

Technology Development for NASA Mars Missions

*Samad Hayati
Chief Technologist
Mars Exploration Directorate
Jet Propulsion Laboratory*

*2nd International Planetary Probe Workshop
AUGUST 23 - 26, 2004
NASA Ames Conference Center
Moffett Field, California USA*



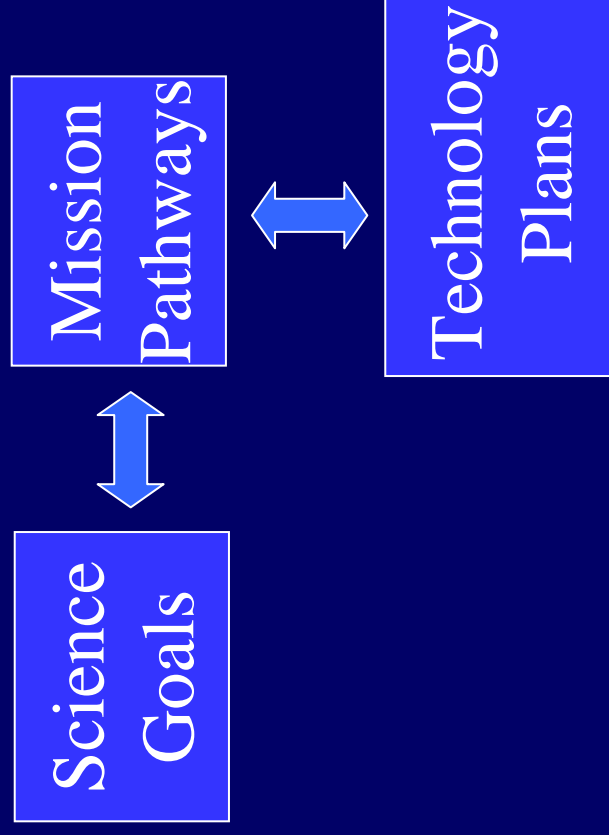
Presentation Content

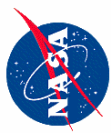
- *Mars mission roadmaps*
- *Focus and Base technology programs*
- *Technology infusion*
- *Feed forward to future missions*



Mars Technology Program (MTP)

- Code S determined that the Mars Exploration Program must have a strong technology component to enable increasingly more capable missions and science
- Accordingly the restructured program contains an average technology investment of ~ 10% over a decade



