Mars Exploration Rover (MER) Project

Microscopic Imager Calibration Plan
Rev. A

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CHANGE LOG

DATE	SECTIONS CHANGED	REASON FOR CHANGE	REVISION
9/24/01	1.2, 3.4.8, 4.1, 4.3.3	Add discussion of Level 2 req't 921	1.7
9/24/01	Tables 1.2.1, 4.1.1	Update requirement number TBDs to 922 and 923	1.7
9/24/01	7	Add archiving of Calibration Report	Initial Release
10/2/01	3.4.8.3	Remove wavelength dependence	Draft A
10/2/01	Signature page	Add Schwochert, Thompson, Baumgartner	Draft A
10/28/01	3.3	Update calibration schedule	Rev. A

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1 INTRODUCTION

The Athena Microscopic Imager (MI) will acquire images of natural surfaces with a resolution of 30 µm/pixel. It will be mounted on the Instrument Deployment Device (IDD), allowing it to be placed near surfaces that can also be examined by other Rover instruments. The optics will employ a simple, fixed focus design that provides at least 6 mm depth-of-field at 30-µm/pixel sampling. The Microscopic Imager will acquire images using only solar or skylight illumination of the target surface. Stereoscopic observations will be obtained by moving the Microscopic Imager between two successive frames. The spectral bandpass of the Microscopic Imager will be restricted to 400-680 nm by the addition of a single filter. A bright target illuminated directly by the sun under low opacity conditions is predicted to provide a 20% full well response with an integration time of 35 msec. A more typical shadowed target will require integration times of at least 570 msec to produce a response of 20% full well.

Coarse (~2 mm precision) focusing will be achieved by moving the IDD away from a target after the contact sensor is activated. Multiple images taken at various distances will be acquired to ensure good focus on all parts of rough surfaces. Position and orientation data for each acquired image will be stored in the rover computer and returned to Earth with the image data. The Microscopic Imager optics will be protected from the martian environment by a dust cover. When closed, the cover will prevent dust that is falling vertically from the martian atmosphere from settling onto MI optical surfaces in any IDD configuration, and will minimize accumulation of dust produced by the Rock Abrasion Tool (RAT) operation on MI optical surfaces.

1.1 Purpose

The purpose of this plan is to define a consistent method to calibrate the MI, by 1) establishing a framework for the generation of Controlled Documents used to assemble the MI, and 2) defining or referencing the methods and types of tests used to validate the radiometric, geometric, thermal, optical, and mechanical performance against the functional requirements outlined in the Camera Functional Requirements Document (FRD) (JPL Doc. # D-19702, MER 420-2-409) and other MER project requirements. This plan also establishes a prioritized test sequence, so that verification of requirements takes place in a systematic and timely fashion, and describes performance of preflight calibration, the result of which will be delivery of a fully tested instrument that meets or exceeds the functional requirements. The tests described in this plan will provide the data needed to clearly understand the accuracy, precision, and limitations of MI calibration.

The MI calibration plan is divided into three major parts: component-level tests, stand-alone camera test and calibration, and system level test and calibration. Also included is software testing, as it relates to functional tests and calibration, although more extensive software testing will be addressed in a separate procedure. Inflight calibration plans are briefly discussed, followed by the calibration data archiving plan. Component level CCD screening and selection tests are addressed in a separate procedure: MER 420-1-485, D-20247.

1.2 Requirements

The primary goal of calibration and testing of the MI is to verify that the instrument will meet or exceed all of the MER Project requirements relevant to close-up imaging on Mars. Meeting these requirements and achieving the levels of calibration accuracy described below will ensure that the MI returns images, possibly taken under a wide variety of illumination conditions, that will yield useful new information about Mars. The spectral bandpass was chosen to mimic the photopic response of the human eye, simplifying interpretability and testing. The IFOV and f/# were selected after considerations of tradeoffs among overall FOV, diffraction blurring, operational complexity, and the expected size of natural features of interest. The relevant requirements are compiled in the MER Project System Level 2 Requirements Document (JPL D-19650), MER Flight System Level 3 Requirements Document (JPL D-TBD), MER Science Requirements Document (JPL D-19638; MER 420-2-128), MER Cameras Level 3 Requirements (ECR 100497), and the MER Camera Functional Requirements Document (MER 420-2-409; JPL D-19702). The requirements in these documents that are relevant to MI calibration and testing are summarized in Tables 1.2.1 and 4.1.1. Note that Level 3 requirement #51 applies to the optics only, not the MI camera system.

Table 1.2.1: MER Requirements Relevant to MI Component Level and Standalone Calibration and Testing

Level	ID #	Requirement
2	921	The Project System shall be capable of coregistering images from the Microscopic Imager with images and panoramas from the Pancam, Hazcam, Navcam observations of Mars.
2	922	The Project System shall ensure that the quality of the calibration of the science instruments be sufficient to satisfy the requirements and objectives in the Science Requirements Document and the Level 1 science requirements.
2	923	It shall be possible to produce radiometrically calibrated images from the Microscopic Imager, Hazcam, and Navcam observations on Mars, using pre-launch calibration data.
3	46	The Microscopic Imager shall have an Instantaneous Field of View (IFOV) of 30 ± 1.5 micrometers/pixel on-axis.
3	47	The Microscopic Imager shall have a Field of View (FOV) of 1024 x 1024 square pixels.
3	48	The Microscopic Imager shall have a spectral bandpass of 400-680 nanometers.
3	49	The Microscopic Imager shall have an effective depth of field of ≥ ±3 millimeters.
3	51	The Microscopic Imager shall have an MTF of ≥0.35 @ 30 lp/mm over spectral bandpass at best focus.
3	52	The Microscopic Imager optical design shall minimize the contributions of stray and scattered light onto the CCD.
3	53	Radiometric calibration of the Microscopic Imager shall be performed with an absolute accuracy of ≤20%.
3	54	Radiometric calibration of the Microscopic Imager shall be performed with a relative (pixel-to-pixel) accuracy of ≤5%.
3	55	The Microscopic Imager Signal to Noise Ratio (SNR) shall be ≥100 for exposures of ≥20% full well over the spectral bandpass and within the calibrated operating temperature range.
3	56	The Microscopic Imager shall have a temperature sensor, accurate to ± 2 deg. Celsius, on the CCD package that can be read-out and associated with the image data in telemetry.
3	58	The Microscopic Imager shall be able to have the sun in its field of view (powered and unpowered) and not sustain permanent damage.
4	TBD	Working f/# = 15 ± 0.75
4	TBD	Operating temperature within calibrated specifications = -55±2°C to +5±2°C.

1.3 Scope

This plan covers all MI "Deliverables" as described in the MER Project Implementation Plan (JPL D-19620).

