THE MAST CAMERAS AND MARS DESCENT IMAGER (MARDI) FOR THE 2009 MARS SCIENCE LABORATORY. M. C. Malin[1], J. F. Bell[2], J. Cameron[3], W. E. Dietrich[4], K. S. Edgett[1], B. Hallet[5], K. E. Herkenhoff[6], M. T. Lemmon[7], T. J. Parker[8], R. J. Sullivan[2], D. Y. Sumner[9], P. C. Thomas[2], E. E. Wohl[10], M. A. Ravine[1], M. A. Caplinger[1], and J. N. Maki[8], [1]Malin Space Science Systems, San Diego, CA, [2]Cornell University, Ithaca, NY, [3]Lightstorm Entertainment, Los Angeles, CA, [4]University of California, Berkeley, [5]University of Washington, Seattle, WA, [6]US Geological Survey, Flagstaff, AZ, [7]Texas A&M University, College Station, TX, [8]Jet Propulsion Laboratory, Pasadena, CA, [9]Univ. of California, Davis, [10]Colorado State University, Ft. Collins, CO.

Introduction: Based on operational experience gained during the Mars Exploration Rover (MER) mission, we proposed and were selected to conduct two related imaging experiments: (1) an investigation of the geology and short-term atmospheric vertical wind profile local to the Mars Science Laboratory (MSL) landing site using descent imaging, and (2) a broadly-based scientific investigation of the MSL locale employing visible and very near infra-red imaging techniques from a pair of mast-mounted, high resolution cameras. Both instruments share a common electronics design, a design also employed for the MSL Mars Hand Lens Imager (MAHLI) [1]. The primary differences between the cameras are in the nature and number of mechanisms and specific optics tailored to each camera's requirements.

Mast Cameras: The Mast Camera (MastCam, Fig. 1) system begins with the same abilities as the MER Pancam [2] but incorporates several innovations: (a) telephoto zoom, (b) focus, (c) true color (in addition to scientific color), and (d) high-speed data acquisition, processing and storage. Zoom, focus, and high-speed data acquisition (enabled by high internal data rates and a large internal storage buffer) provide options for mission operational time savings, permit investigators to examine geologic features that are otherwise out of the rover's reach, and view rocks and fines near the rover at resolutions as high as 150 µm/pixel. The high-speed/high-processing/high-data capacity capabilities (which we term, collectively, video) provides the opportunity to observe time-dependent or transient phenomena, such as eolian transport of fine-grained materials disrupted or disturbed by rover hardware interaction with the surface, and atmospheric events such as cloud movement and dust devils, as they happen.

The MastCam primary objective is to characterize and determine details of the history and processes recorded in geologic material at the MSL site, particularly as they pertain to habitability. MastCam will acquire panoramic, stereo, color, multispectral (400-1100 nm; Table 1), and selected mosaics, zoom (close-up) images, and high-definition video and high definition stereo (3-D) video observations to address the following specific objectives:

1. Observe Landscape Physiography and Processes. Provide a full description of the topography, geomorphology, and geologic setting of the MSL landing site, and the nature of past and present geologic processes at the site.
2. Examine the Properties of Rocks. Observe rocks (outcrops and clasts 3-4 mm) and the results of interaction of rover hardware with rocks to help determine morphology, texture, structure, mineralogy, stratigraphy, rock type, history/sequence, depositional, diagenetic, and weathering processes for these materials.
3. Study the Properties of Fines. Examine martian fines (clasts <4 mm) to determine the processes that acted on these materials and individual grains within them, including physical and mechanical properties, the results of interaction of rover hardware with fines, plus stratigraphy, texture, mineralogy, and depositional processes.
4. View Frost, Ice, and Related Processes. Characterize frost or ice, if present, to determine texture, morphology, thickness, stratigraphic position, and relation to regolith and, if possible, observe changes over time; also examine ice-related (*e.g.*, periglacial) geomorphic features.
5. Document Atmospheric and Meteorologic Events and Processes. Observe clouds, dust-raising events, properties of suspended aerosols (dust, ice crystals), and (using the video capability) eolian transport of fines.
6. Support and Facilitate Rover Operations, Analytical Laboratory Sampling, Contact Instrument Science, and Other MSL Science. To assist rover navigation, acquire images that help determine the location of the Sun, horizon features, and provide information pertinent to rover trafficability (*e.g.*, hazards at hundreds of meters distance). For MSL science instruments, provide data that help the MSL science teams identify materials to be collected for, and characterize samples before delivery to, the MSL Analytical Laboratory; help teams identify and document materials to be examined by the Contact Instruments; and acquire images that support other MSL instruments that may need them.

