LOW-COST MARS IN-SITU ASTROBIOLOGY MEASUREMENTS AND STRATEGY.

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Introduction: Identifying evidence of Martian life would revolutionize our understanding of biological processes and predictions about the likelihood of life elsewhere. Of all Solar System bodies, Mars remains a primary life-detection target because conditions during its first 500 million years resembled those on Earth when early life emerged [1]. The search for life on Mars should include identifying preserved remains of ancient life from this more habitable epoch in Martian history relative to today, as well as searching for evidence of potential modern survivors that could have found refuge in locations with available liquid water and protection from the harsh surface environment [2].

Low-Cost Astrobiology Mission Motivation & Potential Objectives: Low-cost astrobiology missions to Mars could search for indicators of extant organisms or preserved remains of ancient organisms and help improve our understanding of the modern habitability of Mars with a relatively simple and complementary set of analytical instrumentation. With lower-cost, smaller-size payloads, multiple high-priority astrobiology landing sites could be explored per mission with a distributed network [3]. Measurements made with low-cost instruments would be unlikely to provide conclusive evidence of life but could help determine which regions should be further investigated with follow-on missions (including human missions), either with more comprehensive in-situ instrumentation or sample-return. This mode of Mars exploration would represent a shift in the current paradigm away from site selection relying primarily on remote sensing to be more like the iterative exploration used in astrobiologically significant environments on Earth. In-situ screening of multiple candidate landing sites for organic content, geochemistry, and mineralogy would increase probability of life detection by prioritizing sites for resource-intensive, more-conclusive analyses. Low-cost surface networks would increase reconnaissance of organic matter as direct sample contact is required for the most definitive detection of organics.

Potential objectives for a low-cost Mars astrobiology mission include:

(O1) Determine the variability of astrobiologically-relevant gases at the surface. Methane is a primary astrobiology gas target [4], as well as other gases such as small hydrocarbons, water, hydrogen, and carbon dioxide. These gases could indicate the metabolic activity of an extant population, a reservoir of stored organics (*biotic or abiotic in origin*) undergoing thermogenic alteration, or abiotic reactions occurring (*e.g., via Fischer-Tropsch chemistry*) [5]. Trace gases could be detected through measurements made at the surface after disruption of regolith (e.g. impact or drilling plus thermal processing) at high-priority sites, which would increase likelihood of release. Methane release and sequestration would best be elucidated via surface measurements versus atmospheric measurements [6]. Thus, distributed network sensors would be beneficial in determining methane "hotspots."

(O2) Characterize organic material contained in regolith. One of the best indicators of ancient life on Mars may be preserved organic matter. On Earth, there are molecules that retain biogenic patterns and structures that elucidate the origin and evolution of life that is preserved over geological timescales [7]. Current understanding of the Martian organic inventory comes from studies of Martian meteorites [8] and the in-situ measurements of the Viking landers and Mars Science Laboratory rover [9]. These molecules, namely lipids and insoluble macromolecular material, require sample-processing steps and large analytical instrumentation to elucidate their origin [10]. However, simpler techniques may be used to first probe whether organics are present in soils before resource-intensive analysis.

(O3) Determine if liquid water and salts were or are present at geomorphologically significant sites. In the search for extant life, understanding water availability is paramount. In hyperarid terrestrial deserts, a concentration of organisms is typically found where water activity is the highest for the longest time relative to other features (e.g., deliquescent salts, in rock habitats that retain water) [11]. Additionally, lipids are found to be well preserved in salts over long geologic time periods [12]. On Mars, there are several promising geomorphologic features that are potentially associated with the presence of liquid water. They require in-situ investigations to follow up on remote sensing observations to gain a better understanding if and how liquid water was or is involved in their formation (e.g., gullies, recurring slope linea) [13]. This might be achieved through measuring local relative humidity, soil conductivity, and salt content.

