The Mars Orbiting Space Telescope (MOST)

Advancing Planetary Science (+Astrophysics, Heliophysics), Space Technology, and Human Spaceflight

Overview:

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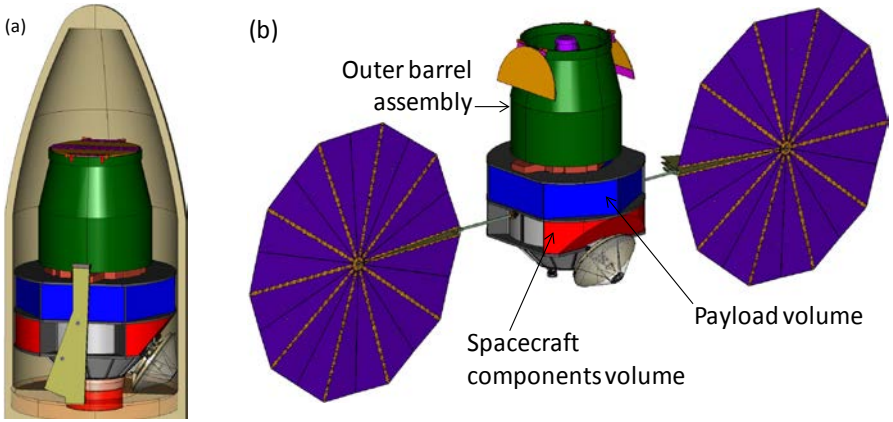
Key collaborator: Lockheed Martin Space Systems Company, Denver.

Goals:

1. Achieve groundbreaking advances in understanding Mars habitability, ancient and modern.
2. Support future Mars exploration (relay from surface assets, locate and characterize landing sites, optical communication experiment).
3. Demonstrate solar electric propulsion at a scale needed for human exploration.
4. In Astronomy mode, achieve Decadal science goals in Planetary Science and contribute to Astrophysics and Heliophysics.

Advantages of being in Mars orbit rather than low Earth orbit: lower orbital velocity, outside geocorona for UVS, different viewing geometries for a range of science objectives, solar conjunction at different times.

Graphics:



(a) Launch configuration in an Atlas 5 meter fairing. (b) Operation configuration. MOST will have 3 major operational modes: Mars observation and relay, Astronomy, and downlink.

Description:

High-heritage spacecraft design, using solar electrical propulsion to deliver a large mass to Mars orbit with standard launch vehicles.

2000 kg payload mass, >5500 W power at Mars.

Human or robotically serviceable payload midsection.

High data rates for science by virtue of the large power budget available for data transmission, and the stable pointing for Ka and optical comm.

3 main science instruments:

Imaging Spectral Mapper (ISM): 0.4-5.2 microns, 30 bandpasses, 0.21 m/pixel on Mars from 400 km orbit (0.52 µrad/pixel)

High Resolution Imager (HRI): 0.2-1.1 microns, 12 filters, IFOV 0.04" (0.19 µrad/pixel)

Ultraviolet Spectrometer (UVS), 110-315 nm like HST/STIS

Observations:

Mars mineral mapping at 21 cm/pixel; imaging at 8 cm/pixel

Astronomy mode: broad suite of science like HST

Technology readiness: high-TRL detectors and spacecraft

External collaborations: TBD

Human exploration capabilities: Electric Propulsion

The MOST Value to NASA:

This mission supports many NASA endeavors, across all of the concept goal categories:

The UVS will continue the profound Hubble efforts in this wavelength– with a larger field of view and better seeing–and will be complementary to the IR capabilities of James Webb and WFIRST.

All 3 instruments enable observations of astrophysical and planetary targets (including upper atmosphere and auroral phenomena for heliophysics).

The ISM and HRI will provide unprecedented high spatial and spectral resolution coverage of the most compelling locales on Mars.

The mission itself is a major technological stepping stone to human exploration using electric propulsion.

Additional small instruments can be accommodated, including UHF relays to support Mars rovers.

Ideal for optical communications technology, given high power and pointing stability and desire to return much more data than otherwise possible.

