



# Summary of the Final Report

25 September 2012

**MPPG**

**Mars Program Planning Group**



# Introduction and Context



- The MPPG effort was initiated by NASA in March 2012, motivated by:
  - The need to re-plan a U.S. Mars program in light of the President’s FY2013 Budget Submittal
  - The NRC 2011 Planetary Science Decadal Survey recommendations for Mars exploration in the context of the budget submittal, and subsequent new discoveries
  - The POTUS challenge for humans in Mars orbit in the 2030s
- The purpose of the MPPG was to develop foundations for a program-level architecture for robotic exploration of Mars that is consistent with the President’s challenge of sending humans to Mars in the decade of the 2030s, yet remain responsive to the primary scientific goals of the 2011 NRC Decadal Survey for Planetary Science.
- Consistent with its charter, MPPG reached out to internal and external science, technology and engineering communities, to develop mission options and program architecture alternatives for NASA’s consideration

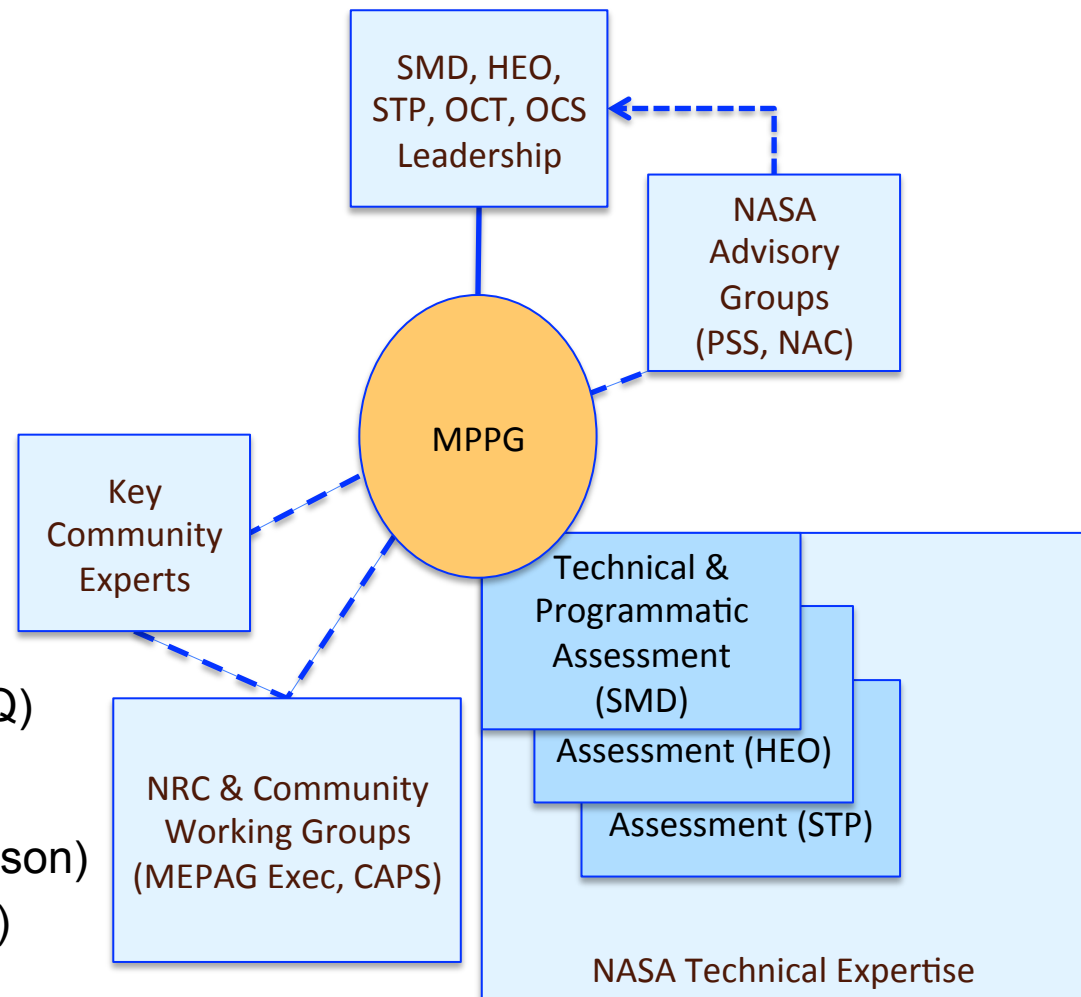
# MPPG Core Team & Approach



- Orlando Figueroa (Chair)
- Jim Garvin (SMD/GSFC)
- Michele Gates (HEOMD/HQ)
- Randy Lillard (STP/HQ)
- Dan McCleese (JPL)
- Jack Mustard (Brown Univ.)
- Firouz Naderi (JPL)
- Lisa Pratt (Indiana Univ.)
- John Shannon (HEOMD/HQ)
- George Tahu (Exec Officer, HQ)

## Ex-Officio

- Ramon DePaula (SMD/Intl Liaison)
- Mike Wargo (HEOMD/Science)

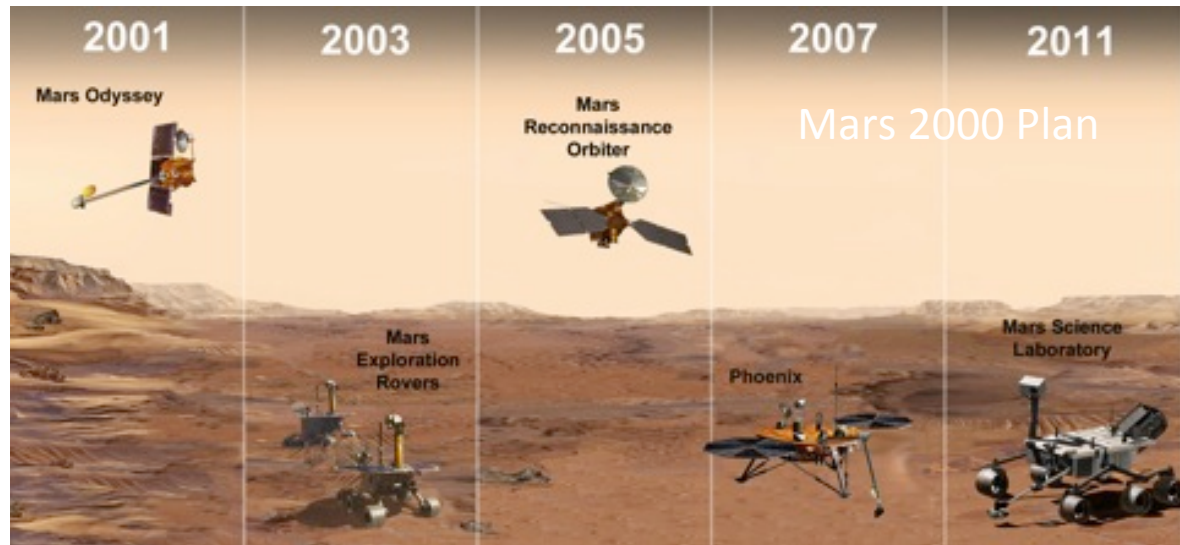




# Objectives and Constraints

- MPPG was chartered to provide options that integrate science, human exploration and technology at an Agency level with Mars Exploration as a common objective
- Critical Boundary Conditions
  - NASA FY13 Budget submittal through FY2017
  - Imperative for strategic collaboration between HEOMD, Science, Technology
  - Remain responsive to the primary scientific goals of the NRC Decadal Survey
- The immediate focus of the MPPG was on the collection of multiple mission concept options for the 2018/2020 Mars launch opportunities.
- To maintain the successful strategic structure of the MEP, and ensure relevancy of the possible 2018/2020 missions to the longer term science and exploration priorities, MPPG was asked to provide notional architecture/pathways spanning to the 2030s

# The Mars 2000 Plan and MPPG



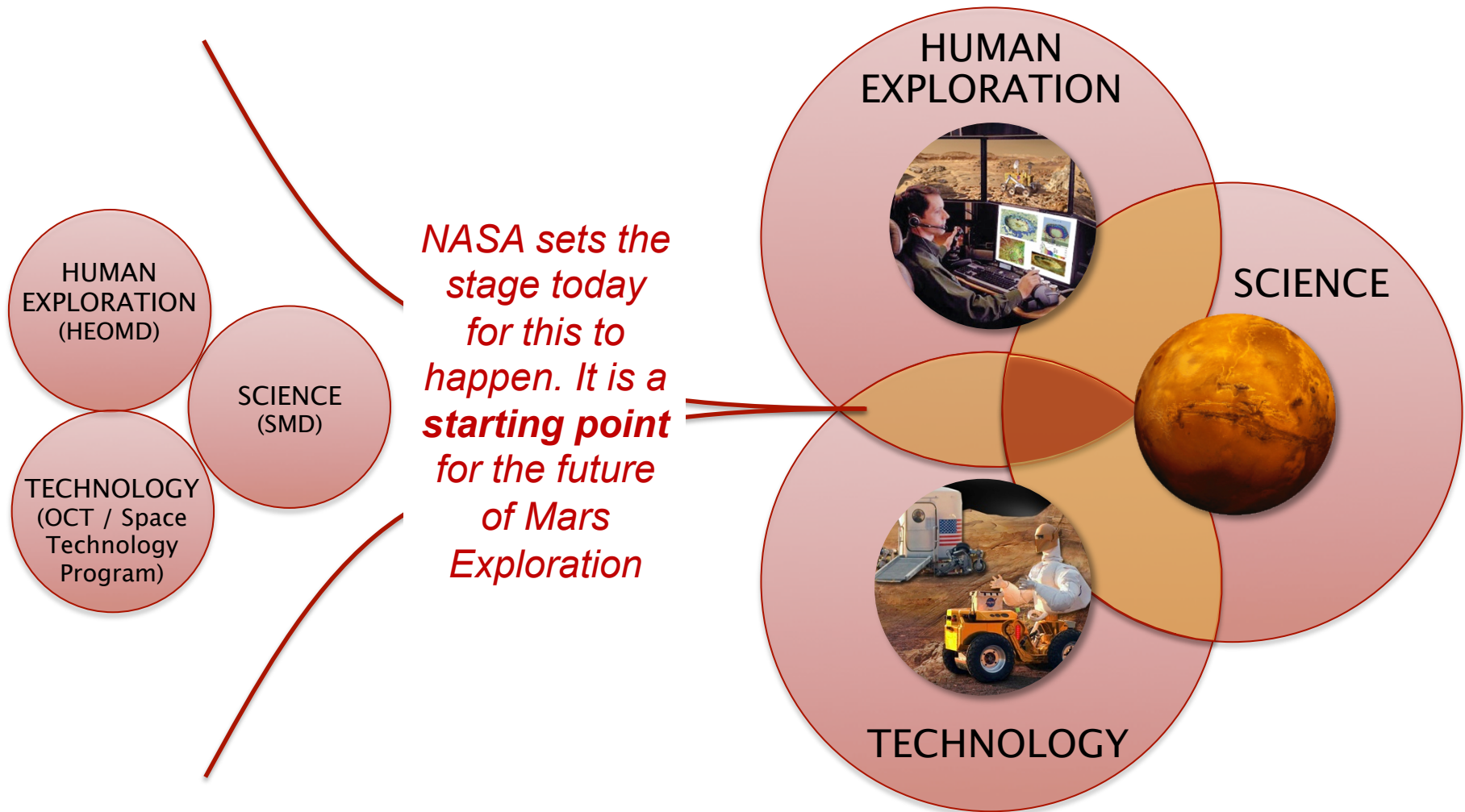
- MPPG approach to planning retained the key features of the highly successful and resilient Mars 2000 Plan.
  - A science theme and overarching program strategy, reflected in the sequence of interconnected strategic missions, with competed opportunities “Scouts” (Phoenix and MAVEN) for other Mars science; InSight (a Discovery mission for 2016) will contribute to the science legacy
- An extraordinary decade of scientific discovery, created by the Mars Exploration strategy which was scripted in the summer of 2000, ends with the promise of the Mars Science Laboratory

# Mars Exploration as a Common Goal for NASA



T O D A Y

F U T U R E



*NASA sets the stage today for this to happen. It is a starting point for the future of Mars Exploration*



# MPPG - The Bottom Line

- MPPG explored many options and alternatives for creating a meaningful collaboration between science and human exploration of Mars, while leveraging and focusing technology investments towards a common goal.
- The MPPG finds that sample return architectures provide a promising intersection of objectives and integrated strategy for long term SMD/HEOMD/STP collaboration
- Multiple program architectures can be assembled by varying the scope, sequence, and risk posture assumed for the building blocks provided and analyzed by MPPG; NASA can choose from these to build a program strategy consistent with its long term objectives

