A Strategy for Revolutionizing Access to the Mars Surface:

Frequent. Affordable. Bold.

A report out from A Keck Institute for Space Studies Workshop: Revolutionizing Access to the Martian Surface

Study Leads: Chris Culbert (JSC), Bethany Ehlmann (Caltech), Abigail Fraeman (JPL)

Bethany Ehlmann

California Institute of Technology

Overview

Mars exploration has progressed to the point that the most pressing scientific questions and needed measurements can only be addressed by missions to the surface. To enable a cadence of multiple landed missions at Mars, new cost-efficient approaches are required.

We studied how to substantially reduce the cost associated with landed missions to Mars by novel system designs (e.g., for delivery to Mars, entry-descent-landing, landed asset design, operations) and examining cost models, institutional/project management processes, and non-traditional partnerships with industry.

Under the auspices of the Keck Institute for Space Studies, we convened a broad group of workshop participants (next slide)
https://kiss.caltech.edu/programs.html#access2mars
Workshop 1: April 2021
3-month summer study period; working groups addressed specific programmatic, cultural, and engineering factors
Workshop 2: September 2021.
Final report and town hall AGU 2021 - Monday, 13 Dec 2021, 11:15-12:15 CST
https://agu.confex.com/agu/fm21/meetingapp.cgi/Session/118920

Workshop Participants

Representing multiple NASA Centers, industry (old space and new space), and academia
Participants represented a mix of scientists, engineers, and costing/business development leaders.

- Sam Albert - University of Colorado Boulder
- Don Banfield - Cornell University
- Jon Bapst - JPL
- Dave Bearden - JPL
- Kevin Bonnet - University of Colorado Boulder
- Joel Burdick - Caltech
- Wendy Calvin - University Nevada, Reno
- Barbara Cohen - NASA Goddard Space Flight Center
- Tim Crain - Intuitive Machines
- Chris Culbert - NASA Johnson Space Center [study co-lead]
- Charles (Chad) Edwards - JPL
- Bethany Ehlmann - Caltech [study co-lead]
- Giusy Falcone - University of Illinois
- Abigail Fraeman - JPL [study co-lead]
- Elizabeth Frank - First Mode
- Andrew Horchler - Astrobotic
- Mark Johnson - Lockheed Martin
- Brett Kennedy - JPL
- Laura Kerber - JPL
- Rob Manning - JPL
- David Masten - Masten Space Systems
- Larry Matthies - JPL
- Michelle Munk - NASA Langley Research Center
- David Murrow - Lockheed Martin
- Paul Niles - NASA Johnson Space Center
- Mark Panning - JPL
- Zachary (Zach) Putnam - University of Illinois
- Eva Scheller - Caltech
- Rachel Sheppard - JPL
- Nathan Stein - Caltech
- Skylar Wei - Caltech
- Ryan Woolley - JPL
- Paul Wooster - SpaceX

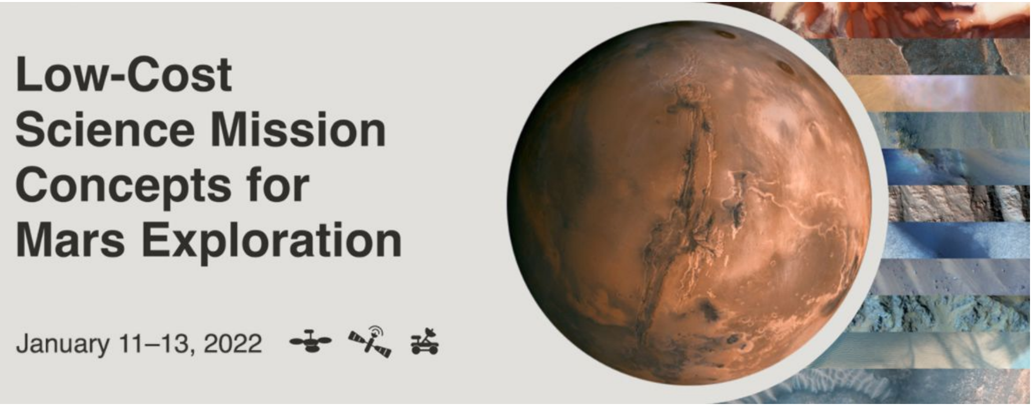
KISS Revolutionizing Access to Mars Wkshp1 Team Photo

Report & Release Schedule

AGU rollout - here now!

