

OPERATION OF MRO's HIGH RESOLUTION IMAGING SCIENCE EXPERIMENT (HiRISE): MAXIMIZING SCIENCE PARTICIPATION. E. Eliason¹, C. J. Hansen², A. McEwen³, W.A. Delamere⁴, N. Bridges², J. Grant⁵, V. Gulick⁶, K. Herkenhoff¹, L. Keszthelyi¹, R. Kirk¹, M. Mellon⁷, P. Smith³, S. Squyres⁸, N. Thomas⁹, and C. Weitz¹⁰. ¹USGS, ²JPL, ³LPL, University of Arizona, ⁴Ball Aerospace and Tech. Corp., ⁵CEPS, Smithsonian Ins., ⁶NASA Ames/SETI, ⁷University of Colorado, ⁸Cornell University, ⁹University of Bern, Switzerland, ¹⁰PSI/NASA

Introduction: Science return from the Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE) will be optimized by maximizing science participation in the experiment. MRO is expected to arrive at Mars in March 2006, and the primary science phase begins near the end of 2006 after aerobraking (6 months) and a transition phase. The primary science phase lasts for almost 2 Earth years, followed by a 2-year relay phase in which science observations by MRO are expected to continue.

We expect to acquire ~10,000 images with HiRISE over the course of MRO's two earth-year mission. HiRISE can acquire images with a ground sampling dimension of as little as 30 cm (from a typical altitude of 300 km), in up to 3 colors, and many targets will be re-imaged for stereo [1, 2]. With such high spatial resolution, the percent coverage of Mars will be very limited in spite of the relatively high data rate of MRO (~10x greater than MGS or Odyssey). We expect to cover ~1% of Mars at ~1m/pixel or better, ~0.1% at full resolution, and ~0.05% in color or in stereo. Therefore, the placement of each HiRISE image must be carefully considered in order to maximize the scientific return from MRO.

We believe that every observation should be the result of a mini research project based on pre-existing datasets. During operations, we will need a large database of carefully researched "suggested" observations to select from. The HiRISE team is dedicated to involving the broad Mars community in creating this database, to the fullest degree that is both practical and legal. The philosophy of the team and the design of the ground data system are geared to enabling community involvement. A key aspect of this is that image data will be made available to the planetary community for science analysis as quickly as possible to encourage feedback and new ideas for targets.

Selection of targets: In order to make sure that the best possible targets are imaged, the HiRISE Co-Investigators (Co-I's) will take on responsibility for a particular science theme (e.g. volcanism, fluvial processes, polar geology, etc). For each theme, key issues will be identified along with the particular targets that could advance our understanding of Mars if imaged at high resolution. The Co-I in charge of a given theme will evaluate and prioritize suggested targets from the

community, then advocate these targets through the sequence planning process. Workshops in conjunction with large science meetings will be held to facilitate science community input.

The community will be invited to propose image investigations that address our understanding of processes on Mars. The web portal to the data base of potential HiRISE targets will be open to the community for their direct input. This software, "HiWEB," will be based on the successful "Marsoweb" site developed for the '03 Mars Exploration Rovers' landing site evaluation. A scientist will be able to input the suggested target coordinates and describe their objectives. Potential landing site targets will be supplied by Mars Exploration Program representatives to the project, also via a process that solicits input from the science community.

Operations Concept: The operation concept features scientists monitoring the entire uplink planning process. Co-I's will make sure that the big-picture view of what we're trying to learn about Mars is present in every decision, including prioritization of targets, resource negotiations, and optimization of the camera configuration. They will be assisted by operations staff knowledgeable about the software tools used to plan command sequences, and camera and spacecraft limitations. The targeting tool, named "HiPLAN," is based on the JMARS tool developed by Mars Odyssey's THEMIS team to target THEMIS images.

The MRO spacecraft is nominally pointed nadir, but may be maneuvered up to 30 degrees off-nadir to acquire a target. The Context Imager (CTX) and CRISM instruments will also have desired targets. The MRO Project Scientist, working with scientists from each team and representatives from the Mars Exploration Program, will plan timelines of all off-nadir images approximately 3 weeks ahead of their acquisition. Updates to the ephemeris will be used to adjust the actual off-nadir angle and timing. Co-I's will take turns participating in this process to advocate investigations and to work with CTX and CRISM on joint investigations.

