

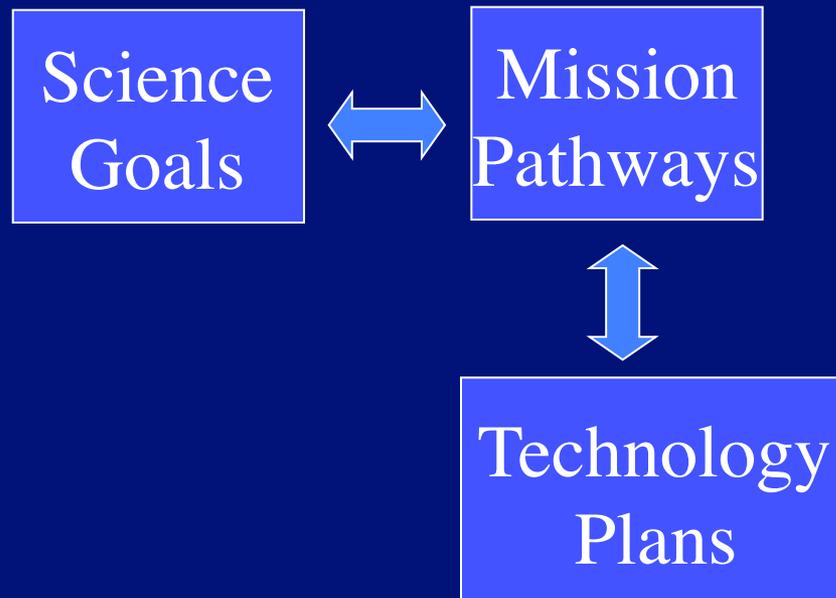


Presentation Content

- *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	<i>MSL to Low Lat.</i>	<i>Scout</i>	Ground-Breaking MSR	<i>Scout</i>	<i>Astrobiology Field Lab or Deep Drill</i>	<i>Scout</i>	<i>All core missions to mid-latitudes. Mission in '18 driven by MSL results and budget.</i>
Explore Hydrothermal Habitats	<i>MSL to Hydrothermal Deposit</i>	<i>Scout</i>	Astrobiology Field Laboratory	<i>Scout</i>	<i>Deep Drill</i>	<i>Scout</i>	<i>All core missions sent to active or extinct hydrothermal deposits.</i>
Search for Present Life	<i>MSL to N. Pole or Active Vent</i>	<i>Scout</i>	<i>Scout</i>	<i>MSR with Rover</i>	<i>Scout</i>	<i>Deep Drill</i>	<i>Missions to modern habitat. Path has highest risk.</i>
Explore Evolution of Mars	<i>MSL to Low Lat.</i>	<i>Scout</i>	<i>Ground-Breaking MSR</i>	<i>Aeronomy</i>	Network	<i>Scout</i>	<i>Path rests on proof that Mars was never wet.</i>

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Identify Key Targets

Robotic Trailblazers

Human Missions to the Moon

Go Beyond

Exploration Testbeds, Resources, and Solar System History

Past and Present Water and Life; Testbeds and Resources

Underground Oceans, Biological Chemistry, and Life

Earth-Like Planets and Life

Moon

Mars

Outer Moons

Extrasolar Planets

Building Blocks

Deep Impact Comet Mission
Stardust Comet Return
New Horizons Pluto Flyby
MESSENGER Mercury Orbiter
Dawn Asteroid Orbiter
Lunar Orbiter
Robotic Landing