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Principal author: Alfred S. McEwen (University of Arizona, 1541 E. University Blvd, Tucson, AZ 85711; 520-270-0701; mcewen@lpl.arizona.edu; Professor and PI of MRO/HiRISE).
Key Collaborator: Lockheed Martin Space Systems Company, Denver.
Abbreviated Concept Summary: Use solar Electric Propulsion to put a spacecraft with one of the 2.4-m telescopes from NRO into Mars circular orbit, to observe Mars and beyond with 3 major instruments: UV spectrometer (115-310 nm), visible high-resolution imaging (0.04”), and pushbroom spectral mapping from 0.4 to 5.2 microns.
Primary concept goal categories: Planetary Science (+Astrophysics and Heliophysics), Space Technology, and Human Spaceflight.

Goals

Top priority science goals in the planetary Decadal Survey can be addressed via a large telescope in Mars orbit. When pointed at Mars, MOST can significantly advance our understanding of the past and present habitability of Mars, both from direct science observations and by providing critical support to robotic and potential human exploration on the surface of Mars or its moons. When pointed at targets outside the Mars system, MOST will advance space science by providing unique capabilities from residing in Mars rather than Earth orbit. We propose an inclined circular orbit around Mars so that MOST can observe all of the sky and observe Mars over many times of day.

We propose a streamlined but powerful baseline suite of three instruments: (1) Imaging Spectral Mapper (ISM), 0.4-5.2 microns with ~30 filter strips for pushbroom imaging with IFOV 0.108” (0.526 µrad/pixel); (2) High-Resolution Imager (HRI), visible camera with IFOV 0.04” (0.19 µrad/pixel); (3) and an ultraviolet imaging spectrometer (UVS) similar to HST/STIS.

This mission supports many NASA endeavors: the UVS will continue the profound Hubble efforts in this wavelength– with a larger field of view–and will be complementary to the IR capabilities of James Webb and WFIRST; all 3 instruments enable observations of astrophysical and planetary targets (including upper atmosphere and auroral phenomena for heliophysics); the ISM will provide unprecedented high spatial and spectral resolution coverage of the most compelling locales on Mars; and the mission itself is a major technological stepping stone to human exploration by virtue of using EP to deliver a high-mass system to Mars. MOST can accommodate additional small instruments such as for radiation and Mars atmospheric monitoring and a deep space atomic clock. We expect MOST will carry UHF relays to support landed assets.

Benefits

Mars Science: ISM will return visible-NIR imaging and mineralogic data with up to 100x higher spatial resolution than MRO/CRISM. CRISM data have proven revolutionary to our understanding of Mars habitability and identification of the most promising locations for future in-situ exploration and sample return[1]. From observations by past landers and rovers and from HiRISE color data, we know that unique mineral signatures are best exposed over small-scale outcrops (e.g., Fig. 1). ISM, with resolution of 0.21 m/pixel at 400 km altitude, will fully resolve half-meter scale features and identify the dominant minerals that have distinctive absorption bands from 0.4-5.2 microns, and measure surface temperatures when >180 K. HRI will be able to image small areas at 8 cm/pixel (from 400 km), ~4x better than HiRISE.

There are 2 major scientific goals at Mars: (1) understand ancient processes and potential habitability; and (2) understand current processes and present-day habitability. For the latter objective we are especially interested in the recurring slope lineae, seasonal flows on warm Martian slopes that are best explained by flow of salty water[2-4]. These flows are up to a few meters wide, below the resolution of CRISM but well resolved by MOST. Furthermore, MRO observes in the middle afternoon when water is least stable; a different orbit[4] is possible for MOST. The signature of water should be obvious from compositional and temperature observations at multiple times of day, including the early morning, given the behavior of deliquescent salts known to be present on Mars[5]. Although anhydrous chlorides lack absorption bands, the composition of the salt will be detectable when in the form of brine-wetted soil or hydrated minerals. MOST can also observe the atmosphere of Mars at its limb, to measure vertical profiles of water vapor and other gases.