Nadir targets of opportunity will be planned ~1 week before acquisition. These are selected by the rotating Co-I from the data base of suggested observations. The camera has a number of configuration parameters [2] which will be set by the Co-I based on the science

requirements associated with a given image, the atmospheric opacity of Mars, and the data volume available.

In the same distributed operations architecture used by Mars Global Surveyor and Odyssey, MRO science teams will operate their instruments from their home institutions. The Operations Center (HiROC) in Tucson, Arizona, will be the hub of uplink planning and downlink data processing. The vision for HiROC is shown in Figure 1. Requests for targets come in from the Co-I's, outside scientists, scientists from other MRO instrument teams, and the general public (filtered through NASA Quest, [3]) via HiWEB and are stored in the "HiCAT" target data base. The actual orbits on

which targets will be imaged are planned using HiPLAN. A final piece of software, "HiCOMMAND," is used to format instrument commands for uplink to the spacecraft.

Closure of the loop is also illustrated in Figure 1, showing the routing of data and reporting back through HiCAT. HiWEB will be used to access acquired images. This is designed deliberately to encourage and facilitate the incorporation of feedback into the planning process, again underscoring our philosophy that each image should be viewed as a mini-research effort, potentially leading to new avenues of investigation.

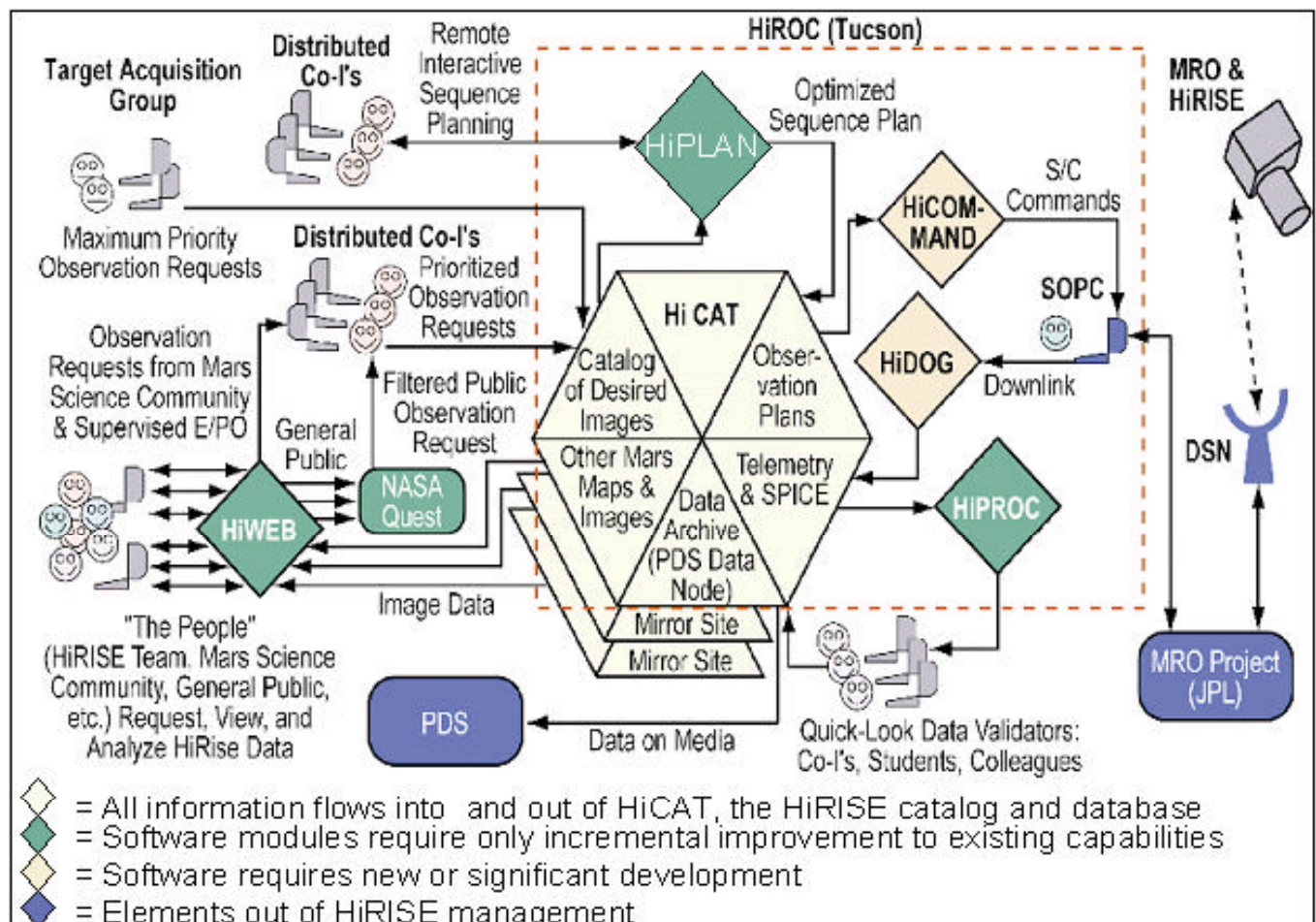


Figure 1 – HiRISE Ground Operations System designed to optimize Mars science, exploration, and E/PO. Observations can be requested and images viewed by anyone via the user-friendly web interface, HiWEB. Co-Is will plan observation sequences with HiPLAN, and instrument commands generated by HiCOMMAND will be sent to the secure Science Operations and Planning Computer (SOPC) for uplink to the spacecraft. Images returned from the spacecraft flow back through the downlink organizer (HiCAT) and are stored in the HiCAT database via a dedicated line to the MRO Operations Center at JPL. The images are processed by the HiPROC procedure and checked by student validators and others to verify processing results. The processed and validated images will be made available to scientists through HiWEB. Periodic deliveries of the HiRISE standard data products are provided to the PDS on hard media.

