Abstracts submitted by the Mars community

for presentation within MEPAG Meeting 36 (April 3-5, 2018)

Forum & discussion regarding preparation for the next Planetary Science Decadal Survey

Abstracts are ordered alphabetically (by first author), then by order of addition. This listing (and all meeting information) is posted at https://mepag.jpl.nasa.gov/meetings.cfm?expand=m36.

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REVOLUTIONIZING OUR UNDERSTANDING OF THE EVOLUTION OF MARS AND THE HISTORY OF THE INNER SOLAR SYSTEM. F. S. Anderson[1], T. J. Whitaker[1], and J. L. Levine[2], [1]Southwest Research Institute, 1050 Walnut St, Boulder CO; anderson@boulder.swri.edu, [2]Colgate University, Hamilton, NY 13346.

Introduction: The next Decadal Survey should advocate for new chronology missions for Mars, building on the results of Mars Sample Return (MSR). The Mars Exploration Program Advisory Group has established a key goal of "Understanding the origin and evolution of Mars as a geological system" (MEPAG Goal 3 and subgoals therein [1]) and is a component of one of the most important goals of planetary science: understanding the history and duration of events in the solar system, in order to place the evolution of life, and humanity, in context [2].

Unfortunately, the timing and duration of geologic processes on Mars, and throughout the inner solar system, suffer from uncertainties that are much larger than commonly acknowledged. The geologic history of Mars, and the inner solar system, is extrapolated from models of lunar impactor flux, crater counts, and ~270 kg of lunar samples analyzed and dated in terrestrial labs. However, the lunar samples primarily constrain the era from 3.5-4 Ga. For terrains younger than 3.5 Ga, uncertainties exceed 1 Ga [3]; specifically, ~3.5 Ga terrains may be 1.1 Ga younger. For Mars, additional problems are caused by uncertainty in "...the ratio of Mars to moon impact rates", which results in "...absolute ages on Mars [that] are only good to a factor of 2 to 4" [4]. For example, the range in estimated terrain age for the Amazonian period varies by nearly 700 Ma, not including the potential uncertainty of 1.1 Ga from the Moon [5-9]. Clarifying the relationship between impactor flux and surface age will require obtaining new dates from multiple terrains with a variety of crater densities. These new constraints will provide regional geologic insights as well as global constraints on crater density and age, and finally, enable new models of solar system flux and the surface age of other planetary bodies, such as the Moon.

Importance: These issues can lead to important changes in our understanding of the history of the solar system, and and hence the environment within which life evolved. For example, if new lunar crater counts based on better high resolution imaging derived from the Lunar Reconnaissance Orbiter Camera are accurate, then numerous consequences arise, including (1) the extension of the era of volcanism on the Moon and Mars by up to 1.1 Ga, (2) extending the end of the era of water on Mars by up to 1.1 Ga, and (3) that life arose on Earth not during a period of impact rate diminution, but instead during a period of bombardment twice as high as previously recognized. Following previous work, refinements in cratering flux will furthermore be propagated to Mercury [e.g., 10, 11], Venus [e.g., 12, 13, 14], Earth (where the record of ancient impacts has been erased by erosion and plate tectonics [15]), and models of early solar system dynamics [16].

Approaches: There are two complimentary approaches to improving our current understanding of solar system history. The first is the return of samples for in-/organic analysis and dating on Earth using the exquisite precision and range of current and future laboratory instruments. However, a limitation of this approach is caused by the need to sample a wide range of terrains, ultimately requiring many sample returns. After all, Apollo will likely remain the best sample return mission ever, yet the most important decadal survey goals for the Moon focus on the obtaining more samples for dating [2]. Given the great cost of sample return missions, the Decadal Survey explicitly supports in-situ dating [2], with a goal of ±200 Ma or better described in the NASA Technology Roadmap [17].

Methods: In order to support future Mars missions, we have developed an instrument called the Chemistry, Organics, and Dating EXperiment (CODEX) that interrogates hundreds of locations on a sample surface in a 2D grid using three modes: A) laser ablation mass spectrometry to measure elemental abundance, B) two-step laser desorption/ionization mass spectrometry to measure organics, and C) laser desorption resonance ionization mass spectrometry to measure rubidium-strontium geochronology. CODEX produces images of the spatial distribution of chemical elements and organics, and determines the isochron age of the sample. Understanding the rates of change for planetary processes (such as the history of water, climate, and potential biology) as well as providing a new understanding of impactor flux for the inner solar system requires multiple new spatially diverse absolute dating measurements.

References: 1. MEPAG, 2015. 2. NRC, 2012. 3. Robbins, EPSL, 403, 2014. 4. Hartmann, pers. comm. 2012. 5. Hartmann & Neukum, SSR, 96, 2001. 6. Hartmann et al, 1049, 1981. 7. Neukum et al, SSR, 96, 2001. 8. Tanaka et al, 345, 1992. 9. Robbins & Hynek, LPSC #1719, 2013. 10. Fassett et al, GRL, 38, 2011. 11. Marchi et al, Nature, 499, 2013. 12. Bougher et al, 1997. 13. Korycansky & Zahnle, PSS, 53, 2005. 14. Le Feuvre & Wieczorek, Icarus, 214, 1, 2011. 15. Grieve & Shoemaker, 417, 1994. 16. Michel & Morbidelli, MAPS, 42, 1861, 2007. 17. NRC, NASA Technology Roadmaps, 2015.

CO_2 JETS AND THEIR INFLUENCE ON THE MARTIAN POLAR ATMOSPHERE

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Intoduction: Every local spring, CO_2 gas jets erupt in the south polar region of Mars. They deposit ground material on top of the bright reflective CO_2 ice, rendering dark appearing jet deposits in orbiting remote sensing images, like shown in Fig. 1. Despite the fact that their nature seems to be well understood as a phenomenon related to basal sublimation of the seasonal CO_2 ice layer [1, 2], the actual eruptions have never been observed. The energetic conditions most conducive to these eruptions are calculated to be best from noon (at spring equinox) towards earlier local times in the days following equinox [3]. However, all remote sensing missions with instruments that could have observed these jets being active (MEX, MGS, and MRO) had a sun-synchronous orbit with local times in the afternoons.

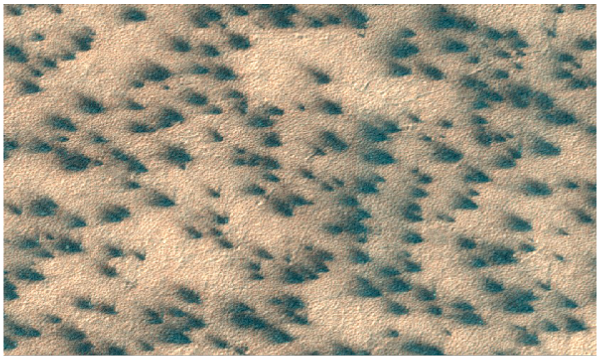

Figure 1 Subsection of HiRISE image `ESP_011296_0975`.

It is important to quantify the influence these jets have on the local atmosphere, which are twofold. First, jets inject dust into the boundary layer which causes changes in the local heat budget by increased absorption. Second, the dark jet deposits on top of a highly reflective surface is changing the amount and spectral composition of the backscattered radiation of the surface. This again affects the local energy budget of the lower atmosphere.

These effects are important to study for a better understanding of the polar atmosphere at Mars. The polar atmosphere influences greatly, if not dominates, the atmosphere development of the whole planet, specifically in spring when 30 % of the atmosphere is being exchanged with the surface at the poles. Because of the created density variations in the polar atmosphere from local heating by dust, improving the understanding of these phenomena could even improve the safety for polar surface missions during the entry phase.

Proposed R&A activities: The dust injection is proportional to the power the CO_2 jets possess, but the observed deposits' area is a convoluted funcion of jet height and wind strength at the time of eruption. We need to create geophysical jet models embedded into realistic background wind scenarios to constrain the amount of dust that is entered into the atmosphere. Furthermore, we need to study the effect of the jets on the vertical and horizontal dust distribution and how this affects local and polar weather as a whole via meso-scale simulations embedded into higher resolution GCMs.

Proposed mission activities Advances in SmallSat technologies like attitude control and camera readout electronics have made it possible to reduce the size of science-producing cameras to ≈ 3x1 U (i.e. 30 x 10 x 10 cm) (see Fig.2). We are studying a SmallSat mission that would primarily focus on Martian south polar processes. Advantages of a SmallSat are low inertia, enabling stereo-imaging by rotating the S/C, and an orbit control enabling the change of observed local time within the same spring season. In addition to the above described prime objectives that can be addressed, such mission can also monitor water ice clouds that have a strong dependence on local time. We partnered with SmallSat bus provider ExoTerra that is able to provide an ion-driven propulsion system with solar panels that provide adequate power at the Mars orbit. We have developed a preliminary optical design for a telescope that is reaching imaging capabilities near that of the MRO CTX camera and are investigating a telescope-spectrometer combo sharing the same telescope. Planning this mission with a SmallSat enables us to adapt the local orbit to react on observations made.

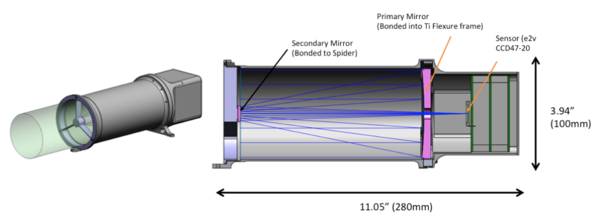

Figure 2 Preliminary instrument design.

References: [1] Kieffer, HH. *Journal of Geophysical Research*, 112:08005 (2007). doi:10.1029/2006JE002816. [2] Hansen, CJ, Thomas, N, Portyankina, G, et al. *Icarus*, 205:283–295 (2010). doi:10.1016/j.icarus.2009.07.021. [3] Portyankina, G, Markiewicz, WJ, Thomas, N, et al. *Icarus*, 205:311–320 (2010). doi:10.1016/j.icarus.2009.08.029.

M-PRESS: Mars-Polar Reconnaissance of Environment & Subsurface Stratigraphy. S. Byrne[1], P.O. Hayne[2], I.B. Smith[3], and K. Zacny[4], [1]University of Arizona, Tucson, AZ. [2]University of Colorado, Boulder, CO. [3]Planetary Science Institute, Denver, CO. [4]Honeybee Robotics, Pasadena, CA. Correspondence: shane@lpl.arizona.edu

Motivation: Climate change on terrestrial planets is perhaps the most pressing scientific issue of our day, and its study is of broad significance. Mars' continuously varying orbital elements lead to climatic variations that (like on Earth) redistribute ices and affect seasonal volatile cycles. Mars' climate represents a simplified version of Earth's in that it lacks oceans, life, thick cloud cover and human activity. Understanding the martian climate record and how it connects to orbital variations represents an achievable goal that helps understanding of terrestrial planet climate.

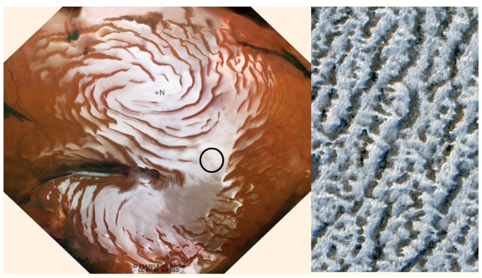

Figure 1. (Left) HRSC mosaic of the NRC with circular area required for a MER-sized landing ellipse of unknown orientation. (Right) example of NRC surface where light/dark patches are ~20m across.

An archive of martian climate exists in the layers of the North Polar Layered Deposits (NPLD). Rapid progress has been made in characterizing these deposits from orbit over the past decade. Radar data show contiguous layering over their ~1000 km extent and ~2 km thickness [1-3]. Imagery and topography of exposures have enabled mapping of layers <1 m thick and detection of periodic signals in their stratigraphy [4-6].

The NPLD are covered with a residual ice cap (NRC, Fig.1) that is the dominant source and sink of atmospheric water vapor for the entire planet. It is composed of large-grained and dust-free H_2O ice [7,8] with finer-grained H_2O-frost present during spring [9].

The NPLD and NRC are a scientifically-compelling target for a lander with three main goals:

1) Quantify NRC/current-climate interaction.
2) Determine what is recorded in NPLD layers.
3) Connect uppermost layers to orbital data

A 2017 Keck Institute for Space Studies study on Mars polar exploration brought together >30 experts to determine required measurements and mission concepts to accomplish these goals. Here, we report on a landed mission that reflects the study's findings.

Implementation: The M-PRESS concept performs year-round meteorology as well as physical and chemical characterization of the surface and subsurface. M-PRESS uses a pathfinder/MER landing system (Fig. 2) to minimize surface contamination and deliver ~200kg. At this latitude, energy-intensive summer activities benefit from constant solar power, while winter meteorology is enabled by RHUs with powersticks.

The NRC is the safest place to land on Mars. It is one of the smoothest locations at MOLA scales [10], and no boulders are present. Its elevation (-4000 to -2000 m) is comparable or lower than other recent sites. Precision landing is not required and MER-scale landing ellipses fit entirely within its boundaries (Fig.1).

Year-round meteorology is enabled by a standard MET package as well as a Differential Absorption Lidar that characterizes the vertical distribution of water vapor and precipitation, a Sonic Anemometer that quantifies near-surface winds and eddy fluxes and a Tunable Laser Spectrometer (TLS) that characterizes near-surface water vapor and isotopic ratios.

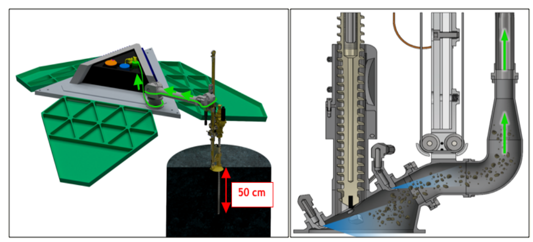

Figure 2: (Left) MER-style lander with deployed 50 cm drill. (Right) Pneumatic sample delivery mechanism.

A 50 cm drill pneumatically delivers samples at ~5 cm intervals to instruments (Fig. 2). A fiber-optic rotary joint and borehole microscopic imager allows characterization of subsurface composition, porosity and layering *in situ*. Samples are analyzed by a TLS (ice isotopes), and a near-IR Raman Spectrometer (abundances of salts, silicates and oxides). A Ground Penetrating Radar connects near-surface layers to orbital observations.

M-PRESS fits the constraints of the Discovery program. The delivery vehicle is build-to-print and over-engineered for an NRC landing. M-PRESS instruments have spaceflight heritage or current TRL levels of 5-6. Cost constraints can be satisfied with an international contribution of one major instrument (<30% payload).

We will present additional detail on the science goals, payload, and relationship to MEPAG goals.

References: [1] Phillips et al., Science, 2008. [2] Putzig et al., Icarus, 2009. [3] Smith et al., Science, 2016. [4] Fishbaugh et al., GRL, 2010. [5] Becerra et al., JGR, 2016. [6] Becerra et al., GRL, 2017. [7] Kieffer, JGR, 1990. [8] Langevin et al., Science, 2005. [9] Brown et al., Icarus, 2016. [10] Aharonson et al., JGR, 2001.