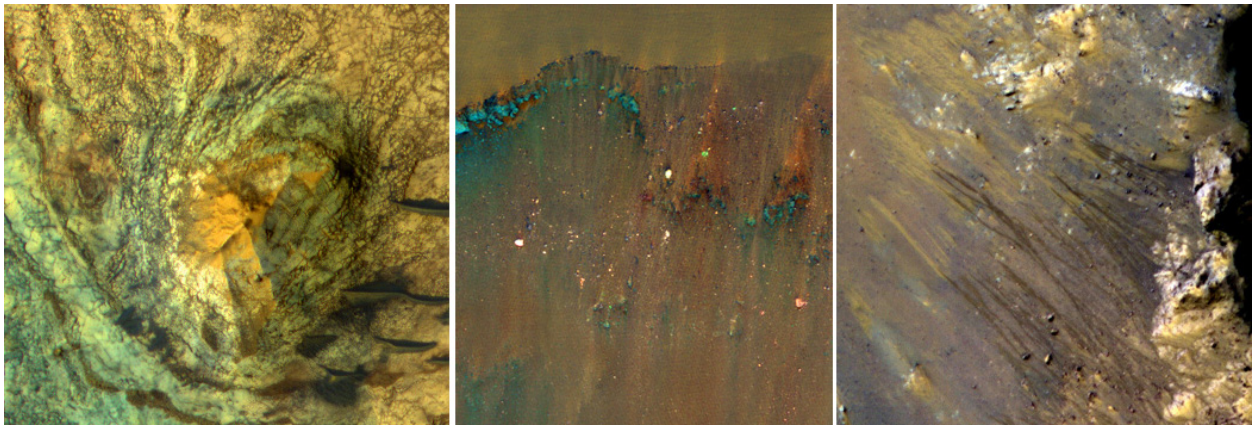

Figure 1. Small samples of 3 HiRISE images showing (left) a color change that cuts across depositional layers indicating post-depositional alteration in very ancient (~4 b.y. old) deposits; (middle) layers and rocks within an alluvial fan ~1 to 3 b.y. old; (right) currently active seasonal flows on steep slopes (flowing downhill to upper left). HiRISE shows color variability in 3 broad bandpasses, insufficient to determine the compositions; CRISM can acquire ~10x10 pixels of compositional data across each of these areas; and MOST can return compositional data at finer scales (0.21 m/pixel from 400 km) than these HiRISE color images (~0.6 m/pixel).

Mars Mission Support: MOST can provide significant operational support to Mars exploration by rovers and even people. It can carry a UHF antenna for relay of data from landed assets to Earth. An optical communication experiment can be considered, compatible with the high power and high pointing stability required by MOST for other reasons. The very high-resolution imaging can support engineering evaluation of landed assets. Small instruments could be added to monitor the atmosphere of Mars, as support to EDL. Perhaps the most important contribution will come from identification of environments that could be habitable today, to plan planetary protection efforts needed for future exploration[6].

Astronomy: When pointed away from Mars, MOST will provide excellent visible and ultraviolet imaging capability for a wide range of Decadal science in astrophysics, heliophysics, and planetary science. UV instruments on HST, Cassini, and New Horizons have demonstrated the profound diagnostic value of this wavelength range for planetary atmospheres. Without an upcoming dedicated outer planets NASA mission, especially to Uranus and Neptune, scientific observations of these bodies will be limited to ground- and space-based observatories. Clearly there are advantages to space-based telescopes for observing these bodies; in addition there are some significant advantages to such a telescope in Mars rather than Earth orbit. It puts the telescope outside the geocorona, for observations at Lyman-alpha and other UV wavelengths, to better observe young galaxies and planetary atmospheres and exospheres. The orbital velocity around Mars is slower than around Earth, improving astronomical observations compared to HST (but fine guidance and tracking is still required). MOST can provide a larger baseline for stereoscopic viewing of targets combined with Earth-based telescopes. A greater range of viewing angles for targets in the outer solar system are possible from Mars than from Earth. The inner asteroid belt can be viewed from significantly closer range. Solar conjunction occurs at different times from Earth and Mars, so together more continuous monitoring is enabled.

Instrument Design

We envision that MOST will carry 3 main science experiments:

ISM: A very high-resolution Imaging Spectral Mapper (0.4-5.2 microns, ~30 bandpasses), with spatial resolution better than MRO's HiRISE and the compositional capability of CRISM. It will operate in pushbroom mode using HgCdTe detectors such as the 2048 x 2048 Teledyne H2RG, which has QE > 70% from 0.8-5.3 microns. Covering a 1° swath width requires 17 detectors. Each detector will be covered by ~30 filters, enabling digital time delay integration (TDI) over from 8 to 64 lines per bandpass (as needed to achieve >200:1 SNR for Mars). The median read noise (<70 at 10 MHz), which becomes sqrt(70^2 x #TDI lines) or up to 560 e- for 64 TDI lines, is acceptable for the high signal levels when imaging Mars. The S/C must slew at a rate that reduces the line time at least 10x compared to constant nadir pointing, to increase exposure time per line and to keep the data readout rate below the 320 Mpixel/s limit of the H2RD. The number of lines to read out (spectral bands x TDI lines) will be limited at the lower altitudes by the readout rate. ISM requires detector cooling to 100 K; optics at 250 K. The

multiple images will enable excellent measurement and correction of pointing jitter to accurately register the bandpasses and remove geometric distortions (suitable for stereo mapping of landing sites). Storage and real-time compression will enable acquisition of long images, >100,000 lines. A single observation (for example, 2048 pixels x 17 detectors x 12 colors x 100,000 lines x 2 compressed bpp) would require 83 Gbits of data to transmit to the ground. ISM will be used for only the very highest-priority targets, a few hundred per Mars year, leaving ample time for non-Mars science.

