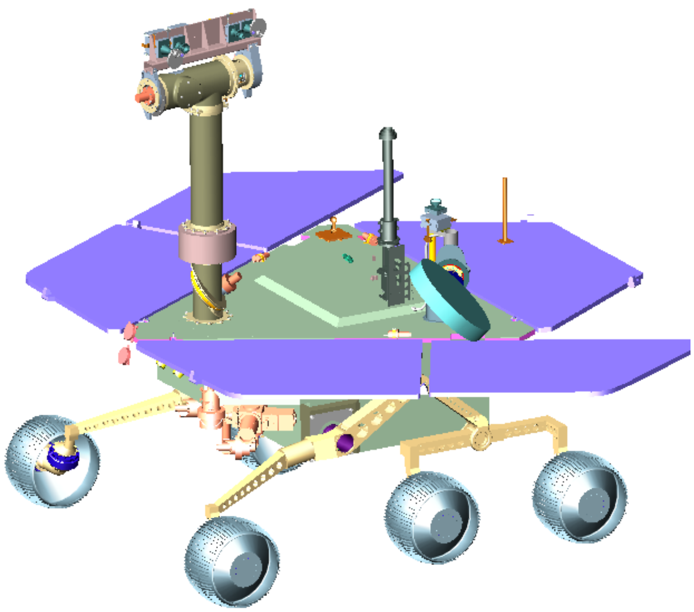
NASA ANNOUNCEMENT OF OPPORTUNITY

PROPOSAL INFORMATION PACKAGE



Mars Exploration Rover Mission Participating Scientist Program

August 28, 2001

DISCLAIMER: This Proposal Information Package has been prepared in good faith, with available information. This mission, however, is still in the design phase. While every effort will be made to implement the designs described in this package, budgetary, programmatic, schedule, and technical problems may occur during development. These problems may result in changes to the design of the Flight System (spacecraft hardware and flight software) and plans for the Mission System (test, training, operations, processes, and ground data system).

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1.1 Document Overview

This Proposal Information Package (PIP) document describes the relevant aspects of the Mars Exploration Rover (MER) Project, in support of the Announcement of Opportunity (A.O.) for MER Participating Scientists. Questions about the material in this Proposal Information Package may be submitted in writing or electronically to the MER Project Scientist:

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Questions will be answered as promptly as possible. Each day Monday through Friday, there will be one update by 9 AM Eastern Time to the question and answer list at the following NASA Headquarters website: http://spacescience.nasa.gov by opening "Research," and then "Current (Open) Solicitations" from the menu. Anonymity of persons who submit questions will be preserved.

Section 1 of this Proposal Information Package is an overview of the MER Project and mission plans. Descriptions of the rover instruments and science investigations are provided in Section 2. An overall description of the rover is given in Section 3, and a description of rover operations in Section 4. Sections 5 and 6 highlight the preliminary plans for preflight instrument calibration, rover tests, operations training, and post-landing operations, in which Participating Scientists are expected to be involved. Plans for generation, validation, and transfer of data products to the Planetary Data System are described in Section 7. Section 8 provides additional miscellaneous information. Acronyms and abbreviations are listed in Section 9.

1.2 MER Mission Summary

The Mars Exploration Rover Project will use the 2003 launch opportunity to deliver two mobile science vehicles to different sites in the equatorial region of Mars. The two rovers will document the geology of the landing sites and gather compositional, mineralogical, and textural information about selected Martian soils and rocks. A complete list of the science and measurement objectives is provided in Section 2.1 of the Announcement of Opportunity for MER Participating Scientists. The fixed Mars-arrival dates are January 4, 2004, for the Mars Exploration Rover A (MER-A), and January 25, 2004, for the Mars Exploration Rover B (MER-B). Total surface mission lifetime will be at least 91 sols (about 93.5 Earth days), but science data collection will not begin until the second sol, allowing a 90 sol science mission duration.

During the 90 sols, each Mars Exploration Rover will collect data about the composition and mineralogy of targeted Martian soil and rocks, and also will provide images to document the geologic context of those targeted materials.

Both MER-A and MER-B spacecraft payloads are planned to have a launch weight of approximately 1063 kg. Both are planned to launch within 18-day launch periods from Cape Canaveral Air Station to achieve Type 1 trajectories to Mars. A Delta II 7925 launch vehicle will launch the MER-A spacecraft payload within the period from May 30 through June 16, 2003. A Delta II “Heavy” 7925H vehicle will launch the MER-B spacecraft within the period from June 27 through July 14, 2003.

Both MER flight systems are planned to be interchangeable and consist of a cruise stage with heatshield, a backshell, and an Entry, Descent and Landing (EDL) system. The EDL system includes a parachute, airbags, lander structure, and roving surface vehicle, which contains much of the electronics used in all mission configurations. The roving surface vehicle is enclosed inside the lander during flight.

During the 7 to 7.5-month interplanetary flights of both spacecraft (which include Cruise and Approach mission phases), event windows will be scheduled to perform five Trajectory Correction Maneuvers (TCMs) to assure arrival at the intended landing sites. Navigation and rover and instrument checks during cruise will test capabilities that will be executed during the EDL and Surface phases. In flight, the spacecraft spins at 2 rpm with a fixed orientation. This orientation will be updated periodically to maintain antenna pointing toward Earth, and solar panel pointing toward Sun as their relative positions change during flight. Due to a wide separation between Sun and Earth relative to the early trajectories, both MER spacecraft will use a backshell Low Gain Antenna (LGA) for early Cruise communications, off-pointed from about 60° down to 5° off Earth. Once the off-Earth pointing can be maintained within approximately ± 5°, the spacecraft will use a Medium Gain Antenna (MGA) for communications for the rest of Cruise.

About 12 hours before landing, each spacecraft will perform the fifth TCM, and a few hours later will begin its Entry, Descent and Landing (EDL) phase. EDL includes a turn-to-entry attitude at approximately 1 hour before encountering the Mars atmosphere. After the turn, the backshell LGA will be used at low communication rates until it is jettisoned during the cruise stage separation event just before atmospheric entry. A short blackout will be followed by 6 minutes or so of a series of approximately 36 10-second duration signal tones that signal the accomplishment of various expected EDL steps through landing. These challenging communications conditions require ground array capability using both a 34 m and 70 m ground antenna.

Entry, Descent, and Landing for MER-A and B will adopt the method used for Mars Pathfinder. That is, a heatshield and parachute will slow descent through the Martian atmosphere, then retro-rockets will fire against the surface, and then airbags will cushion the surface impact. After the airbag assembly rolls to a stop, the system will retract the airbags, open the three lander petals while righting the landing structure, and prepare the rover to leave the lander. One patch antenna on the base of each lander, combined with use of the Rover LGA, provides an opportunity (depending on the lander orientation) of allowing continuation of signal tone transmission until the petals are open, to provide status of the early landed autonomous activities. Both MERs will land in the Martian afternoon while the Earth is still in view, allowing the transmission of signal tones, coded to indicate the accomplishment of critical steps in the EDL timeline. Figure 1 is an illustration of the baseline sequence for Entry, Descent, and Landing for MER-A (MER-B is similar).

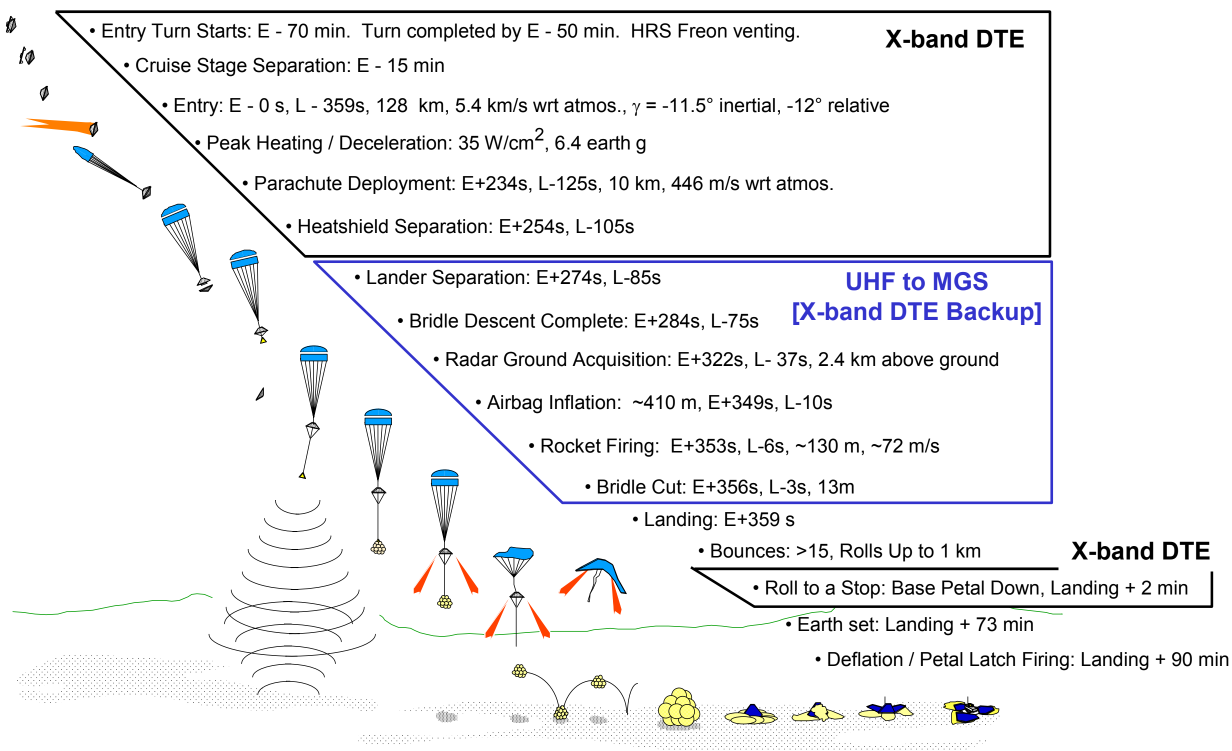

Figure 1. Baseline MER-A EDL Sequence for a May 30, 2003, launch, and landing at 5 N latitude.

After landing, the 184 kg MER-A rover will begin its 91-sol (93.5 day) surface operations phase. Thirty-five days later, the MER-B will land on Mars. Retraction of airbags, lander righting and petal opening, and deployment of the rover solar arrays will occur after Earth set and without direct Earth communication. While on the lander structure, the rover will deploy several critical mechanisms, including solar arrays to provide power, a high gain antenna to support X-band direct-to-Earth telecommunications, an instrument mast, and the rover wheels and mobility structure.

After the camera mast is deployed, each MER will take panoramic color and infrared views of its landing site. After all the required rover mechanical reconfiguration is complete, the six-wheeled rover will cut its last ties to the lander and will drive over the deflated and retracted airbags and onto the Martian surface. Communications sessions with Earth will transmit the panoramic images and the health and state of the rover following the mechanical deployments. Based on continuing Earth analysis of the initial panoramas and subsequent images and other data, each rover will navigate to selected soil and rock targets, and analyze them using a suite of onboard instruments. The surface operations will be planned to achieve the baseline mission success criteria (Section 1.5), to be flexible enough to respond to observation opportunities as they are identified, and to allow recovery from unexpected events. To achieve full mission success, at least one rover shall demonstrate a traverse distance (odometery) of at least 600 meters.

Each rover will use a stereo pair of monochrome navigation cameras (Navcam) in addition to the panoramic color camera stereo pair (Pancam) on the mast to image prospective travel paths and science targets. Once a target objective is selected by operations teams on Earth, each rover will travel to the selected target areas using two lower sets of stereo hazard cameras (Hazcams), mounted front and aft on the rover bodies under the solar panels. The Hazcam images will supply information about the upcoming terrain to software onboard, which can autonomously navigate the rover to the selected area, or can stop to get updated instructions from Earth if conditions are unexpectedly challenging.

The rovers use five science instruments to collect data about the landing sites and the selected rock and soil targets. The two remote sensing science instruments on the rovers are a stereoscopic multispectral (visible to near-infrared) imager (Pancam), and a thermal infrared spectrometer (Mini-TES). These instruments, as well as the Navcams, are mounted on a masthead, providing boresights approximately 1.5 meters above the ground. The mast can turn 360° in azimuth, giving both instruments and the Navcam a complete panoramic view along the horizon. Images from the stereo pair of hazard cameras (Hazcams) that are mounted on the front and back of the rover can also be transmitted to Earth.

A second set of payload elements will closely observe or contact the soil and rock targets. These are mounted on a turret at the end of a 5 degree-of-freedom arm, known as the Instrument Deployment Device (IDD). The four devices are a Mössbauer spectrometer (MB), an Alpha Particle X-ray Spectrometer (APXS), a Microscopic Imager (MI), and a Rock Abrasion Tool (RAT). The IDD instruments will provide compositional data about selected surface soil and rocks, including elemental chemistry, iron oxidation state and mineralogy, and fine-scale morphology. The rock abrasion tool will remove the outer surfaces of rocks, to allow analysis of the newly-exposed rock interiors. In each sol, surface operations will be planned with operations personnel on Earth and uplinked to the rover, in order to select rock and soil targets that will reveal the most about Martian geologic processes and history. Together with the Pancam and Mini-TES, the MB, APXS, MI, RAT, and Magnet Array comprise the Athena payload suite. See Section 2.1 for a complete description of the Athena payload.

The rovers are capable of approximately a hundred meters of travel in a single sol, depending on the terrain, in order to explore the landing site and get to the most valuable targets. The lander has no imaging capability, so there will be no pictures of the rovers themselves in operation. The images and spectra obtained by the rovers will support target selection and provide geologic context for the targets, as well as document these new locations on Mars. The target composition data combined with the context and landing site information are intended to support the testing of hypotheses regarding the geologic history and the nature of past aqueous processes.

The prime missions will be complete after 91 sols of surface operations. During the entire surface phases for both missions, both power and telecom capabilities will constantly decrease, as Earth and the Sun become more distant from Mars and as dust collects on the solar panels.

1.3 MER Science Measurement Objectives

The following set of science measurement objectives are derived from the science objectives listed in section 2.1 of the Announcement of Opportunity. The MER Project has a requirement to ensure that the quality of the science measurements and the quality of the instrument calibration is sufficient to satisfy these measurement objectives.

- Characterize and map the rock and soil types in the terrain explored by the rover, based on their surface texture, physical properties, and composition.

- Characterize the large-scale morphologic properties of the site: topography, rock and outcrop morphology, stratigraphic and other geologic relationships, and soil characteristics.

- Identify mineral phases in selected targets of rock (including rock interiors) and soil.

- Determine the major and minor element chemistry of selected targets of rock (including rock interiors) and soil.

- Determine the temperature, water vapor abundance in the atmospheric boundary layer, and the aerosol-induced atmospheric opacity.

- Determine the relative abundances of the iron bearing phases in selected targets or rocks (including rock interiors) and soil.

- Determine the oxidation state of the iron bearing minerals in selected targets of rock (including rock interiors) and soil.

- Detect the presence of nanophase and amorphous iron-bearing minerals in selected targets of rock and soil.

- Determine the magnetic phase(s) in the airborne dust and characterize their relative abundances.

- Estimate the mineralogy of individual rocks and soil units around the rover remotely, for target selection.

- Characterize the small-scale texture and color properties of individual rocks and soil units around the rover remotely, for target selection.

- Determine the fine-scale texture, morphology, and physical properties of selected targets of rock (including rock interiors) and soil.

- Characterize the relative abundances of all mineral phases in selected targets of rock (including rock interiors) and soil.

1.4 Mars Exploration Program Measurement Objectives

The following measurement objectives were derived by NASA Headquarters from the Mars Exploration Program Objectives listed in Section 2.2 of the Announcement of Opportunity. They are not included in the requirements for the MER Project, but they do represent objectives that might be included in MER Participating Scientist proposals.

- Determine relative error rates for commanded versus actual navigation in multiple terrain and soil types.
- Identify navigation performance limitations.
- Identify and quantify navigation strategies and corresponding Mars terrains to improve rover mobility and performance.
- Identify and quantify characteristics of navigable Mars terrains.
- Identify derived terrain characteristics.
- Determine navigation error rates.
- Determine system resistance to loss of traction or immobilization.
- Environmental (including dust) effects on sensors, instruments, mobility subsystems and the overall system.
- Identify thermal trending, including hibernation temperature gradients.
- Identify environmentally-induced performance degradation.
- Evaluate system and component performance and performance degradation.
- Quantify effects of system posture to facilitate science task execution, maximize solar illumination, and minimize adverse environmental effects.
- Identify operational utilization of all rover actuators, motors, avionics and subsystems.
- Analyze non-elevation map feature extraction, including color and texture analysis, soil cohesion and friction, rock stability and science value estimation.
- Extract geometric bounds of terrain features with accurate and reliable description assignments, and development of context-dependent representations of the environment (e.g. science or navigation).

1.5 Full Mission Success Criteria

The criteria for full mission success have been established by NASA Headquarters for the Mars Exploration Rover Project, and the official wording is shown below. These are the criteria that must be met before the MER missions are considered a full success:

1. Launch two identical lander/rover missions to Mars during the 2003 launch opportunity, from the Eastern Test Range aboard separate Delta II-class expendable launch vehicles.

2. The MER-2003 rovers shall each acquire science data and conduct in-situ analysis for 90 sols, and shall be designed for operations independent of the lander.

3. At each landing site, operate the Athena instrument suite (i.e. Pancam, Mini-TES, APXS, Microscopic Imager, and Mössbauer spectrometer) during the 90-sol operational phase of the rover mission.

4. At each landing site, acquire at least one full-color and at least one stereo 360° panoramic image of the landing site with the Pancam, with a resolution of less than 0.3 mrad per pixel. Acquire at least one image of a freshly exposed Mars rock that is also analyzed by another Athena instrument (i.e., Microscopic Imager, Mini-TES, APXS, or Mössbauer spectrometer).

5. Drive the rovers to a total of at least eight separate locations and use the instrument suite to investigate the context and diversity of the Mars geologic environment. Every reasonable effort shall be made to maximize the separation between investigation locations to increase site diversity, without compromising overall mission safety or probability of success.

6. To investigate complex science operations on remote planetary surfaces, the MER-A and MER-B missions shall operate simultaneously on the surface of Mars for a period of at least 30 sols.

7. At least one of the rovers shall demonstrate a total traverse path length of at least 600 meters, with a goal of 1000 meters.

1.6 MER Team Structure During Landed Operations

The MER Mission Operations System organization includes the following operations teams:

- Science Team
- Mission Planning Team (MPT)
- Integrated Sequencing Team (IST)
- Mission Control Real Time Operations Team (RTO Team)
- Ground Data System Team (GDS Team)
- Navigation Team (NAV Team)
- Spacecraft/Rover Engineering Team (S/RET)
- Deep Space Mission Support Team (DSMS Team)

1.6.1 Science Team

The Science Team is broken down into three distinct entities: the Science Operations Working Group (SOWG), the Science Operations Support Team (SOST), and the Remote Scientists. The Science Team is responsible for working to achieve the MER science objectives. The Science Team members include the Athena Science Team members (PI, Deputy PI, Co-Is, and the Participating Scientists selected via this Announcement of Opportunity), the Project Scientist and her staff; the Experiment Representatives, Investigation Scientists, the MER Science Office Manager and assistants, and the JPL data visualization and modeling experts. The majority of the Science Team will be located in the Surface Operations Mission Support Area at JPL during mission operations. The Remote Scientists are members of the Science Team not located at JPL during surface operations, and will have very limited and non-critical participation in operations. Science Team members may rotate between Remote Scientists and SOWG and SOST positions.

During the Science Operations Working Group Meetings, the SOWG will develop sol-by-sol rover science activity plans and long-range (multi-week) strategic science activity plans. The science activity plans will fully specify all science and instrument calibration activities as well as the associated observation and traverse targets. The SOWG meeting is led by the SOWG Chair, who is responsible for guiding the group to a consensus on science activity plans. The SOWG will also perform analyses of science data and participate in press conference and outreach activities. There will be two Science Operations Working Groups, one for MER-A and one for MER-B. There will exist some crossover and coordination between the two teams.

The Payload Downlink Leads for each payload element provide the status of their payload element to the SOST Downlink Coordinator, who coordinates the payload status reports and acts as a liaison to the S/RET.

The SOST is responsible for assessing the performance of the science instruments, processing the science and engineering downlink telemetry associated with the instruments, and supporting the archival of collected data in the Downlink Assessment Process. The SOST consists of Payload Downlink Leads (PDLs), Payload Uplink Leads (PULs), MIPL image processing engineers, and the SOST Downlink Coordinator. The PDLs and PULs report to the Payload Element Leads on all science issues. The SOST will also participate in the SOWG activity planning meeting. Finally, the SOST provides Payload Uplink Leads to the Integrated Sequence Team for the Uplink Process. There will be two Science Operations Support Teams, one for each rover.

1.6.2 Mission Planning Team

The Mission Planning Team (MPT) leads the mission planning during surface operations. During the surface phase of operations, the MPT is responsible for developing the long term (multi-week) strategic surface operations scenarios, coordinating MER-A and MER-B mission activities to achieve mission success, and providing updates for the spacecraft models. The MPT schedules DSN coverage during surface operations, as well as coordinates communications opportunities with other orbiting assets. There will be a single Mission Planning Team to service both MER missions.

1.6.3 Integrated Sequencing Team

The Integrated Sequencing Team (IST) is responsible for building and validating all sequences to be transmitted to the spacecraft. The team is "integrated" in that it draws on the membership of other teams (Science Operations Support Team, SOWG Chair, and Spacecraft/Rover Engineering Team) to perform its functions. During the sequence building process, IST members from other teams report to and take direction from the IST Lead.

The IST will receive detailed science activity plan inputs from the SOWG, as well as engineering activity plans from the Spacecraft/Rover Engineering Team. The IST will then generate a set of command sequences that implement these plans. The IST will validate the sequences to ensure that they are conflict-free and do not exceed the available time, power, thermal, and data volume resource allocations. After validation, they will prepare the sequences for upload to the spacecraft. The sequences will be delivered to the RTO team for actual uplink.

During the surface mission phase, the IST will assess the feasibility of proposed science activities in support of the SOWG science activity planning process. After receipt of the science activity plans submitted by the SOWG, the IST will plan and sequence all commands, including rover traverses and IDD articulations, in order to achieve the specified observations. The IST is expected to generate command sequences every sol of the surface mission that encompass: 1) nominal operations for the sol and the pre-uplink portion of the next sol, and 2) safe, scientifically useful observations for the rest of the following sol in the event that the next sequence uplink is not successful. The IST will also generate contingency sequence loads as needed. There will be two Integrated Sequence Teams, one for MER-A and one for MER-B.

1.6.4 Mission Control Real Time Operations Team

The Mission Control Real Time Operations (RTO) Team is responsible for radiating commands and sequences to the spacecraft during all phases of operations. The Mission Control RTO Team will monitor spacecraft and ground functionality, as well as ensure an appropriate DSN configuration. There will be a single Mission Control Real Time Operations Team used to control both MER missions.

1.6.5 Ground Data System Team

The Ground Data System (GDS) Team is responsible for ensuring that all components of the GDS function properly during all phases of operations. The ground software, hardware, tools, and networks used to support mission operations will be integrated, maintained, and managed by the GDS Team. Ground anomalies and GDS upgrades will also be the responsibility of the GDS Team. There will be a single Ground Data System Team to support the MER missions.

1.6.6 Navigation Team

The Navigation Team (NAV) is responsible for providing spacecraft flight navigation (trajectory determination and control) from launch through atmospheric entry. Specific activities include TCM design and analysis, orbit perturbation analysis, and Doppler ranging data interpretation.

During the surface phase of operations, the NAV Team is responsible for determining the geodetic locations of the MER rovers on the surface of Mars. There will be a single Navigation Team to support the MER missions.

1.6.7 Spacecraft/Rover Engineering Team

During surface operations, the Spacecraft/Rover Engineering Team (S/RET) is responsible for rover state of health and performance assessment, instrument health assessment, EDL data processing, and anomaly resolution. The S/RET is also responsible for engineering planning of the rover for each sol's activity. There will be two Spacecraft/Rover Engineering Teams, one for MER-A and one for MER-B. A member of the S/RET will serve as the Tactical Operations Lead during the downlink shift. The downlink Tactical Operations Lead has responsibility for the on-time delivery of all science and engineering products needed to support the uplink planning process. The authority of the Tactical Operations Lead is second only to the Mission Manager. While the Tactical Operations Lead has authority to determine priorities between science and engineering, he or she will not influence relative priorities among science objectives.

1.6.8 Deep Space Mission Support Team

The Deep Space Mission Support (DSMS) Team is responsible for providing multi-mission DSMS services (e.g. Deep Space Network, Navigation and Ancillary Information Facility). This team is entirely multi-mission with no MER Project-dedicated team lead.

1.7 MER Project Science Group (PSG) and Athena Science Team

The PSG and Athena Science Team will hold joint meetings on a regular basis, typically three 3-day meetings at JPL and one at Cornell University each year. The frequency will be dictated by the needs of the Project. These meetings will provide updates on Project and Athena Science Team accomplishments, plans, and concerns, and will address issues affecting science return. So far, the PSG has formed two working groups, the Science Operations Working Group (SOWG) and the Data Archive Working Group (DAWG). During the Development Phase of the Project, the PSG SOWG Chair is Steve Squyres. The PSG DAWG Chair is Ray Arvidson. DAWG responsibilities are described in Section 7.7.

1.7.1 MER PSG

The members of the MER PSG are:

- Steven Squyres (Athena PI), Cornell University
- Ray Arvidson (in his role as the Data Archiving Interdisciplinary Scientist Support Investigator), Washington University, St. Louis
- Joy Crisp, MER Project Scientist, JPL
- Cathy Weitz, MER Program Scientist, NASA Headquarters

Albert Haldemann, MER Deputy Project Scientist, JPL, is an ex-officio member of the PSG.