Mars Polar Mission Concept Study for the 2013 Visions and Voyages Decadal Survey. W. M. Calvin, Geological Sciences and Engineering, University of Nevada, Reno, wcalvin@unr.edu.

Introduction: While Mars Sample Return emerged as the highest priority mission for the decade from 2013 to 2022 in the Visions and Voyages decadal survey [1], it was also recognized by the Mars Panel and the Steering Committee that much high priority Mars Science would not be accomplished along the path to sample return. Two additional studies emerged including the Mars Geophysical Network (whose science is captured by the Insight mission) and Mars Polar Climate Concepts including both orbiter and lander options [2].

Following up on scientific results from the Phoenix (PHX) mission and other high-latitude ice studies, there was strong community support behind a mission to the exposed polar-layered deposits (PLDs). The purpose behind the decadal study [2] was to understand what types of mission architectures could best achieve the primary science goals articulated by the Mars polar community at that time [3], including several white papers submitted to Decadal Survey. Drilling, roving, and specific orbital observations have been proposed as methods to access the stratigraphy and climate history locked in these deposits. The prioritized science questions defined at that time [3]:

1. What is the mechanism of climate change on Mars? How has it shaped the physical characteristics of the PLDs? How does climate change on Mars relate to climate change on Earth? What chronology, compositional variability, and record of climatic change are expressed in the PLDs?

2. How old are the PLDs and how do they evolve? What are their glacial, fluvial, depositional, and erosional histories, and how are they affected by planetary-scale cycles of water, dust, and CO_2?

3. What is the astrobiological potential of the observable water ice deposits? Where is ice sequestered outside the polar regions, and what disequilibrium processes allow it to persist there?

4. What is the mass and energy budget of the PLDs? How have volatiles and dust been exchanged between polar and non-polar reservoirs, and how has this exchange affected the past and present distribution of surface and subsurface ice?

Orbiter Concepts: The study consider two orbiter concepts, one likely to fit in the Discovery cost cap with two possible science options and a more capable New Frontiers class orbiter mission. For Discovery, Option 1 would study current climate and weather and seasonal cap properties, the second option was focused on the polar energy balance and composition of the residual ice deposits. The New Frontiers class orbiter would accomplish all of the science objectives of the two Discovery class options. Since that time, an additional orbital concept study was undertaken by MEPAG [4] with several science themes that built on the decadal survey study and new discoveries including the distribution and origin of ice reservoirs and dynamic processes in the current martian atmosphere.

Landed Concepts: The decadal polar mission study considered three landed missions, two stationary landers and a rover. The simplest lander system would land within a large chasma, make high priority atmospheric measurements and remotely image stratigraphy and composition of the residual ice. However sub-surface access at the poles via sampling or drilling has been widely proposed as the only way to constrain recent Martian climate history [5,6], understand the stratigraphic record preserved in the polar layered deposits [7], and search for potential biomarkers in buried ground ice - one of the most habitable places on Mars [8]. Hence the second stationary lander included a meter-scale drill and the rover would traverse and collect small cores, similar to MSL, to sample lateral compositional variations as well as current accumulation/ablation rates. These latter two concepts are likely to be New Frontiers class and similar concepts were reiterated at a recent Keck Institute Workshop [9]. Detailed mission concepts for landed polar science would benefit from additional study and engineering development.

References: [1] National Research Council. 2011. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. Washington, DC: The National Academies Press. doi: 10.17226/13117. [2] Mission Concept Study, Planetary Science Decadal Survey, Mars Polar Climate Concepts, available at http://sites.nationalacademies.org/ssb/ssb_059331. [3] Fishbaugh, K., et al. Icarus, 196, 305–317, 2008. [4] NEX-SAG, 2015, available at https://mepag.jpl.nasa.gov/reports.cfm [5] M. H. Hecht, et al. *Concepts and Approaches for Mars Exploration (2012), Abstract #4330*. [6] W. M. Calvin, C. L. Kahn, *Concepts and Approaches for Mars Exploration (2012), Abstract #4298.* [7] M. H. Hecht, Chronos Team *Fourth International Conference on Mars Polar Science and Exploration (2006), Abstract #8096.* [8] C. P. McKay, et al. *Concepts and Approaches for Mars Exploration (2012), Abstract #4091.* [9] Keck Institute Workshop, "Unlocking the Climate Record Stored Within Mars' Polar Layered Deposits (I and II)" http://kiss.caltech.edu/workshops/polar/polar2.html

MARS EXPLORATION GOALS ACHIEVED BY AN ORBITAL IMAGING RADAR.

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Introduction: Mars exploration to date has provided a wealth of information on the geologic history of the planet, the roles of impact cratering and ancient hydrologic processes, and the current nature and inventory of water ice. Our understanding of many of these topics remains incomplete due to both the extensive sediment cover and the limitations of current shallow subsurface investigations. An orbital polarimetric synthetic aperture radar (SAR) can reveal geologic features beneath meters of dust, probe the uppermost layers of the polar deposits, and map shallow reservoirs of ground ice for climate studies and future exploration. SAR systems use proven hardware and analysis methods, and can be accommodated on a Discovery class bus or as part of the instrument suite of a Next Mars Orbiter (NeMO) [1].

The Hidden Face of Mars: Our current best understanding of the shallow subsurface of Mars, and the possibility of widespread ice deposits, comes from the SHARAD instrument on MRO [2-6]. Radar sounders are excellent tools for profiling along a ground track, but they do not form high-resolution two-dimensional surface coverage and cannot characterize the uppermost ~10 m of the terrain. Even an enhanced sounder (e.g., higher frequency, higher bandwidth than SHARAD) will have significant challenges in detecting shallow interfaces.

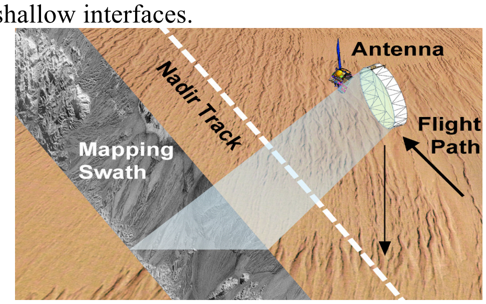

Fig. 1. Imaging radar viewing geometry.

Orbital imaging radar provides a 2-d image similar to that of a visible/IR camera, but with the capability to probe several meters in dusty material and 10's of meters in polar ice (Fig. 1). This type of mapping will reveal previously unseen geologic features related to volcanic, impact, fluvial, and other processes. A SAR can also measure the full polarimetric properties of the scattered signal to detect the unique signature of ice layers that are a few meters thick and extend over much of a resolution cell.

A SAR with readily achievable requirements can provide a *global* map at 75-m resolution of the subsurface geology through 3-5 m or more of mantling dust or sand. Spatial resolution comparable to THEMIS-VIS at 18 m per pixel can be achieved with the same penetration depth, and spotlight SAR processing can provide even finer resolution for targeted sites. Loss properties of materials on Mars have been directly measured using SHARAD [6], and confirm the expected depth of mapping.

Direct support for the success of an orbital SAR comes from Earth-based radar maps of Mars, which reveal stunning details of lava flows and other features hidden by dust (Fig. 2) [7]. An orbital sensor will yield 50-100 fold finer spatial resolution and about 5-fold greater depth of penetration than the Arecibo measurements. These results will transform our understanding of regional geology, ancient habitable settings, and the current inventory of shallow ground ice.

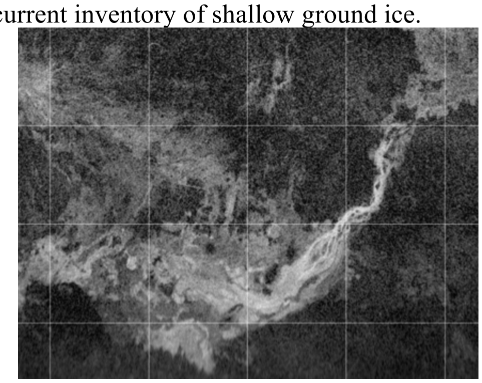

Fig. 2. Arecibo radar view of roughness changes in lava flows beneath dust across Elysium Planitia [7].

Instrument: A SAR optimized for these goals can be accommodated by a Discovery-class spacecraft, or as part of a suite on a larger bus. The radar requires an antenna: a 6-m deployable mesh is adequate for the science described here. The radar wavelength should be 30-60 cm, based on experience with subsurface lunar probing, and fully polarimetric capability is required to allow for flexibility in probing ice and other deposits.

References: [1] MEPAG NEX-SAG report (2015); [2] Plaut, J. J., et al. (2008), GRL, 36, L02203; [3] Holt, J. W., et al. (2008), Science, 322 (5905), 125-1238; [4] Bramson, A. M., et al. (2015), GRL, 42, 6566-6574; [5] Stuurman, C. M., et al. (2016), *GRL,* 43, 9484-9491; [6] Campbell, B.A., and G.A. Morgan (2018), GRL, in press.; [7] Harmon, J.K., and M. Nolan (2007), 7th Mars Conf., abs. 3136. *A portion of this research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.*

FUTURE MARS EXPLORATION: THE PRESENT IS THE KEY TO THE PAST. C. M. Dundas[1], S. Byrne[2], M. Chojnacki[2], I. J. Daubar[3], C. J. Hansen[4], A. S. McEwen[2], L. Ojha[5], G. Portyankina[6]. [1]USGS (cdundas@usgs.gov), [2]University of Arizona, [3]JPL/Caltech, [4]PSI, [5]Johns Hopkins University, [6]University of Colorado.

Introduction: Observations of changes on the surface of Mars have multiplied in recent years. These changes are the key to understanding current processes, a necessary step before extrapolating back through geologic time. Here we provide a summary of known surface activity, requirements for future measurements, and connections to MEPAG goals.

Current Surface Changes: Observations of surface changes date to early telescopic and orbital observations of albedo variations [1-2] and Viking Lander observations [3]. Global changes continue to be monitored [e.g., 4] and higher-resolution observations have revealed many other forms of surface activity. The walls of CO_2 ice pits on the south polar cap retreat several meters annually [5]. Hundreds of new impact craters have been observed [6-7]. New deposits occur in gullies [6], and slope streaks form in dusty regions [8]. Recurring Slope Lineae (RSL) are a widespread, distinct surface process [9]. Avalanches and blockfalls occur on steep north polar units [10]. Additional slope changes include equatorial slumps [11] and shifting high-latitude boulders [12]. Araneiform features are forming in the southern hemisphere [13], driven by seasonal CO_2 defrosting [14]. Dune movement occurs planet-wide [15], primarily in the polar erg where CO_2-frost and wind processes combine [16]. Dust devil tracks regularly shift the surface albedo on short timescales [17]. Landed studies of surface changes have primarily observed eolian processes and traces of seasonal frost [3, 18-20].

Relation to MEPAG Goals: The MEPAG Goals Document [21] includes few direct references to active processes. However, Investigation IV.B.3.1 calls for change detection surveys, and several goals require an understanding of current processes, particularly Goal III.A (Determine the geologic record…and interpret the processes that have created that record) and its sub-objectives, and for interpreting landforms for Goal II (Understand the processes and history of climate). This understanding is critical to determine how surface processes have varied in the past and whether others should be invoked. Although detections of change are now abundant, we are only beginning to understand the driving processes, some of which have no Earth analog. For instance, active sand movement on Mars has led to a new understanding of the initiation of saltation [22]. Major changes in gullies associated with CO_2 frost have raised the possibility that they form without liquid water [23], while the processes driving RSL remain enigmatic [24]. Changes in the south polar residual cap are evident but the sign of the mass balance is not certain and may be zero [25]. Active processes also expose fresh subsurface material for investigation [26].

Future Exploration: Information needed to study active processes includes 1) improved monitoring of changes of all types to expand the change record and capture currently undetected subtle or rare events, 2) volume measurements (fluxes), 3) seasonal and geographic distribution, 4) better temporal resolution (e.g., do RSL grow gradually or in steps?) and 5) the local environmental conditions triggering activity. Orbital and landed data are both relevant for all of these, but 1–3 are best accomplished with a large sampling observed from orbit, requiring HiRISE-class or better imaging and topography [27]. Some environmental data can be determined from orbit, but 4–5 (and the detailed workings of processes) are best studied *in situ*. Detailed studies of new deposits would also help interpret older materials planet-wide. Different types of change require different measurements, particularly in possible Special Regions (e.g., gullies, RSL) where landed investigations may be needed to confirm or rule out liquid water.

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WHY MULTIPLE LANDED MISSIONS TO MARS ARE CRUCIAL TO UNDERSTANDING THE EVOLUTION OF TERRESTRIAL PLANET HABITABILITY: KEY NEXT STEPS IN ADVANCE OF THE DECADAL SURVEY.

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Prior white papers: A large number of members of the planetary science community have highlighted the importance of multiple missions of landed exploration on Mars to answer the most fundamental science questions about terrestrial planet evolution, including a 2018 white paper to the National Academies Astrobiology strategy committee [1; 15 authors], a *JGR-Planets* paper highlighting key questions about terrestrial planet evolution answerable on Mars and the measurements needed to address them [2; 46 authors], a report at the February 2017 Vision 2050 meeting [3; 19 authors], and multiple abstracts at the 2011 Mars Program Planning workshop [e.g., 4,5].

Rationale In Brief: Key questions about the evolution of terrestrial habitability include: What were the timing and effects of large impacts and stellar evolution on atmospheres of our solar system's rocky planets? What is the effect of loss of a magnetic field on atmospheric loss rates and composition? What has been the evolution of Martian atmospheric composition and volatiles? How does the history of volcanism and tectonics affect habitability? How do cycles of obliquity and eccentricity influence long-term climate?

Mars possesses a unique, continuous rock record from its first two billion years and is the only place in the solar system allowing access to a rock record that allows systematically addressing these questions. Key measurements, which can only be acquired in situ, are indicated in Figure 1.

Importantly, no single stratigraphy on Mars records all 2 billion years of time. Moreover, as on Earth, orbital data [6] has shown the record of Mars first two billion years is diverse, with multiple habitable environments, varying in space and time across the planet. Thus, interrogation of multiple geologic sections is needed to understand the time evolution of the Mars system and controlling processes.

Mission Concept Studies Required: Current costing paradigms present a quandary for Mars exploration. In internal JPL efforts, a 2 MER type rover mission is costed as more expensive than its actual executed cost adjusted for inflation, an outcome that is related to assumptions, which must be reexamined. Given that the drivers of cost growth on serial builds are new designs for capability (e.g. corer and instruments on M2020) and required modifications due to original component obsolescence, the experience of MER and logic dictates multiple simultaneous builds will realize cost savings relative to serial builds. Detailed, pre-set interfaces can also prevent cost overruns due to instrument redesigns for interface changes.