Advanced Review Copy online now at the link in the slide footer

Final version posted for release before the upcoming conference

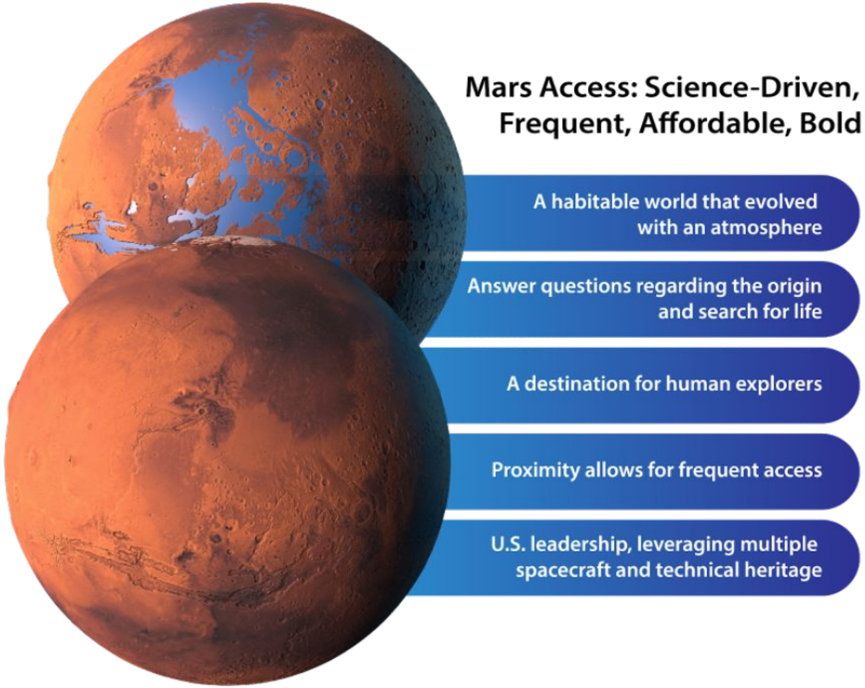


Wendy Calvin

University of Nevada, Reno

Access to Mars' Surface: Why Needed Now?

- Key science questions require in situ access (MASWG report)
- Continuity of progress and presence of US leadership at Mars (human, robotic)
- Mars Sample Return has primary importance and nothing in this strategy is intended to replace or delay MSR.
- But we believe there are opportunities to augment and expand on that critical investment at a relatively low cost with high potential for community engagement.



MASWG Pointed to the Importance of Surface Access

Mars Architecture Strategy Working Group, November 2020 report

Science Goal Mission Element	M-Arc	SSc	DSc	NFc	FLG
Orbit-based characterization of atmospheric circulation, transport processes	3,4	■	■		
Transport of dust/aerosols and their relationship to atmospheric escape and climate	4	■	■		
Low-altitude global magnetic field survey, gravity mapping	2	□	■		
Environmental transitions in the ancient record by high resolution orbital imaging spectroscopy	1	□	■		
In-situ geophysics (subsurface ice/water w/ resistivity, GPR; seismo., magnetism)	2	□	■	■	
In situ surface-atmosphere boundary layer interactions (trace gas measurements)	4	□	■	■	
In situ, mobile geological explorers for characterizing ancient habitable environments, environmental change, organics detection	1	□	□	■	■
Global orbital radar mapping of ice reservoirs	3		□	■	■
In situ mid-latitude ice sampling for characterization	3		□	■	■
In situ polar layer deposit climate record determination	3			□	■
In situ geochronology for Martian and solar system chronology	1,2,3			□	■
In situ life/organics detection in Martian ice, deep subsurface	1,2,3			□	■

□ possible or partial priority science at this class ■ achieves priority science at this class

Finding 7: Affordable access to the surface.

