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# ***Science Perspectives for Candidate Mars Mission Architectures for 2016-2026***

***Mars Architecture Tiger Team (MATT-3)***  
**Philip Christensen, Chair**

**Report to MEP**

***March 12, 2009***





## ***MATT-3 Study: Participants***

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## MATT-3 Study: Key Directives

- Focus on a program that achieves fundamental science and addresses the highest priority goals for Mars Exploration

*Note: Blue text => MATT-3 Directives or Changes from MATT-2*

- **Assess potential program architectures for a NASA-only program\***, with an emphasis on the 2016, 2018, and 2020 opportunities, in light of:

- The MSL launch slip to 2011 and the associated reduction in funding available for a 2016 mission
  - Assume (*for discussion only; budgets have not been decided*) ~\$700M for 2016 mission (through launch); ~\$1.3B for 2018
- Recent discoveries (including the published report on methane)

**\*NOTE:** *The directive to consider a NASA only program is not intended to preclude international partnering. In fact, there are ongoing discussions between NASA and ESA on potential collaborations for Mars. MATT-3 may be asked to consider the gain from such collaborations as the opportunities are defined.*



## ***MATT-3 Study: Context***

### **MATT-3 study builds on earlier work:**

#### **•NRC:**

- NRC Reports and Decadal Survey
  - Major Milestone: NRC Special Committee (drawn largely from the NRC Committee on Evolution and Life) and Report: *An Astrobiology Strategy for Exploration of Mars*

#### **•MEPAG:**

- MEPAG Goals, Objectives, Investigations documentation
- Mars Next Decade (ND) and Mars Strategic Science (MSS) SAGs
- MATT-1 and MATT-2 Discussions
- Consulted the JPL Mars Office Advanced Studies Team regarding mission costs and feasibility



## ***MATT-3 Questions***

- 1) Are there any changes to the goals and guiding principles described by MATT-2?**
- 2) Are there any changes to the rationale for a Mars Program?**
- 3) Are the individual mission building blocks identified by MATT still appropriate?**
- 4) What is the long-term (20-year) focus of the Mars Program - i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?**
- 5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**
  - Does the discovery of methane apparently varying in space and time cause MEP to emphasize a more astrobiological pathway?**
- 6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?**



## ***MATT-3 Activities to Date***

- **MATT-3 proceeded as follows:**

- **Met three times via telecon over the past month. Additional discussions are planned following the MEPAG meeting to incorporate MEPAG discussion into the final report.**

***A mid-term briefing was made to MEPAG on March 3, 2009.***

- **Revisited the science goals for potential missions in 2016 and beyond. These goals:**
  - Are consistent with the “**Explore** Habitable Environments” theme
  - Are responsive to the NRC/Decadal Survey Priorities
  - Address MEPAG Goals, Objectives and Investigations
- **Reexamined the major program goals, guiding principles, and mission “building blocks” that address the mission science goals for the decade**
  - Building blocks include: MSR, MPR, MSO/MSO-lite, NET, Scout
    - Mission “blocks” identified at a high level--see following slides
- **Revaluated potential architectures against the MSL launch slip, the expected MEP budget, and new discoveries**



## Goals for the Next Decade

- **The MEP has "followed the water" and discovered a diverse suite of water-related features and environments.**
  - There are unanswered questions about each of these environments that MER showed can be addressed with *in situ* measurements
  - There are also unanswered questions about present habitability, especially whether trace gases are a signature of present habitable environments
  - There remain major questions about the state of the interior and the history of tectonic, volcanic, aqueous processes that are highly relevant to habitable environments
- **The focus on future missions should be “**explore** habitable environments” of the past and present, including the “how, when and why” of environmental change. Key measurements are:**
  - Rock and mineral textures, grain- to outcrop-scale mineralogy, and elemental abundances & gradients in different classes of aqueous deposits
  - Abundances and spatial/temporal variations of trace gases and isotopes in the present atmosphere
  - Nature and history of the interior and of processes shaping the surface
- **The most comprehensive measurements of water-formed deposits would be made on returned samples**



## ***Re-affirmed Program Rationale***

- **Mars has a unique combination of characteristics that translate into high science priority for Mars exploration**
  - Diverse surface deposits whose mineralogy and morphology provide evidence for environments habitable by life, and evidence for methane that could indicate persistence of wet environments
  - Accessibility to robotic and human missions, with feedback into follow-on investigations on a decadal time-scale
- **Questions pertaining to past & present habitable environments and their geologic context should drive future exploration:**
  - When and where did liquid water persist with a sufficiently high activity to support life? Did life or pre-biotic chemistry develop?
  - What drove a fundamental change, from the Noachian to Hesperian periods, in the surface environment recorded in aqueous deposits?
  - How did Mars' internal evolution influence the surface environment?
- **Both landed and orbital investigations are required to address these questions. Their sequential nature & the need for orbital assets to support landed science dictate a coherent program.**



## ***MATT Study: Expected Outcomes***

**The MEP mission architectures developed by MATT for 2013-2026 strive to achieve the following objectives:**

- Investigate the physics, chemistry, and dynamics of the upper atmosphere, the effects of solar wind and radiation, and the escape of volatiles to space => MAVEN
- Determine the composition and structure of the current atmosphere => MSO/**MSO-lite**
- Explore a diversity of surface environments using rovers with sample acquisition, analysis, and caching capabilities => MPR
- Investigate the deep interior using a network of landed geophysical experiments => NET
- Return carefully selected and well-documented samples from a potentially habitable environment to Earth for detailed analysis => MSR+precursors
- Respond to new discoveries through focused missions => Scout, as well as strategic missions



## ***MATT-3 Guiding Principles (1 of 3)***

### **MATT-3 developed these strategic principles to guide mission architecture development:**

- Conduct a Mars Sample Return Mission (MSR) at the earliest opportunity, while recognizing that the timing of MSR is budget driven.
  - Returned samples to meet minimum requirements set out in the ND-SAG report
- MEP should proceed with a balanced scientific program while taking specific steps toward a MSR mission
  - Immediately start and sustain a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling => ***MSL delay has eliminated early funding for technology***
  - Address non-MSR high priority science objectives, particularly as endorsed by NRC strategies and the Decadal Survey (sample return, aeronomy, network)
- Conduct major surface landings no more than 4 launch opportunities apart (3 is preferred) in order to:
  - Respond to discoveries from previous surface missions and new discoveries from orbit
  - Use developed technologies and experienced personnel to reduce risk and cost to future missions, especially MSR
  - ***Implies launch of rover mission in 2018 or 2020***



## *MATT Guiding Principles (2 of 3)*

- **Controlling costs and cost risk is vital and can be achieved in the near-term while still making progress on science objectives by:**
  - **Utilizing the technology investment of MEP (landing systems, orbiters, aeroshells, and rovers) as much as possible for future landed missions**
  - **Not taking on too many technological objectives in any one Mars mission, even while making real progress toward MSR**
- Require that landed missions leading to MSR:
  - Demonstrate **elements of** the sample acquisition and caching technologies or prepare an actual sample cache for MSR that meets the minimum requirements set out in the ND-SAG report
    - **Preparation of the actual cache could be triggered by earlier discovery at a landed site**
  - Provide scientific feed-forward to MSR by:
    - Investigating new sites to explore the diversity of Mars revealed from orbit and to provide an optimized choice for MSR (may require precision landing)
    - **Utilizing new instrumentation and/or new access capability (e.g., drilling) at the same site to follow up a discovery**



## ***MATT Guiding Principles (3 of 3)***

- Provide long-lived orbiters to observe the atmosphere and seasonal surface change, and to provide telecom and critical event support
  - Provides flexibility to MSR flight configurations and is especially synergistic with network science and telecom needs
- Scout missions are included in the architecture to provide:
  - Rapid, innovative response to new discoveries
  - Opportunity to sustain program balance and diversity
  - Low-cost Scout missions were inserted as opportunities permitted and budget profiles demanded



## **MEP Building Blocks for 2016-2026 (1 of 3)**

**MATT-1, -2, and -3 identified these potential mission building blocks to address the key scientific objectives for 2016-2026:**

- **Mars Sample Return Lander (MSR-L) and Orbiter (MSR-O):**
  - Two flight elements: Lander/Rover/Ascent Vehicle & Orbiter/Capture/Return Vehicle
  - High-priority in NRC reports and Decadal Survey; must address multiple science goals with samples meeting the minimum requirements set out in the ND-SAG report
- **Mars Science Orbiter (MSO and MSO-lite)**
  - Atmospheric composition, state, and surface climatology remote sensing plus telecom
    - Respond to reported **(and now published)** methane discovery
  - Science Definition Team formed and report given to MEP
  - **MSO-lite assessed by MSO-SDT (see later summary)**



## ***MEP Building Blocks for 2016-2026 (2 of 3)***

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Prospector Rover (MPR, also called Mid-Range Rover)**
  - At least MER-class rover deployed to new water-related geologic targets
  - Precision landing (<6-km diameter error ellipse) enables access to new sites
  - Conducts independent science but with scientific and technical feed-forward to MSR
  - As a precursor, this can demonstrate feed-forward capabilities for MSR and opens the possibility for payload trade-offs (e.g., caching and cache delivery) with MSR Lander
- **Network (NET):**
  - 4 or more landed stations arrayed in a geophysical network to characterize interior structure, composition, and process, as well as surface environments
  - Meteorological measurements are leveraged by concurrent remote sensing from orbit
  - High-priority in NRC reports and Decadal Survey



## *MEP Building Blocks for 2016-2026 (3 of 3)*

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Scout Missions (Scout)**
  - Competed missions to pursue innovative thrusts to major missions goals
  
- **MATT-3 discussed the possibility of developing a “vertical sampling” building block as an additional component of the Mars architecture**
  - **Could be responsive to potential MSL or ExoMars discoveries**



## ***MSO-Lite Study Report Summary - M. Smith Chair***

**MSO-min: Minimum mission could follow up on the methane discovery within the harsh constraints outlined for a 2016 U.S. Mars mission**