Human Landings*

Mars Testbed
Mars Testbed
Mars Testbed
Mars Testbed



Mars Human Landings*

Mars Robotic Missions

Mars Rovers
Recon Orbiter
Phoenix Lander
Mobile Lab

Mars Scout
Sample Return
Mars Scout
Field Lab
Mars Scout

Cassini Saturn Arrival
Cassini Titan Landing



Jupiter Icy Moons Orbiter

Jupiter

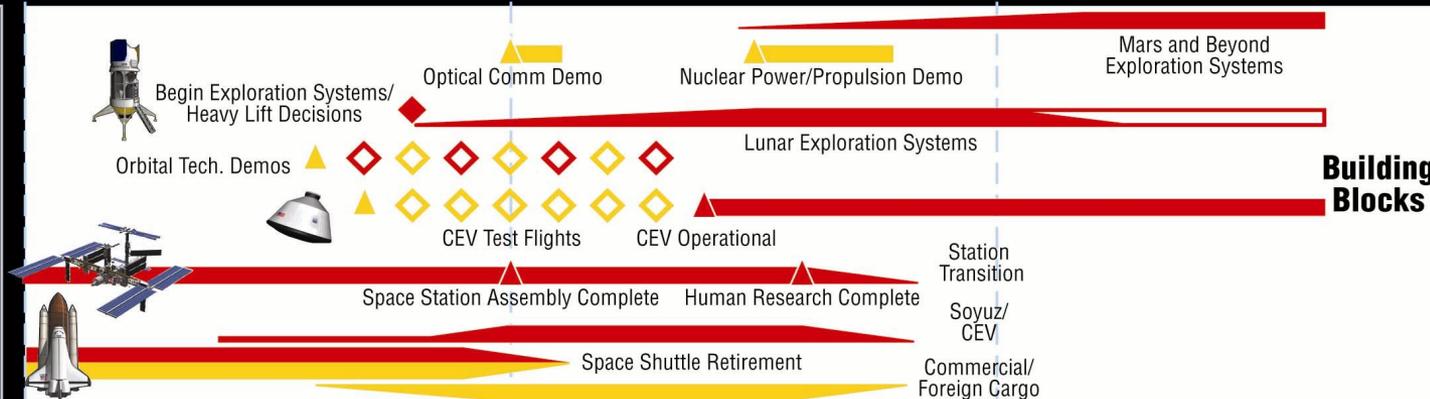


Hubble Space Telescope
Kepler Mission
Webb Space Telescope
Spitzer Space Telescope
Interferometry Mission
Terrestrial Planet Finder