# Topics Covered



1. Science Pathways
2. Workshop at LPI
  - a. Results in the context of MPPG
3. Collaboration between Human Exploration and Science
4. Cross-cutting and Enabling Technologies
5. Possible Program Architectures – Pathway Implementations
  - a. Science Pathways A1, A2 and B
  - b. Orbital and Landed Platforms
  - c. Cost Picture and the Early Opportunities
6. Other Programmatic Considerations
  - a. International Collaboration
  - b. R&A, Instrument Technology Investments, E&PO
7. MPPG Summary



# SCIENCE PATHWAYS



# What are Scientific PATHWAYS?



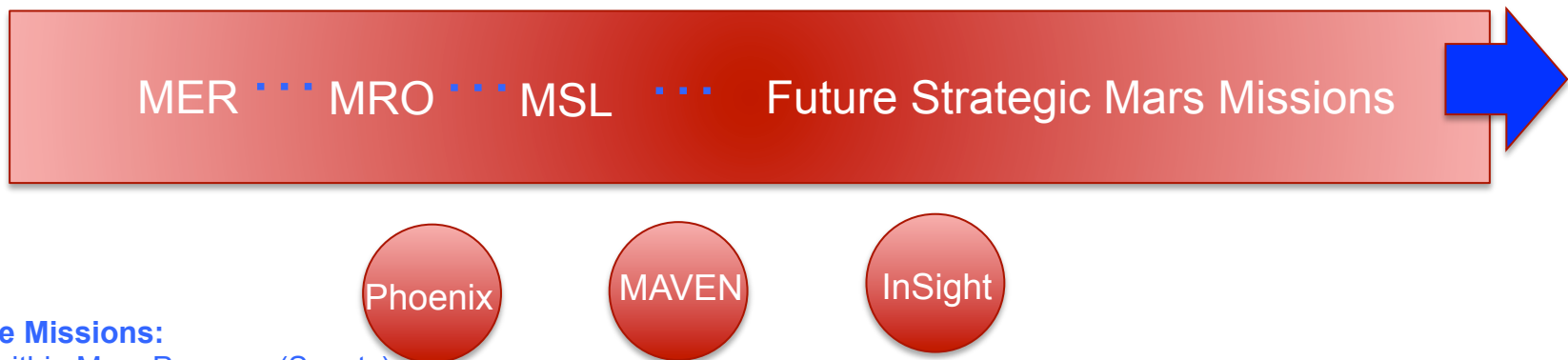
- The Mars exploration strategy of the last decade proved to be extraordinarily productive scientifically
  - 2000 re-planning provided critical trajectory for science and implementation
- **Discovery-driven Scientific Pathways:**
  - First employed in the 2000 Mars Program re-planning effort, pathways include strategic plans for science and missions, program analysis, and active community participation
  - MPPG employed pathways as a vehicle to analyze options as:
    - Foundation for a more strategic collaboration between SMD/HEOMD/OCT/OCS towards a common Agency-level goal
    - Catalysts for new scientific discoveries, ideas, and advances in technology
  - Pathways helped establish early priorities, common understanding, and intersections



# Strategic vs. Stand-alone Missions

- Mars exploration in SMD has had (and should have) two types of missions:
  - **Strategic missions:** A mission within a chain of strategically laid-out, coupled missions that follow a scientific line of inquiry
  - **Stand-alone missions:** A single isolated mission accomplishing a significant science objective, but independent from the main scientific strategy
    - These missions used to be part of the Mars Program and competed as Scouts (Phoenix and MAVEN)
    - Now no longer in the Mars Program, they compete with other planetary science as a part of Discovery Program (InSight)

## Sequence of Strategic Missions



### Stand-alone Missions:

Previously within Mars Program (Scouts)

Now compete with other science in Discovery Program

# MPPG Science Traceability – Candidate Pathways



Science Questions	Science Pathways	Functional Requirements (Examples)	Architecture	NRC/MEPAG Priorities
NRC Decadal Survey, MEPAG Goals (includes HEO needs via SKG's)	Search for Signs of Past Life	Context & in situ analysis, sample preservation, sample return	Commence sample return using existing data	Highest priority science and approach
			<i>In situ</i> exploration prior to returning optimal suite of samples	Highest priority science
		In situ analysis for bio-signatures and organics	Measurements can be included in sample return architectures, or via stand-alone surface astrobiology observatory	High priority science, lower priority approach, higher science risk
	Modern Environments as Habitats	In situ and orbital measurements. Vehicles depend on findings (orbiter, rover, deep drill)	Depends on new discoveries, and challenges (e.g., planetary protection)	Consistent with NRC Decadal recommendation for competition as Discovery or future New Frontier missions
	Dynamics/Interior	Surface Networks; Active Geophysical Experiments	Multiple static landers with long term monitoring	
Mars Systems Science	Orbital & Surface measurements	Missions respond to discoveries		

# Seek Signs of Past Life – Highest Priority Science



## Pathways A1 and A2

Commence Sample Return using existing data



- Search for signs of past life with samples collected from a site--identified using existing data--and returned to Earth for analysis
- This is most directly responsive to the NRC Decadal Survey recommendations
- Collect scientifically-selected samples from a site which has been determined to have astrobiological significance
- Timing of returned samples paced solely by available funds, not further scientific discoveries

## Pathway B

Multi-site Investigation to Optimize Search for Past Life



- Search for signs of past life through in situ observations and ultimately analysis of carefully selected samples returned to Earth
- Sample Return commences only after in situ measurements and sampling of multiple sites (3) and Science Community decision process as to which to return to Earth
- The emphasis of this pathway is searching for samples capable of preserving evidence of past life

# Pathway A: Commence Sample Return



**Objective:** Search for signs of past life with samples collected from a site - determined to have astrobiological significance using existing data--and returned to Earth for analysis

- Highest priority large mission recommended by the NRC Decadal Survey
- Relative to NRC Decadal suggested plan, MPPG mission concepts have reduced cost
- Site for MSR is chosen on the basis of current and continuing Mars orbiter remote sensing observations
- Pathway A further breaks down into the following two candidate implementation options:
  - Pathway A1: Objectives of MSR distributed across multiple focused spacecraft, multiple launches (3-4 missions)
  - Pathway A2: Combine functions into a smaller set (1-2) of larger multifunction spacecraft, and opportunity for lower total cost

# Pathway B: Investigate Multiple Sites Before Commencing Sample Return



**Objective:** Search for signs of past life through in-situ observations and selection of samples at multiple sites (3). Using in-situ information, Science Community selects optimal sample suite to be returned to Earth.

Pathway B reflects challenges experienced when searching for signs of past life on Earth:

- Preservation of biological signatures is rare on Earth, and investigations at multiple sites on Mars dramatically improves the probability of identifying biologically-relevant samples
  - Sites visited chosen on the basis of orbiter remote sensing observations
  - Samples would be returned from site where in-situ measurements show that rock units formed under conditions most favorable for habitability and bio-signature preservation

# “Modern Environments as Habitats” as a Pathway?



- Objective:** Investigate alternative pathways not aligned with NRC Decadal Survey recommendations, including “modern environments as habitats” (Extant Life Systems)
- New discoveries since the NRC Decadal Survey may suggest liquid water on or near the surface (if confirmed, program could seek extant life systems)
  - Community experts strongly advocated that this line of scientific inquiry (applies to others) not aligned with “Seeking Signs of Past Life” theme (Pathways A and B), be openly competed payloads on MEP strategic missions, or stand alone in Discovery, and judged on the basis of their intrinsic scientific merit as compared to others
  - Specific to “Modern Environments as Habitats”:
    - Measurements are only preliminary and immature, and pursuit and understanding of modern habitats or extant life poses scientific risks (with post Viking consequences)
    - Premature given progress and evidence that continue to validate the pursuit of the ancient life theme for the past ~16 years
    - If signs of past life are discovered there would be a greater imperative to search for extant life systems
    - Orbital reconnaissance and pursuit of understanding of new settings (brine flows, permafrost, exposed surface ice, trace gas vents) is underway and requires more time to be complete (MRO, MAVEN, ESA/RSA TGO)



# Mars System Science as a Pathway?



**Objective:** Faced with the complex history and physical diversity of Mars, advance Mars System Science in order to fill critical knowledge gaps prior to an undertaking as challenging as human exploration while responding to new discoveries about “active environments on Mars” (relevant to future Sample Return science possibilities or others)

- This pathway seeks to improve our fundamental understanding of Mars’ surface and interior in order to better inform the search for evidence of life before undertaking Sample Return and/or human exploration (surface)
- This pathway could be the path of choice if MSL revealed significant misinterpretations of orbital observations of the Gale Crater region and history
- There are multiple alternative foci within this pathway, including attention to the thermal evolution of the Martian crust and deeper interior and volcanism
- On the basis of discussions with Community Experts and analysis by MPPG members, this pathway was REJECTED because:
  - *Elements of this pathway are well-suited for open competition within AO-based opportunities such as payload selection, Discovery or New Frontiers*



# **WORKSHOP AT THE LUNAR & PLANETARY INSTITUTE**

# Mars Concepts & Approaches Workshop

Hosted by Lunar & Planetary Institute (LPI), June 12-14, 2012



- Workshop forum organized by Lunar and Planetary Institute (LPI) for the community to discuss ideas and approaches for Mars exploration
- Included both near-term (2018-2024) and longer-term (2024-2030's) timeframes
- Included both science approaches (missions, payloads, strategies) and engineering & technology approaches (mobility, sample collection and return, aerial platforms)
- LPI summary report submitted to NASA: June 18

## **Participation Statistics**

Abstracts Submitted:	390
Abstracts Selected for Presentation:	170
Abstracts Selected for Print Only:	146
Participating Countries	10

# LPI Workshop – The Results in Context of MPPG



Workshop summarized near-term science, mission and technology concepts for robotic Mars missions that support the Mars community consensus science goals, especially as delineated in the 2013-2022 Planetary Science Decadal Survey.

*(see Mackwell et al., 2012, <http://www.lpi.usra.edu/meetings/marsconcepts2012/>)*

## Major Science Themes Discussed:

- Ensuring the scientific success of MSR
- Search for past and present life (payloads, strategies)
- Exploration of unique environments to understand planetary evolution and habitability
- Martian interior through seismic studies
- Climate evolution and atmospheric processes/escape
- Phobos and Deimos – origin and composition

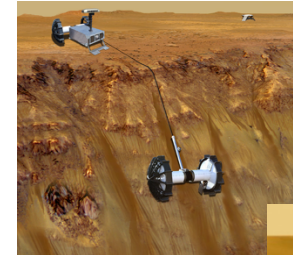
# LPI Workshop – The Results in Context of MPPG



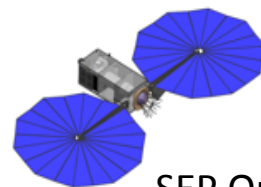
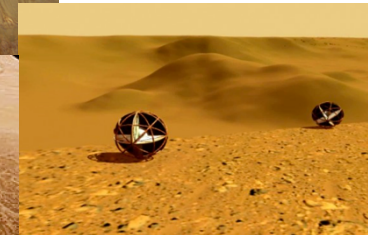
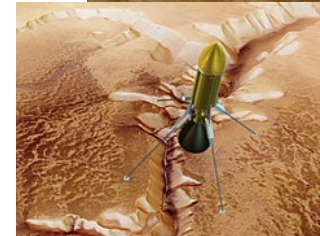
<http://www.lpi.usra.edu/meetings/marsconcepts2012/>

Expanded the trade space for alternative concepts to access the surface, sampling/analysis instrumentation, and surface system capabilities

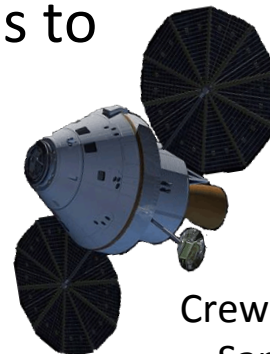
Selected ideas served as a catalyst for MPPG to charter sub-teams to explore lower cost approaches to sample return