1.7.2 <u>Athena Science Team</u>

The current members of the Athena Science Team are:

- Steven Squyres (PI), Cornell University
- Ray Arvidson (Deputy PI), Washington University, St. Louis
- Jim Bell (Pancam Payload Element Lead), Cornell University
- Mike Carr, USGS, Menlo Park
- Phil Christensen (Mini-TES Payload Element Lead), Arizona State University
- Dave Des Marais, NASA Ames
- Tom Economou, University of Chicago
- Steve Gorevan (Rock Abrasion Tool Payload Element Lead), Honeybee Robotics
- Larry Haskin, Washington University, St. Louis
- Ken Herkenhoff (Microscopic Imager Payload Element Lead), USGS, Flagstaff
- Göstar Klingelhöfer (Mössbauer Payload Element Lead), Johannes Gutenberg-University, Germany
- Andy Knoll, Harvard University
- Morten Bo Madsen (Magnet Array Provider), Copenhagen Univ., Denmark
- Mike Malin, Malin Space Sciences Systems
- Hap McSween, University of Tennessee
- Dick Morris, NASA JSC
- Rudi Rieder (APXS Payload Element Lead), Max Planck Inst. für Chemie, Germany
- Michael Sims, NASA Ames
- Larry Soderblom, USGS Flagstaff
- Claude d'Uston, CESR, France
- Heinrich Wänke, Max Planck Inst. fur Chemie, Germany
- Tom Wdowiak, University of Alabama, Birmingham

The Participating Scientists selected via this Announcement of Opportunity will be added to the Athena Science Team.

1.7.2.1 Science Operations Working Group (SOWG) Chairs

This is a role description that applies during operations tests and landed operations, and does not apply to the role of the PSG SOWG Chair during Development Phase.

Six members of the Athena Science Team (PI, Deputy PI, and four chosen from among the Co-I's and Participating Scientists) will be designated as SOWG Chairs. For each sol, there will be an SOWG Chair, a Backup SOWG Chair, and a Secondary Backup SOWG Chair designated for each rover. The SOWG Chair and Backup SOWG Chair must be in residence at JPL during landed operations. The Athena PI is responsible for establishing the SOWG Chair rotation schedule. Two of the six SOWG Chairs will be the Athena PI and Deputy PI. After selection of the Participating Scientists, the other four will be recommended by the Athena PI and selected by NASA Headquarters.

Specific responsibilities of the SOWG Chair on each sol are to:

- Lead the Science Assessment Meeting. The purpose of this meeting is to bring the Science Team up to date on latest findings from Science Theme Groups. The meeting allows cross-disciplinary discussions that may stimulate new ideas on plans for upcoming sols. It is also used to make plans for upcoming press conferences, including selection of participants and data products.

- Lead the SOWG meeting, guiding the group to a consensus on an activity plan (including identification of critical data products) for the coming sol, which is consistent with rover safety, mission constraints, and mission science objectives. The SOWG Chair is empowered to provide adjudication when a consensus cannot be reached.

- Participate as a member of the Integrated Sequence Team. The SOWG Chair is available to provide scientific guidance to the other members of the Integrated Sequence Team if the activity plan arrived at by the SOWG requires modification. Under such circumstances, the SOWG Chair's responsibility is to assure that the final sequence is as compatible as possible with the original intent of the SOWG.

The Backup SOWG Chair on each sol also participates in the SOWG meeting, but does not serve as a member of the Integrated Sequence Team unless the SOWG Chair is unable to do so. During dual-rover operations, there will be daily tag-up meeting involving the two SOWG Chairs, the Project Scientist, and the Athena PI to identify lessons learned and to share them between the two SOWGs.

SOWG Chairs will all be individuals with broad knowledge of Martian scientific issues, as well as deep understanding of all elements of the Athena Payload and all significant aspects of MER rover operational procedures and constraints. Before landing, SOWG Chairs will exercise their roles in Operational Readiness Tests (ORTs) and other operations testing.

1.7.2.2 Payload Element Leads (PELs)

This is a role that applies through the Development and Operations phases of the Project. During Operations, the PELs are members of the Science Operations Support Team.

Each Athena payload element has a Payload Element Lead (PEL), selected by the Athena PI from among the Co-Is. The six PELs are:

- <u>Pancam</u>: Jim Bell
- <u>Mini-TES</u>: Phil Christensen
- <u>Mössbauer</u>: Göstar Klingelhöfer
- <u>APXS</u>: Rudi Rieder

- Microscopic Imager: Ken Herkenhoff
- Rock Abrasion Tool: Steve Gorevan

The Athena PI is ultimately responsible for ensuring that pre-flight calibration and test are carried out for the Athena payload, for operating the Athena payload elements on the surface of Mars, and for assuring that the data products associated with the Athena payload are generated, validated, and archived, in accordance with the MER Archive Generation, Validation and Transfer Plan. Specific responsibilities delegated to the six PELs for their respective payload elements are:

- Generate a Calibration Plan that assures calibration to the highest scientific standards.
- Carry out calibration, and generate a Calibration Report that fully documents the procedures that were followed and the results that were obtained.
- Working with the Deputy Principal Investigator, assure that calibration data are archived in a timely fashion in PDS-compliant formats, in accordance with the Mars Program Data Management Plan and the MER Archive Generation, Validation, and Transfer Plan.
- Support payload integration and test during ATLO.
- Develop software necessary for processing and analysis of both calibration and flight data.
- Coordinate science operations associated with their payload element during all ORTs, MER rover field tests, and other operations tests.
- Coordinate science operations associated with their payload element when the rovers are on the Martian surface. Sol-to-sol operations responsibility will normally be delegated to Payload Downlink Leads (PDLs) and Payload Uplink Leads (PULs).
- Lead the generation of all archival data products derived from their payload element, and assure that these products conform to the highest scientific standards.
- Deposit reduced data, associated software, documentation, and other pertinent investigation information in the Planetary Data System, in accordance with the Mars Program Data Management Plan and the MER Archive Generation, Validation, and Transfer Plan.
- Participate in the analysis of data from the MER mission, and in the publication of scientific results.

1.7.2.3 Payload Uplink Leads (PULs)

This is a role that applies during operations tests and landed operations. During the sequence build and validation process, the PULs are members of the Integrated Sequence Team. At other times, the PULs are members of the SOST.

The six PELs are responsible for overall operation of their payload elements. However, simultaneous operation of two MER rovers will require the availability of a significant number of individuals who are fully trained in the operation of each of the Athena payload elements, and to whom the PELs can delegate sol-to-sol operations responsibilities as necessary. PULs will be assigned by the PELs, with the concurrence of the MER Science Manager, Spacecraft Team Chief, Integrated Sequencing Team Chief, and the Athena PI.

Specific responsibilities of the PUL on each sol are to:

- Participate in the SOWG meeting, serving as an advocate for use of their payload element.

- Assist the SOWG chair during the SOWG meeting in devising a time-ordered list of payload activities.
- After the SOWG meeting, serve as a member of the Integrated Sequence Team, generating and validating instrument commands that are consistent with the time-ordered activity list produced by the SOWG.
- As a member of the Integrated Sequence Team, assess the compatibility of instrument commands with operational constraints, and modify them as necessary. The PUL is fully empowered during Integrated Sequence Team activities to modify command sequences as necessary to fit within operational constraints. The PUL will work with the SOWG chair (who is also a member of the Integrated Sequence Team) to assure that the modified command sequences is as compatible as possible with the SOWG's activity plan for that sol.

When acting as a member of the IST, the PUL reports to and takes direction from the IST Lead, who has ultimate responsibility for timely delivery of the command sequences for a given sol. For all other science issues, the PUL reports to and takes direction from the PEL.

1.7.2.4 Payload Downlink Leads (PDLs)

This is a role that applies during operations tests and landed operations. During Operations, the PDLs are members of the Science Operations Support Team.

There are many hours between when downlink analysis begins and when the next sol's sequence has been fully validated and is ready for uplink. Accordingly, the PUL cannot also lead data analysis for each sol without working an unacceptably long shift. For this reason, the PEL for each payload element will also designate a Payload Downlink Lead for each sol, with the concurrence of the MER Science Manager, Spacecraft Team Chief, Integrated Sequencing Team Chief, and Athena PI. This individual must be someone who is sufficiently familiar with the payload element hardware to lead the assessment of its state of health. He/she must also be sufficiently familiar with the data analysis process for that payload element to lead it during the interval between downlink and the start of the SOWG meeting.

Specific responsibilities of the Payload Downlink Lead on each sol are to:

- Coordinate science downlink data processing and analysis for the specific payload element, including both science data analysis and assessment of the health of the payload element.
- Participate in the Science Assessment Meeting, presenting new scientific findings from analysis of telemetry from that payload element.
- Participate in a science crossover meeting, which takes place immediately before the SOWG meeting. At the science crossover meeting, brief the PUL on new scientific results and instrument state of health.
- Report on the health of the payload element at the SOWG meeting.
- Coordinate with the downlink Tactical Operations Lead.

In order to gain the necessary experience for their payload element, Payload Downlink Leads will be individuals who have participated extensively in calibration, ATLO testing, and ORTs.

1.7.2.5 Science Theme Leads (STLs)

This is a role description that applies during operations tests and landed operations. During Operations, the Science Theme Leads (and all the members of their groups) are members of the Science Operations Working Group.

The Science Team will be organized to include at least five Science Theme Groups that each serve as a forum where discipline-specific science analysis, discussion, and planning takes place. The Science Theme Groups will include:

- Geology
- Geochemistry/mineralogy
- Soil/rock physical properties
- Atmospheric science
- Long-term strategic planning

There will be one of each of these groups per rover. Additional Science Theme Groups (STGs) may be established as scientific discoveries warrant. Athena Science Team members will join the various Science Theme Groups based on their scientific interests. The groups will be responsible for organizing themselves and selecting the STLs. The exception is the Long-strategic planning STGs, whose STLs will be selected by the PI due to their role in planning multi-sol operations. Because of their management roles in other areas, the PI, Deputy PI, and PELs will not serve as STLs.

Specific responsibilities of each STL on each sol are to:

- Lead discussion and analysis by their science theme group that is aimed at establishing scientific goals and objectives for coming sols.
- Present their science theme group's findings at the science assessment meeting.
- Present their science theme group's findings and recommendations at the SOWG meeting.

The long-term strategic planning Science Theme Group must work with the MER Mission Planning Team to integrate strategic science goals into mission plan.

It is anticipated that many of the scientific publications describing the results of the MER investigations will arise from within the Science Theme Groups.

1.7.2.6 Athena Co-Is and Participating Scientists: General Responsibilities

Athena Co-Investigators (Co-Is) and Participating Scientists assist the Athena PI in meeting his responsibilities and are involved in calibration, testing, science planning (by the Science Operations Working Group), generation of higher-level science data products, and science analysis. At various times, Participating Scientists or Co-Is who are not already designated as PELs or PULs may serve as SOWG chairs or Science Theme Leads.

All Co-Is and Participating Scientists have the following general responsibilities:

- Assist the Athena PI in meeting his responsibilities.
- Participate in Athena Science Team meetings.
- Participate in operations training, MER Project Operational Readiness Tests, rover field tests, and other operations tests.
- Serve as SOWG members.
- Serve as members of Science Theme Groups.
- Be in conformance with the policies in the Mars Program Data Management Plan.
- Prepare preliminary reports, quick-release products, detailed scientific summaries, and public information releases, as appropriate.
- Deposit reduced data, associated software, documentation, and other pertinent investigation information for which they are responsible in the Planetary Data System, in accordance with the Mars Program Data Management Plan and MER Archive Generation, Validation, and Transfer Plan.

Along with these general responsibilities (and other responsibilities as listed in previous sections), many Co-Is have additional specific responsibilities. Participating Scientists will also have additional specific responsibilities, in accordance with the investigations described in their NASA-selected proposals. Participating Scientists will have the same data and publication rights as Co-Is.

1.8 Landing Site Selection Process

Selection of the landing site for the MER lander and rover is a joint science community/MER Project activity. The first MER landing site workshop was held at NASA Ames on January 24-25, 2001. Web sites for landing site workshops and landing site information (including a list of candidate sites, engineering constraints, 3-sigma landing ellipse sizes and orientations, and remote sensing data for the candidate sites) can be found here:

http://cass.jsc.nasa.gov/meetings/mer2003/pdf/program.pdf

http://marsoweb.nas.nasa.gov/landingsites/

http://webgis.wr.usgs.gov/mer/

The MER landing sites will be chosen to maximize the science return for the science objectives (which are listed in the Announcement of Opportunity associated with this PIP), within the constraints of the Project (schedule, risk, etc.). The MER-A landing site will be located between 15º S and 5ºN latitudes, and MER-B will be located between 10ºS and 10ºN. The landing sites will be selected so that they show two different types of evidence for the action of liquid water, such as mineralogic or geomorphologic (crater lake sediments, outflow sediments, or hydrothermal deposits, etc.) and where hypotheses related to aqueous activity can be further tested using the rovers and their payloads. Table 1 shows the schedule for landing site selection.

Table 1: Landing site selection and certification schedule.

Define preliminary engineering constraints	completed
Define preliminary remote sensing criteria	completed
Preliminary identification of potential landing	completed

sites	
First Landing Site Selection Workshop	completed Jan. 24-25, 2001
Construct a list of high and medium priority prospective landing sites for MOC targeting	Completed
Detailed science and engineering evaluation of candidate landing sites	2/2001 - 5/2003
Collect MOC targeted data	2/2001 – 4/2002
Landing Site Meeting to reprioritize the sites	9/2001
Collect THEMIS data	1/2002 – 5/2003
Second Landing Site Selection Workshop	3/2002
MER Project Certification Group certifies safety and selects target regions	4/2002
NASA HQ review and approval of target region selections	4/2002
Target regions delivered to Launch Vehicle engineers	6/2002
Third Landing Site Selection Workshop	2/2003
MER Project Certification Group reevaluates the safety of the sites and selects final ellipses	4/2003
NASA HQ review and approval of final ellipses	4/2003
NASA HQ risk assessment of MER	5/2003
Earliest launch date for MER-A	5/30/2003

1.9 Red Rover Goes to Mars

The ongoing educational program of the Planetary Society called "Red Rover Goes to Mars" will have a joint activity with the MER Project. NASA Headquarters has selected Lou Friedman as the Principal Investigator and Glenn Cunningham as the Project Manager. This joint educational outreach activity will involve student scientist participation with science experiment teams as well as a student scientist representative on the Science Operations Working Group (SOWG). The details of this have not yet been worked out, but the preliminary concept involves student scientists carrying out education experiments with rover instruments. Student "astronauts" would participate in suggesting commands for the MER rovers, working from a "Mars base" on Earth. Further information on Red Rover Goes to Mars is available at: http://planetary.org.

2 SCIENTIFIC INSTRUMENTS AND INVESTIGATIONS

2.1 Athena Payload Summary

This section summarizes the entire payload, and is followed by subsections that are much more detailed descriptions of each part of the payload. The Athena payload is a suite of scientific instruments and tools for geologic exploration of the Martian surface, designed to meet the MER science and measurement objectives. Two identical copies of the Athena payload will be flown on the two Mars Exploration Rovers.

The major elements of the Athena Mars Exploration Rover payload are:

- **Panoramic Camera (Pancam)**, a high-resolution stereo color panoramic imager;
- **Miniature Thermal Emission Spectrometer (Mini-TES)**, a mid-infrared spectrometer for remote investigation of mineralogy of rocks and soils;
- **Mössbauer Spectrometer (MB)** for in-situ determination of the mineralogy of Fe-bearing rocks and soils;
- **Magnet Array** that can separate magnetic soil particles from non-magnetic ones
- **Alpha Particle X-Ray Spectrometer (APXS)** for in-situ elemental analysis
- **Microscopic Imager (MI)** for close-up imaging of rock and soil surfaces
- **Rock Abrasion Tool (RAT)** for removing weathered rock surfaces and exposing fresh material for characterization

The location of the payload elements on the rover is shown in Figure 2.

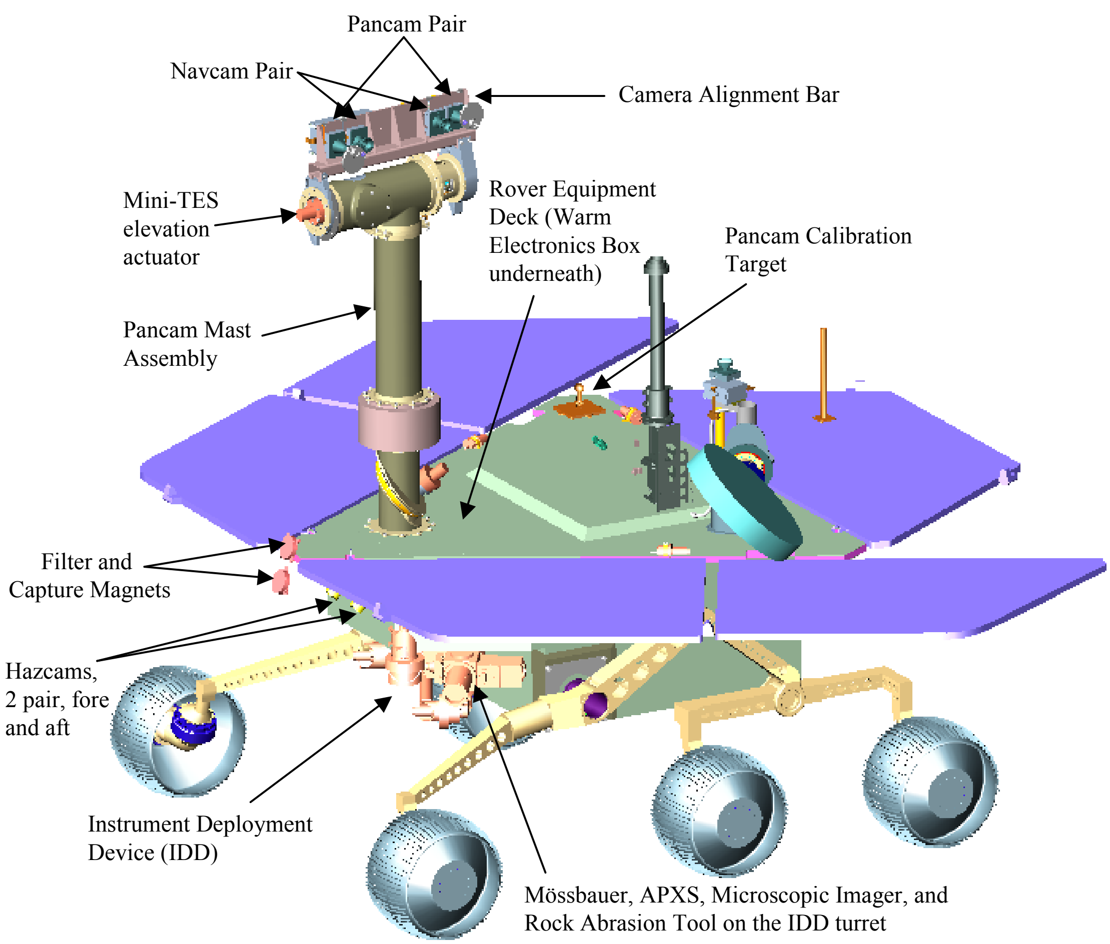

Figure 2. Schematic diagram showing the Athena payload and cameras on the rover.

The topography, morphology, mineralogy, and texture of the scene around the rover will be revealed by Pancam and Mini-TES, which are an imager and an infrared spectrometer, respectively, integrated with a single mast. Pancam views the surface around the rover in stereo and color. The detectors are 1024 × 1024 CCDs, and the electronics provide 12-bit analog-to-digital conversion. Filters provide 14 color spectral bandpasses over the spectral region from 400 to 1100 nm. Narrow-angle optics provide an angular resolution of 0.28 mrad/pixel. The Miniature Thermal Emission Spectrometer (Mini-TES) is a point spectrometer operating in the thermal infrared. It produces high spectral resolution (10 cm^{-1}) image cubes with a wavelength range of 5-29 μm, a nominal signal/noise ratio of 450:1, and angular resolution modes of 20 and 8 mrad. The wavelength region over which it operates samples the diagnostic fundamental absorption features of rock-forming minerals, and also provides some capability to see through dust coatings that could tend to obscure spectral features. The mineralogical information that Mini-TES provides will be used to select from a distance the rocks and soils that will be investigated in more detail. Along with its mineralogical capabilities, Mini-TES can provide information on the thermophysical properties of rocks and soils. Viewing upward, it can also provide temperature profiles through the Martian atmospheric boundary layer.

After promising samples have been identified from a distance using Pancam and Mini-TES, they will be studied in more detail using two compositional sensors that can be placed directly against them by an instrument arm (the Instrument Deployment Device). These are an Alpha Particle-X-Ray Spectrometer (APXS) and a Mössbauer Spectrometer (MB). The APXS is derived from the instrument that flew on Mars Pathfinder. Radioactive alpha sources and two detection modes (alpha and X-ray) provide elemental abundances of rocks and soils to complement and constrain mineralogical data. The Mössbauer Spectrometer is a diagnostic instrument for the mineralogy and oxidation state of iron-bearing phases. The instrument measures the resonant absorption of gamma rays produced by a ^{57}Co source to determine splitting of nuclear energy levels in Fe atoms that is related to the electronic environment surrounding them. The Mössbauer Spectrometer (as well as the other in-situ instruments) will be able to analyze a small permanent magnet array that will attract magnetic particles that settle from the Martian atmosphere.

The instrument arm also carries a Microscopic Imager (MI) that will obtain high-resolution images of the same materials for which compositional data will be obtained. Its spatial resolution is 30 μm/pixel over a 6-mm depth of field. It uses the same CCD detectors and electronics as Pancam.

Some Martian rock surfaces are likely to be dust-covered, coated, weathered, or otherwise unrepresentative of the rock’s interior. For this reason the Athena payload includes a Rock Abrasion Tool (RAT). The RAT is also carried on the rover’s instrument arm (IDD). When placed against a rock, it uses mechanical grinding heads to remove 5 mm of material over a circular area 45 mm in diameter. The resultant exposed region is large enough to be investigated in detail using all of the instruments on the payload.

The subsections that follow contain more detailed descriptions of each of the payload elements.

2.1.1 Pancam

Pancam uses 1024 × 2048 pixel Mitel CCD array detectors developed for the MER Project. The arrays are operated in frame transfer mode, with one 1024 × 1024-pixel region comprising the active imaging area and the adjacent 1024 × 1024 region serving as a frame transfer buffer. The frame transfer buffer has an opaque cover that prevents more than 99% of light at all wavelengths from 400 to 1100 nm from being detected by this region of the CCD. The pixels are continuous, and the pitch is 12 μm in both directions. The arrays are capable of exposure times from 0 msec (to characterize the "readout smear" signal acquired during the ~ 5 msec required to transfer the image to the frame transfer buffer) to 30 sec. Under expected operating conditions, the arrays have at least 150,000 electrons of full-well depth, and a read noise of less than 50 electrons. Dark current varies with temperature; it is negligible at -55°C and is less than 1200 electrons/sec at 0°C. Analog to digital converters provide a digital output with 12-bit encoding, and SNR greater than 200 at all signal levels above 20% of full scale. The detector response has linearity better than 99% for signals between 10% to 90% of full well.

Each array is combined with optics and a small filter wheel to form one "eye" of a multispectral, stereoscopic imaging system. The optics for both cameras consist of identical 3-element symmetrical lenses with an effective focal length of 38 mm and a focal ratio of f/20. This combination yields an IFOV of 0.28 mrad/pixel and a square FOV of 16.8° × 16.8° per eye. The optics and filters are protected from direct exposure to the Martian environment by a sapphire window at the front of the optics barrel. The optical design provides for more than 90% of the encircled energy to be contained in an area equal to 3 × 3 IFOVs, and 99% in an area equal to 5 × 5 IFOVs, across the entire range of spectral responsivity of the instrument and over the required operating temperature range for performance of Pancam within specifications (-55°C to 0°C). The optical design allows Pancam to maintain optimal focus from infinity to within 3 meters of the rover. At ranges closer than 3 meters, Pancam images have some defocus blur. Approximate estimates of blur diameters encompassing 86% of the encircled energy, for various distances from the camera lens to an object, are shown in Table 2. Note that the diffraction Airy disc is about 2 pixels wide for an object distance of 3 m.

Table 2. Approximate blur diameter as a function of distance between front of lens and object.

Object Distance (m)	Blur Diameter (pixels)
0.5	14.5
1.0	6
2.0	2.3
3.0	1

Each filter wheel has eight positions, allowing multispectral sky imaging and surface mineralogic studies in the 400-1100 nm wavelength region. The left wheel contains one "clear" (empty) position. The other filter wheel positions contain circular 10 mm diameter narrowband interference filters with the central wavelengths and bandpasses listed in Table 3. One filter on each eye has a neutral density ND 5.0 coating (0.001% transmission) to allow direct imaging of the Sun at two wavelengths.

Table 3. Pancam multispectral filter set: Wavelength and (bandwidth), in nm.