What is required is at least two studies with two thrusts: (1) examination by multiple centers and with experienced mission personnel minimalist multi-rover missions built to support capable in situ instrument payloads that make the measurements in Fig. 1 and (2) examination of novel smaller concepts like larger versions of Mars Drop [7] to vet alternative means of surface access and mobility by hoppers, helicopters or high-precision landings.

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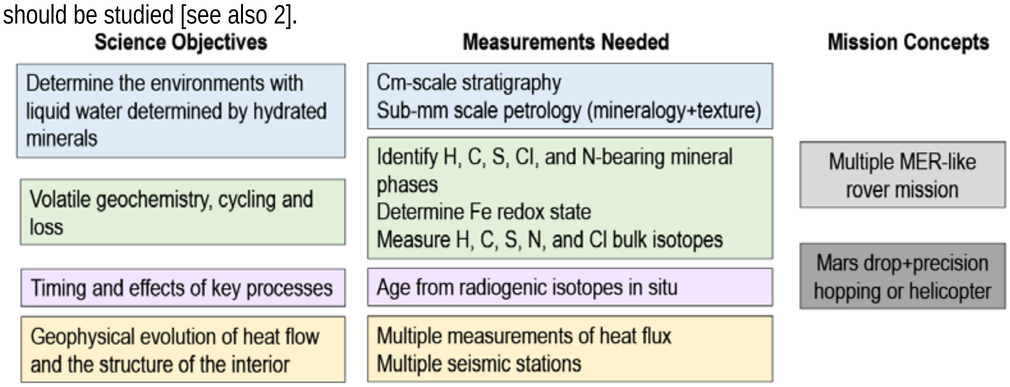
Fig. 1. Mapping scientific objectives to measurements needed to potential mission concepts which should be studied [see also 2].



SMALLSAT MISSIONS TO MAKE MULTI-POINT MEASUREMENTS OF THE MARTIAN MAGNETOSPHERE, IONOSPHERE, AND CRUSTAL MAGNETIC FIELDS.
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Mars-Bound SmallSats Are Possible: Recent advances in propulsion technology and interplanetary navigation theoretically allow very small spacecraft to travel directly to planetary destinations from near-Earth-space. Because there are currently many launches with excess mass capability (NASA, military, and even commercial), we anticipate a dramatic increase in the number of opportunities for missions to planetary targets. Spacecraft as small as 12U CubeSats can use solar electric propulsion to travel from Earth-orbit to Mars-orbit in approximately 2-3 years.

Important Science Can be Done with Multi-Point Particles and Fields Instruments: World-class instruments that require only modest mass, power, and telemetry resources (e.g. Goddard's mini-fluxgate vector magnetometer) can be easily accommodated on such missions. Mission scenarios that place SmallSats in Mars orbit combine the novelty of SmallSat design philosophies with comparatively conventional orbital mission requirements (vs. missions that require unusual mission design requirements, e.g. landers). Making use of the comparatively modest resources required for such mission architectures allows multiple SmallSats to be deployed which allows fundamental science questions to be addressed. The broad importance of multi-point measurements for space science is emphasized by the numerous Earth-based multi-point missions such as MMS, THEMIS, Cluster, and Swarm.

Magnetic Gradiometry Allows Investigation of the Geophysical History of the Martian Surface: The geophysical history of the martian surface and interior is at least partially recorded in the pattern of crustal magnetic fields that are present on the surface. By using magnetic measurements from multiple spacecraft it is possible to make such spatially enhanced crustal field maps. This technique is known as magnetic gradiometry. The difference between two near-by orbital measurements gives a much more accurate estimate of the actual field geometry emanating from the surface. By conducting multi-point magnetic gradiometry measurements, we will be able to address the fundamental geophysical history of Mars**.**

Investigating the Time-Variable Martian Magnetosphere and Ionosphere: MAVEN has confirmed that Mars is currently experiencing atmospheric loss due to its interaction with the solar wind. However, the details of the physical processes driving this loss and the time variable nature of this loss (time variability at the short time-scale, at the solar cycle time-scale, and at the billion-year time-scale) are both unconstrained. These are particularly complicated issues because of the difficulty of disentangling time-variable phenomena from spatially-variable phenomena with just one spacecraft. These details are important not just for understanding the nature of climate change at Mars but also in the wide variety of planetary environments that are beginning to be explored in exoplanets. Making measurements with world class space plasma physics instruments from two or more spacecraft in the uniquely hybrid martian magnetosphere will drastically improve our understanding of these phenomena.

These Science Objectives Are Part of the MEPAG Goals: Both of these science objectives (the geophysical history of the martian surface and the time-variability martian magnetosphere) are directly important to MEPAG science goals. Specifically, Goal II (Understand the process and history of climate on Mars) and Goal III (Understand the origin and evolution of Mars as a geological system) are both addressed by these objectives. Making important progress on these goals with modest SmallSat missions would be an important part of the Mars Exploration Program portfolio of missions for the coming decade.

ASSESSING MARTIAN CAVE EXPLORATION FOR THE NEXT DECADAL SURVEY. A. A. Fraeman[1], J. C. Castillo[1], E. J. Wyatt[1], S. A. Chien[1], S. J. Herzig[1], J. L. Gao[1], M. Troesch[1], T. Stegun Vaquero[1], W. B. Walsh[1], K. V. Belov[1], K. L. Mitchell[1], J. Lazio[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (abigail.a.fraeman@jpl.nasa.gov).

Introduction: Mars cave exploration is a topic of growing interest in the planetary science community as well as for human exploration. Hundreds of Martian candidate cave-related features have been identified in orbital datasets, most commonly associated with lava tubes [1]. Caves offer stable physio-chemical environments, may trap volatiles, enhance secondary mineral precipitation and microbial growth, are expected to preserve biosignatures, and provide record of past climate [eg. 2, 3]. Investigation of petrological sequences on skylight and cave walls can provide critical constraints on lava temperature and cooling history, leading to insights into Martian magmatic processes and differentiation. Caves are also believed to offer stable, radiation-shielding environment and potential to act as volatile traps, which will be important in future human missions [4].

Science Definition and Links to MEPAG Goals: Building on previous studies, we identified that a future mission to Martian caves should provide reconnaissance both for scientific and human exploration. Key science objectives for this pathfinder mission would be to map the cave geometry, determine traversability challenges, document the cave environment, and map the compositional and lithological diversity of the cave materials, including looking for volatiles, and organics.

Cave exploration would support MEPAG high level science objectives (IB) to determine if environments with high potential for current habitability and expression of biosignatures contain evidence of extant life, (IIIA) document the geologic record preserved in the crust and interpret the processes that have created that record, and (IVB) obtain knowledge of Mars sufficient to design and implement a human mission to the Martian surface with acceptable cost, risk, and performance.

Information needed to mature concept for decadal survey: The science goals should drive mission design, instruments and resource requirements. A payload could leverage recent or emerging miniaturized instrument developed for CubeSat-class deep space missions because of the mild radiation and thermal environment expected in caves. Here we focus on what is needed to understand how a reconnaissance mission might be carried out with a constellation of small (10s kg) platforms.

Mission architecture challenges: Managing the resulting complex design space, and performing associated trade studies to find well-balanced solutions, requires appropriate computational methods and tools to support mission designers and systems engineers in their decision-making processes. We are developing tools to study heterogeneous architectures where responsibilities (science, telecom) are distributed among assets. Our study includes trade-offs between potential power sources, homogeneity and heterogeneity of the assets, as well as distribution of science instruments to optimize cost and achieved benefit.

Telecommunication Challenges: The cave environment presents a significant challenge in maintaining reliable communications. Moving close to a cave wall or operating in small caves could all lead to substantial challenges for communication. In the most extreme case, two mobile assets could be in direct line of sight yet unable to communicate. This concept represents a perfect example for the application of disruption tolerant network (DTN) technologies. In order to allow a deeper analysis of these challenges, we have launched an effort to develop the capability for measuring and characterizing radio signal propagation at much higher fidelity in order to make sound design decision for in-cave communications.

Coordinated Autonomy: Novel operational concepts will be required, which are expected to include higher levels of autonomy and frequent communication among assets for autonomous coordination. A few different exploration strategies are being investigated for autonomous multi-rover cave exploration. The Dynamic Zonal Relay Algorithm spreads out the rovers along the length of the cave such that each rover investigates a specific area of the cave while maintaining communication distance to the neighboring rovers. The Sneakernet Relay Algorithm is an extension of the Dynamic Zonal Relay Algorithm where the rovers move beyond the communication range to neighboring rovers, allowing for data acquisition deeper in the cave. The Scout Observation Algorithm works on the premise that there are multiple scouting rovers and a single more capable science rover.

Summary: Advanced design of a Martian cave exploration concept has highlighted the need for novel approaches to communication and science acquisition. We note that these approaches may also be highly relevant to additional future Martian mission studies that utilize networks of assets to explore a single surface site.

Acknowledgements: This work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

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Monitoring from Orbit whether Mars is still Seismically Active

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In the early years of planetary exploration, seismometers were placed on the Moon and on Mars. Moonquakes were confirmed but attempts to record martian tremors during the Viking missions failed. A new attempt will be made with NASA's landed InSight mission scheduled for launch in May 2018. However, a single point seismometer deployment is not an efficient (and cost-effective) way to gather information about residual tectonic activity on Mars.

My work on pre-earthquake processes has led to the discovery of a stimulated infrared emission from the Earth's surface when stresses build up deep in the crust. The underlying process is the stress-activation of peroxy defects that are ubiquitous in crustal rocks. When the peroxy defects break up, they release electrons (e') and holes ($h^\bullet$), of which the holes have the remarkable ability to flow out of the stressed rock volume, propagating fast (~100 m/sec) and far (tens of kilometers or more) into the surrounding rocks. The $h^\bullet$ become trapped at the Earth surface, preferentially at topographic highs. There they recombine emitting IR radiation, which has a unique spectroscopic signature.

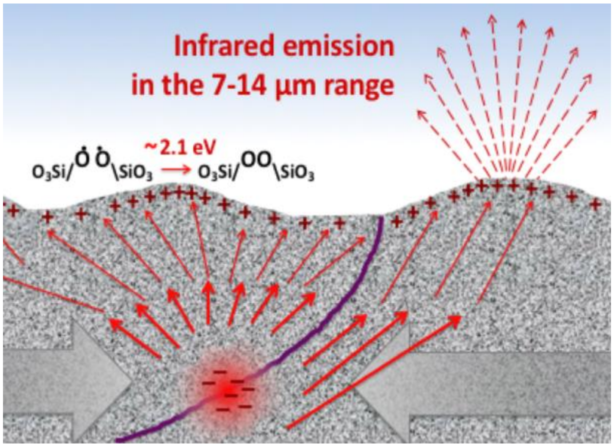

Fig. 1: Stress-activated positive hole charge carriers spreading through the rock column and recombining at the surface with concomitant IR emission

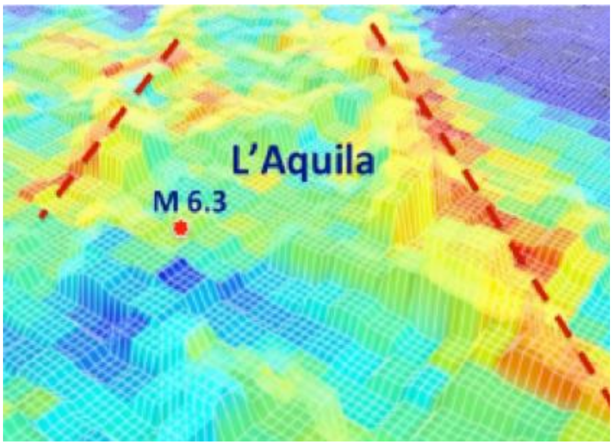

Fig. 2: Enhanced IR emission 3 nights before the M6.3 L'Aquila earthquake in Italy coming from the mountains, incl. Gran Sasso Massif to the right.

Figure 1 shows schematically the basic process. Figure 2 shows an example from Italy, where a strong earthquake was preceded by stimulated IR emission. If this IR can be spectroscopically resolved, the characteristic emission bands of the radiative de-excitation of peroxy (10-14 μm) can be used as fingerprint.

This leads to the following proposal: Place either a simple IR or a hyperspectral IR camera into orbit around Mars and record its IR emission, preferentially from the night-side. Any stresses building up within the martian crust will lead to IR from the martian surface. A favorable factor is that the IR intensity is expected to be highly non-linear and particularly sensitive to relatively low stress levels.

THE IMPORTANCE OF PRIMARY MARTIAN SURFACE AND AIRFALL DUST SAMPLE RETURN FOR TOXICOLOGICAL HAZARD EVALUATIONS FOR HUMAN EXPLORATION. A. D. Harrington and F. M. McCubbin, Astromaterials Research and Exploration Sciences (ARES) Division, NASA Johnson Space Center, 2101 NASA Parkway Mail Code XI2, Houston TX 77058, Andrea.D.Harrington@NASA.gov.

Introduction: Manned missions to the Moon highlight a major hazard for future human exploration of the Moon and beyond: surface dust. Not only did the dust cause mechanical and structural integrity issues with the suits, the dust 'storm' generated upon reentrance into the crew cabin caused "lunar hay fever" and "almost blindness [1-3]". It was further reported that the allergic response to the dust worsened with each exposure [4]. Due to the prevalence of these high exposures, the Human Research Roadmap developed by NASA identifies the *Risk of Adverse Health and Performance Effects of Celestial Dust Exposure* as an area of concern [5]. Extended human exploration will further increase the probability of inadvertent and repeated exposures to celestial dusts. Going forward, hazard assessments of celestial dusts will be determined through sample return efforts prior to astronaut deployment.

Lunar samples returned by the Apollo missions are the most toxicologically evaluated celestial dust samples on Earth. Studies on the lunar highland regolith indicate that the dust is not only respirable but also reactive [2, 6-9] and moderately toxic, generating a greater pulmonary response than titanium oxide but a lower response than quartz [6]. However, there is actually little data related to physicochemical characteristics of particulates and cardiopulmonary toxicity, especially as it relates to celestial dust exposure.

Broad Toxicological Evaluations of Meteorites. Studies investigating the role of a particulate's innate geochemical features (e.g., bulk chemistry, internal composition, morphology, size, and reactivity) in generating adverse toxicological responses *in vitro* and *in vivo* are underway [10]. The highly interdisciplinary studies focus on the relative toxicity of six meteorite samples representing either basalt or regolith breccia on the surfaces of the Moon, Mars, and Asteroid 4Vesta. Notably, the martian meteorites generated two of the greatest acute pulmonary inflammatory responses (API) but only the basaltic sample is significantly reactive geochemically. Furthermore, while there is no direct correlation between a particle's ability to generate ROS acellularly and its ability to generate API, assorted API markers did demonstrate strong positive correlations with Fenton metal content and the ratio of Fenton metals to silicon [10].

