Pancam: A Multispectral Imaging Investigation on the NASA 2003 Mars Exploration Rover Mission.

J.F. Bell III[1], S.W. Squyres[1], K.E. Herkenhoff[2], J. Maki[3], M. Schwochert[3], A. Dingizian[3], D. Brown[3], R.V. Morris[4], H.M. Arneson[1], M.J. Johnson[1], J. Joseph[1], J.N. Sohl-Dickstein[1], and the Athena Science Team. [1]Cornell University, Dept. of Astronomy, Ithaca NY 14853-6801; jfb8@cornell.edu, [2]USGS Branch of Astrogeology, Flagstaff AZ 86001, [3]JPL/Caltech, Pasadena CA 91109, [4]NASA/JSC, Code SR, Houston TX 77058.

Introduction: One of the six science payload elements carried on each of the NASA Mars Exploration Rovers (MER; Figure 1) is the Panoramic Camera System, or Pancam. Pancam consists of three major components: a pair of digital CCD cameras, the Pancam Mast Assembly (PMA), and a radiometric calibration target [1]. The PMA provides the azimuth and elevation actuation for the cameras as well as a 1.5 meter high vantage point from which to image. The calibration target provides a set of reference color and grayscale standards for calibration validation, and a shadow post for quantification of the direct *vs.* diffuse illumination of the scene. Pancam is a multispectral, stereoscopic, panoramic imaging system, with a field of regard provided by the PMA that extends across 360° of azimuth and from zenith to nadir, providing a complete view of the scene around the rover in up to 12 unique wavelengths. The major characteristics of Pancam are summarized in Table 1.

The scientific goals of the Pancam investigation are to: (a) obtain monoscopic and stereoscopic images and mosaics to assess the morphology, topography, magnetic properties, and geologic context of the two MER landing sites–nominally Gusev crater and Meridiani Planum; (b) obtain multispectral images of selected regions to determine surface color and mineralogic properties; (c) obtain multispectral images over a range of viewing geometries to constrain surface photometric and physical properties; and (d) obtain images of the Martian sky and Sun to determine dust and aerosol opacity and physical properties. In addition, Pancam also serves a variety of operational functions on the MER mission, including (e) serving as the primary Sun-finding camera for rover navigation; (f) resolving objects on the scale of the rover wheels to distances of ~100 m to help guide tactical rover navigation decisions; (g) providing stereo coverage adequate for the generation of digital terrain models to help guide and refine strategic rover traverse decisions; (h) providing high resolution images and other context information to guide the selection of the most interesting *in situ* sampling targets; and (i) supporting acquisition and release of exciting education and public outreach (E/PO) products.

Pancam utilizes two 1024×2048 Mitel frame transfer CCD detector arrays, each having a 1024×1024 active imaging area, a 1024×1024 masked frame transfer storage area, and 32 additional serial register reference pixels per row for offset monitoring (Figure 2). Each array is combined with optics and a small 8-position filter wheel to become one "eye" of a multispectral, stereoscopic imaging system. The optics for both cameras consist of identical 3-element symmetrical lenses with an effective focal length of 42 mm and a focal ratio of *f*/20, yielding an IFOV of 0.28 mrad/pixel or a rectangular Field of View (FOV) of 16°× 16° per eye (Figures 3,4). The two eyes are separated by 30 cm horizontally and have a 1° toe-in to provide adequate parallax for stereo imaging (Figure 5). The camera FOVs have been determined relative to the adjacent wide-field stereo Navigation Cameras, and the Mini-TES FOV. The Pancam optical design is optimized for best focus at 3 meters range, and allows Pancam to maintain acceptable focus from infinity to within 1.5 meters of the rover.

Each eye's 8-position filter wheel allows multispectral sky imaging, direct Sun imaging, and surface geologic and mineralogic studies in the 400-1100 nm wavelength region (Table 2 and Figure 6). The filters have been selected to sample (a) the near-UV to visible ferric absorption edge from ~440 to 750 nm, the slope of which has been shown to be an indicator of ferric mineral crystallinity [*e.g.,* 2], (b) two crystalline ferric oxide absorption features typically centered near 650 nm and 860-900 nm, which have specific band centers that are diagnostic of oxide vs. oxyhydroxide compositions [*e.g.,* 2,3], and (c) the short wavelength wing of the classic "1 micron" absorption band in ferrous silicates like pyroxene, which has a band shape and position that can be diagnostic of the specific pyroxene (Ca, Fe, Mg) chemistry [*e.g.,* 4].

