THE MARS SCIENCE LABORATORY (MSL) MARS HAND LENS IMAGER (MAHLI) FLIGHT INSTRUMENT. K. S. Edgett[1], M. A. Ravine[1], M. A. Caplinger[1], F. T. Ghaemi[1], J. A. Schaffner[1], M. C. Malin[1], J. M. Baker[2], D. R. DiBiase[2], J. Laramee[2], J. N. Maki[3], R. G. Willson[3], J. F. Bell III[4], J. F. Cameron[5], W. E. Dietrich[6], L. J. Edwards[7], B. Hallet[8], K. E. Herkenhoff[9], E. Heydari[10], L. C. Kah[11], M. T. Lemmon[12], M. E. Minitti[13], T. S. Olson[14], T. J. Parker[3], S. K. Rowland[15], J. Schieber[16], R. J. Sullivan[4], D. Y. Sumner[17], P. C. Thomas[4], and R. A. Yingst[18], [1]Malin Space Science Systems, PO Box 910148, San Diego CA 92191-0148, [2]Alliance Spacesystems, LLC, [3]Jet Propulsion Laboratory, [4]Cornell University, [5]Lightstorm Entertainment, [6]University of California–Berkeley, [7]NASA Ames Research Center, [8]University of Washington, [9]US Geological Survey–Flagstaff, [10]Jackson State University, [11]University of Tennessee–Knoxville, [12]Texas A&M University, [13]Arizona State University, [14]Salish Kootenai College, [15]University of Hawaii, [16]Indiana University–Bloomington, [17]University of California–Davis, [18]Planetary Science Institute.

Introduction: The Mars Science Laboratory (MSL) is NASA's next rover mission to Mars, planned for launch in 2011. Four years ago, Edgett *et al.* [1] described the science objectives of the MSL Mars Hand Lens Imager (MAHLI) investigation. The instrument has now been built and the camera head (Fig. 1) was delivered in October 2008 to Caltech's Jet Propulsion Laboratory (JPL) for eventual integration with the rover. This extended abstract briefly describes the flight instrument and its capabilities.

Overview: MAHLI is essentially a 2 megapixel CCD camera with a focusable macro lens that acquires images of a color quality equivalent to that of consumer digital cameras. The MAHLI will be used to acquire images of geologic materials at a range of scales; it can be focused at working distances between 22.5 mm and infinity. At 22.5 mm, the images will have a pixel scale resolution of about 14.5 µm/pixel and a depth of field of about 0.9 mm. Depth of field increases and spatial resolution decreases with increasing working distance; the resolution at 66 mm working distance is about the same (31 µm/pixel) as that of the Mars Exploration Rover (MER) Microscopic Imager (MI) [2]. MAHLI camera head placement is dependent upon the capabilities of the MSL robotic arm, which presently has a placement uncertainty of as much as 20 mm in 3 dimensions; hence, acquisition of images at the minimum working distance may be challenging.

The instrument consists of 3 parts: a camera head, a Digital Electronics Assembly (DEA), and a calibration target. The camera head and DEA are connected to each other by a JPL-provided cable which transmits data, commands, and power. JPL is also providing a contact sensor (2 "pokers" of design similar to the MER MI contact sensor [2]).

MAHLI shares common electronics, detector, and software designs with the MSL Mars Descent Imager (MARDI) and the two Mast Cameras (Mastcam). All four instruments were developed by, and will be operated by, Malin Space Science Systems.

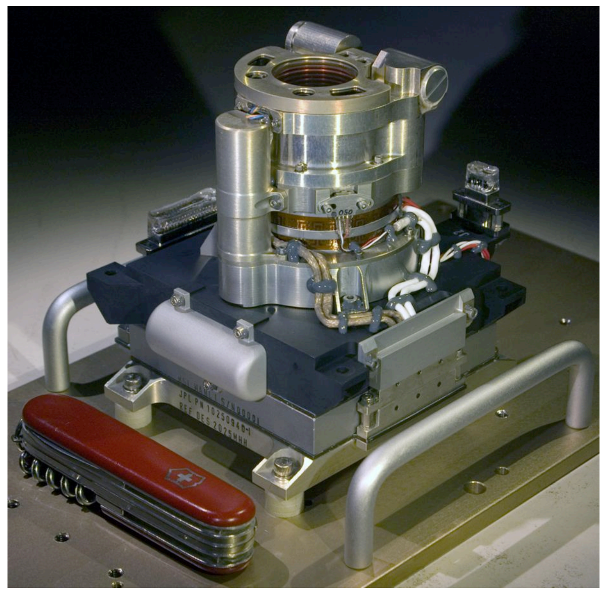

Fig. 1. The flight MAHLI camera head with pocket knife (88.9 mm long) for scale.

Camera Head: The camera head is to be mounted on the rover's robotic arm turret and consists of 3 functional elements: an optomechanical assembly, a focal plane assembly, and the camera head electronics assembly. The latter two are common to the Mastcams and MARDI.

Focal Plane Assembly (FPA) and Camera Head Electronics. The FPA includes a CCD and associated electronics to amplify and digitize its output. The detector is a Kodak KAI-2020CM interline transfer CCD without the standard cover glass. The array has 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 [3]. The camera head electronics communicate with the DEA to power and command the camera head and transmit the data back to the DEA.

