THE MARS EXPLORATION ROVER CAMERAS: A STATUS REPORT. M. A. Schwochert[1] and J. N. Maki[1], [1]Jet Propulsion Laboratory, 4800 Oak Grove Drive Pasadena, CA 91109.; Mark.A.Schwochert@jpl.nasa.gov.

Introduction: With more than 68,000 images returned from the surface of Mars to date, the Mars Exploration Rover (MER) camera suite continues to perform extremely well. Image signal to noise ratios (SNRs) are greater than 200:1, flat fields remain stable, and single-pixel degradation has been negligible. Acting as the eyes of the robotic field geologists, the 18 MER cameras continue to play a leading role in major scientific findings at both Gusez Crater [1] and Meridiana Planum [2].

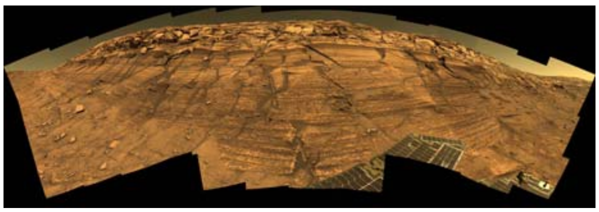

Figure 1: Pancam panorama of "Burns Cliff" taken in "Endurance Crater" using Mars Exploration Rover Opportunity Pancam Camera. This 180 degree mosaic is an approximate true color image using 3 of the Pancam's 13 color filters.
Image Credit: NASA/JPL/Cornell.

Figure 2: This Micro-Imager image reveals features that were likely produced by liquid water.
Image credit: NASA/JPL/Cornell/USGS

All 4 types of cameras, the hazard avoidance (Hazcam), navigation (Navcam), the color panoramic (Pancam) and the microscopic imager (MI), continue to return data from the Martian surface from both Rovers (see table 1). In addition to the rover cameras, each lander utilized a descent imager (DI) to help facilitate safe landing and provide landing site context [3].
The Pancam [4] and MI [5] are part of the scientific instrument payload of the rovers. In addition to gathering science image data, the Pacams also support sun finding and measure atmospheric dust optical depth. The Hazcam and Navcam stereo pairs are used for traverse planning, autonomous navigation and general imaging[6,7].

Camera	Spirit (# of images)	Opportunity (# of images)
EDL	3	3
Rear Hazcam	1254	388
Front Hazcam	5589	1748
Navcam	4682	5173
MI	1655	2349
Pancam	23425	21997
Total	**36608**	**31658**

Table 1: Number of images returned by the MER Camera Suite as of Januuary 4, 2005.

Figure 3: Navcam mosaic acquired immediately after the Spirit rover egress from the lander.

Modular design approach. The strategy of adopting a common design approach for all of the MER cameras and image data has resulted in significant cost savings and complexity reduction. Because each camera shares the identical electrical and mouting interfaces (the only difference between the cameras are the lens assemblies [8]), the operation of the cameras on the Martian surface is greatly simplified. Because each camera utilizes identical frame transfer CCDs with the same 1024x1024 pixel format, identical ground processing software is used on all the image data.

The modular design approach was key to minimizing the camera cost by reducing the non-recurring design effort. It also eased assembly, testing and reduced the number of required spare parts. Twenty (20) flight, four (4) flight spare and seventeen (17) engineering model cameras were designed, assembled, tested and delivered by JPL's Instruments and Science Data Systems Division to the MER project for less than $14M ($700k per flight camera).

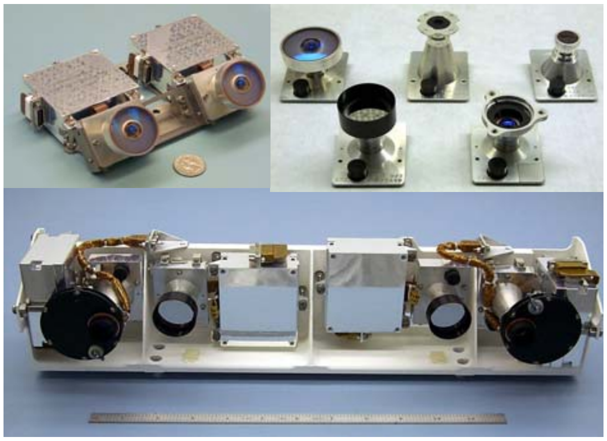

Figure 4: Pancam and Navcam stereo pair cameras shown mounted to the Pancam Mast Assembly camera bar (12inch/30.5cm ruler shown for scale). Also shown above are an Engineering model Hazcam stereo pair mounted on camera bar bracket (US 25¢ piece shown for scale) and the five types of MER camera lens assemblies.