A critical scientific need for Mars exploration is affordable access to multiple places on the Martian surface with adequate payload/mobility to make the measurements that would revolutionize our understanding of the Mars system.

- Understanding Mars has a habitable world–and potentially an abode for life–requires multiple types of measurements, probing different time periods of history, in multiple locations (similar to Earth history)

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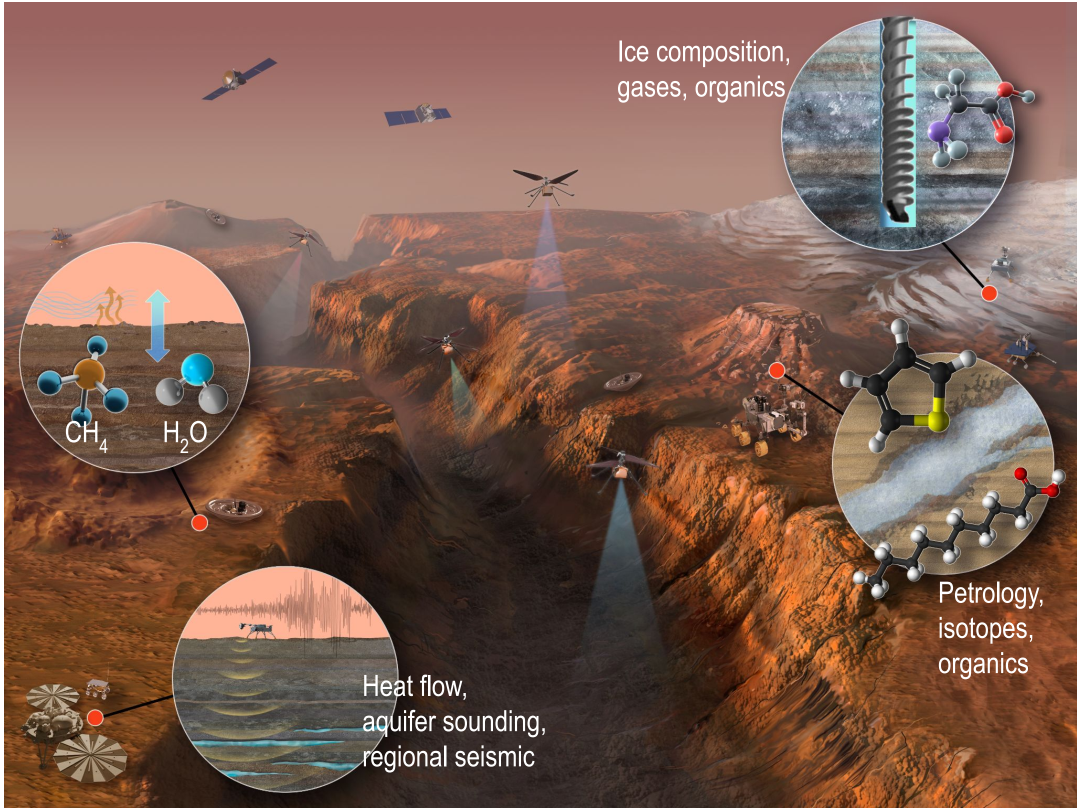
Full report Advance Review Copy at https://www.kiss.caltech.edu/final_reports/Access2Mars_final_report.pdf

The Vision - Science Mission Types for Landed Access

Mission Science Objective	Lander	Lander Network	Aerial Mobility	Rover mobility	Large Landed Mass
Surface-atmosphere boundary layer interactions (incl. trace gases)	X	X	X	X	X
Geophysics (subsurface ice/water, seismology, magnetism)		X	X	X	X
Polar layered deposit climate record			X	X	X
Geology for ancient habitable environments, environmental change			X	X	X
Geochronology for Martian and solar system chronology				X	X
Life/organics detection in Martian ice, deep subsurface				X	X
Mid-latitude ice sampling for characterization					X