1.4 Applicable Documents

- Product Delivery System Manual (JPL D-TBD)
- MER Mission Assurance Plan (MER 7924-013 (TBC), JPL D-TBD)
- MER Configuration Management Plan (MER 420-1-102, JPL D-19641)
- Camera Functional Requirements Document (MER 420-2-409, JPL D-19702)
- MI IICD (JPL D-TBD)
- Safety Data Package (JPL D-TBD)
- MER Environmental Requirements Document (JPL D-19272)
- MER Planetary Protection Plan (JPL D-19534)
- MER CCD Test Plan (MER 420-1-485, JPL D-20247)
- MER Camera CCD Specification Document (MER 420-7-495, JPL D-20365)
- MER Archive Generation, Validation, and Transfer Plan (MER 420-1-200; JPL D-19658).

1.5 Calibration Plan

1.5.1 Objectives

- To validate the design and implementation of the MI instrument;

- To maintain the MI Planetary Protection Control Plan's specified standards of cleanliness in all test phases and activities, including the preparation and maintenance of support facilities and equipment;

- To collect baseline data sets of engineering data in the various instrument states. These data sets shall be used during the I, T&C Program phases at JPL and elsewhere to assure correct instrument operation. These data sets shall also be used for trend analysis to detect any long-term change or degradation in instrument performance;

- To monitor and document hours of use and/or cycles of limited life items, such as mechanisms and electronics;

- To implement procedures developed by the Optics and Calibration teams to perform thorough calibration and performance verification.

1.5.2 Performance Verification

This Calibration Plan shall comply with the test requirements outlined in the MER Environmental Verification Matrix. Instrument compliance to this matrix shall be the responsibility of the Integration, Test and Calibration Lead. Measuring and test equipment shall be used in a manner that ensures that the measurement uncertainty is known and is consistent with the required measurement capability.

Accuracy of the required measurements shall be known and appropriate equipment shall be selected to perform the measurements. All measuring and test equipment used for verification of products shall be calibrated using calibration standards traceable to the national standard. The calibration status of measuring equipment shall be identified with calibration stickers. The equipment shall be maintained and its placement and use shall be controlled.

2 COMPONENT-LEVEL TESTING AND CALIBRATION

Details of the design and operation of the MI CCD can be found in the Mars Exploration Rover Camera CCD Specification Document (MER 420-7-495, JPL D-20365). Before the cameras are assembled, the CCDs, filters, dust covers and optical assemblies must be tested and calibrated. These tests will be performed at JPL, with the exception of the optical barrel transmission test, which may be performed at Kaiser Electro-Optics (KEO). The component level tests are listed in Table 2.0.1.

Table 2.0.1. MI Component Level Calibration and Testing

Test	*Brief Description*
CCD Component Level Testing	
Operating voltage windows	See JPL D-20247
Photon transfer/linearity	Determine CCD linearity, read noise, full well, gain, bias, and dark current in both full resolution and summation modes
Dark current	See JPL D-20247
Flat field	See JPL D-20247
Pinholes	See JPL D-20247
Image	Record images in both full-resolution and summation modes
Temperature cycling	See JPL D-20247
Impedance	See JPL D-20247
Spectral quantum efficiency	See JPL D-20247
Full well map	See JPL D-20247
Charge transfer efficiency	See JPL D-20247
Radiation tolerance (qualification test)	See JPL D-20247
Life testing (qualification test)	See JPL D-20247
Transfer area mask transmission	See JPL D-20247
Residual bulk image	Possible additional test; only significant below -70°C
Other Component Level Tests	
Optical barrel transmission	Determine throughput of each flight and flight spare optics barrel from 400 to 700 nm
Filter blocking and transmission	Determine throughput of filter in bandpass and integrated rejection band
Dust cover spectral transmission	Determine throughput of dust cover (or material from same batch)

2.1 Stand-alone CCD test and calibration

Refer to MER CCD Test Plan (MER 420-1-485, JPL D-20247). All of the CCD tests are high priority. The details of the CCD test plan may be changed based on ongoing CCD characterization and testing, in particular the evaluation of spectral quantum efficiency and residual bulk image at various temperatures.

2.2 Optical barrel transmission

2.2.1 Priority

Low. If system spectral response calibration (section 3.4.3) is successful, optical barrel transmission measurements will not be needed.

2.2.2 Purpose and Description

Transmission of the MI optics barrel must be measured before integration of the optics into the camera. These data will be used to determine the spectral radiometric response of the camera in the event that the monochromator calibration (section 3.4.3) is unsuccessful. The results of this test will also serve as acceptance criteria for the optical barrel assemblies.

2.2.3 Parameters and Range

Spectral transmittance of each optical barrel assembly from 350 to 1100 nm in 10 nm steps. If measurements across this entire range are not feasible, transmittance from 400 to 700 nm is acceptable.

2.2.4 Accuracy and Relationship to Requirements

Transmittance accuracy of ±5% to meet Level 3 requirement #53 (absolute radiometric calibration accuracy). Wavelength steps of 10 nm will ensure that MI spectral bandpass is adequately sampled. If absolute spectral calibration is not feasible, relative spectral transmittance is acceptable.

2.2.5 Environmental Conditions

Ambient.

2.2.6 Supporting Instrumentation, Tests, and Calibrations

Calibrated spectrophotometer or monochromator and photodiode.

2.2.7 Data Processing and Products

Table of transmittance values at each wavelength.

2.2.8 Comments

Filter spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy. Therefore, system spectral response calibration (section 3.4.3) has higher priority than this test.

2.3 Filter blocking and transmission

2.3.1 Priority

Low. If system spectral response calibration (section 3.4.3) is successful, filter blocking and transmission measurements will not be needed.

2.3.2 Purpose and Description

Transmission of the Schott BG-40 filter over the entire spectral bandpass (350 to 1100 nm) must be measured before integration of the filter into the optical assembly. These data will be used to determine the absolute and spectral radiometric response of the camera in the event that the monochromator calibration (section 3.4.3) is unsuccessful. The results of this test will also serve as acceptance criteria for the Schott filter.

2.3.3 Parameters and Range

Spectral transmittance of each filter assembly from 350 to 1100 nm in 10 nm steps.

2.3.4 Accuracy and Relationship to Requirements

Transmission accuracy of ±2% and 1 part in 10^4 blocking to meet Level 3 requirement #53 (absolute radiometric calibration accuracy). Wavelength steps of 10 nm will ensure that MI spectral bandpass is adequately sampled.

2.3.5 Environmental Conditions

Ambient.

2.3.6 Supporting Instrumentation, Tests, and Calibrations

Calibrated spectrophotometer.

2.3.7 Data Processing and Products

Table of transmittance values at each wavelength.

2.3.8 Comments

Optics spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy. Therefore, system spectral response calibration (section 3.4.3) has higher priority than this test.

2.4 Dust Cover Spectral Transmission

2.4.1 Priority

Medium.