Life Finder
Planet Imager
Deep Space Telescope Deployment/Upgrades

Key

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

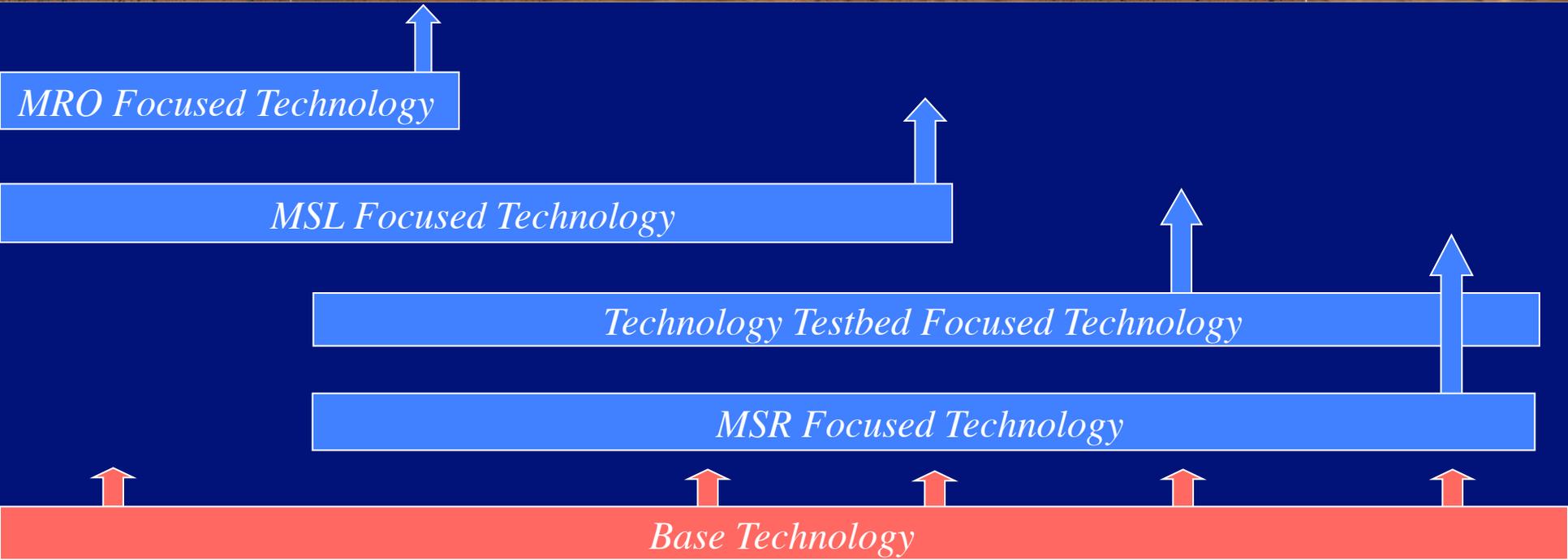
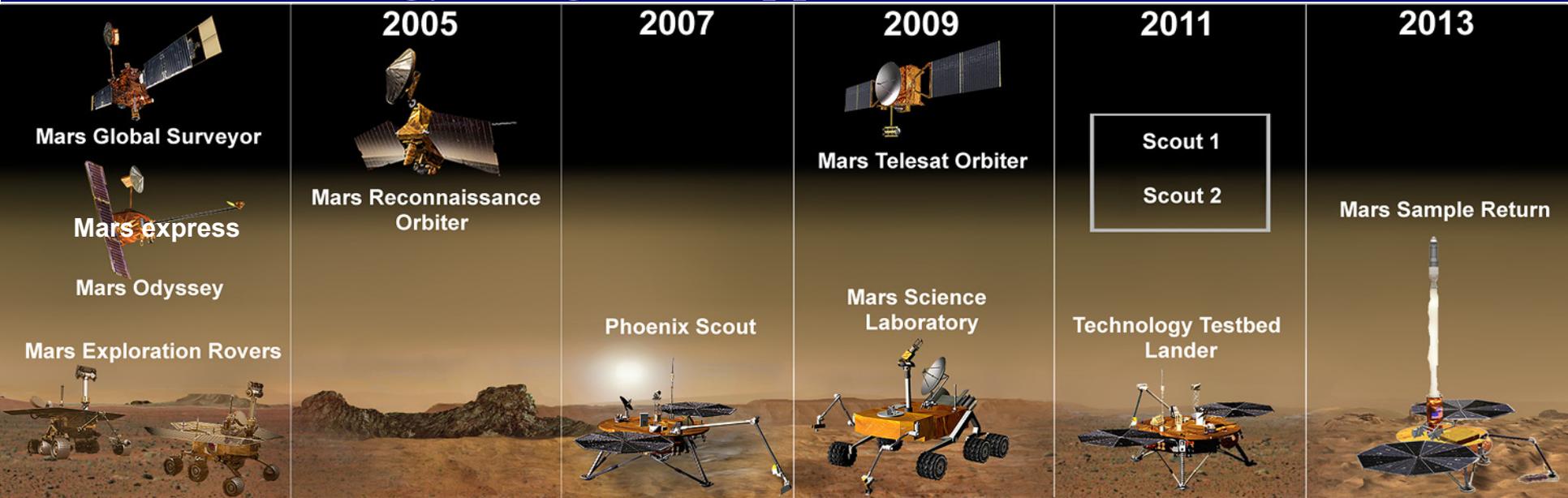


