Starting Small at Mars, and then Going Big

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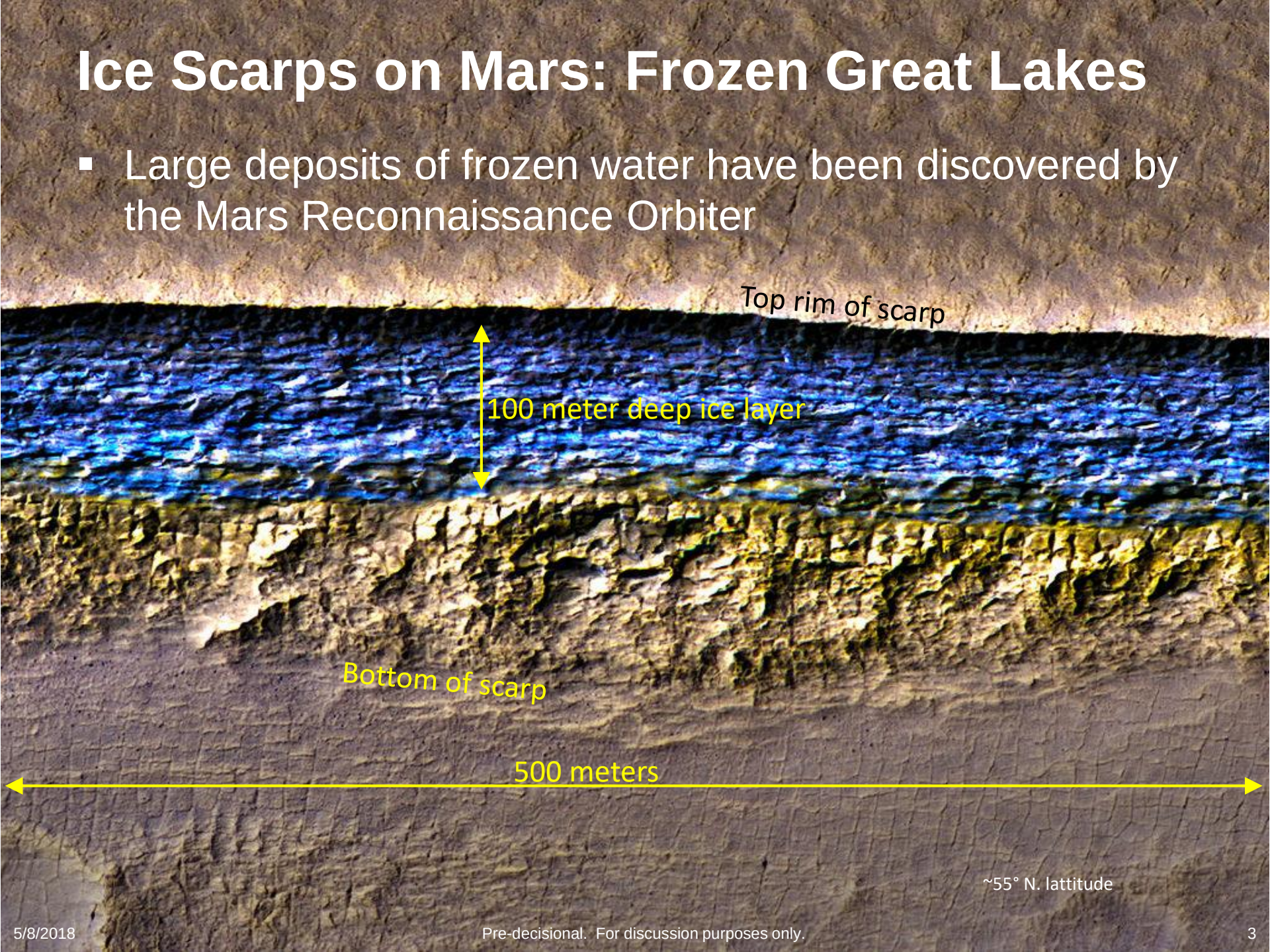
Presentation at the National Space Society
Los Angeles, California
May 25, 2018

Why Mars?