Examples of Extreme Terrain Vehicles



SEP Orbiter & Return to Beyond Earth Orbit

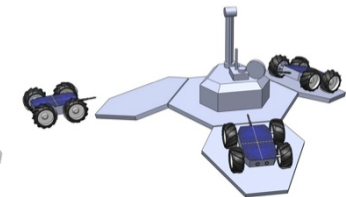


Crew Based Sample Return to Earth

Microsats



Mini-Rovers



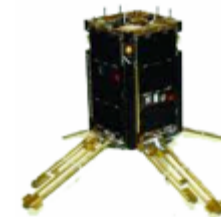
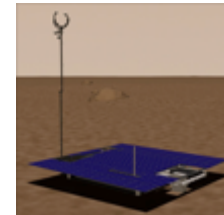
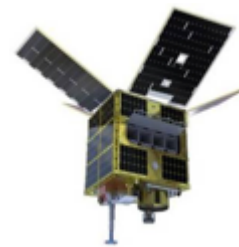
Mini-MAV



# LPI Workshop – The Results in Context of MPPG



- Ideas for Smallsats/Cubesats to complement and augment orbital & surface measurements
  - Including opportunities for student experiments
- P-POD dispensers on Mars orbiters and/or cube accommodation slots on landers may be feasible within the core mission options explored by MPPG



## Example Applications:

- Phobos Sampling
- ChipSat Re-entry Sensors
- Radio Occultation
- Weather Network
- Climate Lander
- Atmospheric Sounding
- Human Health Risks



# **COLLABORATION BETWEEN HUMAN EXPLORATION, SCIENCE, AND TECHNOLOGY**



# Human Exploration at Mars

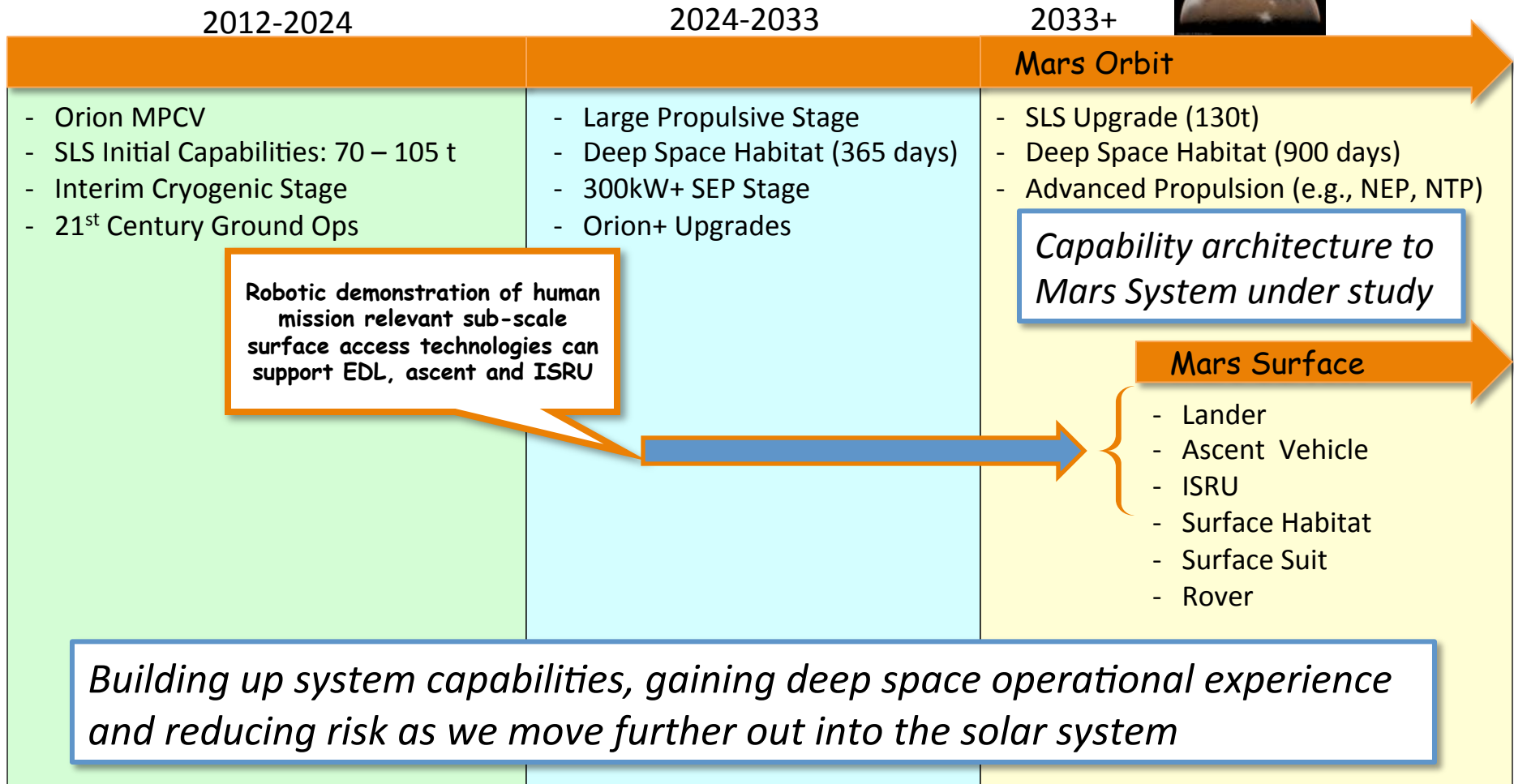
- HEOMD is demonstrating capabilities and reducing risk for human Mars exploration
  - *Near Term (2012-2022): Core Capability Development, Mid-Phase Risk Reduction*
  - *Mid-Term (2022-2033): Core Capability Operations and Upgrade and Late Phase Risk Reduction*
  - *Long Term (2033+): Humans at Mars*
- Primary risks to mitigate for in-space segment, including on ISS
  - *Life support*
  - *Spacecraft reliability, supportability and maintainability*
  - *Human performance for long durations in deep space*
  - *Transportation system performance*
- Understanding the risks to the crew of landing on, operating on, and then ascending from Mars, require additional measurements, technology, and systems development



# Capabilities Needed for Humans at Mars in 2030's



Epoch of first use:



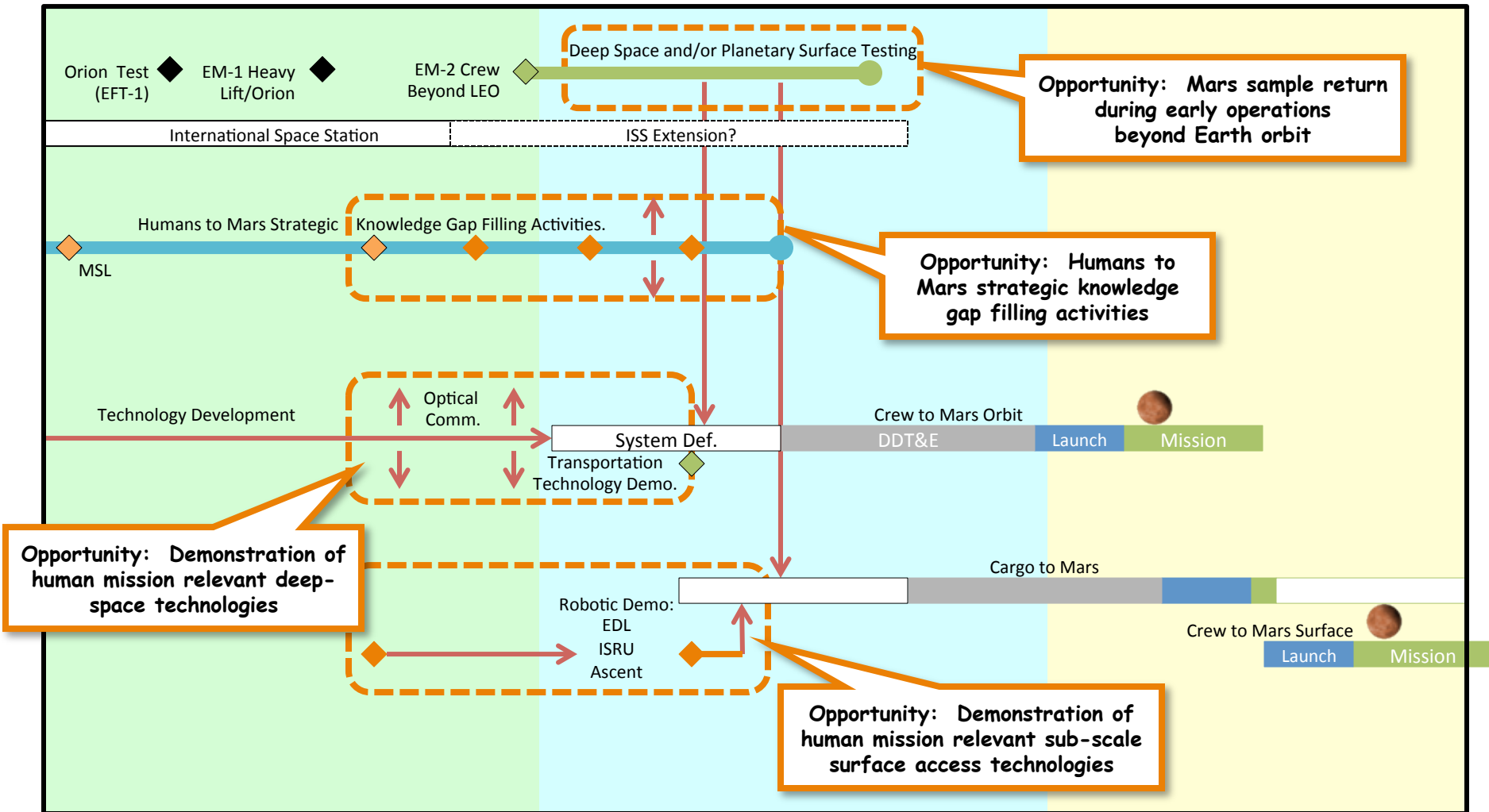
# Human Exploration / Science / Technology Intersections



2012-2022

2022-2033

2033+



For MPPG Planning Purposes – Pre-Decisional



# Defining Types of Collaboration

- **Clean-Interface Collaboration** (*payloads, demo's, SKG fillers*)
  - HEOMD experiments as piggyback on SMD missions, such as ODYSSEY, MRO, PHOENIX, MSL
  - No critical dependencies
  - All architectures/science pathways can support these
- **Interdependent Collaboration**
  - Joint activities associated with greater capabilities, such as high data rate communication, higher-mass EDL, surface power, ascent technologies, advanced sample handling and isolation, resource utilization
  - Dependencies that require cooperative management, shared resources, and agreement on approach to achieve the missions
  - Program linkages at each step, culminating in capabilities required for human access to Mars
  - SOME EXAMPLES:
    - Orbiters that image, discover resources, measure atmospheric state
    - Landers that provide ground-truth and identify samples (context)
    - Landers that demonstrate safety, EDL (e.g. MSL), resource utilization experiments

# Opportunities for Collaboration between Human Exploration and Science



- In the process of preparing for the human exploration of Mars, several opportunities exist for collaboration between human exploration and science
  - Science-focused missions provide opportunities for measurements of the Martian system to fill Strategic Knowledge Gaps (SKG's)
  - HEO developed launch capabilities may provide opportunities for science missions to reduce launch costs
  - Human capabilities and assets Beyond Earth Orbit can play a role in retrieval and return of samples from the surface of Mars
  - Future robotic technology precursor missions provide additional opportunities for access to the Martian system for scientific objectives

# Science/Human Exploration/Technology



✓ Addressed in architecture and mission options presented by MPPG

## Technology on Orbiting/Landed Assets

- ✓ High Data Rate/Bandwidth Communications
- ✓ Precision Navigation
- ✓ Enhanced Surface Mobility
- ✓ Targeted Observation/Instrumentation
- ✓ Sample Acquisition, Handling and Caching
- ✓ Autonomous Rendezvous and Docking
- ✓ Advanced SEP Propulsion
- ✓ Mars Ascent Vehicle
- ✓ ISRU demo
- ✓ Robotic Aerocapture
- ✓ Robotic Scale EDL

## Science/Precursor Measurement Payloads on Orbiting/Landed Assets

- ✓ Environmental Measurements
  - Radiation
  - Atmospheric properties
  - Climate
- ✓ Resources (Orbiters or Landed Tech Demos)
- ✓ Dust & Regolith Properties/Safety
- ✓ Site identification/selection/certification

### CONSTRUCTION ZONE: FORWARD WORK

#### Human Subscale Technology Demos with Opportunities for Science/Precursor Measurements

- 10% Subscale of human mission EDL
- Hypersonic Inflatables (HEO/HIAD)
- Mid-L/D Rigid Aeroshells
- Supersonic Retro-propulsion
- ISRU (Oxygen) Production
- ISRU-Enabled Mars Ascent Vehicle
- Aerocapture
- Advanced TPS including High-speed Earth Return

- Requires long term investment in technology
- Tips the scale to different architecture and scale of missions beyond typical robotic missions

# HEO Measurement Options on Robotic Missions



**MEPAG Precursor Science Analysis Group report\* emphasizes measurements of Mars' atmospheric conditions and the surface radiation environment to reduce risk and also provide significant science value.**

## **Robotic Orbiter(s)**

- Orbital atmospheric information related to MOI/EDL.
- Radiation—simultaneous orbital and surface measurements valuable.
- High resolution imaging and mineral mapping of the surface support:
  - Forward PP assessments
  - Landing site identification, selection and certification
  - Resource identification

## **Robotic Lander/Rover(s)**

The following measurements could be made from landed assets:

- EDL profiles of atmospheric state
- Dust properties, regolith composition, regolith structure
- Atmospheric electrical characteristics
- Atmospheric and climate measurements to obtain time dependent density profiles (simultaneous with orbital measurements).
- Radiation measurements (simultaneous with orbital measurements).