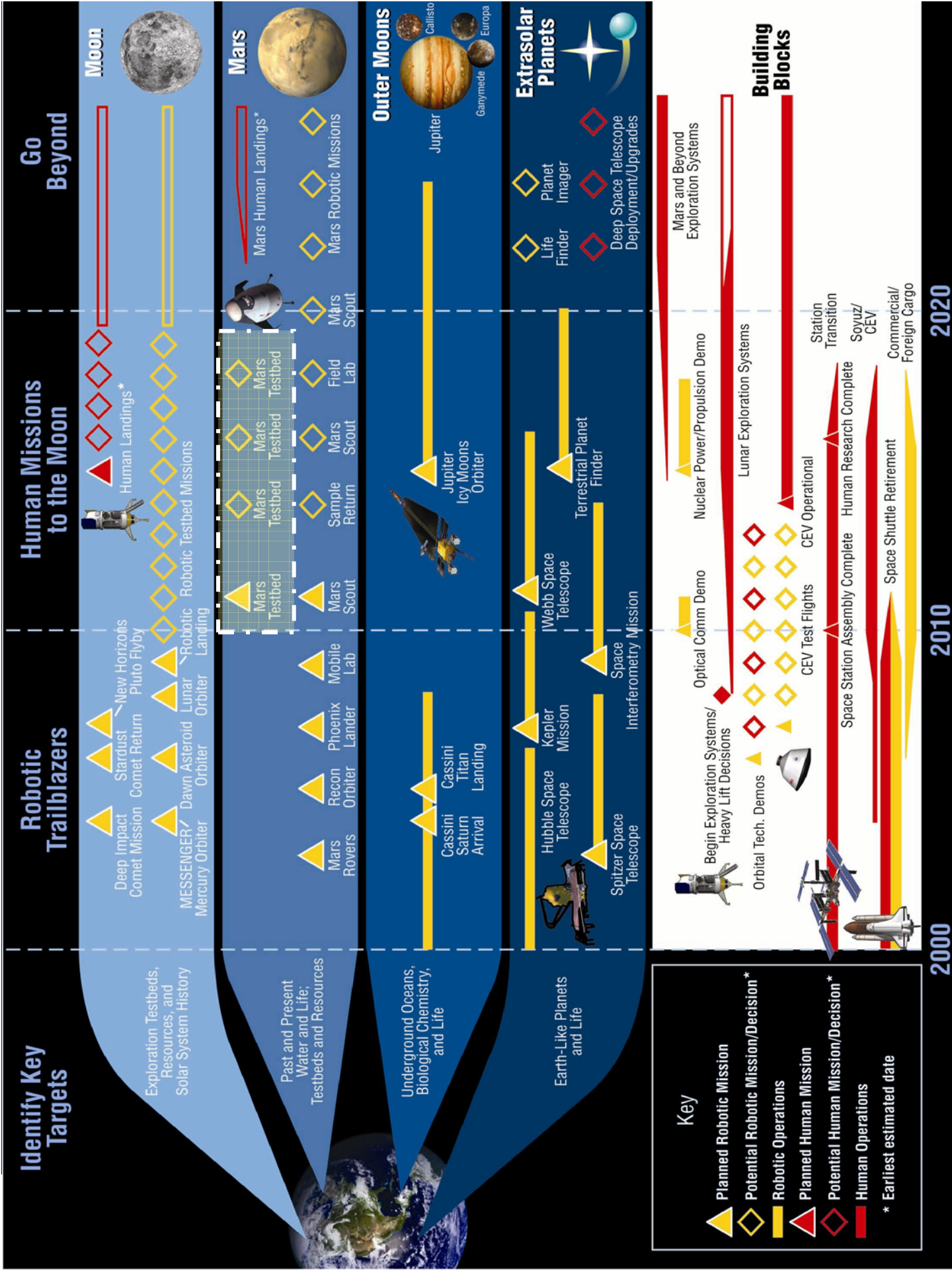


Mars Exploration Pathways Missions

2009 - 2020



| Pathway | 2009 | 2011 | 2013 | 2016 | 2018 | 2020 | NOTES |
|----------------------------------|-------------------------------|-------|-------------------------------|----------------|--------------------------------------|---------------------|--|
| Search for Evidence of Past Life | MSL to Low Lat. | Scout | Ground-Breaking MSR | Scout | Astrobiology Field Lab or Deep Drill | Scout | All core missions to mid-latitudes. Mission in '18 driven by MSL results and budget. |
| Explore Hydrothermal Habitats | MSL to Hydrothermal Deposit | Scout | Astrobiology Field Laboratory | Scout | Deep Drill | Scout | All core missions sent to active or extinct hydrothermal deposits. |
| Search for Present Life | MSL to N. Pole or Active Vent | Scout | Scout | MSR with Rover | Scout | Deep Drill | Missions to modern habitat. Path has highest risk. |
| Explore Evolution of Mars | MSL to Low Lat. | Scout | Ground-Breaking MSR | Aeronomy | Network | Scout | Path rests on proof that Mars was never wet. |
| | telecom | | | | | replacement Telecom | 3 |



Key

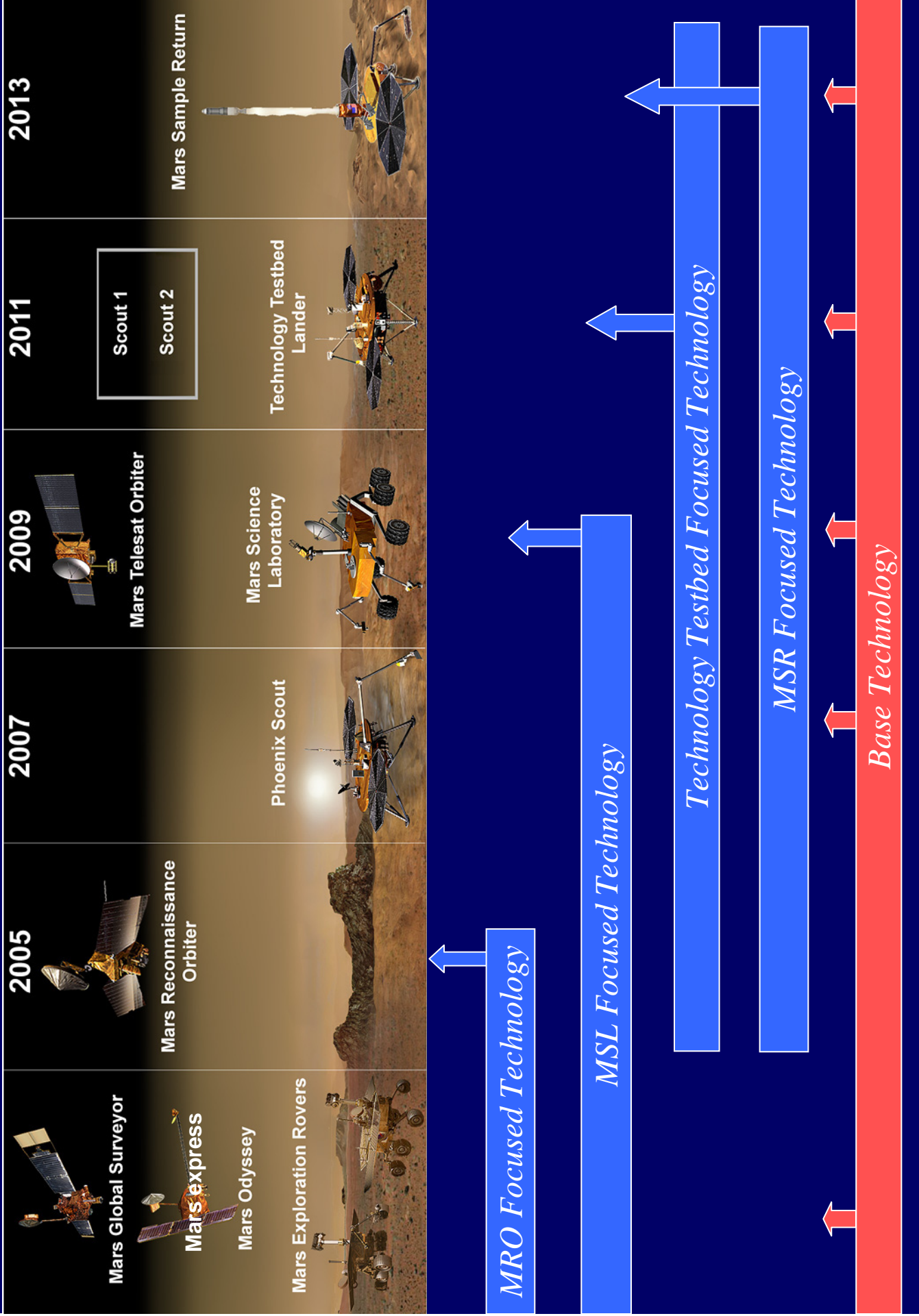
- ▶ Planned Robotic Mission
- ◊ Potential Robotic Mission/Decision*
- ▬ Robotic Operations
- ▶ Planned Human Mission
- ◊ Potential Human Mission/Decision*
- ▬ Human Operations
- * Earliest estimated date