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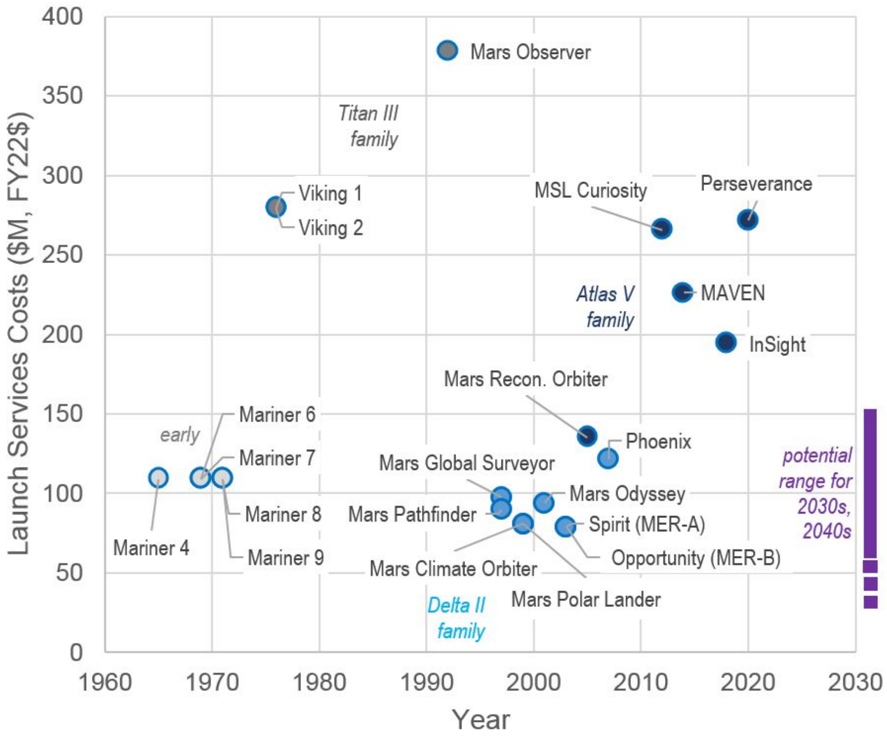
Chad Edwards

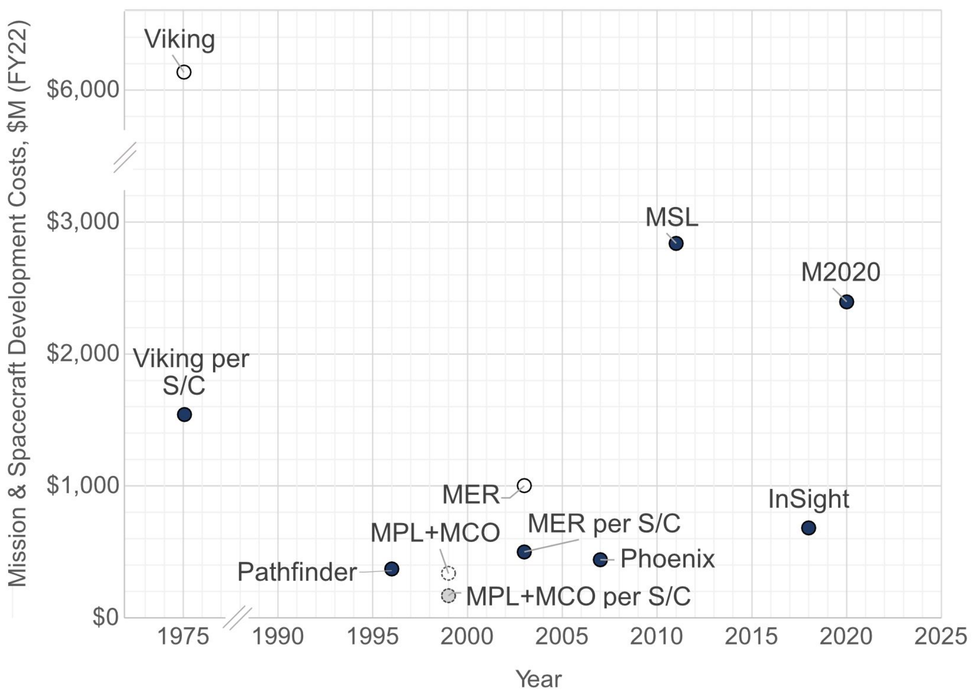
Jet Propulsion Laboratory, California Institute of Technology