The Necessity of Sample Return for Permissible Exposure Limit Determination. Although the mitigation of risk associated with broad toxicological human hazard assessments is vital to the process, the determination of permissible exposure limits (PELs) is the essential next step. Without these limits, the astronauts are at risk of overexposure which could lead to negative health outcomes and compromise both the mission and all of the astronaut's lives.

Based on broad toxicological assessments of an array of celestial dusts, relatively small differences in geochemistry can lead to significant differences in cardiopulmonary inflammation [10]. Given this, it is crucial to determine the PELs utilizing samples of the actual dust astronauts will be exposed. In the case of human exploration of Mars, these samples are in the form of surface regolith dusts and airfall samples. Differences in chemistry, formation, and weathering preclude the use of ground core samples for PEL determination.

Although geophysicochemical features have been the focus of toxicological evaluations of celestial dusts, the presence of biological organisms is an even greater risk to human health. In fact, the presence of extant life within returned samples is such a concern that no PELs will be able to be determined based on geophysicochemical features until the dust is found to be sterile. Given this, it is important to not only bring back samples of surface and airfall dust but also to ensure the samples are pristine (e.g. free of terrestrial contamination and unaltered due to sample collection, caching, and return procedures).

Conclusions: Toxicological evaluations demonstrate statistical differences in cardiopulmonary responses upon exposure to celestial basalt and regolith samples [10]. These differences highlight the need to perform future toxicological evaluations (e.g. PELs) on primary martian surface and airfall dust samples in order to allow for the proper evaluation of risk to human health.

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Mars PolarDROP: Distributed Micro-landers to Investigate the Polar Ice Caps and Climate of Mars. P.O. Hayne[1], S. Byrne[2], I.B. Smith[3], D. Banfield[4], and R. L. Staehle[5], [1]University of Colorado (Paul.Hayne@Colorado.edu) [2]Lunar and Planetary Laboratory, University of Arizona [3]Planetary Science Institute [4]Cornell University [5]NASA – Jet Propulsion Laboratory, California Institute of Technology.

Motivation: Understanding the recent climate history of Mars requires models that can accurately reproduce observations of the present-day atmosphere. To extrapolate backward in time, these models must also account for volatile exchange between the atmosphere and the polar deposits [1,2]. The polar layered deposits (PLD) record climate variations spanning the last several million years, due to obliquity-driven insolation cycles [3]. However, to interpret this climate record, observational data are lacking in several key areas: 1) surface winds are largely unknown, especially in the polar regions [4,5], 2) quantities of water and CO_2 exchanged with the polar caps are poorly constrained [6], and 3) the spatial scales of fine layers in the PLD may be unresolved from orbit [7]. Therefore, new measurements are needed in order to validate models and confidently extend them to past climate regimes.

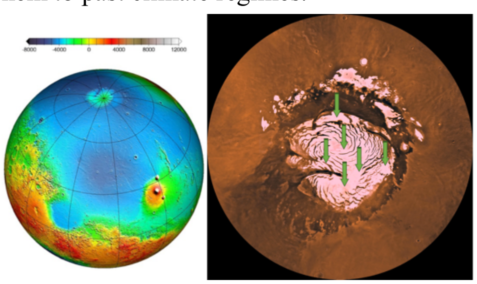

Figure 1. (Left) MOLA topography showing the Vastitas Borealis region, which presents low elevation ideal for entry, descent and landing (Right) Possible distributed landing sites on the northern polar ice cap, indicated by arrows.

A 2017 Keck Institute for Space Studies (KISS) study on Mars polar exploration brought together >30 experts to determine required measurements to investigate the climate record contained in the PLD [8]. This study also developed mission concepts to accomplish these measurements. Here, we report on a mission concept (Mars PolarDROP) using micro-landers to accomplish a critical subset of these measurements.

Science Objectives: As part of the larger KISS study, we developed a set of major science questions to be addressed in order to extract and interpret the climate record stored in Mars' PLD:

a) What are the present and past fluxes of volatiles, dust, and energy into and out of the polar regions?
b) How do orbital forcings and exchange with other reservoirs affect those fluxes?
c) What chemical and physical processes form and modify layers?
d) What is the timespan, completeness, and temporal resolution of the PLD climate record?

The Mars PolarDROP concept addresses Questions (a), (c), and (d), through the following science Objectives:

1) Constrain and validate mesoscale models of polar atmospheric circulation, boundary layer turbulence, and volatile exchange
2) Resolve the thinnest layers in the PLD to constrain rates of accumulation/ablation and link to orbital observations
3) Determine isotopic fractionation recording volatile exchange in the PLD

Implementation: The micro-landers are based on the MarsDROP concept [9], using small probes with parawings to deliver ~1 kg science payload to the surface. Every Mars PolarDROP probe carries meteorological instruments to measure wind velocity, temperature, pressure, and humidity. Possible additional measurements include: 1) ground-penetrating radar to resolve thin layers in the PLD, and 2) tunable laser spectoscopy to determine isotopic abundances in the icy layers. The probes can be dispersed across the NPLD, which is a low-hazard landing site. Any number of probes could be utilized to address the science objectives with varying degrees of completeness.

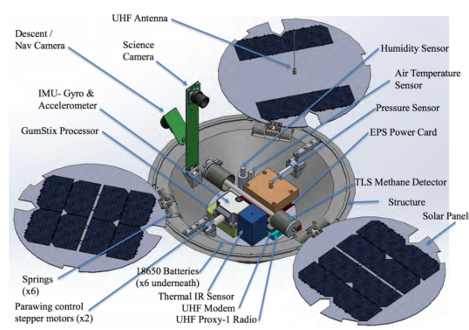

Figure 2: Schematic of a MarsDROP [9] micro-lander with one possible payload configuration. Mars PolarDROP would enable *in situ* measurements of ice composition and layering, as well as local meteorology. The central structure is ~0.3 m in diameter.

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NEW EFFORTS TO UPDATE NASA'S GLOBAL REFERENCE ATMOSPHERIC MODELS (GRAM). H. L. Justh[1], A. M. Dwyer Cianciolo[2], K. L. Burns[3], J. Hoffman[4], R. W. Powell[5], and P. W. White[6]. [1]NASA, Marshall Space Flight Center, Mail Code EV44, Marshall Space Flight Center, AL, 35812, hilary.l.justh@nasa.gov, [2]NASA, Langley Research Center, Mail Stop 489, Hampton, VA 23681, alicia.m.dwyercianciolo@nasa.gov, [3]Jacobs Space Exploration Group, 1500 Perimeter Pkwy., Suite 400, Huntsville, AL 35806, kerry.l.burns@nasa.gov, [4]Analytical Mechanics Associates, 21 Enterprise Pkwy., Suite 300, Hampton, VA 23666, james.hoffman-1@nasa.gov, [5]Analytical Mechanics Associates, 21 Enterprise Pkwy., Suite 300, Hampton, VA 23666, richard.w.powell@nasa.gov and [6]NASA, Marshall Space Flight Center, Mail Code EV44, Marshall Space Flight Center, AL, 35812, patrick.w.white@nasa.gov.

Introduction: NASA is at the forefront of planetary exploration. The inability to test planetary spacecraft in the flight environment prior to a mission requires engineers to rely on ground-based testing and models of the vehicle and expected environments. One of the most widely used engineering models of the atmosphere for many NASA projects is the Global Reference Atmospheric Model (GRAM) developed by the NASA Marshall Space Flight Center (MSFC). Over the past decade GRAM upgrades and maintenance have depended on inconsistent and waning project-specific support. Recently, the NASA Science Mission Directorate (SMD) has agreed to provide funding support in Fiscal Year 2018 and 2019 to upgrade the GRAMs. This poster summarizes the objectives, tasks and milestones of this effort.

GRAM Upgrade Objectives, Tasks, and Milestones:

Objectives. The GRAM upgrade effort will focus on three primary objectives: upgrade atmosphere models within the GRAMs, modernize the GRAM code, and socialize plans and status to improve communication between GRAM users, modelers and GRAM developers.

Tasks. The priority of this effort is to update the atmosphere models in the GRAMs and to establish a foundation for developing GRAMs for additional destinations. This includes determining which atmosphere models have upgrades currently available and incorporating them into the GRAMs. Planetary mission atmospheric data will be used as the basis for comparison studies of the GRAM models. Another key element of this effort is modernizing the GRAM code. This task involves creating a new framework that transitions the original Fortran code to C++. This effort will take advantage of object-oriented capabilities of C++. In addition to the model and code upgrades, socializing the status of the upgrades and advocating and promoting its continued use in proposals and projects will be conducted by the study coordinators and leads.

Milestones. Project milestones for fiscal year 2018/2019 and beyond have been determined and include: surveying users to prioritize investments, meeting with key modeling groups, identifying, obtaining and implementing atmosphere model upgrades for GRAMs as well as observational and mission data sets for GRAM comparisons, upgrading the GRAM code framework, and releasing updated and new GRAMs that will include programming and user guides.

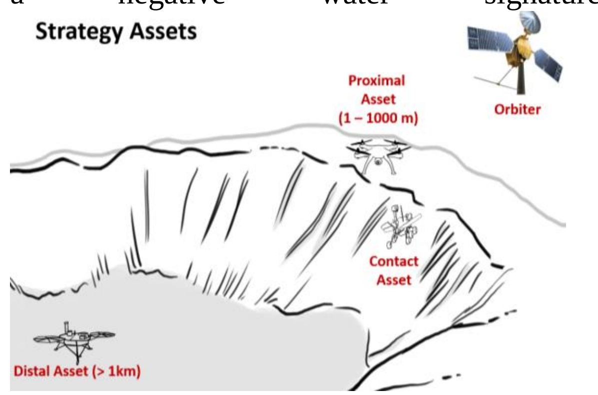
Conclusions: The GRAMs are a critical tool set that influences mission selection and decisions. The funding provided by SMD is vital to address current limitations and accomplish GRAM developmental goals.

Acknowledgements: The authors gratefully acknowledge support from the NASA SMD.

A New Concept Study for Exploring and Sampling Recurring Slope Lineae (RSL) and other Extreme Terrains, L. Kerber[1], R.C. Anderson[1], I. A. D. Nesnas[1], J. W. Burdick[2], F. Calef III[1], G. Meirion-Griffith[1], T. Brown[1], J. Sawoniewicz[1], A. Stefanini[1], M. Paton[1], M. Tanner[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, Engineering and Applied Science, California Institute of Technology, Pasadena, CA 91109, Robert.C.Anderson@jpl.nasa.gov

Introduction: Recurring Slope Lineae, RSL, are terrain discolorations that meet three criteria: 1) they increase in length, 2) they fade, and 3) the periodically recur. They have been observed on some martian crater walls during the warm seasons. Their seasonal behavior and preferential occurrence on warm equator-facing slopes suggest that some volatile, such as liquid brines, may be involved. Since their discovery in 2011, several hypotheses have been proposed to explain this phenomenon. In 2015, signatures of hydrated minerals were detected from the MRO mission imaging spectrometer, providing further evidence that supports the hypothesis of “briny seeps.” However, questions remain regarding the mechanism for replenishing the water. Since RSL have only been observed on slopes at the angle of repose of the regolith, others have hypothesized that these features result from dry avalanches possibly triggered by sublimation of frozen CO2 along crater walls. To date, there has been no single hypothesis that can explain all current observations. A JPL study on the Exploration of RSL and gullies took place in June. A consensus has emerged from that study that a mission to explore RSL would have to provide in situ measurements on RSL to be able to disambiguate among the various hypotheses.

Approach and Results: Our first-year effort was split into two phases. The first phase focused on understanding RSL based on orbital imagery, developing a science traceability matrix, and investigate trades for accessing RSL. The second phase focused on advancing rappelling mobility technology by designing and fabricating a tether management system for the Axel rappelling rover. RSL Hypotheses: There are currently three hypotheses for explaining RSL: (1) dry flows [1], (2) volatile-triggered dry flows (either CO2 or H2O triggered) [2], or (3) wet flows either from deliquescence [3], from shallow water sources [4], or from deep underground aquifers. Information about RSL can be gathered from multiple assets (Fig. 1): (i) orbital, (ii) distal (here defined as a near-surface at > 1 km from the RSL source), (iii) proximal (from a 1 km to 1 m), and (iv) contact referring to assets < 1 m to the surface. We examined “what can be learned” from each of the four asset types based on required observations that fall in these three categories: (1) characterization and distribution of RSL, (2) a positive water signature, and (3) a negative water signature.



Without proximal or contact measurements, we are unlikely to be able to disambiguate a negative water signature or identify the water source for a positive signature. Accessing RSL: We examined over 22 possible concepts for accessing RSL, which can be sorted into the following categories: (1) surface ascent (crater floor up), (2) surface descent (crater rim down), (3) aerial (both balloon and rotary winged aircraft), (4) missiles, and (5) tether riders.

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MARS WEATHER AND CLIMATE: AN ORBITAL CONSTELLATION FOR ATMOSPHERIC PROFILING AND SURFACE THERMOPHYSICS

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Goals: Over the last decade considerable progress has been made in understanding the structure of the martian atmosphere and surface-atmosphere interactions. Current work focuses on identifying dynamical processes and radiative effects that are responsible for shaping the atmosphere of Mars. Progress in the area of weather and climate on Mars will depend on achieving two major science goals:

1. **Build a long-term record of the current martian climate to characterize the Amazonian**
2. **Globally characterize martian weather**

Goal 1 addresses the question of whether there are significant changes in the martian climate on 10 to 1000 year timescales [1]. With atmospheric and surface observations by the Thermal Emission Spectrometer (TES) from MY 24-26 and by the Mars Climate Sounder (MCS) from MY 28 to the present (MY 34) [2] we are about to enter an era where time series of orbital measurements allow extrapolation to Amazonian time scales. Only long-term climatologies allow the characterization of interannual variabilities and systematics [3]. Global dust events have major impacts on the surface and atmosphere in some years but the hiatus in their occurrence since MY 28 emphasizes the need for long-term observaions. Trends, e.g. in dust storm occurrences and dust fluxes, will only be uncovered by long-term stable and consistent measurements.

Goal 2 addresses improving understanding of short-term processes that form martian weather. One issue that limits progress in this area is the lack of coverage of observations at multiple local times, such that many short-term processes are not well characterized. These include forcing of semi-diurnal tides and higher order modes, which reveal strong radiative influences of water ice clouds and affect the general atmospheric circulation [4]. Furthermore, the inhomogeneous vertical distribution of atmospheric dust suggests that convective activity triggered by solar heating of dust may play a crucial role in dust transport and possibly the formation and growth of global dust events [5]. In addition, diurnal H_2O and CO_2 frosts may have a significant impact on the regolith structure that is not well described [6]. Characterizing such processes globally at timescales of less than a sol would also provide an improved basis for assimilating data into General Circulation Models, which has proven challenging [7]. Assimilating near real-time atmospheric and surface data could pave the way towards forecasting martian weather in support of landing, aerocapture and surface operations of future manned and robotic missions.