2.4.2 Purpose and Description

Determine spectral transmission of flight dust covers or material from same batch using spectrophotometer.

2.4.3 Parameters and Range

Spectral transmittance of each dust cover assembly from 350 to 1100 nm in 10 nm steps.

2.4.4 Accuracy and Relationship to Requirements

Transmittance accuracy of ±2% to meet Level 3 requirement #53 (absolute radiometric accuracy). Wavelength steps of 10 nm will ensure that MI spectral bandpass is adequately sampled.

2.4.5 Environmental Conditions

Ambient.

2.4.6 Supporting Instrumentation, Tests, and Calibrations

Calibrated spectrophotometer.

2.4.7 Data Processing and Products

Table of transmittance values at each wavelength.

2.4.8 Comments

Filter spectral transmission and CCD spectral quantum efficiency measurement uncertainties also contribute to overall radiometric calibration uncertainty. CCD spectral QE will not be measured to high level of accuracy.

3 STAND-ALONE CAMERA TESTING AND CALIBRATION

3.1 Overview

The MI utilizes a 1024 × 2048 Mitel frame transfer CCD detector array with 1024 × 1024 imaging pixels. The array is combined with optics and a single filter to yield images of surfaces approximating the view through a hand lens. The required operating temperature range for performance of the MI within specifications is -55°C to 5°C, and for survival is from -105°C to +50°C. Signal-to-noise ratio (SNR) is required to be ≥100 for nominal observing conditions (≥20% full well within operating temperature range). Dark current is expected to be significant at the high end of the operating temperature range, and therefore must be well calibrated. The spectral QE of the CCD is also expected to vary with temperature. Hence, temperature-dependent calibrations and tests will be performed in a thermal/vacuum chamber at temperatures spanning the required operating temperature range. Full sets of calibration data will be acquired with the MI temperature stabilized at the extremes of the operating temperature range, and perhaps at other temperatures if component-level tests results indicate that full calibration data are needed at other temperatures. In any case, additional calibration data should be acquired during temperature transitions.

3.2 Tests and Procedures

Table 3.2.1 provides a prioritized overview of the stand-alone camera calibration and testing requirements. Each of these tests will be performed at JPL, and is described in more detail below. The CCD blooming and readout smear tests have low priority because the goal of the tests is to simply characterize the blooming behavior and “shutter effect” in support of flight software (autoexposure and shutter correction algorithm) development. These tests could be performed on the EM MI if the calibration schedule does not allow them to be performed on the flight units. The temperature sensor functional test and rock target observations have medium priority because they do not directly affect MI calibration accuracy. It is not possible to accurately calibrate the CCD temperature sensor once it has been integrated into the camera. Scattered and stray light can substantially affect calibration accuracy, but it will be difficult to apply laboratory test results to inflight observations of scattered/stray light from complex sources. Therefore, the scattered/stray light test has medium priority. The other tests have high priority because they address significant sources of calibration uncertainty that must be properly evaluated to achieve the requirements listed above.

Table 3.2.1. MI standalone calibration and testing

Test name	Subtest	Accuracy	Priority	Environmental Conditions
1. Light Transfer			High	
	system linearity	± 1%, from 10 to 90% full well		-55°C and +5°C; pressure ≤ 10^{-6} torr
	read noise	± 2 e-		-55°C and +5°C; pressure ≤ 10^{-6} torr
	full well	± 5% e-		-55°C and +5°C; pressure ≤ 10^{-6} torr
	gain	± 2% e-/DN		-55°C and +5°C; pressure ≤ 10^{-6} torr
	bias (offset)	± 5% DN		-55°C and +5°C; pressure ≤ 10^{-6} torr
	dark current and noise	±0.1 e-, RMS noise		-55°C and +5°C; pressure ≤ 10^{-6} torr
2. Absolute and Relative Radiometry		≤ 20% absolute; ≤ 5 % relative	High	-55°C and +5°C; pressure ≤ 10^{-6} torr
3. System Spectral Response		wavelength, ± 0.2 nm; flux, ±7%	High	-55°C and +5°C; pressure ≤ 10^{-6} torr
4. CCD Blooming Behavior		±5%, adjacent pixels	Low	-55°C and +5°C; pressure ≤ 10^{-6} torr
5. CCD Temperature Sensor Functional Test			Medium	-55°C and +5°C; pressure ≤ 10^{-6} torr
6. Observation of Rock Target		± 1 mm focus control	Medium	Ambient
7. CCD Readout Smear		± 1% pixel response	Low	Ambient
8. Grid Target Imaging			High	Ambient
	Effective Focal Length	± 2% of EFL		
	Field of View	± 0.2°		
	Geometric Distortion	± 0.3%		
9. Bar Target Imaging			High	Ambient
	Depth of Field	± 1 mm		
	MTF	± 10 % at 30 lp/mm		
10. Scattered and Stray Light		Factor of 2 to 10	Medium	Ambient

3.3 Schedule

The tests requiring thermal/vacuum conditions will be performed in a chamber in JPL building 168. The preliminary schedules (as of October 25, 2001) for MER-A and MER-B MI thermal/vacuum testing are shown in Tables 3.3.1 and 3.3.2. The first 6 items in the schedules are in preparation for calibration. However, it will be possible to perform a limited number of tests during various parts of this pre-calibration period (for example, observing targets through the chamber window while the camera is going through its 24 hour temperature dwell tests).

Table 3.3.1. MER-A MI Standalone Camera Calibration Schedule

Activity	Starting date	Ending date	Days
Chamber Setup	2/25/02	2/26/02	2
Pump-down	2/27/02	2/27/02	1
Bake-out	2/28/02	3/5/02	6
Non-operating Thermal	3/6/02	3/7/02	2
Operating Functional	3/8/02	3/11/02	4
Thermal Cycle/Dwell	3/12/02	3/18/02	7
Radiometric Calibration	3/19/02	4/1/02	14
Monochromator Setup	4/2/02	4/3/02	2
Spectral Calibration	4/4/02	4/9/02	6
Other Calibration Tests	4/10/02	4/11/02	2
Required at ATLO	**5/1/02**		

Table 3.3.2. MER-B MI Standalone Camera Calibration Schedule

Activity	Starting date	Ending date	Days
Chamber Setup	n/a	n/a	--
Pump-down	4/12/02	4/12/02	1
Bake-out	4/15/02	4/18/02	4
Non-operating Thermal	4/19/02	4/22/02	4
Operating Functional	4/23/02	4/24/02	2
Thermal Cycle/Dwell	4/25/02	5/1/02	7
Radiometric Calibration	5/2/02	5/15/02	14
Monochromator Setup	5/16/02	5/17/02	2
Spectral Calibration	5/18/02	5/23/02	6
Other Calibration Tests	5/24/02	5/28/02	5
Required at ATLO	**6/7/02**		

The MI ATLO calibration and test schedule is still TBD, but is expected to occur in late 2002 to early 2003.