- ⇒ Will significantly improve knowledge of atmospheric composition and chemistry within the context of understanding Mars habitability
- ⇒ Extend record of climatology to characterize long-term trends for climate & transport model validation

**MSO-lite: Augmented mission can provide significant gain given increased resources or foreign partnering**

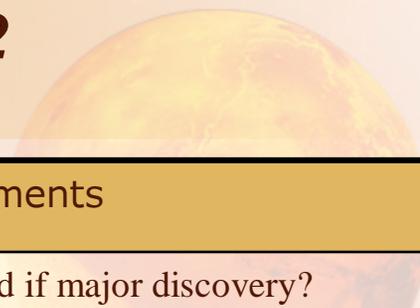
- ⇒ More detailed mapping to identify localized source regions
- ⇒ Validate and significantly improve knowledge of current climate and models of transport, including inverse modeling for gas sources
- ⇒ Still further augmentation required for surface change detection

**MSO: Full-up mission provides opportunity for all of the above, possibly longer life, global surface change detection and site certification**

***Note: Telecom support included in all concepts***



## Mission Scenarios - MATT-2



Option	2016	2018	2020 <sup>#2</sup>	2022 <sup>#2</sup>	2024	2026	Comments
2018a <sup>#1</sup>	MSR-O	MSR-L	MSO	NET	Scout	MPR	Funded if major discovery?
2018b <sup>#1</sup>	MSO	MSR-L	MSR-O	NET	Scout	MPR	Restarts climate record; trace gases
2018c <sup>#1</sup>	MPR	MSR-L	MSR-O	MSO	NET	Scout	Gap in climate record; telecom?
2020a	MPR	MSO	MSR-L	MSR-O	NET	Scout	MPR helps optimize MSR
2020b	MPR	Scout	MSR-L	MSR-O	MSO	NET	Gap in climate record, early Scout
2022a	MPR	MSO	NET	MSR-L	MSR-O	Scout	Early NET; MPR helps MSR
2022b	MSO	MPR	NET	MSR-L	MSR-O	Scout	Early NET, but 8 years between major landers (MSL to MPR)
2024a	MPR	MSO	NET	Scout	MSR-L	MSR-O	Early NET; 8 years between major landers; very late sample return

MSO = Mars Science Orbiter  
 MPR = Mars Prospector Rover (MER or MSL class Rover with precision landing and sampling/caching capability)  
 MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)  
 NET = Mars Network Landers (“Netlander”) mission

**FOOTNOTES:**  
 #1 Requires early peak funding well above the guidelines; 2018b most affordable of these options  
 #2 Celestial mechanics are most demanding in the 2020 and 2022 launch opportunities; arrival conditions (Mars atmospheric pressure, dust opacity) challenging after 2020

*Preferred Scenario for given MSR-L Launch Opportunity*





# Scientifically Compelling Scenarios - MATT-3

Option	2016	2018	2020	2022	2024	2026	Comments
	2014-2018 budget guideline precludes MSR before 2022						
M3.1 [2022b]	MSO-lite #1	MPR #2	NET	MSR-L	MSR-O	Scout	MPR occurs 2 periods before 2022 MSR, which will need additional funding for tech development
M3.2 [Swap in 2022b]	MSO-lite #1	MPR #2	NET	MSR-O	MSR-L	Scout	Gives chance for robust technology program preparing for MSR and time to respond to MPR tech demo
M3.3 [Trades in 2024a]	MSO-lite #1	NET	MPR	Scout	MSR-L	MSR-O	Lowest cost early, but 8 years between MSL & MPR; MPR just 2 periods before MSR; early NET

### FOOTNOTES:

#1 MSO-lite affordable for \$750M; preferable to MSO-min in order to map potential localized sources of key trace gases

#2 MPR may exceed the guideline ~\$1.3B (\$1.6B required?)

MSO = Mars Science Orbiter

MPR = Mars Prospector Rover (MER class [?] Rover with precision landing and sampling/caching capability)

MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)

NET = Mars Network mission (3-4 Landers)

*Preferred Scenario*





## ***Proposed Architecture Rationale***

- ***A Mars Sample Return mission remains an anchor point of the Mars Exploration Program; thus the preference for an early MSR launch [M3.1]***
- ***The proposed scenarios are scientifically compelling because each accomplishes the previous Decadal Survey high priority mission goals (aeronomy, network, sample return) while responding to recent discoveries by MEP***
  - ***MSO-lite in 2016 provides the broad atmospheric survey and mapping needed to follow-up the reported methane discoveries and to investigate the nature of its origin, while accommodating the tight budget requirements for 2016 [M3.1-M3.3]***
  - ***MPR in 2018 [M3.1-M3.2] or 2020 [M3.3] investigates the newly found diversity of potentially habitable sites while demonstrating feed-forward technologies for sample return***
  - ***NET in 2020 or 2018 [M3.3] will enhance our understanding of Mars as a system, while searching for possible sub-surface activity implied by the methane detection***
- ***These scenarios are consistent with the recommendations of MATT-1 and MATT-2, as altered by the MSL slip***



## Issues, Findings, and Future Work (1 of 2)

**A#1**

- ***The implications of potential MSL and ExoMars results need further study in order to define the full suite of possibilities for the landed mission in 2018.***
  - For example, an MSL discovery indicating the need for a significant change of payload (e.g., new instruments) or the need for vertical drilling may necessitate altering the architectures for 2018 and 2020.
  - This analysis should assess the options of:
    - The MPR rover concept (e.g. precision landing, different site with MER-class payload, sample caching):
    - A rover with significant *in situ* astrobiological science (ExoMars-like?)
    - Vertical sampling capability versus sample coring and caching

**A#2**

- ***Is a “vertical sampling” mission building block needed?***
- ***Starting and sustaining a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling, is essential to reducing risk and controlling cost for MSR and precursors***

**A#n => Actions MEPAG may want to pursue**



## Issues, Findings, and Future Work (2 of 2)

**A#3**

- *MATT finds that MSO-lite (preferred to MSO-min) is an affordable, highly valuable scientific mission for 2016. Does MEPAG agree?*
- *MEPAG may wish to consider the consequences of MSO-lite instead of MSO in the context of the long-range architecture choices. These consequences include:*
  - *Loss of follow-on of HiRISE-class imaging for site certification*
  - *Possible loss of meter-scale imaging for change detection*
  - *Reduced telecom capability or duration*
  - *Further reduction to MSO-min jeopardizes the ability to identify potential localized trace gas sources*
- *MEPAG should consider how best to prepare for the selection of future landing sites*

**A#4**

- *What are the implications if follow-on high-resolution imaging is not available from MSO-lite?*
- *Should a landing site selection process be established now to best utilize the existing missions for the future program?*



## Summary (1 of 2)

- ***Mars Sample Return remains an anchor point of the Mars Exploration Program and should be conducted at the earliest opportunity within the available budget constraints***
- ***MSO-lite would make a significant scientific contribution to our understanding of martian trace gases and atmospheric state, and could be achieved in a U.S.-only program for 2016***
- ***Given the conditions of an MSL launch slip to 2011 and reduced funding for the 2016 mission, the preferred architecture is:***
  - **Now:** Start technology program focused on developments that enable MPR and feed-forward to MSR
  - **2016:** Launch Mars Science Orbiter (**MSO-lite: trace gas survey, atmospheric state, telecom support**)
  - **2018:** Launch Mars Prospector Rover (MPR) to a new site
  - **2020:** Launch Network Mission (NET)
  - **2022-2024:** Launch MSR-L and MSR-O



## ***Summary (2 of 2)***

- ***Future landed missions should utilize the technology investment of MEP (landing systems, aeroshells, rovers, and orbiters) in order to contain cost and risk, while continuing to make significant progress toward Mars sample return***
- ***MATT was directed to consider a NASA-only program and its findings are not meant to preclude international partnering.***
  - ***Significant partnerships with non-NASA partners could considerably enhance the overall program***
  - ***Many missions considered here are well-suited to international participation and partnering***
    - ***Prime examples for major subsystems or flight elements are MSR and Network***
    - ***Opportunities for participation also exist for MSO and MPR***



# MATT-2 Option Is: Mars Exploration Program

Launch Year

2011

2013

2016

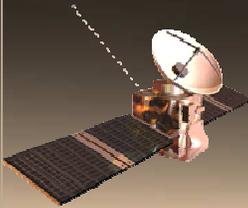
2018

2020

2022

2024

MAVEN



MSO

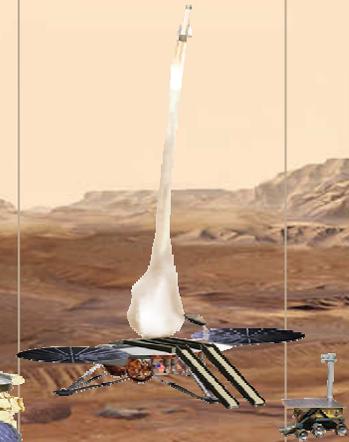
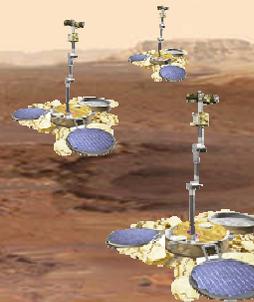
Mars Sample  
Return

Mars  
Prospector  
Rover

Mars  
Network



ExoMars  
(ESA)





# MATT-3 Option Is: Mars Exploration Program

Launch Year

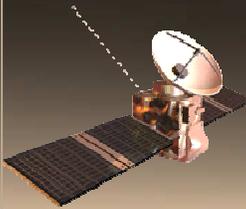
2011



Mars Science Laboratory

2013

MAVEN



2016

MSO-lite



ExoMars (ESA)