Optomechanical Assembly. The optomechanical assembly includes the integrated optics, focus and dust cover mechanisms, and a single drive motor to adjust focus and open/close the dust cover. All moving parts are sealed to prevent dust contamination.

The optics (Fig. 2) consist of a group of 6 fixed lens elements, a movable group of 3 elements, and the front element, a fixed sapphire window [4]. The design effective focal length ranges from 18.4 mm at 22.5 mm working distance to 21.4 mm at infinity. Over that same range, the focal ratio and field of view range from *f*/9.8 and 33.8° to *f*/8.5 and 38.5°. Undesired near-infrared radiation is blocked using a coating deposited on the inside surface of the sapphire window. The combination of glass element transmission properties, infrared cut-off filter, and RGB microfilters result in a spectral range of 380–680 nm for MAHLI images.

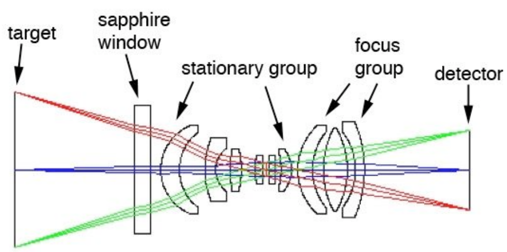

Fig. 2. MAHLI optics diagram, with ray traces.

The MAHLI mechanical design and assembly, performed by Alliance Spacesystems, LLC (Pasadena, CA), was described by DiBiase and Laramee [5]. The lens focus group and dust cover are driven by a single Aeroflex 10 mm stepper motor with a 256:1 gearhead assembly. Individual motor steps are counted to determine focus group position, which in turn relates to working distance and image pixel scale. The camera can focus and images can be acquired with the dust cover open or closed. A Lexan® window permits imaging through the cover if necessary; the nominal approach is to acquire images with the cover open.

A MAHLI image may be acquired with natural sunlight illumination or by use of the camera head's white light and longwave ultraviolet (UV) LEDs. The instrument has two banks of two white light LEDs; each bank can be commanded on/off separately. The UV LEDs shine at 365 nm for night-time imaging to look for fluorescent materials. The UV LEDs are included on an experimental, best-efforts basis. The dust cover Lexan® window permits the LEDs to shine through the cover if necessary.

Digital Electronics Assembly (DEA): The MAHLI DEA is packaged with the Mastcam and MARDI DEA and housed within the rover body. The DEA incorporates all of the circuit elements required for data processing, compression, and buffering. It also includes all power conversion and regulation capabilities for both the DEA and camera head. The DEA accepts 12-bit images from the camera head and converts them to 8-bit images, performs commanded image compression, and buffers them in non-volatile memory. The DEA has an 8 Gigabyte non-volatile flash memory storage capability; volatile storage is in a 128 Megabyte SDRAM buffer.

MAHLI data can be commanded as full-frame (1600 x 1200 pixels) or sub-frame images. The camera has autofocus and autoexposure capabilities. In addition, it can acquire 720p, ~7 Hz high definition video. High speed pixel processing, including Bayer pattern filter interpolation and JPEG-based image compression, are performed in hardware in a field programmable gate array (FPGA). The DEA also has software to perform on-board focus stack merging (z-stacking) to return a best-focus image and range map of selected targets. Stereopair views of targets are obtained by moving the camera using the rover's robotic arm.

MAHLI Flight Calibration Target: The MAHLI flight calibration target consists of a machined titanium plate (109.5 mm by 55 mm) that will be mounted vertically (to reduce dust accumulation) on the rover's robotic arm azimuth motor housing. To this plate is bonded a suite of targets to test white and color balance, UV LED function, resolution, and overall camera performance. The white balance and color targets use spare materials (RTV impregnated with pigments), manufactured by Dan Britt (Univ. Central Florida), from the MER Pancam calibration target [6]. The fluorescent target, also manufactured by Britt, consists of RTV impregnated with SpectraFluor Red, a Spectra Systems, Inc. (Providence, RI) pigment that emits red light (peak at 626 nm) under 365 nm illumination. The resolution target, manufactured by Applied Image, Inc. (Rochester, NY), is based on the U.S. Air Force 1951 bar target with black bars printed on white opal glass.

Example MAHLI Images: Pre-launch images of geologic materials imaged by MAHLI are online at: http://www.msss.com/msl/mahli/prelaunch_images/.

References: [1] Edgett, K. S. *et al.* (2005) *LPSC XXXVI,* Abstract #1170. [2] Herkenhoff, K. E. *et al.* (1997) *JGR, 108*(E12), doi:10.1029/2003JE002076. [3] Bayer, B. E. (1976) U.S. Patent 3971065. [4] Ghaemi, F. T. (2009) Design and fabrication of lenses for the color science cameras aboard the Mars Science Laboratory rover, paper submitted to SPIE, December 2008. [5] DiBiase, D. R., and J. Laramee (2009) Mars Hand Lens Imager Camera: Lens Mechanical Design, paper submitted the IEEE Aerospace Conference. [6] Bell, J. F. III *et al.* (2003) *JGR, 108*, doi:10.1029/2003JE002070.