Concept: The proposed goals require global profile measurements of atmospheric temperature, dust, water ice and water vapor, as well as surface temperature, at multiple local times. We suggest a constellation of SmallSats or CubeSats in Mars orbit to perform these measurements. The satellites would be deployed in low-altitude orbits of moderate to high inclination around Mars. A constant node spacing of 45° between orbits would ensure that atmospheric and surface observations over the same areas would be performed in regular local time intervals of 3 hours.

Measurements would be based on passive infrared radiometry in limb and nadir geometry as demonstrated by MCS [8] operating on MRO since 2006. Profiles of temperature, dust and water ice with 5 km vertical resolution have been retrieved from these measurements [9] together with atmospherically corrected surface temperature [6]. Future measurements with the same approach and technology would ensure comparability with the existing 6 Mars Year climatology [2].

The mission concept would advance the understanding of how physical processes in our solar system operate, interact and evolve as outlined in the 2014 NASA Science Plan. The MEPAG Goals document explicitly solicits the measurement of atmospheric parameters at multiple local times.

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The Icebreaker Mission to Mars: Habitable Conditions on Modern Mars Warrants a Search for Life. C.P. McKay, C.R. Stoker, B.J. Glass, A. Davila, NASA Ames Research Center, Moffett Field CA & the IcebreakerTeam chris.mckay@nasa.gov

Introduction: The 2008 Phoenix Mars lander mission sampled ground ice at 68°N latitude. Mission results, considered along with climate modeling studies, suggest that high latitude ice-rich regolith at low elevations is habitable for life [1]. This talk will review the evidence and describe a low cost life search mission to search for modern life on Mars.

Habitable Conditions Evidence from Phoenix: Digging with a robotic arm revealed an ice table within 3-5 cm of the surface. Evidence for liquid water processes was observed including: 1) beneath 3 -5 cm of dry soil, segregated pure ice was discovered in patches covering 10% of the area explored, 2) pure calcite mineral, which forms under aqueous conditions, was detected in the soil, 3) perchlorate salt, highly soluble in liquid water, was observed at varying concentrations with higher concentrations seen in soil clods [2]. Carbon and nitrogen sources are available to support chemoautotrophic metabolism. The Thermal Evolved Gas Analysis (TEGA) instrument searched for soil organics but perchlorate was discovered in the soil [3]; any organic carbon in the soil would not have been detectable due to reaction with perchlorate during the heating step used for releasing volatiles. While current climate conditions are too cold to support metabolism, climate modeling studies [4] show that variations in solar insolation associated with changes in the season of perihelion occurring on 25kyr timescales and obliquity variations on 125kyr timescales [5] cause warmer and colder periods to occur in the N. polar region. The current epoch is cold because orbital tilt is low and summer occurs at apehelion. As recently as 17kyr ago, when summer solstice was at perihelion, temperatures were warm enough to allow pure liquid water to form at the surface [4]. At orbital tilts > 35°, insolation is equivalent to levels experienced in Earth's polar regions at the present time. At 45° temperatures allowing microbial growth persist to 75 cm depth [6].

Terrestrial permafrost communities are an example of possible life in the ice-rich regolith. Studies in permafrost have shown that microorganisms can function in ice-soil mixtures at temperatures as low as -20°C, living in the thin films of interfacial water [7]. In addition, it is well established that ground ice preserves living cells, biological material, and organic compounds for long periods of time, and living microorganisms have been preserved under frozen conditions for thousands and sometimes millions of years[8]. If life survives in these areas, growing when conditions allow, biomolecular evidence of life should accumulate in the soils.

The presence of habitable conditions on Mars that persist over geological timescales to the present suggests that searching for biochemical evidence of modern life is warranted. The Mars Icebreaker Life mission [9] was proposed with that goal to the NASA Discovery call in 2015 and a future proposal is planned. The mission plans to land in the same region as Phoenix with a payload designed to address the following science goals: (1) search for biomolecular evidence of life; (2) search for organic matter from either exogeneous or endogeneous sources using methods not impacted by the presence of perchlorate; (3) assess the habitability of the ice bearing soils. The Icebreaker Life payload features a 1-m drill to auger subsurface material to the surface where it is delivered to payload instruments. Three instruments were proposed for the mission: The Signs of Life Detector (SOLID) [10] uses immunoassay to search for up to 300 biomolecules that are universally present and deeply rooted in the tree of Earth life. The Laser Desorption Mass Spectrometer (LDMS) [11] performs a broad search for organic compounds of low to moderate molecular weight that may be cosmogenic in origin or degraded biomolecules. The results are not impacted by the presence of perchlorate. The Wet Chemistry Laboratory (WCL) [3] detects soluble species of potential nutrients and reactive oxidants, providing insight into the habitability potential of icy soils.

Over the past few years there has been growing interest in life detection missions. This interest has been primarily driven by mission concepts to the ocean worlds of the outer Solar System – especially Enceladus. For the next Discovery call the Icebreaker payload will benefit from the technologies and approaches developed by the ocean worlds missions.

The Icebreaker payload fits on the same spacecraft/ lander used by Phoenix. The mission can be accomplished for modest cost, searching for a record of modern life on Mars while meeting planetary protection requirements.

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MONITORING THE WEATHER ON MARS WITH AN AREOSTATIONARY SMALLSAT.

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Introduction: The spatial distribution and temporal evolution of dust and water ice aerosols are essential observables for any fundamental or applied study related to the atmosphere of Mars, including weather monitoring for robotic and future human exploration missions.

The dust cycle –which dust storms are the most remarkable manifestation of- is considered to be the key process controlling the variability of the Martian atmospheric circulation at inter-annual and seasonal time scales, as well as the weather variability at much shorter time scales. It has also been demonstrated that the radiative effects of the presence of water ice clouds are very important in understanding the details of the atmospheric thermal and dynamical structures.

Science objectives: We propose to focus the attention on tracking[1] Martian dust storms and water ice clouds, helping to address the scientific questions: *What are the processes controlling the dynamics of dust and water ice aerosols, and promoting the evolution of regional dust storms into planetary-encircling storms?* These questions are aligned with MEPAG's and the "Vision and Voyages" Decadal Survey's goals.

Measurements needed: Monitoring in detail the dynamics of dust storms (i.e. their onset, transport, and decay) and water ice clouds (i.e. their formation, evolution, and dissipation) requires both continuous and synoptic observations[2] of Martian aerosols from space.

The key factor to achieve this objective is the choice of the satellite orbit. None of the satellites already in orbit around Mars or currently planned has the required orbital characteristics. Polar Sun-synchronous orbits ensure (asynoptic) global coverage –mostly for mapping surface features and properties- but prevent frequent atmospheric observations at the same locations. Quasi-polar eccentric orbits (e.g. NASA's MAVEN or ESA's Mars Express) provide some coverage at different local times, and synoptic views of the Martian disk near apoapsis, but they still cannot achieve continuous monitoring of rapidly evolving meteorological phenomena at fixed locations.

[1] We refer to *aerosol tracking* as the process of following the evolution of the aerosol spatial distribution.
[2] By *continuous monitoring* we mean obtaining data at a high rate for a long time. By *synoptic monitoring* we mean obtaining data simultaneously over a large area.

Mission concept: A truly innovative method to obtain continuous and synoptic observations of the aerosol distribution (at least the horizontal one) would be to use a spacecraft in Mars-synchronous (areosynchronous) orbit, which can additionally be circular and equatorial (i.e. Mars-stationary, or areostationary). The planned Emirates Mars Mission is the only spacecraft whose orbit approaches the unique coverage offered by a truly areosynchronous or areostationary satellite.

For Mars, the areostationary altitude is 17,031.5 km above the equator (semi-major axis = 20,428.5 km). The sub-spacecraft point is at 0° latitude at the chosen longitude, and the satellite can observe the surface up to 80° away from nadir, although the portion of the disk useful for scientific purposes might be limited to about 60°. In Fig.1 we show how a regional dust storm that developed in Martian year 24 is seen during several daylight orbits of the Mars Global Surveyor polar orbiter (left panel), compared to a reconstruction of the storm as it would be seen from the vantage point of an areostationary satellite (right panel).

We have elaborated a mission concept to put a stand-alone SmallSat in an areostationary orbit around Mars. This would offer the unequaled possibility to monitor the weather and obtain a novel set of frequent measurements of aerosol optical depth throughout multiple local times over a large portion of the planet. The use of a low-cost SmallSat with a focused meteorological science objective, included as a secondary payload of a primary mission, is a key innovation with respect to previous orbiter missions to Mars.

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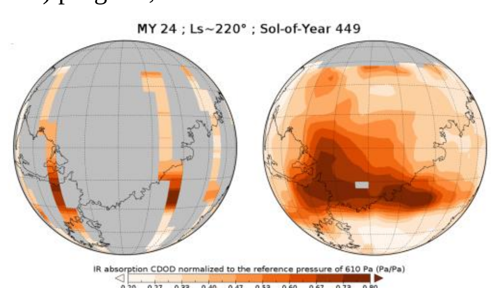

Figure 1: A regional dust storm from Mars Global Surveyor/Thermal Emission Spectrometer gridded IR column dust opacities accumulated in 1 sol (left), and reconstructed with data gridded over 7 sols (right). Vertical perspective views.

RATIONALE AND CONCEPT FOR A SYNTHETIC APERTURE RADAR AND SUB-SURFACE ICE SOUNDER FOR MARS. G. R. Osinski[1,2], A. Baylis[3], I. Barnard[3], P. Allen[3], R. Caves[4], E. Cloutis[5], P. Fulford[6], J. B. Garvin[7], J. W. Holt[8], D. Lacelle[9], C. D. Neish[1], B. Rabus[10], M. Schmidt[11], J. Sharma[4], R. J. Soare[12], L. L. Tornabene[1], A. Thompson[4], [1]Centre for Planetary Science and Exploration / Dept. of Earth Sciences, University of Western Ontario, ON, Canada, [2]Dept. of Physics and Astronomy, University of Western Ontario, ON, Canada, [3]MDA Corporation, Sainte-Anne-de-Bellevue, QC, Canada, [4]MDA Corporation, Richmond, BC, Canada, [5]Dept. of Geography, University of Winnipeg, MB, Canada, [6]MDA Corporation, Brampton, ON, Canada, [7]NASA Goddard Space Flight Center, MD, USA, [8]Institute for Geophysics and Dept. of Geological Sciences, University of Texas at Austin, TX, USA, [9]Dept. of Geography, University of Ottawa, ON, Canada, [10]School of Engineering Science, Simon Fraser University, BC, Canada, [11]Dept. of Earth Sciences, Brock University, Canada, [11]Dept. Geography, Dawson College, Canada (gosinski@uwo.ca).

Introduction: A wealth of mission data has provided insight into the current distribution of H_2O on Mars. Data from the gamma ray spectrometer (GRS) onboard the Mars Odyssey spacecraft indicates that the upper ~1 m of the Martian surface contains an extensive amount of ground ice at latitudes >40–50° [1]; direct observations from the Phoenix lander confirmed these observations at a single location [2]. Subsurface radar sounding of glacial landforms using the SHARAD instrument suggests that water ice may be present depths of 10s to 100s metres (e.g., [3, 4]).

Despite the large number of missions and huge number of studies, *there exists a fundamental gap in our knowledge about the distribution and amount of ice present at depths of >1 m to ~10 m on Mars.* This is mirrored by the findings of the Final Report of the MEPAG Next Orbiter Science Analysis Group (NEX-SAG). The report concludes that a "Polarimetric radar imaging (SAR) with penetration depth of a few (<10) meters" was critical for addressing the resource, science, and reconnaissance objectives of the Next Mars Orbiter (NeMO) mission.

In April 2017, MDA Corporation began a Concept Study for a Sub-Surface Ice Sounder for a future Mars orbiter under contract from the Canadian Space Agency (CSA). The Concept Study team comprises a Technical Team (Technical Lead: I. Bernard) and a Science Team (PI: G. R. Osinski) led by Program Manager A. Baylis. In this contribution we provide an overview of the concept as it stands, discuss open questions, and welcome feedback and involvement from the international planetary science community.

Science objectives: For the purposes of this Concept Study, the Science Team has defined the following 5 science objectives: 1) Determine the overall spatial and vertical distribution of shallow ground ice deposits in the Martian mid- to high-latitudes; 2) Characterize the properties of the upper portion of the polar layered deposits; 3) Map and quantify shallow ground ice in areas of possible brine flow and monitor for recent RSL and gully formation activity; 4) Detect, characterize and map exposed and buried fluvial landforms in ancient Martian terrains; 5) Determine the surface properties of impact and volcanic deposits.

Requirements for radar instrument: In the following sections we outline the current status of the instrument requirements. It is important to note that these are draft and the concept is still evolving.

SAR Imaging Mode. The science goals specified above can be met with a polarimetric Strip-map approach, in general. The science objectives identify the imaging characteristics of the radar in terms of high resolution (2–3 m), medium resolution (~5–7m) and low resolution (<15 m). In these different modes, the desirable coverage of the instrument in a nominal 687day mission is: ~0.5 % of Mars in HR mode; ~5% of Mars in MR mode with repeat coverage by seasons; ~35% of Mars in LR mode with repeat coverage by seasons. A range of incidence angles from ~30 to 50 degrees and both fully polarimetric (quad-pol) and compact-pol options are currently being considered.

SAR Sounder Mode. The current configuration is for a nadir looking sounder mode with vertical resolution of 1 m and along track sampling of <50 m. The target is >60% coverage in this mode.

Operating frequency. Previous studies [5] have largely considered P-band radar operating at ~500 MHz and < 1 GHz. Various options including a P-band radar (~500 mHz centre frequency), an L-band radar (~1.1 GHz) and a dual frequency solution are being studied by the instrument team.

Future work: This concept is the focus of ongoing work. We welcome input from the community.

Acknowledgements: This work is funded by the Canadian Space Agency.

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High priority science objectives that are best achieved from Mars orbit. D. Rogers[1]*, T. Glotch[1], C. Edwards[2], S. Ruff[3], V. Hamilton[4], B. Ehlmann[5], A. McEwen[6], M. Salvatore[2], B. Horgan[7], J. Wray[8], [1]Stony Brook Univ., [2]Northern Arizona Univ., [3]Arizona State Univ.,[4]Southwest Research Inst., [5]Jet Propulsion Laboratory, California Inst. Technology, [6]Univ. of Arizona, [7]Purdue University, [8]Georgia Inst. Technology *deanne.rogers@stonybrook.edu

Introduction: The MEPAG Goals document includes a number of high priority science objectives that can only be achieved from an orbital/aerial platform, as described in the 2015 NEX-SAG report [1]. Meeting these objectives would require a high-resolution imager, IR (SWIR and/or MIR) spectral imaging, thermal imaging, an imaging radar, atmospheric sounding instruments, and a wide-angle weather camera [1]. Some of these instruments cannot be accommodated by present small satellite capability, and use as a suite requires a capable orbiter. Here we reiterate the importance of the NEX-SAG mission concept, because it would: (a) address multiple high-priority MEPAG science objectives, (b) provide important measurements for understanding terrestrial planet evolution and habitability [2], and (c) provide critical information to enhance landed science and planning for human exploration. Mars Sample Return (MSR) remains the highest priority for the Mars community. But, these other high priority objectives should not be eclipsed by MSR within the Mars programming in the coming decade, particularly if a future Mars exploration strategy includes additional rovers and/or human exploration.