2018

Mars Prospector Rover



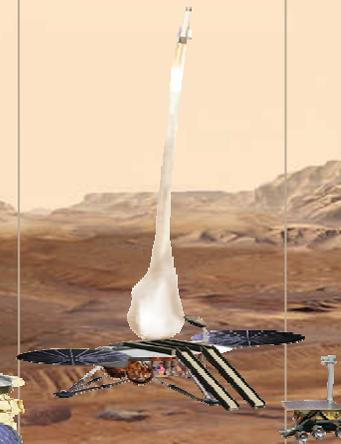
2020

Mars Network



2022

Mars Sample Return



2024





## **MATT-3 Questions & Answers (1 of 4)**

**1) Are there any changes to the goals and guiding principles described by MATT-2?**

- Science goals are unchanged; there are nuanced changes to the MATT-2 guiding principles

**2) Are there any changes to the rationale for a Mars Program?**

**No. The program has and will continue to be an effective approach to pursuing NASA's programmatic objectives for Mars and Solar System exploration by:**

- Responding rapidly to scientific discoveries while pursuing ambitious goals to understand Mars as a system, its change with time, and its life potential
- Enabling robust scientific data return from landed missions and providing critical event coverage
- Reducing programmatic mission risk overall and risk in specific critical mission events



## ***MATT-3 Questions & Answers (2 of 4)***

***3) Are the individual mission building blocks identified by MATT still appropriate?***

- **Yes, but MATT recommends that MEPAG consider vertical access and associated scientific investigations as a potential new building block**

***4) What is the long-term (20-year) focus of the Mars Program; i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?***

- **MATT-3 finds that MSR should still be the driving objective of MEP in the next decade, while continuing to pursue as resources permit a balanced program of Mars scientific investigation**



## **MATT-3 Questions & Answers (3 of 4)**

**5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**

**An MSO/MSO-lite mission in 2016 is affordable and the mission of choice to follow the methane detection; it also provides a critical link in telecommunications support.**

- MATT-3 did consider a Scout option in 2016 but found it to not be the preferred approach because:**
  - 1. An orbiter was considered necessary for telecom support, thereby limiting the range of Scout missions that could be proposed; furthermore, long-lived telecom would be difficult to support in a cost-constrained Scout mission**
  - 2. There is not time to competitively select a Scout mission before decisions about potential collaborations of NASA and ESA for 2016 must be made. Negotiations on mission elements and the infrastructure considerations mentioned above argue for a core orbiter mission**
- An Announcement of Opportunity for MSO/MSO-lite should indicate that PI-provided payload suites can be proposed as well as individual instruments**



## ***MATT-3 Questions & Answers (4 of 4)***

***6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?***

- The Mars rover mission (new site, precision landing, sample caching demonstration) previously advocated for 2016 is still a candidate for 2018/2020, within the program objectives & MATT guiding principles.***
- However, MEPAG should form a SAG to examine the goals and scope of a rover mission for 2018 or 2020, and the measurements and technology required to achieved them within the scope of a tight budget.***



## ***Back-Up***



## ***Option: Mid-Range Rover/Prospector***

- **Concept: MER-Class Rover Deployed to New Class of Sites**
- **Goals:**
  - Respond to recent discoveries showing a variety of aqueous mineral deposits and geomorphic structures reflecting water activity on Mars
  - Characterize site & prepare sample cache for possible retrieval by future MSR
- **Approach:**
  - MER-class payloads, with modest augmentation as capability allows
  - Takes advantage of latest EDL development and preserves it for MSR
    - Key is access to new sites not reachable with current MER/MSL landing error ellipses
  - Updates “Sky Crane” technology to enable precision landing (< 6 km diameter ellipse)
    - Capability needed to get to the most compelling sites
    - Capability also useful for MSR collection/rendezvous to return samples
  - Conducts (“Prospector Option”) sample selection, encapsulation and general handling needed for MSR, provides retrievable sample cache
- **Issues:**
  - Requires (modest?) improvement of EDL system
  - Prospector concept requires development of sample handling capabilities
  - Requires new EDL design for implementation (I.e., cannot use MER/MSL technologies)
  - Builds on recent discoveries, but delays broadening scope of Mars science exploration

## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/lite/min	MPR	NET	MSR	
<b>I. Life on Mars: Past or Present</b>	<b>A. Habitability</b>	1	Establish Current Distribution of all Water Forms						
		2	Geological History of Water						
		3	Characterize Materials with C, H, O, N, P & S		trace gases				
		4	Determine Potential Energy Sources for Biology						
	<b>B. Carbon Cycle</b>	1	Determine Distribution/Composition of Organic C		trace gases				
		2	Characterize Inorganic Carbon Reservoirs						
		3	Characterize links between C and H, O, N, P, & S						
		4	Characterize Reduced Near-Surface Compounds						
	<b>C. Biosignatures</b>	1	Characterize Complex Organics						
		2	Characterize Chemical and/or Isotopic Signatures						
		3	Characterize Mineralogic Signature Morphology						
		4	Identify Chemical Variations Requiring Life						
	<b>II. Climate: History &amp; Processes</b>	<b>A. Present</b>	1	Characterize Present Cycles of H <sub>2</sub> O, CO <sub>2</sub> , Dust				with MET	
			2	Characterize Key 4-D Photochemical Distributions		With mapping			
			3	Capture Volatile, Ice & Dust Atmos.-Sfc. Exchange				with MET	
			4	Search for Microclimates				with MET	
<b>B. Recent</b>		1	Determine Isotope, Noble gas, Trace Gas Amounts/Evolutions						
		2	Characterize Climate Change Recorded in PLD	non-polar	non-polar?	non-polar	non-polar	non-polar	
		3	Relate Geomorphic Features to Past Climates						
<b>C. Ancient</b>		1	Characterize Atmospheric Escape						
		2	Find Physical/Chemical Records of Past Climates						
		3	Determine Isotope, Noble gas, Trace Gas Evolutions						

Major Contribution

Significant Contribution

## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/ite/min	MPR	NET	MSR
III. Geology/Geophysics: Surface/Interior Evolution	A. Crustal Geologic Processes	1	Characterize Major Geologic Units and Processes		with imaging			
		2	Evaluate Surface Modification Processes over time					
		3	Constrain Absolute Ages of Major Processes					
		4	Identify/Characterize Hydrothermal Environments					
		5	Evaluate Igneous Processes & their Evolution					
		6	Characterize Surface-Atmosphere Interactions					
		7	Determine Tectonic History & Crustal Modification					
		8	Determine the 3-D State of Present Water					
		9	Determine Nature/Origin of Crustal Magnetization					
		10	Evaluate the effect of Large-Scale Impacts					
	B. Interior	1	Characterize Structure & Dynamics of the Interior		out-gassing			
		2	Determine Origin & History of the Magnetic Field					
		3	Determine Chemical & Thermal Evolution of the Planet					
C.	*	Determine the Origin, Composition and Internal Structure of Phobos and Deimos						
IV. Preparation	A	*	Obtain Knowledge of Mars to Design/Implement Human Mission with acceptable cost, risk and performance <i>*11 Investigations</i>					
	B	*	Conduct risk and/or cost reduction technology and infrastructure demonstrations as part of Mars missions <i>*6 Investigations</i>	EDL (Sky-Crane)		Precision Landing; Caching		Ascent; Capture; Return
	C	*	Characterize Mars Atmosphere for Safe Operation of Spacecraft <i>*4 Investigations</i>					

Major Contribution



Significant Contribution



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# ***Science Perspectives for Candidate Mars Mission Architectures for 2016-2026***

***Mars Architecture Tiger Team (MATT-3)***  
**Philip Christensen, Chair**

**Report to MEP**

***March 12, 2009***





## ***MATT-3 Study: Participants***

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## MATT-3 Study: Key Directives

- Focus on a program that achieves fundamental science and addresses the highest priority goals for Mars Exploration

*Note: Blue text => MATT-3 Directives or Changes from MATT-2*

- **Assess potential program architectures for a NASA-only program\***, with an emphasis on the 2016, 2018, and 2020 opportunities, in light of:

- The MSL launch slip to 2011 and the associated reduction in funding available for a 2016 mission
  - Assume *(for discussion only; budgets have not been decided)* ~\$700M for 2016 mission (through launch); ~\$1.3B for 2018
- Recent discoveries (including the published report on methane)

**\*NOTE:** *The directive to consider a NASA only program is not intended to preclude international partnering. In fact, there are ongoing discussions between NASA and ESA on potential collaborations for Mars. MATT-3 may be asked to consider the gain from such collaborations as the opportunities are defined.*



## *MATT-3 Study: Context*

### **MATT-3 study builds on earlier work:**

#### **•NRC:**

- NRC Reports and Decadal Survey
  - Major Milestone: NRC Special Committee (drawn largely from the NRC Committee on Evolution and Life) and Report: *An Astrobiology Strategy for Exploration of Mars*

#### **•MEPAG:**

- MEPAG Goals, Objectives, Investigations documentation
- Mars Next Decade (ND) and Mars Strategic Science (MSS) SAGs
- MATT-1 and MATT-2 Discussions
- Consulted the JPL Mars Office Advanced Studies Team regarding mission costs and feasibility



## ***MATT-3 Questions***

- 1) Are there any changes to the goals and guiding principles described by MATT-2?**
- 2) Are there any changes to the rationale for a Mars Program?**
- 3) Are the individual mission building blocks identified by MATT still appropriate?**
- 4) What is the long-term (20-year) focus of the Mars Program - i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?**
- 5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**
  - Does the discovery of methane apparently varying in space and time cause MEP to emphasize a more astrobiological pathway?**
- 6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?**



## *MATT-3 Activities to Date*

- **MATT-3 proceeded as follows:**

- **Met three times via telecon over the past month. Additional discussions are planned following the MEPAG meeting to incorporate MEPAG discussion into the final report.**

