THE MARS SCIENCE LABORATORY (MSL) HAZARD AVOIDANCE CAMERAS (HAZCAMS). J. N. Maki[1], D. Thiessen[1], A.Pourangi[1], P. Kobzeff[1], L. Scherr[1], T. Elliott[1], A. Dingizian[1], Beverly St. Ange[1], [1]Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109.

Introduction: The Mars Science Laboratory (MSL) Rover, scheduled to land on Mars on August 6th 2012 UTC, utilizes 8 Hazard Avoidance Cameras (Hazcams). The key requirements of the Hazcam imaging system are: 1) Provide image data for the onboard detection of navigation hazards during a rover traverse, 2) Provide terrain context immediately forward and rear of the rover (in particular the area not viewable by the mast-mounted cameras) for traverse planning, 3) Support Robotic Arm (RA) operations, including the transfer of material to the surface sampling system, 4) Support rover fine positioning near RA targets, 5) Wide field of view (120 degrees), 2 mrad/pixel angular resolution, 6) Stereo ranging to an accuracy of +/- 5 mm, and 7) Broadband, visible filter. The Hazcams were built at the Jet Propulsion Laboratory in Pasadena, CA.

Instrument Details: The mounting locations of the Hazcams are shown in figures 1 and 2.

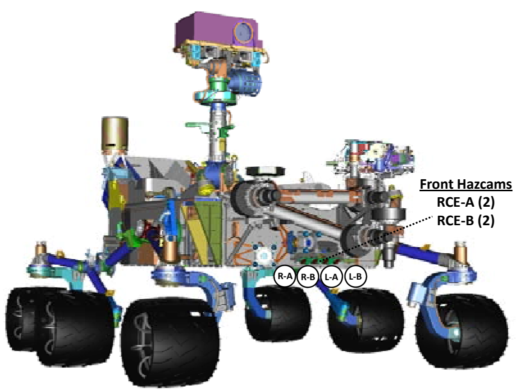

Figure 1. Location of MSL Front Hazcams.

The Front Hazcams are body-mounted to the front of the rover chassis with a 16.6 cm stereo baseline. There are two stereo pairs of Front Hazcams (one stereo pair is connected to the Rover Compute Element (RCE) “A” electronics and the other pair is connected to the rovers RCE “B” electronics. In a manner similar to the MSL Navcams [1], only one RCE is active at a time, the second RCE is for fault redundancy. The Rear Hazcams are body-mounted to the rear of the rover chassis with a 10 cm stereo baseline. Unlike the Front Hazcams, which are grouped together near the center of the front of the rover, the RCE-A and RCE-B Rear Hazcam stereo pairs are mounted on opposite sides of the RTG (Radioisotope Thermoelectric Generator). As a result, the two sets of cameras (RCE-A and RCE-B) see different views out the rear of the rover.

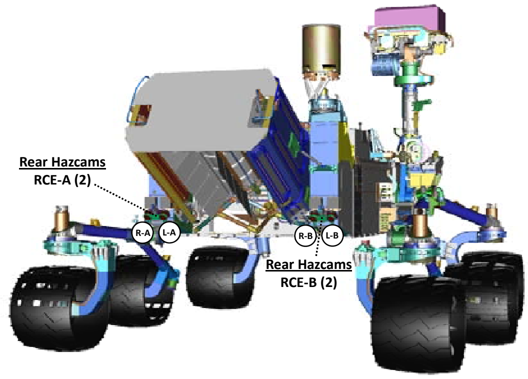

Figure 2. Location of the MSL Rear Hazcams.

The Hazcams are composed of two mechanical housings: a detector head and an electronics box (figure 3). The detector head contains an optical lens assembly and a charge-coupled device (CCD) detector. The electronics box contains the CCD driver electronics, a 12-bit analog-to-digital converter (ADC), and the camera/rover interface electronics. The camera electronics box contains a heater resistor circuit that warms up the electronics (if necessary) to above the minimum operating temperature of -55 degrees C. Because the detector head is thermally isolated from the electronics box, the camera electronics can be heated without significantly warming the detector head, which helps to keep thermally induced CCD dark current to a minimum. Each Hazcam weighs approximately 245 grams and uses approximately 2.2 Watts of power. The MSL Hazcams are build-to-print copies of the Mars Exploration Rover (MER) cameras, which are described in detail in [2]. The main difference between the MER and MSL cameras is that the MSL Hazcams have

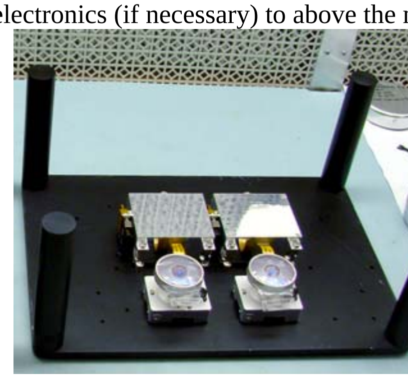

Figure 3. MSL Hazcam camera(s).

slightly more powerful heaters to allow operation at colder ambient temperatures.