2000

2010

2020

Mars Technology Program Supports all NASA Mars Missions





Mars Technology Program Elements

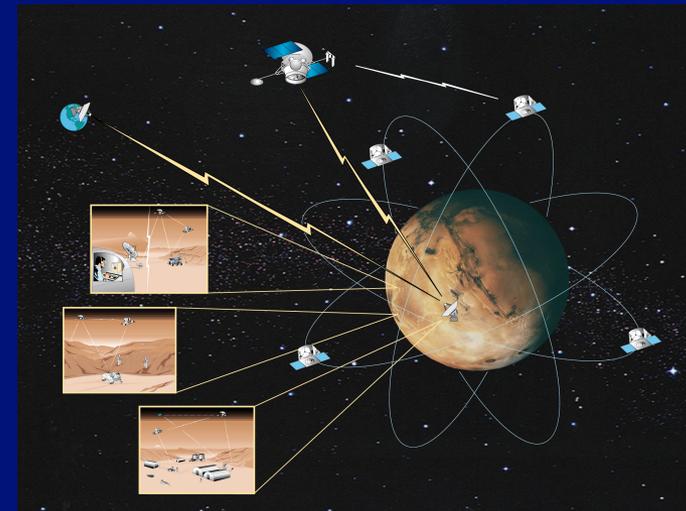
- ***Focused Technology***

- *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***

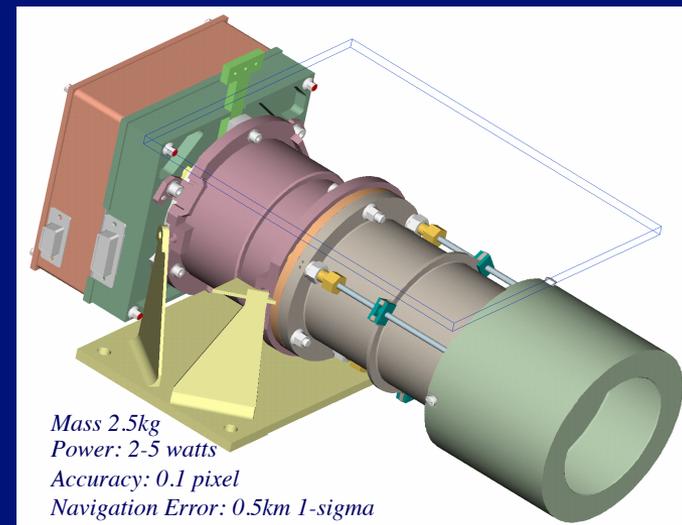
- *Is exploratory in nature*
- *Provides seed corn for future mission technologies*
- *Includes push technology development*
- *Enables new types of missions*
- *100% competed via NASA NRA process*

- *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*



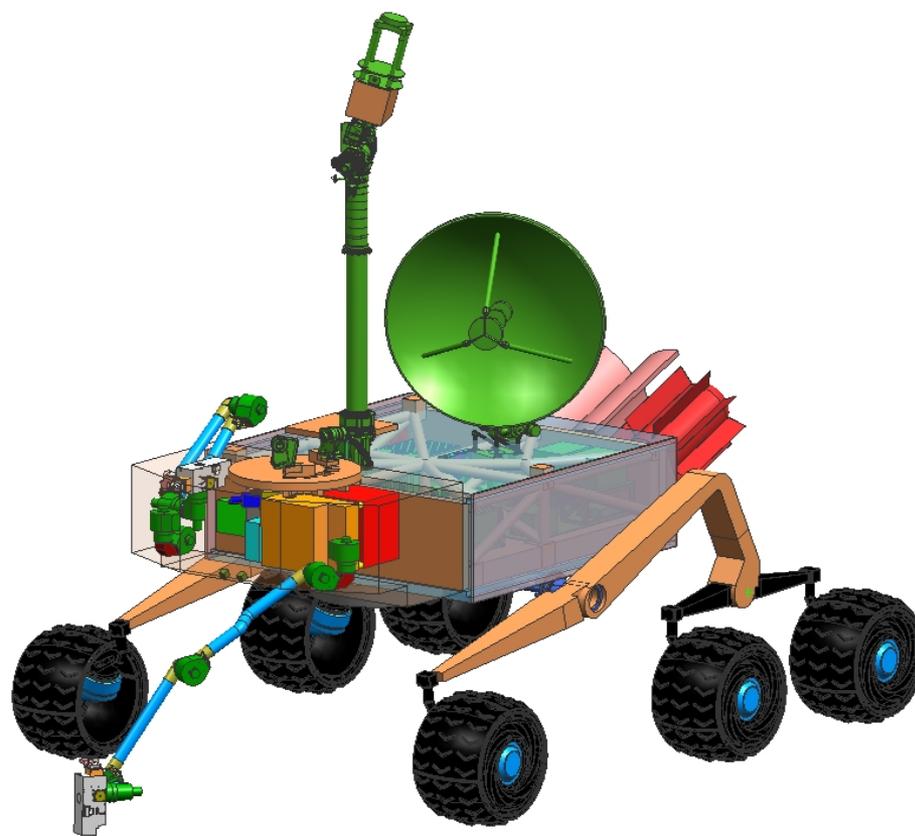
- *Optical Navigation Camera:*
 - *Lightweight, low power, high resolution navigation camera for all future Mars missions*
 - *Instrument development and flight test validation is funded by MTP*
 - *Protoflight unit delivery 9/04*