Staffing for calibration activities includes JPL engineering, science, and calibration team support plus science team support from the PEL, Athena Co-Is, Athena team collaborators, and other graduate and undergraduate student helpers as needed. A staffing plan will be generated for each calibration run assuring that the science team will be prepared to support 24/7 calibration activities with up to 3 shifts consisting of at least 3 science team members or collaborators/designates per shift.

3.4 Detailed Test Descriptions

3.4.1 Light Transfer

3.4.1.1 Priority

High.

3.4.1.2 Purpose and Description

Measure the system light transfer curve for each camera by illuminating the CCD with a series of broadband flat fields ranging from zero to average full-well (approx. 220,000 electrons); obtain at least 3 frames at each level. These measurements will yield the linearity of the camera system response to an incident photon stimulus, the system gain and bias (offset), the system read noise, dark current, and the average full-well value for 5 regions (4 corners plus center of frame).

3.4.1.3 Parameters and Range

Obtain exposures at 11 well depths (0, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 0.9, 0.95, 1.0, and 1.1 times full well). Determine system linearity, gain, bias (offset), read noise, dark current, and average number of electrons in full-well for each region. Evaluate coherent noise, if any. The test setup should be adjusted so that integration times are similar to those expected during flight (0.1 to 2 sec).

3.4.1.4 Accuracy and Relationship to Requirements

Pixel response for each exposure to ±1%, to derive system linearity to ±1%, from 0.1 to 0.9 times full well. Measure read noise to ±2 electrons, system gain to ±2% (electrons/DN), bias to ± 5%, dark noise to ±0.1 electron RMS, full well to ±5%. These accuracies are consistent with Level 3 requirement #53 (absolute radiometric accuracy).

3.4.1.5 Environmental Conditions

Temperature = -55°C and +5°C; pressure ≤ 10^{-6} torr. Additional dark current and noise data should be acquired at other temperatures during transitions.

3.4.1.6 Supporting Instrumentation, Tests, and Calibrations

Window transmission vs. wavelength; calibrate red radiometer and verify sphere uniformity to 1% level.

3.4.1.7 Data Processing and Products

For linearity, analyze the response of 50 × 50 pixel regions, perform linear least squares fit to average signal between 0.1 and 0.9 times full well; determine nonlinear residuals and goodness of fit. Read noise is constant offset (at zero exposure) in plot of pixel signal variance vs. signal level. To find full well depth, track exposures into saturation on central (higher transmission) portion of CCD. Gain is inverse of slope from linear least squares fit of pixel signal variance vs. signal level. The bias is the mean of zero exposure dark frames. Dark current and dark noise are the mean and RMS deviation of bias-subtracted frames, respectively. Coherent noise, if observed, should be characterized with respect to potential noise sources. Products include digital archive of photon transfer curve (plot of noise vs. signal) and linearity graph (plot of average DN vs. exposure time) for five areas on the CCD frame, showing any departures from linearity; line trace showing full well of each pixel, column trace showing full well of each pixel in given region; images of fixed and random system noise; bad pixel map. Digital archive of each image.

3.4.1.8 Comments

None.

3.4.2 Absolute and Relative Radiometry

3.4.2.1 Priority:

High

3.4.2.2 Purpose and Description

Present absolutely-calibrated, uniform (± 1%) light source to camera and acquire images over light transfer test range of source intensities. Obtain 3 identical images per light level, and 30 identical images only at the half well level.

3.4.2.3 Parameters and Range

Absolute conversion between DN and radiance; flat field images. The test setup should be adjusted so that integration times are similar to those expected during flight (0.1 to 2 sec).

3.4.2.4 Accuracy and Relationship to Requirements

± 20% absolute, ± 5% relative to meet Level 3 requirements #53 and #54 (absolute and relative calibration accuracy).

3.4.2.5 Environmental Conditions

Temperature = -55°C and +5°C; pressure ≤ 10^{-6} torr.

3.4.2.6 Supporting Instrumentation, Tests, and Calibrations

Vacuum chamber window transmission vs. wavelength; need to calibrate red radiometer and verify sphere uniformity to 1% level. Radiometric calibration should be traceable to NIST standards.

3.4.2.7 Data Processing and Products

Dark and noise subtract. Relate DN to source absolute radiance.

3.4.2.8 Comments

Will require setup time plus approximately 8 minutes to obtain images.

3.4.3 System Spectral Response

3.4.3.1 Priority

High. Planned CCD spectral quantum efficiency measurements may not provide sufficient data to allow the spectral response of the MI to be accurately determined. Therefore, this test has higher priority than the component-level spectral transmission tests.

3.4.3.2 Purpose and Description

Measure camera system relative spectral response directly rather than calculating spectral response by combining optics and filter spectral transmission and CCD spectral QE. Present monochromatic flux bundle to MI, with image of monochromator slit entirely contained within each image frame.

3.4.3.3 Parameters and Range

Monochromator wavelength stepped by 10 nm or less between 350 and 800 nm, wavelength stepped by 40 nm or less between 800 to 1100 nm. Measure integral camera response at each wavelength.

3.4.3.4 Accuracy and Relationship to Requirements

Wavelength accuracy, ± 0.2 nm. Relative flux accuracy, ±7%. Test will verify compliance with Level 2 requirement #922 (calibration quality) and Level 3 requirement #48 (spectral bandpass).

3.4.3.5 Environmental Conditions

Temperature = -55°C and +5°C; pressure ≤ 10^{-6} torr.

3.4.3.6 Supporting Instrumentation, Tests, and Calibrations

Monochromator calibration; photodiode calibration; lamp stability test; chamber window throughput calibration.

3.4.3.7 Data Processing and Products

Dark subtract. Sum all photoelectrons on chip, compare with photodiode output. Digital archive of each image.

3.4.3.8 Comments

Interception of monochromator flux by camera must be independent of wavelength.

3.4.4 CCD Blooming Behavior

3.4.4.1 Priority

Low.

3.4.4.2 Purpose and Description

Characterize CCD performance when signal exceeds the full well capacity. Take images at lower signal level (shorter integration or reduced illumination) immediately following bloomed image to evaluate residual effects, if any. Results will aid in design of autoexposure algorithm.

3.4.4.3 Parameters and Range

Measure the horizontal and vertical charge distribution of a CCD image illuminated at 5, 10, and 20 times full-well level at five locations in the array (in the four corners and in the center), both for a point and extended area broadband source; 3 frames each.

3.4.4.4 Accuracy and Relationship to Requirements

Signal level in adjacent pixels to ±5%, in compliance with Level 3 requirement #54 (relative radiometric accuracy).

3.4.4.5 Environmental Conditions

Temperature = -55°C and +5°C; pressure ≤ 10^{-6} torr.