LEFT CAMERA		RIGHT CAMERA	
L1	EMPTY	R1	430 (SP)*
L2	750 (20)	R2	750 (20)
L3	670 (20)	R3	800 (20)
L4	600 (20)	R4	860 (25)
L5	530 (20)	R5	900 (25)
L6	480 (25)	R6	930 (30)
L7	430 (SP)*	R7	980 (LP)*
L8	440 Solar ND*	R8	880 Solar ND*
* SP indicates short-pass filter; LP indicates long-pass filter			

Radiometric calibration of both Pancam cameras will be performed with an absolute accuracy of 7% or better and a relative precision (pixel-to-pixel) of 1% or better. Calibration will be achieved using a combination of preflight calibration data and inflight images of a Pancam calibration target carried by the rover. The Pancam calibration target is placed within unobstructed view of both camera heads and will be fully illuminated by the Sun between at least 10:00 AM and 2:00 PM local solar time for nominal rover orientations. The target has three gray regions of variable reflectivity (approximately 20%, 40%, and 60%) and four colored regions (peak reflectance in the blue, green, red, and near-infrared) for colorimetric calibration. It includes a vertical post that will cast a shadow simultaneously across all three gray surfaces at some time within the 10:00 AM to 2:00 PM nominal operating range. The calibration target is large enough that defocus blur will not produce significant degradation of the calibration images.

The two Pancam eyes are mounted on a mast on the rover deck. The mast is referred to as the Pancam Mast Assembly (PMA) (See Figure 3), and also includes several key components for the Mini-TES. The PMA is erected to the vertical position by a deployment actuator at its base. The cameras are located on a "camera bar" with a boresight 180° from the Mini-TES boresight (Figure 4). The rover navigation cameras (Navcams) are also located on this same camera bar, and point in the same direction as Pancam. The boresight of the Pancam cameras is approximately 1.5 m above the Martian surface when the PMA is in the deployed position. The cameras are moved together by ± 90° in elevation using a geared brush motor on the camera bar. The entire PMA head, including the cameras, can be rotated 360° in azimuth by a geared brush motor assembly. A separate geared brush motor provides elevation actuation for the Mini-TES elevation mirror assembly. Hard stops are provided for all actuation axes.

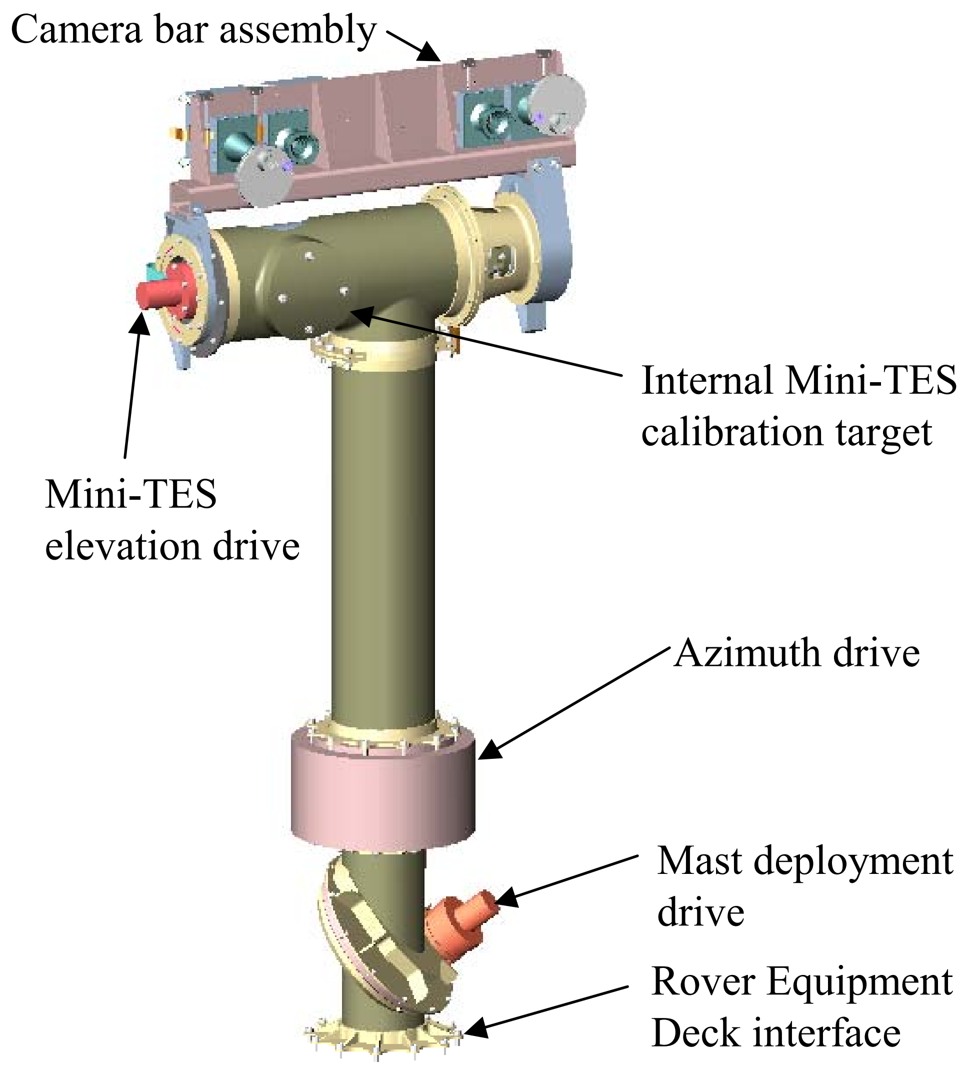

Figure 3. Pancam Mast Assembly (PMA) configuration.

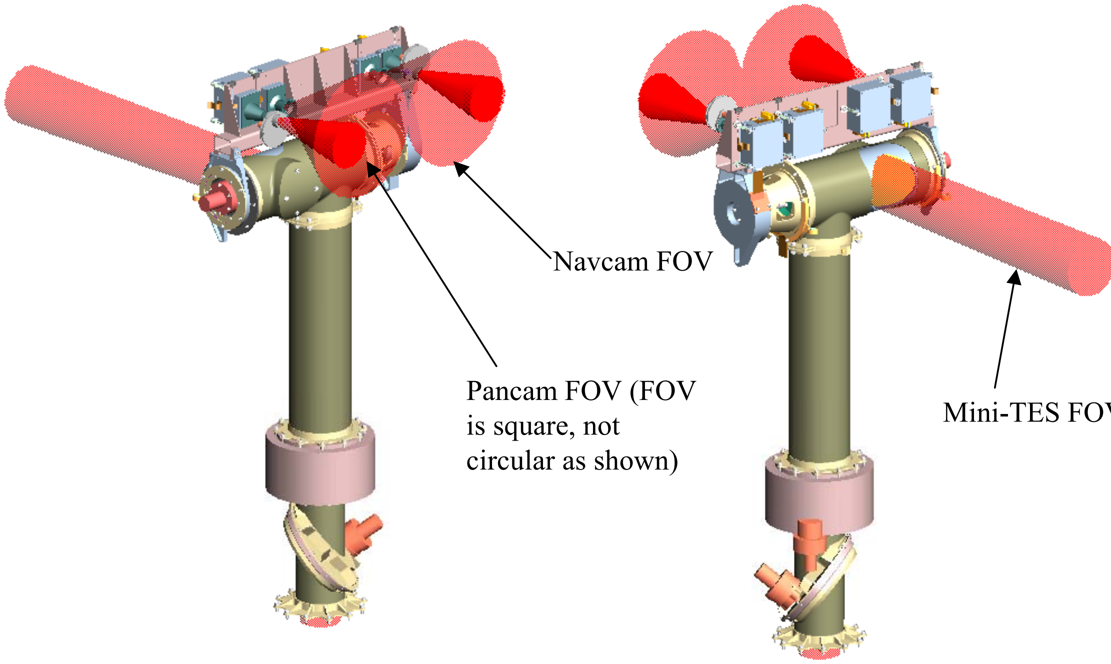

Figure 4. Pancam, Navcam, and Mini-TES Fields of View (FOV).

The two Pancam eyes are separated by 30 cm horizontally and have a 1° toe-in. This separation and toe-in provide an adequate convergence distance for scientifically useful stereo topographic and ranging solutions to be obtained from the near-field (5-10 m) to approximately 100 m from the rover. Pointing control is better than 2° in azimuth and 1° in elevation. Pointing knowledge relative to the hardstops is 0.1° over the entire range of motion of Pancam.

Pancam will operate primarily during the daytime to obtain high-quality measurements of sunlight reflected off rock and soil surfaces and airborne dust particles, as well as direct solar images using the two ND filters. Twilight or nighttime sky or astronomical object imaging may be possible but has not been accepted by the Project. The required operating temperature range for performance of Pancam within specifications is -55°C to 0°C.

Pancam will be commanded by and will return digital data directly to the rover computer. The computer provides the capability to perform a limited set of image processing tasks on Pancam data prior to transmission. These tasks include (1) bias and dark current subtraction, (2) electronic shutter effect correction, (3) bad pixel replacement, (4) rudimentary automatic exposure control capability to maximize the SNR of downlinked data while preventing data saturation, (5) image subsampling and subframing, and (6) image compression using a JPL-developed wavelet compression algorithm called ICER.

Pancam telemetry is collected by the rover computer and downlinked according to an overall priority queue scheme agreed upon in advance by the MER Science Operations Working Group.

2.1.2 Mini-TES

Mini-TES is a Michelson interferometer that provides a spectral resolution of 10 cm^{-1} over the wavelength range from 5-29 μm (2000 - 345 cm^{-1}). The instrument is mounted on the rover, and views the terrain around the rover by using the PMA as a periscope. The boresight of the Mini-TES is approximately 1.4 m above the Martian surface when the PMA is in the deployed position. A scan mirror assembly atop the PMA reflects radiation down through the PMA and into the telescope and interferometer. The scan mirror assembly allows Mini-TES to provide spectral image cubes over a 360° range in azimuth and from –50° to +30° in elevation. The scan mirror assembly also provides a view of internal and external, full-aperture calibration targets. The elevation mirror can be slewed to a stowed position in which a cover blocks the Mini-TES aperture in the PMA, protecting the optics from dust accumulation.

Mini-TES has two spatial resolution modes. A solenoid-activated field stop can be removed from the optical path to provide an IFOV of 20 mrad, or inserted to provide an IFOV of 8 mrad. Baffles in the PMA define the stray energy field of view and are designed to minimize stray energy from outside the 20 mrad IFOV from entering the interferometer. The inside of the PMA is designed to minimize the stray background energy from the PMA itself.

During data acquisition, the PMA's elevation mirror and azimuth actuator are sequenced to generate a raster image of the scene. The scan mirror assembly can also be commanded to allow Mini-TES to view the internal and external calibration targets regularly in order to maintain instrument calibration during an image acquisition. The elevation and azimuth servos move and settle to each commanded position ±1 mrad. Elevation steps of up to 20 mrad in size take place within the 200 msec retrace period of the Mini-TES interferometer, while azimuth steps may take as long as 1 second. Slews to the calibration targets take significantly longer.

The Mini-TES telescope at the base of the PMA is a reflecting Cassegrain configuration with a mirror diameter of 6.35 cm, a focal ratio of f/12, and an intermediate field stop that feeds an approximately collimated beam into the Mini-TES interferometer. The 6.35-cm telescope diameter defines the minimum size of the Mini-TES beam; the beam diverges further at an angle of either 8 or 20 mrad, depending on the resolution mode chosen. The optical design provides for more than 85% of the encircled energy to be contained in an area equal to a single IFOV, 98% within an area equal to 2 × 2 IFOV, and 99.8% within an area equal to 3 × 3 IFOV. Focus is maintained from 2 meters to infinity, with a blur of no more than 15% of an IFOV at infinity focus.

The Mini-TES Michelson interferometer uses the same flexure-mounted linear motor mechanism and drive electronics as the Mars Observer (MO)/Mars Global Surveyor (MGS) TES instrument. The system uses a 980-nm interferometer to generate interference fringes that control the linear drive servo and time the acquisition of the IR spectrometer data samples. The design is simplified from the TES by combining the infrared and visible counting interferometers into one interferometer at one end of the motor drive and replacing neon bulbs with redundant laser diodes. Double-sided interferograms at a spectral resolution of 10 cm^{-1} are obtained with a mirror travel distance of 0.55 mm in 1.8 sec. A voltage ramp is used to drive the mirror at a fixed velocity, and position feedback is obtained from a linear voltage displacement transducer.

Optical switches sense beginning of scan and synchronize the interferometer with the elevation and azimuth drive motors.

Mini-TES uses a single uncooled deuterated triglycine sulfate pyroelectric detector sized to define the instrument's 20-mrad IFOV. The IFOV, dwell time, and interferometer scan rate have been selected to produce frequencies in the range of 15 to 120 Hz which is the range over which minimum noise equivalent spectral radiance (NESR) can be achieved. The detector provides the necessary performance over a temperature range from –10 to +20°C and with reduced performance from –40 to +35°C.

The NESR of the Mini-TES for a single spectral accumulation interval at 10 μm observing a scene at 270 K and 20 mrad will be less than 1.25×10^{-8} W cm^{-2} sec^{-1} sr^{-1}, corresponding to a signal-to-noise ratio (SNR) of at least 450 for coaddition of two observations. Radiometric calibration of Mini-TES over its full spectral range will be performed with an absolute accuracy of 5% or better and a relative precision (pixel-to-pixel) of 2% or better when viewing a 270 K blackbody. The internal calibration target is located inside the head of the PMA, and the external target is located on the deck of the rover. Both targets have V-grooved surfaces and are coated with high emissivity paint. Temperature sensors affixed to both targets have an absolute accuracy of ± 0.2°C and a precision of ± 0.1°C.

The instrument's electronics are based on the electronics of the MO/MGS TES. A 14.515 MHz internally generated clock signal provides the control timing for the interferometer motor controller and synchronizes the scan timing and data collection events with the rover computer. Detection of start of scan by the optical switches also signals to the rover computer that data collection has begun. This signal triggers an internal timer that initiates retrace of the interferometer mirror after 1.8 seconds. Signals from the detector are fed through a pre-amplifier, variable gain post-amplifiers for each field of view, an analog multiplexer, a 16-bit A/D converter, and into an output buffer.

Mini-TES begins collecting data at the application of power. The instrument acquires data in a cyclic fashion, with a period of two seconds corresponding to the Michelson mirror scan followed by its retrace. Spectral integration is coordinated with the PMA elevation and azimuth drive mechanisms using the rover computer. In each two-second period (known as one ICK), the hardware fills up the Mini-TES data buffer with header data, interferogram data from the selected spectrometer field of view, and the telemetry data.

Mini-TES flight software controls the transfer of the data from the Mini-TES data buffer to the rover CPU memory. Once the Mini-TES data are available in the rover memory, the flight software performs a Fourier transform on the interferogram in order to generate a spectrum. Aggregation of data reduces the total volume of data to be downlinked. Separate programmable data aggregation modes in the spatial domain (averaging spectra from consecutive ICKs) or in the spectral domain (averaging data from contiguous spectral points) are available. Data volume is further reduced via lossless compression using a Rice algorithm. Compressed data then undergo final formatting and transfer to rover data storage for downlink.

The rover computer issues commands to PMA motor driver circuitry in order to synchronize the mirror movements to the Mini-TES data acquisition. Direct commands from the rover computer control instrument power and selectable gain state, field of view, motor on/off, laser heater on/off, redundant start-of-scan optical switches, and redundant laser diodes.

Mini-TES operates primarily during mid-day (10 a.m. to 3 p.m. local time) to obtain high-quality spectral measurements of emitted infrared energy. Nighttime observations may be obtained to measure surface and atmospheric temperatures of the full diurnal cycle for thermophysical and boundary layer studies.

2.1.3 Mössbauer Spectrometer (MB)

The Athena Mössbauer spectrometer uses a vibrationally-modulated ^{57}Co source to illuminate target materials. Backscattered gamma signals are binned according to the source velocity, revealing hyperfine splitting of ^{57}Fe nuclear levels that provides mineralogical information about the target. The main parts of the instrument are the Mössbauer drive that moves the ^{57}Co source with a well-known velocity, the γ- and X-ray detectors that detect the backscattered radiation, the microcontroller unit, the ^{57}Co/Rh Mössbauer source, and the radiation collimator and shielding.

The spectrometer is split into the sensor head on the rover's Instrument Deployment Device, and the electronics in the rover's Warm Electronics Box (WEB). The sensor head carries the Mössbauer drive with the analog part of the drive control unit, the ^{57}Co/Rh Mössbauer source, the radiation collimator and shielding, the four PIN-diode detector channels including pulse amplifiers, and one reference detector channel to monitor the velocity of the drive using a weak ^{57}Co source and a well known Mössbauer reference absorber in transmission geometry.

The Mössbauer electronics are on the payload card in the Rover Electronics Module (REM), which is part of the WEB. The WEB electronics for the Mössbauer include the microcontroller and memories for data acquisition and temporary storage, voltage supply regulators, and detector bias voltage generators. An extra FPGA logic unit provides functions for internal communication, generates the velocity signal for the drive, and contains fast pulse counters for the detector signals.

The analog signals of the five detector channels are analyzed by discriminators for 14.4 keV and 6.4 keV peaks. Upper and lower threshold values of the discriminators are generated by digital to analog converters (DACs). These values can be changed automatically to follow the temperature drift of the amplifiers. Digital signals from the discriminators are sent to the velocity-synchronized counters whenever a detected pulse is within the specified range. Mössbauer spectra for the two different energies of 6.4 keV and 14.41 keV are sampled separately.

The Mössbauer spectrometer has its own internal microcontroller, so that it can collect data independently of the rover computer. This microcontroller is part of the electronics on the payload card in the REM. Instrument parameters are stored in a fault-tolerant fashion in 3 separate FRAMs and default values for these parameters are taken from ROM in case of an error. Every 60 minutes during a measurement, data is stored into the EEPROM. In case of a failure of the power supply, after restart of the instrument the data acquisition will continue with this data. Each Mössbauer spectrum consists of 512 × 3-byte integers. The pulses from the 4 counters are added by hardware for each counter, normally creating one spectrum for each detector. The spectra are sampled into an SRAM of 128 Kbytes size.

Measurements are made by placing the instrument directly against a rock or soil sample. Physical contact is required to provide an optimal measurement distance and to minimize possible microphonic noise on the velocity-modulated energy of the emitted γ rays. The mechanical construction of the robotic arm (IDD) and the interface limit vibration-induced velocity noise at the sensor head to less than 0.1 mm/s. A contact plate is mounted at the front part of the sensor head, assuring an optimal distance from the sensor head to the sample of approximately 9 to 10 mm. A heavy metal collimator in front of the source provides an irradiated spot of nominally 15 mm (up to 20 mm, depending on actual sample distance and shape) in diameter on the surface of the sample. The IDD can position the instrument with an accuracy of better than 0.4 cm or better with respect to the position observed by other IDD-mounted instruments. The average depth of sampling by Mössbauer data is about 200 to 300 μm.

Mössbauer parameters are temperature dependent. Especially for small particles exhibiting superparamagnetic behavior (e.g., nanophase Fe oxides), the Mössbauer spectrum may change drastically with temperature. The observation of such changes will help in determining the nature of the iron-bearing phases. Therefore Mössbauer measurements will be performed over a range of diurnal temperatures spanning both the daytime maxima and the nighttime minima.

One Mössbauer measurement takes approximately 12 hours, depending on the phases present in the sample and the total iron content. The temperature variation for one spectral accumulation interval will not be larger than about ± 10°C. When larger variations occur, spectra for different temperature ranges are stored separately, resulting in an increase in the total data volume (depending on the number of temperature intervals required), and a decrease of statistical quality for the individual subspectra.

In parallel with the measurements of samples, calibration spectra will be taken using the reference channel implemented in the instrument. A calibration target containing a thin slab of magnetite-rich rock will also be included on the rover where it can be viewed directly by the instrument soon after landing, as well as later in the mission if necessary.

The performance of the Mössbauer Spectrometer can be defined by measurements made in transmission geometry with a Mössbauer source in front of the instrument at a distance of 5 cm, and in a backscattering geometry with the source internal to the instrument in its flight configuration. Instrument performance requirements for such purposes are specified for a Mössbauer source strength of 100 mCi for the backscattering mode, 10–20 mCi for transmission mode, an integration time of 10 minutes for the energy spectra (backscattering and transmission), and an integration time of 10 hours for the Mössbauer backscattering spectrum.

(1) Specifications for the energy spectra taken in transmission mode (see Figure 5) at a temperature of +20 (±1)°C are:

- noise level: The intensity at (A) (channel 11) will not exceed 20.000 (± 1000) counts;
- at (B) (“valley”, channel 15), the intensity will be less than 8900 (± 500) counts; and

- the peak-to-valley ratio (ratio of intensities at (C) (channel 19) and (B)) will be equal to or larger than 1.5.

(2) Specifications for the energy spectra taken in backscattering mode (see Figure 6) at a temperature of +20 (± 1)°C are:

- noise level: The intensity at (A) (channel 18) will not exceed (50 ± 10) counts;
- at (B) (channel 36) the intensity will be less than 23 ± 5 counts;
- within the energy range channel 25 to channel 50 the intensity will be between 2 and 25 counts; and
- at (C) (channel 145) the tantalum X-ray line generated in the collimator will be visible; the intensity will be 18 ± 4 counts.

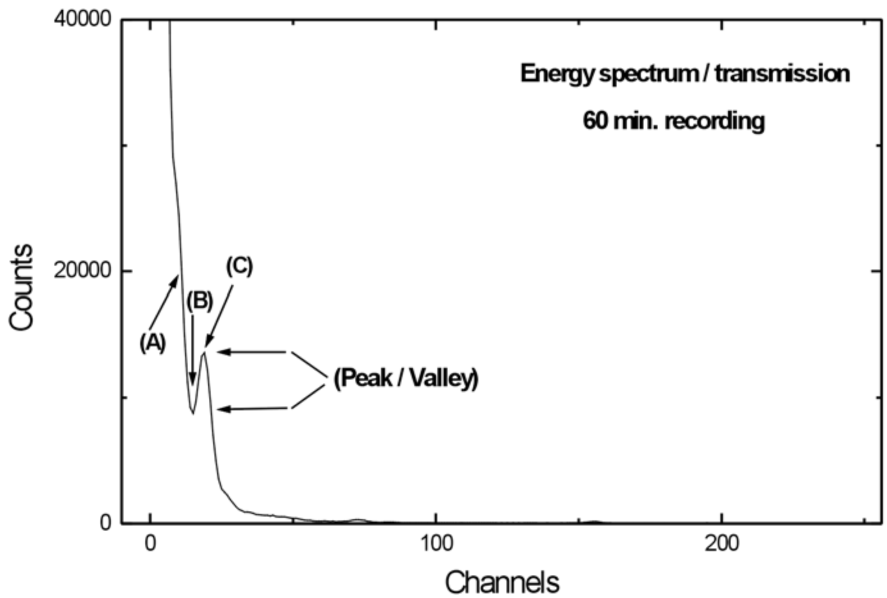

Figure 5. Energy spectrum of a ^{57}Co Mössbauer source, taken in transmission mode.

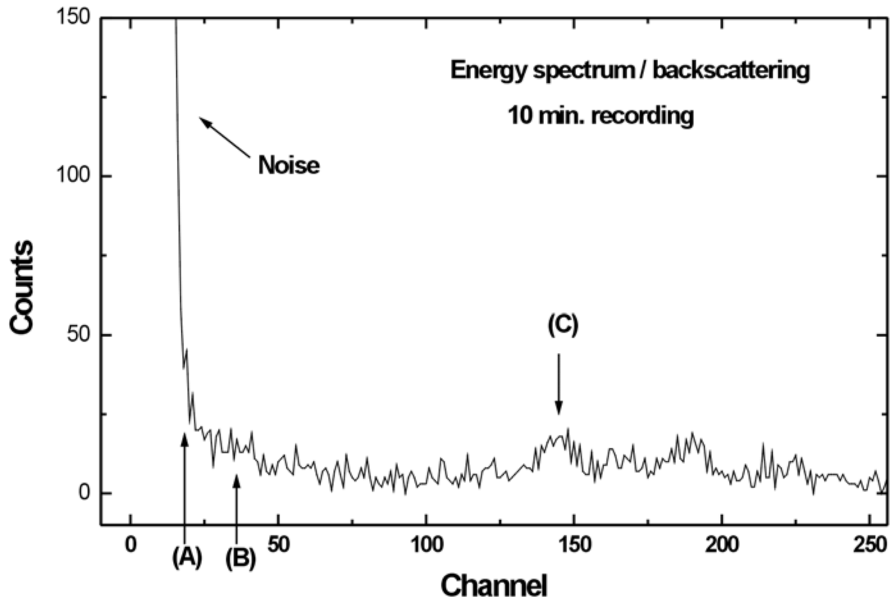

Figure 6. Energy spectrum of a ^{57}Co Mössbauer source, taken in backscattering mode on the Mössbauer calibration target.

(3) Specifications for the Mössbauer spectra taken in backscattering mode (see Figure 7) on its magnetite-rich calibration target at a temperature of +20 (± 1) °C are that:

- the peak/background ratio will not be less than 1.11 for a source activity between 80 and 120 mCi; and
- the magnetite signal will be visible with a peak/background ratio of not less than 1.005.