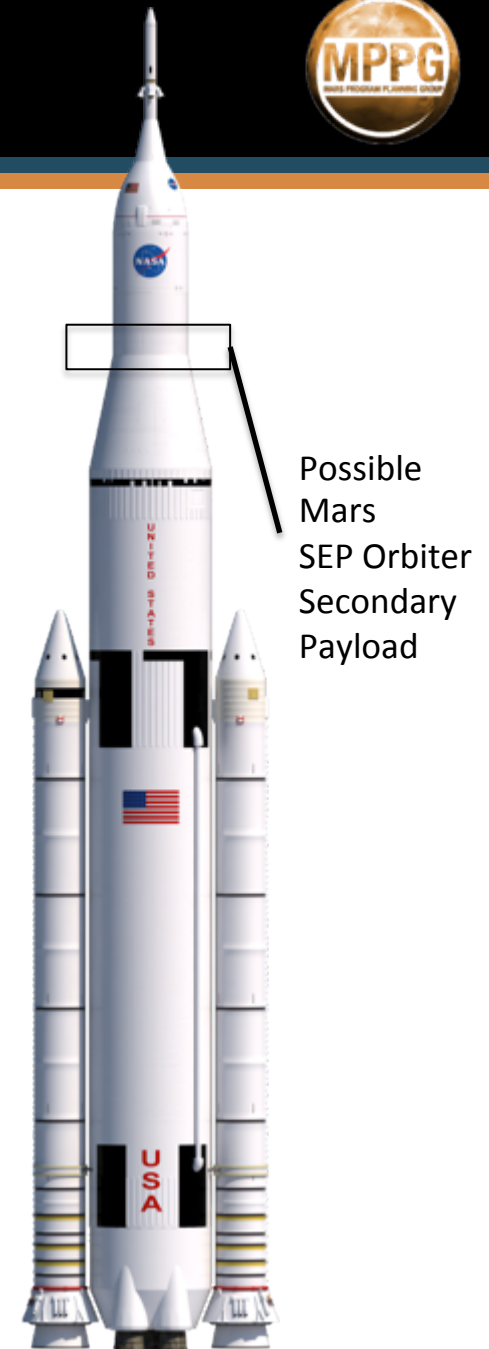
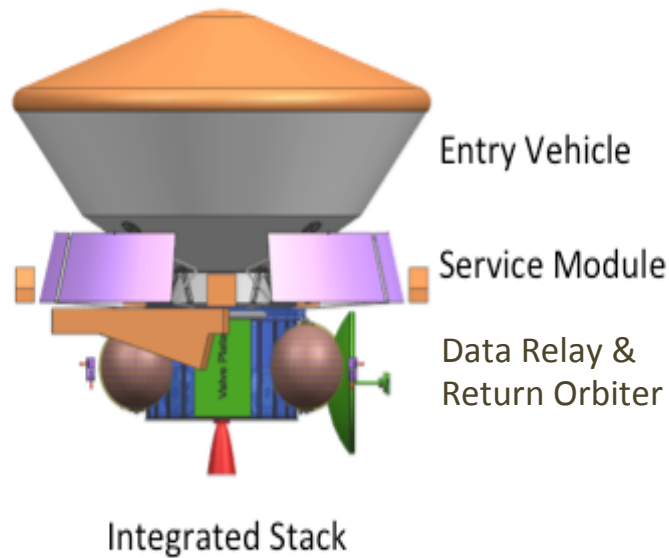
\*([http://mepag.jpl.nasa.gov/reports/psag\\_files/P-SAG\\_final\\_report\\_06-30-12\\_main\\_v26.pdf](http://mepag.jpl.nasa.gov/reports/psag_files/P-SAG_final_report_06-30-12_main_v26.pdf))

# Opportunity: Science Payloads on SLS



2024+ single-shot MSR on SLS

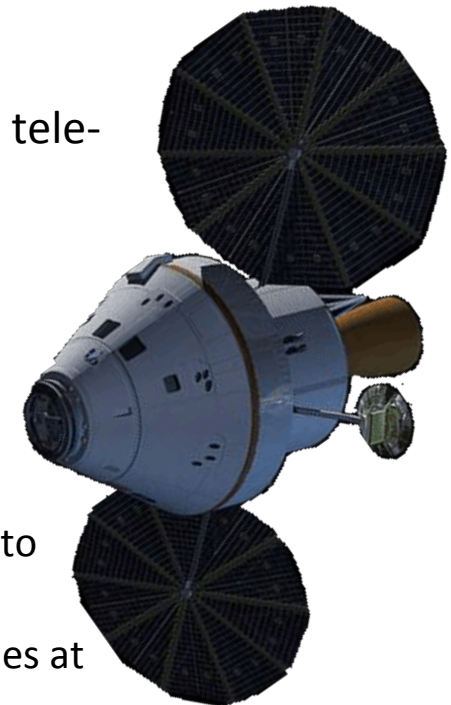
Launch cadence and availability may provide a single-shot Mars Sample Return (MSR) opportunity; backup would be Delta IV Heavy or Falcon 9H



# Opportunity: Mars Sample Recovery & Return During Early Crewed Operations Beyond Earth Orbit

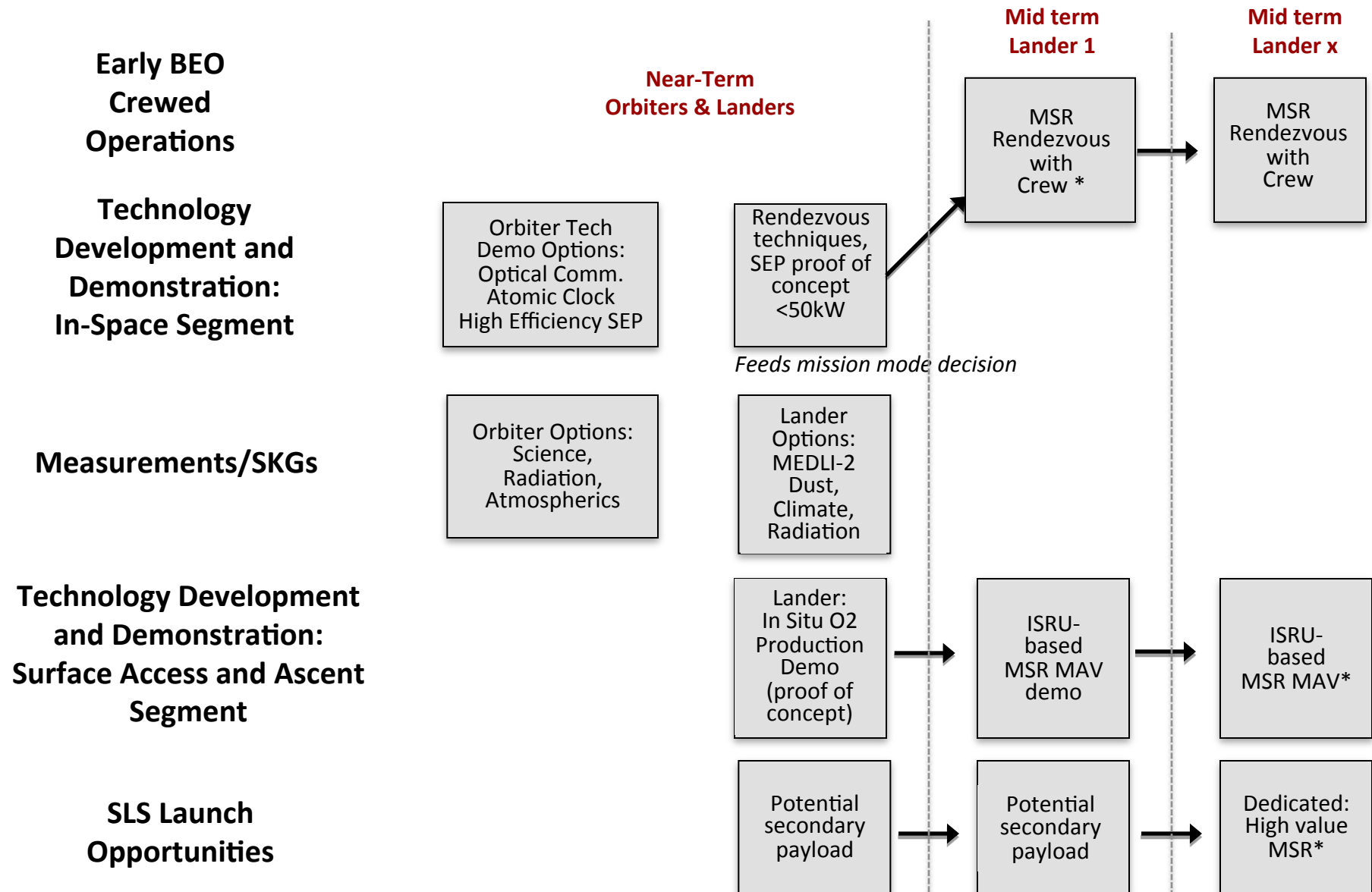


- SEP enabled robotic vehicle delivers samples to Beyond Earth Orbit (BEO) for a crew based retrieval
  - Beyond Earth Capability planned after 2021
- Sample canister could be captured, inspected, encased and retrieved tele-robotically
  - Robot brings sample back and rendezvous with a crewed vehicle
  - Cleaned sample canister would be then enclosed in a stowage case, and stowed in Orion for Earth return.
- This approach deals with key planetary protection concerns
  - Crew inspection, cleaning, and encapsulation of sample enclosures prior to Earth return
  - Removes the need to robotically “break the chain” of contact with samples at Mars, thus reducing complexity and cost of robotic missions.
- Crew entry system eliminates need for robotic Earth entry system
- Provides an early opportunity for collaboration and demonstration of capability also applicable in Mars orbit