3.4.4.6 Supporting Instrumentation, Tests, and Calibrations

Point sources and 10" integrating sphere.

3.4.4.7 Data Processing and Products

CCD images, digital archive of horizontal and vertical and/or diagonal charge distribution, as appropriate for each location. Evaluate residual image, if any.

3.4.4.8 Comments

Repeat test at 2 times full well if time available.

3.4.5 CCD Temperature Sensor Functional Test

3.4.5.1 Priority

Medium.

3.4.5.2 Purpose and Description

Verify proper function of temperature sensor by comparing with a reference sensor at high and low temperatures.

3.4.5.3 Parameters and Range

CCD temperature sensor output and reference sensor output at full range of temperatures reached in chamber.

3.4.5.4 Accuracy and Relationship to Requirements

Temperatures measured to ±2°C or better to meet Level 3 requirement #56 (temperature sensor accuracy = ±2°C).

3.4.5.5 Environmental Conditions

Temperature = -55°C and +5°C; pressure ≤ 10^{-6} torr.

3.4.5.6 Supporting Instrumentation, Tests, and Calibrations

CCD temperature sensor calibration; reference temperature sensor calibration. Flight-like temperature sensor circuitry; precision calibrated temperature sensor on CCD housing.

3.4.5.7 Data Processing and Products

Convert reference temperature sensor output to °C based on supporting calibration, plot temperature vs. CCD sensor output.

3.4.5.8 Comments

Take and record data frequently during chamber temperature changes. Functional test and calibration of temperature sensor should be performed during system thermal/vacuum testing.

3.4.6 Observations of Rock Targets

3.4.6.1 Priority

Medium.

3.4.6.2 Purpose and Description

Take images of rock target(s) in good focus to provide data for software testing and calibration pipeline verification. The same target(s) will be observed by the other Athena flight instruments for comparison.

3.4.6.3 Parameters and Range

Series of images at target distances at least 10 mm either side of best focus. Measure distance from target to camera for each position. The test setup should be adjusted so that integration times are similar to those expected during flight (0.1 to 2 sec).

3.4.6.4 Accuracy and Relationship to Requirements

± 1 mm focus control, to verify Level 3 requirement #49 (depth of field).

3.4.6.5 Environmental Conditions

Ambient.

3.4.6.6 Supporting Instrumentation, Tests, and Calibrations

Rock target (selected from set shown in Fig. 1), light source, measurements of distance between camera and target.

3.4.6.7 Data Processing and Products

Confirm acquisition of well-focused images and out of focus images on either side.

3.4.6.8 Comments

Rock target will be provided by Athena Co-I Dick Morris (JSC).

3.4.7 CCD Electronic Shutter Effect (Readout Smear)

3.4.7.1 Priority

Low.

3.4.7.2 Purpose and Description

To determine the integration times at which frame transfer of the image of a bright spot from imaging to storage areas on the CCD will leave a “readout smear” or shutter effect. This should be done with the final flight electronics, which govern the frame transfer speed.

3.4.7.3 Parameters and Range

Images taken at several integration times including minimum integration time. Integration time should be increased until shutter effect can no longer be measured.

3.4.7.4 Accuracy and Relationship to Requirements

Pixel response for each exposure to ±1%, in compliance with Level 3 requirement #54 (relative radiometric accuracy).

3.4.7.5 Environmental Conditions

Ambient.

3.4.7.6 Supporting Instrumentation, Tests, and Calibrations

Flight electronics; targets, linear motion, and 10" integrating sphere.

3.4.7.7 Data Processing and Products

Dark subtract. Compare long and short exposures to determine radiometric error; calculate minimum integration time for which radiometric error is less than 1%. Digital archive of each image.

3.4.7.8 Comments

Dark current at ambient temperature will limit accuracy of measurement of shutter effect.

3.4.8 Grid Target Imaging

3.4.8.1 Priority

High.

3.4.8.2 Purpose and Description

Image a well-known grid target at best focus. Characterize the geometric distortion introduced by the MI into its images. Measure the effective focal length and field of view by measuring dimensions of target image. Multiple images needed to reduce errors in image location precision. These data will be used to construct the MI camera models.

3.4.8.3 Parameters and Range

Effective focal length, field of view, and geometric distortion. Intersections are to be spaced 50 pixels apart both horizontally and vertically and are to cover the entire field of view. Images are to be obtained at 2 exposure levels, with 2 different target rotational orientations and 2 different target translational locations.

3.4.8.4 Accuracy and Relationship to Requirements

Accuracy of effective focal length to ±2%, field of view accurate to ± 0.2°, geometric distortion accurate to ± 0.3%. Such accuracies are consistent with Level 2 requirement #921 (image coregistration) and Level 3 requirement #46 (IFOV).

3.4.8.5 Environmental Conditions

Ambient if image signal/noise of at least 50 can be obtained.

3.4.8.6 Supporting Instrumentation, Tests, and Calibrations

Well-known grid target, light source, TBD alignment tools. The target grid pattern should be known to a precision of 3 micrometers or better. A target that will meet this requirement is available (Cassini WAC test target).

3.4.8.7 Data Processing and Products

Measure locations of intersections of a grid target in images to ±0.1 pixel using centroiding algorithm; compare image locations with their locations in object space. Produce file of geometric distortion vs. field position and wavelength, value of effective focal length on axis, value of field of view. Document residual errors between the image-space and object-space grid intersection locations after a best-fit matching of the 2 data sets by adjustments in scale, translation, rotation, skew, and/or aspect ratio. Table of maximum and RMS values of the residuals for each grid target image. Digital archive files for use in geometric distortion correction software. Digital image showing (for all intersections) the magnitude and directions of distortions.

3.4.8.8 Comments

None.

3.4.9 Bar Target Imaging

3.4.9.1 Priority

High.

3.4.9.2 Purpose and Description

Determine depth of field (defocus blur) and camera modulation transfer function (MTF) by imaging bar target and knife edge or point source at various distances from camera, including best focus.

3.4.9.3 Parameters and Range

Observe bar target and knife edge or point source at 5 positions on CCD from -5 to +5 mm about best focus in 1 mm steps. Measure distance from target to camera.

3.4.9.4 Accuracy and Relationship to Requirements

Distance from camera measured to accuracy of ±1 mm; MTF measured to ±10% at 30 lp/mm and Nyquist frequency. Level 3 requirement #51 (optics MTF) will be verified by testing the optics at the component level.

3.4.9.5 Environmental Conditions

Ambient.

3.4.9.6 Supporting Instrumentation, Tests, and Calibrations

Knife edge, point source, bar target, light source, TBD alignment tools. Dimensions of point source and bar targets known to accuracy of ±3 micrometers.

3.4.9.7 Data Processing and Products

Archive each image; compute MTF and point spread function vs. position within field of view and depth of field.