ISM will be optimized for Mars and its moons, but will also be useful for many other targets when in astronomy mode; slower readout rates with less noise will be used. Up to 10 of the spectral bandpasses may be optimized for non-Mars science.

HRI: A high-resolution imager, IFOV 0.04" (0.19 μrad/pixel) with a silicon CMOS detector to image in either framing or pushbroom mode, including 2D digital TDI to increase SNR when imaging Mars or any other fast-moving scene. New CMOS detectors[7] can achieve read noise levels of less than 1 e-, enabling observation of very faint astronomical targets. The backside-thinned detector will have a high QE from ~0.2-1.1 microns. A filter wheel (~12 slots) will enable acquisition of color images of distant targets. Large-format stitched CMOS detectors enable large arrays; we envision 4096 x 8192 pixels. HRI will be optimized for astronomical targets, but can image narrow strips of terrain on Mars (636 m wide swath at 8 cm/pixel from 400 km).

UVS: ultraviolet spectrometer (~115-315 nm), to continue the unique capabilities of HST in wavelengths that can't be acquired by ground-based telescopes. We consider HST/STIS microchannel array capability as an example (http://www.stsci.edu/hst/stis/design/), but improvements are possible.

Spacecraft Design

The Lockheed Martin spacecraft design utilizes established hardware, software, technology, and processes from Earth sensing, planetary spacecraft, and powerful space-based astronomical observatories built by LM in the last 40 years.

The bus is a combination of flight proven heritage components and subsystems configured for the Large Optical Payload, with the inclusion of electric propulsion (EP) for efficient delivery of the observatory to Mars orbit. The spacecraft accommodates a 2000 kg payload/instrument mass and >5500 W of total power during science operations. The bus uses a compact, stiff structure that has been tailored to an optical payload and can be compatible with Atlas V, Delta IV, and Falcon launch vehicles (see quad chart). Its simple design is highly centralized, enabling for straightforward integration to the telescope payload, high pointing stability, low disturbances for long stare times, and thermal stability. A human or robotically serviceable payload midsection accommodates at least three instruments via an isolated optical bench, provides all instrument interfaces needs, and offers the ability for each instrument to be readily exchanged. The high-heritage approach also relies on LM's proven ability to integrate large optical systems (Hubble, SIRTF, GeoEye-2) and related planetary flight systems.

The baseline telecom system provides high data rates for science by virtue of the large power budget available for data transmission, and the stable pointing. The avionics and power distribution systems provide common interfaces and functionality for instruments assuring low risk, and uses proven flight software. A capable GN&C system provides precision pointing and control that is at least as good as MRO. The spacecraft carries a hydrazine ACS system specifically to manage spacecraft attitude, particularly to transition the spacecraft between Mars-observing and deep-space views.

Operation

The spacecraft uses a heritage EP system to deliver the large payload mass to Mars orbit. The spacecraft can begin science observations of solar system or astrophysical objects during cruise. The observatory can begin Mars observations during spiral down to the final science orbit, similar to the decreasing altitude orbit of Dawn around Vesta. Once in the final science orbit, the spacecraft has three basic operational modes: (1) Mars observations, (2) observing targets outside the Mars system, (3) downlink with Earth. All science observations can be competed, following the utilization of other ground- and space-based high-capability assets.

References: [1]Murchie, S. et al., 2009, JGR 114, E00D06. [2]McEwen, A.S. et al., 2011, Science 333, 740. [3]Chevrier, V.F., and E.G. Rivera-Valentin, 2012. GRL 39. [4]Paige, D.A., et al., 2012, LPI Contrib. 1679, #4235. [5]Gough, R. V. et al., 2011, EPSL 312, 371-377. [6]Kminek, G., et al., 2010, ASR 46, 811-829. [7]Janesick, J., J. Andrews, and T. Elliot, 2010, Proceedings of the SPIE, paper 7742-11.