2000

2010

2020

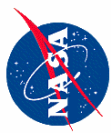
Mars Technology Program Supports all NASA Mars Missions



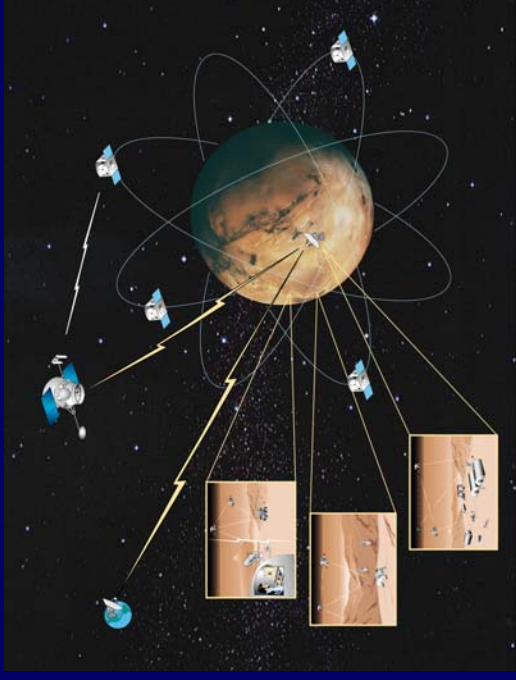


Mars Technology Program Elements

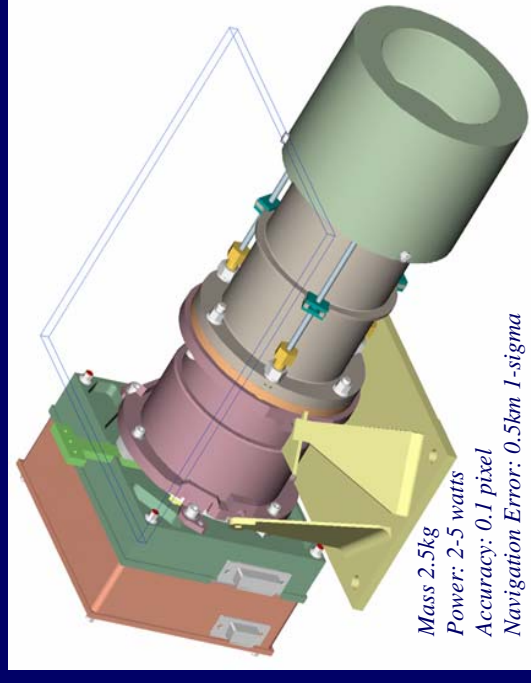
- *Focused Technology*
 - *Driven by requirements of missions such as MSL and MSR*
 - *Technology development is strongly coupled and interactive with the project early in the design phase*
 - *Technology must reach maturity (TRL 6) by Project PDR*
 - *Directed or competed*
 - *Day-to-day management is done by projects*
- *Base Technology*
 - *Is exploratory in nature*
 - *Provides seed corn for future mission technologies*
 - *Includes push technology development*
 - *Enables new types of missions*
 - *100% competed via NASA NRA process*