Electra Data Rate: 1-2 Mbps

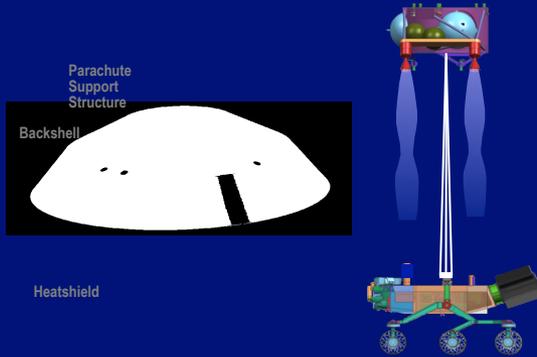




Mars Science Laboratory (MSL, 2009)



MSL Focused Technology



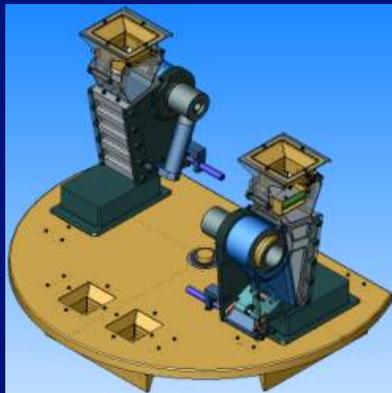
Entry, Descent, and Landing:

- *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)