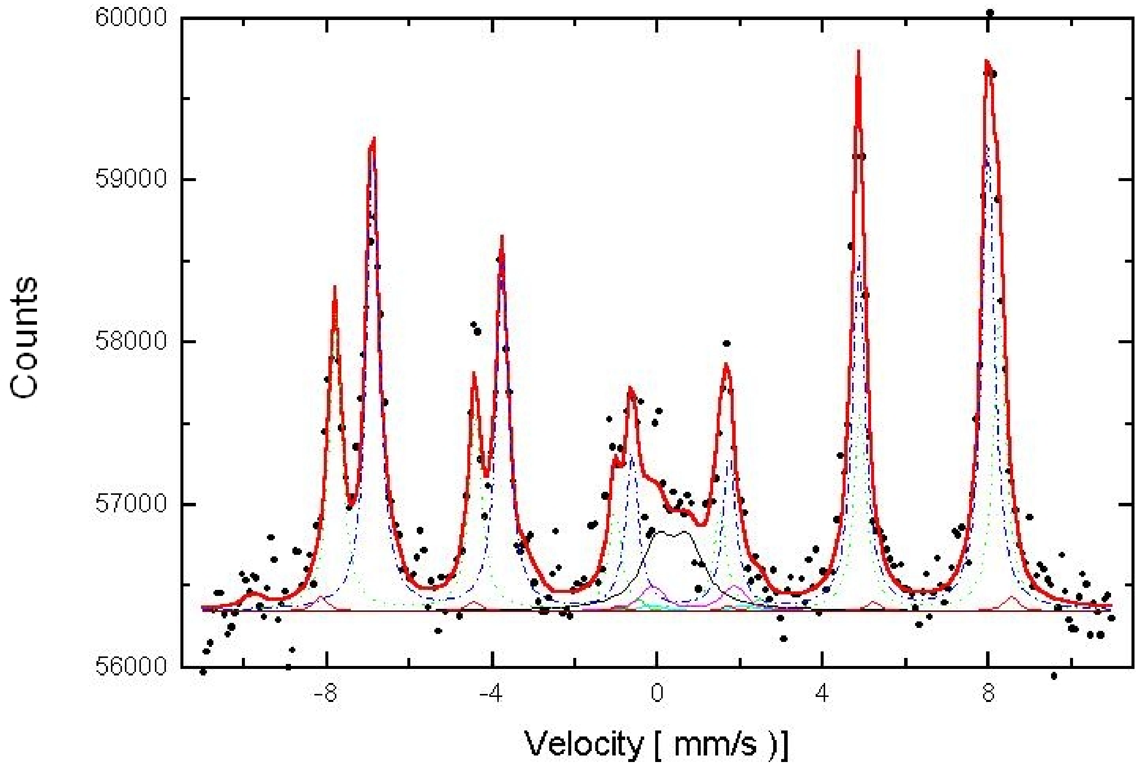

Figure 7. Mössbauer backscattering spectrum of the Mössbauer calibration target.

2.1.4 Alpha Particle X-Ray Spectrometer (APXS)

The Athena Alpha Particle X-ray Spectrometer works by exposing Martian materials to energetic alpha particles and X-rays from a radioactive ^{244}Cm source, and then measuring the energy spectra of backscattered alphas and emitted X-rays. The instrument is conceptually similar to the APXS instrument that flew on the Mars Pathfinder mission. However, there are several differences that improve the instrument's reliability and performance. Unlike the Pathfinder APXS, the Athena APXS does not have a proton mode. The proton mode has been dropped because recent increases in the spectral resolution and sensitivity of the X-ray mode have made it unnecessary. Significant modifications have also been made to the instrument to reduce the CO_2-induced background that was observed on Pathfinder, to improve X-ray spectral resolution, and to decrease susceptibility to electromagnetic interference. In addition, the Athena APXS will undergo extensive preflight calibration under Mars-ambient conditions, and will have two onboard reference targets for post-landing calibration on Mars.

The APXS instrument consists of a sensor head mounted on the rover's Instrument Deployment Device (IDD), and electronics mounted in the rover's Warm Electronics Box (WEB).

The sensor head contains six ^{244}Cm alpha radioactive sources with a total source strength of about 30 mCi. The sources are each covered with 3-µm aluminum foils that reduce the energy of emitted alpha particles from the initial value of 5.8 MeV to about 5.2 MeV. At this energy, the alpha particle scattering cross section of carbon is significantly reduced. The reduction is accompanied by a slight degradation of the alpha spectral resolution caused by broadening of the excitation spectrum, but the net result is a significant suppression of atmospheric background in the alpha spectra. Collimators in front of the sources define the instrument's field of view, which is about 38 mm at the normal working distance of 2.9 cm.

Surrounding the sources are six thin alpha detectors. The FWHM for the alpha mode of a ^{244}Cm peak at 5.8 MeV is less than 100 keV. Interior to the ring of sources is a single high-resolution silicon drift X-ray detector with a 5-µm beryllium entrance window. The FWHM of this detector at 6.4 keV is about 160 eV, compared to 260 eV for the Pathfinder APXS. The noise level in the X-ray mode will be less than 600 eV at temperatures below –30°C, and the efficiency at the 1.24 keV line of Mg will be at least 20%.

Preamplifiers for both detector channels and a circuit to generate detector bias voltages are also mounted on the sensor head, significantly reducing the instrument's susceptibility to electromagnetic interference.

The entrance to the detector head is normally protected from Martian dust and other potential contaminants by a pair of doors. These doors swing inward and lock open when the sensor head is pressed against a target or other hard surface. They can be closed again by actuation of a release mechanism. The inner surfaces of the doors provide a calibration reference surface for the instrument. The sensor head can also, if desired, be brought into contact with the magnetite-rich calibration target designed for the Mössbauer spectrometer.

Signals from both detector channels are processed by electronics that are part of the Rover Electronics Module in the WEB. Alpha signals from charge-sensitive preamplifiers (and similarly, X-ray signals from a customized voltage-sensitive preamplifier in the sensor head) are further amplified and filtered (semi-Gaussian pulse shapes) and then routed to peak detectors, a multiplexer, and into a 16-bit A/D converter for digitization. Signals from comparators that trigger if signals exceed a preset level initiate a sequence of logic signals necessary for peak detection (sample gate and signal hold) and the conversion process (program interrupt, alpha/X-ray flags). A microcontroller selects the appropriate input to the multiplexer and controls analog-to-digital conversion. The analyzed events are stored in the microprocessor buffer memory, building up alpha and X-ray spectra.

The rover can place the APXS sensor head in contact with rock surfaces or soil surfaces at inclinations within the range of 0 to 90°. Under nominal conditions, it should be possible to position the instrument centerline within 0.4 cm of a target location that has been observed by another IDD instrument.

Proper preflight calibration is essential to analysis of APXS data, so the Athena APXS will undergo an extensive calibration program. All calibration measurements will be made in a chamber filled with a mixture of gases that closely matches the composition of the Martian atmosphere, at the appropriate atmospheric density. Calibration measurements will include:

- spectral “library” measurements of pure elements and oxides;
- geochemical standards that span the full range of plausible Martian surface compositions;
- standard targets under a range of atmospheric densities and measurement geometries;
- standard targets in both natural and powdered form, to investigate texture effects;
- the APXS flight calibration target;
- the magnets of the magnet array;
- several blind certified geochemical reference standards, for independent assessment of the accuracy with which compositions can be measured.

All of these measurements will be made using the flight radiation sources.

The accumulation time for the APXS will typically be at least 10 hours per sample analysis, although significantly shorter durations are possible when only the X-ray mode is used. Most data accumulation will take place during the night when the ambient Martian temperature is the lowest, giving the best energy resolution on all spectra. However, it is desirable to break the total accumulation time in several shorter accumulation periods. The APXS can store up to 12 sets of accumulated spectra and can transmit the data to the rover either after each accumulation period, or all sets of spectra at the end of the final accumulation period.

The X-ray mode is sensitive to major elements, such as Mg, Al, Si, K, Ca, and Fe, and to minor elements including Na, P, S, Cl, Ti, Cr, and Mn. The alpha mode is sensitive to lighter elements, particularly C and O. The depth of analysis varies with atomic number, ranging from approximately 1 to 10 μm for the alpha mode, to 10 to 20 μm for sodium in the X-ray mode, and approximately 50 to 100 μm for iron in the X-ray mode. The detection limits are typically 0.5 to 1 weight percent, depending on the element. The APXS is insensitive to small variations of the geometry of the sample surface because all major and minor elements are determined, and can be summed to 100 weight percent.

2.1.5 Microscopic Imager (MI)

The Athena Microscopic Imager is a high-resolution imaging system mounted on the IDD. The camera body is identical to the ones used by Pancam, so the field of view is 1024 × 1024 pixels in size and the instrument has the same basic radiometric performance characteristics as Pancam. There is a single broadband filter, so imaging with the Microscopic Imager is monochromatic.

The MI optics employ a simple, fixed focus design at f/15 that provides ± 3 mm depth-of-field at 30μm/pixel sampling. The field of view is therefore 31 mm × 31 mm at the working distance. The focal length is 20 mm, and the working distance is 63 mm from the front of the lens barrel to the object plane. The object-to-image distance is 100 mm. Preflight geometric calibration will thoroughly characterize the geometric distortion of the system.

The spectral bandpass of the MI optical system is 400 - 680 nm. At best focus, the modulation transfer function of the optics is at least 0.35 at 30 line pairs per mm over this bandpass.

Radiometric calibration of the Microscopic Imager will be performed with a relative (pixel-to-pixel) accuracy of ≤ 5%, and an absolute accuracy of ≤ 20%. Calibration measurements will be obtained every 10 nm over the instrument's full spectral bandpass. The MI signal to noise ratio will be at least 100 for exposures of greater than 20% full well over the spectral bandpass and within the calibrated operating temperature range (-55 to +5º C).

No onboard radiometric calibration target is provided for inflight calibration of the MI. It is likely that the MI will be able to view the Compositional Calibration Target, and that this target will provide fiducial marks that can be used to perform a focus check. The MI will be able to acquire unfocussed images of the Martian sky, providing flat fields.

The MI will be mounted on the Instrument Deployment Device (IDD), allowing it to be placed against surfaces that can also be examined by the other Athena instruments. The IDD will have a minimum controllable motion along a science target's surface normal vector of 2 ± 1 mm RMS, allowing it to image a rough surface in a sequence of images. After placing the MI in position for imaging, the motion of the IDD damps down to an amplitude of less than 30 μm (*i.e.*, less than one MI pixel) within 15 seconds. Whenever the MI is not in use, the MI optics are protected from contamination by a transparent cover. Preflight calibration imaging will establish the transmission properties of the cover. The cover is opened only for MI imaging sequences. A contact sensor attached to the MI will be used to detect rock and other hard surfaces, to help ensure accurate positioning and protect the MI from accidental damage.

The MI acquires images using only solar or skylight illumination of the target surface. Stereoscopic observations and mosaics can be obtained by moving the MI between successive frames. Stereo images and images taken at various distances from the target will be used to derive the 3-dimensional character of the target surface. Images of the same target taken from different distances will also be combined to produce an image of the target that is well focused across the entire frame.

2.1.6 Rock Abrasion Tool (RAT)

The Rock Abrasion Tool (RAT) will be used to penetrate through designated Mars surface targets, exposing materials more likely to preserve evidence of environmental conditions at the time of their formation. The fresh surfaces exposed can then be characterized by all of the Athena instruments. The RAT is a diamond-tipped grinding tool capable of removing a cylindrical area 4.5 cm in diameter and at least 0.5 cm deep from Mars surface targets. This operation takes about 2 hours for dense basalt.

The RAT has a total of three actuator-based drive trains (Figure 8). One actuator causes the two grinding bars (or heads) to rotate at high speeds. Each of these grinding heads has two cutting elements, which excavate a circular area associated with each grinding head as the head rotates. A second actuator causes the two grinding wheels to revolve around one another at a much slower rate, sweeping the two circular cutting areas around the full 4.5-cm diameter cutting region. Finally, a third "z-axis" actuator translates the entire cutting head toward the surface target, causing it to penetrate to the commanded depth.

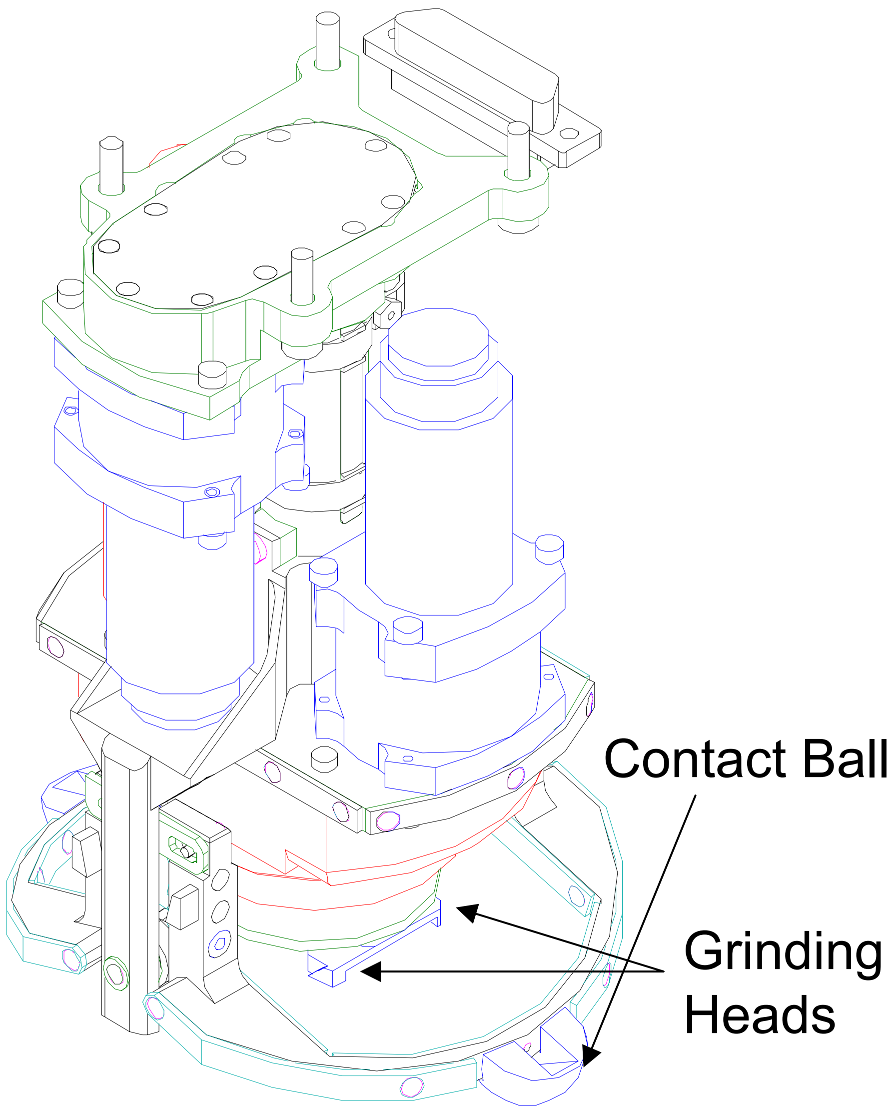

Figure 8. Mechanical design of the Rock Abrasion Tool.

In order to grind a strong rock, the IDD places the RAT directly against it. Contact is made on two small contact balls external to the grinding heads. The contact balls are mounted on a ring surrounding the heads. This arrangement allows for contact adjustment in two axes orthogonal to the orientation of the rock surface. Once pressed firmly against the rock by the IDD, all further actuations take place within the RAT itself. Rotation and revolution of the grinding wheels is initiated, and they are slowly translated toward the rock surface by the z-axis actuator until contact is made. Encoders monitor penetration progress, and allow closed-loop control of the grinding process. A dust skirt (not shown in Figure 8) around the cutting surfaces helps prevent release of dust that might contaminate instruments.

The RAT is designed to preserve petrologic textures of the prepared rock surfaces as fully as possible, so that they can be viewed effectively using the MI. The grinding process is slow enough that no measurable modification of target chemistry or mineralogy by frictional heating is anticipated. The grinding heads can be passed over a passive brush mounted on the IDD so that contamination of the exposed surface by cuttings from the upper layers of the surface target (and previous surface targets) is minimized. Grinding wheel materials are selected so that contamination of rock surfaces due to wear of the grinding heads themselves is minimized.

During the operation of the RAT, the rover will monitor currents, temperatures, switch states, and encoder readouts for all three RAT actuators. These data can be compared with data obtained during RAT grinding conducted on terrestrial analogs, in order to infer information about the strength and density of the surface targets on Mars. A pre-flight test program is planned to establish some of the relationships among these parameters and target strength and density, but prior to launch, the terrestrial analog database will be limited in scope. Further post-launch testing with an engineering model or flight spare RAT is possible.

2.1.7 Magnet Array

The objective of the magnet array is to attract airborne Martian magnetic materials, and to hold them in a way that is optimized for investigation by means of the other Athena instruments. The Athena magnets are similar to the magnet arrays carried on the Mars Pathfinder and Mars Polar Lander missions. However, the experiment is a significant scientific step beyond its predecessors, because of the unique mineralogical capabilities of the Athena Mössbauer Spectrometer. The magnets also fill an important scientific gap left by the fact that the APXS on the Sojourner Rover never measured the composition of the dust that adhered to the Mars Pathfinder ramp magnet. The Athena magnets include (1) one filter magnet and one capture magnet mounted on the rover's Magnet Array, (2) a "sweep magnet" mounted on the rover deck, and (3) four RAT magnets, mounted within the Rock Abrasion Tool.

2.1.7.1 Filter and Capture Magnets

The filter and capture magnets are mounted on a Magnet Array on each rover, which is accessible to the Mössbauer Spectrometer and APXS. It has not yet been established whether the magnets will be visible to the Microscopic Imager and/or Pancam. The stronger "capture" magnet is designed to attract all ferro/ferromagnetic dust, while the weaker "filter" magnet is designed to attract only the most magnetic dust.

The filter and capture magnets are each contained within an aluminum disk 45 mm in diameter. Each will be positioned as high as possible on the rover, in a position where it is not "shadowed" by the solar panels. Both will be mounted such that their surface normals are oriented between horizontal and 45° above horizontal.

The capture magnet is designed to accumulate a homogenous layer of dust as efficiently as possible, and to provide a relatively constant magnetic field at the position of the dust layer. The magnetic field strength is approximately 280 mT at the active surface. Based on experience from the magnetic properties experiment on Mars Pathfinder, it is expected that the capture magnet will collect sufficient material for Mössbauer Analysis in about 15 sols.

The filter magnet will also collect airborne dust particles carried to the magnet by the atmosphere. The filter magnet is designed to accumulate a homogenous layer of strongly magnetic dust, and to attract weakly magnetic dust as little as possible. Thus this magnet will separate out and keep attached to its surface a magnetic subset of the Martian dust particles from the bulk material (if the properties of the dust allows this). Furthermore, the filter magnet is designed to provide a relatively constant magnetic field at the position of the dust layer. The magnetic field strength at the active surface is approximately 140 mT. Based on experience from the magnetic properties experiment on Mars Pathfinder, it is expected that the filter magnet will collect sufficient material for Mössbauer Analysis in about 30 sols.

2.1.7.2 Sweep Magnet

An unresolved question from the Viking and Pathfinder missions is whether magnets are culling a population of more strongly magnetic particles from the airborne dust, or whether all dust particles have similar magnetic properties. The sweep magnet is designed to answer this question. This magnet consists of a thin-walled magnetic tube magnetized along its symmetry axis. With this configuration it is possible to make a strong magnet (~350 mT at the surface) capable of deflecting the paths of wind-transported, magnetic particles arriving at the surface of the magnet. Magnetic particles will accumulate on a narrow ring corresponding to the magnetic tube. The central surface inside the ring magnet will only collect non-magnetic dust particles. At greater radial distances from the ring magnet, both magnetic and non-magnetic particles will accumulate. Pancam images of the sweep magnet will provide spectral information on the dust collected, and thus provide information on the magnetic vs. non-magnetic particles in the Martian dust. Based on experience from the magnetic properties experiment on Mars Pathfinder, it is expected that the sweep magnet will collect sufficient material to detect the contrast caused by accumulation of magnetic particles within a few sols.

Approximate dimensions for the sweep magnet are 20 mm × 14 mm × 6 mm. The exact position of this magnet has not yet been determined, but it will be placed somewhere on the rover deck, probably close to the Pancam calibration target.

2.1.7.3 RAT Magnets

Use of the Rock Abrasion Tool (RAT) will produce small particles of abraded Martian rock. The objective of the RAT magnets is to sample and concentrate the magnetic portion of the abraded rock so that Pancam multispectral images can be acquired for these particles. These images can be used for characterizing the mineralogy of the magnetic phases in Martian rocks. The RAT magnets will have different strengths, providing a range of conditions for magnetic particles to be attracted and held.

A set of four 7 mm diameter × 9 mm thick magnets will be mounted within the RAT (Figure 9). The Instrument Positioning System will position the RAT so that Pancam can view these magnets before and after abrading selected rocks with the RAT. A preliminary design for the RAT magnets includes a passive, temperature-driven retraction mechanism that will allow magnetic materials to fall away from the RAT at night, permitting multiple uses on more than one rock.

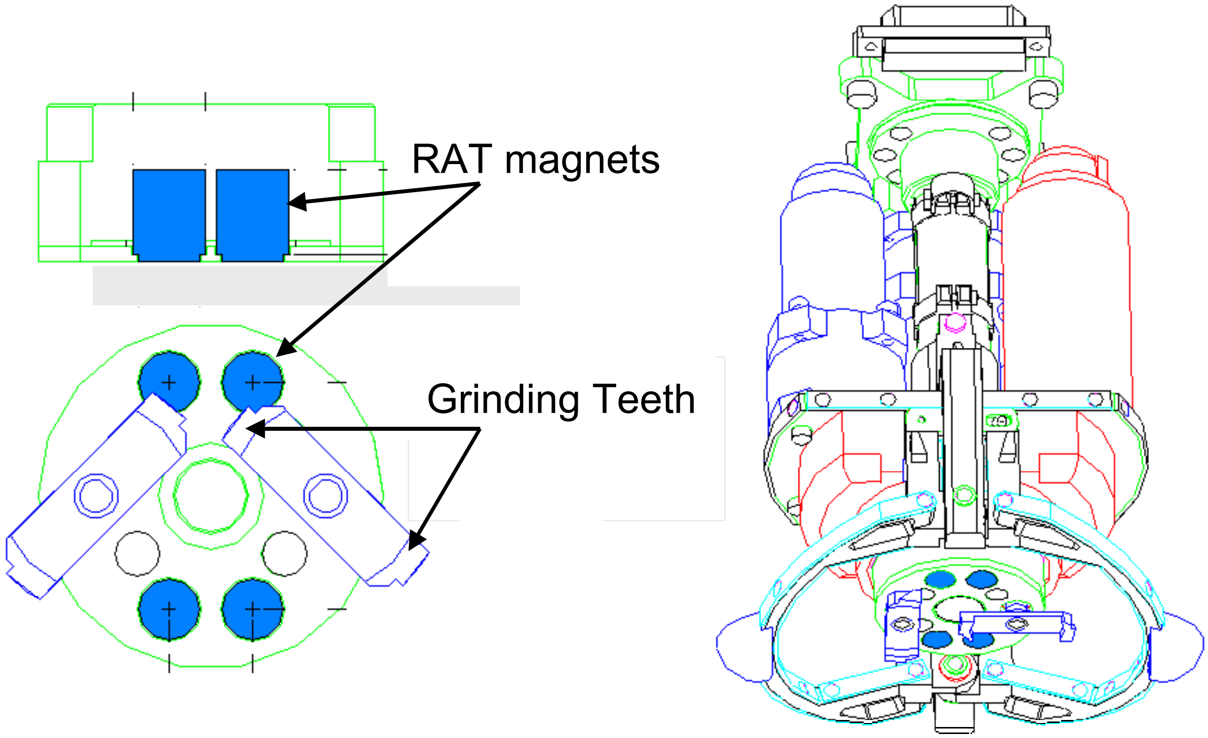

Figure 9. Location of RAT magnets (solid blue) as seen in a view of the bottom of the RAT (lower left), in a side view of the assembly just above the grinding teeth (upper left), and in the base of the full RAT assembly (right).

2.2 <u>Instrument Positioning System</u>

The Instrument Positioning System (IPS) covers all aspects of the placement of the payload instruments onto science targets and calibration/magnet targets including

- Perception
- Vision (Hazcams)
- Contact sensing
- Rover navigation for placing science targets within the IPS workspace
- Instrument Delivery Device (IDD) and manipulation
- Flight software for IDD and payload instruments
- System integration and test

The Athena in-situ payload elements (Mössbauer Spectrometer, APXS, Microscopic Imager, and RAT) are mounted on the arm of the Instrument Positioning System (IPS), which is used to bring the instruments into close proximity or into contact, as required, with samples on the surface of Mars. This robotic arm is called the Instrument Deployment Device (IDD) and is a robotically controlled, five degree-of-freedom arm (shown in Figure 10) approximately 68 cm long, which places the in-situ instruments (Figure 11) normal to surfaces of designated rocks and soil in front of the rover. Placement is based on information from the front Hazcam stereo pair and also on contact sensors located on the front of the instruments.

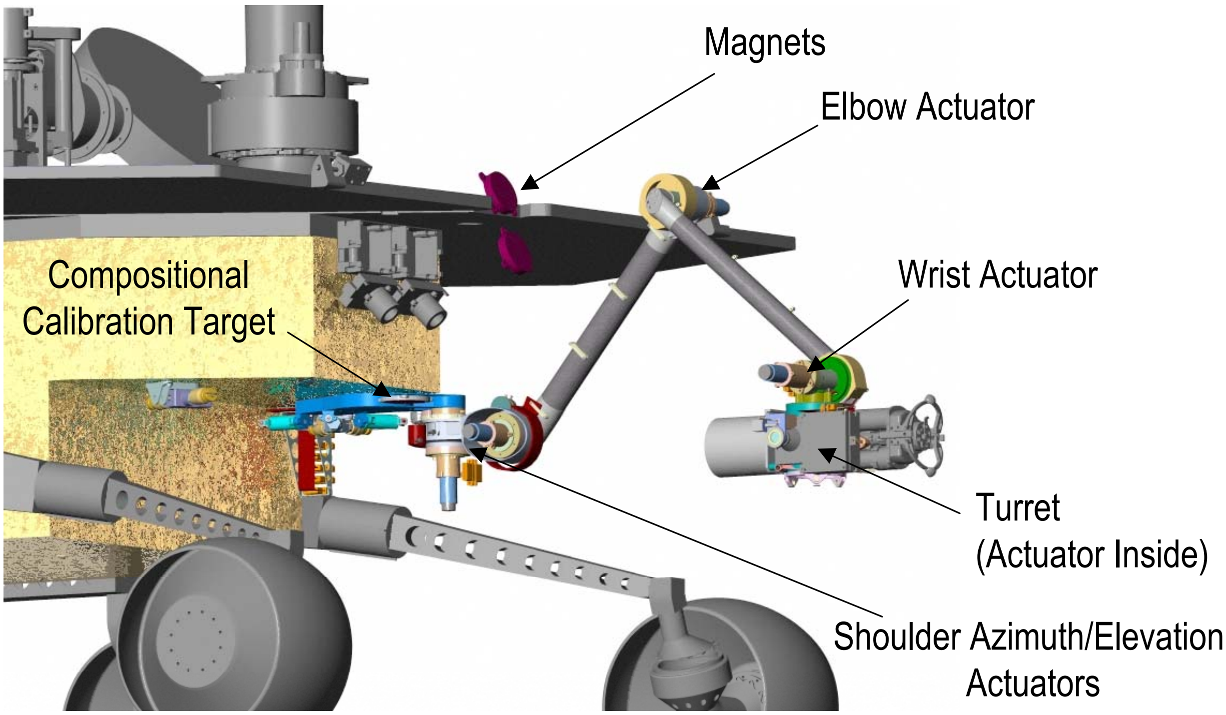

Figure 10. Diagram showing the Instrument Deployment Device on the rover, with the payload turret on the end of the arm.