3.4.9.8 Comments

Can be performed during camera assembly and focus if desired; TBD number of spatial frequencies.

3.4.10 Scattered and Stray Light

3.4.10.1 Priority

Medium.

3.4.10.2 Purpose and Description

To determine the intensity of light reaching the CCD from off-axis or internally-scattered sources (ghosts), as a function of source intensity and either distance off-axis or (for bright point-like sources) position on-axis. Direct a collimated beam towards camera entrance pupil.

3.4.10.3 Parameters and Range

Move the beam in 10° angular increments past the edge of field to a TBD deg final angle, taking illuminated and background frames at each location. Perform this on one axis.

3.4.10.4 Accuracy and Relationship to Requirements

Factor of 2 to 10 in scattered/stray light relative to source will verify that Level 3 requirement #53 has been met.

3.4.10.5 Environmental Conditions

Ambient.

3.4.10.6 Supporting Instrumentation, Tests, and Calibrations

Collimator, camera holding bracket, 1-axis angular motion, black shroud, target, 10" sphere light source. Perform light source stability test; measure reflectivity of black shroud material.

3.4.10.7 Data Processing and Products

Background subtracted from illuminated frames, which are then compared to a background frame. Curves of scattered light intensity vs. field angle for off-axis sources. Magnitude and preferential orientation of any internal ghost images.

3.4.10.8 Comments

Compare to stray light analysis; cold reduces dark current (increases contrast), but then we've got to image through chamber window, which could detract substantially from results. Probably better to use bright sources at ambient without window.

4 SYSTEM LEVEL CALIBRATION AND TESTING

4.1 Overview

The Calibration and Test activities at the IDD-integrated level are primarily geometric in nature, designed to determine the physical layout of the camera relative to the IDD as well as to assess the actual IDD pointing performance compared to MI Level 3 requirements (Table 4.1.1). All of the tests can be performed in room temperature and pressure (STP) conditions, and a subset of these tests will be performed during ATLO in thermal vacuum conditions to validate performance in the flight environment.

Table 4.1.1: MER Requirements relevant to MI System-Level Calibration and Testing

Level	ID #	Requirement
2	921	The Project System shall be capable of coregistering images from the Microscopic Imager with images and panoramas from the Pancam, Hazcam, Navcam observations of Mars.
2	922	The Project System shall ensure that the quality of the calibration of the science instruments be sufficient to satisfy the requirements and objectives in the Science Requirements Document and the Level 1 science requirements.
2	923	It shall be possible to produce radiometrically calibrated images from the Microscopic Imager, Hazcam, and Navcam observations on Mars, using pre-launch calibration data.
3	310	The IDD shall be capable of positioning instruments to an angular accuracy of 5 degrees in free space within the dexterous workspace of the IPS.
3	312	The IDD shall be capable of positioning instruments to a positional accuracy of 5 mm in free space within the dexterous workspace of the IPS.
3	313	The IDD shall be capable of repeatably positioning instruments to +/- 4 mm in position and +/- 3 degrees in orientation.
3	316	The IDD shall have a minimum controllable motion along a science target's surface normal vector of 2 mm +/- 1 mm RMS.
3	1071	The IPS shall be capable of positioning each in-situ payload element to within 10 mm of a science target that has not been previously contacted by another in-situ instrument.
3	1072	The IPS shall be capable of orienting each in-situ payload element to within 10 degrees of normal to a science target's local surface that has not been previously contacted by another in-situ instrument.
3	1073	After placing the MI in position for imaging, the motion of the IDD shall damp down to an amplitude of less than 30 microns within 15 seconds.

4.2 Tests and Procedures

Table 4.2.1 provides a prioritized overview of the MI and IDD system-level calibration and testing plan. “Flight-like” environmental conditions refer to thermal/vacuum environment during integrated system tests. Each of these tests is described in more detail below. The dust cover flat field test has medium priority because imaging through the dust cover is not required except in the event of dust cover actuator failure. Stray/scattered light test has medium priority because it will be difficult to apply laboratory test results to inflight observations of scattered/stray light from complex sources.

Table 4.2.1 - Overview of MI/IDD System-Level Calibration and Test Plan

Test	*Priority*	*Environmental Conditions*
1. Dust cover flat field	Medium	Ambient
2. Target imaging CCT Magnet array	High	Flight-like
3. IDD tests Positioning control Positioning knowledge Contact sensor position MI boresight alignment Vibration damping time	High	Flight-like
4. Stray/scattered light	Medium	Ambient
5. Coherent noise	High	Flight-like

4.3 Detailed test descriptions

4.3.1 Dust Cover Flat Field

4.3.1.1 Priority

Medium.

4.3.1.2 Purpose and Description

Determine effects of variations in dust cover transmission on MI flat field by imaging spatially flat target through dust cover.

4.3.1.3 Parameters and Range

At least 3 well-exposed (above half well) flat field images with dust cover open; at least 3 well-exposed (above half well) flat field images with dust cover closed.

4.3.1.4 Accuracy and Relationship to Requirements

Pixel response across entire image accurate to ±2%, in compliance with Level 3 requirement #54 (relative radiometric accuracy).

4.3.1.5 Environmental Conditions

Ambient.

4.3.1.6 Supporting Instrumentation, Tests, and Calibrations

10-inch integrating sphere, dust cover actuator support electronics or integrated rover. Dark frames at same temperature and integration time or dark current model.

4.3.1.7 Data Processing and Products

Average multiple dark-corrected images taken with cover closed, divide result by average of multiple dark-corrected images taken with cover open. Archive all image data.

4.3.1.8 Comments

The MI dust cover will not be integrated until after the standalone camera calibration.

4.3.2 Target Imaging

4.3.2.1 Priority

High.

4.3.2.2 Purpose and Description

Take multiple images of CCT and magnet array on flight rover to confirm IDD positioning accuracy. Test flight software commands to position MI on CCT and magnet array repeatably.

4.3.2.3 Parameters and Range

Images of CCT and magnet array at various distances from target, from contact through best focus to 10 mm beyond best focus, in 3 mm steps.

4.3.2.4 Accuracy and Relationship to Requirements

Knowledge of MI position relative to target to ±1 mm, in order to verify Level 3 requirements #310, #312, #313, #316 (IDD positioning).

4.3.2.5 Environmental Conditions

Thermal/vacuum simulating landed environment.

4.3.2.6 Supporting Instrumentation, Tests, and Calibrations

Simulations of IDD positioning in Mars gravity relative to Earth gravity. Geometric layout of target features to ±15 micrometers. Dark frames at same temperature and integration time or dark current model.

4.3.2.7 Data Processing and Products

Dark-correct each image, process to identify best-focused image. Determine optimal IDD command sequence to image each target. Archive all image data and command sequences used to acquire them.