MRO Focused Technology

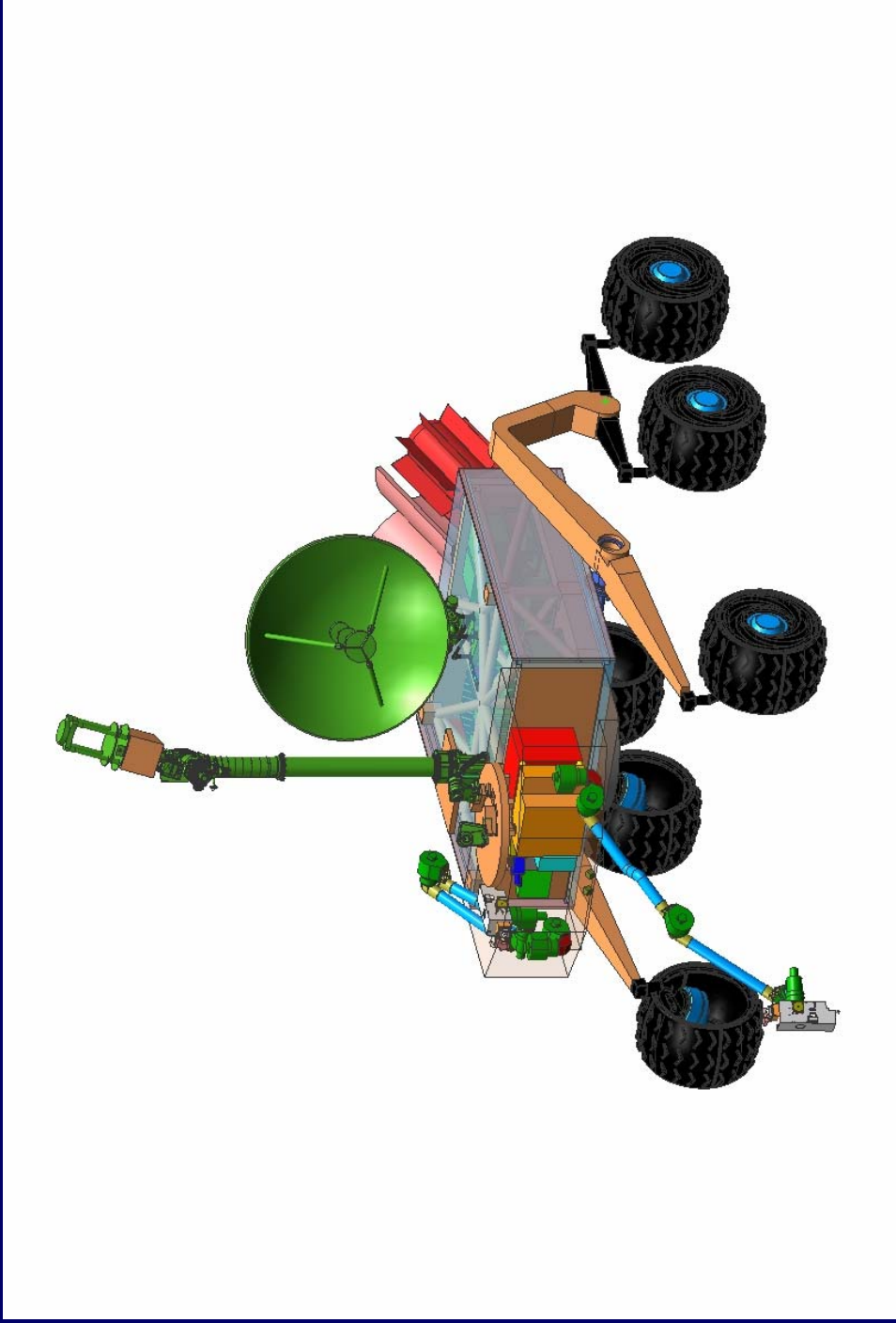


- *Electra Payload:*
 - *Software reconfigurable radio system for near- and far-term Mars missions*
 - *Electra will be used on all Mars missions including appropriate scout missions.*
 - *EM delivered*
- *Optical Navigation Camera:*
 - *Lightweight, low power, high resolution navigation camera for all future Mars missions*
 - *Instrument development and flight test validation is funded by MTP*
 - *Protoflight unit delivery 9/04*

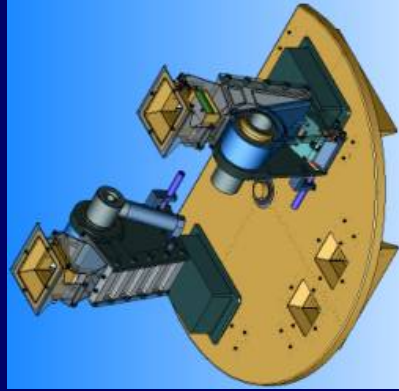
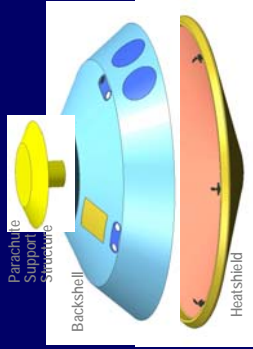
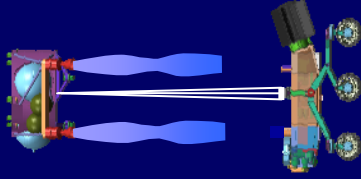




Mars Science Laboratory (MSL, 2009)



MSL Focused Technology



Entry, Descent, and Landing:

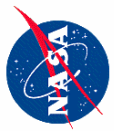
- *Guided entry*
- *Engine development*
- *Soft landing (Skycrane)*