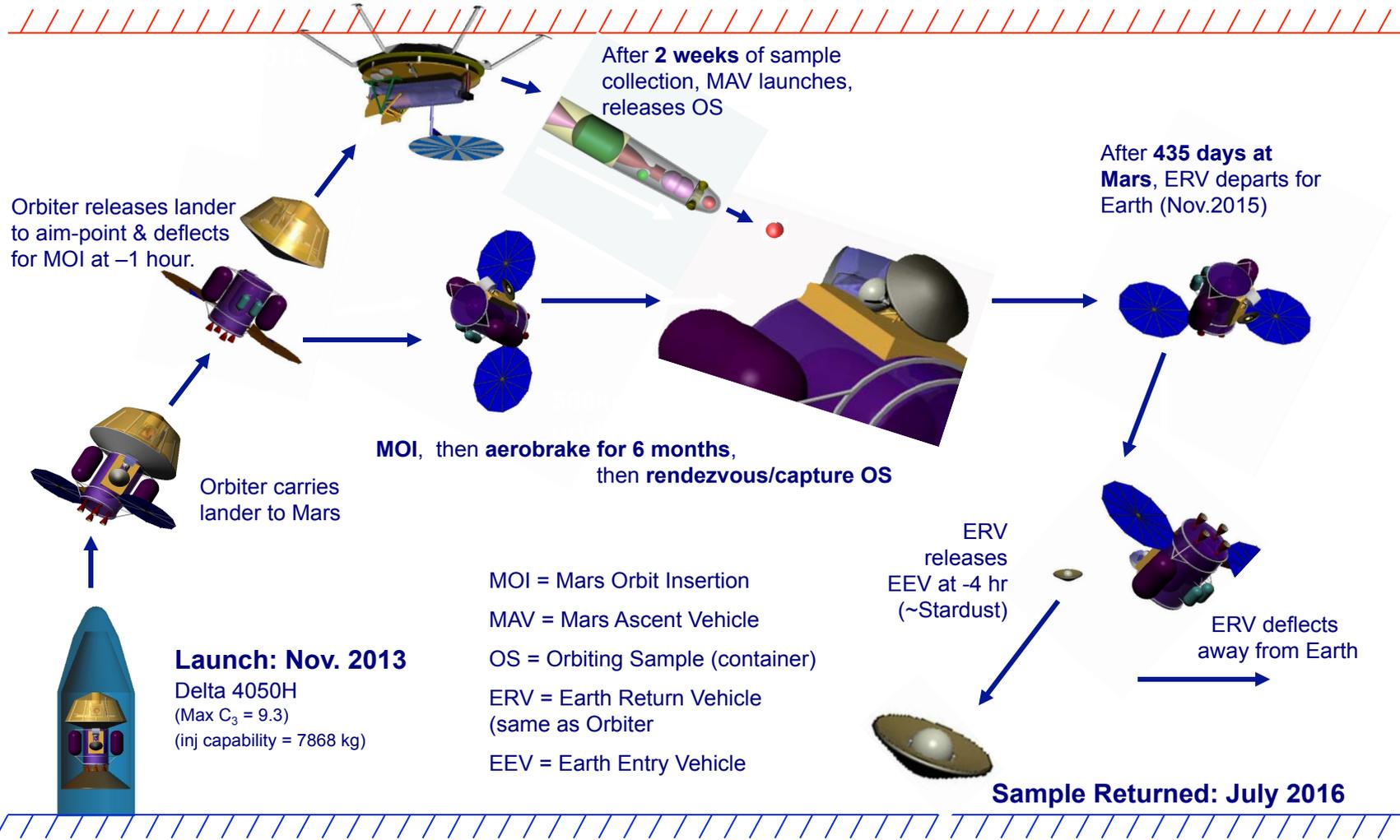


Mars Sample Return Mission



Scenario

Mars

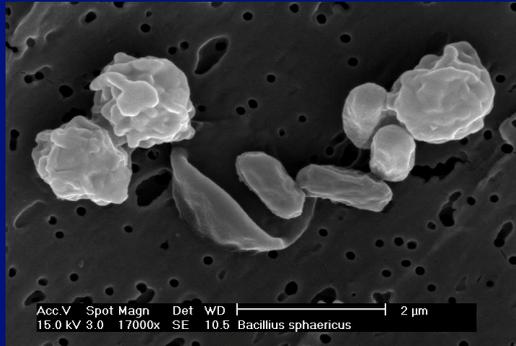


Launch: Nov. 2013
 Delta 4050H
 (Max C_3 = 9.3)
 (inj capability = 7868 kg)

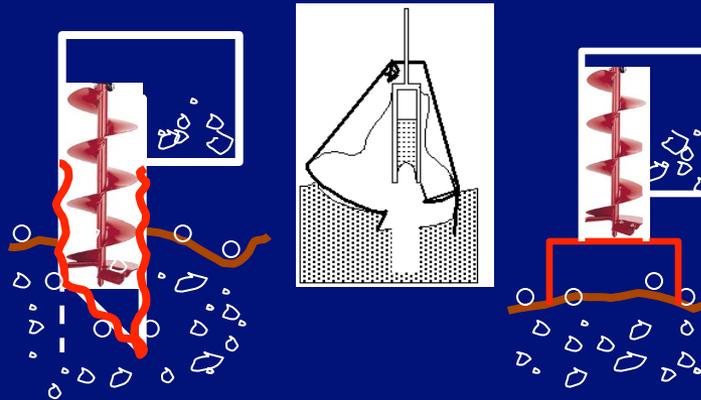
- MOI = Mars Orbit Insertion
- MAV = Mars Ascent Vehicle
- OS = Orbiting Sample (container)
- ERV = Earth Return Vehicle (same as Orbiter)
- EEV = Earth Entry Vehicle