Image Processing: The goal of the data processing system is to provide timely access to the imaging and to keep up with the high volume (minimum of 9.1 Tb) of instrument data expected to be collected over the nominal two year primary science phase (PSP). To meet this goal HiROC will employ automated event-driven methods for downloading and processing HiRISE instrument science data. The data processing begins when the downlink organizer, “Hi-DOG” (Figure 1), retrieves instrument data from the MRO operations center at JPL and delivers it to Hi-CAT. “HiPROC,” the automated processing engine, will decompress the data if compressed by the onboard FELICS compressor [4], perform radiometric and geometric processing, and format data products according to PDS standards [5].

Raw spacecraft images (EDRs) will be created within days of the telemetry reaching the ground. The output of each CCD detector array is stored as an individual EDR file resulting in as many as 14 EDR files per observation depending on how many CCD detectors were commanded to operate. Data processing staff will visually validate the EDR products to identify problem images and potential instrument performance problems.

The radiometric calibration process normalizes for global camera operational modes, corrects for the variable sensitivity across the CCD detector arrays, and converts pixel values to radiometric units. The result is an “ideal” image where pixel values are proportional to scene brightness.

The geometric processing applied to HiRISE imaging will depend on the instrument's pixel binning modes [2] used in an observation. Image observations with no pixel binning, offering the highest resolution capability of the instrument, are vulnerable to the effects of spacecraft jitter requiring an analysis (see below) to improve the instrument pointing history and model the point-spread function (PSF).

Processing on Binned Imaging: HiPROC will create radiometrically corrected geometrically processed images (RDRs) of the binned images within several weeks of data acquisition. The geometric processing includes correcting camera optical distortion and transformation from spacecraft viewing coordinates to map coordinates. Because of the minimal effects from spacecraft jitter on binned imaging, the geometric processing will use the mission-produced reconstructed spacecraft navigation and instrument pointing data to model the observation's viewing geometry. Three-color observations are processed to create color registered images using the blue-green, panchromatic red, and

NIR filter data. The RDR color products will be scaled to the largest binning mode used in the color observation (typically the blue-green and NIR filter imaging will be binned).