***A mid-term briefing was made to MEPAG on March 3, 2009.***

- **Revisited the science goals for potential missions in 2016 and beyond. These goals:**
  - Are consistent with the “**Explore** Habitable Environments” theme
  - Are responsive to the NRC/Decadal Survey Priorities
  - Address MEPAG Goals, Objectives and Investigations
- **Reexamined the major program goals, guiding principles, and mission “building blocks” that address the mission science goals for the decade**
  - Building blocks include: MSR, MPR, MSO/MSO-lite, NET, Scout
    - Mission “blocks” identified at a high level--see following slides
- **Revaluated potential architectures against the MSL launch slip, the expected MEP budget, and new discoveries**



## Goals for the Next Decade

- **The MEP has "followed the water" and discovered a diverse suite of water-related features and environments.**
  - There are unanswered questions about each of these environments that MER showed can be addressed with *in situ* measurements
  - There are also unanswered questions about present habitability, especially whether trace gases are a signature of present habitable environments
  - There remain major questions about the state of the interior and the history of tectonic, volcanic, aqueous processes that are highly relevant to habitable environments
- **The focus on future missions should be “**explore** habitable environments” of the past and present, including the “how, when and why” of environmental change. Key measurements are:**
  - Rock and mineral textures, grain- to outcrop-scale mineralogy, and elemental abundances & gradients in different classes of aqueous deposits
  - Abundances and spatial/temporal variations of trace gases and isotopes in the present atmosphere
  - Nature and history of the interior and of processes shaping the surface
- **The most comprehensive measurements of water-formed deposits would be made on returned samples**



## ***Re-affirmed Program Rationale***

- **Mars has a unique combination of characteristics that translate into high science priority for Mars exploration**
  - Diverse surface deposits whose mineralogy and morphology provide evidence for environments habitable by life, and evidence for methane that could indicate persistence of wet environments
  - Accessibility to robotic and human missions, with feedback into follow-on investigations on a decadal time-scale
- **Questions pertaining to past & present habitable environments and their geologic context should drive future exploration:**
  - When and where did liquid water persist with a sufficiently high activity to support life? Did life or pre-biotic chemistry develop?
  - What drove a fundamental change, from the Noachian to Hesperian periods, in the surface environment recorded in aqueous deposits?
  - How did Mars' internal evolution influence the surface environment?
- **Both landed and orbital investigations are required to address these questions. Their sequential nature & the need for orbital assets to support landed science dictate a coherent program.**



## ***MATT Study: Expected Outcomes***

**The MEP mission architectures developed by MATT for 2013-2026 strive to achieve the following objectives:**

- Investigate the physics, chemistry, and dynamics of the upper atmosphere, the effects of solar wind and radiation, and the escape of volatiles to space => MAVEN
- Determine the composition and structure of the current atmosphere => MSO/**MSO-lite**
- Explore a diversity of surface environments using rovers with sample acquisition, analysis, and caching capabilities => MPR
- Investigate the deep interior using a network of landed geophysical experiments => NET
- Return carefully selected and well-documented samples from a potentially habitable environment to Earth for detailed analysis => MSR+precursors
- Respond to new discoveries through focused missions => Scout, as well as strategic missions



## ***MATT-3 Guiding Principles (1 of 3)***

### **MATT-3 developed these strategic principles to guide mission architecture development:**

- Conduct a Mars Sample Return Mission (MSR) at the earliest opportunity, while recognizing that the timing of MSR is budget driven.
  - Returned samples to meet minimum requirements set out in the ND-SAG report
- MEP should proceed with a balanced scientific program while taking specific steps toward a MSR mission
  - Immediately start and sustain a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling => ***MSL delay has eliminated early funding for technology***
  - Address non-MSR high priority science objectives, particularly as endorsed by NRC strategies and the Decadal Survey (sample return, aeronomy, network)
- Conduct major surface landings no more than 4 launch opportunities apart (3 is preferred) in order to:
  - Respond to discoveries from previous surface missions and new discoveries from orbit
  - Use developed technologies and experienced personnel to reduce risk and cost to future missions, especially MSR
  - ***Implies launch of rover mission in 2018 or 2020***



## *MATT Guiding Principles (2 of 3)*

- **Controlling costs and cost risk is vital and can be achieved in the near-term while still making progress on science objectives by:**
  - **Utilizing the technology investment of MEP (landing systems, orbiters, aeroshells, and rovers) as much as possible for future landed missions**
  - **Not taking on too many technological objectives in any one Mars mission, even while making real progress toward MSR**
- Require that landed missions leading to MSR:
  - Demonstrate **elements of** the sample acquisition and caching technologies or prepare an actual sample cache for MSR that meets the minimum requirements set out in the ND-SAG report
    - **Preparation of the actual cache could be triggered by earlier discovery at a landed site**
  - Provide scientific feed-forward to MSR by:
    - Investigating new sites to explore the diversity of Mars revealed from orbit and to provide an optimized choice for MSR (may require precision landing)
    - **Utilizing new instrumentation and/or new access capability (e.g., drilling) at the same site to follow up a discovery**



## ***MATT Guiding Principles (3 of 3)***

- Provide long-lived orbiters to observe the atmosphere and seasonal surface change, and to provide telecom and critical event support
  - Provides flexibility to MSR flight configurations and is especially synergistic with network science and telecom needs
- Scout missions are included in the architecture to provide:
  - Rapid, innovative response to new discoveries
  - Opportunity to sustain program balance and diversity
  - Low-cost Scout missions were inserted as opportunities permitted and budget profiles demanded



## *MEP Building Blocks for 2016-2026 (1 of 3)*

**MATT-1, -2, and -3 identified these potential mission building blocks to address the key scientific objectives for 2016-2026:**

- **Mars Sample Return Lander (MSR-L) and Orbiter (MSR-O):**
  - Two flight elements: Lander/Rover/Ascent Vehicle & Orbiter/Capture/Return Vehicle
  - High-priority in NRC reports and Decadal Survey; must address multiple science goals with samples meeting the minimum requirements set out in the ND-SAG report
- **Mars Science Orbiter (MSO and MSO-lite)**
  - Atmospheric composition, state, and surface climatology remote sensing plus telecom
    - Respond to reported **(and now published)** methane discovery
  - Science Definition Team formed and report given to MEP
  - **MSO-lite assessed by MSO-SDT (see later summary)**



## ***MEP Building Blocks for 2016-2026 (2 of 3)***

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Prospector Rover (MPR, also called Mid-Range Rover)**
  - At least MER-class rover deployed to new water-related geologic targets
  - Precision landing (<6-km diameter error ellipse) enables access to new sites
  - Conducts independent science but with scientific and technical feed-forward to MSR
  - As a precursor, this can demonstrate feed-forward capabilities for MSR and opens the possibility for payload trade-offs (e.g., caching and cache delivery) with MSR Lander
- **Network (NET):**
  - 4 or more landed stations arrayed in a geophysical network to characterize interior structure, composition, and process, as well as surface environments
  - Meteorological measurements are leveraged by concurrent remote sensing from orbit
  - High-priority in NRC reports and Decadal Survey



## *MEP Building Blocks for 2016-2026 (3 of 3)*

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Scout Missions (Scout)**
  - Competed missions to pursue innovative thrusts to major missions goals
- **MATT-3 discussed the possibility of developing a “vertical sampling” building block as an additional component of the Mars architecture**
  - **Could be responsive to potential MSL or ExoMars discoveries**



## ***MSO-Lite Study Report Summary - M. Smith Chair***

**MSO-min**: Minimum mission could follow up on the methane discovery within the harsh constraints outlined for a 2016 U.S. Mars mission

- ⇒ Will significantly improve knowledge of atmospheric composition and chemistry within the context of understanding Mars habitability
- ⇒ Extend record of climatology to characterize long-term trends for climate & transport model validation

**MSO-lite**: Augmented mission can provide significant gain given increased resources or foreign partnering

- ⇒ More detailed mapping to identify localized source regions
- ⇒ Validate and significantly improve knowledge of current climate and models of transport, including inverse modeling for gas sources
- ⇒ Still further augmentation required for surface change detection

**MSO**: Full-up mission provides opportunity for all of the above, possibly longer life, global surface change detection and site certification

***Note: Telecom support included in all concepts***



## Mission Scenarios - MATT-2



Option	2016	2018	2020 <sup>#2</sup>	2022 <sup>#2</sup>	2024	2026	Comments
2018a <sup>#1</sup>	MSR-O	MSR-L	MSO	NET	Scout	MPR	Funded if major discovery?
2018b <sup>#1</sup>	MSO	MSR-L	MSR-O	NET	Scout	MPR	Restarts climate record; trace gases
2018c <sup>#1</sup>	MPR	MSR-L	MSR-O	MSO	NET	Scout	Gap in climate record; telecom?
2020a	MPR	MSO	MSR-L	MSR-O	NET	Scout	MPR helps optimize MSR
2020b	MPR	Scout	MSR-L	MSR-O	MSO	NET	Gap in climate record, early Scout
2022a	MPR	MSO	NET	MSR-L	MSR-O	Scout	Early NET; MPR helps MSR
2022b	MSO	MPR	NET	MSR-L	MSR-O	Scout	Early NET, but 8 years between major landers (MSL to MPR)
2024a	MPR	MSO	NET	Scout	MSR-L	MSR-O	Early NET; 8 years between major landers; very late sample return

MSO = Mars Science Orbiter  
 MPR = Mars Prospector Rover (MER or MSL class Rover with precision landing and sampling/caching capability)  
 MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)  
 NET = Mars Network Landers (“Netlander”) mission

**FOOTNOTES:**  
 #1 Requires early peak funding well above the guidelines; 2018b most affordable of these options  
 #2 Celestial mechanics are most demanding in the 2020 and 2022 launch opportunities; arrival conditions (Mars atmospheric pressure, dust opacity) challenging after 2020

*Preferred Scenario for given MSR-L Launch Opportunity*





# Scientifically Compelling Scenarios - MATT-3

Option	2016	2018	2020	2022	2024	2026	Comments
	2014-2018 budget guideline precludes MSR before 2022						
M3.1 [2022b]	MSO-lite #1	MPR #2	NET	MSR-L	MSR-O	Scout	MPR occurs 2 periods before 2022 MSR, which will need additional funding for tech development
M3.2 [Swap in 2022b]	MSO-lite #1	MPR #2	NET	MSR-O	MSR-L	Scout	Gives chance for robust technology program preparing for MSR and time to respond to MPR tech demo
M3.3 [Trades in 2024a]	MSO-lite #1	NET	MPR	Scout	MSR-L	MSR-O	Lowest cost early, but 8 years between MSL & MPR; MPR just 2 periods before MSR; early NET

### FOOTNOTES:

#1 MSO-lite affordable for \$750M; preferable to MSO-min in order to map potential localized sources of key trace gases

#2 MPR may exceed the guideline ~\$1.3B (\$1.6B required?)