The Challenge

Launch Services Costs



Per-Spacecraft Development Costs for Landed Mars Missions

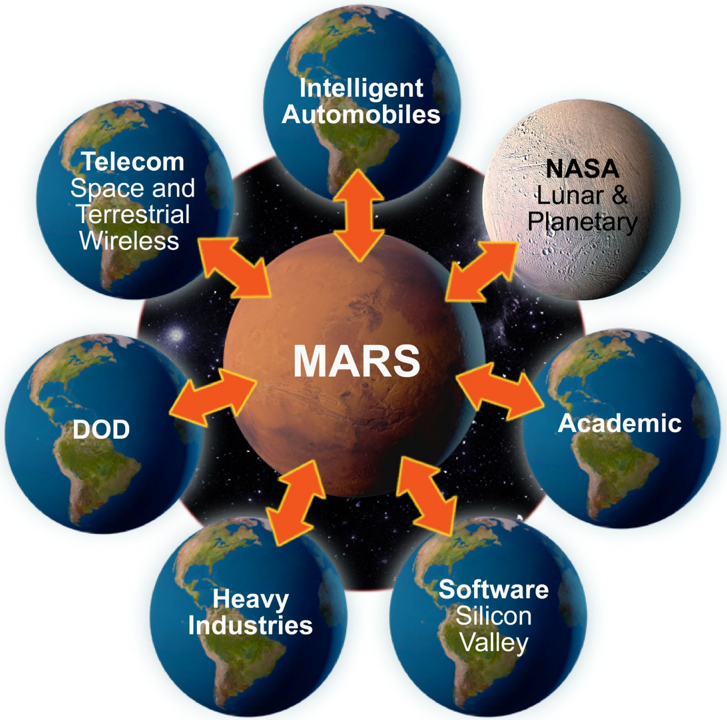


The Challenge

Examined historical landed Mars missions as well as proposed technological approaches for future Mars missions. Key challenge is achieving access at costs at significantly less than $1B/mission to enable more frequent Mars surface access.

- Reducing launch costs - piggyback, rideshare, and new low-cost LVs could save $10s - $100s M/mission
- Leveraging emerging small spacecraft market for highly capable sciencecraft in low SWaP, low-cost implementations
- Seeking reductions in labor, which dominate current mission costs: e.g., simplicity, standardization, reuse, modularity/automation in testing, multi-/simultaneous builds
- Thinking across multiple missions, types of spacecraft, and target bodies can maximize benefit for technology and cost by reducing non-recurring engineering and parts common across missions

Technology Opportunity



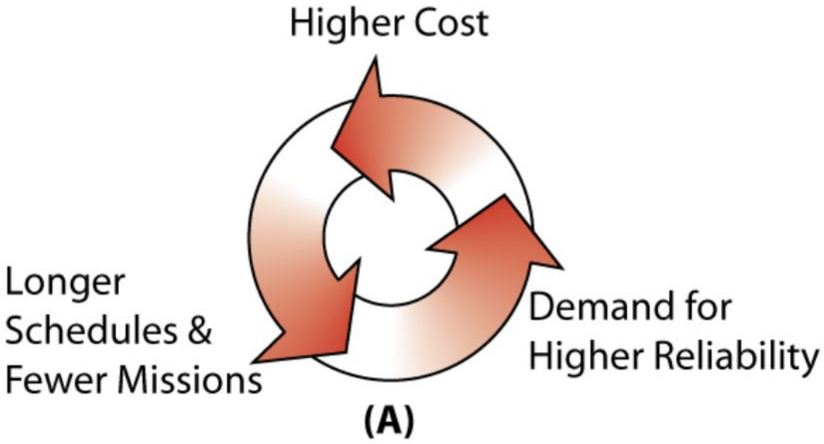
- Assess full range of Mars capability needs
  - Which are Mars-unique?
  - Which are shared with other non-Mars stakeholders and sponsors?
  - Where can we infuse technologies from much larger terrestrial and commercial space investments to reduce costs in areas that are not unique to a Mars surface mission?
- Leverage new partnership approaches to share technologies in mutually beneficial ways.