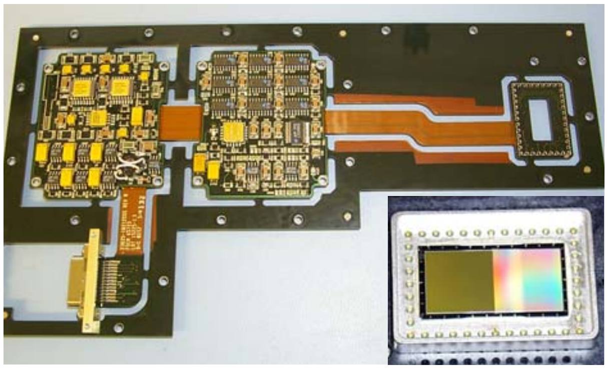

Figure 5: MER camera electronics rigid/flex printed wiring board assembly with CCD package (shown in inset).

Future Use of the MER Cameras: Resource constraints (mass, power and volume) on the rovers were very tight. To ease accommodation the cameras designs were kept as simple as possible. The modular design approach allows for easy adaptation of potential modifications to enhanced performance in support of future Mars or other planetary missions. Higher frame rates can be achieved with use of inter-line transfer CCDs, other detector technologies or by increasing the instrument power allocation. The addition of frame buffering and/or data-compression capability within the camera might also be beneficial to offload the system resources. Different optical designs and filtering to achieve varying fields of view and spectral passbands can also be easily accommodated.

Parameter	Value
Mass	< 265 grams per camera
Volume	< 470 cm^3
Operating Power	2W continuous, 3W peak
Warm-Up Heater	2.7 W
Electrical Interface	LVDS
Encoding	12 bits
Data Transfer Rate	200 kpixels/second
Operating Temp Range	-55°C to + 22°C
Survival Temp Range	-120°C to + 70°C
Detector Full Well	220,000 electrons (e$^-$)
Read Noise	< 25 e$^-$ RMS
Dark Current	25 e$^-$/pixel/sec @ -20°C
Exposure Time Range	0 to 335 sec, 5 msec steps

Table 2: Characteristics common to all of the MER camera types.

Parameter	Camera/Value	
	Pancam	MI
Passband	400-1000 nm	400-680 nm
Working F/#	20	15
Field of View	16x16 deg	30.7x30.7 mm
Best Focus	3000 mm	63 mm
Depth of Field	1500 mm – inf.	+/- 3 mm
Parameter	**Navcam**	**Hazcam**
Passband	600-800 nm	600-800 nm
Working F/#	12	15
Field of View	45x45 deg	120x120 deg
Best Focus	1000 mm	400 mm
Depth of Field	500 mm – inf.	100 mm – inf.

Table 3: Optical properties of the MER science and engineering cameras. (Descent Imager not shown since it is the same as the Navcam with different filtering).

References: [1] Squyres S. W. et al. (2004) *Science*, 305, 794-799. [2] Squyres S. W. et al. (2004) *Science*, 306, 1698-1703. [3] Chang Y. et al. (2004) *IEEE Intelligent Systems*, 13–21. [4] Bell J. F. III et al. (2003) *JGR*, 108 (E12), 8063. [5] Herkenhoff et al. (2003) *JGR*, 108 (E12), 8065. [6] Maki J. N. et al. (2003) *JGR*, 108 (E12), 8071. [7] Eisenman A. R. et al. (2001) *Proc. SPIE.*, *4540*, 288-297. [8] Ford V. G. et al. (2002) *Proc. SPIE*, *4771*, 214–221.