4.3.2.8 Comments

Can be done in ambient conditions if temperature-dependent changes in IDD positioning are known.

4.3.3 Instrument Deployment Device (IDD) Tests

4.3.3.1 Priority

High.

4.3.3.2 Purpose and Description

Take images of precision test target and measure position and orientation of MI relative to rover coordinate frame. Determine IDD positioning control accuracy and repeatability (including backlash) and positioning knowledge accuracy. Determine position of image plane immediately following contact sensing and orientation of MI boresight relative to IDD coordinate frame. Measure damping of IDD vibrations immediately following various IDD motions. These tests will provide information needed to accurately command IDD to acquire MI image sequences, and to construct MI camera models.

4.3.3.3 Parameters and Range

Measure each MI position in Cartesian rover coordinates and each orientation of the MI boresight relative to the rover coordinate frame.

4.3.3.4 Accuracy and Relationship to Requirements

Measure IDD positioning accuracy to ±3 mm and ±3° in order to verify Level 3 requirements #310, 312, 1071 and 1072. Measure IDD positioning repeatability to ±2 mm and ±2° in order to verify Level 3 requirement #313. These measurements will also enable coregistration of MI images with other imaging data (Level 2 requirement #921). Measure IDD incremental positioning along MI boresight to better than ±1 mm to verify Level 3 requirement #316. Measure vibration of IDD 5, 10, 15, and 20 seconds after motion to within ±15 micrometers to verify Level 3 requirement #1073.

4.3.3.5 Environmental Conditions

Thermal/vacuum simulating landed environment.

4.3.3.6 Supporting Instrumentation, Tests, and Calibrations

Simulations of IDD positioning in Mars gravity relative to Earth gravity. Three-dimensional target with dimensions known to ±15 micrometers. Dark frames at same temperature and integration time or accurate dark current model. Locations of target relative to rover to ±1 mm or better. Theodelite measurements of rover, IDD, MI and target positions.

4.3.3.7 Data Processing and Products

Dark-correct each image, process to identify best-focused parts of each image and derive MI position and orientation relative to target. Reduce theodolite data to rover coordinates. Archive all image data and command sequences used to acquire them.

4.3.3.8 Comments

Can be done in ambient conditions if temperature-dependent changes in IDD positioning are known.

4.3.4 Stray/scattered light test

4.3.4.1 Priority

Medium.

4.3.4.2 Purpose and Description

Evaluate effects of scattering of light from components integrated after standalone testing. Take images of dark target with MI dust cover and contact sensor directly illuminated by a source outside of the field of view.

4.3.4.3 Parameters and Range

Move the light source in 10° angular increments past the edge of field to a TBD deg final angle, taking illuminated and background frames at each location. Repeat imaging with dust cover closed. Emphasize configurations in which scattering into MI optics is most likely.

4.3.4.4 Accuracy and Relationship to Requirements

Factor of 2 to 10 in scattered/stray light relative to source will verify that Level 3 requirement #53 has been met.

4.3.4.5 Environmental Conditions

Ambient.

4.3.4.6 Supporting Instrumentation, Tests, and Calibrations

Collimator, 1-axis angular motion, black shroud, target, 10" sphere light source. Perform light source stability test; measure reflectivity of black shroud material.

4.3.4.7 Data Processing and Products

Background subtracted from illuminated frames, which are then compared to a background frame. Curves of scattered light intensity vs. field angle for off-axis sources. Magnitude and preferential orientation of any internal ghost images.

4.3.4.8 Comments

Compare to stray light analysis; cold reduces dark current (increases contrast), but probably too difficult to perform inside thermal/vacuum chamber.

4.3.5 Coherent Noise

4.3.5.1 Priority

High.

4.3.5.2 Purpose and Description

Examine all MI dark images taken during system testing, especially those at low temperatures, for evidence of coherent noise. Noise sources on the integrated flight system should be recognized when subsystems are powered.

4.3.5.3 Parameters and Range

Acquire MI dark frames at a wide variety of temperatures and operating conditions, especially at low temperatures.

4.3.5.4 Accuracy and Relationship to Requirements

Measure amplitude of coherent noise to ±10 e^- to verify that Level 3 requirements #54 (relative radiometric accuracy) and #55 (SNR) are met.

4.3.5.5 Environmental Conditions

Thermal/vacuum simulating landed environment.

4.3.5.6 Supporting Instrumentation, Tests, and Calibrations

Dark frames at similar temperature and integration time taken during standalone camera calibration. Determine source(s) of coherent noise (if any) at subsystem (camera) level. If different noise patterns are detected during system tests, attempt to locate and evaluate noise sources.

4.3.5.7 Data Processing and Products

Contrast-enhance all images in near-real time to search for coherent noise patterns. Archive all image data and command sequences used to acquire them.

4.3.5.8 Comments

Potential noise sources must be operating during these tests.

5 MI SOFTWARE TESTING

5.1 Outline

MI flight software must be tested before launch to verify proper function. Much of the MI flight software (FSW) is similar to the FSW that will support operation of the other MER cameras, so some of the software tests discussed below are duplicated in the test plans for the other cameras. Table 5.1.1 provides a prioritized overview of the MI software calibration and testing requirements. Verification of pixel summing has medium priority because it is less likely to be used on MI images. Each of these tests is described in more detail below.

Table 5.1.1 - Overview of MI Software Calibration and Test Plan

Test	*Priority*
1. Verification of ICER Compression Performance (including effects on radiometry)	High
2. Verification of Auto Exposure Performance	High
3. Verification of Bias and Dark Modeling Subtraction Capabilities	High
4. Verification of Bad Pixel Correction	High
5. Verification of Readout Smear (Electronic Shutter) Correction	High
6. Verification of IDD Pointing and Deployment	High
7. Verification of Subframing	High
8. Verification of Flat Fielding Correction	High
9. Verification of Pixel Summing Capability	Medium
10. Determination of Wall Clock Time to Complete Every Commandable Feature	Medium

5.2 Facilities

Flight system testbed, or similar flight-like computer system.

5.3 Tests and Procedures

5.3.1 ICER Compression Performance

At least one high-signal/noise MI image each of natural rock and soil surfaces (such as those described in section 3.4.6 above) should be compressed losslessly and using various levels of lossy compression. Compare the compressed images with the original 16-bit images and gather statistics of the differences. Deviations between the original and compressed images will be used to assess the effects of various levels of ICER compression on radiometric precision and accuracy.

5.3.2 Auto Exposure Performance

Test automatic exposure algorithm on targets with a variety of entropy characteristics, from flat to very complex (with specular reflections and/or dark shadows). Determine and document optimum algorithm parameters for each type of target.

5.3.3 Bias Levels and Dark Modeling Subtraction Capabilities

Test commandable bias level circuit at various temperatures. Acquire dark current images with target image data and compare results of subtracting entire dark frame with correction using "extra pixel" values.