# Intersections & Opportunities: Science, HEO, Technology Mission Options



\* Would be moved up if budget allows

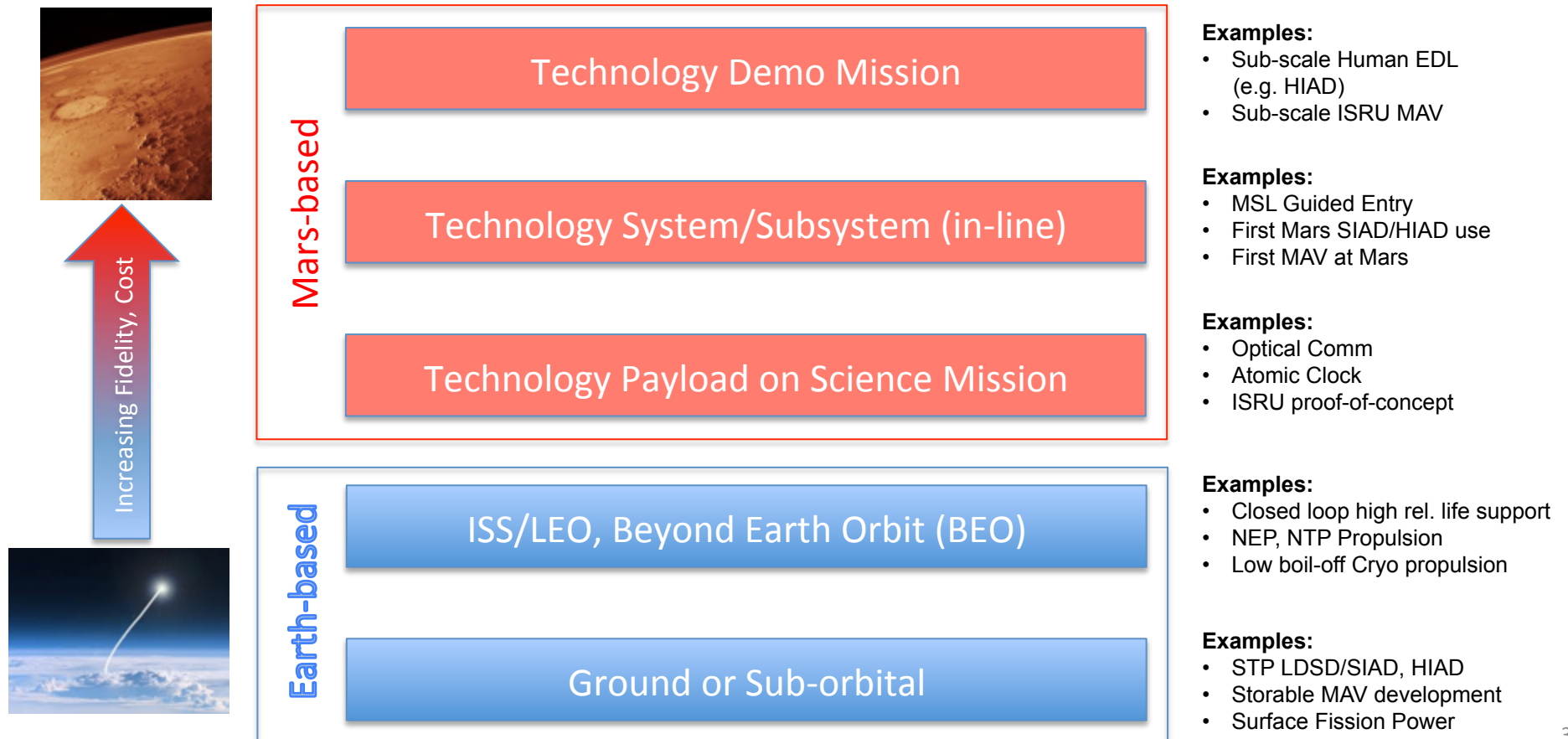


# TECHNOLOGY

# Technology Taxonomy and Development / Demonstration Approach



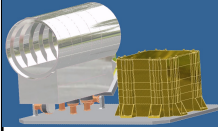



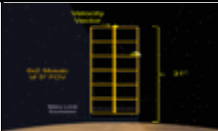
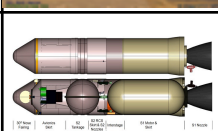
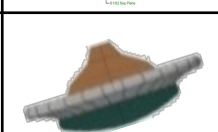
- *Mars technology needs span across science and HEO missions*
  - *Some are unique, but many are common or can be demonstrated on a common mission*
- *Mars technology demonstrations may be conducted at Earth or Mars*
  - *Demonstration environment and mission application can be scaled to meet specific demonstration objectives*



# SMD/STP Technology Efforts with HEOMD Benefit



*In addition to EDL and ISRU, the following **crosscutting** technologies are being developed today by STP (†) and SMD (\*) to support future robotic and human exploration:*

Optical Communications†	High bandwidth, high data rate communication from Mars. Enable order or magnitude or more increase in data rate, and video/voice streaming	Infusion Target: Early Opportunity Orbiter	
Deep Space Atomic Clock†	Precision Navigation for orbital assets, Entry, Descent and Precision landing. Reduces scheduling burden of ground network, enabling significant cost efficiencies	Infusion Target: Early Opportunity Orbiter	
Solar Electric Propulsion†*	Large solar arrays, higher power, high thrust Hall thrusters. Enables flexibility in implementation of the architectures	Infusion Target: Early Opportunity Orbiter	
Sample Acquisition, Handling and Caching*	Enable access and sampling at the surface, analysis. Securing for transfer to another vehicle, and return	Infusion Target: Early Opportunity Lander	
Autonomous Rendezvous and Docking†	Sensors and software to autonomously detect, rendezvous and capture the orbiting sample canister in orbit.	Infusion Target: MSR Orbiter	
Mars Ascent Vehicle	Mars Ascent Vehicle to deliver surface samples into low Mars orbit (including ascent flight dynamics). Conventional non-cryogenic liquid or solid propellants	Infusion Target: MSR Lander	
Large Deployable Supersonic Decelerators†	Next generation deceleration technologies to enable evolution to 1.2-1.5 t landed mass robotic missions from current SOTA < 1 t. Enable greater planet access	Infusion Target: Early-Mid Term Opportunity Lander	

# Key Technologies for Entry, Descent & Landing



<b>Approach Phase</b>		Near-Term Robotic (1-2t)	Sub-scale EDL Precursor (~5 t +)	Human Full-Scale (20-40t)	
Approach Navigation	Precision Star Tracker, Late Update, Optical Nav, Precision IMU	●	●	●	
<b>Entry Phase</b>					
Atmospheric Guidance	Lift Modulation, Drag Modulation	●	●	●	
Hypersonic Decelerators	Deployables: HIAD, ADEPT	○	RO	RO	
	Rigid: Slender body Aeroshell		RO	RO	
<b>Descent Phase</b>					
Supersonic Decelerators	Smart Descent/Deploy Logic	●	○	○	
	30m Supersonic Parachute	●			
	SIAD	●	○	○	
Supersonic Retro-propulsion	High-thrust liquid		○	●	
<b>Landing Phase</b>					
Surface sensing and navigation	Terrain Relative Navigation, ALHAT, Hazard Detection and Avoidance	●	●	●	
Subsonic Propulsion	Storable (Monoprop/biprop), Cryo (biprop)	●	●	●	
Energy Absorption	Airbags, Crushables	●			
High-g Systems	Rough Lander	○			

Potentially Applicable

○

Fully Applicable

●

Investment Priorities

# Key Technologies for ISRU and Mars Ascent



- *Demonstration of ISRU generation of propellants (O<sub>2</sub> and CH<sub>4</sub>), followed by an ISRU-enabled MAV provides significant risk reduction for humans to the surface of Mars*
- *Mars Ascent Vehicle (MAV) is unique in needs for long-term propellant management (storage and/or production) in a challenging thermal environment*

<b>ISRU</b>		Near-Term Robotic	Sub-scale Precursor	Human Full-Scale	
Processing	Atmospheric Processing for Liquid Oxygen		●	●	
	Fuel processing of Surface Available Hydrogen (Ice/Hydrated Mineral Processing)		○	○	
	Other materials – Construction, Radiation Protection		○	○	
Propulsion	LOX/Methane		●	●	
<b>Mars Ascent Vehicle (MAV)</b>		Near-Term Robotic Storable (.2-.3 t)	Sub-scale Precursor ISRU MAV (TBD)	Human Full-scale ISRU MAV (20+ t)	
Propellant Type	Solid vs. Liquid	●	Liquid	Liquid	
Propellant Production	Ox only vs. Ox + Fuel		●	●	
Thermal Control	Isolation from Mars Environment	●	●	●	
Payload Loading	OS Loading, Break-the-Chain	●			

Potentially Applicable

○

Fully Applicable

●

Investment Priorities

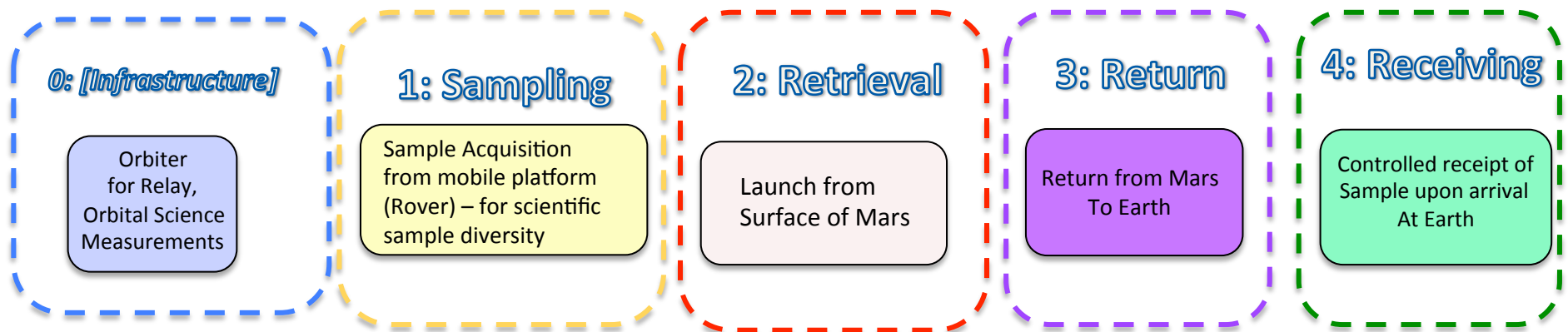


# **POSSIBLE PROGRAM ARCHITECTURES: IMPLEMENTATIONS OF HIGHEST PRIORITY SCIENCE PATHWAYS**

# Key Functions in Sample Return



- Five functional elements are required to return samples from Mars
- These functions can be accomplished in multiple ways and by one or more missions



**Pathways A or B Start at Step 0 OR Step 1**

**Pathway B Dwells on Step 1 to Optimize Samples**

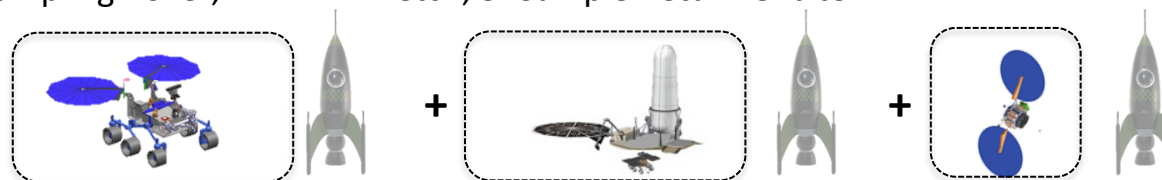


# Sample Return Launch Options

- Mars Sample Return (MSR) can be implemented by breaking the mission into different “Launch” and “Landing” Packages
- MPPG looked at accomplishing MSR in 1, 2 or 3 launches with various cost, cost profile and risk implications

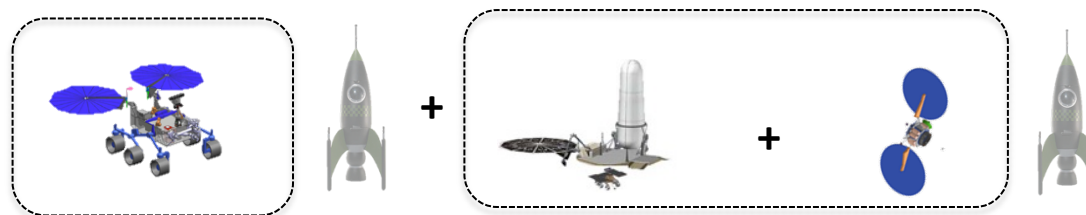
## Three launches

- This is the architecture proposed to the Decadal Survey
  - 1- Sampling Rover, 2- MAV + Fetch, 3- Sample Return Orbiter



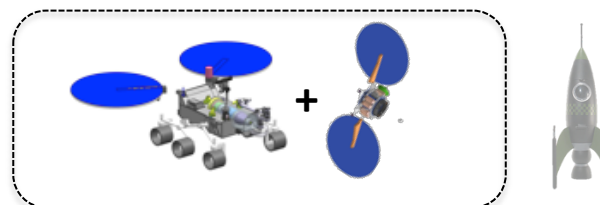
## Two Launches

- Sampling Rover paired with a second launch (MAV/Fetch + Small SEP Return Orbiter) to accomplish a “Two Launch MSR”



## One Launch

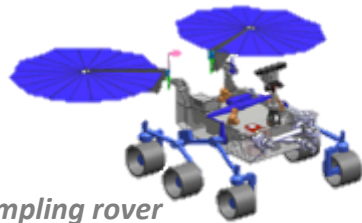
- Sampling rover carrying a MAV, co-manifested with a small SEP orbiter to bring the sample back to Earth/Moon system