Surface System Technology:

- *Increased autonomy*
- *Longer lived actuators*
- *Realistic rover simulation*

Sample Acquisition & Distribution:

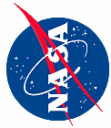
- *Coring/Abrading*
- *Sample acquisition/transfer*
- *Rock crushing*
- *Sample distribution*
- *Planetary protection*



MSL Entry, Descent, and Landing Technologies

- *Aeroshell*
- *Descent Engine*
- *EDL Guidance, Navigation, and Control*
- *EDL Modeling and Simulation*
- *High Flow Regulator for Descent Engine*
- *Subsonic Parachute**
- *Phased Array Terrain Radar**
- *POST-based End-to-End EDL Engineering Simulation for MSL*
- *Safe Landing and Descent Stage*

** No longer in the mission baseline*



Mars Testbed -1 (2011)

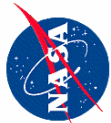


- *Testbeds will be used to develop and test those technologies that will enable human missions to Mars*
- *NASA is currently developing requirements for these missions*
- *Some of the candidate technologies are:*
 - *Aerocapture*
 - *pin-point landing*
 - *ISRU*
 - *Instruments to characterize Martian environment for safety for human missions*
 - *Subsurface access*
 - *Water extraction*
 - *Engineering instrumentation to characterize the atmosphere*
 - *Mach 3 parachute*
 - *Mid L/D probes*



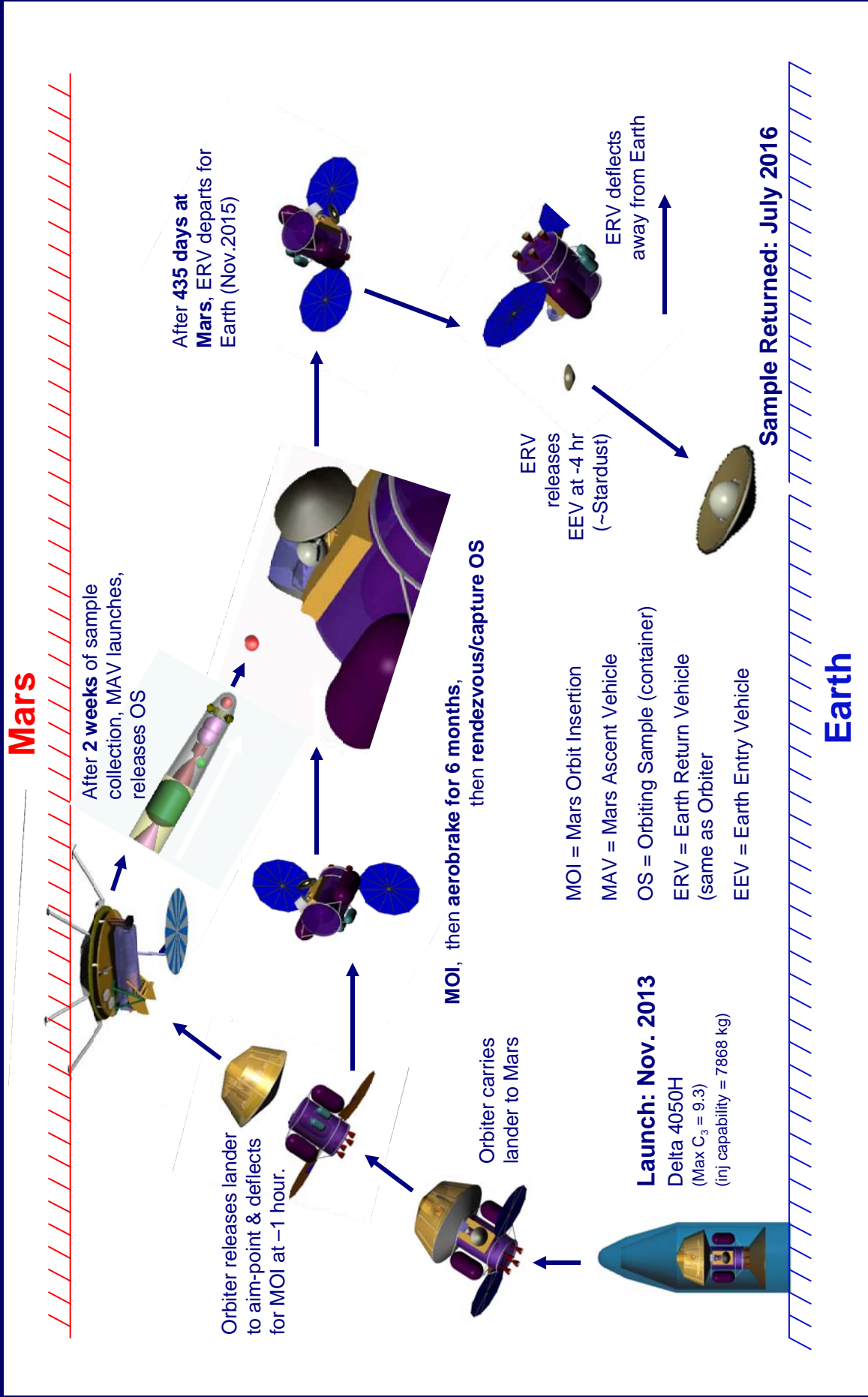
Mars Sample Return (MSR, 2013, or 2016)