High-level science objectives (broadly grouped) and required measurements:

1. Mapping shallow volatile reservoirs to (a) quantify the H_2O and CO_2 inventories, (b) characterize surface/atmosphere exchange, (c) understand recent climate change, and (d) enable accurate assessment of H_2O accessibility/depth for ISRU and human exploration. These science objectives are detailed under MEPAG Goals 1, 2, 4, and require an imaging radar plus thermal IR instrument to characterize regolith overburden.

2. Mapping rock and mineral compositions and abundance to (a) characterize environmental transitions recorded in the stratigraphic record and (b) quantify the bulk H_2O content in preparation for human exploration. These science objectives are described in detail under MEPAG Goals 3 and 4, and would require both high-resolution IR spectral and visible imaging to relate compositional information to stratigraphy.

3. Characterizing dynamic processes with applications to atmospheric processes and identifying possible regions of liquid water/brine flow (recurring slope lineae, or RSL) maps to MEPAG Goals 1, 2, 4. This requires high resolution imaging to monitor RSL and other sites of surface change, and IR imaging spectroscopy to characterize hydration and compositional changes to assess possible modern habitats for life. Measuring winds and characterizing transport and other dynamic processes will help to understand current and past climates and to support entry, descent, and landing.

Benefits from simultaneous flight of all/most instruments: Though each of these measurements could be carried out individually on separate platforms, the impact of the combined measurements would provide insight that is greater than the sum of its parts, in large part because volatiles are time-varying. For example, thermal IR measurements would provide critical thermophysical characterization of the overburden, necessary for accurate retrieval of ice abundance and depth as radar is less sensitive to the upper cm's. For RSL, IR imaging spectroscopy combined with high resolution visible imaging is needed to assess the darkening mechanisms at RSL (wet/dry; salts present/absent) and track changes in near surface water vapor; imaging radar could be used to search for and track changes in adjacent ground ice / subsurface brines [1].

Integration with other Mars Exploration strategies: Lander/rover missions would benefit greatly from detailed contextual information, correlative stratigraphy, and atmospheric data from orbit. For example, detailed petrographic information or radiometric age dates from rovers/samples could be more widely applicable if linked to coeval units mapped from orbit [2]. Currently available data (or those that operating missions might yet acquire) are generally not adequate for the detailed context needed in this regard. In addition, planning for human exploration requires quantification of volatile reservoirs and hydrated mineral species at the scale of meters, especially for assessment of potential Special Regions [3].

Cross-cutting science and opportunities for discovery: The payload described above would also enable (a) increased data coverage of exposed rock stratigraphy and/or landforms for which presently, no high-spatial resolution compositional data (<18 m/pixel) exist, and (b) a new view of the Mars' shallow subsurface with the capability to map/discover buried landforms (e.g. deltas, fluvial units).

Information needed to mature this concept: The technology is mature enough for development to be incorporated on an orbiter in the near future [1]. The concept would benefit from a detailed analysis of science impacts/trades for implementation as a single orbiter for contemporaneous measurements envisioned by NEX-SAG vs. a smaller instrument suite or multiple orbiter implementation. Assessment of whether current data return capabilities are adequate to achieve the spatial coverage needed to meet the science objectives is also needed.

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CONSIDERATIONS OF SPATIAL DATA AND RELATED TECHNOLOGIES WHEN DISCUSSING SHORT- AND LONG-TERM EXPLORATION STRATEGIES OF MARS. J. A. Skinner, Jr. and T. M. Hare, Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: Planetary exploration cannot be efficiently planned for or executed without a coordinated mechanism that regularizes and promotes the acquisition, processing, distribution, use, maintenance, and preservation of spatial data. In short, successful exploration strategies cannot be developed without addressing data and access needs. Terrestrial spatial data is federally recognized as a national capital asset that includes coordinated management for reliable and easy access by scientists, policy-makers, and the general public [1]. Planetary spatial data is no different; it needs to be planned for and coordinated in order to efficiently achieve scientific and exploration goals. With respect to Mars, any consideration of current and future research and exploration is either implicitly or explicitly linked to the availability, co-registration, and interoperability of data. There is an abundance and diversity of data for Mars, which is an obvious boon for research and planning. However, there is potential for inefficiency in data use when there is a lack of coordination between how these data are acquired, processed, and disseminated. As a community, we need to ascertain if the requisite data products not only exist, but if they are also sufficiently coordinated to achieve the stated short- and long-term goals of MEPAG. Advisory groups should work closely together to make this determination.

MAPSIT is a community-based advisory group that is designed to help identify – and advocate the specific steps for closing – knowledge gaps with respect to spatial data products and (or) processes. MAPSIT advocates not only for foundational (*i.e.*, geodetic control, ortho imagery, elevation) and framework data products (*e.g.*, geology, composition, feature inventories), but also the technical capabilities and requirements that enable the creation, dissemination, use, interoperability, and preservation of that data [2]. Here, we aim to highlight considerations as well as start a dialogue regarding data-related knowledge gaps for Mars, which should be critically assessed in tandem with discussion on short- and long-term exploration strategies for Mars.

Data Coordination: Existing community advisory groups, like MEPAG, are best-suited to identify knowledge gaps for their particular body, region, or topic, including foundational data products that are required, priorities for the creation of framework products, and (or) the needed spatial accuracies and precisions to achieve the desired goals. MAPSIT compiles and advocates for the creation of the derived data products and any technical capabilities and requirements that support the use of this data. As such, MAPSIT will leverage existing strategic documents, to the extent possible. However, we identify a critical gap in the MEPAG Goals Document in that the objectives and investigations documented therein are not clearly linked to data and technologies that fundamentally enable these objectives and investigations to be addressed. For example, MEPAG states that co-analysis of data is valuable but does not report the data that needs to be co-analyzed or the relevant infrastructural details that enable co-analysis such as precision of registration (or the degree to which precision is analysis-dependent), cross-compatibility, error reporting, or preferred data formats. A spatial data infrastructure is more far-reaching than specific data products or the mode whereby such products can be accessed. A fully developed data infrastructure consists of coordinated access mechanisms, policies, standards, and users. For example, a body-specific infrastructure would include not only spatial data but also the mechanism for accessing data, the standards that support interoperability between datasets, the policies that define the data standards, and the community who use the data [2]. The MarsGIS initiative is an example of a body-specific spatial data infrastructure that is being developed to support both landing site analysis and eventual human operation on Mars [3].

Recommendation: When preparing for the next Planetary Science Decadal Survey, the community should not only identify specific objectives, goals, and investigations but also consider what data products are required to address these objectives, goals, and investigations as well as the details that surround the creation, dissemination, use, and preservation of these data. Consideration of high-level science objectives, specific types of observations/measurements/analyses, and science and technology strategies all fundamentally rely on data products and the pipelines that create and disseminate those products. We advise MEPAG to create a traceability matrix (or similar) that clearly links goals to current and (or) future data products, spatial accuracy and resolution of those products, and the means by which those data products should be accessed and integrated.

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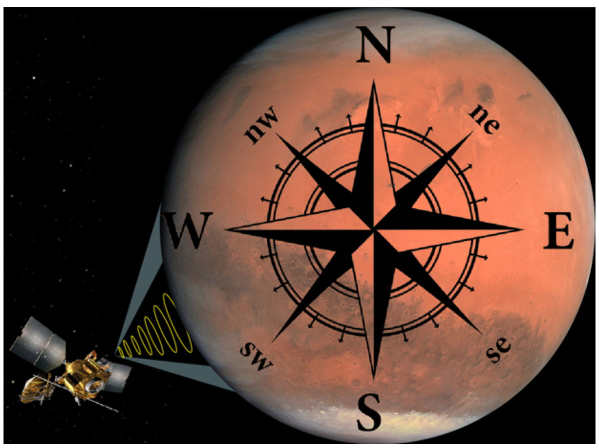
COMPASS: CLIMATE ORBITER FOR MARS POLAR ATMOSPHERIC AND SUBSURFACE SCIENCE. I. B. Smith[1], S. Byrne[2], P. O. Hayne[3], [1]Planetary Science Institute, Lakewood, CO. [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. [3]University of Colorado, Boulder, CO. contact: ibsmith@psi.edu

Motivation: Climate change on terrestrial planets is perhaps the most pressing scientific issue of our day, and its study is of broad significance. Mars' continuously varying orbital elements lead to climatic variations that (like on Earth) redistribute ices and affect seasonal volatile cycles. Mars' climate represents a simplified version of Earth's in that it lacks oceans, life, thick cloud cover and human activity. Understanding today's martian climate and the distribution of ice and other volatiles is paramount to determining the history of climate on Mars.

Mars' atmosphere regularly cycles water vapor, water ice, carbon dioxide, dust, and other aerosols around the planet [1,2]. Ice and dust reservoirs that interact with the atmosphere on different timescales are distributed from the poles to more-accessible mid-latitude locations [3-5].



The COMPASS payload quantifies today's climatic processes and provides the required datasets to satisfy long-standing goals in Mars science. Modeling efforts to understand global, regional, and local circulations require input from detailed, global atmospheric observations. Those models are increasingly deployed for past climatic states, making it critically important to have robust observations of the present state for validation. Future investigations may attempt to extract historical climate by sampling the polar layered deposits, but those investigations must understand present day processes to extrapolate backwards in time.

Science Benefits: In a summary of the 6th International Conference on Mars Polar Science and Exploration, a group of attendees listed the high priority science goals for the Mars polar community [6]. The COMPASS mission concept addresses many of these goals directly (highest ranked goals).

- *Determine the energy and mass balance of the polar ice reservoirs, and characterize volatile fluxes*
- *Inventory and characterize the non-polar ices/volatile reservoirs at the surface and near-surface*
- *Quantify the interplay of local, regional, and global circulations in the polar regions, including polar vortex, katabatic winds, transient eddies, among others*
- *Characterize the transport of volatiles and dust aerosols into and out of the polar regions*

Implementation: COMPASS is a Mars orbiting mission that has the dual goals of investigating the current climate and the climatic record of the Polar Layered Deposits and other icy deposits.

The COMPASS mission concept performs orbital observations of atmospheric transport and constituents by tracking water vapor, water-ice, dust, and storms in time and space. A microwave sounder measures 3D global wind speeds and tracks transport of D/H, ozone, and carbon monoxide, all important tracers of atmospheric activity and interaction with major reservoirs. An advanced Mars Climate Sounder quantifies the 3D distribution of aerosols and the P/T structure of the atmosphere. An advanced Mars Color Imager, places these detailed 3D measurements in the context of daily global imagery and tracks changes in surface dust reservoirs.

To quantify past climates through mapping icy deposits in 3D at the poles and buried in the mid-latitudes COMPASS uses a dual-purpose radar with a sounder and a polarized synthetic aperture mode (SAR). Polarization aids in near-surface (<1 m) ice detection. A sounding mode is similar to the Shallow Radar (SHARAD) on Mars Reconnaissance Orbiter (MRO) but with higher gain and bandwidth, giving finer vertical resolution and greater penetration. A high gain antenna (parabolic or phased array) that serves both the SAR and sounder can be articulated or phase shifted depending on the mode required.

Power, mass, and volume meet requirements of Discovery, and cost can be met by a contribution of one instrument by an international partner.

Acknowledgements: A 2017 Keck Institute for Space Studies study on Mars polar exploration, led by these three authors, brought together >30 experts to determine required measurements and mission concepts to accomplish several goals related to understanding Mars' current and past climate. We report on an orbital mission that reflects the study's findings.

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The 6th International Conference on Mars Polar Science and Exploration: State of knowledge and Top Five Questions. I. B. Smith[1] S. Diniega[2], D. W. Beaty[2], T. Thorsteinsson[3], P. Becerra[4,5], A. M. Bramson[5], S. M. Clifford[6], C. S. Hvidberg[7], G. Portyankina[8], S. Piqueux[1], A. Spiga[9], T. N. Titus[10]. [1]Planetary Science Institute, Lakewood, CO; [2]Jet Propulsion Laboratory/California Institute of Technology; [3]Icelandic Meteorological Office, Reykjavík, Iceland; [4]Phisikalisches Institut, Universität Bern, Bern, Switzerland; [5]Lunar and Planetary Laboratory, University of Arizona; [6]Lunar and Planetary Institute, Houston, TX; [7]Niels Bohr Institute, University of Copenhagen; [8]Laboratory for Atmospheric and Space Physics, University of Colorado; [9]LMD, Université Pierre et Marie Curie, Paris, France; [10]U.S. Geological Survey, Flagstaff, AZ. Contact: ibsmith@psi.edu

Introduction: Mars' polar regions are of special interest to scientists of diverse scientific backgrounds. Unique atmospheric processes have caused large amounts of ice and volatiles to be deposited at the poles, and periodically at lower latitudes. The ice units are geological deposits that are intimately connected to the atmosphere and record climate variations. Thus, this geologic record can only be interpreted in the context of the climate conditions that formed it. In this sense, Mars polar science is uniquely multi-disciplinary, and for the last two decades, the Mars polar science community has benefitted from periodic International Conferences of Mars Polar Science and Exploration (ICMPSE), the most recent of which was held in Reykjavik, Iceland in September, 2016.

The International Conference on Mars Polar Science and Exploration (ICMPSE) has been held six times since 1998, a period of 20 years [1-5].

6th Conference: To discuss observations and interpretations since the 5th ICMPSE in 2011 [5], more than 100 attendees from eleven countries attended the 6th iteration. Nearly a quarter of the Mars polar conference attendees (22) were students, which shows that the field and its many new, exciting discoveries, are attracting new researchers. Institutional support was provided by the NASA Mars Program Office, the European Geophysical Union, and the International Association of Cryospheric Sciences, with additional support coming from the Icelandic Meteorological Office, Planetary Science Institute, and the University of Iceland in Reykjavik.

Presentations highlighted a number of new and exciting results. Researchers found evidence for active atmospheric and surface processes that shape the polar layered deposits (PLD) and nearby landforms. The periodic layering of water ice and dust in the north and south PLDs (as well as CO_2 layering in the south) are being used to constrain the history of accumulation at the poles and to invert for climate records. Finally, ongoing geomorphic activity points to widespread volatile transport between the mid-latitudes and the poles, a process that modifies the surface of sand dunes, gullies, and landforms particular to carbon dioxide frost, such as spiders.

In addition to the oral and poster plenary technical sessions, a total of seven field trip were available to participants and guests. There was widespread participation in visiting the outstanding Mars glacial and volcanic analog sites that Iceland has to offer.