Implementation: MastCam is a high-heritage design based on lessons learned from three previous generations of MSSS instruments: Mars Global Surveyor MOC, Mars Polar Lander and Phoenix MARDI and Mars Reconnaissance Orbiter CTX. MastCam design reflects simplifications resulting in reduced part count while meeting demanding reliability and performance requirements. MastCam consists of two duplicate camera subsystems mounted on the MSL Remote Sensing Mast ≥ 20 cm apart to provide stereo capability. Each subsystem is subdivided into a camera head (optics, and focal plane assembly—FPA), and an electronics box (the CCD clock drivers, digital electronics and power supply). The optics consists of the optical elements, their housing and the zoom/focus/filter wheel mechanism. Each of these functions is driven using a MER-heritage actuator. The FPA module includes the CCD detector (with integral Bayer pattern filter), and all circuit elements that are tightly coupled to it, notably the analog front end integrated circuit. The clock and digital electronics incorporate all the circuit elements required for CCD control, data processing and compression. Maximum flexibility is provided using a high capacity FPGA, programmed using a rigorous logic development process. MastCam provides two modes of image acquisition: a 1200 x 1200 pixel format, single-frame mode, and a 1280 x 720 pixel format high definition video mode. The power module provides the regulated voltages for the camera. The zoom optics provide a field of view of greater than 50° by 50° at the short focal length position, and an image scale of 10 cm/pixel for targets at 1 km at the long focal length position. MastCam is able to autonomously determine focus over distances from 2 m to infinity. MastCam has two types of image buffer: a high speed, 256 megabyte DRAM acquisition buffer, into which mosaics and up to 4 minutes of 10 fps video can be acquired, and a lower speed, 8 gigabyte flash RAM mass memory buffer into which the data in the acquisition buffer are transferred for longer term non-volatile storage. Each camera weighs about 1 kg and draws 13 W when imaging.

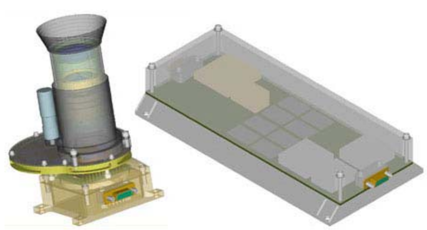

Fig. 1. MastCam camera head (left) and electronics box (right). MSL will carry two of these for stereo.

MARDI: MARDI (Fig. 2) consists of the same basic design elements (optics, FPA, electronics box) as MastCam, including the true color and video capabilities. MARDI objectives are (1) determine the location of MSL to a precision of centimeters, (2) provide context for MSL's geological studies, and (3) determine the atmospheric wind velocity profile experienced by the spacecraft during descent. The MARDI design is based upon and a technical evolution from previous flight instruments, in particular the MPL [3] and Phoenix MARDI and the MRO CTX. Its performance in all aspects (number of images, signal-to-noise, size of images, image quality) will exceed that of the MER/DIMES instrument by a factor of 20-50. MARDI is characterized by small size (~7x7x10 cm, ~600 gm), modest power requirements (10 W operating, 4 W standby, including power supply losses), and high science performance (1600x1200 pixel, low noise images acquired every 0.2 seconds, and ultimate resolution better than 1 cm/pixel). MARDI will acquire 5 frame-per-second MPEG-2-encoded high-definition color digital video, spanning three orders of magnitude in scale, during the roughly 100 seconds between heatshield jettison and rover touchdown. The only requirements levied by MARDI during Entry, Descent, and Landing (EDL) are signals from the spacecraft computer to power-up the camera and begin taking pictures—once started, image acquisition is autonomous. After landing, the rover computer must read out the camera's 256 Mbyte internal memory.

References: [1] Edgett K. S. et al. (2005) *LPSC XXXVI*, #1170. [2] Bell J. F. III et al. (2003) *JGR, 108*, doi: 10.1029/2003JE002070. [3] Malin M. C. (2001) *JGR, 106*, 17635-17650.

Table 1. MSL MastCam Bandpasses

Filter	Left (nm)	Right (nm)
1	420-680	420-680
2	435	535
3	480	800
4	535	865
5	600	905
6	675	935
7	750	1010
8	440 (ND5)	880 (ND5)

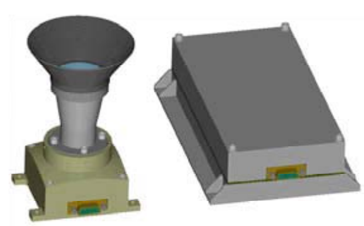

Fig. 2. MSL MARDI camera head, electronics box.