The Mars Science Laboratory (MSL) Mast-Mounted Cameras (Mastcams) Flight Instruments. M. C. Malin[1], M. A. Caplinger[1], K. S. Edgett[1], F. T. Ghaemi[2], M. A. Ravine[1], J. A. Schaffner[1], J. M. Baker[3], J. D. Bardis[4], D. R. DiBiase[4], J. N. Maki[5], R. G. Willson[5], J. F. Bell III[6], W. E. Dietrich[7], L. J. Edwards[8], B. Hallet[9], K. E. Herkenhoff[10], E. Heydari[11], L. C. Kah[12], M. T. Lemmon[13], M. E. Minitti[14], T. S. Olson[15], T. J. Parker[5], S. K. Rowland[16], J. Schieber[17], R. J. Sullivan[6], D. Y. Sumner[18], P. C. Thomas[6], and R. A. Yingst[19], [1]Malin Space Science Systems, PO Box 910148, San Diego CA 92191-0148, [2]Tony Ghaemi Optical Engineering, [3]Northrop Grumman Corporation, [4]Alliance Spacesystems, LLC, [5]Jet Propulsion Laboratory, [6]Cornell University, [7]University of California–Berkeley, [8]NASA Ames Research Center, [9]University of Washingon, [10]US Geological Survey–Flagstaff, [11]Jackson State University, [12]University of Tennessee–Knoxville, [13]Texas A&M University, [14]Arizona State University, [15]Salish Kootenai College, [16]University of Hawaii, [17]Indiana University–Bloomington, [18]University of California–Davis, [19]Planetary Science Institute.

Introduction: The Mast-mounted Cameras (Mastcams) are a two instrument suite of imaging systems on the Mars Science Laboratory rover's Remote Sensing Mast (RSM). Malin et al. [1] described the science objectives of the Mastcam investigation.

History: The Mastcam investigation was proposed to NASA in July 2004 and selected in December 2004. As late as the instrument Critical Design Review in February 2007, the Mastcams consisted of two identical area-array digital cameras with 15:1 zoom telephoto lenses, with electronics identical to those of the MSL MARDI and MAHLI. These cameras would have provided same-focal-length binocular vision for stereoscopic studies as well as 14 filter positions for scientific multispectral studies.

Unfortunately, in September 2007, NASA Associate Administrator (at the time) Alan Stern directed (without consultation with the PI) that the Mastcam be descoped to insure against potential cost increases (the cameras were not and have not at any time been over cost), explicitly directing that the zoom and focus capabilities be removed from the cameras. The PI and his team subsequently successfully argued that the focus capability was necessary to retain technical capabilities that the MSL Project had assumed would be available (e.g., the ability to acquire in-focus images of the sampling workspace). Between November 2007 and January 2008, new camera designs (based on the MAHLI focus mechanism design) were generated.

Designing and developing the new lenses and mechanisms in less than a year—combined with vendor difficulty in fabricating the Mastcam narrowband color filters—resulted in a planned late delivery in December 2008, mitigated by the subsequent launch slip from 2009 to 2011. The cameras have been completed (Fig. 1) and calibrated (Fig. 2), and will be delivered to JPL early in 2010.

Instrument Details: The Mastcams are two cameras with different focal lengths and different science color filters. One camera, referred to as the "M-34" has a 34 mm focal length, f/8 lens that illuminates a 15° × 20° FOV over 1200 × 1600 pixels with slight corner vignetting. A typical image is likely to be 1152 × 1536 pixels owing to JPEG encoding constraints. The other camera, referred to as "M-100," has a 100 mm focal length, f/10 lens that illuminates a 5.1° × 6.8°, 1200 × 1600 pixel FOV. Both cameras can focus from closer than 2.1 m (nearest view to the surface) and to infinity. The M-100 IFOV is 7.4×10^{-5} radians, yielding 7.4 cm/pixel scale at 1 km distance and ~150 µm/pixel scale at 2 m distance. The M-34 IFOV is 2.2×10^{-4} radians, giving a pixel scale of 450 µm at 2 m distance and 22 cm at 1 km. A strict definition of "in focus" is used for these cameras wherein the optical blur circle is ≤ 1 pixel.

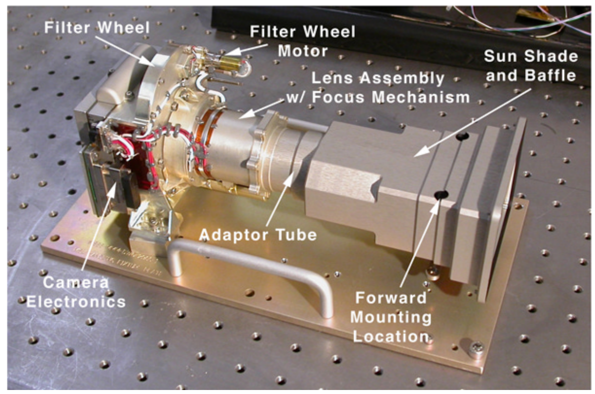

Fig. 1. The flight Mastcam-100 camera head. The 34 mm Mastcam is essentially identical in configuration.