Pancam has been designed to operate within calibrated specifications from -55°C to +5°C. The cameras have undergone standard CCD, radiometric, and geometric calibrations both at the component and system (rover) level. These calibrations include characterization of the dark current and bias, flatfield, and system-level spectral responsivity of each camera.

An onboard calibration target and fiducial marks provide the ability to validate the radiometric and geometric calibration on Mars. The calibration target (Figure 7) is mounted on the -X solar panel and provides a set of well-characterized grayscale and color materials to validate or re-derive the spectroradiometric coefficients needed to convert instrumentally-corrected DNs into calibrated radiances. The target also serves a secondary role as part of a web-based "Mars sundial" E/PO and K-12 curriculum project.

Pancam relies heavily on use of the JPL ICER and LOCO compression algorithms to maximize data return within stringent mission downlink limits. All calibration and flight data products will be generated, archived, and released with the NASA Planetary Data System in PDS image format.

Table 1. Pancam Instrument Characteristics
Mechanical/Environmental
• Two independent digital CCD cameras
• 30 cm stereo separation, 1° toe-in
• Mast-mounted, 1.54 meters above surface
• 360° azimuth and ±90° elevation actuation
• Mass of each camera: ~270 g
• Typical power consumption ~3 W per camera
• Operating temp. within specs: -55°C to +5°C
• Onboard calibration target, fiducial marks
• Each camera has an 8-position filter wheel
• Uses ICER (wavelet) and LOCO (JPEG) compression algorithm
Optics
• 3-element Cooke triplet lens design (G. Smith)
• 43 mm focal length, *f*/20 system
• < 0.01% f tanθ geometric distortion
• Optimal focus: 3 m; Focus range: 1.5 m to ∞
• IFOV = 0.28 mrad/pixel; FOV = 16° × 16°
• Equivalent to a 109 mm lens on a 35 mm camera
• Narrowband interference filters (Omega Optical)
• Sapphire window for dust protection
• External sun shade, internal stray light baffles
• Boresight calibrated with Navcams, Mini-TES
CCD
• 1024 × 2048 Mitel frame transfer CCD
• 12 µm square pixels, 100% fill factor
• Opaque Al shield over storage region
• Full well capacity = 170,000 ± 20,000 e^-
• System Gain = 50±3 e^-/DN
• System Read Noise = 25±5 e^- at -55° C
• SNR ≥ 200 in all λ's at 50% full well
• Absolute radiometry ≤ 7%, relative ≤ 1%
• Dark current @ 27°C = 1.5 nA/cm^2
• Dark current spatial nonuniformity < 5%
• Linearity > 99% from 10 to 90% full well
• Flatfield spatial nonuniformity < 1%
• 32 "reference" pixels beyond imaging area
• CCD frame transfer time = 5.2 msec
• CCD readout rate = 200 kpix/sec (5.2 sec)
• Integration time : 0-350 sec, Δ = 5.1 msec
• 4 × 1 hardware ("on chip") binning option
Calibration Target
• 8 × 8 cm base, 6 cm high post, 60 g mass
• Three rings with 20, 40, 60% reflectivity
• Four colored corners for color calibration
• Vertical post casts shadow across all three rings to calibrate diffuse illumination
• Two mirrored annuli reflect sky color
• Fully illuminated by the Sun from at least 10 a.m. to 2 p.m. local solar time for nominal rover orientations
• Target is embellished with motto, markings, and drawings to be a "Mars Sundial" for E/PO activities

Table 2. Pancam Filter Characteristics

Name	λ_{eff} (nm)	Bandpass (nm)	Comment
Left Camera			
L1	719	179	EMPTY
L2	753	20	Red Stereo L
L3	673	16	Geology
L4	602	17	Geology
L5	535	19	Geology
L6	483	27	Geology
L7	440	25	Blue Stereo L
L8	440	20	Solar ND5
Right Camera			
R1	440	25	Blue Stereo R
R2	754	19	Red Stereo R
R3	803	20	Geology
R4	864	17	Geology
R5	903	25	Geology
R6	933	24	Geology
R7	1001	28	Geology
R8	880	20	Solar ND5

References: [1] Bell, J.F. III *et al.* (2003) submitted to *J. Geophys. Res.* [2] Morris, R.V. *et al.* (2000) *J. Geophys. Res.*, *105*, 1757-1817. [3] Morris, R.V. *et al.* (1985) *J. Geophys. Res.*, *90*, 3126-3144. [4] Cloutis, E.A. *et al.* (1986) *J. Geophys. Res.*, *91,* 11641-11653. [5] Smith, P.H. *et al.* (1997) *J. Geophys. Res., 102,* 4003-4025.