# Pathway A1: Multi-mission MSR



*Optional*



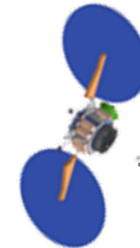
*Sampling rover*

+



*Static MAV & fetch rover*

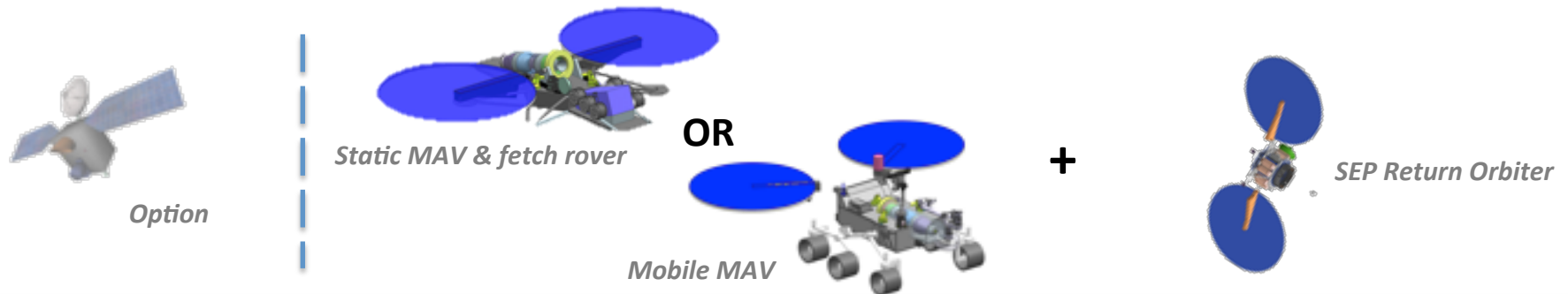
+



*SEP Return Orbiter*

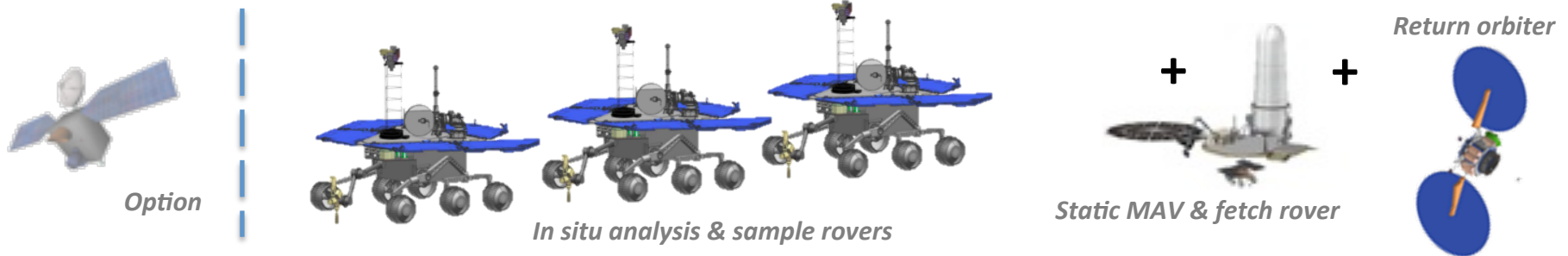
- Architecture for Pathway A1 is multi-mission:
  - New sampling rover concepts have reduced costs by ~50% from prior MAX-C/ExoMars missions evaluated as part of the NRC Decadal Survey (independently costed)
- Architecture Features:
  - De-couples sample acquisition and MAV missions
  - Allows large time allocation for sample acquisition without concern for MAV survival on Mars surface
  - Spreads technical challenges across multiple missions
  - Provides landed mass margins within family with existing MSL CEDL capability
  - Spreads budget needs and reduces peak year program budget demand
  - Missions have opportunities for additional orbital/in situ science
  - Sample return orbiter can be integrated into single launch (e.g. SLS, Falcon heavy) with MAV lander or combined/co-manifest with other missions

# Pathway A2: Integrated Sampling/MAV MSR



- Architecture for Pathway A2 pursues a cost-driven MSR approach with fewer discrete spacecraft-vehicles/launches:
  - Consolidation of functions are made to significantly reduce the life-cycle costs
  - Extensive option space explored, and 7 representative options were detailed
- Architecture features:
  - Landed mission integrates sample acquisition via rover and either fixed platform MAV or mobile MAV into one lander (compared to Pathway A1) and saves the cost of a lander and a launch vehicle
  - Sample return orbiter can be integrated into single launch (e.g., SLS, Falcon heavy) with lander or combined/co-manifest with other missions
  - Mobile MAV eliminates surface mission coordination complexities
  - Lowest overall costs due to elimination of at least one complete mission, but higher peak year budget demand

# Pathway B: Multi-Site Investigation Before MSR



- Architecture for Pathway B employs multiple rovers delivered to independent sites that are investigated to provide detailed understanding of their habitability and bio-signature potential and the optimal sample suite is returned to Earth
- Architecture features:
  - Provides potential to blend in situ science and sample collection at a pace to accommodate available budget
    - Once the selection of the returned sample is made, this Pathway utilizes the same return architecture as Pathway A
  - Production line build of the rovers and cadence of launches offers the opportunity to significantly reduce the cost (in comparison to multiple independent missions)



# Common Aspect of All Pathways

- Maintained heritage from MSL/MER C/EDL and rovers
- Take advantage of guided entry for MSL class landing accuracy
- All MAV landers utilize as-flown MSL Sky Crane capabilities
- Incorporated innovative ideas from past studies and concepts presented at LPI
- Reduced mass of MAV/OS (guided or unguided) can be launched to either deep space or Mars orbit, providing flexibility for return orbiter timing/availability
- Using SEP-based orbiters for sample rendezvous and return
  - Return of sample canisters to crew in BEO (Earth-Moon neighborhood) to be captured by astronauts and returned to Earth [eliminating Earth entry vehicle]
  - Potential co-manifest with other vehicles
- Have options to use lower cost LVs



# **SURFACE AND ORBITAL MISSION CONCEPTS**

# Sampling Rover Concepts Studied

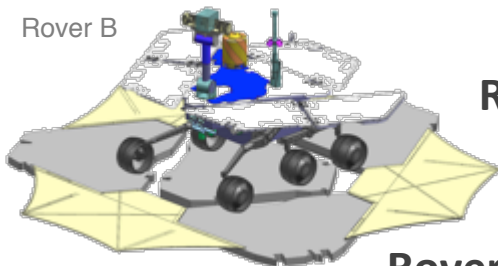


## Four rover options studied

**Rover A:** MER “clone” allowing for sampling and replacing obsolete avionics. Might not fit in the MER volume envelope

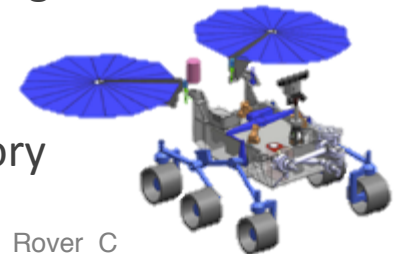


Rover B

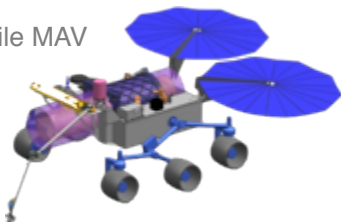


**Rover B:** Similar to Rover A allowing for some volume growth

**Rover C :** based on MSL delivery and chassis, with inventory reuse and some de-scopes (e.g. solar vs. RTG)



Mobile MAV



**Rover D:** derived from Rover C with MAV integrated into vehicle and carried to sampling sites

- Costs reduced from Decadal Survey concept by maximizing heritage and reducing scope and complexity:
  - Developed payload concept compatible with either a MSL or MER rover class
    - All rovers designed for latitudes -15 to +25
  - Strong heritage from MSL and MER, especially C/EDL
    - All rovers delivered with MSL-class accuracy using guided entry (upgrade to MER-based concepts)
    - Landing altitude capability of up to -0.5 km w.r.t. MOLA reference

# Rover Concepts Comparison (1)



Rover A

- MER-based system w/ guided entry addition
- Build on successful MER design heritage.

## Advantages

- Heritage MER mechanical structures and EDL systems
- High EDL heritage
- Feed forward applicability to small surface missions
- Low recurring costs
- Low launch vehicle costs (Falcon 9 v1.1)

## Challenges

- Very limited payload/volume margin

## Costs Estimates

- Internal \$1.1B
- Aerospace ICE \$1.0B
- Aerospace CATE \$1.0B
- LV (F9) \$0.16B ('18) / \$0.19B ('20)
- **Phase A-D ~\$1.1 - 1.3B**



Rover B

- Scaled MER-based system w/ guided entry addition
- Build on successful MER architectural heritage.

## Advantages

- Robust to inheritance assumptions (new systems)
- Feed forward applicability to small/mid surface missions
- Low recurring costs
- Low launch vehicle costs (Falcon 9 v1.1)

## Challenges

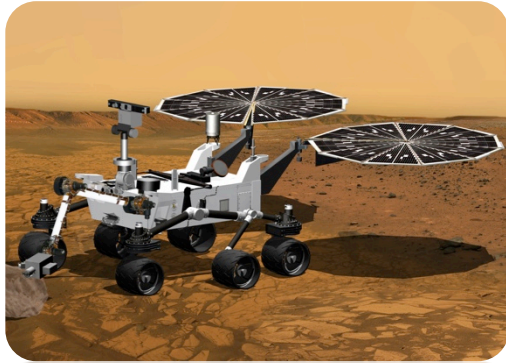
- Requires new airbag & touchdown system development

## Costs Estimates

- Internal \$1.2B
- Aerospace ICE \$1.1B
- Aerospace CATE \$1.1B
- LV (F9) \$0.16B ('18) / \$0.19B ('20)
- **Phase A-D ~\$1.3 - 1.4B**



# Rover Concepts Comparison (2)



Rover C

- Solar MSL-based system
- Build on successful MSL design heritage.

Advantages

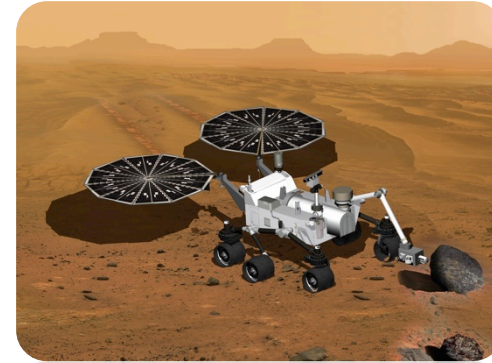
- Robust to payload growth
- Substantial HEO/STP payload opportunity
- Best mobility range/life/mission return
- Substantial redundancy
- High EDL heritage
- Feed forward applicability to large MSR / MAV missions

Challenges

- High launch vehicle costs (Atlas)

Cost Estimates

- Internal \$1.0B
- Aerospace ICE \$1.1B
- Aerospace CATE \$1.3B
- LV (A5) \$0.32B ('18) / \$0.40B ('20)
- **Phase A-D ~\$1.3 - 1.7B**



Rover D

- MSL-based system with integrated MAV
- Build on successful MSL heritage.

Advantages

- Provides capable surface science platform
- Supports agency MAV demonstration / return capability
- Best mobility range/life/mission return
- Substantial redundancy
- High EDL heritage
- Can be coupled w/ return orbiter for lowest MSR cost

Challenges

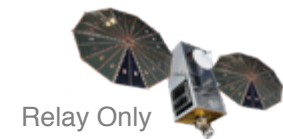
- Rover mechanical mods; MAV development; and LV costs

Cost Estimates (STILL UNDER DEVELOPMENT)

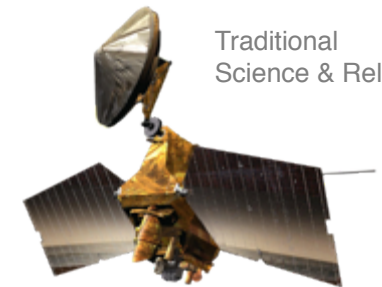
- Internal ~\$1.4B estimate only
- Aerospace ICE N/A
- Aerospace CATE N/A
- LV (A5) \$0.32B ('18) / \$0.40B ('20)
- **Phase A-D TBD**

# Orbiter Concepts Studied

- Orbiters play multiple roles in architectural framework
  - Relay Infrastructure
  - Programmatic infrastructure to provide landing site identification/selection/certification
  - Ongoing or new measurements from orbit—e.g., hi-res imaging/mineral mapping, resource identification, HEO gap-filling measurements for Strategic Knowledge Gaps (SKG's)
  - Sample Return from Mars to Earth
  
- Several orbiter concepts developed that combine one or more of these functions
  - **Relay-only** infrastructure orbiter – Might use Solar Electric Propulsion enabling co-manifest with other mission to partially eliminate launch cost
  - **“Traditional” Science + Relay** Orbiters (a la MRO, ODY) using combinations of chemical and aeroassist propulsion
  - **Sample return orbiters** – Meets up with samples either at a) Low Mars Orbit (chemical or Solar Electric Propulsion) or b) deep space rendezvous (SEP only). Might also co-manifest with landers
  - **Round-trip Science + Sample Return** Orbiters can launch early, perform science mission and return after landed missions conclude