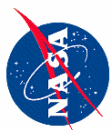




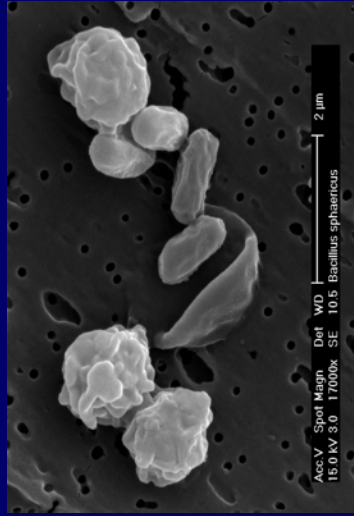
Mars Sample Return Mission JPL

Scenario

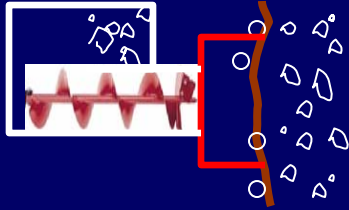
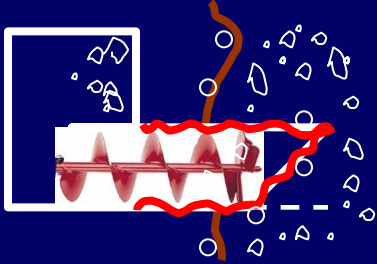
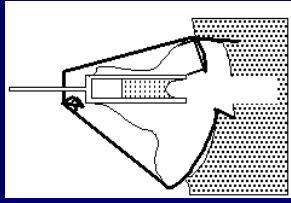




MSR Focused Technology



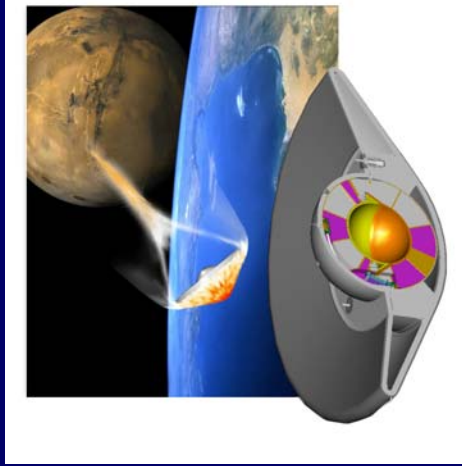
*Forward and Back
Planetary
Protection*



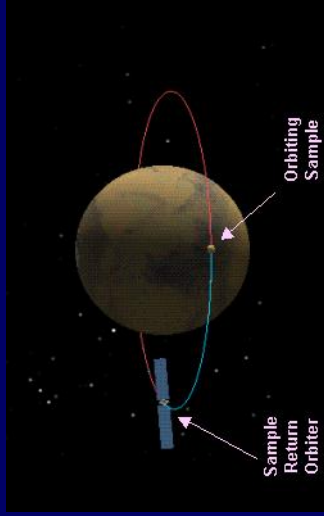
Covered sampling tool



Mars Ascent Vehicle



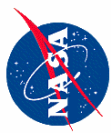
Earth Entry Vehicle



Rendezvous and Capture



*Mars Returned
Sample Handling* 14



Astrobiology Field Laboratory (AFL, 2013 or 2018)

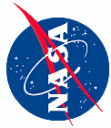
Technology:

- *More autonomy in rover technology*
- *More autonomy and functionality for sample preparation and distribution*



Exploration Metrics

- *800-1000 day landed mission*
- *25 km linear traverse capability @ 0.25 km/sol (4 hours)*
- *Repeatable 4 (rock corer) and 25 (drill) day cycles*
- *2.5 m drilling depth (3-5 holes) @ 0.3 m/sol*
- *100 samples for the organic analysis/biosignature detection suite (pyrolysis and liquid phase organic extraction systems)*



Base Technology

- These are “push” technologies to enable increased capability in future missions
- 100% competed
- Seven areas have been identified as high priority technology areas for Mars missions
- Currently, 87 tasks are within the Base Program