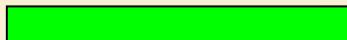
MSO = Mars Science Orbiter

MPR = Mars Prospector Rover (MER class [?]) Rover with precision landing and sampling/caching capability)

MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)

NET = Mars Network mission (3-4 Landers)

*Preferred Scenario*





## ***Proposed Architecture Rationale***

- ***A Mars Sample Return mission remains an anchor point of the Mars Exploration Program; thus the preference for an early MSR launch [M3.1]***
- ***The proposed scenarios are scientifically compelling because each accomplishes the previous Decadal Survey high priority mission goals (aeronomy, network, sample return) while responding to recent discoveries by MEP***
  - ***MSO-lite in 2016 provides the broad atmospheric survey and mapping needed to follow-up the reported methane discoveries and to investigate the nature of its origin, while accommodating the tight budget requirements for 2016 [M3.1-M3.3]***
  - ***MPR in 2018 [M3.1-M3.2] or 2020 [M3.3] investigates the newly found diversity of potentially habitable sites while demonstrating feed-forward technologies for sample return***
  - ***NET in 2020 or 2018 [M3.3] will enhance our understanding of Mars as a system, while searching for possible sub-surface activity implied by the methane detection***
- ***These scenarios are consistent with the recommendations of MATT-1 and MATT-2, as altered by the MSL slip***



## Issues, Findings, and Future Work (1 of 2)

**A#1**

- ***The implications of potential MSL and ExoMars results need further study in order to define the full suite of possibilities for the landed mission in 2018.***
  - For example, an MSL discovery indicating the need for a significant change of payload (e.g., new instruments) or the need for vertical drilling may necessitate altering the architectures for 2018 and 2020.
  - This analysis should assess the options of:
    - The MPR rover concept (e.g. precision landing, different site with MER-class payload, sample caching):
    - A rover with significant *in situ* astrobiological science (ExoMars-like?)
    - Vertical sampling capability versus sample coring and caching

**A#2**

- ***Is a “vertical sampling” mission building block needed?***
- ***Starting and sustaining a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling, is essential to reducing risk and controlling cost for MSR and precursors***

**A#n => Actions MEPAG may want to pursue**



## Issues, Findings, and Future Work (2 of 2)

**A#3**

- *MATT finds that MSO-lite (preferred to MSO-min) is an affordable, highly valuable scientific mission for 2016. Does MEPAG agree?*
- *MEPAG may wish to consider the consequences of MSO-lite instead of MSO in the context of the long-range architecture choices. These consequences include:*
  - *Loss of follow-on of HiRISE-class imaging for site certification*
  - *Possible loss of meter-scale imaging for change detection*
  - *Reduced telecom capability or duration*
  - *Further reduction to MSO-min jeopardizes the ability to identify potential localized trace gas sources*
- *MEPAG should consider how best to prepare for the selection of future landing sites*

**A#4**

- *What are the implications if follow-on high-resolution imaging is not available from MSO-lite?*
- *Should a landing site selection process be established now to best utilize the existing missions for the future program?*



## Summary (1 of 2)

- ***Mars Sample Return remains an anchor point of the Mars Exploration Program and should be conducted at the earliest opportunity within the available budget constraints***
- ***MSO-lite would make a significant scientific contribution to our understanding of martian trace gases and atmospheric state, and could be achieved in a U.S.-only program for 2016***
- ***Given the conditions of an MSL launch slip to 2011 and reduced funding for the 2016 mission, the preferred architecture is:***
  - **Now:** Start technology program focused on developments that enable MPR and feed-forward to MSR
  - **2016:** Launch Mars Science Orbiter (**MSO-lite: trace gas survey, atmospheric state, telecom support**)
  - **2018:** Launch Mars Prospector Rover (MPR) to a new site
  - **2020:** Launch Network Mission (NET)
  - **2022-2024:** Launch MSR-L and MSR-O



## **Summary (2 of 2)**

- ***Future landed missions should utilize the technology investment of MEP (landing systems, aeroshells, rovers, and orbiters) in order to contain cost and risk, while continuing to make significant progress toward Mars sample return***
- ***MATT was directed to consider a NASA-only program and its findings are not meant to preclude international partnering.***
  - ***Significant partnerships with non-NASA partners could considerably enhance the overall program***
  - ***Many missions considered here are well-suited to international participation and partnering***
    - ***Prime examples for major subsystems or flight elements are MSR and Network***
    - ***Opportunities for participation also exist for MSO and MPR***



# MATT-2 Option Is: Mars Exploration Program

Launch Year

2011

2013

2016

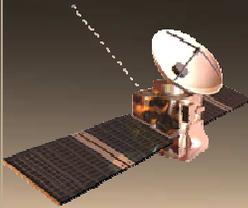
2018

2020

2022

2024

MAVEN



MSO

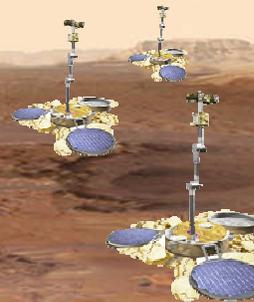
Mars Sample  
Return

Mars  
Prospector  
Rover

Mars  
Network



ExoMars  
(ESA)





# MATT-3 Option Is: Mars Exploration Program

Launch Year

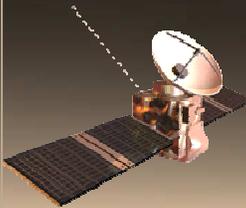
2011



Mars Science Laboratory

2013

MAVEN



2016

MSO-lite



ExoMars (ESA)

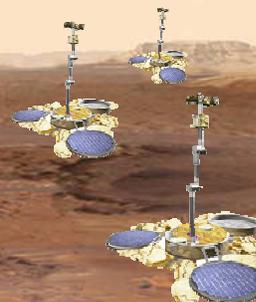
2018

Mars Prospector Rover



2020

Mars Network



2022

Mars Sample Return



2024





## **MATT-3 Questions & Answers (1 of 4)**

**1) Are there any changes to the goals and guiding principles described by MATT-2?**

- Science goals are unchanged; there are nuanced changes to the MATT-2 guiding principles

**2) Are there any changes to the rationale for a Mars Program?**

**No. The program has and will continue to be an effective approach to pursuing NASA's programmatic objectives for Mars and Solar System exploration by:**

- Responding rapidly to scientific discoveries while pursuing ambitious goals to understand Mars as a system, its change with time, and its life potential
- Enabling robust scientific data return from landed missions and providing critical event coverage
- Reducing programmatic mission risk overall and risk in specific critical mission events



## ***MATT-3 Questions & Answers (2 of 4)***

***3) Are the individual mission building blocks identified by MATT still appropriate?***

- Yes, but MATT recommends that MEPAG consider vertical access and associated scientific investigations as a potential new building block

***4) What is the long-term (20-year) focus of the Mars Program; i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?***

- MATT-3 finds that MSR should still be the driving objective of MEP in the next decade, while continuing to pursue as resources permit a balanced program of Mars scientific investigation



## **MATT-3 Questions & Answers (3 of 4)**

**5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**

**An MSO/MSO-lite mission in 2016 is affordable and the mission of choice to follow the methane detection; it also provides a critical link in telecommunications support.**

- MATT-3 did consider a Scout option in 2016 but found it to not be the preferred approach because:**
  - 1. An orbiter was considered necessary for telecom support, thereby limiting the range of Scout missions that could be proposed; furthermore, long-lived telecom would be difficult to support in a cost-constrained Scout mission**
  - 2. There is not time to competitively select a Scout mission before decisions about potential collaborations of NASA and ESA for 2016 must be made. Negotiations on mission elements and the infrastructure considerations mentioned above argue for a core orbiter mission**
- An Announcement of Opportunity for MSO/MSO-lite should indicate that PI-provided payload suites can be proposed as well as individual instruments**



## ***MATT-3 Questions & Answers (4 of 4)***

***6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?***

- The Mars rover mission (new site, precision landing, sample caching demonstration) previously advocated for 2016 is still a candidate for 2018/2020, within the program objectives & MATT guiding principles.***
- However, MEPAG should form a SAG to examine the goals and scope of a rover mission for 2018 or 2020, and the measurements and technology required to achieved them within the scope of a tight budget.***



## ***Back-Up***



## ***Option: Mid-Range Rover/Prospector***

- **Concept: MER-Class Rover Deployed to New Class of Sites**
- **Goals:**
  - Respond to recent discoveries showing a variety of aqueous mineral deposits and geomorphic structures reflecting water activity on Mars
  - Characterize site & prepare sample cache for possible retrieval by future MSR
- **Approach:**
  - MER-class payloads, with modest augmentation as capability allows
  - Takes advantage of latest EDL development and preserves it for MSR
    - Key is access to new sites not reachable with current MER/MSL landing error ellipses
  - Updates “Sky Crane” technology to enable precision landing (< 6 km diameter ellipse)
    - Capability needed to get to the most compelling sites
    - Capability also useful for MSR collection/rendezvous to return samples
  - Conducts (“Prospector Option”) sample selection, encapsulation and general handling needed for MSR, provides retrievable sample cache
- **Issues:**
  - Requires (modest?) improvement of EDL system
  - Prospector concept requires development of sample handling capabilities
  - Requires new EDL design for implementation (I.e., cannot use MER/MSL technologies)
  - Builds on recent discoveries, but delays broadening scope of Mars science exploration

## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/lite/min	MPR	NET	MSR	
<b>I. Life on Mars: Past or Present</b>	<b>A. Habitability</b>	1	Establish Current Distribution of all Water Forms						
		2	Geological History of Water						
		3	Characterize Materials with C, H, O, N, P & S		trace gases				
		4	Determine Potential Energy Sources for Biology						
	<b>B. Carbon Cycle</b>	1	Determine Distribution/Composition of Organic C		trace gases				
		2	Characterize Inorganic Carbon Reservoirs						
		3	Characterize links between C and H, O, N, P, & S						
		4	Characterize Reduced Near-Surface Compounds						
	<b>C. Biosignatures</b>	1	Characterize Complex Organics						
		2	Characterize Chemical and/or Isotopic Signatures						
		3	Characterize Mineralogic Signature Morphology						
		4	Identify Chemical Variations Requiring Life						
	<b>II. Climate: History &amp; Processes</b>	<b>A. Present</b>	1	Characterize Present Cycles of H <sub>2</sub> O, CO <sub>2</sub> , Dust				with MET	
			2	Characterize Key 4-D Photochemical Distributions		With mapping			
			3	Capture Volatile, Ice & Dust Atmos.-Sfc. Exchange				with MET	
			4	Search for Microclimates				with MET	
<b>B. Recent</b>		1	Determine Isotope, Noble gas, Trace Gas Amounts/Evolutions						
		2	Characterize Climate Change Recorded in PLD	non-polar	non-polar?	non-polar	non-polar	non-polar	
		3	Relate Geomorphic Features to Past Climates						
<b>C. Ancient</b>		1	Characterize Atmospheric Escape						
		2	Find Physical/Chemical Records of Past Climates						
		3	Determine Isotope, Noble gas, Trace Gas Evolutions						

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## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/ite/min	MPR	NET	MSR
III. Geology/Geophysics: Surface/Interior Evolution	A. Crustal Geologic Processes	1	Characterize Major Geologic Units and Processes		with imaging			
		2	Evaluate Surface Modification Processes over time					
		3	Constrain Absolute Ages of Major Processes					
		4	Identify/Characterize Hydrothermal Environments					
		5	Evaluate Igneous Processes & their Evolution					
		6	Characterize Surface-Atmosphere Interactions					
		7	Determine Tectonic History & Crustal Modification					
		8	Determine the 3-D State of Present Water					
		9	Determine Nature/Origin of Crustal Magnetization					
		10	Evaluate the effect of Large-Scale Impacts					
	B. Interior	1	Characterize Structure & Dynamics of the Interior		out-gassing			
		2	Determine Origin & History of the Magnetic Field					
		3	Determine Chemical & Thermal Evolution of the Planet					
C.	*	Determine the Origin, Composition and Internal Structure of Phobos and Deimos						
IV. Preparation	A	*	Obtain Knowledge of Mars to Design/Implement Human Mission with acceptable cost, risk and performance <i>*11 Investigations</i>					
	B	*	Conduct risk and/or cost reduction technology and infrastructure demonstrations as part of Mars missions <i>*6 Investigations</i>	EDL (Sky-Crane)		Precision Landing; Caching		Ascent; Capture; Return
	C	*	Characterize Mars Atmosphere for Safe Operation of Spacecraft <i>*4 Investigations</i>					

Major Contribution



Significant Contribution



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# ***Science Perspectives for Candidate Mars Mission Architectures for 2016-2026***

***Mars Architecture Tiger Team (MATT-3)***  
**Philip Christensen, Chair**

**Report to MEP**

***March 12, 2009***





## ***MATT-3 Study: Participants***

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## MATT-3 Study: Key Directives

- Focus on a program that achieves fundamental science and addresses the highest priority goals for Mars Exploration

*Note: Blue text => MATT-3 Directives or Changes from MATT-2*

- **Assess potential program architectures for a NASA-only program\***, with an emphasis on the 2016, 2018, and 2020 opportunities, in light of:

- The MSL launch slip to 2011 and the associated reduction in funding available for a 2016 mission
  - Assume *(for discussion only; budgets have not been decided)* ~\$700M for 2016 mission (through launch); ~\$1.3B for 2018
- Recent discoveries (including the published report on methane)

**\*NOTE: The directive to consider a NASA only program is not intended to preclude international partnering. In fact, there are ongoing discussions between NASA and ESA on potential collaborations for Mars. MATT-3 may be asked to consider the gain from such collaborations as the opportunities are defined.**



## *MATT-3 Study: Context*

### **MATT-3 study builds on earlier work:**

#### **•NRC:**

- NRC Reports and Decadal Survey
  - Major Milestone: NRC Special Committee (drawn largely from the NRC Committee on Evolution and Life) and Report: *An Astrobiology Strategy for Exploration of Mars*

#### **•MEPAG:**

- MEPAG Goals, Objectives, Investigations documentation
- Mars Next Decade (ND) and Mars Strategic Science (MSS) SAGs
- MATT-1 and MATT-2 Discussions
- Consulted the JPL Mars Office Advanced Studies Team regarding mission costs and feasibility



## ***MATT-3 Questions***

- 1) Are there any changes to the goals and guiding principles described by MATT-2?**
- 2) Are there any changes to the rationale for a Mars Program?**
- 3) Are the individual mission building blocks identified by MATT still appropriate?**
- 4) What is the long-term (20-year) focus of the Mars Program - i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?**
- 5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**
  - Does the discovery of methane apparently varying in space and time cause MEP to emphasize a more astrobiological pathway?**
- 6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?**



## ***MATT-3 Activities to Date***

- **MATT-3 proceeded as follows:**

- **Met three times via telecon over the past month. Additional discussions are planned following the MEPAG meeting to incorporate MEPAG discussion into the final report.**

***A mid-term briefing was made to MEPAG on March 3, 2009.***

- **Revisited the science goals for potential missions in 2016 and beyond. These goals:**
  - Are consistent with the “**Explore** Habitable Environments” theme
  - Are responsive to the NRC/Decadal Survey Priorities
  - Address MEPAG Goals, Objectives and Investigations
- **Reexamined the major program goals, guiding principles, and mission “building blocks” that address the mission science goals for the decade**
  - Building blocks include: MSR, MPR, MSO/MSO-lite, NET, Scout
    - Mission “blocks” identified at a high level--see following slides
- **Revaluated potential architectures against the MSL launch slip, the expected MEP budget, and new discoveries**



## Goals for the Next Decade

- **The MEP has "followed the water" and discovered a diverse suite of water-related features and environments.**
  - There are unanswered questions about each of these environments that MER showed can be addressed with *in situ* measurements
  - There are also unanswered questions about present habitability, especially whether trace gases are a signature of present habitable environments
  - There remain major questions about the state of the interior and the history of tectonic, volcanic, aqueous processes that are highly relevant to habitable environments
- **The focus on future missions should be “**explore** habitable environments” of the past and present, including the “how, when and why” of environmental change. Key measurements are:**
  - Rock and mineral textures, grain- to outcrop-scale mineralogy, and elemental abundances & gradients in different classes of aqueous deposits
  - Abundances and spatial/temporal variations of trace gases and isotopes in the present atmosphere
  - Nature and history of the interior and of processes shaping the surface
- **The most comprehensive measurements of water-formed deposits would be made on returned samples**



## ***Re-affirmed Program Rationale***

- **Mars has a unique combination of characteristics that translate into high science priority for Mars exploration**
  - Diverse surface deposits whose mineralogy and morphology provide evidence for environments habitable by life, and evidence for methane that could indicate persistence of wet environments
  - Accessibility to robotic and human missions, with feedback into follow-on investigations on a decadal time-scale
- **Questions pertaining to past & present habitable environments and their geologic context should drive future exploration:**
  - When and where did liquid water persist with a sufficiently high activity to support life? Did life or pre-biotic chemistry develop?
  - What drove a fundamental change, from the Noachian to Hesperian periods, in the surface environment recorded in aqueous deposits?
  - How did Mars' internal evolution influence the surface environment?
- **Both landed and orbital investigations are required to address these questions. Their sequential nature & the need for orbital assets to support landed science dictate a coherent program.**



## ***MATT Study: Expected Outcomes***

**The MEP mission architectures developed by MATT for 2013-2026 strive to achieve the following objectives:**

- Investigate the physics, chemistry, and dynamics of the upper atmosphere, the effects of solar wind and radiation, and the escape of volatiles to space => MAVEN
- Determine the composition and structure of the current atmosphere => MSO/MSO-lite
- Explore a diversity of surface environments using rovers with sample acquisition, analysis, and caching capabilities => MPR
- Investigate the deep interior using a network of landed geophysical experiments => NET
- Return carefully selected and well-documented samples from a potentially habitable environment to Earth for detailed analysis => MSR+precursors
- Respond to new discoveries through focused missions => Scout, as well as strategic missions



## ***MATT-3 Guiding Principles (1 of 3)***

### **MATT-3 developed these strategic principles to guide mission architecture development:**

- Conduct a Mars Sample Return Mission (MSR) at the earliest opportunity, while recognizing that the timing of MSR is budget driven.
  - Returned samples to meet minimum requirements set out in the ND-SAG report
- MEP should proceed with a balanced scientific program while taking specific steps toward a MSR mission
  - Immediately start and sustain a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling => ***MSL delay has eliminated early funding for technology***
  - Address non-MSR high priority science objectives, particularly as endorsed by NRC strategies and the Decadal Survey (sample return, aeronomy, network)
- Conduct major surface landings no more than 4 launch opportunities apart (3 is preferred) in order to:
  - Respond to discoveries from previous surface missions and new discoveries from orbit
  - Use developed technologies and experienced personnel to reduce risk and cost to future missions, especially MSR
  - ***Implies launch of rover mission in 2018 or 2020***



