THE MARS SCIENCE LABORATORY (MSL) NAVIGATION CAMERAS (NAVCAMS). 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 for launch in November/December 2011) will fly four Navigation Cameras (Navcams). The key requirements of the Navcam imaging system are: 1) provide terrain context for traverse planning and Mastcam/Chemcam pointing, 2) provide a 360-degree field of regard at <1 mrad/pixel angular resolution, 3) provide stereo ranging data out to 100 m, and 4) use of a broadband, visible filter. The Navcams were built at the Jet Propulsion Laboratory in Pasadena, CA.

Instrument Details: The mounting locations of the Navcams are shown in figure 1.

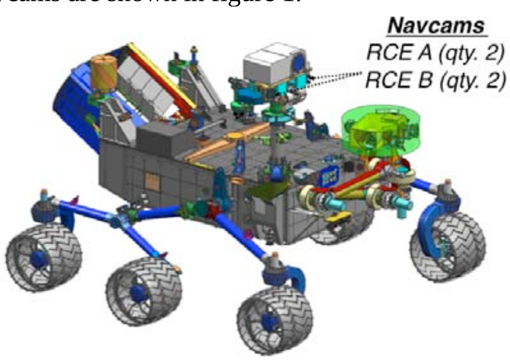

Figure 1. Location of MSL Navcams.

The Navcams are attached to a camera mounting plate with a left/right stereo baseline of approximately 42 cm. There are two pairs of Navcams on the MSL Rover (four Navcams total). One Navcam pair is connected to the Rover Compute Element (RCE) "A-side" electronics and the other pair is connected to the RCE "B-side" electronics. Only one RCE is active at a time, the second RCE is for fault redundancy.

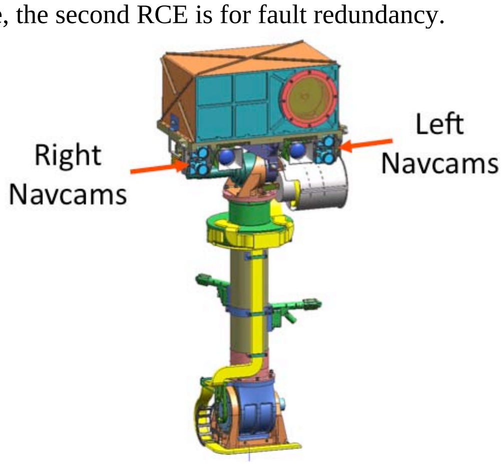

Figure 2. The MSL Navcams on the Remote Sensing Mast (RSM).

The camera plate, which also holds the Mastcam and Chemcam instruments, is mounted to a 0.85-meter high Remote Sensing Mast (RSM), which points the cameras in the azimuth and elevation directions. The RSM is attached to the rover deck, which is 1.1 meters above the nominal surface. The resultant configuration places the Navcams 1.9 meters above the Martian surface (0.4 meters higher than the MER Navcams).

The MSL Navcams are build-to-print copies of the Mars Exploration Rover (MER) cameras, which are described in detail in [1]. The main difference between the MER and MSL cameras is that the MSL Navcams have slightly more powerful heaters to allow operation at colder ambient temperatures.

The Navcam is 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 mini-

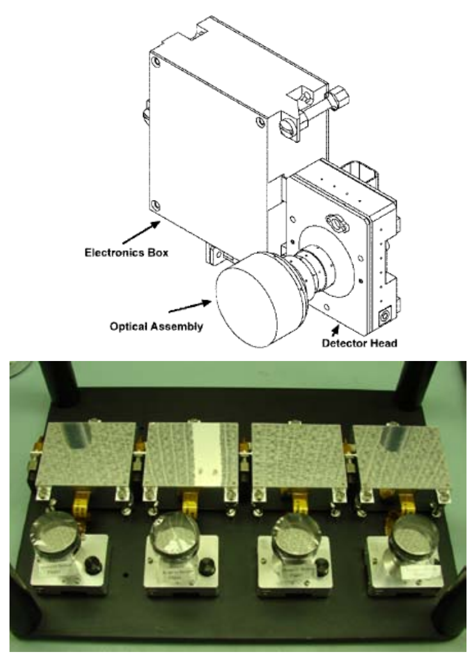

Figure 3. MSL Navcam camera(s).

mum. Each Navcam weighs approximately 220 grams and uses approximately 2.2 Watts of power.

Detector: The MSL Navcams use flight spare detectors from the MER. 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, detector noise, 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 Navcam 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 Navcams are f/12 cameras with a 14.67 mm focal length [2]. Each Navcam camera has a 45 degree x 45 degree field of view (60.7 degree diagonal), which is roughly equivalent to a 40 mm lens on a 35 mm camera. The angular resolution at the center of the field of view is 0.82 mrad/pixel. The depth of field of the Navcam camera ranges from 0.5 m to infinity, with best focus at 1.0 m. The Navcams use a combination of optical filters to create a red bandpass filter centered at approximately 650 nm. Figure 4 shows the Navcam spectral responsivity as a function of wavelength. The nominal Navcam 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.

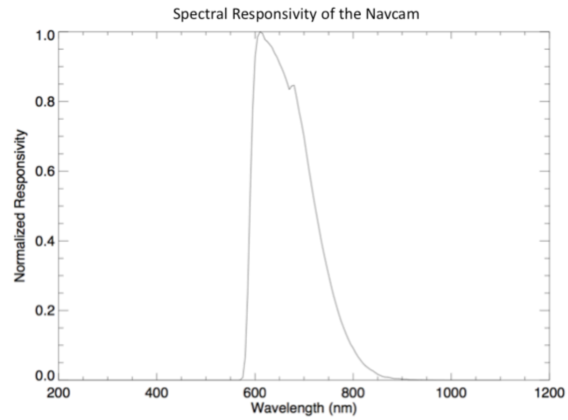

Figure 4. Navcam optical filter bandpass properties.

Table 2. Properties of the Navcam optical assembly

Angular Resolution at the center of the FOV	0.82 mrad/pixel
Focal Length	14.67 mm
f/number	12
Entrance Pupil Diameter	1.25 mm
Field of View	45 x 45 degrees
Diagonal FOV	67 degrees
Depth of Field	0.5 meters – infinity
Best Focus	1.0 meters
Spectral Range	600-800 nm

Operational Use: The MSL Navcams will be utilized in a manner similar to that of the MER Navcams. This usage will include the acquisition of images for rover navigation, robotic arm planning and documentation, remote sensing science instrument pointing, and general surface imaging. In addition to the MER-heritage uses described above the MSL Navcams will also play a key role in the selection, delivery, and documentation of surface material for the MSL Sample Acquisition, Processing, and Handling Subsystem (SA/SPaH).

References: [1] Maki, J. N., et al., Mars Exploration Rover Engineering Cameras, J. Geophys. Res., 108(E12), 8071, doi:10.1029/2003JE002077, 2003. [2] Smith, G.H., Hagerott, E.C., Scherr, L.M., Herkenhoff, K. E., Belll, J. F., Optical designs for the Mars '03 rover cameras (Proceedings Paper), SPIE Proceedings, 5 December 2001, doi: 10.1117/12.449558