High Resolution Surface Science at Mars

Zachary J. Bailey (JPL), zbailey@jpl.nasa.gov; Leslie K. Tamppari (JPL); Robert E. Lock (JPL); Erick J. Sturm (JPL)

Primary Concept Goal Category: Planetary Science, Space Technology

Abbreviated Concept Summary: The proposed mission would place a 2.4 m telescope in orbit around Mars with two focal plane instruments to obtain the highest resolution images and spectral maps of the surface to date (3-10x better than current). This investigation would make major contributions to all of the Mars Program Goals: life, climate, geology and preparation for human presence [1].

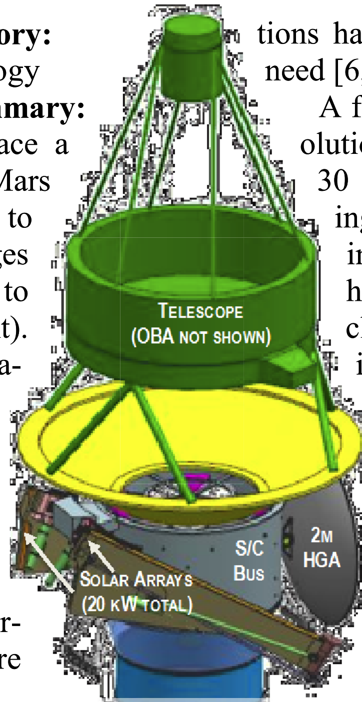

Figure 1. The telescope is forward-mounted on the spacecraft bus, with two solar arrays and the HGA mounted radially.

Science and Programmatic Goals of the Proposed Application: High-resolution Mars surface imaging and mineralogy are critical to answering major outstanding questions about Mars, such as (1) is or was life ever present? (2) what is the climate and geologic history? (3) where did the ancient water go? and (4) where is water accessible now? These experiments are also programmatically critical to select and certify landing sites for robotic or human missions and to provide context and traverse planning support to such missions.

Imaging & Mineralogy Science: Past scientific exploration of Mars has shown that increasing resolution by factors of 3-10 allow for the discovery and understanding of previously unknown characteristics - the currently orbiting Mars Reconnaissance Orbiter (MRO), containing a 30 cm/pixel high-resolution camera (HiRISE) [2] and an 18 m/pixel mineralogy instrument (CRISM) [3], has made major scientific discoveries, including possible liquid brines [4] and widespread aqueously-formed deposits [5]. However, there are mineralogy identifications and morphologies that are at the limit of this resolution; several very-high-resolution imaging and mineralogy investigations have been proposed to address this need [6,7].

A factor of 3 increase in imaging resolution (0.1 m/pixel) would enable a 30 cm object to be identified, allowing detection of finer scaled layering in the polar layered deposits, enhancing our understanding of the climate history of Mars, and in sedimentary, aeolian or fluvial/lacustrine, and volcanic strata exposed on cliff faces or crater walls, improving our understanding of the geologic history of Mars. It would continue the search, at finer scale, for evidence of liquid water, including hydrothermal systems, and the study of current erosional or sedimentary processes, all of which are current program goals [1].

Better than an order of magnitude increase in resolution of spectral maps would allow investigation of the composition of complex-layered terrain, and the search for evidence of small-scale aqueous or hydrothermal activity. For example, special sequences performed by CRISM to "oversample" yielding 6 m/pixel resolution have revealed hydrated sulfates on the rim of Victoria crater [7]. Further, in another super-resolution observation, several CRISM pixels showed a unique signature in the wall of "Matijevic Hill" where the Opportunity Mars rover is conducting observations. The rover team was able to search for, and preliminarily identify, the outcrop that correlates to the CRISM measurement [8].

The power of having coincident high-resolution imaging and mineralogy is the combination of morphological identification and geologic context with mineral identification of the various outcrops. Together, they are powerful in advancing our understanding of Mars.

The proposed orbiter with its enhanced capability would extend exploration and discovery of the Mars surface beyond the MRO lifetime, including monitoring changes on Mars that occur on seasonal time-scales and investigating more of Mars' surface area. Imaging with MRO's 3m/pixel resolution has covered <2% of the surface of Mars to date – there are many more discoveries waiting in the other 98%.

Infrastructure & Human Exploration: Both imaging and surface mineralogy are needed to identify, select, and 'safety certify' future landing sites with the highest potential for landed science discoveries and for sample caching or return by future Mars Sample Return or Human Exploration missions [9,10]. Improved resolution would allow better understanding of landing site slope and rock hazards, understanding of which are needed to certify a landing site. Imaging and spectral map products have been and would be used to select a scientifically interesting site and to distinguish among sites. Increased resolution may reveal layering, minerals, or other details that distinguish among sites. Further, once landed, this capability would support traverse planning for rovers by providing insight into the safest path and the most scientifically interesting areas, while also enhancing rover science by providing a broader geologic context in which to place the rover measurements. This spacecraft would also support the program by providing ongoing telecom relay support for rovers and landers.

Measurement Concept: The spacecraft would employ two focal plane instruments: a visible imager (300–1000 nm) and an imaging spectrometer (300–3000 nm). The instruments share the focal plane of the telescope. The spacecraft would operate from a circular 320 km orbit, selected for the ground resolution it allows. Table 1 shows a comparison of the key parameters between the two instruments described here and the HiRISE and CRISM instruments from MRO.