## *MATT Guiding Principles (2 of 3)*

- **Controlling costs and cost risk is vital and can be achieved in the near-term while still making progress on science objectives by:**
  - **Utilizing the technology investment of MEP (landing systems, orbiters, aeroshells, and rovers) as much as possible for future landed missions**
  - **Not taking on too many technological objectives in any one Mars mission, even while making real progress toward MSR**
- Require that landed missions leading to MSR:
  - Demonstrate **elements of** the sample acquisition and caching technologies or prepare an actual sample cache for MSR that meets the minimum requirements set out in the ND-SAG report
    - **Preparation of the actual cache could be triggered by earlier discovery at a landed site**
  - Provide scientific feed-forward to MSR by:
    - Investigating new sites to explore the diversity of Mars revealed from orbit and to provide an optimized choice for MSR (may require precision landing)
    - **Utilizing new instrumentation and/or new access capability (e.g., drilling) at the same site to follow up a discovery**



## ***MATT Guiding Principles (3 of 3)***

- Provide long-lived orbiters to observe the atmosphere and seasonal surface change, and to provide telecom and critical event support
  - Provides flexibility to MSR flight configurations and is especially synergistic with network science and telecom needs
- Scout missions are included in the architecture to provide:
  - Rapid, innovative response to new discoveries
  - Opportunity to sustain program balance and diversity
  - Low-cost Scout missions were inserted as opportunities permitted and budget profiles demanded



## *MEP Building Blocks for 2016-2026 (1 of 3)*

**MATT-1, -2, and -3 identified these potential mission building blocks to address the key scientific objectives for 2016-2026:**

- **Mars Sample Return Lander (MSR-L) and Orbiter (MSR-O):**
  - Two flight elements: Lander/Rover/Ascent Vehicle & Orbiter/Capture/Return Vehicle
  - High-priority in NRC reports and Decadal Survey; must address multiple science goals with samples meeting the minimum requirements set out in the ND-SAG report
- **Mars Science Orbiter (MSO and MSO-lite)**
  - Atmospheric composition, state, and surface climatology remote sensing plus telecom
    - Respond to reported **(and now published)** methane discovery
  - Science Definition Team formed and report given to MEP
  - **MSO-lite assessed by MSO-SDT (see later summary)**



## ***MEP Building Blocks for 2016-2026 (2 of 3)***

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Prospector Rover (MPR, also called Mid-Range Rover)**
  - At least MER-class rover deployed to new water-related geologic targets
  - Precision landing (<6-km diameter error ellipse) enables access to new sites
  - Conducts independent science but with scientific and technical feed-forward to MSR
  - As a precursor, this can demonstrate feed-forward capabilities for MSR and opens the possibility for payload trade-offs (e.g., caching and cache delivery) with MSR Lander
- **Network (NET):**
  - 4 or more landed stations arrayed in a geophysical network to characterize interior structure, composition, and process, as well as surface environments
  - Meteorological measurements are leveraged by concurrent remote sensing from orbit
  - High-priority in NRC reports and Decadal Survey



## *MEP Building Blocks for 2016-2026 (3 of 3)*

**MATT identified these potential mission building blocks to address the key scientific objectives for 2016-2026 (cont.):**

- **Mars Scout Missions (Scout)**
  - Competed missions to pursue innovative thrusts to major missions goals
- **MATT-3 discussed the possibility of developing a “vertical sampling” building block as an additional component of the Mars architecture**
  - **Could be responsive to potential MSL or ExoMars discoveries**



## ***MSO-Lite Study Report Summary - M. Smith Chair***

**MSO-min**: Minimum mission could follow up on the methane discovery within the harsh constraints outlined for a 2016 U.S. Mars mission

- ⇒ Will significantly improve knowledge of atmospheric composition and chemistry within the context of understanding Mars habitability
- ⇒ Extend record of climatology to characterize long-term trends for climate & transport model validation

**MSO-lite**: Augmented mission can provide significant gain given increased resources or foreign partnering

- ⇒ More detailed mapping to identify localized source regions
- ⇒ Validate and significantly improve knowledge of current climate and models of transport, including inverse modeling for gas sources
- ⇒ Still further augmentation required for surface change detection

**MSO**: Full-up mission provides opportunity for all of the above, possibly longer life, global surface change detection and site certification

***Note: Telecom support included in all concepts***



## Mission Scenarios - MATT-2



Option	2016	2018	2020 <sup>#2</sup>	2022 <sup>#2</sup>	2024	2026	Comments
2018a <sup>#1</sup>	MSR-O	MSR-L	MSO	NET	Scout	MPR	Funded if major discovery?
2018b <sup>#1</sup>	MSO	MSR-L	MSR-O	NET	Scout	MPR	Restarts climate record; trace gases
2018c <sup>#1</sup>	MPR	MSR-L	MSR-O	MSO	NET	Scout	Gap in climate record; telecom?
2020a	MPR	MSO	MSR-L	MSR-O	NET	Scout	MPR helps optimize MSR
2020b	MPR	Scout	MSR-L	MSR-O	MSO	NET	Gap in climate record, early Scout
2022a	MPR	MSO	NET	MSR-L	MSR-O	Scout	Early NET; MPR helps MSR
2022b	MSO	MPR	NET	MSR-L	MSR-O	Scout	Early NET, but 8 years between major landers (MSL to MPR)
2024a	MPR	MSO	NET	Scout	MSR-L	MSR-O	Early NET; 8 years between major landers; very late sample return

MSO = Mars Science Orbiter  
 MPR = Mars Prospector Rover (MER or MSL class Rover with precision landing and sampling/caching capability)  
 MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)  
 NET = Mars Network Landers (“Netlander”) mission

**FOOTNOTES:**  
 #1 Requires early peak funding well above the guidelines; 2018b most affordable of these options  
 #2 Celestial mechanics are most demanding in the 2020 and 2022 launch opportunities; arrival conditions (Mars atmospheric pressure, dust opacity) challenging after 2020

*Preferred Scenario for given MSR-L Launch Opportunity*





# Scientifically Compelling Scenarios - MATT-3

Option	2016	2018	2020	2022	2024	2026	Comments
	2014-2018 budget guideline precludes MSR before 2022						
M3.1 [2022b]	MSO-lite #1	MPR #2	NET	MSR-L	MSR-O	Scout	MPR occurs 2 periods before 2022 MSR, which will need additional funding for tech development
M3.2 [Swap in 2022b]	MSO-lite #1	MPR #2	NET	MSR-O	MSR-L	Scout	Gives chance for robust technology program preparing for MSR and time to respond to MPR tech demo
M3.3 [Trades in 2024a]	MSO-lite #1	NET	MPR	Scout	MSR-L	MSR-O	Lowest cost early, but 8 years between MSL & MPR; MPR just 2 periods before MSR; early NET

### FOOTNOTES:

#1 MSO-lite affordable for \$750M; preferable to MSO-min in order to map potential localized sources of key trace gases

#2 MPR may exceed the guideline ~\$1.3B (\$1.6B required?)

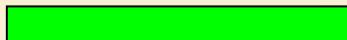
MSO = Mars Science Orbiter

MPR = Mars Prospector Rover (MER class [?]) Rover with precision landing and sampling/caching capability)

MSR = Mars Sample Return Orbiter (MSR-O) and Lander/Rover/MAV (MSR-L)

NET = Mars Network mission (3-4 Landers)

*Preferred Scenario*





## ***Proposed Architecture Rationale***

- ***A Mars Sample Return mission remains an anchor point of the Mars Exploration Program; thus the preference for an early MSR launch [M3.1]***
- ***The proposed scenarios are scientifically compelling because each accomplishes the previous Decadal Survey high priority mission goals (aeronomy, network, sample return) while responding to recent discoveries by MEP***
  - ***MSO-lite in 2016 provides the broad atmospheric survey and mapping needed to follow-up the reported methane discoveries and to investigate the nature of its origin, while accommodating the tight budget requirements for 2016 [M3.1-M3.3]***
  - ***MPR in 2018 [M3.1-M3.2] or 2020 [M3.3] investigates the newly found diversity of potentially habitable sites while demonstrating feed-forward technologies for sample return***
  - ***NET in 2020 or 2018 [M3.3] will enhance our understanding of Mars as a system, while searching for possible sub-surface activity implied by the methane detection***
- ***These scenarios are consistent with the recommendations of MATT-1 and MATT-2, as altered by the MSL slip***



## Issues, Findings, and Future Work (1 of 2)

**A#1**

- ***The implications of potential MSL and ExoMars results need further study in order to define the full suite of possibilities for the landed mission in 2018.***
  - For example, an MSL discovery indicating the need for a significant change of payload (e.g., new instruments) or the need for vertical drilling may necessitate altering the architectures for 2018 and 2020.
  - This analysis should assess the options of:
    - The MPR rover concept (e.g. precision landing, different site with MER-class payload, sample caching):
    - A rover with significant *in situ* astrobiological science (ExoMars-like?)
    - Vertical sampling capability versus sample coring and caching

**A#2**

- ***Is a “vertical sampling” mission building block needed?***
- ***Starting and sustaining a technology program to focus on specific sample return issues including, but not limited to, precision landing and sample handling, is essential to reducing risk and controlling cost for MSR and precursors***

**A#n => Actions MEPAG may want to pursue**



## Issues, Findings, and Future Work (2 of 2)

**A#3**

- *MATT finds that MSO-lite (preferred to MSO-min) is an affordable, highly valuable scientific mission for 2016. Does MEPAG agree?*
- *MEPAG may wish to consider the consequences of MSO-lite instead of MSO in the context of the long-range architecture choices. These consequences include:*
  - *Loss of follow-on of HiRISE-class imaging for site certification*
  - *Possible loss of meter-scale imaging for change detection*
  - *Reduced telecom capability or duration*
  - *Further reduction to MSO-min jeopardizes the ability to identify potential localized trace gas sources*
- *MEPAG should consider how best to prepare for the selection of future landing sites*

**A#4**

- *What are the implications if follow-on high-resolution imaging is not available from MSO-lite?*
- *Should a landing site selection process be established now to best utilize the existing missions for the future program?*