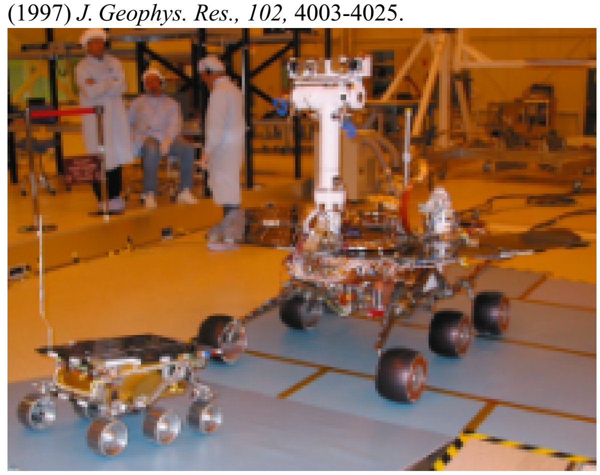

Figure 1. Flight model 2 rover (background) in driving configuration, compared to the Pathfinder flight spare rover Marie Curie (foreground). The Pancams are the two outer cameras on the top of the mast assembly, at a height of approximately 1.5 meters above the surface.

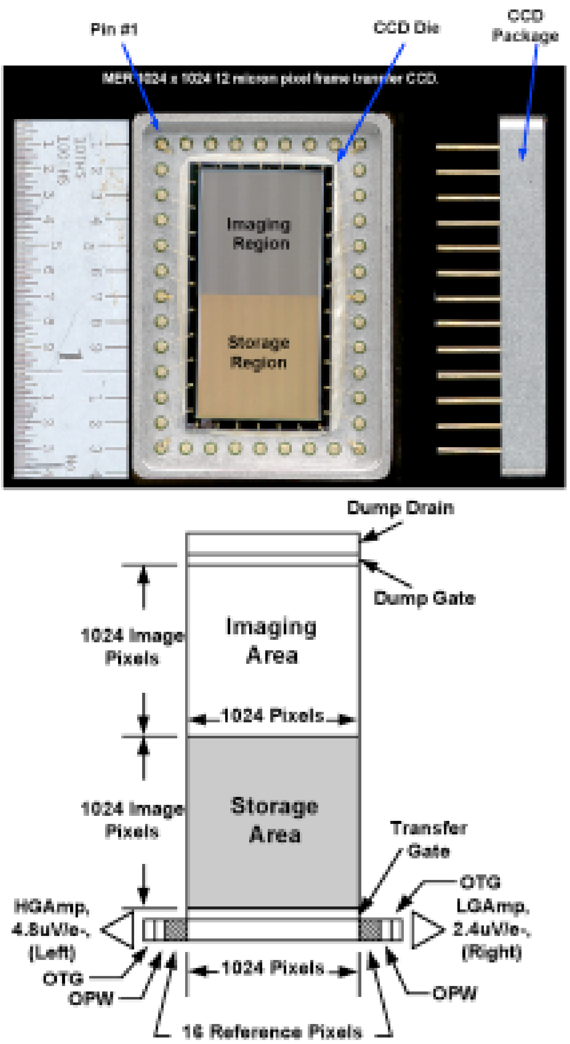

Figure 2. MER CCD package and schematic representation.

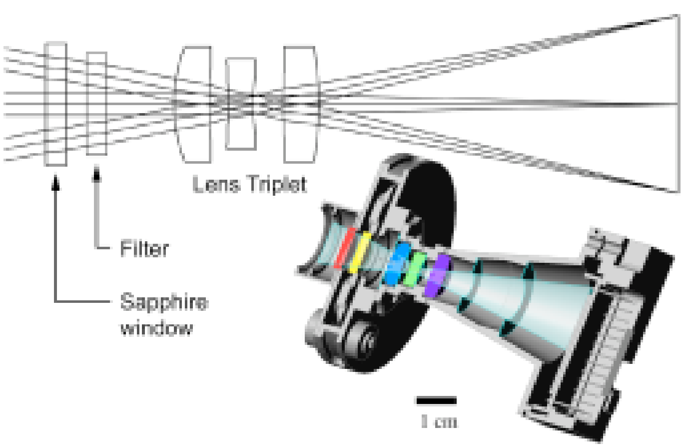

Figure 3. Pancam optics schematic (top) and CAD cross-sectional view (bottom).

