Small Mars Missions based on Common Spacecraft Systems: 3. Mars High Resolution Imager (MHRI).

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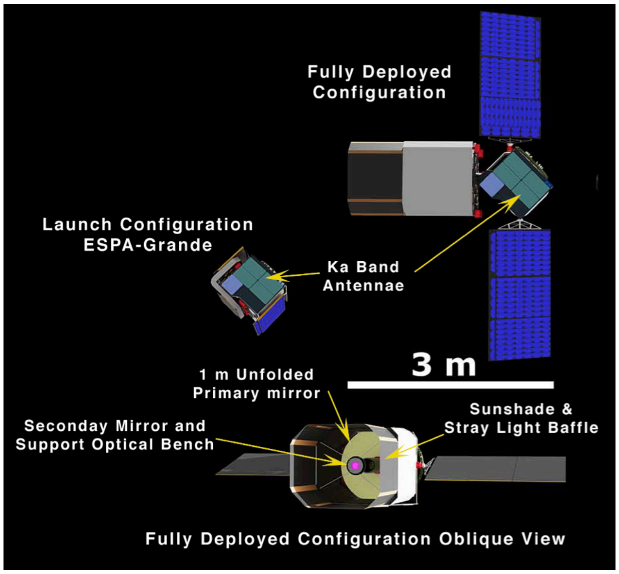
Introduction: We discuss here a second mission based on a common subsystem design, but differing in substantive ways from the first mission, MSO. The primary objectives are still to get into the required orbit of Mars, to increase the launch opportunities, and to return large volumes of science data. MSO is intended to take low resolution images from areostationary orbit, while MHRI is intended to acquire high resolution images from a low altitude sun-synchronous polar orbit -- specifically, thousands of targeted images at high resolution (2-3x better than HiRISE), in stereo and in multiple colors (at reduced resolution). The required payload (large aperture, long focal length camera and sophisticated image processing capabilities) is a more massive payload than MSO.



1 m diameter deployable mirror packaged in an ESPA-Grande form factor

Primary Differences between the MSO & MHRI S/C:

This payload size and mass requires an ESPA-Grande launch slot, to maintain the GTO launch capability. Available launch mass of 450 kg consists of 110 kg for the S/C system and payload, 50 kg for inert propulsion and 290 kg for propellant. The 2900 m/s ⊗V capability is sufficient (with margins) to depart from GTO, insert into a Trans Mars Trajectory, cruise to Mars, insert into a loose, elliptical Mars orbit, aerobrake to reduce apoapsis to 300 km, then maintain a 200 by 300 km altitude for at least 2 Mars years.

Payload: The MHRI payload consists of the primary high-resolution imager (new development and much larger than MSO cameras) and the context imagers (similar to MSO and based on existing MSSS hardware). The C50 visible context camera has 3.5° FOV (~12 km) and 4.6 m/pixel IFOV. Two IR3C infrared cameras provide compositional information mostly for hydrated minerals. Each IR3C has 1.8° FOV (6.4 km resulting in combined ~12 km swath) and 10 m/pixel IFOV, with a spectral range of 1.2 µm to 6.25 µm (8000 cm^{-1} to 1600 cm^{-1}) at 13.33 cm^{-1} spectral sampling.

High Resolution Imager Focal Plane consists of three Teledyne-DALSA I-49-122888-00-R backside illuminated CMOS detector packages, each with two 12,288 7-µm panchromatic channels and four 3072 28-µm color channels, packaged on the same focal plane assembly providing 36K 0.8 µrad panchromatic and 4 9K 3.22 µrad color IFOVs covering ~6 km swaths, sampling 16 cm/pixel (pan) and 64 cm/pixel (color). Additionally, the two panchromatic sensors are offset by ½ pixel along the array (cross-track), that allows for computationally synthesizing between 1.3 and 1.5 times higher spatial samples [1]. Appropriate clocking of ≤198 TDI lines can yield square panchromatic pixels at 10-12 cm/pixel.

High Resolution Imager Optics uses a segmented deployable 1 m aperture primary mirror, with 8.7 m focal length (F/8.7) and 0.8 µrad IFOV.

We baseline a Ritchey–Chrétien telescope design, based on our experience (MGS MOC, LROC NAC) because it is optically and mechanically simple, less sensitive to environment and straightforward to fabricate, as compared to alternatives (e.g., a three- mirror anastigmat). The deployable primary mirror has two optical segments plus the deployable secondary mirror support structure permitting the 1 m aperture and the long focal length to be accommodated in the limited ESPA-Grande volume. Precision alignment of the telescope optical elements uses a combination of mechanical registration (within 20 µm) and piezo-actuators (sub-nanometer steps with 35 µm range). The alignment is established by star imaging and maintained by capacitive sensors during surface imaging. The cross-track field of view is 1.66° covering 5.8 km from 200 km (8.7 km from 300 km).

