THE MARS SCIENCE LABORATORY (MSL) MARS DESCENT IMAGER (MARDI) FLIGHT INSTRUMENT. M. C. Malin[1], M. A. Caplinger[1], K. S. Edgett[1], F. T. Ghaemi[1], M. A. Ravine[1], J. A. Schaffner[1], J. N. Maki[2], R. G. Willson[2], J. F. Bell III[3], J. F. Cameron[4], W. E. Dietrich[5], L. J. Edwards[6], B. Hallet[7], K. E. Herkenhoff[8], E. Heydari[9], L. C. Kah[10], M. T. Lemmon[11], M. E. Minitti[12], T. S. Olson[13], T. J. Parker[2], S. K. Rowland[14], J. Schieber[15], R. J. Sullivan[3], D. Y. Sumner[16], P. C. Thomas[3], and R. A. Yingst[17], [1]Malin Space Science Systems, PO Box 910148, San Diego CA 92191-0148, [2]Jet Propulsion Laboratory, [3]Cornell University, [4]Lightstorm Entertainment, [5]University of California–Berkeley, [6]NASA Ames Research Center, [7]University of Washington, [8]US Geological Survey–Flagstaff, [9]Jackson State University, [10]University of Tennessee–Knoxville, [11]Texas A&M University, [12]Arizona State University, [13]Salish Kootenai College, [14]University of Hawaii, [15]Indiana University–Bloomington, [16]University of California–Davis, [17]Planetary Science Institute.

Introduction: The Mars Descent Imager (MARDI) is a fixed-focus color camera mounted on the forward port side of the Mars Science Laboratory (MSL) rover. The optic axis points in the +Z direction (towards the ground). The camera can obtain 1600 x 1200 pixel images at a rate of 4.5 frames per second throughout the period between heatshield separation and touchdown plus a few seconds (a period of about two minutes). The rover software issues a start imaging command (that includes the frame rate and the number of frames; substantial margin is commanded to take into account unusually long descent durations) and the camera operates thereafter autonomously. The data are written into permanent flash memory in realtime during acquisition for later transmission. Hundreds of images will be acquired at scales many times greater than available from orbit.

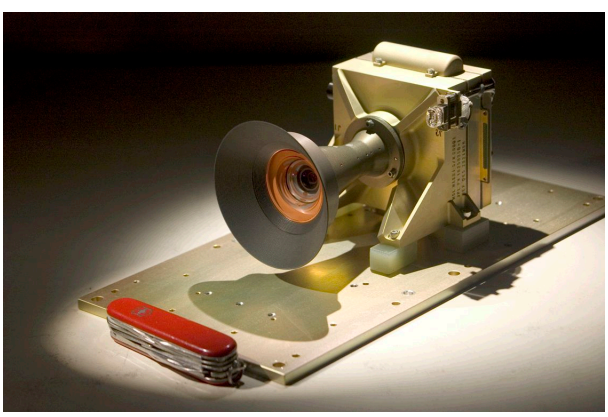

Fig. 1. The flight MARDI camera head with pocket knife (88.9 mm long) for scale.

Objectives: The MARDI (Fig. 1) science investigation primary objectives are to determine where exactly the MSL vehicle has landed and to provide a geologic and engineering-geologic framework of the landing site for early operations [1]. The rover is expected to leave the area imaged by MARDI after the first few weeks of the mission. Vehicle horizontal offset between images within the descent sequence may permit digital elevation models (DEMs) to be created from the descent images. Additional objectives of the investigation are to examine vehicle ground-referenced motion deviations from inertial measurement unit (IMU) derived inertial position during descent to extract wind velocity from the lower boundary layer, and to help develop and test algorithms for future autonomous landing and hazard avoidance systems. Although not an original requirement or objective of the investigation, additional images may be taken during rover traverses for visual odometry and geologic mapping.

History: The MARDI is one of four cameras supporting three science investigations proposed to NASA for MSL in July 2004 by Malin Space Science Systems (MSSS). MARDI, together with the 2 Mast Cameras (Mastcams) and MAHLI (Mars Hand Lens Imager), was selected in December 2004. The four cameras have different optics but share a common electronics design. With the Mastcam and MAHLI, MARDI underwent a Preliminary Design Review in February 2006, and a Critical Design Review in February 2007. Although the design was mature and all of the parts were on hand, in September 2007, NASA Associate Administrator Stern directed (without consultation with the PI) that the MARDI be descoped from the MSL payload for a cost savings of < $100,000. Using its own resources, MSSS completed the instrument and NASA agreed to re-instate the instrument for flight, allocating funds designated for MSSS participation in the Phoenix mission to cover the JPL costs to integrate the camera with the rover. The flight instrument was tested and calibrated in June 2008 and the camera head was delivered to JPL in July 2008. It was subsequently integrated with the rover—mechanically in August 2008 and electronically (with a non-flight Digital Electronics Assembly) in October 2008. MARDI then participated in cruise and EDL testing of the fully-stacked spacecraft in November–December 2008.