Visible Imager: The visible imager would be a push broom-style camera covering visible wavelengths. Due to the high ground speed at this low orbit (~3.1 km/s), time delay integration (TDI), with up to 256 lines, would be employed to achieve long integration times and a high signal-to-noise ratio. The diffraction-limited resolution would be 0.23 m, a factor of four improvement over HiRISE. The detector would have small pixels (5 microns) to achieve a ground sample distance (GSD) of ~8 cm. The imager's swath width would be 1.7 km.

Imaging Spectrometer: The imaging spectrometer would operate in the visible and near-IR wavelengths. The detector would cover a 2 km swath on the ground with 1 m resolution at the longest wavelength. To achieve acceptable performance at these 3 μm wavelengths, the telescope would be operated at 250 K (within the design environment with minimal impacts). The detector would be further cooled to achieve an high signal-to-noise ratio. In order to minimize data volume to the ground, the spectral dimension would be down-sampled to 25 channels. This is acceptable by choosing

Table 1. Comparison of instrument parameters with HiRISE and CRISM from MRO

Parameter	Visible Imager	Imaging Spec.	HiRISE	CRISM
Aperture [m]	2.37	2.37	0.5	0.1
F/#	8	8	24	4
Resolution [m]	0.23	1.0	0.9	38
Ground Sample Distance [m]	0.08	0.5	0.3	18
Pixel size [μm]	5	30	12	27
Detector Size	20000 x 256	4000 x 4000	20000 x 128	640 x 480 (2x)
IFOV [μrad]	0.26	1.58	1	61.5
Swath Width [km]	1.7	2.0	6	9.4 – 11.9
Wavelength Range [nm]	300 - 1000	300 - 3000	350 - 900	362 - 3920
Spectral Bands	1	25	4	540

Table 2. Spacecraft mass estimates show ample contingency and compatibility with an Atlas V 421

MEL	CBE (kg)	Cont.	MEV (kg)
Telescope & Outer Barrel Assembly	1120	5%	1176
Instruments	85	30%	111
Visible Imager	35	30%	46
Near-IR Spectral Mapper	25	30%	33
Optical Comm. Demo	25	30%	33
Spacecraft Bus	1125	30%	1463
Total Spacecraft Dry Mass	**2330**	**18%**	**2749**
SEP Dry Mass Capability			***2855***
SEP Mass Margin	***106***	***5%***	
Propellant			*1563*
Xenon			1414
Hydrazine			149
Total Spacecraft Wet Mass	**3893**	**11%**	**4312**
Atlas V 421 Performance			***4687***
LV Mass Margin	***375***	***9%***	

the channels over known or suspected absorption bands, to retain the science return.

Data Return: The primary science phase is one Mars year. Over this duration, the mission would return at least 4600 high-resolution visible images and 4600 spectral maps through the Ka-Band system. This corresponds to 0.03% and 0.04% surface coverage. The optical communications demo could augment this data return by more than a factor of 5. Areal coverage can be improved by increasing swath width or image length, combined with increased compression and pixel binning.

Spacecraft: The spacecraft consists of a bus, the donated Telescope and Outer Barrel Assembly (OBA), and three payloads – two focal plane instruments, and an optical communication tech demo. Figure 1 shows the spacecraft configuration; the telescope is mounted to the front of the bus with the solar arrays and HGA radially mounted.

Table 2 provides a full spacecraft MEL with margins. The spacecraft bus has an estimated dry mass of 1463 kg (w/ contingency). Since the provided telescope and OBA have been built and tested, a 5% contingency for these components is sufficient. The total s/c dry mass is 2749 kg (w/ contingency). The mission is estimated to cost $0.9B through phase D, including launch vehicle and reserves

The spacecraft would be launched to Mars on an Atlas V 421 to a C_3 of 2.3 km^2/s^2. The spacecraft cruises to Mars and spirals down to the science orbit using a solar-electric propulsion (SEP) system over 670 days. The SEP system consists three BPT-4000 hall-effect thrusters and a 20 kW power system (nominally operated at 16 kW).

The dry mass capability of the SEP system (if operated at a full 20 kW) provides an additional 5% margin over the s/c dry mass. The SEP mass performance (and corresponding mass margin) can be achieved with a longer time of flight (TOF), increased system power, or an additional thruster. The launch vehicle mass margin is 9%; this could be improved by a longer TOF or larger launch vehicle.

The spacecraft uses a Ka-band radio with a 200 W amplifier and 2m high gain antenna. A one Mars year science phase returns an average daily data volume of 55 Gbit with the Ka-band system (assuming an 8-hour daily DSN pass with a 34m antenna). The optical comm. demo payload would return an average daily data volume of 280 Gbit to a 5m telescope at Earth. The telecom system would also contain a UHF radio for data relay from landed spacecraft with a daily data volume of 300 Mbit.

Timeline: The mission would launch in April 2018, arriving in the science orbit in February 2020. The one Mars year science phase would conclude in December 2021.

References: [1] Mars Exploration Program Analysis Group Goals document, Sept. 24, 2010. [2] McEwen, A.S. et al., *JGR* **112**(E5), 2007. [3] Murchie, S.L. et al., *JGR* **112**(E5), 2007. [4] McEwen, A.S., et al., *Science* **333**(6043), 2011. [5] Murchie, S.L., *JGR* **114**(E00D06), 2009. [6] Ravine, M. A. et al. (2012) Concepts and Approaches for Mars Exploration, Abstract #4325. [7] Murchie, S. L. et al. (2012) International Workshop on Instrumentation for Planetary Missions, Abstract #1047. [8] M. Golombek, pers. comm., 2012. [9] Vision and Voyages for Plan. Sci. in the Decade 2013-2022, report to the National Research Council. [10] P-SAG (2012) Analysis of Strategic Knowledge Gaps Associated with Potential Human Missions to the Martian System