Full report Advance Review Copy at https://www.kiss.caltech.edu/final_reports/Access2Mars_final_report.pdf

Elizabeth Frank

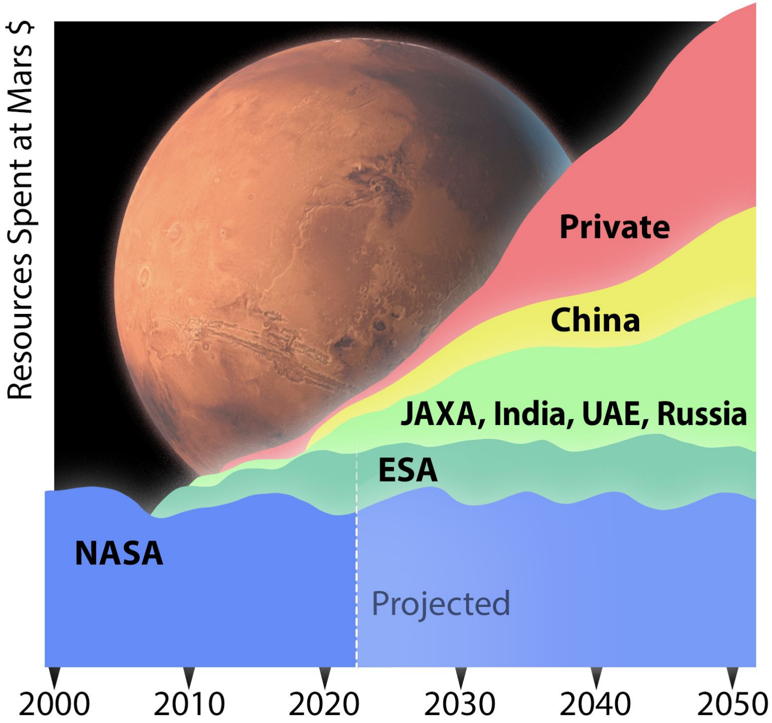
First Mode

Avoiding the Space Spiral



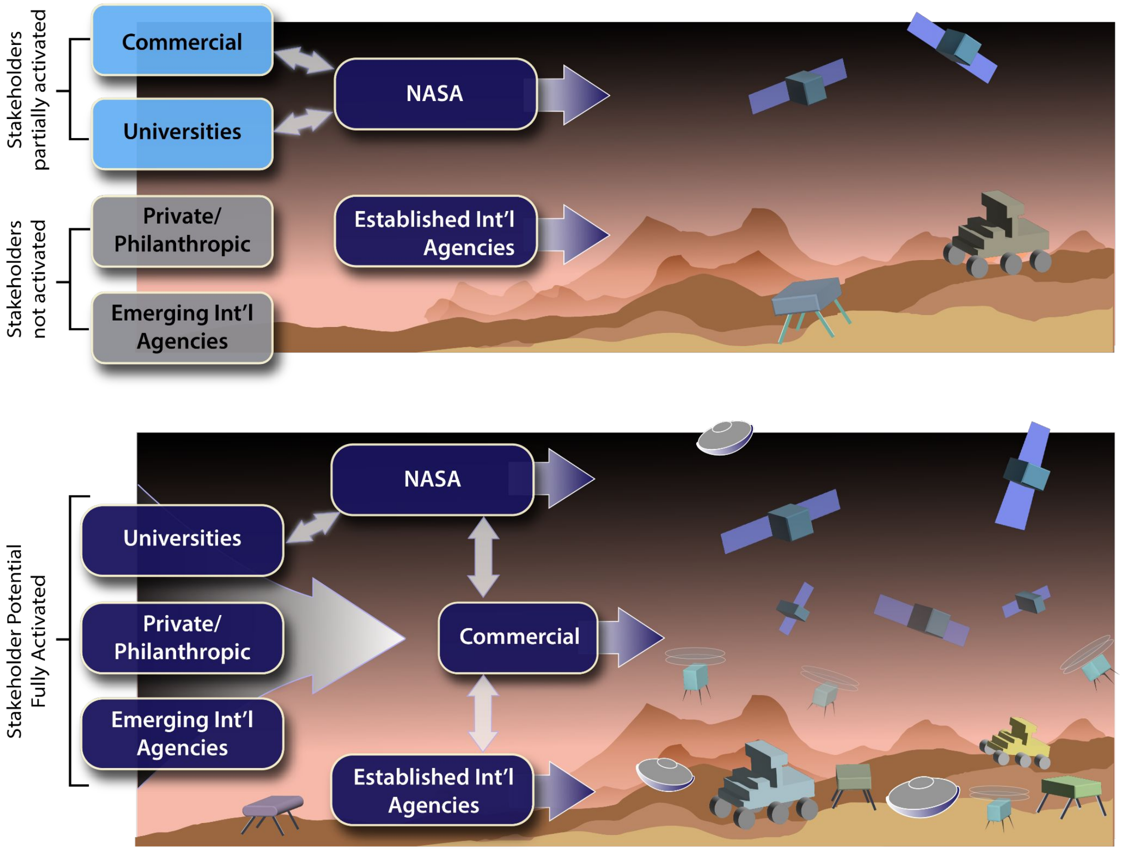
Harnessing Commercial and Societal Trends for Mars