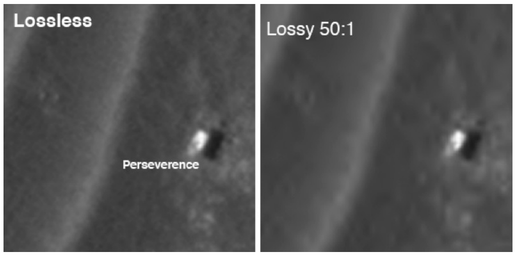
Two primary half-mirror segments are supported on individual substructures, braced against launch loads while stowed and providing the joining interface once deployed. The substructures are connected together through a motor driven hinge. During deployment, each half-mirror substructure is rotated 45° outward, away from its stowed support location.

As the substructures come together to form the assembled primary mirror, they are driven into mechanical alignment through an array of registry interfaces. The assembly is held in place with a series of latches that prevent separation between the substructures during operation. As the primary mirror halves come together the secondary mirror and associated support are pushed away from their launch position by the spider strut assembly. Each of the four struts are connected to the end of a lenticular boom that further extends the secondary mirror assembly to yield a 1 m separation (f/1 primary) distance between the mirrors, with a magnification of 8.7X on the aspherical secondary mirror, to achieve the requisite f/8.7 optical system and 8.7 m focal length. For reference, our Mars Observer Camera had a 7.77X magnification on its secondary.

An optical bench containing the field flattening lenses in a tube, a tubular light shielding baffle, and the image detector FPA are deployed last. From the stowed position the three assemblies are driven forward on a motorized slide mechanism, projecting the optical bench and baffle tube through the center of the primary mirror to the focus position. The detector housing remains behind the primary mirror segments and includes a registration interface that aligns the optics appropriately with the detectors.

The optical bench assembly consists of three lenses for image correction and expansion over the detector area. The elements are fix-mounted with respect to each other within the bench, and the focal plane housing. The light shield tube structure extends beyond the optical bench. The detector assembly includes the electro-optical sensing device(s) and a board stack with readout and processing electronics. The electronics are mounted to the backside of the FPA to reduce harness length for high-speed data transfer between boards. This design allows the optical elements in the tube to be collimated with the sensing devices during assembly on the ground, and held in place to optical tolerances during launch loads.

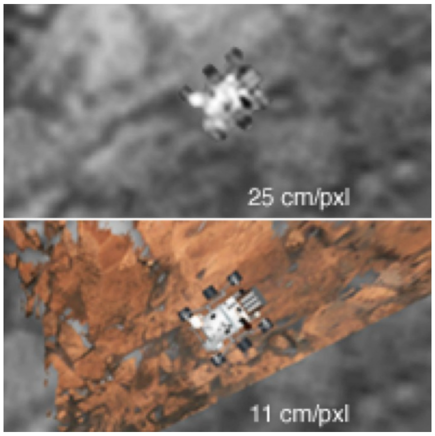
The secondary mirror is attached to a 6-degree of freedom piezo actuated hexapod stage. The hexapod alignment stage is capable of displacements of ±6.5mm laterally and ±5.0mm inline from center at 2.0nm increments and rotations of ±7.0º (122 mrad) in pitch and roll at 0.2µrad increments.



JPEG2000 Compression comparison: Left lossless, right 50:1 lossy. Image is HiRISE view of Perseverence rover at Jezzero

Several techniques will be used to achieve alignment within tolerance and co-phasing of segments to a small fraction of 450 nm (the shortest wavelength of the pan-bandpass mode), including direct metrology and area array detectors that view the different segments of the primary mirror and measure the focus and phase retrieval techniques, using images of stars.

Results: As with many planetary missions, this one is severely limited by downlink rate. A typical (6 km cross track by 12 km along track) high res stereo data set is 1.8E11 bits (16-bit pixels), and the color data for that typical pass is 1.1E10 bits. The context imager provides geometrically constrained stereo observations over a 12 x 12 km area at 1.1E8 bits, and the IR spectrometer would need 1.11E12 bits to cover the same area. Thus a single site from all cameras is 1.3E12 bits. Not all of these bits can be sent to the Earth, but JP2000 compression of 50:1 preserves much of the high spatial resolution data, and 200:1 preserves much of the lower frequency data, and at high downlink rates (800kpbs) about 7 sites could be returned per day, although at low downlink rates this is only 0.5 sites per day. Mission total downlink would permit about 700 sites in a Mars year of observations. Additional downlink capability is being explored.



Top: HiRISE background with model of Curiosity Rover at 25 cm/pxl. Bot: Masstcam mosaic over Top view at 11 cm/pxl

Cost Estimate: The recurring cost for the components in common with the MSO spacecraft being built is $20M. The MHRI propulsion system adds $6M while the MHRI payload is $28M and additional mission development costs are $4M. Total Phase A-D costs are $60M. Phase E costs are $6M/yr for 2 years. Adding a 40% reserve to development costs and 33% reserve to operations yields a total mission cost of $96M.