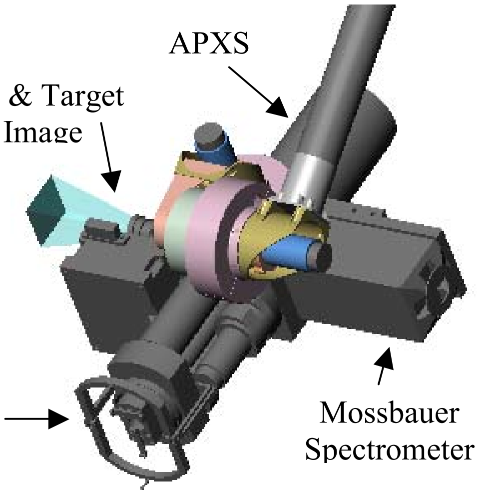

Figure 11. Configuration of instruments and Rock Abrasion Tool (RAT) on the turret at the end of the Instrument Deployment Device.

Current baseline requirements for the Instrument Positioning System (IPS) include that it shall have the capability of autonomous rover navigation resulting in a reachable rock or soil target being within the dexterous workspace of the IPS by the end of one sol, if the rover was within 2 meters of that target at the start of that sol. The dexterous workspace of the IPS is defined as the science target workspace reachable by all in-situ instruments (although not at all azimuth/elevation angles of orientation). The science target workspace for the IPS is a 40 cm diameter cylinder which is 70 cm in height, located directly in front of the rover's front wheels along the centerline of the rover, with the cylinder aligned parallel to the rover's vertical z-axis. The filter and capture magnets and compositional calibration target are also reachable by the Mössbauer and the APXS instruments.

The IPS has the following additional capabilities:

- Once an in-situ instrument has been placed against a science target, the IPS will be capable of removing that instrument from the target and positioning another in-situ instrument against the same target at any time during the Martian diurnal cycle.
- The entire work volume of the IPS will be viewable using the combination of Pancam, Navcam, and the front Hazcams.
- The IPS will 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.
- The IPS will 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.
- The IPS image sensing system (Hazcams and image processing) will provide data enabling the determination of surface location to 5 mm for surfaces within the workspace and within the field-of-view of the imaging system.

- The IPS image sensing system will provide data enabling the determination of surface normal to 5 degrees for surfaces within the dexterous workspace of the IPS and within the field-of-view of the imaging system.
- The IDD will be capable of positioning instruments to an angular accuracy of 5 degrees and positional accuracy of 5 mm in free space within the dexterous workspace of the IPS.
- The IDD will be capable of repeatably positioning instruments to $\pm$ 4 mm in position and $\pm$ 3 degrees in orientation.
- The IDD will have a minimum controllable motion along a science target's surface normal vector of 2 mm $\pm$ 1 mm RMS.
- The IDD will be capable of placing the contact surfaces of all in-situ instruments into direct physical contact with Martian rock and soil samples.

2.3 Engineering Cameras

Along with Pancam and the Microscopic Imager, each MER vehicle includes six engineering cameras, all of which share the same electronics design (Table 4) and spacecraft interfaces as the Athena science cameras. The engineering cameras (Navcam and Hazcams) are designed primarily to support operational activities such as rover navigation, localization, hazard detection, and IDD positioning. However, the operational distinction between science and engineering is only a convention; most downlinked data will have value for both science and engineering. Because of the electronics commonality (between all the cameras including Pancam and MI), image data from all cameras are functionally equivalent and are treated identically in flight software and the ground data system. All cameras contain an electronic serial number readable in software, which uniquely identifies the camera and allows processing software to apply data processing on a camera-specific basis.

Table 4. Detector and electronics characteristics for the engineering and science cameras.

PARAMETER	VALUE	UNIT
Pixel format	1024×2048	pixels
Readout style	Frame transfer	N/A
Imaging area	1024×1024	pixels
Pixel size	12×12	µm
Transparency of shield over image storage area, for all wavelengths between 400 to 1100 nm, and for each pixel	< 1	%
Dark current at 27°C, imaging area [1]	<1.5	nA/cm^2

Dark current at 27°C, light shield area [1]	< 1.5	nA/cm^2
Dark current nonuniformity, pixel-to-pixel within a 9 × 9 pixel box, excluding hot pixels, at 0° C	< 5.0	%
Full well capacity	≥ 150,000	electrons
Linearity, for signals between 10 to 90% full well (no binning)	> 99	%
Pixel-to-pixel nonuniformity at 20% full well and -20° C	< 1	%
Extended pixels beyond imaging area, which can be downlinked	30	pixels
Digitization	12	bits
System readout noise	≤ 50	electrons
CCD readout rate	≥200	kpixels/sec
Exposure time range	0 to > 30	sec
Exposure time step size	5	msec
On-chip binning size	4 × 1	pixels
[1] Pre-launch value. Post-launch value pending radiation testing and analysis		

Engineering camera mounting locations and fields of view are shown in Figure 12. The Navcam stereo camera set is mounted on a bar (shared with the Pancam) which can point the camera pairs ± 90° in elevation (up and down). The Navcam can therefore view elevation angles from +90° to -90°. Stereo pairs of hazard cameras are mounted on the front and back of the rover, beneath the solar panel.

The engineering cameras are designed primarily for operational activities (rover navigation, localization, hazard detection, etc.), and will not be calibrated as rigorously as the science cameras. The Hazcams will be calibrated radiometrically to an absolute accuracy of ≤ 20% over their central 45 degree FOVs, and relative pixel-to-pixel accuracy of ≤ 10% over their entire

FOV. The Navcams will be radiometrically calibrated to an absolute accuracy of $\leq$ 20% over their entire FOVs, and relative accuracy of $\leq$ 5% over their entire FOV.

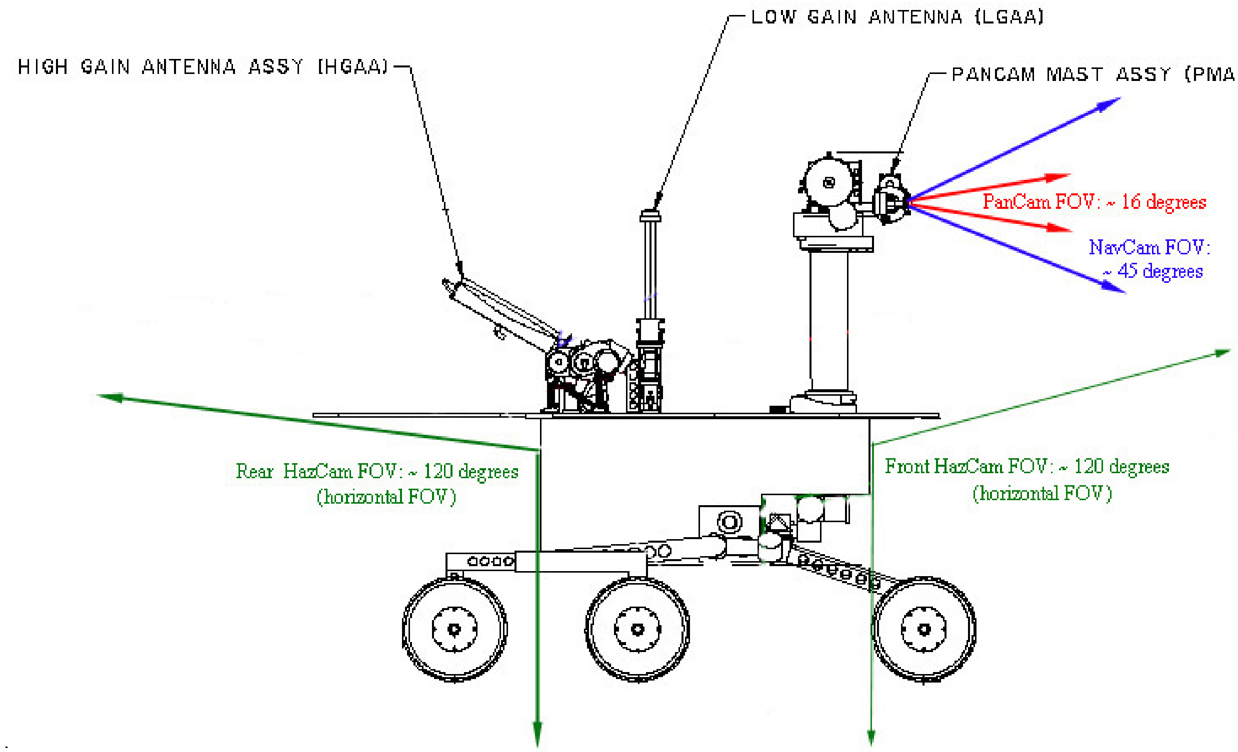

Figure 12. Fields of view of Hazcam, Navcam, and Pancam on the rover.

2.3.1 <u>Hazard Avoidance Cameras (Hazcams)</u>

The hazard-avoidance Cameras (Hazcams) are mounted in stereo pairs, one pair on the front end of the rovers' warm electronics box (WEB) below the solar panel, and one pair on the rear end of the WEB below the solar panel. Each Hazcam assembly includes 2 cameras with a red 580 - 770 nm bandpass filter, mounted to achieve a stereo view (10 cm stereo baseline). They have a 123° × 123° FOV (180° diagonal), and 580 - 770 nm spectral bandpass. Depth of field is 0.1 m to infinity, the focal length is 5.58 mm, and best focus is at 0.4 m. The Hazcams provide imaging primarily of the near field (< 5 m) both in front of and behind the rover. These cameras will be used to determine safe egress directions for the rover and provide for onboard hazard detection using stereo data to build range maps. They also support science operations for selecting near field target and instrument deployment device (IDD) operations.

2.3.2 <u>Navigation Camera (Navcam)</u>

The Navcam is a mast-mounted stereo pair with a spectral bandpass of 580-770 nm. It will be primarily used for navigation purposes and general site characterization, capable of providing 360° panoramic image mosaics and targeted images of interest, including terrain not viewable by the Hazcams. The Navcam stereo pair is boresighted with the Pancam, and Navcam images will also be used for science target selection and analysis. The effective depth of field for the Navcam is 0.5 m to infinity, focal length is 14.67 mm, best focus is at 1m, and the FOV is 45° × 45°.

2.4 Other Experiments

2.4.1 Atmospheric Density Profile

High quality atmospheric density, pressure, and temperature profiles can be obtained from measurements by the rover and backshell IMUs during MER entry. These profiles describe atmospheric structure along the entry trajectory with a unique combination of extensive vertical coverage and high vertical resolution. The measurements are physically independent of other techniques (e.g. infrared remote sounding, radio occultation), and sample altitudes inaccessible to these techniques with superior vertical resolution at all levels. These profiles will extend from above 100 km to approximately the level of parachute deployment (10 km), with a vertical resolution better than 250 m. They describe atmospheric properties that are directly relevant to lander entry, making the atmospheric profiles from MER useful to designers of future Mars missions.

To date, three Mars entry profiles have been derived from the Viking and Pathfinder landers. Scientifically, these profiles represent a unique, in-situ, atmospheric data set. MER will increase the number of profiles to five, greatly improving coverage of season, local time, and location as shown in Table 5.

Table 5. Mars atmosphere entry profiles

Lander	VL1	VL2	Pathfinder	MER-A	MER-B
Season (L_S)	96°	117°	143°	328°	339°
Mars Local Time	16:13	09:06	03:00	approx. 14:00	approx. 13:10
Latitude	22.3°N	47.6°N	19.3°N	15°S – 5°N	10°S – 10°N

The accelerometer calibration, sampling, and data return requirements imposed by these measurements will enhance the engineering analysis of EDL needed to optimize the design of future landers.

For an axially symmetric entry vehicle with a zero angle of attack, atmospheric density along the entry trajectory is derived from accelerometer measurements of the atmospheric drag force, using the expression:

$$\rho(z) = -2\, m\, a(z) / (C_D\, A\, V^2(z))$$

where $\rho(z)$ is atmospheric density at altitude z, $a(z)$ is axial acceleration, and m, A, $V(z)$, and C_D are spacecraft mass, cross-sectional area, velocity, and drag coefficient. m and A are well known entry vehicle constants, but C_D depends on atmospheric pressure and spacecraft velocity and must be derived from experimental drag measurements or fluid dynamics modeling.

The entry vehicle trajectory (position and velocity versus time) throughout entry is derived from accelerometer and gyro data, given an accurate starting trajectory immediately before entry provided by navigation. Trajectory reconstruction during entry is achieved by integrating measured accelerations, and is greatly simplified if the entry vehicle has a low angle of attack (as for Pathfinder and MER). Given a density profile, $\rho(z)$, the pressure profile, P(z), is derived by integrating the hydrostatic equation from the top of the atmosphere. The temperature profile, T(z), is derived from P(z) and $\rho(z)$ using the equation of state, given the mean molecular weight of the atmosphere. Vertical coverage is limited by accelerometer sensitivity (noise level) in the upper atmosphere and by parachute deployment in the lower atmosphere. Profile quality is determined by accelerometer calibration accuracy, and by the accuracy with which spacecraft drag coefficient variation throughout entry is known.

The MER rover and backshell will each carry a Litton LN200 IMU (3-axis accelerometer and 3-axis rate gyros in a single package). They can both be used to extract information about the atmospheric profile during entry.

Before launch, the accelerometer outputs will have to be calibrated as a function of temperature and gravitational acceleration for accelerations of $\leq$ 1g. This calibration will be performed on the flight hardware for all gain settings over the range of temperatures expected during entry measurements, to determine the temperature dependence and repeatability of gains, offsets, and linearity.

After launch, occasional measurements will be made during cruise to study offset drifts with temperature and time. Immediately before EDL several minutes of data should be taken for final offset calibration. High rate measurements ($\geq$ 8Hz) will begin before entry and continue throughout EDL, and for at least two minutes after landing. These measurements will sample the ballistic phase of entry, the lander and backshell gyrations on the parachute, the pyrotechnics of landing, and the final bouncing and rolling before the lander comes to rest. Low rate data taken after landing will sample Martian gravity at the surface and will provide a final accelerometer gain calibration, as Martian gravity is well known at a given location.

2.4.2 Soil Properties Experiment

The Viking Lander and Pathfinder observations showed that the soils at these three Mars landing sites are diverse, with surface deposits of aeolian dust, drifts and dunes, and an underlying indurated deposit that has been called duricrust. The MER rovers may be capable of excavating soils to a depth of 5-10 cm, well beneath the loose deposits and into the duricrust found at the Pathfinder and Viking landing sites. Exposure of fresh subsurface deposits by wheel excavation experiments will help meet MER science objectives related to characterizing the texture, mineralogy, and chemistry of soils at the landing site and along the traverses. The Project will perfom preflight wheel calibration experiments to determine the relationships among voltage, current, and wheel torque as a function of temperature, but the quality and nature of that calibration has not yet been determined. Such calibrations will provide an opportunity to use soil excavation by rover wheels to determine soil physical properties such as cohesive strength and angle of internal friction [see similar investigation reported for Mars Pathfinder rover in Moore, H.M., et al., 1999, Journal of Geophysical Research, v.104, p.8729-8746].

An example of a possible subsurface soil experiment would be to lock all but one front wheel, spin that wheel, and let it dig into the soil. During the experiments, the rover could first characterize the undisturbed surface, conduct subsurface soil excavation experiments, image the wheel with the front Hazcams, back up and then survey results with other imaging systems and, as appropriate, with Mini-TES and the Athena in-situ instrument suite. The engineering and science instrument data would be used to infer physical properties, chemistry, and mineralogy as a function of depth.

2.4.3 Relationship to Orbital Remote Sensing

One of the MER science objectives is to calibrate and validate orbital remote sensing data and to assess the amount and scale of heterogeneity at each landing site. Science investigations could benefit from a combined examination of data from MER and orbital data sets such as MOC, TES, MOLA, and THEMIS. Ties with orbital data could also be used to affect decisions during mission operations, possibly providing recommendations for preferred directions in which to send the rover or additional insight into the local and regional geology.

The Project expects to have the capability to determine the areocentric landing site of each rover to an accuracy (3σ) of 100 meters within 3 sols of landing, given that the rover has not moved more than 10 meters from the landing site during this time. The Project will also have the capability of providing the areocentric rover position to a 3-σ accuracy of 30 meters, given that the rover is stationary to within 3 meters for at least 3 sols. Positioning solutions shall be available within about 1 day after receipt of the navigation measurements by the MER Mission Operations System. The process used for rover position determination, based on radiometric tracking data, produces a vector estimate of the rover position in a Mars cylindrical body-fixed frame. This can be converted to body-centered areocentric coordinates using appropriate rotations and offsets. This body-fixed frame is defined by the North pole of rotation and prime meridian established by the IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites.

In addition, it will also be necessary to determine the locations of pixels or features for remote sensing data in the same coordinates. This means that, for example, MOC images in inertial coordinates need to be converted to the same body-centered coordinates that one has for the rover. After landing and acquiring images from the rover, it will be possible to locate features in Pancam and orbital images and localize or improve our knowledge of where the rover is in the field of view of the orbital data and also improve our knowledge of the conversions from inertial to body-centered coordinates.

3 ROVER DESCRIPTION

The rover is a vehicle for remote operation on the Martian surface, and it carries cameras, sensors, and instruments to maintain its health and to perform science. It has the following capabilities:

1) supports the science instrument payload

2) can traverse up to 100 meters per sol

3) provides a navigational accuracy of 10% or better

4) provides high-speed computational capability and substantial data storage

5) provides X-band for Direct-To-Earth telecommunications, and the ability to communicate with 2001 Mars Odyssey (which will store and relay data to Earth)

The 184 kg MER mobile system consists of a six wheel rocker-bogie suspension system similar to that used on the Mars Pathfinder Sojourner rover, but scaled up. Schematic front and rear views of the rover configuration are shown in Figure 13 and Figure 14.

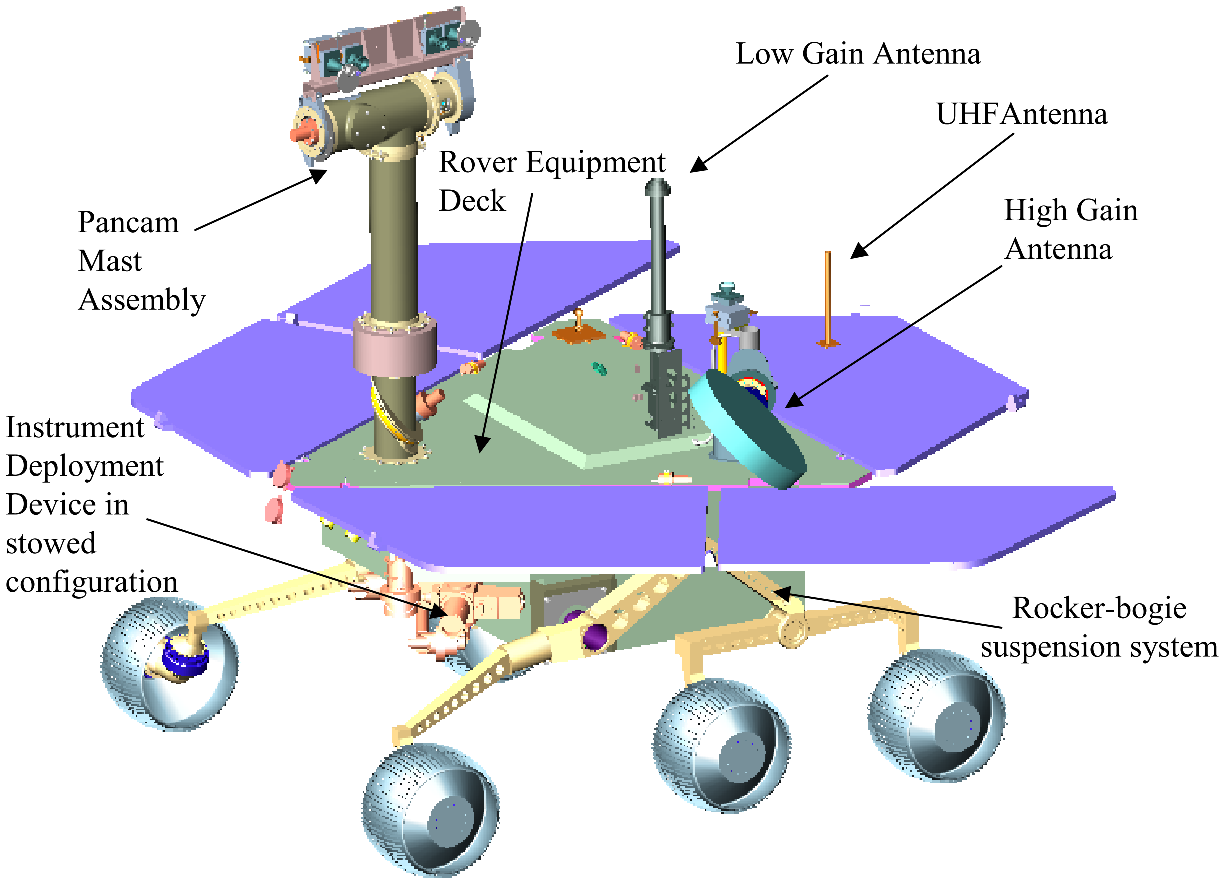

Figure 13. Rover configuration, front view. Deployable solar panels shown in purple.

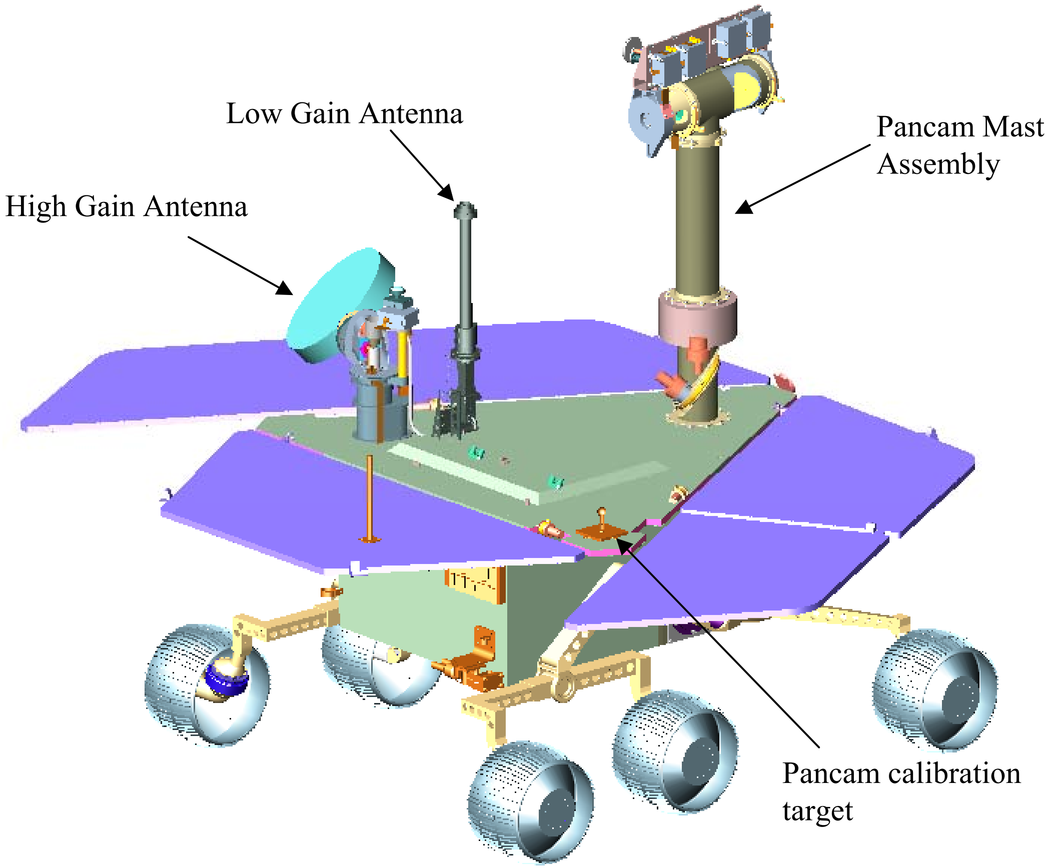

Figure 14. Rover configuration, rear view. Deployable solar panels shown in purple.