- We are at a natural juncture to leverage innovation in the space and technology sectors to enable a program of Mars surface access that grows the U.S. commercial space sector
- The incentives of different stakeholders (e.g. commercial sector, private investments, governments) are aligning in a way that can be harnessed for pushing the bounds of space exploration.
- Key technologies and developments can be leveraged to develop cost-effective ways to explore Mars



Incentivizing Partnerships

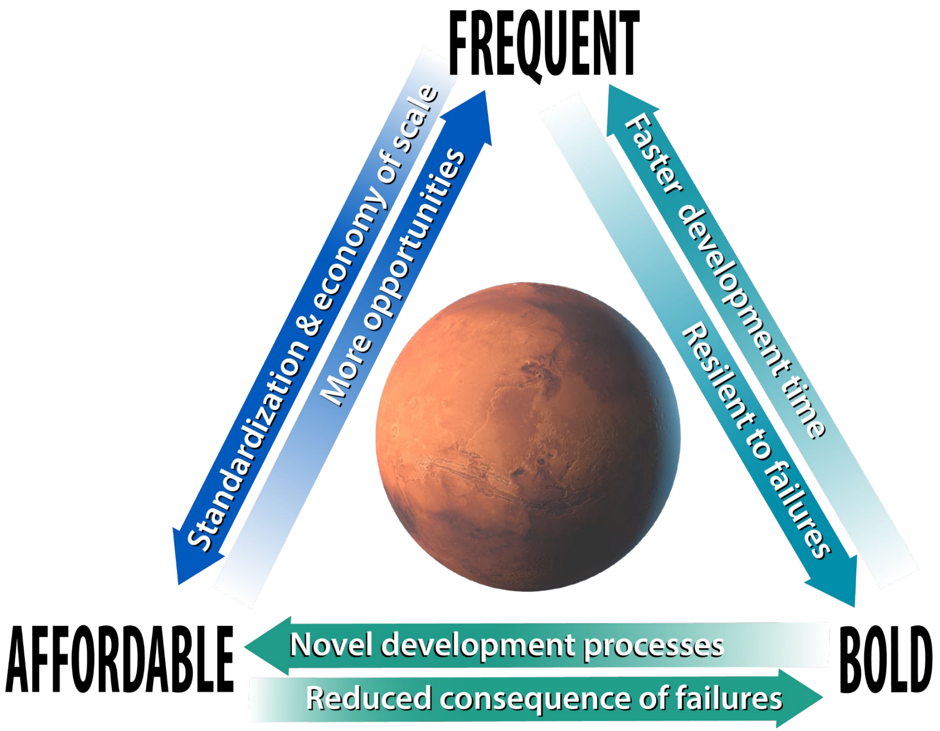
- Changing role of commercial spacecraft builders can activate more stakeholders who have a means to participate
- Opportunity to broaden the value of Mars missions by enabling partners with stakeholders who have motivations in addition to science objectives (teaching/research curriculum, prestige, workforce/tech development)
- Recognize NASA's unique role in creating opportunity but resist the desire to control all aspects of the missions