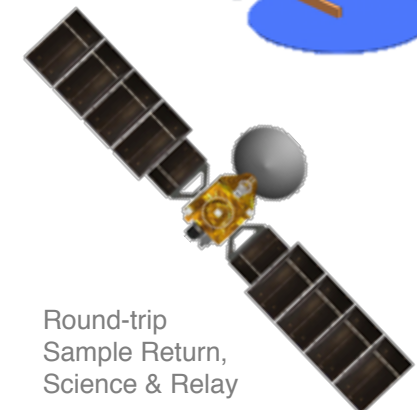
Relay Only



Traditional  
Science & Relay

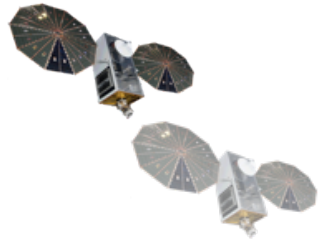


SEP Sample  
Return



Round-trip  
Sample Return,  
Science & Relay

# Orbiter Concepts Comparison



### Single Function Orbiter

- New system
- Can be used for UHF or Sample return
- Single String Design (redundant option to fly 2)

### Advantages

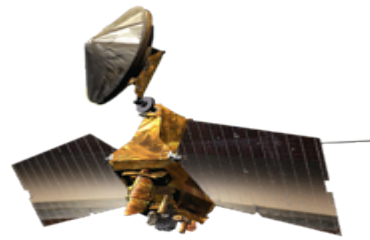
- Simple design
- Additional units lower cost
- Can deliver more frequently
- Very low launch cost as secondary payloads

### Challenges

- Very limited payload
- Limited Lifetime

### Costs Estimates

- Internal \$0.2 B (no payload, launch as secondary)



### Science + Relay Orbiter

- MRO/MAVEN based
- Science and tech demo payloads

### Advantages

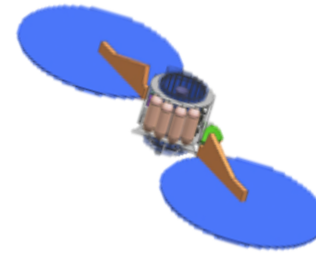
- High bus heritage
- Infrastructure/science instruments have robust heritage
- High data volume
- Large payload capacity

### Challenges

- Compatible orbit selection for science and relay

### Costs Estimates

- Internal \$0.5 B
- Aerospace ICE/CATE \$0.6 B
- LV (F9) \$0.13 B



### SEP Sample Return Orbiter

- New system
- Commercial Components

### Advantages

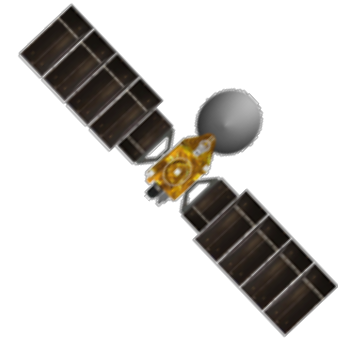
- Co-manifest with Lander
- Augments LV capacity
- Commercial SEP components

### Challenges

- No EDL relay support (arrives later)

### Costs Estimates

- Internal \$0.5 B (Lander carries launch cost)



### Science + Sample Return Orbiter

- MRO/MAVEN Based
- Can support science, relay, tech demo, and sample return

### Advantages

- Science and Relay while waiting
- High bus heritage
- Commercial SEP components
- High mass and data volume
- Very large payload capacity

### Challenges

- Break-off orbital science to return samples to Earth

### Costs Estimates

- Internal \$0.7 B
- LV (F9) \$0.13 B



# **COST PICTURE AND THE EARLY OPPORTUNITIES**

# Cost Analysis Process



- Cost estimates developed for candidate missions, then used to populate different program queues, and ultimately assessed for compatibility with President’s FY13 Budget Submittal
  - Scenarios to explore what is possible with augmented funding were also considered
- Depending on the maturity and anticipated timeliness of launch for each concept, estimates of varying depth/fidelity were developed:



- **Gold Standard:** Independent Cost Estimate (ICE) + Cost and Technical Evaluation (CATE) performed by Aerospace Corporation – equivalent to Decadal Survey Process. Core estimates from study team based on AS BUILT missions (MSL, MER, MRO)



- **Silver Standard:** Parametric Model, Team X Study, Cost by analogy to previously developed systems



- **Bronze Standard:** “Guesstimate” – Expert opinion, interpolated between or extrapolated from other data points of Class A or Class B estimates

# 2018-2024 Example Missions



ID	Function	FY15 \$(B)*	Visual	Estimate Standard
Orbiters				
A	Single Function SEP Orbiter, e.g. UHF, Earth Return (Secondary Launch Option)	TBD: ~0.1– 0.2		
B	Comm.+ HR Camera + Mineral Mapper	0.6 – 0.7		
C	Orbiter B + Optical Comm.	0.6 – 0.8		
D	Orbiter C + Extended Science (e.g., SAR, SOFTS)	0.7 – 0.9		
Landers				
A	MAV on Stationary Lander + Fetch Rover	TBD: ~1.8+		
B	Rover A/B	1.1 – 1.4		
C	Rover C	1.4 – 1.6		
D	Rover C + MAV (Mobile MAV)	TBD: ~1.8+		
E	Athlete + MAV Demo	TBD		
*Costs Phase A-D, including launch (except Orbiter A)				

# Orbiter or Rover First ?



## Arguments for Orbiter First

- Orbiter in '18 provides infrastructure to all landed missions in '20-'26
  - Existing orbiter network can likely support '18 landed mission, but risk increases after '20
- Provides new science for enhanced surface site identification, selection, certification to support all Pathways and future human landing sites
- FY13 President's budget does not support a rover in 2018 (2020 earliest)

## Arguments for Rover First

- '18 provides one of the most energetically favorable launch opportunities
- Lander in '18 or '20 best for preservation of key competencies such as End-to-End EDL and Surface Science Operations and Mobility
- Leverages MSL surface experience to identify/select/analyze/secure high science value samples at a priority site for further study and potentially return

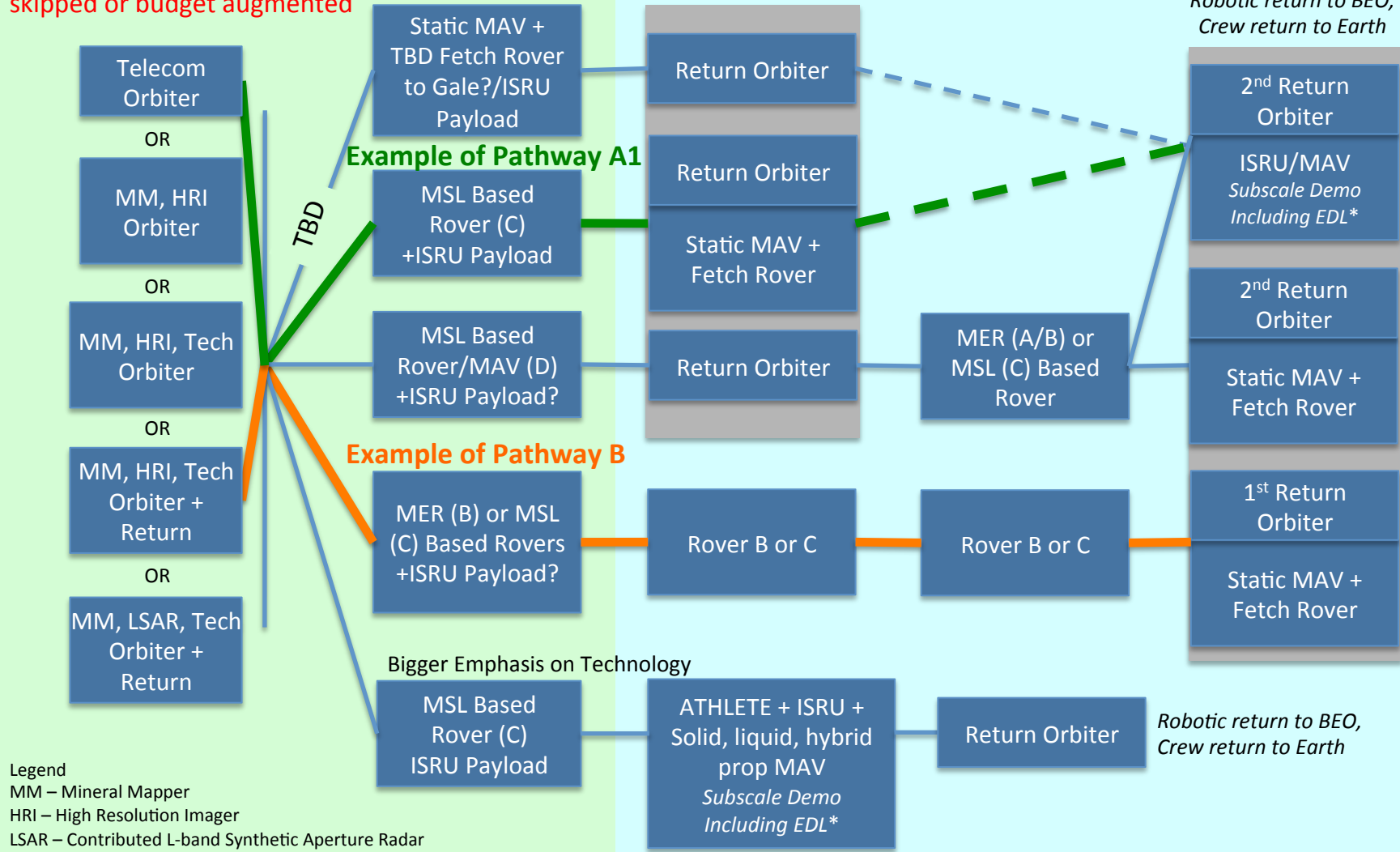
# Example Options for Strategic Collaboration Science / Human Exploration / Technology