## Summary (1 of 2)

- ***Mars Sample Return remains an anchor point of the Mars Exploration Program and should be conducted at the earliest opportunity within the available budget constraints***
- ***MSO-lite would make a significant scientific contribution to our understanding of martian trace gases and atmospheric state, and could be achieved in a U.S.-only program for 2016***
- ***Given the conditions of an MSL launch slip to 2011 and reduced funding for the 2016 mission, the preferred architecture is:***
  - **Now:** Start technology program focused on developments that enable MPR and feed-forward to MSR
  - **2016:** Launch Mars Science Orbiter (**MSO-lite: trace gas survey, atmospheric state, telecom support**)
  - **2018:** Launch Mars Prospector Rover (MPR) to a new site
  - **2020:** Launch Network Mission (NET)
  - **2022-2024:** Launch MSR-L and MSR-O



## **Summary (2 of 2)**

- ***Future landed missions should utilize the technology investment of MEP (landing systems, aeroshells, rovers, and orbiters) in order to contain cost and risk, while continuing to make significant progress toward Mars sample return***
- ***MATT was directed to consider a NASA-only program and its findings are not meant to preclude international partnering.***
  - ***Significant partnerships with non-NASA partners could considerably enhance the overall program***
  - ***Many missions considered here are well-suited to international participation and partnering***
    - ***Prime examples for major subsystems or flight elements are MSR and Network***
    - ***Opportunities for participation also exist for MSO and MPR***



# MATT-2 Option Is: Mars Exploration Program

Launch Year

2011

2013

2016

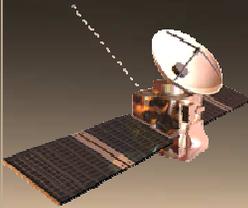
2018

2020

2022

2024

MAVEN



MSO

Mars Sample  
Return

Mars  
Prospector  
Rover

Mars  
Network



ExoMars  
(ESA)





# MATT-3 Option Is: Mars Exploration Program

Launch Year

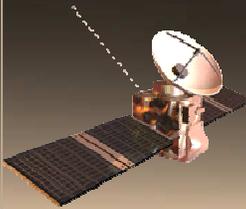
2011



Mars Science Laboratory

2013

MAVEN



2016

MSO-lite



ExoMars (ESA)

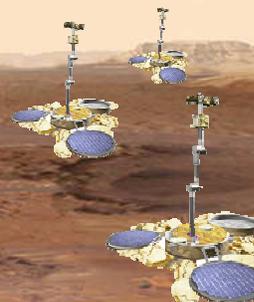
2018

Mars Prospector Rover



2020

Mars Network



2022

Mars Sample Return



2024





## **MATT-3 Questions & Answers (1 of 4)**

**1) Are there any changes to the goals and guiding principles described by MATT-2?**

- Science goals are unchanged; there are nuanced changes to the MATT-2 guiding principles

**2) Are there any changes to the rationale for a Mars Program?**

**No. The program has and will continue to be an effective approach to pursuing NASA's programmatic objectives for Mars and Solar System exploration by:**

- Responding rapidly to scientific discoveries while pursuing ambitious goals to understand Mars as a system, its change with time, and its life potential
- Enabling robust scientific data return from landed missions and providing critical event coverage
- Reducing programmatic mission risk overall and risk in specific critical mission events



## ***MATT-3 Questions & Answers (2 of 4)***

***3) Are the individual mission building blocks identified by MATT still appropriate?***

- **Yes, but MATT recommends that MEPAG consider vertical access and associated scientific investigations as a potential new building block**

***4) What is the long-term (20-year) focus of the Mars Program; i.e. are there alternatives to MSR as the primary objective of the 3<sup>rd</sup> decade?***

- **MATT-3 finds that MSR should still be the driving objective of MEP in the next decade, while continuing to pursue as resources permit a balanced program of Mars scientific investigation**



## **MATT-3 Questions & Answers (3 of 4)**

**5) Given the limited funds available for 2016, what are the primary mission options and possible priorities for a U. S. only program?**

**An MSO/MSO-lite mission in 2016 is affordable and the mission of choice to follow the methane detection; it also provides a critical link in telecommunications support.**

- MATT-3 did consider a Scout option in 2016 but found it to not be the preferred approach because:**
  - 1. An orbiter was considered necessary for telecom support, thereby limiting the range of Scout missions that could be proposed; furthermore, long-lived telecom would be difficult to support in a cost-constrained Scout mission**
  - 2. There is not time to competitively select a Scout mission before decisions about potential collaborations of NASA and ESA for 2016 must be made. Negotiations on mission elements and the infrastructure considerations mentioned above argue for a core orbiter mission**
- An Announcement of Opportunity for MSO/MSO-lite should indicate that PI-provided payload suites can be proposed as well as individual instruments**



## ***MATT-3 Questions & Answers (4 of 4)***

***6) What are science objectives and program goals for a possible 2018 rover/lander in a U.S. only program?***

- The Mars rover mission (new site, precision landing, sample caching demonstration) previously advocated for 2016 is still a candidate for 2018/2020, within the program objectives & MATT guiding principles.***
- However, MEPAG should form a SAG to examine the goals and scope of a rover mission for 2018 or 2020, and the measurements and technology required to achieved them within the scope of a tight budget.***



## ***Back-Up***



## ***Option: Mid-Range Rover/Prospector***

- **Concept: MER-Class Rover Deployed to New Class of Sites**
- **Goals:**
  - Respond to recent discoveries showing a variety of aqueous mineral deposits and geomorphic structures reflecting water activity on Mars
  - Characterize site & prepare sample cache for possible retrieval by future MSR
- **Approach:**
  - MER-class payloads, with modest augmentation as capability allows
  - Takes advantage of latest EDL development and preserves it for MSR
    - Key is access to new sites not reachable with current MER/MSL landing error ellipses
  - Updates “Sky Crane” technology to enable precision landing (< 6 km diameter ellipse)
    - Capability needed to get to the most compelling sites
    - Capability also useful for MSR collection/rendezvous to return samples
  - Conducts (“Prospector Option”) sample selection, encapsulation and general handling needed for MSR, provides retrievable sample cache
- **Issues:**
  - Requires (modest?) improvement of EDL system
  - Prospector concept requires development of sample handling capabilities
  - Requires new EDL design for implementation (I.e., cannot use MER/MSL technologies)
  - Builds on recent discoveries, but delays broadening scope of Mars science exploration

## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/lite/min	MPR	NET	MSR	
<b>I. Life on Mars: Past or Present</b>	<b>A. Habitability</b>	1	Establish Current Distribution of all Water Forms						
		2	Geological History of Water						
		3	Characterize Materials with C, H, O, N, P & S		trace gases				
		4	Determine Potential Energy Sources for Biology						
	<b>B. Carbon Cycle</b>	1	Determine Distribution/Composition of Organic C		trace gases				
		2	Characterize Inorganic Carbon Reservoirs						
		3	Characterize links between C and H, O, N, P, & S						
		4	Characterize Reduced Near-Surface Compounds						
	<b>C. Biosignatures</b>	1	Characterize Complex Organics						
		2	Characterize Chemical and/or Isotopic Signatures						
		3	Characterize Mineralogic Signature Morphology						
		4	Identify Chemical Variations Requiring Life						
	<b>II. Climate: History &amp; Processes</b>	<b>A. Present</b>	1	Characterize Present Cycles of H <sub>2</sub> O, CO <sub>2</sub> , Dust				with MET	
			2	Characterize Key 4-D Photochemical Distributions		With mapping			
			3	Capture Volatile, Ice & Dust Atmos.-Sfc. Exchange				with MET	
			4	Search for Microclimates				with MET	
<b>B. Recent</b>		1	Determine Isotope, Noble gas, Trace Gas Amounts/Evolutions						
		2	Characterize Climate Change Recorded in PLD	non-polar	non-polar?	non-polar	non-polar	non-polar	
		3	Relate Geomorphic Features to Past Climates						
<b>C. Ancient</b>		1	Characterize Atmospheric Escape						
		2	Find Physical/Chemical Records of Past Climates						
		3	Determine Isotope, Noble gas, Trace Gas Evolutions						

Major Contribution

Significant Contribution



## MATT-3 Architecture Traceability to MEPAG Goals/Objectives/Investigations

Goal	Obj.	Priority	Investigation	MSL	MSO Full/ite/min	MPR	NET	MSR
<b>III. Geology/Geophysics: Surface/Interior Evolution</b>	<b>A. Crustal Geologic Processes</b>	1	Characterize Major Geologic Units and Processes		with imaging			
		2	Evaluate Surface Modification Processes over time					
		3	Constrain Absolute Ages of Major Processes					
		4	Identify/Characterize Hydrothermal Environments					
		5	Evaluate Igneous Processes & their Evolution					
		6	Characterize Surface-Atmosphere Interactions					
		7	Determine Tectonic History & Crustal Modification					
		8	Determine the 3-D State of Present Water					
		9	Determine Nature/Origin of Crustal Magnetization					
		10	Evaluate the effect of Large-Scale Impacts					
	<b>B. Interior</b>	1	Characterize Structure & Dynamics of the Interior		out-gassing			
		2	Determine Origin & History of the Magnetic Field					
		3	Determine Chemical & Thermal Evolution of the Planet					
<b>C.</b>	*	Determine the Origin, Composition and Internal Structure of Phobos and Deimos						
<b>IV. Preparation</b>	<b>A</b>	*	Obtain Knowledge of Mars to Design/Implement Human Mission with acceptable cost, risk and performance <i>*11 Investigations</i>					
	<b>B</b>	*	Conduct risk and/or cost reduction technology and infrastructure demonstrations as part of Mars missions <i>*6 Investigations</i>	EDL (Sky-Crane)		Precision Landing; Caching		Ascent; Capture; Return
	<b>C</b>	*	Characterize Mars Atmosphere for Safe Operation of Spacecraft <i>*4 Investigations</i>					

Major Contribution



Significant Contribution