The conference was organized with the goal of enumerating the most important outstanding scientific questions for Mars polar science, and a team of synthesizers collected points of interest from the discussions. Five major questions were defined (no priority order):

1). Polar Atmosphere: What are the dynamical and physical atmospheric processes at various spatial and temporal scales in the polar regions, and how do they contribute to the global cycle of volatiles and dust?

2). Perennial Polar Ices: What do characteristics of the Martian polar ice deposits reveal about their formation and evolution?

3). Climate Record: How has the Martian (polar) climate evolved through geologic history, and what is its connection to Mars' astronomical parameters? What are the absolute ages of strata in the observable climate record?

4). Non-polar Ice: What is the history and present state of the mid- and low-latitude volatile reservoirs?

5). Present-day Surface Activity: What are the roles of volatiles and dust in surface processes actively shaping the present polar regions of Mars?

These top questions are mapped into sub-questions that more directly highlight the most pressing directions of investigation for the near-future.

Acknowledgements: The authors wish to thank the participants of the 6th International Conference on Mars Polar Science and Exploration for an incredible learning experience and for the stimulating discussions, both in the conference setting and in the field, which led to the formulation of these key questions. NASA support for DWB, SP, and SD is acknowledged. CNES support for AS is acknowledged. Conference web support and overall planning were supported by the expert staff at the Lunar and Planetary Institute, Houston, TX. We are also exceedingly appreciative to the University of Iceland and Rector Benediktsson for contributing the beautiful Ceremonial Hall, where the oral sessions were held. This support made the conference much more affordable for all who attended.

To view the full conference program and abstracts, visit: http://www.hou.usra.edu/meetings/marspolar2016/

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MarsDrop: Getting Miniature Instruments to the Surface of Mars as Secondary Payloads.

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Small (~1 kg) instrument payloads could be carried to Mars' surface utilizing the MarsDrop delivery system, based on an architecture that takes advantage of the extra cruise stage mass capability available on most Mars missions[1].

From canyons to glaciers, from geology to astrobiology, the amount of exciting surface science awaiting us at Mars greatly outstrips the available mission opportunities. Whether from the destination risks or just from the significant expense of a traditional Mars lander, the majority of proposed scientific surface missions are eliminated from consideration. By utilizing The Aerospace Corporation's Reentry Breakup Recorder (REBR) entry system already proven at Earth with entry velocities greater than for Mars missions, and adding a parawing for descent and landing that has been tested above the Earth's stratosphere at Mars dynamic pressure and density, a 3 kg entry vehicle can deliver small instruments to targeted locations. Such a vehicle could be accommodated on direct-entry Mars missions for <10 - 20 kg total mass allocation per MarsDrop secondary lander, including the attachment/jettison equipment on the primary cruise stage or launch vehicle upper stage. Depending on orbital parameters, similar mass allocations could accommodate such secondary landers on missions where an orbiter is the primary spacecraft.

CubeSat and SmallSat-class componentry, such as that utilized for JPL's Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment (INSPIRE)[2], Mars CubeSat One (MarCO)[3], and other sources, would provide the needed electrical power, computing, and telecommunications resources to enable surface operations for 90 sols, and potentially much longer.

MarsDrop's small size could enable sterilization of its components, sterile assembly, and encapsulation in a sterile plastic shrink-wrap bag for ground handling. This bio-barrier bag would later burn off during hypersonic Mars entry. As a result, "special regions" on Mars, where the presence of part-time liquid water is possible, could be feasible targets within NASA planetary protection guidelines.

Information about the MarsDrop concept is pre-decisional and is presented for planning and discussion purposes only.

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[2] Klesh A. T. & Halatek L. (2014), *International Astronautical Congress*, Toronto, IAC1-14.B4.8.1.

[3] Klesh A. T. & Krajewski J. A. (2016) "MarCO – Ready for Launch" *CubeSat Developers Workshop*, California Polytechnic University-San Luis Obispo. 2016/4/21.

Considerations Related to Planning for the Exploration of the Martian Subsurface

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The Martian subsurface is of enormous interest for astrobiology, geochemistry, climatology, and In Situ Resource Utilization (ISRU) objectives, which cannot be addressed with surface missions alone. Specifically, subsurface data are needed to continue the search for extinct of extant life started by the Viking landers more than forty years ago and to prepare for human exploration. If Mars ever had life, whether it emerged on or below the surface, then as the atmosphere thinned and global temperatures dropped [1], life may have followed the groundwater table to progressively greater depths where stable liquid water could persist. At such depths, life could have been sustained by hydrothermal activity and rock-water reactions. Hence, the subsurface likely represents the longest-lived habitable environment on Mars. Moreover, while the preservation of ancient molecular biosignatures on Mars is debated, the consensus is that detection at depths greater than a few meters is favored because of the shielding from harmful radiation [e.g., 2, 3] and the possibility to preserve water/ice resources.

On one hand, if Mars hosts extant life, then the most likely place to find evidence of it may well be at depths of a few hundred meters to many kilometers, where groundwater may persist depending on local geothermal gradient [e.g., 4, 5]. On the other hand, we also face today the need to determine the presence and accessibility of resources for potential use (ISRU) and hazards to human health within the Martian subsurface, as part of the process of planning future human missions to the Red Planet.

The need to explore the Martian subsurface for astrobiology/science and resource purposes, with the support of national space agencies, academia, and the commercial sector has motivated a Keck Institute of Space Studies workshop titled "*MarsX: Mars Subsurface Exploration for Life and Resources*", held Feb. 12-16, 2018 in Pasadena, CA, with participants from NASA, JPL, ESA, SpaceX, Schlumberger, Honeybee Robotics, and various universities and research institutes.

The goal of the workshop team was to identify astrobiologically and resource-related (a) scientific measurements, instruments, and technologies, and (b) mission concepts and strategies that enable chemical characterization, mapping, and ground-truthing of subsurface volatiles, focusing on H_2O, and the overburden across multiple spatial scales, from meters to multiple kilometers.

Here, we report the outcome of this workshop, focusing on key subsurface measurements and regions of interest, the feasibility of needed exploration technologies (drilling, sounding, analytic tools, and others), and goal-oriented mission ideas to chart a roadmap for Mars subsurface access as it applies to the search for life and resources.

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A Discovery-class Mars Climate Mission.

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Science Motivation:

The Mars Exploration Program Analysis Group (MEPAG [1]) and other NASA committees (e.g., the Next Orbiter Science Analysis Group [NEX-SAG; 2]) have cited high-priority science knowledge gaps related to understanding the current Martian climate and weather. Understanding weather and climate drivers, general behavior, stability and history could be improved through a combination of high-TRL existing instruments, flown together on a focused mission or as part of a larger mission architecture. The information gained would provide insight into past climate and be useful for future robotic and human exploration needs as well.

Fortunately, Mars research has benefitted from several orbiting spacecraft that have characterized the Martian atmosphere fairly well in terms of temperature, pressure, dust and ice aerosols, and column water vapor amount. Additionally, the ExoMars Trace Gas Orbiter will measure profiles of the abundance of many key trace gases, and MAVEN is studying the upper atmosphere and its interaction with the space environment.

However, water vapor and wind vertical profiles are very limited, and existing temperature retrievals can be hindered by large amounts of aerosols [3]. Water vapor vertical distributions are important for understanding water cycling between ice and sub-surface reservoirs. Further, water vapor profiles along with simultaneous temperature profiles, even in the presence of dust and ice, are critical to understand cloud formation which has a surprisingly large radiative impact on the atmosphere[4]. Winds are almost completely unmeasured, yet are critical for understanding fundamental Martian processes driving the dust and water cycles. In addition, winds are desired for safe landing of robotic and human spacecraft. In lieu of actual measurements, global circulation model output is often used to aid in spacecraft and mission design, but the models are largely unvalidated against winds. Finally, measurements of T, aerosol and water vapor are needed simultaneously with wind measurements, to fully understand the impact of thermal forcing on wind, and the consequences for transport, as presented in A finding of the NEX-SAG: *"Observation of wind velocity is the single most valuable new measurement that can be made to advance knowledge of atmospheric dynamic processes. Near-simultaneous observations of atmospheric wind velocities, temperatures, aerosols, & water vapor with global coverage are required to properly understand the complex interactions that define the current climate."*

In order to obtain these measurements, we propose a Mars Climate Mission concept, that would include at a minimum three instruments: a sub-mm sounder, a thermal infrared profiler, and a wide-angle camera.

Instrumentation Concept:

A passive sub-mm limb sounding instrument is ideally suited to provide the needed wind, water vapor, and temperature profile measurements. The technique has high heritage in Earth-science, and dramatic advances in associated technology in the past decade (driven in part by the communications industry) enable significant reductions in needed power, mass and complexity. Such an instrument can make measurements both day and night, and in the presence of atmospheric dust loading, measuring between 0–80 km, at ~5 km vertical resolution[5]. To measure the vertical distribution of dust and water-ice aerosols in the atmosphere, a thermal IR profiler similar to the MCS aboard MRO [6] would be ideal and would also provide additional temperature and water vapor measurements to those from the sub-mm instrument, meausured over a similar altitude range with comparable vertical resolution, both day and night. Finally, a wide-angle camera similar to MARCI [7] would facilitate placement of the other measurements into the big picture of weather patterns seen via global maps. Such a payload would likely be in the 40 kg and $55M range and high TRL. An enhancement would be to add a Doppler lidar for higher vertical resolution wind information.

Mission Concept:

This instrument payload could fly on a chemical or solar-electric propulsion system or could be a subset of a larger payload. Ideally it would orbit Mars for at least 1 Mars year. A solar electric propulsion option would allow the orbit to be changed to one that precesses such that multiple local times are sampled over the course of several 10s of sols.

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A Sub-millimeter sounder for vertically measuring Mars winds, water vapor, and temperature.

L. K. Tamppari[1], N. J. Livesey[1], W. G. Read[1], G. Chaottopadhyay[1], R. T. Clancy[2], F. Forget[3], P. Hartogh[4], S. C. R. Rafkin[5], D. Banfield.[6] [1]Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA (leslie.tamppari@jpl.nasa.gov), [2]Space Science Institute, [3]Laboratoire de Météorologie Dynamique du CNRS, Université Paris, [4] Max-Planck-Institut für Sonnensystemforschung. [6]Cornell University, Ithaca, NY.

Introduction: The vertical water vapor and winds on Mars are not well known, yet are critical for understanding fundamental Martian processes and for ensuring safe landing of robotic and human spacecraft.

NASA's Next Orbiter Science Analysis Group [NEX-SAG; 1] recognized the need for these measurements and envisioned a sub-mm instrument aboard a possible Mars orbiter launced in 2022. One of the five compelling science objectives noted was to *"Measure winds and characterize transport and other dynamic processes to understand current climate, water, and dust cycles, with extrapolation to past climates"* and a Finding was *"Observation of wind velocity is the single most valuable new measurement that can be made to advance knowledge of atmospheric dynamic processes. Near-simultaneous observations of atmospheric wind velocities, temperatures, aerosols, and water vapor with global coverage are required to properly understand the complex interactions that define the current climate."*

The various Mars orbiting spacecraft that have been flown to date have characterized the Martian atmosphere fairly well in terms of temperature, pressure, dust and ice aerosols, and column water vapor amount. The ExoMars Trace Gas Orbiter will measure profiles of the abundance of many key trace gases, and MAVEN is studying the upper atmosphere and its interaction with the space environment.

However, measurements of T, aerosol and water vapor are needed simultaneously with wind measurements, to fully understand the impact of thermal forcing on wind, and the consequences for transport.

Sub-millimeter Instrument Design Concept: A passive sub-mm limb sounding instrument is ideally suited to provide the needed wind, water vapor, and temperature profile measurements. The technique has high heritage in Earth-science, and dramatic advances in associated technology in the past decade (driven in part by the communications industry) enable significant reductions in needed power, mass and complexity. Such an instrument can make measurements both day and night, and in the presence of atmospheric dust loading. Our instrument design will be optimized to sample winds, temperature, and water vapor between 0–80 km, at ~5 km vertical resolution.

Our concept [2] for such an instrument builds on prior JPL-led instruments such as the Microwave Limb Sounder currently flying on EOS *Aura* [3], and the MIRO instrument aboard *Rosetta* [4]. The instrument would employ a single, steerable antenna (~23 cm diameter), and observe a diverse set of spectral lines, both weak and strong, from multiple species to cover the full range of altitude desired (Fig. 1).

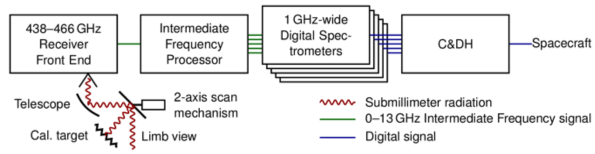

Figure 1: Block diagram of instrument

Performance Analysis. Initial simulations have been undertaken to show performance of our notional sub-mm sounder (Fig. 3). These simulations employed algorithms and software developed for Aura MLS (suitably adapted to the Martian atmosphere) to model performance of the instrument under conditions taken from the Mars Climate Database.

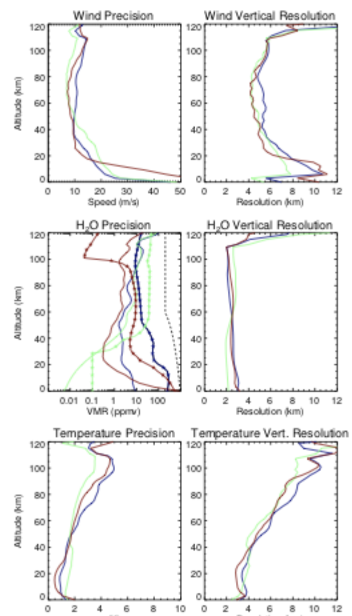

Figure 2: Precision and vertical resolution for a variety of frequencies for wind speed (top), water vapor (middle), and temperature (bottom).

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MARS MISSION CONCEPT: MARS ICE CONDENSATION AND DENSITY ORBITER.

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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; however, no other landed mission has probed the Martian high latitudes and polar regions.

This abstract will focus on polar processes and describes a set of investigations that will be crucial to fully unravel 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, enabling CO_2 ice grain size and H_2O ice and dust contamination to be constrained. Surface compositional information has been gleaned from visible, near infrared, and short –wave infrared imaging and spectroscopy. However, these instruments depend on reflected solar light and are accordingly useless 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 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, can be used to constrain the seasonal cap bulk density, but not local variations related to accumulation modes or temporal changes in density, porosity, and grain size [1-3].

Neutron and gamma ray observations have provided another method to determine the cap mass and distribution of CO_2 on broad spatial scales (of a few hundred square kilometers) [4].

Composition, Density, & Condensation Modes: The CO_2 ice that forms in the polar night is mostly CO_2 ice with small amounts of dust and H_2O. It is possible that a layer of H_2O ice may exist as a bottom layer since the surface will reach the freezing temperature of H_2O before it reaches that of CO_2. The seasonal CO_2 may also have density gradient as the two accumulation modes, direct condensation and snowfall, are superimposed. Additionally, the sintering process may cause surface ice-grain sizes to increase [5-7].