Early Opportunities 2018-2022

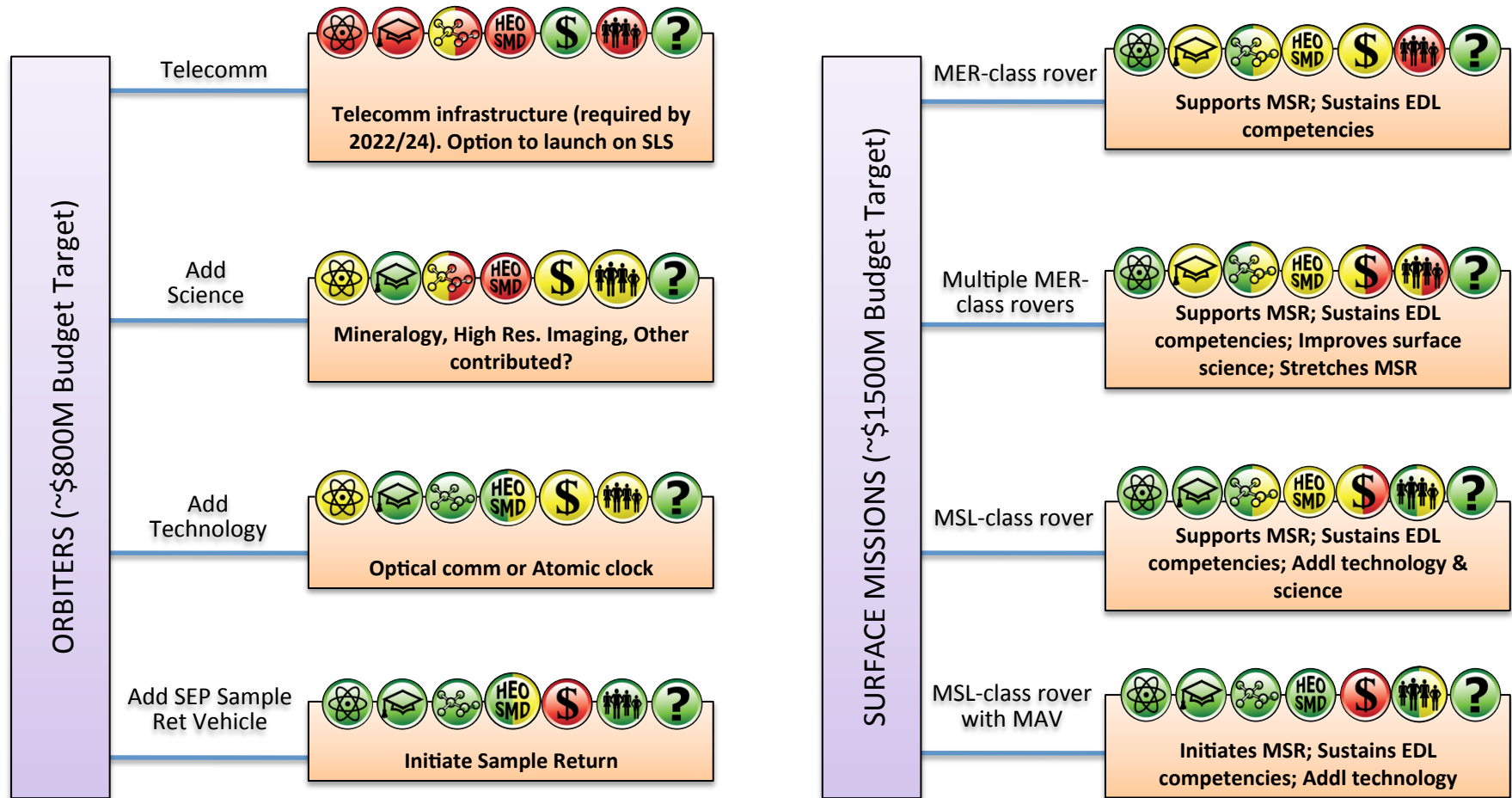
2024+

Sequence can be reversed if 2018 opportunity is skipped or budget augmented





# Input for Follow-on Benefits Assessment



## Legend





# OTHER PROGRAMMATIC CONSIDERATIONS

# International Collaboration



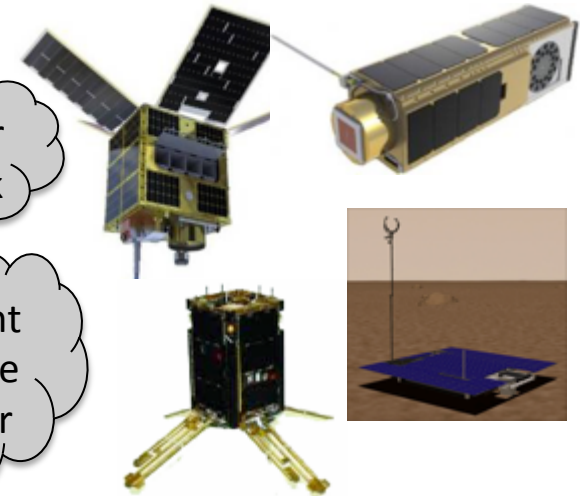
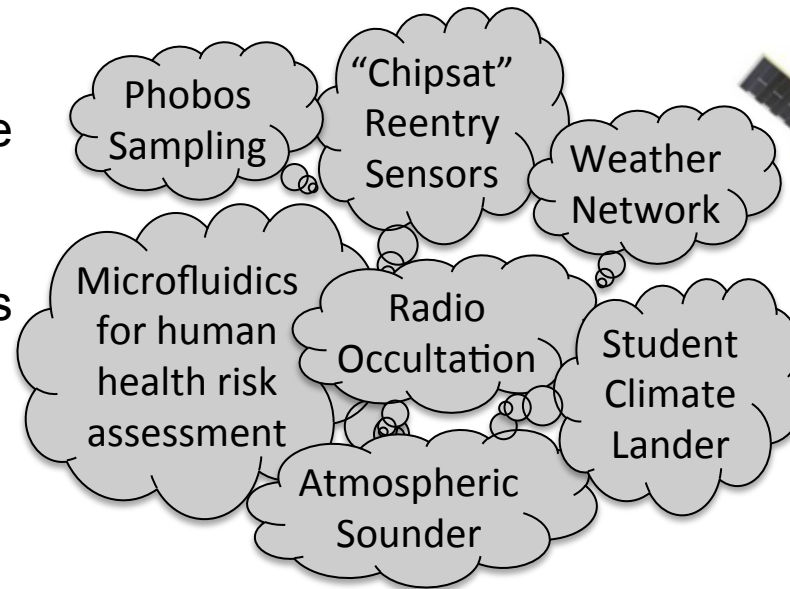
- MPPG reached out to the international community, but only peripherally
  - They attended/presented at LPI, and participated in follow up conversations to identify specific areas of collaboration (e.g. CSA interests in SAR and robotic arms)
  - Long standing conversations among HEOMD international partners continue through the International Space Exploration Coordination Group (ISECG)
- Exploration of Mars continues to be of interest to NASA's international partners, and is considered a necessary component to enable human missions to Mars
  - Existing partners are expected to play critical roles in human exploration
  - Possible scenarios leading from ISS and LEO to Mars are being discussed to build a common vision, and leverage current investments in preparatory activities

# Smallsat / Cubesat / Student Payloads at Mars



Small/Cube/Nano-Satellites, offer increasingly sophisticated measurement capabilities in small, low-mass (1 – 10 kg), low-power, low-cost (\$1 – 10M) packages that are adaptable for Mars.

P-POD dispensers on Mars orbiters and/or cube accommodation slots on landers may be feasible within the mission options explored by MPPG



A Mars Program element can provide an opportunity for SMD/HEO/STP/OCT/OCS collaboration in further developing the technologies, compete for opportunities for multiple mission designs, and down-select for implementation

# Research & Analysis Program, Instrument Technologies



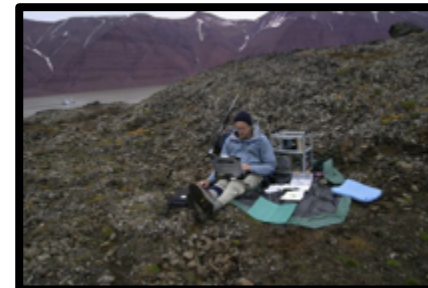
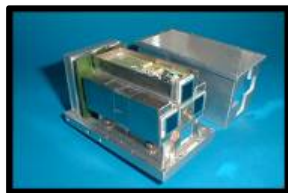
## Mars science Research and Analysis programs

- Maintain healthy Science research activities to capitalize on data sets collected by on-going Mars missions
- Address fundamental understanding of Mars system science and signs of ancient life via bio-signatures
- Trade/maintain science pipelines



## Mars instrument technology developments

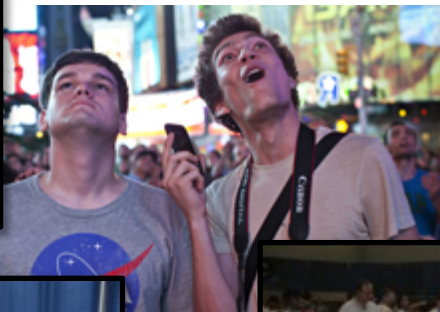
- Create/maintain instrument system technology development program to address future mission needs
- Pursue next generation/breakthrough remote sensing/in situ instrumentation/experiment concepts
- Reduce risks to future instrument development for Mars missions



# Education & Public Outreach



- Mars activities provide world wide attention with potential to strongly motivate next generation talent in science, technology, engineering and mathematics
- Mars E/PO program has adopted a thematic approach (i.e. not mission by mission but program-wide) and has been excellent in its focus and reach
- Provide 1% of program funding for E/PO





# MPPG SUMMARY

# MPPG Summary of Findings and Observations



1. MPPG options address the primary objectives of the NRC Decadal Survey, with human exploration capabilities playing an increasing role over time, in the scientific exploration of Mars
2. Sample return architectures provide a promising intersection of objectives for long term SMD/HEOMD/STP collaboration, particularly in EDL and ISRU/Mars ascent technologies
3. MPPG offers several options to implement an integrated strategy for Mars exploration, providing flexibility and resiliency while recognizing the programmatic and fiscal challenges
  - a. Provides a compelling science program, with sample return as a centerpiece in the overarching theme of Search for Signs of Past Life; endorses competition for other Mars science beyond the central theme
  - b. Leverages robotic missions to fill Strategic Knowledge Gaps (SKGs) for human exploration and strengthen scientific collaboration
  - c. Technologies and capabilities are identified that are of mutual benefit and enable humans at Mars orbit in the 2030's, with opportunities for increased collaboration in the future
  - d. Options represent ~50% cost reduction compared to NRC Decadal concepts, and are responsive to Decadal objectives; implementation options include: 1) spreading risk and cost across several missions, 2) MSR in a single mission, and 3) improving probability of returning samples that preserve evidence of past life.
4. A variety of “building block” rovers and orbiters are suggested and costed, to facilitate planning of the new program architecture by NASA
  - a. The building blocks provide options to specifically target the early mission opportunities
5. Return of samples to Beyond Earth Orbit (BEO) to be recovered by astronauts offers an early intersection of robotic and human flight programs, as capability is developed for human surface exploration of Mars



# Gale Crater: Mount Sharp Flank



# Acronyms



A5 = Atlas V  
ADEPT = Adaptable, Deployable Entry and Placement Technology  
ALHAT = Autonomous Landing and Hazard Avoidance Technology  
AO = Announcement of Opportunity  
BEO = Beyond Earth Orbit  
CAPS = NRC Committee on Astrobiology and Planetary Science  
CATE = Cost and Technical Evaluation  
C/EDL = Cruise, Entry, Descent, and Landing  
CSA = Canadian Space Agency  
DCSS = Delta Cryogenic Second Stage  
DDT&E = Design, Development, Test & Evaluation  
DSAC = Deep Space Atomic Clock  
EDL = Entry, Descent, and Landing  
EEV = Earth Entry Vehicle  
EFT-N = SLS Exploration Flight Test #N (-1, -2, etc.)  
EM-N = SLS Exploration Mission #N (-1, -2, etc.)  
E/PO = Education & Public Outreach  
FoM(s) = Figure(s) of Merit  
F9 = Falcon 9  
GFA = Gap Filling Activity  
GSFC = Goddard Space Flight Center  
HEOMD/HEO = Human Exploration and Operations Mission Directorate  
HIAD = Hypersonic Inflatable Aeroassist Device  
HQ = Headquarters  
HRI = High resolution imager  
HRP = Human Research Program  
ICE = Independent Cost Estimate  
IFM = In-Flight Maintenance

IMEWG = International Mars Exploration Working Group  
InSight = Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport  
ISECG = International Space Exploration Coordination Group  
ISRU = In Situ Resource Utilization  
ISS = International Space Station  
JPL = Jet Propulsion Laboratory  
JSC = Johnson Space Center  
KSC = Kennedy Space Center  
LDSD = Low Density Supersonic Decelerator Project  
LEO = Low Earth Orbit  
LMK = SLS Launch Mission Kit  
LOX = Liquid Oxygen  
LPI = Lunar and Planetary Institute  
LV = Launch Vehicle  
MAVEN = Mars Atmosphere and Volatiles Evolution  
MAV = Mars Ascent Vehicle  
MAX-C = Mars Astrobiology Explorer/Cacher  
MEDLI = Mars EDL Instrumentation  
MEP = Mars Exploration Program  
MER = Mars Exploration Rovers  
MEPAG = Mars Exploration Program Analysis Group  
MM = Mineral mapper  
MOI = Mars Orbit Insertion maneuver  
MPCV = Multi-Purpose Crew Vehicle  
MPPG = Mars Program Planning Group  
MRO = Mars Reconnaissance Orbiter  
MSA = MPCV Spacecraft Adapter

MSL = Mars Science Lander/Curiosity  
MSR = Mars Sample Return  
NAI = NASA Astrobiology Institute  
NEP = Nuclear Electric Propulsion  
NRC = National Research Council  
NTP = Nuclear Thermal Propulsion  
ODY = 2001 Mars Odyssey  
OCS = Office of Chief Scientist  
OCT = Office of Chief Technologist  
OMB = Office of Management and Budget  
OMS = Orbital Maneuvering System  
OS = Orbiting Sample Container  
P-POD = Poly-Picosat Orbital Deployer  
P-SAG = MEPAG Precursor Science Analysis Group  
POTUS = President of the United States  
PP = Planetary Protection  
RT = Round-trip  
RTG = Radioisotope Thermoelectric Generator  
SAR = Synthetic Aperture Radar  
SDT = Science Definition Team  
SEP = Solar Electric Propulsion  
SIAD = Supersonic Inflatable Aeroassist Device  
SKG = Strategic Knowledge Gap (for human exploration)  
SMD = Science Mission Directorate  
SLS = Space Launch System  
STP = Space Technology Program  
SRV = Sample Return Vehicle  
TBD = To Be Determined  
TLI = Trans-lunar Injection  
UHF = Ultra-High Frequency