Proximity Telecom/Navigation

Rover Technology

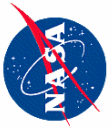
Subsurface Access

Planetary Protection

Advance EDL

Low Cost Mission Technologies

Mars Science Instruments

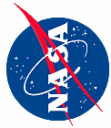


Technology Infusion

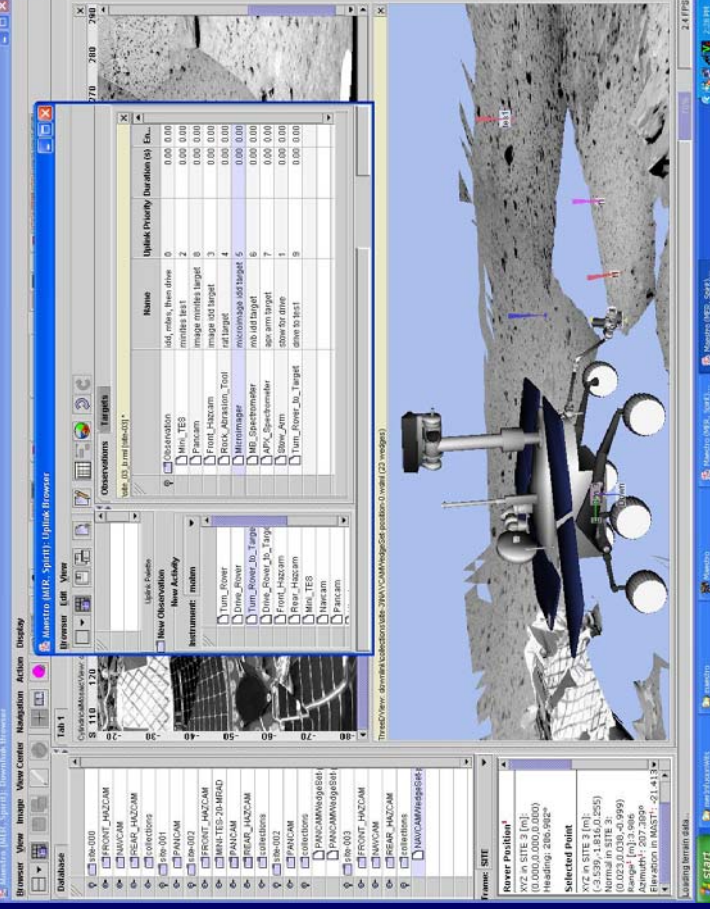
- *MTP's effectiveness is measured by its success in technology infusion into Mars missions*
- *Factors enabling technology infusion are:*
 - *Careful selection of technologies based on future mission needs*
 - *Technology funding contingent upon well defined and measured performance matrices*
 - *Technology integration/validation to demonstrate capabilities*
- *Ten technologies were successfully infused into Mars Exploration Rover (MER) mission*
- *MRO mission will fly two new technologies:*
 - *Electra UHF proximity radio*
 - *Optical Navigation Camera (ONC)*

Technologies Infused to MER

| | | Description | | | |
|----|--|---|---|--|--|
| | Technology | Funding Source | Description | PI/Technologist | |
| 1 | Stereo Vision | NASA, caltech DRD, Army, DARPA | Provides 3-D terrain maps for rovers, manipulators, and human operators | Larry Matthies Mark Maimone | |
| 2 | Long Range Science Rover | NASA (Code R and MTP) | Provides increased traverse range of rover operations, improved traverse accuracy, landerless and distributed ground operations with a large reduction in mass | Samad Hayati Richard Volpe | |
| 3 | Science Activity Planner | NASA (Code R and MTP) | Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists | Paul Backes Jeff Norris | |
| 4 | Viz - 3D Terrain Visualization | NASA (Code R) | Enables the Science team to operate a rover simulation with an interactive time of day shadow simulation, provides multiple views onto the visualization, demonstrates a proof of concept rover command specification | Larry Edwards | |
| 5 | FIDO: Field Integrated Design and Operations Rover | NASA (MTP) | Developed TRL 4-6 rover system designs, advancing NASA capabilities for Mars exploration; demonstrated this in full-scale terrestrial field trials, Integrated/operated miniaturized science payloads of mission interest, coupling terrestrial field trials to flight requirements | Paul Schenker Eric Baumgartner | |
| 6 | Manipulator Collision Prevention Software | NASA (MTP) | Computationally efficient algorithm for predicting and preventing collisions between manipulator and rover/terrain. | Eric Baumgartner Chris Leger | |
| 7 | Descent Image Motion Estimation System (DIMES) | NASA (Code R and MTP) | Software and hardware system for measuring horizontal velocity during descent, Algorithm combines image feature correlation with gyroscope attitude and radar altitude measurements. | Andrew Johnson Yang Cheng et al. | |
| 8 | Parallel Telemetry Processor (PTeP) | NASA (Code R and MTP) | Data cataloging system from PTeP is used in the MER mission to catalog database files for the Science Activity Planner science operations tool | Mark Powell Paul Backes | |
| 9 | Visual Odometry | NASA (MTP) | Onboard rover motion estimation by feature tracking with stereo imagery, enables rover motion estimation with error < 2% of distance traveled | Larry Matthies Yang Cheng | |
| 10 | Rover Localization and Mapping | NASA (MTP) | An image network is formed by finding correspondences within and between stereo image pairs, then bundle adjustment (a geometrical optimization technique) is used to determine camera and landmark positions, resulting in localization accuracy good for travel up 1 km | Ron Li Clark Olson et. al. | |
| 11 | Grid-based Estimation of Surface Traversability Applied to Local Terrain (GESTALT) | NASA (Code R and MTP) | Performs traversability analysis on 3-D range data to predict vehicle safety at all nearby locations; robust to partial sensor data and imprecise position estimation. Configurable for avoiding obstacle during long traverse or for driving toward rocks for science analysis | Mark Maimone | |
| 12 | Collaborative Information Portal (CIP) | NASA (Code R) | An enhanced situational awareness tool to provide mission management, scientists and engineers with insight into the status of mission operations. | Joan Walton John Schreiner | |
| 13 | MAPGEN and Constraint Editor | NASA (Code R) | Provides mixed initiative decision support system for complex activity planning with constraints, activity plan development and what-if analysis, automated activity and resource conflict resolution to improve resource management for the rover, enabling increased science activities | Kanna Rajan John Bresina | |
| 14 | MERboard | NASA (Code R) | Replaced flip chart based manual Sol Tree process with computer tool, capability for re-planning, calculation of mission success criteria for different planning options | Jay Trimble | |
| 15 | Science Process Design and Evaluation | NASA (Code R) | Created a system to capture and handover science intent information across multiple shifts - previous process required continuous team member presence of same people in long monolithic uplink shift - not sustainable from a human factors standpoint | Roxana Wales Jay Trimble | |
| 16 | Fatigue Countermeasures | NASA (Code R) | Procedures, scheduling techniques and countermeasures for Operating on "Mars-time" | Melissa Mallis | |
| 17 | Static Analysis of MER Flight Software | NASA (Code R) | Static analysis, based on abstract interpretation, offers compile-time techniques used to exhaustively check for runtime errors (e.g., out-of-bound array accesses) in large software systems (~500 KLOC). | Guillaume Brat | |
| 18 | Lithium-Ion Batteries | NASA (Code R and MTP), Air Force (AFRL) | Significant mass and volume savings (3-4 X) compared to the SOA Ni-Cd and Ni-H2 batteries. | Richard Ewell | |