Each MER is a 6-wheeled vehicle, 184 kg in mass (including payload), and approximately 142 cm long, 123 cm wide and 156 cm tall (with the Pancam Mast Assembly deployed). The rover solar panels, with five deployable sections, makes the deck system ~230 cm wide at its deck height approximately 67 cm off the ground.   The solar array assembly is distributed over those five deployed sections and the Rover Equipment Deck (the triangular area between the deployed sections). The rover has a ground clearance of 28 cm and a wheel diameter of ~25 cm enabling it to easily overcome isolated hazards such as rocks 20 cm tall. The mass is centered and is located low enough to allow a tilt of 45° in any direction without overturning, although fault protection limits prevent the vehicle from exceeding tilts of 30° during traverses.

The rover includes a rocker bogie design for wheel mounting, which allows the traversing of obstacles of more than a wheel diameter in size. Each of the six wheels has cleats and is independently actuated and geared, providing for climbing in soft sand and scrambling over rocks. The front and rear wheels are independently steered, allowing the vehicle to turn in place, or to drive in arcing turns.

The vehicle has a top speed on flat ground of 0.6 m/min. The rover is powered by a 1.38 m^2 solar array configuration. Power delivery capability of the combined arrays is greater than 800 Whrs until Sol 28 and greater than 600 Whr at Sol 90. The rover's solar array is backed up by 2 secondary lithium-ion rechargeable batteries. The combined panel and battery system allows the rover to draw 140 W of peak power. The peak panel production is more than 77 W for 3 hours each sol on Mars. The power requirement for driving is 50 W, not including command and data handling.

The software in the main computer of the rover, once initiated, executes a control loop which monitors status of the vehicle, checks for the presence of commands to execute, maintains a buffer of telemetry and performs health checks. Activities such as imaging, driving, rock abrasion or instrument operations are performed under commands transmitted in a sequence to the rover from a ground control station. Each command execution results in the generation of telemetry, which is stored for eventual transmission.

Data and command sequences are transmitted to and from Earth by an X-band telecommunications system. An articulated High Gain Antenna supports baseline operations, while a Low Gain Antenna would be used for unexpected conditions. The rover also carries a UHF radio for rover-to-orbiter relay communications. Rover telecommunications capabilities are described further in Section 4.8.2.

In addition to the imaging and science instrument data collected in these activities, certain ancillary engineering data are also available and collected. These data in form of voltages, currents, encoder readings, potentiometer readings, and temperature measurements constitute the status of the engineering systems in use. Additional derived data products such as rover position and orientation, battery state of charge and solar array output, are also available and expected to be used to associate imaging and science instrument data with time and rover state. Depending on operating mode, this engineering data may be available as frequently as once each 8th of a second (the real-time information of the Command and Data Handling). Derived data products are by necessity, integrated in time and available less frequently.

4 ROVER OPERATIONS

4.1 Introduction

The science strategy for the MER rovers relies on the use of remote sensing to identify promising candidate rocks and soils, followed by detailed in-situ analysis of the selected targets. Pancam is used to assess the morphology and color of candidate targets, and Mini-TES is used to assess their mineralogy. Once promising targets have been identified, the rover can traverse to them and examine them in detail with any of the *in-situ* instruments: the Microscopic Imager for fine-scale structure, the Mössbauer Spectrometer for mineralogy, and the APXS for elemental chemistry. Where appropriate, fresh rock surfaces can be exposed using the Rock Abrasion Tool.

Figure 15 shows in flowchart form how the rover will typically be operated.

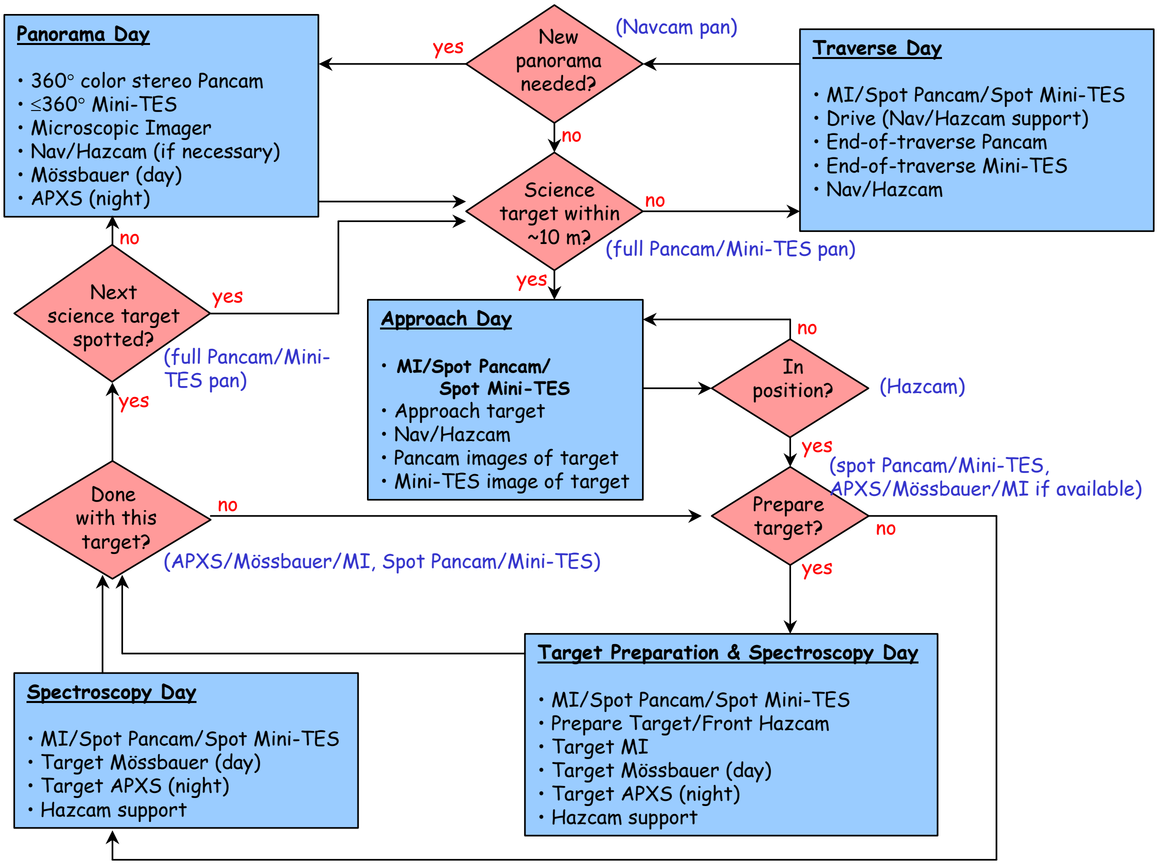

Figure 15. MER rover operations flowchart (items in parentheses indicate data products used to make the decisions).

For most normal operations, there are five general classes of daily operations that can take place in a sol:

- Panorama Day: Acquire remote sensing data of the scene around the rover.
- Traverse Day: Move up to 100 meters in the direction of some selected target or area of interest.
- Approach Day: Move to within the IDD workspace of a target.
- Target Preparation and Spectroscopy Day: Use the RAT to prepare a rock target surface and perform some *in-situ* analyses on it.
- Spectroscopy Day: Perform detailed *in-situ* analyses on a target.

Each of these is discussed in detail in the following subsections.

4.2 <u>Panorama Day</u>

A panorama day is used when detailed remote sensing information is needed to select candidate targets for subsequent *in-situ* analysis.

Although their focus is on remote sensing, panorama days can begin with a Microscopic Imager sequence on some "target of opportunity" that lies within the work volume of the arm. This sequence is performed without moving the rover.

The main events of a panorama day are collection of a 360º Pancam panorama, and a Mini-TES panorama. Observing time and data volume may be distributed in different ways. Further, there is flexibility with respect to the organization of observations. In some instances it may be beneficial to perform two successive panorama days from the same location, allowing acquisition of more data (allowing for instance, less compression, expanded elevation angular coverage, or additional spectral channels) to provide a more comprehensive view of the scene. For example, two panorama days in succession are planned to fully document the scene around the lander before the rover is first deployed.

During a panorama day, target-of-opportunity Mössbauer observations may also be made on a target within the IDD's work volume.

After a panorama day, overnight target-of-opportunity observations may be made on a target within the IDD's work volume using the APXS and/or Mössbauer Spectrometer.

4.3 <u>Traverse Day</u>

The primary objective on a traverse day is to move the rover from one location to another. The first event of a traverse day can be collection of Pancam and Mini-TES data on areas of interest, along with a target-of-opportunity Microscopic Imager sequence on some area within the work volume of the arm. After the arm has been stowed, the rover drives to locations specified in lander-centered coordinates, using a combination of low-level motion commands and higher-level waypoint commands. When executing waypoint commands, the rover will autonomously detect and avoid obstacles (*e.g.*, rocks and steep slopes) using its front Hazcams and navigation software. The rover will traverse at a rate of approximately 1 cm/sec, including time required for hazard sensing; this will support traverses of several meters per sol up to 100 m/sol, if desired.

In order to help reconstruct the events of the traverse afterwards, Navcam panoramas are obtained at points along the traverse. Hazcam images are also acquired at frequent intervals for onboard processing. Some or all of these images can be downlinked at the end of the sol to aid traverse reconstruction, although data bandwidth restrictions are significant. At the end of the traverse, front/rear Hazcam images and a full or partial Navcam panorama are acquired to document the rover's new location. Any remaining time and power for that sol can then be used to acquire Pancam and Mini-TES data.

4.4 Approach Day

Approach days are used to attempt to place the rover close enough to a science target so that it may be investigated with the *in-situ* elements of the payload. Depending on their geometry and their initial distance from the rover, some targets may require two or more successive approach days before the target is found to be within the work volume of the arm. The distance traveled during the final approach day in an approach sequence will often be no more than 2 meters.

An approach day can begin with Pancam and Mini-TES investigation of areas of interest, and/or a target-of-opportunity Microscopic Imager sequence on some area within the arm's work volume. The rover is then commanded to drive to a location that will place the target that has been selected for detailed *in-situ* analysis within the work volume of the arm. The sol concludes with Navcam and Hazcam images to document the new position, and Pancam and Mini-TES data in the direction of the intended target.

4.5 Target Preparation and Spectroscopy Day

Target preparation and spectroscopy days are used to expose a fresh rock surface with the RAT and then to conduct in-situ analyses on that newly exposed surface.

A target preparation and spectroscopy day can begin with Pancam and Mini-TES investigation of any areas of interest around the rover, and/or a Microscopic Imager sequence on some area within the arm's work volume. The MI target typically would be the same spot to be exposed by the RAT. The main event of the day is the use of the RAT to grind away rock over an area 4.5 cm in diameter. The nominal depth of grinding is 5 mm. In some geometries of rock surface and IDD orientation, grinding to a few more mm depth may be possible. It is also possible to choose to grind to a shallower depth. Once grinding has finished, the remaining time and power for the sol can be devoted to some combination of Microscopic Imager, Mössbauer Spectrometer, and APXS data collection on the exposed surface. All arm activities are documented as fully as possible with front Hazcam images.

4.6 Spectroscopy Day

The purpose of a Spectroscopy Day is to perform detailed *in-situ* investigation of a rock or soil target.

A spectroscopy day can begin with Pancam and Mini-TES investigation of any areas of interest around the rover. The main events of the day are observations of the target with the Microscopic Imager, the Mössbauer Spectrometer and the APXS. MI imaging takes place first, followed by long (~10 to 12 hour) integrations with the Mössbauer and the APXS. APXS measurements are normally performed last, taking advantage of the cold late-night/early-morning temperatures to maximize the performance of the X-ray channel. As is the case for a target preparation and spectroscopy day, all arm activities on a spectroscopy day are documented as fully as possible with front Hazcam images.

After the final day of *in-situ* investigation of a target has been completed, the first event of the next day, before leaving the target for good, is to acquire high-resolution Pancam and Mini-TES data for the target. This provides a complete suite of observations, including exposed rock surfaces, with all five Athena instruments.

4.7 Additional Rover Activities

The rover operations flow depicted in Figure 15 allows for considerable flexibility. For example, multiple cycles of target preparation – grinding a short distance followed by *in-situ* observations and then more grinding – are possible if the scientific circumstances warrant it. Such activities take considerable time, however, and the SOWG will have to balance the scientific return against the intense time demands imposed by the short MER mission duration.

Some important scientific activities are not captured by Figure 15. These include:
- Calibration measurements for the Mössbauer Spectrometer and APXS.
- Observations of the Magnet Array by the Mössbauer Spectrometer and the APXS.
- Observations of the Martian sky with Mini-TES and Pancam.
- Mini-TES observations of rocks and soils at multiple times of day to determine thermal inertia.
- Trenching activities that use the rover wheels to expose subsurface materials.
- Reporting of motor currents and rocker-bogie angles during specific traverses in order to characterize the terrain.

These additional activities will be worked into the main operations flow as the scientific circumstances and the availability of time, power, and downlink bandwidth permit.

It is important to note is that all science activities during the first hour or so of each sol take place before that sol's uplink has been received from Earth. Therefore, such pre-uplink activities must have been planned 2 sols in advance. Generally speaking, then, all "overnight" planning must include both the post-uplink activities for the next sol and the pre-uplink activities for the sol after that. It should be noted that arm instruments can only be placed on targets when the images necessary to position the arm have been obtained and have been analyzed on the ground. Therefore, on any sol that follows a traverse day or an approach day, all arm activities (for example, MI imaging on a target of opportunity) must take place after the uplink.

4.8 Operational Constraints (Data Volume, Power, and Time)

4.8.1 Full Mission Return

Mission Return has been defined by the Project as an example of the quantity and type of data that could be collected and sent back to Earth from either one of the rovers. The only required activities that must be accomplished to achieve full success are itemized in Section 1.5. Beyond that, however, the Project defined a Full Mission Return to ensure that each rover and the Mission System would be designed to be capable of returning a representative data set that could meaningfully address the science objectives. Full Mission Return does not represent the actual data that will be returned, however, because during landed operations on Mars, the Science Operations Working Group will determine the best balance between the use of the different payload elements and rover driving, depending on what is encountered at the landing site. By defining the capability to include a wide range of types of activities, a variety of alternative operational scenarios are possible. The current Full Mission Return includes the following:

2	Abraded rock surfaces analyzed by APXS, MB, and MI
5	Natural rock surfaces analyzed by APXS, MB, and MI
1	Soil patch analyzed by APXS, MB, and MI
6	Total number of different rocks and soils analyzed
600	Meters driven
2	Pancam panoramas (360 deg × 45 deg, red stereo 16:1 compression, green 64:1, blue 64:1)
2	Mini-TES panoramas (360 deg × 30 deg, 20 mrad resolution, 2.3 × 1.15 deg/pixel)
1914	Additional Pancam Mbits
81	Additional Mini-TES Mbits
181	Additional Microscopic Imager Mbits
23	Daytime Mini-TES sky
5	Nighttime Mini-TES sky
4	Mössbauer calibrations
2	APXS calibrations
3	MB capture magnet
2	MB filter magnet
2	APXS capture magnet
1	APXS filter magnet
1	Soil properties experiment (trenching and examination of dig area)
3	Thermal inertia measurements (30×45 deg, Mini-TES daytime and nighttime measurements)

Assumptions that were used to define Full Mission Return include:

<u>(1) MER-B has the lowest-case energy across the 10ºS - 10ºN latitude band, with a surface mission duration of 91 sols</u>

<u>(2) 10% operations margin on Current Best Estimate (CBE) energy available, plus an additional 20% margin on CBE plus contingency energy available for design uncertainties</u>

<u>(3) X-band communications:</u>

- 70m DSN support for 75% of the time, 34m for 15% of the time, and no coverage 10% of the time. "No coverage" sols occur on the sol numbers divisible by ten.
- 70 m and 34 m sols are distributed so that 5 sols of 70 m coverage are followed by 1 sol of 34 m coverage, skipping over the no-coverage sols.
- Morning commanding of the rover through Direct to Earth (DTE).
- DSN sessions at least 1 hour in length, two communications sessions per sol.
- X-band data rates range from 7200 b/s (MER-A arrival) to 2300 b/s (MER-B end of mission).

- Critical operations data sent through DTE X-band link only, to show that the mission requirements could be accomplished even if a Mars orbiter was unavailable.

(4) Telecom support from the Mars Odyssey UHF relay:

- 2 UHF relay passes per sol, 5.5 minutes per sol, 128 kb/s above 30º elevation.
- UHF relay capabilities show what additional data could be returned using the UHF link. This was used to derive expected mission return

(5) Operations Time Margin:

- Every third sol fails to successfully accomplish its objective and every sixth sol DTE communication succeeds even though the objectives fail. This accounts for anomalies such as missed downlink or uplink sessions, difficulties with rover positioning, sols spent in fault recovery, etc.

(6) Power is generated assuming average daily atmospheric optical depth (τ) of 0.5

- Power generation assumes the lowest power generation for any latitude in the landing site range for each sol.

(7) Power will degrade due to dust accumulation

- Approximated by the equation: $P_N = P_0 (e^{-0.0018N})$, where P_N is power generated on sol N and P_0 is the power available on Sol N, if there is zero dust accumulation.

(8) 20% of the solar array is shadowed by components of the rover above the solar array

4.8.2 Telecommunications Constraints

During the prime surface mission of 91 sols, the range from Earth to Mars increases from 1.1 AU at the beginning to 2.0 AU at the end of the MER-A mission. The Earth to Mars range increases from 1.3 to 2.1 AU for the MER-B prime mission. The X-band system is the primary system for receiving all commands from Earth and for transmitting all critical telemetry data to Earth. Critical telemetry is that which is necessary in order to do next-sol commanding of the rover. UHF transmits non-critical telemetry to 2001 Mars Odyssey and then it is sent from Odyssey to Earth. Should the X-band communications fail, then the UHF communication system will serve as a backup. In that case, the rovers will receive commands and transmit all telemetry through 2001 Mars Odyssey.

Two X-band communications sessions are planned per sol in order to receive commands and send telemetry. These scheduled sessions use the HGA. The length of each session is determined by ground models of DC power on the rover, and in general the session duration diminishes as the mission progresses. The morning session will be used to uplink the sequence for the day and to return any data from the previous day or night. The HGA is capable of transmitting > 1.8 kb/s (several times higher than this for MER-A at the beginning of the mission) as long as it is pointed to within 2º of Earth and a 70m DSN station is used.

There may be 2, 1, or no UHF passes per sol using 2001 Mars Odyssey as a relay spacecraft for telemetry data. Typically, there will be three possible communication passes out of four passes over any two sols. Although Odyssey will have a line-of-sight to the MER rover twice a day around 4 to 5 am and pm Mars Local Solar Time, the rover will be commanded to communicate only when the pass duration is longer than 1 minute. Typical passes vary from 4 to 8 minutes. There will be sols in which only one 32 kb/s pass is possible. Typically, we will use the 128 kb/s mode. Average MER data return from Odyssey is expected to be approximately 40 Mbits per sol (averaged over 2 sols). There is also a possibility of using the Mars Relay on Mars Global Surveyor, which provides the capability of 128 kb/s data return, to offset any shortfall that might arise in Odyssey's relay performance.

In the plan for baseline operations, the UHF transceiver will be commanded to turn on 15 minutes prior to the pass in the receive mode to allow for uncertainties in the timing of the pass and for FSW data staging. The Odyssey spacecraft will configure the rover UHF system in its operational configuration for the pass and thereby set the coding, data rate (32 kb/s, 128 kb/s, or 256 kb/s), and protocol.

At times, the UHF transceiver will be configured in its transponder mode so that Odyssey can estimate 2-way Doppler to MER and thereby provide data to navigators on Earth to refine the rover's position. This is also discussed in more detail in Section 2.4.3.

4.8.3 Thermal Constraints

For thermal survival, the rover requires a minimum amount of power to be dissipated in the Warm Electronics Box to keep components above their minimum flight acceptance temperatures. This can be achieved through the use of survival heaters or self-heating of components from their operation. In addition, there is a maximum amount of thermal dissipation or maximum time of use for some components, in order to prevent overheating.

4.8.4 Timing Constraints

Different activities can only occur, or preferably occur, at certain times of the Martian solar day, as shown in Figure 16. Long APXS and Mössbauer measurement integrations will typically occur in the evening and nighttime when the rover is not moving. Driving is restricted to mid-day.

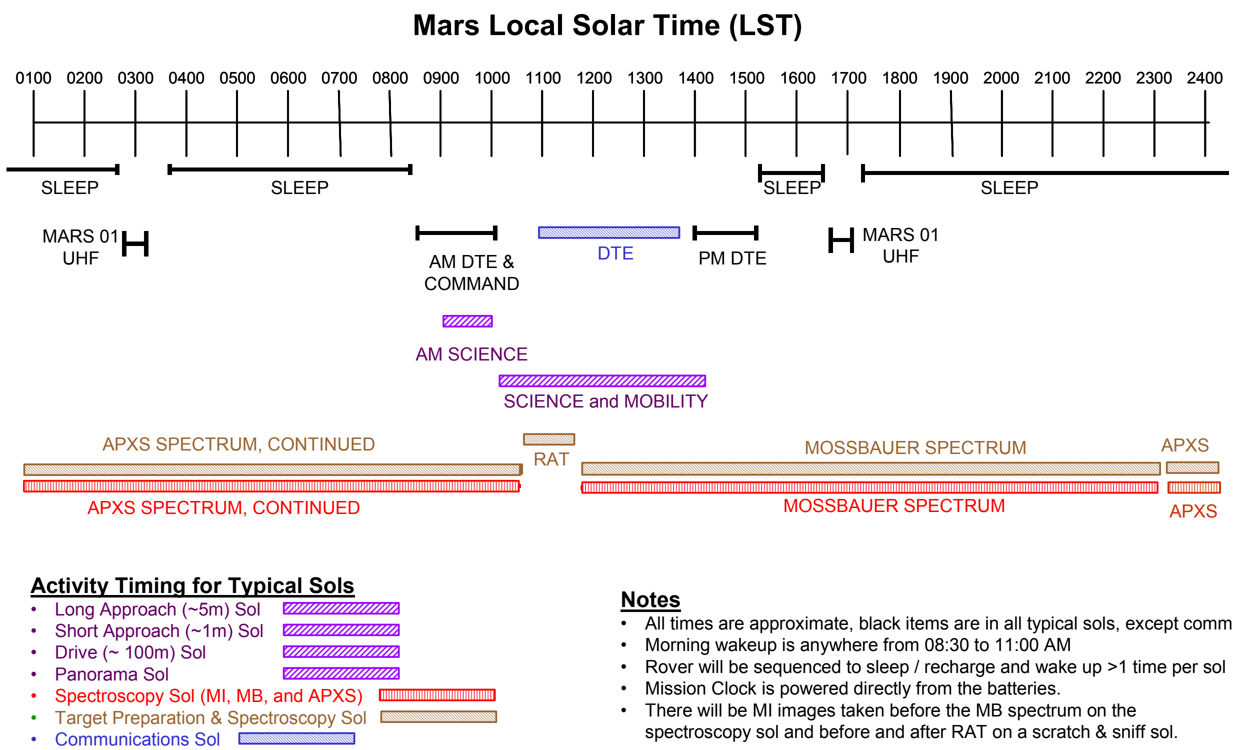

Figure 16. Typical sol activity timeline (not all activities depicted in this chart can occur on the same sol).

4.8.5 Constraints on Particular Science Scenarios

Each rover and payload activity requires a certain amount of time, power, and results in acquisition of a certain number of Mbits. Figure 17 shows an example scenario of typical rover/science activities, to illustrate what MER-B can achieve at a landing site that provides the least energy within the 10ºS – 10ºN latitude band. Note that these 33 sols worth of activities could require all 90 sols of the primary mission to complete (the other sols being communications days or no-activity days due to anomalies). This example achieves in-situ analysis of 8 rock (3 of which are abraded) and 2 soil targets distributed over 4 locations, and 300 m of driving. Other scenarios have been run which achieve the Full Mission Success including 600 m of driving. Figure 17 shows the types of rover days and the amount of data acquired for each day while allowing for plenty of margin on the operational resources. If the conservative assumptions that went into the definition of the margins on resources are not realized, then additional mission return will be possible.

Assumptions:										
Mission Success defined as 8 targets distributed over 4 locations, 6 rocks (3 RATs), 2 soils										
Location = circle with 25 m radius										
Drive between two locations = 80 meters minimum										
Targets physically unique										
Sol	**Description**	**module name**	**Soil targets Visited**	**Rock targets Visited**	**Rocks RATted**	**Locations Visited**	**Meters Traveled**	**Meters Total**	**Mbits**	**W-hr**
1	Landing					1		0		
2	Panorama	PAN-A						0	99.1	45.5
3	Panorama	PAN-B						0	4.3	42.5
4	Deploy	APP-L					5	5	34.5	40.4
5	Spectroscopy-S	SPEC-STO	1					5	10.5	72.4
6	Approach	APP-L					5	10	34.5	40.4
7	Approach	APP-S					1	11	31.7	34.2
8	Spectroscopy-R	SPEC-STO		1				11	10.5	72.4
9	Target Prep/Spec.	SS-DEP			1			11	18.2	79.1
10	Approach	APP-L					5	16	34.5	40.4
11	Approach	APP-S					1	17	31.7	34.2
12	Spectroscopy-R	SPEC-STO		1				17	10.5	72.4
13	Traverse	DRV80				1	80	97	28.7	90.9
14	Approach	APP-L					5	102	34.5	40.4
15	Approach	APP-S					1	103	31.7	34.2
16	Spectroscopy-R	SPEC-STO		1				103	10.5	72.4
17	Target Prep/Spec.	SS-DEP			1			103	18.2	79.1
18	Traverse	DRV80				1	80	183	28.7	90.9
19	Panorama	PAN-A						183	99.1	45.5
20	Panorama	PAN-B						183	4.3	42.5
21	Approach	APP-L					5	188	34.5	40.4
22	Spectroscopy-S	SPEC-STO	1					188	10.5	72.4
23	Approach	APP-L					5	193	34.5	40.4
24	Approach	APP-S					1	194	31.7	34.2
25	Spectroscopy-R	SPEC-STO		1				194	10.5	72.4
26	Target Prep/Spec.	SS-DEP			1			194	18.2	79.1
27	Traverse	DRV80				1	80	274	28.7	90.9
28	Approach	APP-L					5	279	34.5	40.4
29	Approach	APP-S					1	280	31.7	34.2
30	Spectroscopy-R	SPEC-STO		1				280	10.5	72.4
31	Approach	APP-L					5	285	34.5	40.4
32	Approach	APP-S					1	286	31.7	34.2
33	Spectroscopy-R	SPEC-STO		1				286	10.5	72.4
		TOTALS:	**Soil targets**	**Rock targets**	**Rocks**	**Locations**		**Total**	**Total**	**Total**
			Visited	**Visited**	**RATted**	**Visited**		**Meters**	**Mbits**	**W-hr**
			2	**6**	**3**	**4**		**286**	**898**	**1794**

Figure 17. Power and data constraints for a generic scenario. Days of communication only (and no science or driving) or "lost" days are not shown.