Each camera has an 8 Gbyte internal buffer that permits it to store about 4,200 raw frames. Each is capable of losslessly compressing the images, or applying lossy JPEG compression, in realtime during acquisition and storage, or during readout of the buffer. A full-scale mosaic of 360° × 80° imaged in 3 science color filters with ≥ 20% overlap between adjacent images with lossless compression is about 6.6 GBytes; with minimally lossy JPEG compression, ≤ 2.5× (3.2 bits/pixel), a mosaic including all science filters could be acquired. This is much more than can be sent back to Earth under normal communication limitations. Subframing of images is also available during image acqusition but not after and pixel summing is not available. Color 144 × 192 pixel thumbnail images can be created and compressed during readout, or from previously acquired raw or compressed images. Mosaics of thumbnail images from the M-34 can be used to synthesize wider-angle FOVs.

Fig. 2. Mosiac of 3 Mastcam-100 images of a rock sample target provided by Richard Morris, and the flight Mastcam Calibration Target (MER Pancam spare unit, foreground), imaged from 2.1 m distance through the broadband Bayer filters.

Both Mastcams are color imagers (Fig. 2). Integrated over each detector is an RGB Bayer pattern filter. A broadband (IR cutoff) filter through which RGB imaging will occur is included in one of the 8 filter positions within each camera's filter wheel. Both cameras also have a narrow band filter with 10^5 neutral density attenuation to image the sun. The filters are distributed between the 34 mm and 100 mm cameras to ensure each can address some of the compositional objectives of the investigation should the other camera fail. The science filters are imaged through the RGB filter array (Fig. 3); for some science filters, the throughput in some pixels of the unit cell will be poorer than in other pixels, but beyond 700 nm, all three Bayer colors have nearly identical throughput (i.e., they have large IR leaks, that we are using to our advantage). In-flight calibration uses the MER Pancam [2] spare target (foreground at bottom of Fig. 2) with magnets mounted beneath the 4 color chips and "white" and gray surfaces to provide dust-free spots (following the approach of the Phoenix SSI team).

Mastcam hardware and internal processing permits a wide range of operational flexibility. Each camera is capable of acquiring images at very high frame rates compared to previous missions, including 720p high definition video (720 × 1280 pixel) at ~8 frames per second, and full science frames at somewhat greater than 4.5 fps. Traverse of the full focus range requires between 45 and 60 seconds, but autofocus around a known focus position can be accomplished much faster. Changes to consecutive filter positions takes 5–8 seconds, and between 30 and 45 seconds to rotate the filter wheel a full 360°. Mosaic acquisition is paced by the time it takes the rover RSM to move and for motion induced vibration to settle (≥ 5 seconds between movements). The cameras include auto- and commanded-focus capability and auto- and commanded-exposure control. Radiometric accuracy is better than 10–15%, and precision 5–8%. Exposure times are expected to vary from a few tens of msec to a couple of hundred msec, depending on the filter bandpass and the desired signal-to-noise ratio.

References: [1] Malin, M. C. *et al.* (2005) *LPSC XXXVI,* Abstract #1214. [2] Bell III, J.F. *et al.* (2003) JGR, 108, E12, 8063.

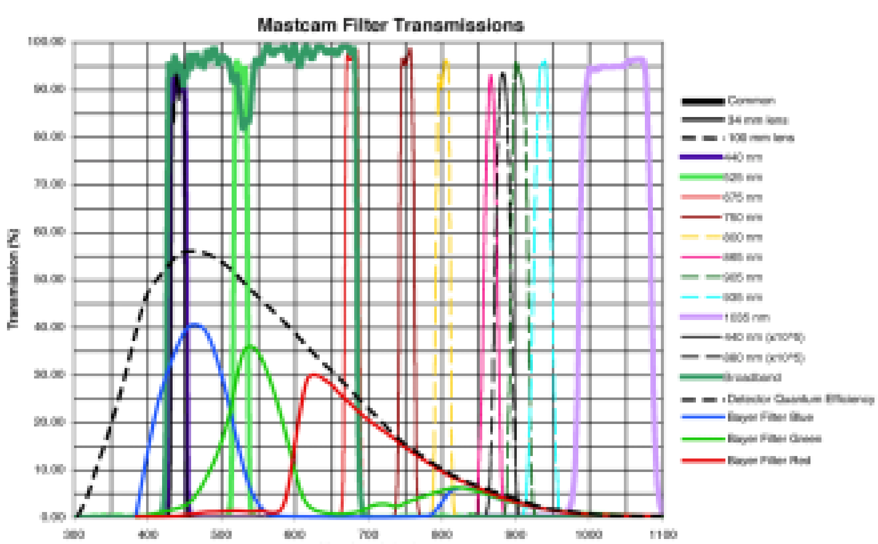

Fig. 3. Mastcam Bayer pattern filter and science filter transmission.