Chris Culbert

NASA Johnson Space Center

Key Elements of the FAB Mars Exploration Strategy



- Frequent: Two missions to Mars at every opportunity
- Initial focus on low cost, smaller missions that can fit in a moderate extension to MSR budget.
- Take advantage of emerging commercial capabilities and interests, international partners
- Be aggressive defining mission timelines, goals, capabilities, and budgets
- Balance mission cost, complexity, pace, and risk in a measured manner that relies upon multiple frequent missions to achieve goals

Near Term Programmatic Steps

1. Identify where early mission activities might align with commercial interests while also supporting the longer term goals of FAB.
2. Start a process to identify the types of technical capabilities that might be readily available for near-term Mars missions and those that might be available in the mid-term with modest investment.
3. Start an instrument development track.
4. Fund a number of short term study/analysis activities with commercial companies to more deeply assess feasibility of the commercial concept and relevance to program needs, including consulting technical support from NASA.
5. Work with entities such as MEPAG to develop a science roadmap
6. Create agreements (contracts, grants, Space Act Agreements, cooperative agreements, etc.) for partnering with one or more entities to develop, deliver, or provide services for FAB activities.

Missions Programmatic Plan

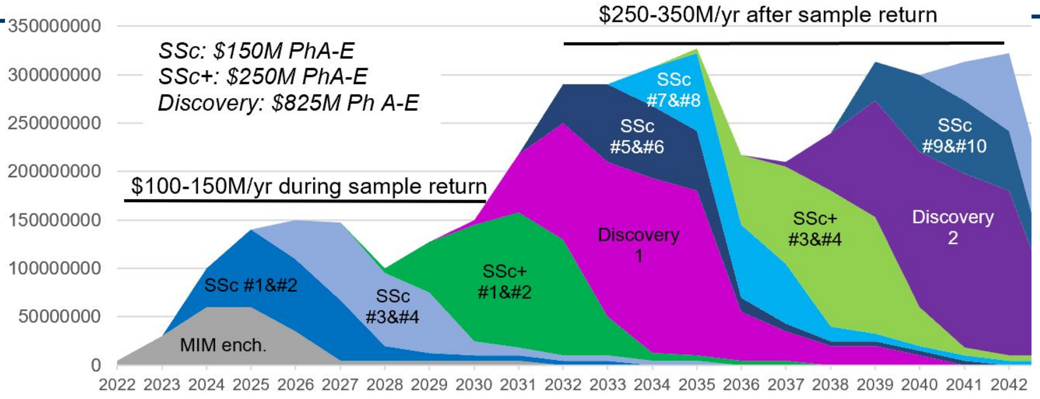
Missions start from a “minimum viable product”, e.g. small hard landers and communications satellites, and evolve the desired capabilities in this new risk environment (SSc: $150M).

Investments in commercial technology to “close the gap” will enable mobility, soft landing, and higher mass after several years (SSc+ $250M; Discovery+secondary $825M).

Funding must be consistent and committed over a set number of years; the program should be renewable beyond that timeframe, based on overall program performance.

- An annual budget of $250-350M per year (in line with the CLPS Lunar plan) should support the FAB style mission components of this notional program and progress can commence at a lower level even during sample return.
- The 2x/opportunity FAB-style missions will not preclude traditional flagship and higher class missions, if the science req’ts warrant such approaches.

Fast, Affordable, Bold Mars Exploration Mission Cadence



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EXTRAS

Figure E. Per unit cost drops with multiple flight copies. Analysis of expenditures for ST-5 mission from New Millennium program. The ST-5 project was the development and simultaneous launch of three small, 20-kilogram-class spacecraft as a precursor to future constellation missions. First flight unit costs included non-recurring costs, which were approximately 60% of the total. Substantial cost savings were achieved in the first few copies of a spacecraft manufacture, even without investments in assembly line manufacturing. (Fig. adapted from Chen and McLennan 2004)