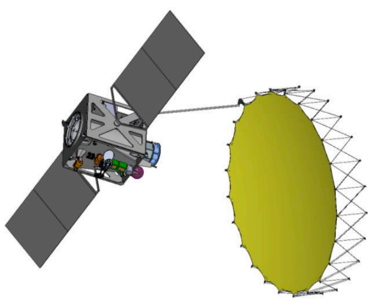

Fig. 3: COMPASS spacecraft with deployed six-meter mesh antenna. Orbital motion parallel to solar panels. CROME is located on the deck facing the antenna.

AMCS (Advanced Mars Climate Sounder), a thermal IR limb sounder based on MRO's MCS [10] and LRO's Diviner will retrieve temperature and content of water vapor, dust, and condensates as a function of height. Nadir observations can monitor surface frosts and surficial thermal behavior to deduce the presence of the shallowest and lowest-latitude ground ice. AMCS will have twice the vertical resolution of MCS and new filters specifically designed to discriminate water vapor from the other atmospheric components.

WAVE (Wind And Vapor Experiment), a sub-mm limb sounder [11], allows the systematic measurement of winds for the first time. Two antennae observe the limb allowing for reconstruction of both horizontal velocity components as a function of height. Water vapor and temperature profiles will be retrieved under higher optical depth conditions than suitable for AMCS. Isotopic abundances will be tracked as tracers between sources and sinks of water vapor.

MAVRIC (Mars Atmosphere Volatile and Resource Investigation Camera), a wide-angle camera with a near-simultaneous stereo imaging capability, images limb-to-limb each dayside pass in several visible and near-IR bands. Daily global coverage permits characterization of seasonal frost, clouds and dust storm evolution. Near-IR bands allow discrimination of CO_2 and H_2O frosts, while multiple visible bands allow discrimination of dust and volatile clouds.

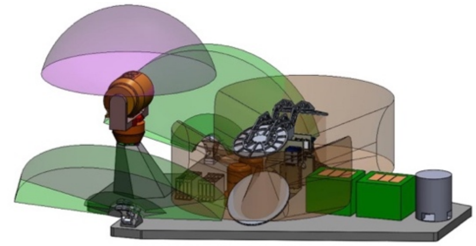

Fig. 4: COMPASS nadir instrument panel with FOVs indicated for AMCS (purple), WAVE (brown) and MAVRIC (green). Orbital motion into page.

COMPASS will have a low-eccentricity sun-synchronous orbit during its one-Mars-year (2-Earth-years) primary science mission. With an inclination of 93°, such an orbit is naturally concentrated in the ice-rich higher latitudes and provides near-global coverage. An equator-crossing local time of 3 pm allows integration of the IR sounder and wide-angle imaging data with the legacy datasets of MRO, Mars Odyssey and Mars Global Surveyor. An orbital altitude of 250–300 km enables high-resolution observations and low atmospheric drag over the course of the primary mission.

COMPASS brings together highly-experienced partners and high-heritage technology resulting in high science return at low risk and cost. The University of Arizona (UA) runs the PI office and Science Operations Center utilizing experience from the Osiris-Rex mission and the Phoenix Lander. The Laboratory for Atmospheric and Space Physics (LASP) provides the Astrolabe spacecraft bus (similar to that used by the Emirates Mars Mission) as well as mission management and operations. The Canadian Space Agency (CSA) contributes CROME based on Earth-orbiting heritage through industry partner MDA Corporation. The Jet Propulsion Laboratory (JPL) provides AMCS and WAVE based on heritage instruments in orbit around Mars and Earth respectively. The Applied Physics Laboratory (APL) provides a MAVRIC based on existing Mars systems. Our diverse science team is comprised of leaders in the field from throughout the US, Canada and Europe.

References: [1] Byrne et al. (2009) *Ann. Rev. Earth Planet. Sci.* [2] Jakoksky and Haberle (1992) [3] Schoghofer and Aharonson (2005) [4] Malin et al. (2001) *JGR* [5] Thomas et al. (2009) *Icarus* [6] Phillips et al. (2011) *Science* [7] Leighton and Murray (1966) *Science* [8] Head et al. (2003) [9] McCleese *et al.* (2016), *International Mars Polar Conference,* Iceland. [10] Kleinboehl et al. (2016) 3rd Int. Workshop on Inst. for Planetary Missions. [11] Read et al. (20018) Plan. Space Sci.