Figures 18-23 show more detail on resources required for particular kinds of data acquisition, including variations in data compression, spatial resolution, spectral channels, azimuth and elevation coverage, etc. Other combinations of parameters can be estimated from these charts; they do not represent the only combinations that can be requested in rover commands, they are only a representative set to illustrate the resources required for different types of activities and the kinds of activities that are possible.

Payload Activity	Description	Mbits (Pancam without calibration)	Time (Pancam without calibration) (min)	# Frames	# calibrations
PCCUBE12	Pancam cube lossless 12-color 256x256 (calibration)	6.29	2.47		
PCCUBE4	Pancam cube lossless 4-color 256x256 (calibration)	2.10	0.82		
PCFRAME	Pancam 16x16 summed	0.03	0.21	1.0	
PCSUN	Pancam 2-filter image, 64x64 subsampled, uncompressed	0.07	0.41	2.0	
PCVER	PanCAM 1x1 RRGB 16:1	2.10	0.82	4.0	1
PCPAN0	Pancam 360x45 8-8-32-32 - 159.53	191.46	62.63	292.1	2
PCPAN0_CRIT	red channel 16:1 (or other channel combinations)	38.29	15.66	73.0	
PCPAN0_ROUTINE	noncritical portion of PCPAN0	153.17	46.98		
PCPAN1	Pancam 360x45 16-16-64-64 - 78.26	95.73	47.21	292.1	2
PCPAN1_CRIT	red channel 16:1 (or other channel combinations)	38.29	11.80	73.0	
PCPAN1_ROUTINE	noncritical portion of PCPAN1	57.44	35.40		
PCPAN2	Pancam 60x45 16-16-64-64	15.96	7.87	48.7	1
PCPAN3	Pancam 90x45 16-16-64-64	23.93	11.80	73.0	1
PCPAN3B	Pancam 90x30 16-16-64-64	15.96	7.87	48.7	1
PCPAN3C	Pancam 60x30 16-16-64-64	10.64	5.25	32.5	1
PCPAN4	Pancam 360x30 16-16-64-64	63.82	37.17	194.8	2
PCWEDGE0	Pancam 60x45 16:1 12-color wedges	47.87	30.11	146.1	1
PCWEDGE1	Pancam 90x45 16:1 12-color wedges	114.88	45.16	219.1	1
PCWEDGE2	Pancam 2x4 16:1 12-color wedge	50.33	19.79	96.0	1
PCWEDGE3	Pancam2x2 16:1 12-color wedge	25.17	9.89	48.0	1
PCWEDGE4	Pancam 12-color image 16:1	6.29	2.47	12.0	1
PCWEDGE5	Pancam 2x2 16:1 4-color wedge	8.39	3.30	16.0	1
PCWEDGE6	Pancam 3x3 16:1 12-color wedge	56.62	11.13	108.0	1
PCCUBE12-512	Pancam cube lossless 12-color 512x512	25.17	2.47	12.00	1

Figure 18. Data and time resources for typical Pancam activities.

Payload Activity	Description	Mbits	Time (minutes)
MTPAN0	Mini-TES 20mrad 60x30 1.15 deg/pix	2.862	123.46
MTPAN1	Mini-TES 20mrad 360x30 1.15 deg/pix	17.010	724.29
MTPAN1H	Mini-TES 20 mrad 180x30 1.15 deg/pix (half MTPAN1)	8.505	362.14
MTPAN2	Mini-TES 20mrad 360x30 2.3 deg/pix samp.	4.424	199.90
MTPAN3	MiniTES 20mrad 360x30 2.3x1.15 deg/pix samp.	8.532	364.22
MTPAN4	Mini-TES 20mrad 180x30 2.3x1.15 deg/pix samp.	4.266	183.11
MTPAN5	Mini-TES 20 mrad 45x45 1.15 deg/pix samp.	3.200	135.24
MTPAN6	Mini-TES 20 mrad 36x36 2.3 deg/pix samp.	0.512	24.57
MTPAN7	Mini-TES 20 mrad 16x16 1.15 deg/pix samp.	0.392	19.54
MT8MR	Mini-TES 8mrad 1 pixel, 50 icks	0.002	3.80
MTEXCAL	MiniTES 20mrad external cal target	0.002	1.00
MTPAN9	MiniTES 20mrad 4.58x4.58 deg .2865 deg steps	0.512	24.61
MTPAN60	Mini-TES 20 mrad 60x30 2.3x1.15deg/pix samp.	1.458	63.81
MTPAN90-1	Mini-TES 20 mrad 90x30 2.3x1.15deg/pix samp. 1-ick	1.120	29.64
MTPAN90-2	Mini-TES 20 mrad 90x30 2.3x1.15deg/pix samp. 2-ick	1.120	52.04
MT3PIX	3 successive Mini-TES 20mrad pixels, 5 icks	0.006	1.63
MTPAN10	MiniTES 20 mrad 5 mrad steps, 10 mrad steps outside	0.00	1.00

Figure 19. Data and time resources for typical Mini-TES activities.

	Instrument Activity	deg horiz.	deg. horiz./ pixel	deg. vert.	deg. vert./ pixel	data volume	acquisition time (hr)	# internal cals every 5 min.	extra icks for az settle (x4)	estimated cal and settle time (hr)	est. total data acquisition time (hr)
MTPAN0	MiniTES 20mrad 60x30 1.15 deg/pix	60	1.146	30	1.146	2.86	1.59	19	209.44	0.47	2.06
MTPAN1	MiniTES 20mrad 360x30 1.15 deg/pix	360	1.146	30	1.146	17.01	9.45	113	1256.64	2.62	12.07
MTPAN2	MiniTES 20mrad 360x30 2.3 deg/pix samp.	360	2.292	30	2.292	4.42	2.46	29	628.32	0.87	3.33
MTPAN3	MiniTES 20mrad 360x30 2.3x1.15 deg/pix samp.	360	2.292	30	1.146	8.53	4.74	57	628.32	1.33	6.07
MTPAN4	MiniTES 20mrad 180x30 2.3x1.15 deg/pix samp.	180	2.292	30	1.146	4.27	2.37	28	314.16	0.68	3.05
MTPAN5	MiniTES 20mrad 45x45 1.15 degree	45	1.146	45	1.146	3.20	1.78	21	157.07	0.48	2.25
MTPAN6	MiniTES 20mrad 36x36 2.3 degree	36	2.292	36	2.292	0.51	0.28	3	62.83	0.13	0.41
MTPAN7	MiniTES 20mrad 16x16 1.15 deg/pix	16	1.146	16	1.146	0.39	0.22	3	55.85	0.11	0.33
MT8MR	MiniTES 1.83x1.83 deg 8 mrad spot	1.833	0.458	1.833	0.458	0.03	0.64	8	16.00	0.17	0.81
MTPAN120	MiniTES 20mrad 120x30 2.3x1.15 deg/pix samp.	120	2.292	30	1.146	2.86	1.59	19	209.44	0.47	2.06
MTPAN150	MiniTES 20mrad 150x30 2.3x1.15 deg/pix samp.	150	2.292	30	1.146	3.56	1.98	24	261.80	0.57	2.55
MTPAN60	MiniTES 20mrad 60x30 2.3x1.15 deg/pix samp.	60	2.292	30	1.146	1.46	0.81	10	104.72	0.25	1.06
MTPAN90-1	MiniTES 20mrad 90x30 2.3x2.3MTPAN90 1-ick	90	2.292	30	2.292	1.12	0.31	4	157.07	0.18	0.49
MTPAN90-2	MiniTES 20mrad 90x30 2.3x2.3MTPAN90 2-ick	90	2.292	30	2.292	1.12	0.62	7	157.07	0.25	0.87
MT3PIX	3 successive Mini-TES 20mrad pixels, 5 icks	1.146	1.146	1.146	1.146	0.01	0.01	1	4.00	0.04	0.04
MTPAN8	MiniTES 20mrad 4.58x4.58 deg with center MT8MR	4.580	1.146	4.580	1.146	0.06	0.66	8	25.59	0.18	0.84
MTPAN9	MiniTES 20mrad 4.58x4.58 deg .2865 deg steps	4.580	0.2865	4.58	0.2865	0.51	0.28	3	63.94	0.13	0.41
MTPAN10	MiniTES 20 mrad 5 mrad steps, 10 mrad steps outside	9.186	0.573	9.186	0.573	0.96	0.53	6	96.10	0.19	0.73

Figure 20. Details on characteristics of Mini-TES data acquisition.

Payload Activity	Description	Mbits	Time (minutes)	# Frames
NC16	Navcam 45x45 16:1 stereo	1.05	0.41	1
NC12	Navcam 45x45 12:1 stereo	1.40	0.46	1
NCHALF16	Navcam 180x45 16:1 (5 stereo images)	5.24	4.12	10
NCHALF24	Navcam 180x45 24:1 (5 stereo images)	3.50	3.49	10
NCHALF12	Navcam 180x45 12:1 (5 stereo images)	6.99	4.64	10
NCFULL16	Navcam 360x45 16:1 (10 stereo images)	10.49	8.24	20
NCFULL12	Navcam 360x45 12:1 (10 stereo images)	13.98	9.27	20
HC-FR	Front/Rear Hazcam 12:1 stereo	2.80	1.85	4
MI5	Micro Imager 5 images 8:1 (new)	5.24	2.73	5
MI2	Micro Imager 2 images 8:1 (new)	2.10	1.09	2
ARMDEPLOY	Deploy arm	0.00	5.00	
ARMROTATE	Rotate arm wrist actuator	0.00	2.00	
ARMMOVE	Move arm to a new position	0.00	2.00	
ARMSTOW	Stow arm	0.00	5.00	
ARMROLLROCK	Push rock with arm	0.00	5.00	
RVRROLL	DRIVE 20 meters (.6m/s)	0.00	33.33	
RVRROLL	DRIVE 5 meters (.6m/s)	0.00	8.33	
RVRROLL	DRIVE 1 meter (.6m/s)	0.00	1.67	
RAT	Abrade rock surface	0.00	60.00	
RVRWHEELIE	Dig trench with one wheel	0.00	3.00	
RVRPLOW	Lock one wheel and drive	0.00	3.00	
MBDAY	Moessbauer	1.00		
APXS	APXS	0.09		
MBCAL		1.00		
APXSCAL		0.09		
MBNIGHT		1.00		
LEGENDS?:	Atomospheric Observations:			
PC_SUNSET	sunset monitoring	10 PCSUN	0.66	
PC_OP_DEPTH	tau, optical depth	PCSUN	0.07	
MT_GRAVITY	gravity waves	20 MT3PIX	0.12	
MT_DLY_BNDRY	daytime boundary layer	6 MT3PIX	0.04	
MT_FULL_BNDRY	full sol boundary layer	9 MT3PIX	0.05	
PC_CONDENSATE	condensate monitoring	25 PCFRAME	0.82	
PC_AERO_PM	aerosol scattering afternoon	16 PCFRAME	0.52	
PC_AERO_NOON	aerosol scattering noon with tau	PCSUN	0.07	

Figure 21. Data and time resources for other typical activities (Navcam, driving, IDD, atmospheric measurements, etc.).

	Atmospheric measurement groupings	ACTIVITES	Time (min) including external MT calibration	Data (Mbits)
1				
	optical depth	PCSUN	0.41	0.07
		Totals	0.41	0.07
2				
	optical depth	PCSUN	0.41	0.07
	sunset monitoring	10 PCSUN	4.12	0.66
	gravity wave	20 MT3PIX	34.67	0.12
	boundary layer	6 MT3PIX	9.80	0.04
		Totals	49.00	0.88
3				
	optical depth + aerosol scattering	2 PCSUN	0.82	0.13
	aerosol scattering	16 PCFRAME	3.30	0.52
	condensate monitoring	25 PCFRAME	5.15	0.82
	boundary layer	8 MT3PIX	15.07	0.05
		Totals	24.34	1.52
2F				
	sunset monitoring	10 PCSUN	4.12	0.66
	gravity wave	20 MT3PIX	36.67	0.12
	full sol boundary layer	11 MT3PIX	17.97	0.07
	optical depth	PCSUN	0.41	0.07
		Totals	59.17	0.91
3F				
	optical depth + aerosol scattering	2 PCSUN	0.82	0.13
	aerosol scattering	16 PCFRAME	3.30	0.52
	condensate monitoring	25 PCFRAME	5.15	0.82
	full sol boundary layer	12 MT3PIX	23.60	0.07
		Totals	32.87	1.55

Figure 22. Data characteristics for some possible atmospheric observations.

	Each Occurrence						
Menu of Representative "Beyond Success Options"	Science Data Generated (Mbits)	Activity Duration (min)	Energy (W-hr)	Frequency of event	Total Science Data Generated (Mbits)	Total Activity Duration (min)	Energy (W-hr)
Moessbauer calibration	1.0	605.0	36.9	4.0	4.0	2420.0	147.6
APXS calibration	0.1	613.0	32.3	2.0	0.2	1226.0	64.7
Microscopic Image	11.4	28.0	6.1		0.0	0.0	0.0
Microscopic Image-stereo	18.1	35.7	7.3		0.0	0.0	0.0
PCVER	4.0	1.6	0.4	40.0	160.0	66.0	15.0
PC/MT Spot 1	8.4	22.8	5.3		0.0	0.0	0.0
PC/MT Spot 2	26.5	35.3	8.1		0.0	0.0	0.0
PC/MT Spot 3	59.2	147.2	34.1		0.0	0.0	0.0
PC/MT Spot 4	15.0	129.5	30.0		0.0	0.0	0.0
PC/MT Spot 5	13.5	69.8	16.2		0.0	0.0	0.0
PC/MT Spot 6	12.5	29.6	6.8		0.0	0.0	0.0
PC/MT Spot 7	30.5	29.6	6.8		0.0	0.0	0.0
PC/MT 360 Panoramas	103.3	379.6	88.0	1.0	103.3	379.6	88.0
PC/MT Super Panoramas	202.6	788.3	182.6	1.0	202.6	788.3	182.6
					0.0	0.0	0.0
Atmospheres 1	0.1	0.6	0.1	60.0	6.0	38.7	8.8
Atmospheres 2	1.3	20.1	4.6	12.0	15.1	241.2	55.1
Atmospheres 3	2.3	18.5	5.4	12.0	27.1	222.3	65.0
Atmospheres 2F	1.3	22.1	5.1	3.0	3.8	66.3	15.2
Atmospheres 3F	2.3	20.5	5.9	3.0	6.9	61.6	17.6
Moessbauer filter magnet	1.0	605.0	36.9	2.0	2.0	1210.0	73.8
Moessbauer capture magnet	0.1	613.0	32.3	1.0	0.1	613.0	32.3
APXS filter magnet	0.1	613.0	32.3	2.0	0.2	1226.0	64.7
APXS capture magnet	0.1	613.0	32.3	1.0	0.1	613.0	32.3
PLOW	48.9	104.3	36.4	1.0	48.9	104.3	36.4
TRENCH	32.2	69.5	24.5	1.0	32.2	69.5	24.5
THERMAL INERTIA	17.4	89.4	20.7	3.0	52.1	268.3	62.1
HAZMOVIE	69.9	0.0	0.0	1.0	69.9	0.0	0.0
DRV100 (100 m traverse)	32.2	192.7	113.0	10.0	321.6	1926.9	1130.2
DRV1000 (DRV100x10)	321.6	1926.9	1130.2		0.0	0.0	0.0
				TOTALS	**1056**	**192**	**2116**
					Mbits	Hours	W-hr

Figure 23. Representative selection of "Beyond Success Options" that fit within the energy and data constraints for a 90-sol MER-B mission. Data amounts listed do not include command and data handling Mbits.

5 PRE-FLIGHT SCIENCE ACTIVITIES

5.1 Instrument Calibration

Participating Scientists are encouraged to participate in camera calibration activities at JPL, if their science investigation includes use of the cameras. Such participation would provide hands-on experience with camera operability. However, much of the camera calibration work will have been completed by the time Participating Scientists are selected. The Flight Unit Calibration for the engineering cameras, Pancam, and Microscopic Imager is currently scheduled to be done at JPL from February 14, 2002, through March 14, 2002.

There may be opportunities for Participating Scientists to become involved with calibration of the other instruments as well, but those detailed calibration plans and schedules are not yet available. After selection, Participating Scientists will be encouraged to work with the Athena PI to arrange for calibration participation.

5.2 Test and Training for Operations

Minimum requirements for the training of Participating Scientists are described in the Announcement of Opportunity.

The MER Test and Training Plan (not currently available) will describe the training required by each mission operations team or team member, and will indicate which members will require certification for flight operations. The Test and Training Plan will also identify the training that will be provided to the mission operations teams to ensure they are ready to support flight. Training planned to be provided to the MER mission operations teams include:

- Classroom instruction and description on key flight system and subsystems, voice loop protocol, critical mission events and operations, mission and navigation plans, flight operations procedures, flight rules and constraints, and contingency operations.
- Participation in the following major operational tests: sequence verification tests, end-to-end information system tests, thread tests, system verification tests, mission system tests, field tests, and operational readiness tests.

Key to a successful mission will be training the mission operations teams in an environment that is as flight-like as possible. Therefore the major operational tests will be conducted:

- Using the MER testbeds (surface system testbed, cruise/entry-descent-landing testbed, and/or software testbed).
- Using GDS hardware, the latest versions of the GDS software, and exchanging files described in approved software interface specifications.

- Using mission operations teams operating from mission support areas that will be used during flight.
- Using procedures compliant with operational interface agreements.
- In compliance with the latest versions of flight rules and constraints.

Operational readiness tests (ORTs) will be conducted beginning approximately five months before launch to demonstrate the readiness of the MER mission operations system and flight teams to support flight operations. ORTs will be conducted using the MER testbeds to stand-in for the flight vehicle. Tests will be conducted using operational tools, processes, and procedures, and will adhere to flight timelines.

5.2.1 Testbeds

The **Analysis Testbed** will be used for the purpose of verifying Guidance, Navigation, and Control algorithms. No flight hardware will be included in this testbed.

The **Flight Software (FSW) Development Testbed** will be used for the purpose of unit testing, integration, and verification by FSW development teams. No flight hardware will be included in this testbed.

The **Cruise/EDL Testbed (CETB)** will be used for pre-ATLO payload and engineering subsystem integration. It will include flight system (non-rover) engineering model avionics, realistic simulations of devices and dynamics, and have real-time hardware-in-the-loop. It will be used for unit testing, verification, performance, and mission scenario testing.

The **Surface System Testbed (SSTB)** will be used for unit testing, integration, navigation and mobility functional testing, software development and verification, algorithm verification, characterization, performance, and mission scenario testing. It will include rover engineering model avionics, devices with stimulation from simulations and dynamics, and real-time hardware-in-the-loop.

5.2.2 Types of Tests

Sequence Verification Tests (SVT) are performed in either CETB or SSTB, depending upon the function being tested, and during ATLO for the purpose of verifying mission critical event sequences. Operations personnel will develop the sequence and command products used for these tests using engineering versions of the MOS tools. Real-time monitoring of telemetry and post-test review of test data will be performed by the operations personnel using operations software tools.

End-to-End Information System Tests (EEIS) are performed in during ATLO for the purpose of validating data flow through all portions of the MOS, including the flight system, DSN, ground system, and remote science sites. Launch site data flow validation will also be included. Flight versions of MOS tools will be utilized during the tests for the purpose of generating test products and monitoring telemetry. These tests may be split into multiple pieces to focus on various components of the complete system.

Mission Operation System (MOS) Thread Tests are performed either using the CETB or the SSTB for the purpose of validating critical operations data flows and processes and training the operations team on inter-team processes and procedures. Operations personnel will be responsible for developing operations products using engineering versions of the appropriate tools, processes and procedures. The following processes will be exercised during thread testing: Uplink, Downlink, Navigation, and Surface Operations.

Project System Tests (PST) will be performed during ATLO, and will bring operations tools and personnel into the ATLO verification of mission critical sequences. Operations personnel will be responsible for developing the sequence and command products for the test, as well as performing real-time monitoring and post-test review of test data, all using operations tools.

Operational Readiness Tests (ORTs) are performed using either the CETB or the SSTB, depending on the function being tested, for the purpose of demonstrating the readiness of the MOS to support flight operations. These tests will attempt to simulate the actual flight environment as much as possible. Operations personnel will be responsible for performing all flight tasks using operations tools, processes and procedures. All ORTs will strictly adhere to flight timelines ("Mars Time").

Proto-ORTs are similar to ORTs. However, they are performed earlier in the test program for the purpose of determining the focus areas for future operations development work, holes in design, etc. Operations personnel will be responsible for performing all flight tasks using operations tools, processes and procedures where possible. These tests will not necessarily adhere to the flight-like timeline.

Mini-ORTs are similar to ORTs and will be performed on the flight testbed. However, these tests are designed to validate specific flight functions (e.g., rover surface operations: rock approach, fine positioning, and instrument placement). Operations personnel will be responsible for performing all flight tasks using operations tools, processes and procedures where possible. These tests will not necessarily adhere to the flight-like timeline.

Field Tests are performed using the SSTB in a natural terrain test course. The purpose of the test is to validate specific surface operations, including target selection, long distance traverse and target approach. These tests may be performed as ORTs or mini-ORTs.

5.2.3 Test Schedule

Figure 24 and Figure 25 summarize the preliminary pre-launch and post-launch test and training schedules for the MER Project.

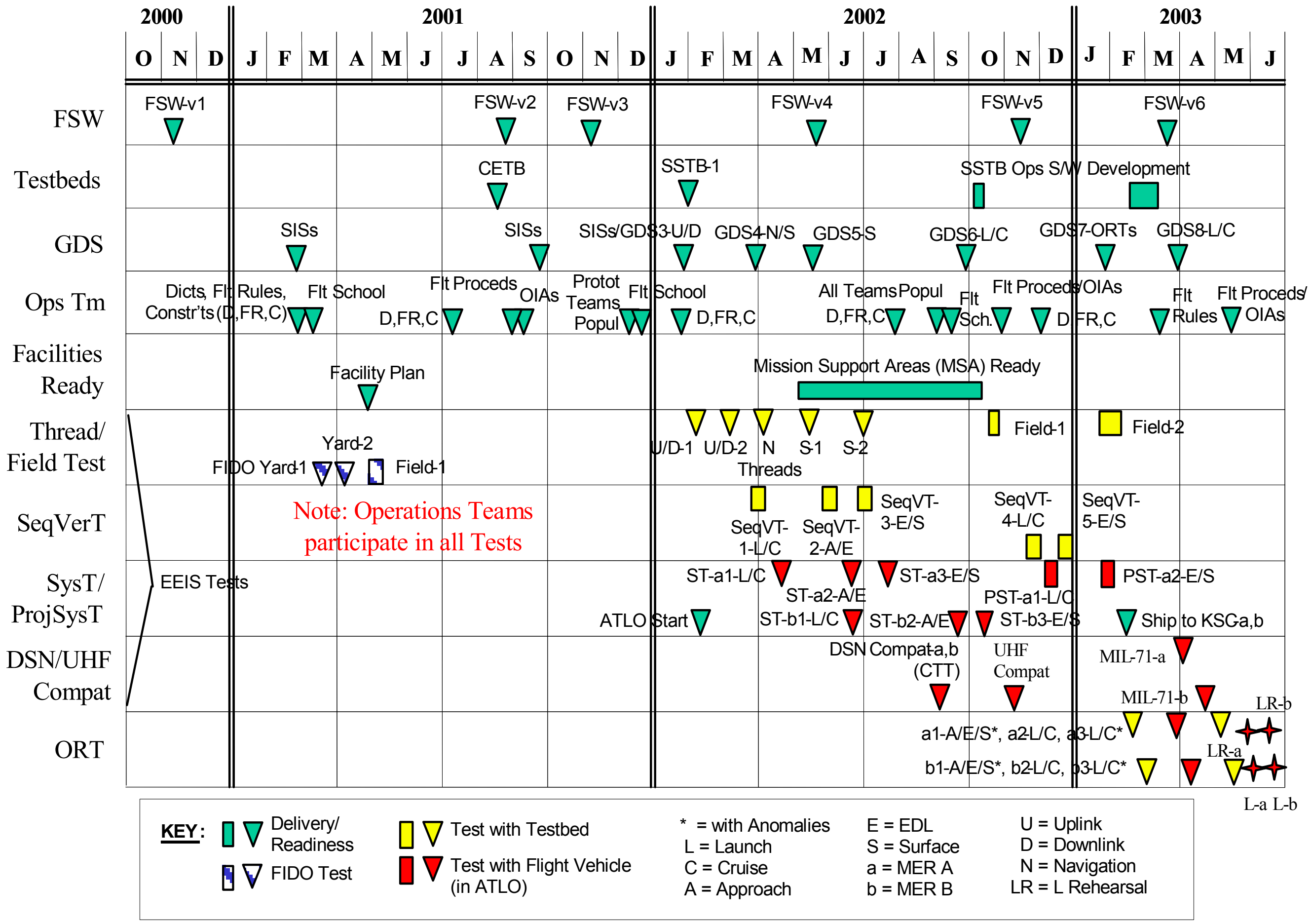

Figure 24. Pre-launch test and training schedule.