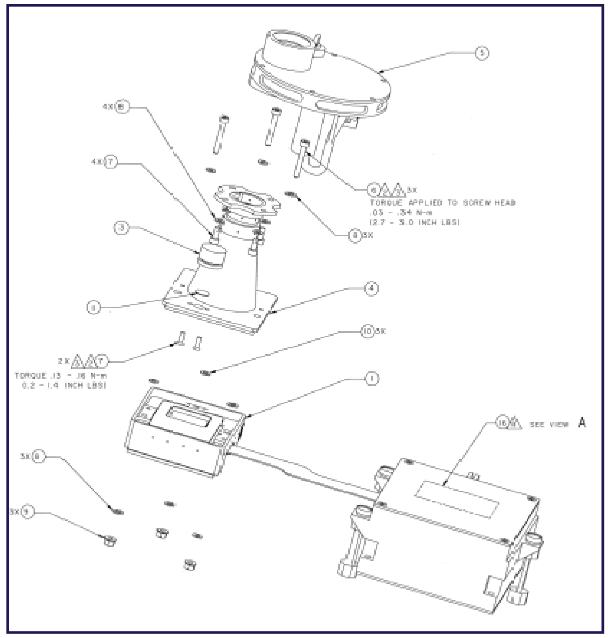

Figure 4. Schematic of the MER Pancam instrument. The instrument consists of a filter wheel, motor and housing (top), optics lens barrel assembly (middle left), CCD housing assembly (lower left), and a separate box containing the FPGA and other electronics (bottom). For scale, the electronics box is ~6.5 cm long.

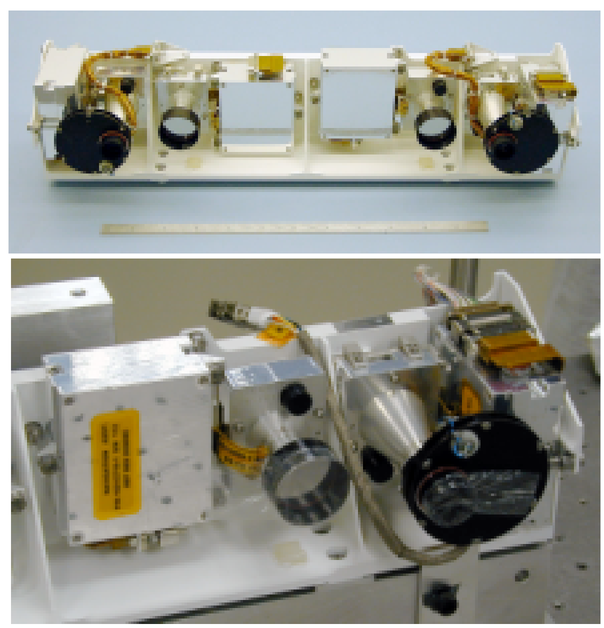

Figure 5. The MER-2 flight rover's camera bar (top), and an enlarged view (bottom) of the left Pancam (far right) and Navcam (center) instruments. The ruler at top is 30.5 cm long. The Pancam are toed-in by 1° to optimize near-field stereo ranging overlap.