Detector: As with the MSL Navcams [1], the MSL Hazcams use flight spare detectors from the MER project. The detectors are 1024 x 2048 pixel Charge Coupled Device (CCD) devices with 12-micron square pixels and a 100% optical fill factor (see table 1). The CCDs operate in frame transfer mode, which divides the detector into two regions: a 1024 x 1024 pixel photosensitive imaging region where the image is recorded, and a 1024 x 1024 shielded storage region in which the recorded image is shifted into and stored during detector readout. The transfer of data from the imaging region to the storage region takes 5.1 ms, and the readout of data from the storage region takes 5.4 s. In addition to the imaging pixels the CCDs also include non-imaging pixels to allow the monitoring of the CCD electronics offset and readout noise. Given the relatively low readout noise and small dark current rates in the Martian operating environments, the signal-to-noise ratio (SNR) of the detector system is essentially Poisson limited. At 50% full well, and an operating temperature of -55 deg. C, the SNR is >200 to 1.

Table 1. Properties of the Hazcam detectors

CCD Full Well	170,000 electrons
CCD Readout Noise (at -55 °C)	25 electrons
CCD Gain (at -55 °C)	50 electrons/DN
ADC Digitization	12 bits/pixel
Frame Transfer Time	5.1 msec
CCD Readout Time (full-frame mode)	5.4 seconds
CCD Readout Time (4 x 1 binned mode)	1.4 seconds
Pixel Size	12 x 12 microns
Fill Factor	100 %
SNR	> 200:1
Exposure time	0-335.5 seconds, in steps of 5.12 msec

Optics: The Hazcams are f/15 cameras with a 5.58 mm focal length. Each Hazcam camera has a 124 degree x 124 degree field of view (180 degree diagonal). The angular resolution at the center of the field of view is 2.1 mrad/pixel. The depth of field of the Hazcam camera ranges from 0.10 m to infinity, with best focus at 0.5 m. The Hazcams use a combination of optical filters to create a red bandpass filter centered at approximately 650 nm. Figure 4 shows the Hazcam spectral responsivity as a function of wavelength. The nominal Hazcam exposure time for a noontime image on the surface of Mars (tau = 0.5) is approximately 0.25 s. This exposure time is 50 times the frame transfer time of 5.1 ms, which ensures that the image signal is significantly larger than the image smear acquired during the frame transfer.

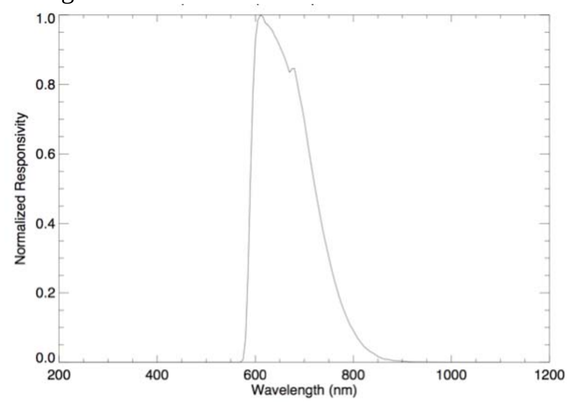

Figure 4. Hazcam optical filter bandpass.

Table 2. Hazcam optical properties

Angular Resolution at the center of the FOV	2.1 mrad/pixel
Focal Length	5.58 mm
f/number	15
Entrance Pupil Diameter	0.37 mm
Field of View	124 x 124 degrees
Diagonal FOV	180 degrees
Depth of Field	0.10 meters – infinity
Best Focus	0.5 meters
Spectral Range	600-800 nm

Operational Use: The MSL Hazcams will be utilized in a manner similar to that of the MER Hazcams. This usage will include the acquisition of images for robotic arm planning, operational and scientific documentation, rover fine positioning, and general surface imaging.

References: [1] Maki, J.N., et al., The Mars Science Laboratory (MSL) Navigation Cameras (Navcams), 42nd Lunar and Planetary Science Conference, 2011. [2] Maki, J. N., et al., Mars Exploration Rover Engineering Cameras, J. Geophys. Res., 108(E12), 8071, doi:10.1029/2003JE002077, 2003, [3] Smith, G. H., et al., J. F., Optical designs for the Mars '03 rover cameras (Proceedings Paper), SPIE Proceedings, 5 December 2001, doi: 10.1117/12.449558.