Instrument Details: The MARDI, like the MSL Mastcams and MAHLI, consists of 2 parts: a camera head, mounted on the rover body, and a Digital Electronics Assembly (DEA), housed inside the warm elec-

tronics box of the rover's chassis. The DEA and camera head electronics are the same design as those of MAHLI and Mastcam. The camera, like the Mastcams and MAHLI, uses a Kodak KAI-2020CM interline transfer CCD with 1600 by 1200 active 7.4 µm square pixels. Red/green/blue (RGB) color imaging similar to the colors the human eye sees (twice as much green as red and blue) is achieved using filtered microlenses arranged in a Bayer pattern [2].

The rectangular field of view (FOV) of the detector is inscribed within a 90° diameter circular FOV, yielding a 70° by 55° frame with the long axis transverse to the direction of motion. The instantaneous field of view (IFOV) of the camera is ~0.76 milliradians, which provides in-focus pixel scales that range from about 1.5 m at 2 km altitude to 1.5 mm at 2 m altitude, and cover between 2.4 x 1.8 km and 2.4 x 1.8 m at these respective altitudes. At distances less than 2 m, out-of-focus blurring increases at the same rate that spatial scale decreases, resulting in a constant scale of 0.75 mm/pixel (calibration demonstrates the potential for acquiring 1.5 mm resolution images of the surface after landing).

An 8 Gbyte internal buffer permits the camera to acquire over 4,000 raw frames (equivalent to 800 seconds of descent, which is many times the actual descent duration). For a landing at 3 p.m. local time (incidence = 55°) and an albedo of 0.2, the nominal SNR will be ~80:1 in the green and red, and >50:1 in the blue. Lossy JPEG or lossless predictive compression is applied, and 200 x 150 pixel thumbnails are created, during read out from the buffer.

Large angular rate motion while the vehicle is descending on parachute, and rocket thruster induced vibratory motion, are likely to blur some of the images despite a 1.3 millisecond exposure time.

A white swatch of beta cloth is affixed to the interior surface of the MSL heat shield to serve as a MARDI white balance target as the heat shield falls away during descent to the martian surface.

To demonstrate the color capabilities of the MARDI (as well as MAHLI and Mastcam Bayer-only imaging), Fig. 2 shows a picture acquired by the flight MARDI during instrument calibration and characterization testing in June 2008.

Example MARDI Images: Additional pre-launch images acquired by the flight MARDI are online at: http://www.msss.com/msl/mardi/prelaunch_images/.

References: [1] Malin, M. C. *et al.* (2005) *LPSC XXXVI,* Abstract #1214. [2] Bayer, B. E. (1976) U.S. Patent 3971065.

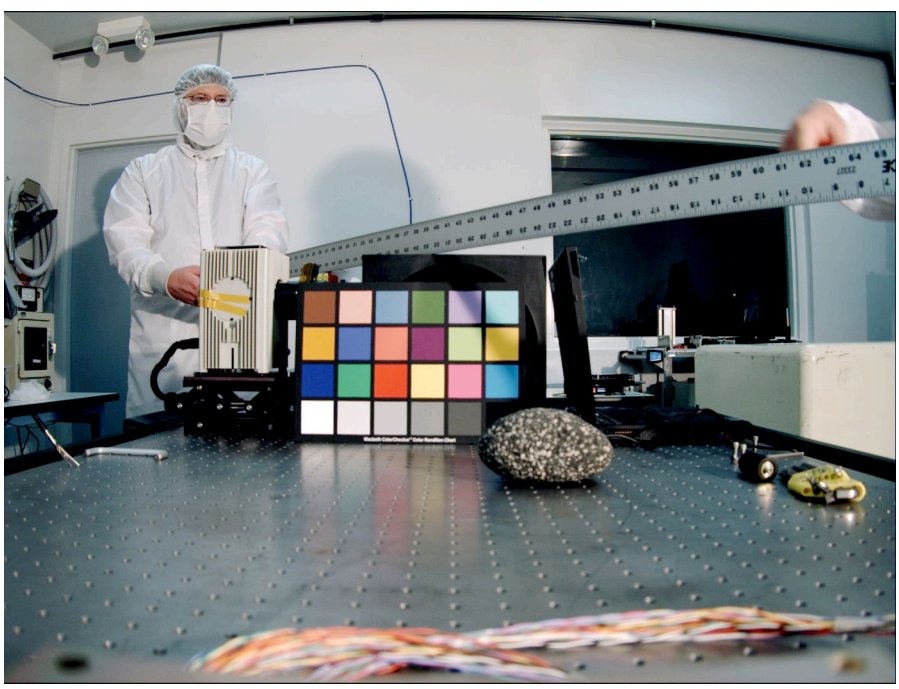

Fig. 2. Image acquired by the flight MARDI during calibration testing at MSSS in June 2008. This image, which includes a Macbeth® ColorChecker® chart near the center of the frame, demonstrates the MARDI RGB Bayer pattern filter color imaging capability. The rounded, spotted cobble in front of the lower right corner of the Macbeth® chart is located 70 cm from the camera, approximately the distance MARDI will be from the ground at touchdown and throughout MSL's surface mission.