Processing on Full-Resolution Imaging: With the instrument's 1 microradian instantaneous field-of-view, the full-resolution (unbinned) imaging is sensitive to spacecraft jitter resulting from the spacecraft's reaction wheel rotation and other moving parts. High-frequency spacecraft jitter broadens the PSF and reduces spatial resolution. Lower frequency spacecraft jitter distorts the image geometry. We have been exploring methods for internally characterizing the jitter effects on imaging. The CCD layout on the detector array [2] allows for 48-pixel overlap among adjacent detectors in the orbit cross-track direction. In the down-track direction the CCDs are offset by different amounts ranging from 608 (the minimum offset) to 640 lines. Ground features in the image data can be correlated between the 48-pixel overlapping pairs or triplets of CCDs to characterize the divergence between actual and predicted spacecraft motion. Based on the spacecraft jitter analysis a more accurate model of the instrument pointing history can be constructed to improve the geometric processing. The high-frequency component of the jitter analysis is used to construct a varying PSF model throughout an observation. The PSF model is used to perform image sharpening through an adaptive PSF deconvolution.

The Integrated Software for Imagers and Spectrometers (ISIS) [6] will be used for image processing and analysis. ISIS offers image analysis, cartographic processing and mosaicking capabilities, control to geodetic networks, and data archive preparation tools (see URL: <http://www.flag.wr.usgs.gov/isis-bin/isis.cgi>). The HiRISE processing capabilities added to ISIS will be freely available to the science community through periodic distribution of ISIS, allowing scientists to perform specialized cartographic and image processing on HiRISE data at their home institutions.

Data Products: The standard data products produced by the team will be the EDR and binned RDR products (panchromatic and color). The standard data products will be made available to the general science community within weeks of data acquisition through HiWEB's data distribution capability and periodically delivered to NASA's permanent archiving institution. The standard data products do not rely on specialized processing techniques, such as jitter analysis and adaptive point-spread function deconvolution, that may require intensive work by an image processing analyst.

Special Data Products: The special data products produced by the team will include full-resolution RDR products (panchromatic and color) and Digital Elevation Models (DEMs) generated by application of digital photogrammetric methods applied to stereo-pair imaging. Special data products will be created on a limited basis to support landing site assessment and analysis of observations of special interest.

Full-Resolution DEMs and registered ortho-mosaics will be produced using a Leica commercial digital photogrammetric workstation and the SOCET SET® software system. The automatic terrain extraction software uses multi-resolution area-based correlation to generate DEMs from stereo images in batch mode. An interactive process allows analysts to view images, find correlation errors, and edit the DEM model. For full-resolution images the DEM models are expected to have horizontal resolution of ~1.5 m and vertical precision of ~0.2 meter.

PDS Delivery: The MRO Project requires instrument teams to maintain an updated dataset of the best version of data until meaningful changes in data calibration no longer occur and support the timely processing and distribution of data including their final deposition to the permanent archive facility at the Planetary

Data System (PDS) [7]. The distribution of data products to the PDS will be coordinated through the Project's Data Archive Working Group (DARWG) made up of representatives from the MRO project, science payload teams, and the PDS. The DARWG provides the oversight for data product preparation, acceptance, validation and delivery to the archive facility. PDS deliveries of HiRISE EDR products start 6 months from the beginning of PSP and 12 months for RDR products. Subsequent deliveries occur at 3 month intervals. The later delivery schedule for RDR products is intended to allow the team to refine the instrument's radiometric and geometric camera models using in-orbit Mars observation data.

References: [1] McEwen, A. this conference. [2] Delamere, W. A. this conference. [3] Gulick, V. this conference. [4] Howard, P.G. and J.S. Vitter (1993) *Proc. Data Compression Conference*, J.A. Storer & M. Cohn, eds., Snowbird, Utah, 351-360. [5] Planetary Data System Standards Reference (2002) JPL Document D-7669. [6] Eliason, E.M. (1997) LPS XXVIII, 331-332. [7] McMahon, S.K. (1996) *Planetary and Space Sciences*, 44,1, 3-11.