5.3.4 Bad Pixel Correction

Construct bad pixel map and table. Confirm that algorithm corrects all bad pixels.

5.3.5 Readout Smear (Electronic Shutter) Correction

Test algorithm at various integration times, from minimum to smear threshold derived from standalone calibration (section 3.4.7). Confirm that FSW correctly recognizes when integration time is below threshold and automatically acquires and subtracts a zero-exposure frame.

5.3.6 IDD Pointing and Deployment

Verify ability to position and point MI at wide variety of targets. Target geometry should extremes of IDD workspace.

5.3.7 Subframing

Acquire full frames and subframes of high-entropy target to confirm that subframing software performs correctly.

5.3.8 Flat Fielding Correction

Load flat field correction image/table into memory, ensure that high-signal/noise target image is properly flattened.

5.3.9 Pixel Summing Capability

Acquire full image frame and summed frames to confirm that arithmetic is performed properly by pixel summing algrorithm.

5.3.10 Command Execution Time

Log execution time of all MI-related commands.

5.4 Responsibilities

PEL: Approval of test plan, evaluation of data quality, acceptance of test results.
FSW team: Approval of test plan, code modifications, configuration control.

6 INFLIGHT CALIBRATION

In order to verify the accuracy of preflight calibration and to identify changes in camera performance, acquisition of a limited amount of inflight calibration data is planned. Analysis of these data will enable updating of calibration parameters if necessary, perhaps improving MI calibration. Anticipated inflight calibration activities are described below.

6.1 Darks

During cruise to Mars, MI dark current images and extra pixel data will be acquired and returned to Earth. These dark data should be acquired at different temperatures if possible and losslessly compressed. This will serve as a functional test and permit the dark current model to be verified and/or updated. Extra pixel data will also be acquired and returned during the landed mission.

6.2 Target Imaging

During surface operations, in particular during the "calibration campaign" soon after landing, images of the CCT and magnet array will serve to verify IDD positioning accuracy and MI focus distance. This test will take advantage of the experience and sequences derived from the system level test 4.3.2 described above. Any changes with respect to preflight calibration data will be analyzed and may be used to modify MI/IDD command sequences.

6.3 Sky Flat Fields

MI images of the martian sky, taken with the dust cover open and closed, will be used to verify flat field calibration and perhaps update it. Sky images could be acquired while the Mössbauer or APX spectrometers are placed against a surface target, for example.

7 CALIBRATION DATA FORMAT AND ARCHIVING

All calibration data will be acquired in the PDS file format, so that it can be archived directly into the PDS without having to go through a file conversion. Calibration file labels and the details of the format itself will be defined by the Athena Data and Archives Working Group (DAWG) and are described in the MER Archive Generation, Validation, and Transfer Plan (MER 420-1-200; JPL D-19658).

Within 6 months of the completion of ATLO calibration activities, the MI PEL will deliver a detailed MI Calibration Report to the Principal Investigator that fully documents the procedures that were followed and the results that were obtained. A single report shall contain the detailed calibration data and algorithms for both MER-A and MER-B flight units. This calibration report will be archived in the PDS.

8 CALIBRATION AND TEST SCHEDULE AND STAFFING

Staffing for calibration activities includes JPL engineering, science, and calibration team support plus science team support from the PEL, Athena Co-Is, Athena team affiliates, and their graduate and undergraduate student helpers as needed. A staffing plan will be generated for each calibration run assuring that the science team will be prepared to support 24/7 calibration activities with up to 3 shifts consisting of at least 3 science team members or affiliates/designates per shift.

The MI system-level calibration and test schedule is still largely TBD, but the tests described in section 4 are expected to occur in late 2002 to early 2003.

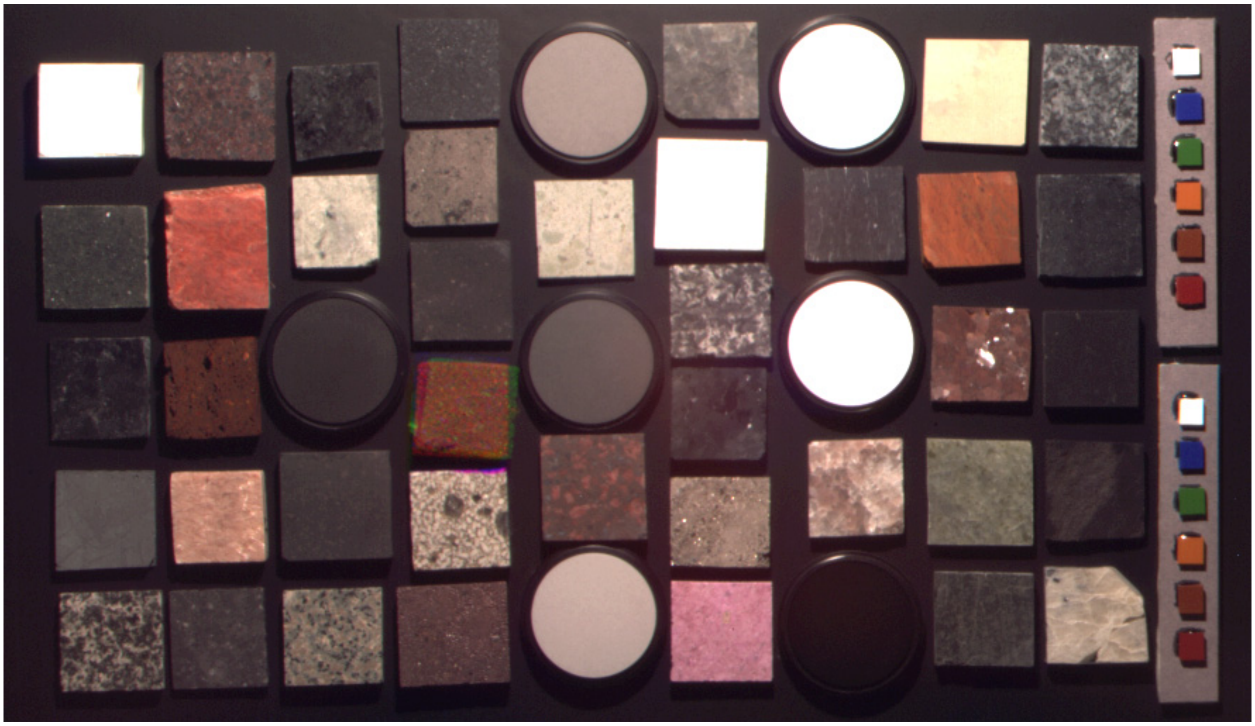

Figure 1: Example of a rock and standards calibration target designed by Athena Co-I Dick Morris, imaged by the APEX Pancam instrument during standalone camera calibration in 1999. Each rock tile is approximately 2.5 cm square.