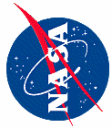
Technology Infusion into MER Science Activity Planner (SAP)



- SAP is the primary science operation tool for MER and is used on daily basis
- Developed as a ground operations software, started in 1995
- Provides downlink data visualization, science activity planning, merging of science plans from multiple scientists
- Public outreach version, called *Maestro*, along with *actual Spirit and Opportunity* data sets, is available for download from MER mission main web page; hundreds of thousands of public downloads in first month of the mission

• **Winner of NASA's best software award for FY '04**

- **FUTURE USERS and APPLICATIONS**
- '07 Phoenix – downlink data visualization and robotic arm command generation
- '09 Mars Science Laboratory – downlink data visualization and science goal specification



Technology Feed Forward to Mars Missions Entry, Descent, and Landing Example

*MRO
('05)*

Optical Navigation Camera is used to perform Optical Navigation - Demonstrates improved entry accuracy

*MSL
('09)*

Guided Entry technology improves landing accuracy by an order of magnitude. Skycrane technology enables robust landing of larger payloads than MER rover

*Testbed
Mission
('11)*


Terrain based navigation and optimized descent in conjunction with optical navigation and guided entry demonstrates 100 meter pin-point landing capability

*MSR
('13)*

Above technologies provide ability to return samples from very specific regions of Mars or samples cached by MSL




New MTP Website (<http://marstech.jpl.nasa.gov>)



Jet Propulsion Laboratory
California Institute of Technology

+ View the NASA Portal

JPL HOME
EARTH
SOLAR SYSTEM
STARS & GALAXIES
TECHNOLOGY



Mars Technology Program

SEARCH MTP

[HOME](#)

[MARS TECHNOLOGY PROGRAM](#)

[PARTICIPANTS](#)

[NEWS](#)

[MARS PROGRAM STRUCTURE](#)

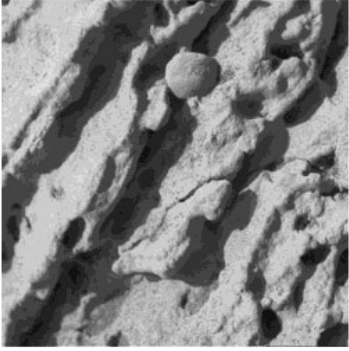
[CONTACTS](#)

OVERVIEW

NASA is pursuing an aggressive, science-driven agenda of robotic exploration of Mars with a series of orbiters and landers. These missions carry science instruments selected to answer questions the planetary science community has posed to better characterize the planet (See Mars Exploration Program Analysis Group, MEPAG). The overarching objective is increased understanding with regard to Life, Climate, Geology, and Preparation for Human Exploration.

Many new technologies need to be developed and infused into future Mars missions, which demand the following capabilities:

- Better landing accuracy, with active hazard-detection-and-avoidance capability.
- Access to high-priority sites with terrain too complex for landing current rovers.
- Increased mobility to sample diverse geological sites and reach targets of interest.
- Longer-lived surface systems to allow for year-long surface exploration.
- Technologies to access the subsurface and acquire samples for in situ analysis.
- New and improved science instruments.
- In situ sample acquisition, preparation, and distribution systems.
- Increased autonomy to enable increased science return.
- Planetary protection techniques.
- Sample-return technologies for bringing samples to Earth for analysis.



Mars Exploration Rover Mission
(Mars Rock Formation Poses Mystery)

The Mars Technology Program (MTP) is responsible for technology-development