CO_2 Accumulation Modes: What is the nature of CO_2 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 CO_2 precipitation (snow).

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

CO_2 Ice Density: What are the densities, column abundances and areal coverage of the CO_2 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 10º of L_s.

Investigation: Measure the column mass abundance of the CO_2 ice in the seasonal polar caps with accuracy of 50 kg/m^2 sampled at approximately every 10º of L_s.

Mission Concept: The key instrument to these investigations, which has yet to fly to Mars, is an imaging LIDAR system that is sensitive to (and can differentiate between) CO_2 and H_2O ice [8]. 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. Interferometric synthetic-aperture radar could also monitor ice thickness and possible changes in ice properties. A thermal neutron imaging system could directly monitor ice column abundance. A thermal emission spectrometer or bolometer could indirectly derive column abundance and grain sizes.

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

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NOW YOU HAVE IT, WHAT DO YOU DO WITH IT? A MISSION TO A RETURNED MARS SAMPLE.

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Introduction: Given the planned launch by NASA of a sample-caching rover in 2020, and with serious discussion by an international consortium of completing the Mars sample-return in subsequent launch opportunities, it is time to begin serious definition and development focused on the analysis, containment, and protection of that sample. Given the long lead times involved in providing for such a "mission," it is imperative that preparations for handling a Mars sample begin soon.

NASA has long been committed to following the recommendations of the Space Studies Board (SSB) in its reports on sample handling and testing [1, 2], many of which are now reflected in the COSPAR Planetary Protection Policy [3]. In particular, the 1997 SSB study *Mars Sample Return: Issues and Recommendations* [1], recommended that: 1) "samples returned from Mars by spacecraft should be contained and treated as potentially hazardous until proven otherwise," and 2) until "rigorous physical, chemical, and biological analyses confirm that there is no indication of the presence of any exogenous biological entity."

"Testing" is Required: In the late 1990s the development of a protocol to support the analysis of the samples in a containment facility was begun by NASA in cooperation with CNES. The result was a "Draft Test Protocol" (DTP) that outlined requirements "for the safe receiving, handling, testing, distributing, and archiving of martian materials here on Earth" [4]. The DTP addressed, in a comprehensive fashion, aspects of sample handling and testing, as well as physical-chemical analyses and curation considerations for untested portions of the samples, to ensure that controlled distribution of the samples outside of containment could be accomplished after the requirements of the DTP are met.

Subsequent to the completion of the initial version of the DTP a stringent review and revision process took place, with a blue-ribbon review (Chaired by Joshua Lederberg of Rockefeller U. and Lynn Goldman of Johns Hopkins U.). After review and further revisions, the "Final" version of the DTP published in October 2002, represented a consensus understanding of what is required to meet planetary protection requirements for a Mars sample return mission. Among other things, the review of the DTP noted that there were aspects of Mars sample testing that would require dedicating portions of the sample to biohazard testing, as no amount of theoretical "analysis," if unsupported by actual physical, chemical, and biological tests, would suffice—and even then, a strong case would need to be made with the regulatory agencies to tie tests on one portion of the sample to the safety of the remaining portions.

What Has Changed? There have been numerous improvements and updates to the study of biology and extraterrestrial samples in the 15 years since it was published [e.g., 5], supported by several focused activities and studies that have occurred since the DTP was published [e.g., 6]. In particular, there has been an increased realization that a broad commonality exists between the physical and chemical analyses required to complete a biohazard and life-detection protocol and those necessary for an "early" characterization of returned martian samples. This has the potential to conserve a larger proportion of Mars material than would be possible if the two activities were not linked.

Now is the Time: The current notional timeline discussed by NASA for a Mars sample return mission could bring a sample back to Earth as early as 2029 [7]. Based on the recommendations of the DTP [4], and the SSB [1, 2] the planning for a Mars sample receiving facility (SRF) should therefore be started in 2018, or as stated in [2], "in the earliest phases of the Mars sample return mission." Such planning can refresh and broaden the participant base, make specific improvements to the existing DTP, and update it to reflect current analytical and biological research, while including early science and opportunities, such as advanced robotics, for a more effective and less contaminating protocol execution.

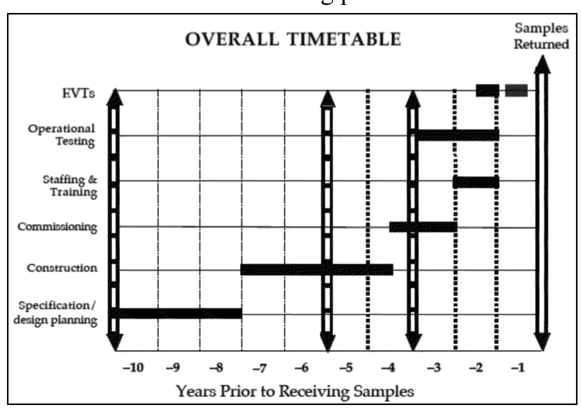

Fig. 1: A timetable for a Mars sample analysis "mission."

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THE FUTURE OF MRO/HIRISE.

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Introduction: The High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaisance Orbiter (MRO) has been orbiting Mars since 2006. The nominal mission ended in 2010, but MRO has continued science and relay operations, now in its 4th extended mission. Both the spacecraft and instrument have experienced a variety of anomalies and degradation over time. This presentation describes the accomplishements to date of HiRISE and prospects for the future, with perhaps another decade of imaging.

HiRISE obtains the highest-resolution orbital images of Mars, ranging from 25-35 cm/pixel scale. To acquire such images with a high signal:noise ratio (SNR), HiRISE uses time delay integration (TDI), imaging each patch of ground up to 128 times and summing the signal. Producing sharp images over such a small instantaneous field of view (~1 microradian/pixel) and with 128 TDI lines requires very stable pointing from the spacecraft. HiRISE has 14 CCD detectors: 10 in a broad-band (RED) channel that cover the ~5-6 km wide image swath, plus 2 with a blue-green (BG) filter and 2 with a near-infrared (NIR) filter, producing 3-color imaging in a narrow central swath of each image.

HiRISE Accomplishments: HiRISE has returned over 53,000 large (~giga-pixel) images of Mars, covering a total of 3% of the martian surface if all coverage was unique. HiRISE data have been used to find the best landing sites for multiple landers and rovers. Over 5,400 stereo pairs have been acquired, with over 500 full-resolution digital terrain models (DTMs) produced and archived (https://www.uahirise.org/dtm/). More than 1,300 peer-reviewed publications with "HiRISE" and "Mars" are found by the NASA ADS full-text search.

HiRISE image anomalies:

1. The electronics supporting RED9 was lost in 2011, narrowing the swath width by 10%. Fortunately there have been no further electronics failures to date, but this remains a distinct possibility in the future.

2. Soon after launch we discovered bit flips in some image channels. This problem has affected more and more image channels (each CCD has 2 readout channels). Fortunately we can mitigate this problem by warming the focal plane electronics (FPE) prior to Mars imaging, but this results in shorter images. Early images had up to 120,000 lines at full resolution (no pixel binning), the maximum now is near 50,000 lines (or 150,000 lines with 2x2 binning).

3. The percentage of images with noticeable blur (0.3-1.5 pixels) was up to about 75% of full-resolution images near the end of 2017 (at apoapsis), but has since dropped to <20%. This and other data make it clear that the blur is due to temperature fluctuations in the secondary mirror assembly, related to apoapsis and steps taken to prolong MRO spacecraft battery life. We expect to eliminate this problem via revised thermal control settings.

MRO orbit expectations: MRO has been in a sun-synchronous (nearly polar) orbit at close to 3 PM Local Mean Solar Time (LMST), which is usually close to ideal for imaging the surface because the illumination angle accentuates topography while still providing ample signal for high SNR. However, MRO's batteries are gradually losing capacity. To attempt to keep MRO functioning for another decade, a number of changes are being made to prolong battery life, including a plan to move to a later LMST (near 4:30 PM) after the Mars2020 rover landing (Feb. 2021). This later time of day reduces the duration of eclipses, when the solar arrays are not illuminated and battery power must be used.

The change to 4:30 PM LMST will provide several disadvantages and one advantage to HiRISE science. First, it complicates change detection because we cannot re-image with similar lighting conditions. Second, it limits the latitude range of useful imaging within each season, reducing the seasonal range for monitoring polar processes. Third, it means that stereo pairs must be completed more rapidly to avoid large changes in shadow lengths and positions, although this could be operationally mitigated. An advantage is that relatively flat equatorial regions are better imaged later in the day, to accentuate subtle topographic shading.

Future HiRISE images: Expect more binned images due to the later LMST with lower brightness levels. However, we can cover four times as much of Mars with bin-2 images, and ~0.6 cm/pixel remains better than any other orbital imaging of Mars. There will still be many opportunities for high-quality, full-resolution images.

HiRISE-2? HiRISE-class imaging is highly recommended in a study of the next Mars orbiter (https://mepag.jpl.nasa.gov/reports.cfm). Extending the high-resolution mapping and monitoring has great scientific value and is essential for landing sites. Advances in detector and electronics technologies since 2002 would lead to significantly improved images.

MARTIAN SUBSURFACE ICE SCIENCE INVESTIGATION WITH A SPECIAL REGIONS DRILL.

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Introduction: Subsurface water ice is a fundamental unexplored record of Mars that is expected to provide key insights into past and present near-surfaces processes that influence both surface and atmospheric conditions on regional to planetary scales. Such science investigations will access, sample, and measure the physical and chemical conditions of the subsurface, will yield significant science returns and would address questions that are not possible with surface investigations. We propose an astrobiology mission concept that aims for due diligence in the search for extant life on Mars [1].

Importantly, subsurface ice is an accessible, possible abode for extant life on Mars. It has been a target for exploration by astrobiologists for decades. In situ, robotic access to pristine subsurface ice will enable evaluation of its indigenous biological potential before human presence.

Drilling: In order to drill subsurface ice and support science measurements, we need to know where ice is accessible at scales relevant to sampling (less than or equal to 1 m resolution) before drilling. Doing so, mitigates the risk of dry holes. Accessible-ice mapping might be accomplished by remote and/or in situ prospecting. Further, drilling must be robotic because a direct human presence would pose an inadvertent and high contamination risk to science [2]. Drilling could be accomplished with an auger-type drill that provides sample "bites" for science measurements. As such, coring would not be required to meet science requirements. Auger drilling is a well-established technology for applications on Earth. ESA's ExoMars 2020 rover will be the first spacecraft to drill the subsurface on Mars.

During subsurface ice drilling, some ice is expected to melt. As a consequence, drilling will create a "spacecraft-induced Special Region". The drill will be a Special Regions drill, which means it would need to meet requirements for a planetary protection category IVc mission; however, any intent to search for life signature in borehole samples would heighten the mission classification to category IVb. Both planetary protection requirements and science integrity will demand a high level of bioburden and biomolecular contamination control.

A mission requirement would be to confirm the distribution and nature (massive ice, ice cement, or mineral hydration) of subsurface water in collected samples as compared to that detected by remote or prospecting instruments. Doing so will support modeling that may extend science insights into climatic and geohydrologic processes.

Science Requirements: The prime science goal of an astrobiology mission targeting subsurface ice would be to search for signs of life, particularly extant life (or cryogenically, well-preserved ancient life). Multiple and independent measurement types are needed for determination of whether life is present. A second objection, assuming life presence is indicated, would be to test if it has Earth-like biochemistry. Other objectives strive to build an understanding of subsurface ice habitability or ecology and they include measurements of general oxidant, organic, and solution (pH, eH, δD, $\delta^{18}O$, ions) chemistry, and perhaps bioavailable elements (CHNOPS, metals) and radioactive isotopes for dating materials and processes.

Samples for in situ measurements must include samples below tolerable radiation dose rates for Earth-like organisms, i.e., below the "critical depth" (CD), currently assessed at 1.5-2.5 m depending on model variables [3-5]. The threshold mission requires 2 drill holes at a single sampling location, 4-6 samples per hole, with at least one sample per hole from below the CD. The baseline mission requires 2-3 drill holes from each of 2-3 geological sampling locations, 8-12 samples per hole, with at least two samples per hole from at or below the CD.

The mission concept presented here is motivated by science interests but such an investigation would also support objectives to determine resource availability and hazards for humans.

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PLANETARY PROTECTION OBJECTIVES FOR MARS MISSION CONCEPTS OF THE NEXT DECADE.

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Introduction:

How will planetary protection be implemented once humans arrive at Mars? The international consensus policy on planetary protection [1] has provided a framework under which, based on best available scientific data, Mars has been protected against "*harmful contamination*" by terrestrial biota, as required under the terms of the 1967 Outer Space Treaty [2].

For robotic missions, this has been achieved by managing the viable microbial burden flown to Mars on spacecraft hardware, to limit the possibility that a terrestrial organism will be transported to a martian environment where it can replicate. However, studies have determined [e.g., 3] that this paradigm is unsustainable in the context of the crewed exploration of Mars: Current technology does not allow complete isolation between a crewed habitat on Mars and the martian environment. But the policy does not suggest that control of microbial contamination should be discontinued at the start of crewed exploration. On the contrary, the policy states: "*The intent of this planetary protection policy is the same whether a mission to Mars is conducted robotically or with human explorers. Accordingly, planetary protection goals should not be relaxed to accommodate a human mission to Mars. Rather, they become even more directly relevant to such missions—even if specific implementation requirements must differ*" [1].

Path Forward:

So how will the "*specific implementation requirements*" needed to protect future exploration be determined? Data and findings from Mars missions in the 2020s will be critical in providing the foundational information for design and operation of crewed missions to the surface planned for the 2030s, including the planetary protection aspects.

An incremental evaluation and development of requirements specific to crewed exploration is under way within the international scientific community. Hogan *et al.* [4] proposed a concept for establishing zones where terrestrial contamination could be managed with different levels of rigor, according to perceived threat of harmful contamination. However, there are gaps in our knowledge of Mars that would allow us to define zone boundaries and scale. These knowledge gaps were discussed at a 2015 NASA workshop [5,6].

For example, intrinsic to the safe delivery and return of astronauts from Mars (while at the same time avoiding the harmful contamination of the planet based on "zoning") is an increased understanding of the interaction of terrestrial biology with the martian environment. This includes, for example, a better understanding of the fate and effect of viable terrestrial microorganisms released deliberately or accidentally into the martian environment, as well as the effect on astronauts of exposure to martian material.

The knowledge gaps identified in the 2015 workshop were refined and prioritized at a COSPAR workshop in 2016 [7] and a future workshop [8] is planned to identify instrument and measurement capabilities needed to address and close the high priority knowledge gaps.

Conclusion:

Measurements that are needed for development of planetary protection requirements for crewed missions are synergistic with the overall scientific goals of understanding Mars' habitability, climate processes and geology. However, care needs to be taken by space agencies to ensure the instruments flown are capable of making measurements at the level of resolution needed for planetary protection purposes as well as for acquisition of new scientific understanding.

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