Measurement Options: These objectives could be met using several types of analytical instrumentation in combination (**Table 1**). One key to developing a low-cost astrobiology relevant mission concept is to develop science measurements that are focused and are possible in a small, ruggedized package that requires simple ancillary support hardware, such as sample handling and processing hardware.

NASA programs such as PISCASO, ColdTech, ECI, and MATISSE are developing technology for future missions. Additionally, over the last few decades, Research and Technology development funding for non-NASA based analytical chemistry techniques has doubled ~ every 10 years due to needs in healthcare and environmental sciences [14]. While many of these developments are currently at low to mid-TRL, NASA researchers are beginning the process of raising their TRL for future flight opportunities.

A few techniques discussed here are examples but do not form an exhaustive list. Our focus was to identify potential instrumentation able to withstand high deceleration shock events (< 2000 g pulse) for low mission cost and mass ($100-300M; 5-12 kg) [15]. Contact with regolith is required in some instances, and penetration via an impactor would likely improve detection probability.

Carbon Nanotube (CNT) Based Gas Sensors. High-surface-area CNT chemiresistors have improved sensitivity and recovery time relative to traditional bulk material counterparts; they can detect trace (~ppm) CH_4, CO NH_3, NO, SO_2, and H_2O_2 [16,17]. Heritage derives from extensive use of similar gas sensors on the International Space Station [18]. These fingernail-sized sensors require minimal mass, power, and volume. Sensitivity, gas discrimination and selectivity might require improvement for Mars mission implementation.

Pyrolysis (Py) + CNT Gas Sensors. CNT sensors could also be used with basic pyrolysis. Regolith can be heated through a simple mechanism (e.g., contact with a heated wire) and volatile emissions detected in a compact instrument outfitted with CNTs as a simplified evolved-gas analyzer, particularly for simple hydrocarbons (e.g. ethane, propane, butane). They could be measured with commercially available technology (e.g., Sensirion's VOC Sensor SGP40). These measurements could be indicative of breakdown of larger organics in Martian regolith. To gain resolution between small aliphatic hydrocarbons, a simple, monolithic GC column [19] could be used.

Total organic carbon (TOC) would be a useful measurement to corroborate the presence/abundance of organic matter measured as evolved hydrocarbon volatiles by CNT gas sensors. TOC could be measured using a pyrolyzer coupled with a solid-state oxygen source [20] to oxidize all carbon species, the evolved CO_2 then measured with a ruggedized commercial sensor (e.g., mouser.com/c/ds/?q=IR15TT). TOC has also been measured in water systems using boron-doped diamond sensor electrodes at 10-100 mg/L [21].

Electrochemical Sensors. The electrochemical sensors on the Wet Chemistry Laboratory (WCL) flown on the Phoenix Mars mission [22] measured multiple ions including perchlorate. A microfluidic implementation (*low SWaP*) of WCL has been developed recently for Icy-Worlds applications [23] to measure a range of ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2}, CO_3^{2-}), and could be useful for geochemical characterization at astrobiologically-significant sites.

Miniature Raman. Raman remains an important tool in characterization of the bulk properties of carbonaceous matter contained in Martian soils (e.g., diagnostic functional groups) using a standoff technique [24]. Raman systems such as the Raman Laser Spectrometer (RLS) for ExoMars survived drop tests up to 2500 g [25], making them a potential candidate for "rough" landings. Additionally, miniature Raman probes have been recently developed for medical purposes [26] as well as planetary missions [27].

Payload Combinations: Science objectives (above) could be addressed using a combination of small, rugged sensors (**Table 1**).

Table 1: Astrobiology Objectives Addressed by Low-SWaP Instruments

	O1: Variability of Gases at Surface	O2: Organics in Regolith	O3: Liquid Water and Salts
Relevant to:	*extant or ancient life*	*extant or ancient life*	*extant life*
CNT Gas Sensors	X		
Py + CNTs		X	
Electrochemical Sensors for Ions			X
Electrochemical Sensors for TOC		X	
Miniature Raman		X	X

Blue X= standoff technique; **Red X**= contact with soil required

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