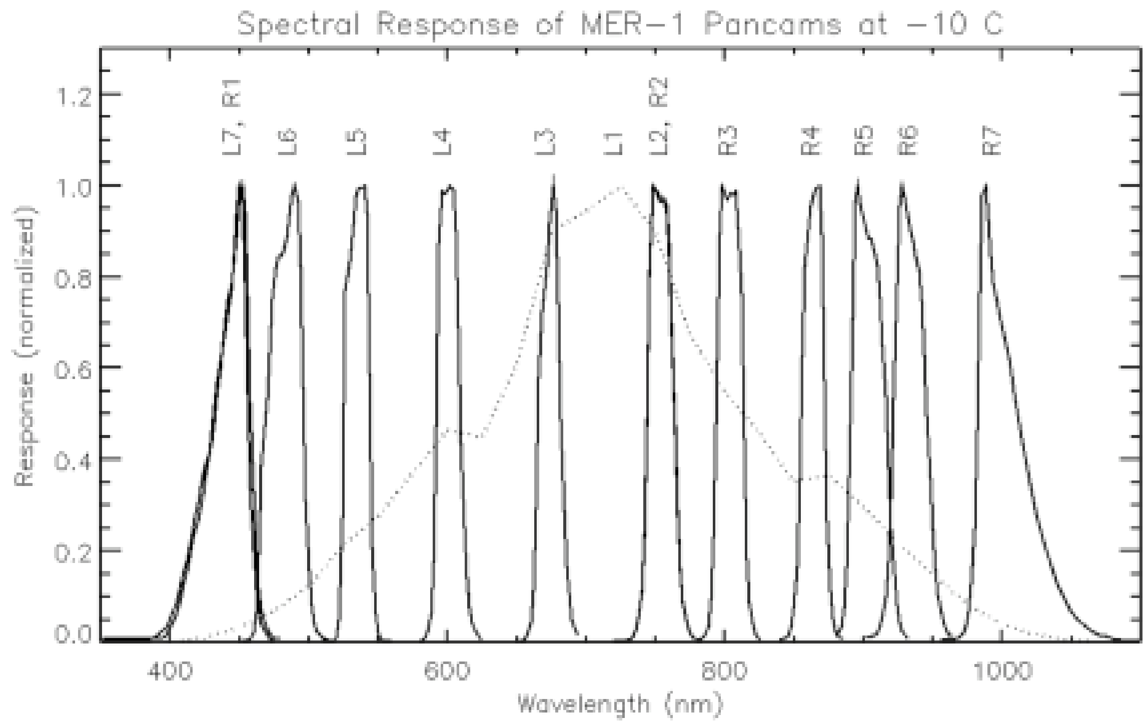

Figure 6. Normalized spectral response profiles of the Pancam multispectral "geology" filters. "L" designates left camera, "R" designates right. Solar ND filters not shown.

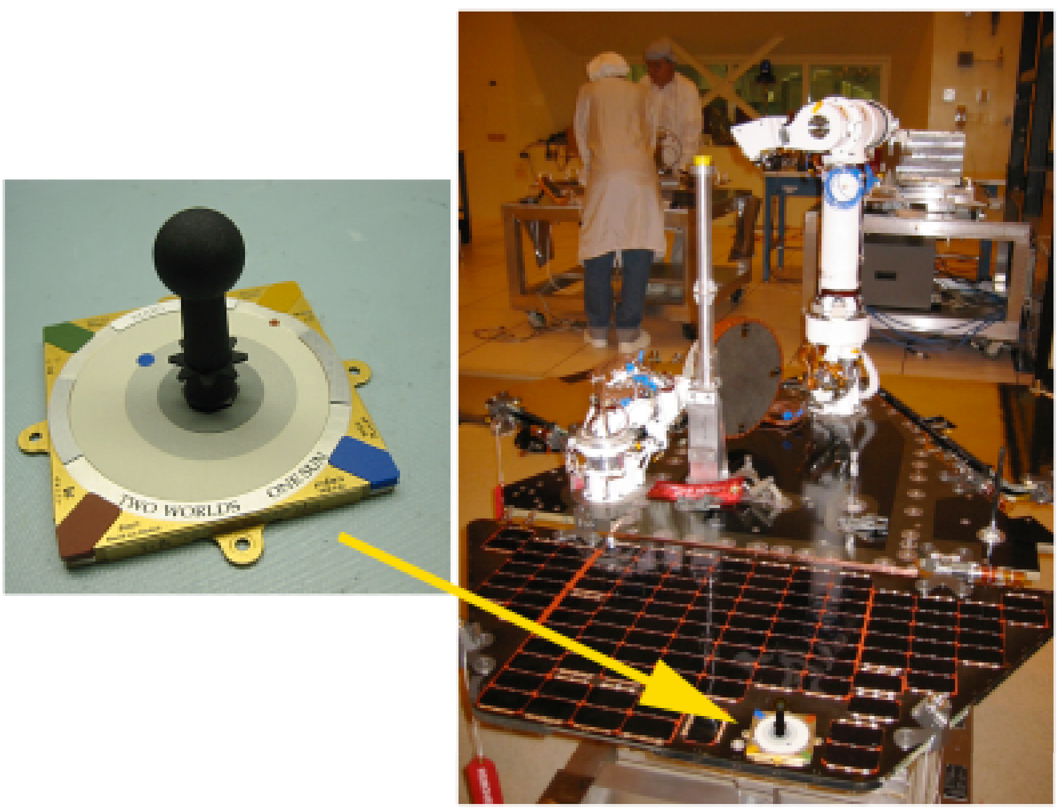

Figure 7. Pancam calibration target. The three grayscale rings are 20%, 40%, and 60% reflective, and the colored corners contain oxide pigments with distinct spectral characteristics in the visible to near-IR. The base is 8 × 8 cm size and the post is 6 cm high. The basic design is modeled closely on the Mars Pathfinder IMP target design [5].