Earth

MSR Focused Technology



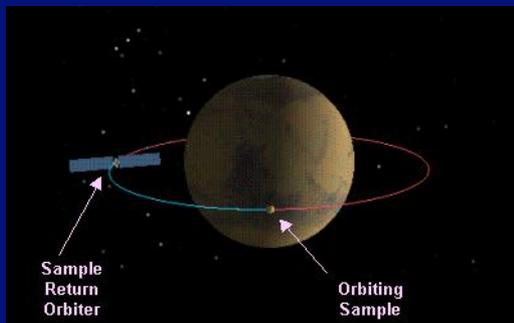
*Forward and Back
Planetary
Protection*



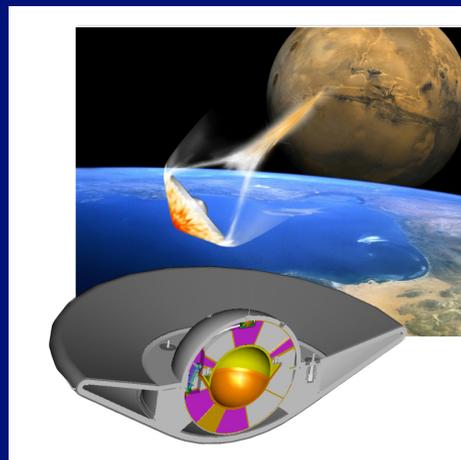
Covered sampling tool



Mars Ascent Vehicle



Rendezvous and Capture



Earth Entry Vehicle



*Mars Returned
Sample Handling*

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

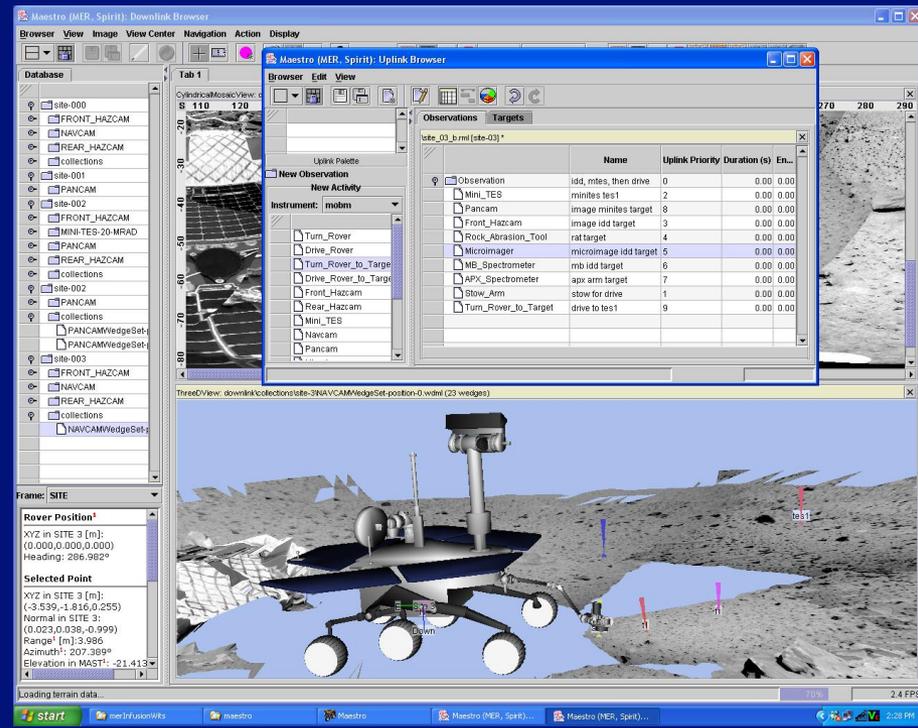
- *MTP's effectiveness is measured by its success in technology infusion into Mars missions*
- *Factors enabling technology infusion are:*
 - *Careful selection of technologies based on future mission needs*
 - *Technology funding contingent upon well defined and measured performance matrices*
 - *Technology 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

	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*
- *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*

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



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

SEARCH JPL

JPL HOME
EARTH
SOLAR SYSTEM
STARS & GALAXIES
TECHNOLOGY



Mars Technology Program

SEARCH MTP

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.

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MARS TECHNOLOGY PROGRAM

PARTICIPANTS

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MARS PROGRAM STRUCTURE

CONTACTS



[Mars Exploration Rover Mission](#)
[\(Mars Rock Formation Poses Mystery\)](#)

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