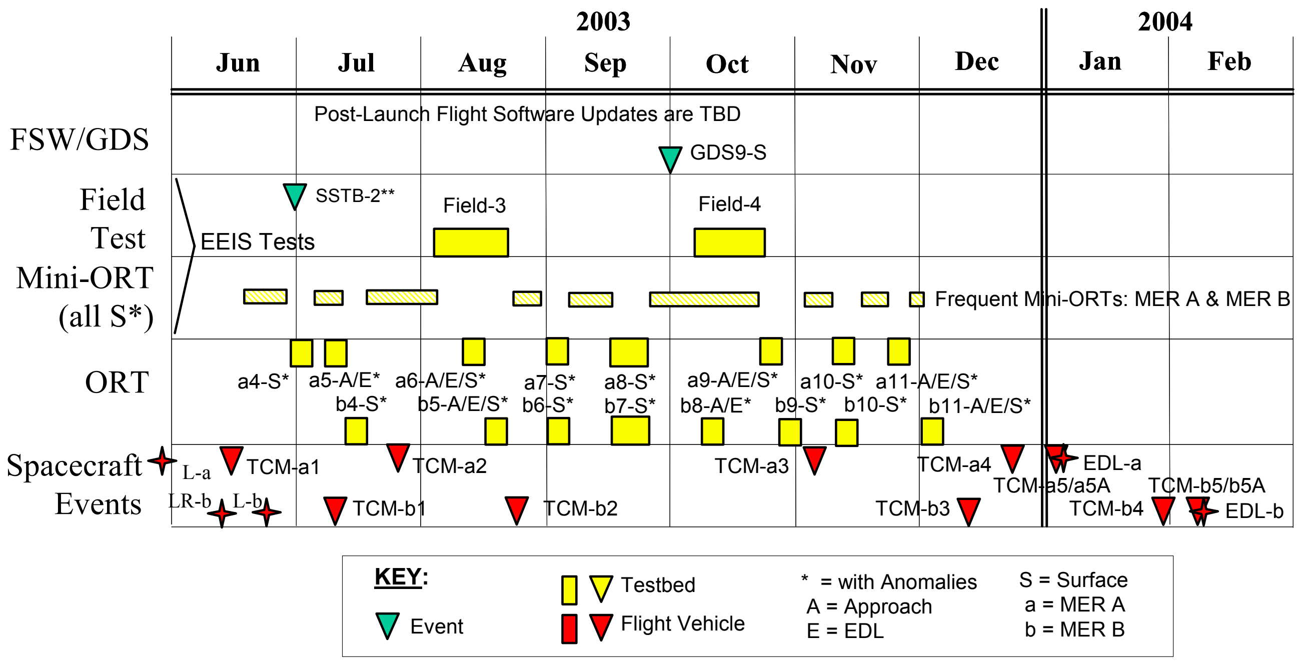

Figure 25. Post-launch test and training schedule.

6 TACTICAL SCIENCE OPERATIONS DURING THE LANDED MISSION

The Tactical Overnight Build Process occurs during the surface operations phase, and will be rehearsed during the Operations Readiness Tests. Each sol, members of the SOWG and the SOST will participate in a rover preparation meeting while the DTE downlink is concurrently taking place. This meeting will cover the expected data return based upon the previous sol's planned activities. Once all data has been collected, the Science Team will perform immediate science data analysis during the 3 to 4 hours after the end of the DTE downlink. This work requires the delivery of the high priority standard data products by the Multi-mission Image Processing Laboratory (MIPL) early in this phase. The science analysis related to each science theme is carried out within the Science Theme Groups while the Payload Downlink Leads coordinate science downlink data processing and analysis for their payload element, including assessment of instrument health and science data analysis. This science and instrument assessment is used in the SOWG meeting to help in the formulation of the science activity plan for the next sol. An uplink/downlink crossover meeting will be held for each payload element. These parallel meetings serve as the transition between downlink evaluation and uplink planning. The Payload Downlink Leads will brief the Payload Uplink Leads as to the state of health of the instruments and the science instrument goals for the next sol. The Science Operations Working Group meeting will then be held to plan the detailed science activities of the next sol. The detailed science activity plan will be generated and delivered to the Integrated Sequence Team for implementation as part of the next sols's command load.

The current baseline for the staffing schedule for tactical operations follows "Mars Time," with the capability to command the rover every sol. Working "Mars Time" brings with it some difficulties in human adjustment because the Martian solar day is 24 hrs and 37 min long. Experts in the field of Human Factors and Circadian Rhythm have been consulted, and the Project is examining possible alternative staffing schedules that would follow "Earth Time" or begin on "Mars Time" and transition to "Earth Time" at some point in the mission. It is unknown at this point what the final staffing configuration will be. As a baseline plan, Participating Scientists should be prepared to work "Mars Time" during landed operations.

Figure 26 displays the science analysis and planning activities that occur each sol. Long-term science planning and/or more detailed analyses require the use of more specialized data products that the science team generates using specialized software tools developed for that purpose.

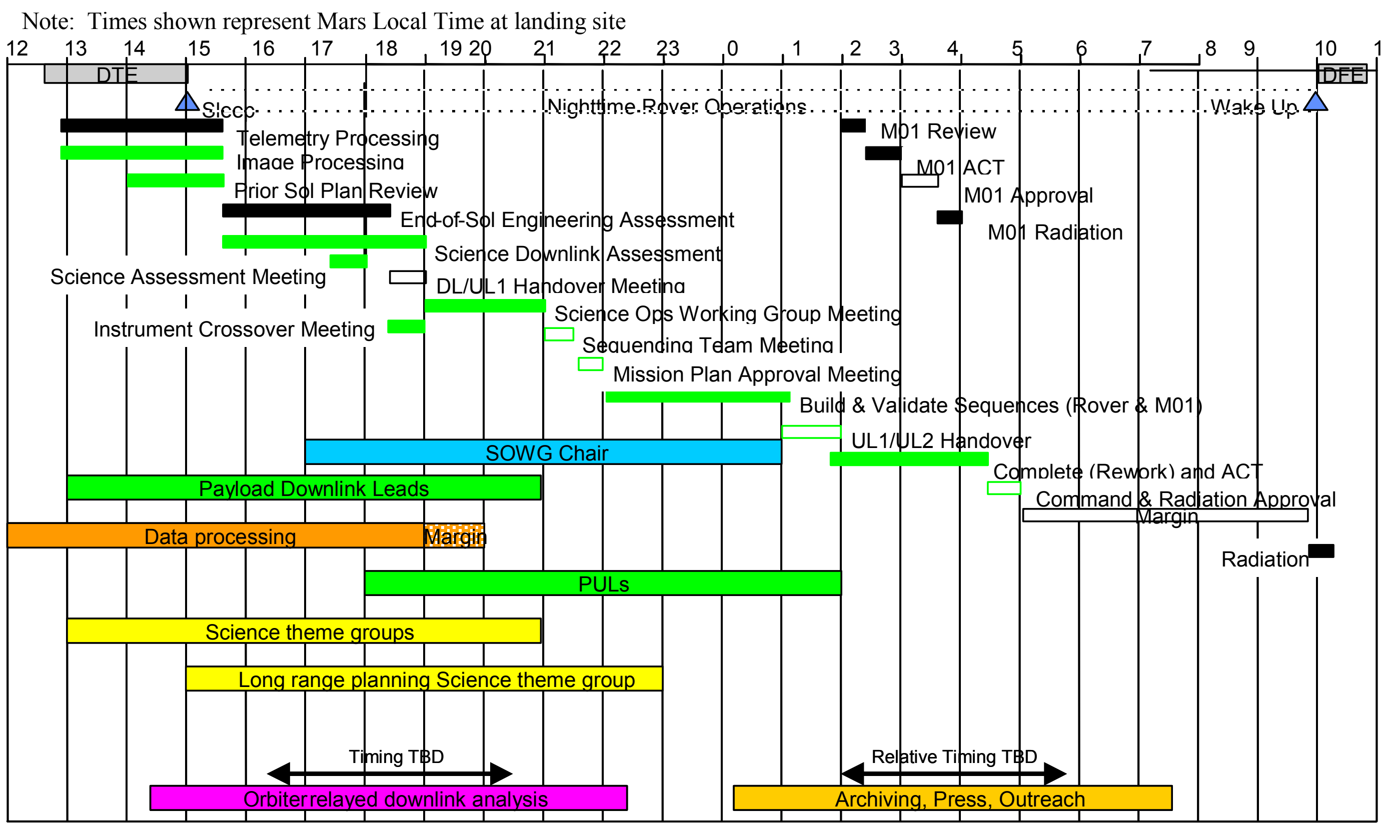

Figure 26. Tactical science shifts during operations.

7 PRELIMINARY PLANS FOR MER DATA PRODUCTS

7.1 Introduction

This portion of the proposal information package provides an overview of plans for data generation, validation, and transfer to the Planetary Data System (PDS) of MER archives containing raw and reduced data, documentation, and algorithms/software.

7.2 Data Flow

As part of the Ground Data System, the Multi-mission Image Processing Laboratory (MIPL) will generate Experiment Data Records (EDRs) for all the Athena science instruments. The Science Team will download EDRs from the MER operations file server at JPL to the SOWG and SOST areas at JPL and at their home institutions for analysis. Payload Element Leads will then generate Reduced Data Records (RDRs) in the form of standard products (Table 6 defines processing levels associated with RDRs).

Table 6. Definitions of processing levels for science data sets.

NASA	CODMAC	Description
Packet data	Raw – Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded.
Level 0	Edited - Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed.
Level 1A	Calibrated - Level 3	Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied).
Level 1B	Resampled - Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances).
Level 1C	Derived - Level 5	Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction).
Level 2	Derived - Level 5	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling.
Level 3	Derived - Level 5	Geophysical parameters mapped onto uniform space-time grids.

EDRs and RDRs, together with supporting documentation, calibration data, software, engineering data, and SPICE kernels, will be accessible to mission personnel and the Athena Team on the MER operations file server. PELs may upload their RDR products to

the file server or provide pointers to the products on their home systems. Web-based search tools will be available for searching and retrieval of data products. Table 7 lists the elements that comprise the MER archives, Table 8 lists the suppliers of data and information for the archives, and

Table 9 lists the standard data products expected to be produced.

Table 7. Components of MER archives.

Component	Contents
SPICE Archives	SPICE Kernel Software Interface Specification Documents SPICE Kernels NAIF Software
Science Data Archives	High-level mission, spacecraft, instrument, and data set descriptions for the PDS Catalog Software Interface Specification (SIS) Documents Archive Volume Software Interface Specification Documents Processing Descriptions, Algorithms, and Software (to use in understanding reduced data product generation) Instrument Calibration Reports and associated data needed to understand level 1 product generation Experiment Data Records and Reduced Data Records with PDS Labels Saved Preliminary Products
Engineering Data Archives	Software Interface Specification Documents Uplink sequences and notebook entries Rover engineering data products and Telemetry data packets

Table 8. MER data archive component suppliers.

Product	Supplier
EDRs for all Athena instruments	MIPL
Pancam RDRs	* J. Bell, Cornell Univ.
Navcam RDRs	* J. Bell, Cornell Univ.
Hazcam RDRs	* J. Bell, Cornell Univ.
MI RDRs	K. Herkenhoff, USGS/Flagstaff
Mini-TES RDRs	P. Christensen, Arizona State Univ.
APXS RDRs	R. Rieder, Max Planck Inst., Germany

MB RDRs	G. Klingelhöfer, Gutenberg Univ., Germany
RAT RDRs	S. Gorevan, Honeybee Robotics
Rover Engineering Data	MER Project
SPICE	NAIF
Raw telemetry	NAIF
* Coordinates generation of RDRs among Cornell, Ames, USGS, and MIPL participants	

Table 9. MER standard data products.

Instrument	Product
Pancam, Navcam, Hazcam, Microscopic Imager	Experiment Data Records (EDRs)
	Quick-look mosaics and connectivity maps
	Calibrated images
	*Mosaics and/or image cubes
	*Geometric/map products
	*Atmospheric opacity determinations
	*Parameter maps from mosaics
Mini-TES	Experiment Data Records (EDRs)
	Calibrated spectral radiances
	*Spectral radiance image cubes
	*Spectral emissivity image cubes
	*Temperature and thermal inertia maps
	*Atmospheric sounding profiles
Mössbauer and APX Spectrometers	Experiment Data Records: counts per energy (APXS) or velocity (MB) channel
	*APXS-based elemental and oxide abundances
	*MB-based estimates of parameters such as ferrous to ferric ratio and the presence and abundance of iron-bearing minerals
Rock Abrasion Tool	TBD
Rover engineering data	TBD
NAIF / SPICE	SPK kernels
	PcK kernels for times of interest
	I kernels for instruments
	C kernels for spacecraft and instrument rotations

Instrument	Product
	E kernels showing sequences and Experimenter's Notebooks depicting events
* Asterisks indicate special data products	

EDR and RDR standard data products and supporting materials in the integrated archives will be released to the PDS at scheduled intervals. Payload Element Leads (PELs) are responsible for preparing the data and supporting materials for release to the PDS. A data release may take the form of electronic transfer or delivery on physical media to the appropriate PDS Node. PDS personnel will work closely with science team members to ensure a smooth transfer. Participating Scientists will be encouraged to assist the PELs with their archiving tasks and/or take responsibility for preparing their own special data products for delivery to the PDS. It is expected that the data delivered to the PDS will be made available online to the science community and the public through the PDS Planetary Atlas and a version of the MER Analyst's Notebook (see Section 7.6). When data products have been released to the PDS, they are regarded as publicly available. Released data products will be made available through a publicly accessible version of the Web-based search and retrieval tools used by MER personnel.

Although online access will be the primary distribution method for MER archives, the PDS requires that archives be stored on appropriate physical media (e.g., CDs or DVDs) for long-term maintenance at the PDS and at the National Space Science Data Center (NSSDC). Furthermore, the PDS is required to provide data on physical media to the NASA Regional Planetary Image Facilities (RPIFs). Therefore PDS will ensure that all MER EDR and RDR archives are copied to physical media.

7.3 Data Validation and Peer Review

MER science archives will be validated before being released to the PDS. Validation is accomplished in two parts: validation for scientific integrity and validation for compliance with PDS standards. Validation will be overseen by the MMO Science Data Validation Team (SDVT), which will include representatives from each Payload Element Lead team and PDS.

Science team members are expected to conduct validation for scientific integrity in the course of their analysis of EDRs and their production of RDRs. The details of the science validation process are the responsibility of the Payload Element Leads.

Validation for compliance with PDS standards is also the responsibility of each Payload Element Lead, with help from the PDS Node that will receive the data products. PDS will provide software tools, examples, and advice to help make this part of the validation as efficient as possible.

A data set can be considered as the collection of all standard products of a particular type from a particular instrument, along with the complete set of documentation, software, indexes, and other material needed to understand and use the data. For example, the set of all Pancam EDR images and supporting materials would be one data set.

A data set must pass a peer review before it is accepted by PDS. The data set providers (*e.g.*, the Payload Element Leads) and the associated PDS Nodes will be coordinated by the DAWG to invite a small group of scientists outside the mission to form a peer review committee. The committee will examine the data set to make sure it is complete, well documented, and generally usable by scientists not involved in the mission. The committee may impose liens on the data set providers that must be resolved before the data set is accepted. The committee will include a PDS representative to ensure that the data set is in compliance with PDS standards. In the case of an active mission in which a data set is delivered in stages over time, a formal peer review is usually held only for the first delivery. As long as subsequent deliveries are similar in format to the first one, additional peer reviews are not necessary; however, the PDS representative will check each delivery for PDS compliance.

7.4 Integrated Archives

The concept of integrated archives is the key to making the best use of the data returned by the various science instruments on MER. Unlike previous orbital and landed missions in which instruments were operated mostly independently of one another, in a rover mission the instruments must operate in close coordination. Furthermore, a rover mission is non-deterministic; a decision to conduct a sequence of observations may be driven by recently acquired data rather than by a plan determined in advance. The Athena Team and the general science community will require access to science data archives that are integrated across instruments by time, by location, and by observation target, at a minimum. Two complementary systems, the Planetary Atlas and the Analyst's Notebook, will provide the desired accessibility.

7.5 The Planetary Atlas

The Planetary Atlas is a Web-based system of access to planetary science data developed by the PDS Imaging Node and already in use with data from other missions. The Planetary Atlas allows selection based on various search criteria, browsing of image data, and downloading in various formats. A version of the Atlas adapted specifically to the needs of the MER mission will be available for use by mission personnel. The Atlas can also be used by the general science community to view and download data products that have been made public.

7.6 The Analyst's Notebook

The Analyst's Notebook is a Web-based tool for correlating data products from various Athena instruments based on acquisition time, location along a rover traverse, target, instrument, and other criteria. The Notebook will allow the browsing of MER data archives to select subsets of data as a function of acquisition time, location, instrument, and other criteria. Using the Notebook, a scientist can virtually replay mission events to better select and understand data products of interest. The Analyst's Notebook will be designed and implemented by the Deputy Principal Investigator at Washington University, based in part on the previous Experimenter's Notebooks built to support analyses of data collected during the FIDO rover field trials.

The Planetary Atlas and the Analyst's Notebook are intended to be complementary tools. The Planetary Atlas will probably be used to satisfy most requests for locating and downloading data products from MER mission personnel and the general science community. The Analyst's Notebook will probably be used by a smaller set of scientists who need access to the most detailed information available about the data.

7.7 Data Archiving Roles and Responsibilities

In this section the roles and responsibilities for personnel and organizations involved in MER archive generation, validation, transfer, and distribution are summarized.

The MER Project has overall responsibility for generation and validation of archives for release to the PDS. The Project is also responsible for distribution of data and associated information to MER personnel. The MER Science Manager is responsible for the management of data archive planning and implementation. The MER Project Scientist will review the data analysis plans in order to ensure timely and adequate analysis of spacecraft data and delivery of documented complete data to the appropriate archives according to schedules agreed upon.

The Data Archive Working Group (DAWG) will coordinate the planning of the generation, validation, and release of PDS-compliant archives to the PDS. The DAWG is a working group of the MER Project Science Group and reports to the MER Project Scientist. The DAWG Chair is the MER Interdisciplinary Scientist for Data and Archives (also Athena Deputy Principal Investigator). Membership will include the MER Project Scientists, the Athena Principal Investigator and Payload Element Leads, representatives from NAIF and MIPL, the SDVT Chair, and project personnel selected to ensure that raw packets, engineering data sets, and documentation are included in archives. Representative PDS personnel will be liaison members of DAWG. For the most part, the DAWG's work will take place before mission operations begin. During the active mission the DAWG will remain ready to meet if necessary.

MIPL is responsible for generating validated, PDS-compatible archives containing Experiment Data Records (Level 0) from the Athena science instruments.

The MER Project is responsible for archiving rover engineering data.

The Athena Principal Investigator is responsible for ensuring generation of validated, PDS-compatible archives containing derived data products (Level 1 and above) from Athena data, along with documentation, algorithms or software for generating derived data products, calibration data and reports, and other supporting materials. He will delegate the work to the Payload Element Leads and other Athena Team members.

The PDS is the designated point of contact for MER on archive-related issues. The PDS is also the interface between MER and the National Space Science Data Center (NSSDC). The PDS will work with the DAWG to ensure that the MER archives are compatible with PDS standards and formats. Personnel from the PDS Geosciences, Imaging, Atmospheres, and NAIF Nodes will be liaison DAWG Members.

7.8 Archive Generation, Validation, and Release Schedules

As discussed above, standard products will be generated systematically during the course of the mission. These products will be used for analyses, and some will be posted for education and outreach. A final and important purpose for the standard products is to provide the research community with the best-derived data for their analysis.

Each rover will acquire data for a 90-sol primary mission, and those data will be delivered to the PDS in the form of integrated archive deliveries. All NASA Level 1 data for Sol 1 through 30 will be archived no later than 6 months after Sol 30, for each rover. All NASA Level 1 data for Sol 31 through Sol 90 will be archived no later than 6 months after Sol 90, for each rover. An extended mission may take place beyond the 90 sols for either or both rovers. In that case, an additional data release for data from Sol 91 to the end of the mission will occur no more than six months after the end of the extended mission for each rover. During the up-to-six-month preparation intervals, the data will be processed to standard products, validated through analyses, assembled into archives, and checked for compliance with PDS standards.

A significant subset of data will also be released quickly through publicly accessible World Wide Web sites and as hard copies, particularly images. Both data sets will be declared as released and available to the public once posted.

8 ADDITIONAL INFORMATION

Table 9 lists Web sites that may provide helpful information.

Table 10. Related Web sites

Mars Exploration Program	http://mars.jpl.nasa.gov
Athena Payload	http://athena.cornell.edu
FIDO Rover	http://fido.jpl.nasa.gov
FIDO Field Tests and Analyst's Notebook	http://wufs.wustl.edu/fido/
Red Rover Goes to Mars	http://rrgtm.planetary.org
Planetary Data System	http://pds.jpl.nasa.gov
NAIF/SPICE	http://pds.jpl.nasa.gov/naif.html
ASU Thermal Emission Spectral Library (5-45 µm spectral wavelength range)	http://tes.asu.edu/speclib/
ASTER Spectral Library (0.4-25 µm)	http://speclib.jpl.nasa.gov
USGS Digital Spectral Library (0.2 – 3 µm)	http://speclab.cr.usgs.gov/spectral-lib.html

9 ACRONYMS, ABBREVIATIONS, AND INITIALISMS

Table 11. List of acronyms, abbreviations, and initialisms

A/D	analog-to-digital
A.O.	Announcement of Opportunity
APXS	alpha particle X-ray spectrometer
ARC	Ames Research Center (NASA)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASU	Arizona State University
ATLO	Spacecraft Assembly, Test, and Launch Operations
AU	Astronomical Unit
CCD	charge coupled device
CD	compact disk
CESR	Centre d'Etude Spatiale des Rayonnements
CETB	Cruise/EDL Testbed
CODMAC	Committee on Data Management, Archiving, and Computing
Co-I	Co-Investigator
CPU	central processing unit
DAC	digital to analog converter
DAWG	Data Archive Working Group
DC	direct current
DL	downlink
DSMS	Deep Space Mission Support
DSN	Deep Space Network
DTE	Direct-to-Earth

DVD	digital video disk
EDL	entry, descent, and landing
EDR	Experiment Data Records
EEIS	End-to-End Information System
EEPROM	electrically erasable programmable read only memory
FIDO	Field Integrated Design and Operations
Flt	Flight
FOV	field of view
FPGA	field programmable gate array
FRAM	ferroelectric random access memory
FSW	flight software
FWHM	full-width at half-maximum
GDS	Ground Data System
Hazcam	Hazard Camera
HGAA	High Gain Antenna Assembly
HQ	Headquarters
IAU	International Astronomical Union
ICK	2-second time interval for the Mini-TES
IDD	instrument deployment device
IFOV	instantaneous field of view
IMU	inertial measurement unit
IPS	Instrument Positioning System
IR	Infrared
IST	Integrated Sequence Team

JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LGA	low gain antenna
L_s	areocentric longitude of the Sun
LST	Local Solar Time
MB	Mössbauer
MEP	Mars Exploration Program
MER	Mars Exploration Rover
MGA	medium gain antenna
MGS	Mars Global Surveyor
MI	Microscopic Imager
Mini-TES	Miniature Thermal Emission Spectrometer
MIPL	Multimission Image Processing Laboratory
MMO	Mission Management Office
MO	Mars Observer
MOC	Mars Orbiter Camera
MOLA	Mars Orbiter Laser Altimeter
MOS	Mission Operation System
MPT	Mission Planning Team
N/A	not applicable
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NAV	navigation team
Navcam	Navigation Camera

ND	neutral density
NESR	noise equivalent spectral radiance
NSSDC	National Space Science Data Center
OIA	Operational Interface Agreement
ORT	Operational Readiness Test
OSS	Office of Space Science
Pancam	Panoramic Camera
PDL	Payload Downlink Lead
PDS	Planetary Data System
PEL	Payload Element Lead
PI	Principal Investigator
PIN	positive-intrinsic-negative
PIP	proposal information package
PMA	Pancam Mast Assembly
PSG	Project Science Group
PST	Project System Test
PUL	Payload Uplink Lead
RAT	Rock Abrasion Tool
RDR	Reduced data Record
REM	Rover Electronics Module
RMS	root mean square
ROM	read-only memory
RPIF	Regional Planetary Imaging Facility
rpm	revolutions per minute

RTO	Mission Control Real Time Operations
SDVT	Science Data Validation Team
SIS	Software Interface Specification
SNR	signal-to-noise ratio
Sol	one Martian solar day
SOST	Science Operations Support Team
SOWG	Science Operations Working Group
SPICE	Spacecraft Planet Instrument Camera-Matrix Events
SRAM	static random access memory
SRET	Spacecraft/Rover Engineering Team
SSTB	Surface System Testbed
STG	Science Theme Group
STL	Science Theme Lead
SVT	Sequence Verification Test
TCM	trajectory correction maneuver
TES	Thermal Emission Spectrometer
THEMIS	Thermal Emission Imaging System
UHF	ultra-high frequency
UL	uplink
USGS	United States Geological Survey
VL1	Viking Lander 1
VL2	Viking Lander 2
WEB	Warm Electronics Box