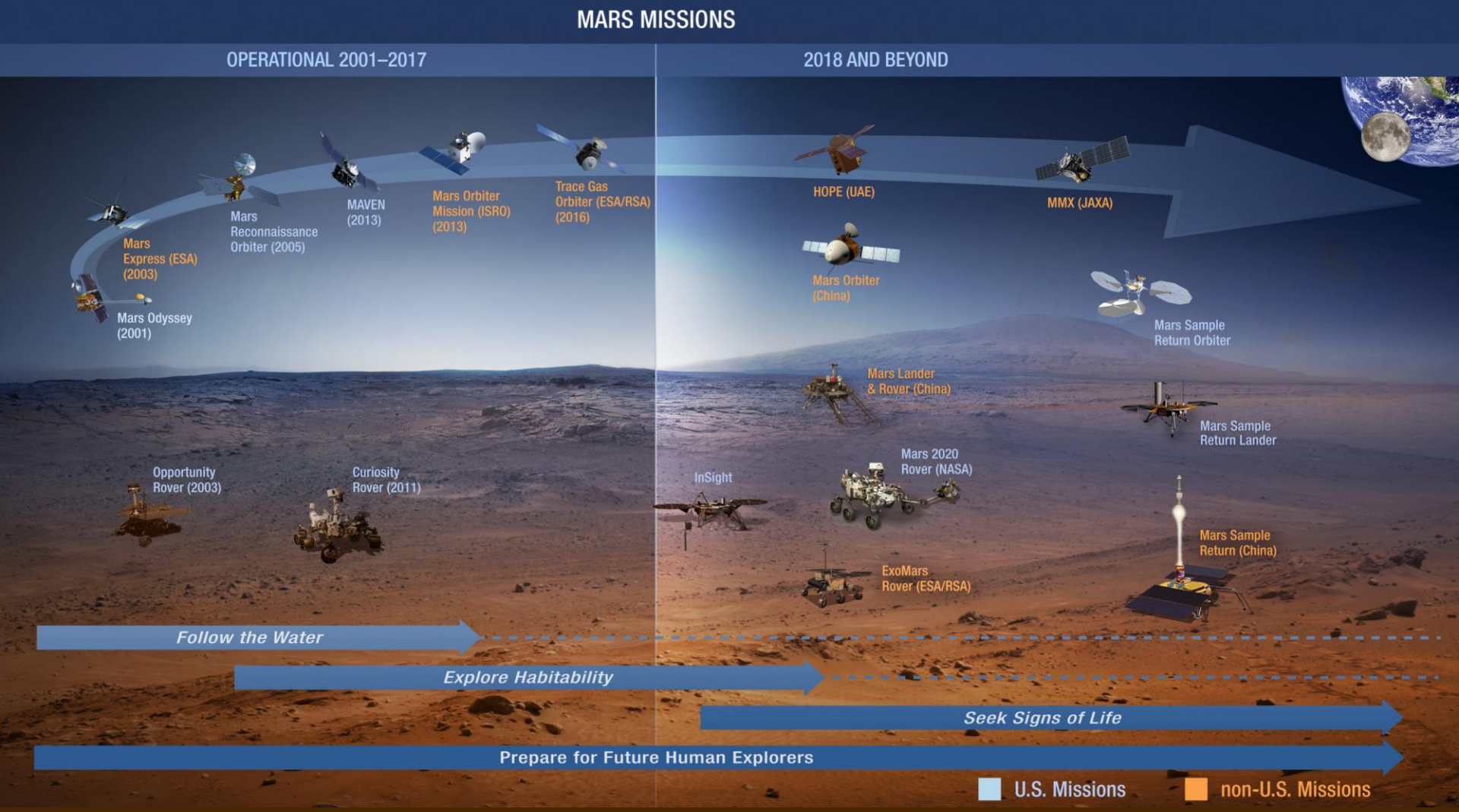
- **Mars science is compelling**
  - Mars was Earth-like over 3 billion years ago
  - Possibility of discovering fossils of extinct microbial life
  - Possibility of discovering current microbial life underground
  - Humans on-site would be more expedient than robots
- **Mars is the most hospitable planet beyond Earth that is accessible**
  - 24.7 hour day
  - Closest gravity to Earth (~1/3 g)
  - Water ice glaciers just under the surface
  - CO_2 atmosphere as a readily available resource

Ice Scarps on Mars: Frozen Great Lakes

- Large deposits of frozen water have been discovered by the Mars Reconnaissance Orbiter

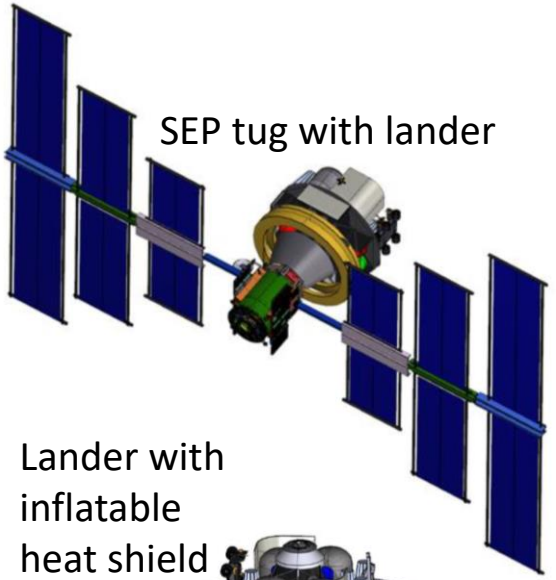


Robotic Exploration Missions

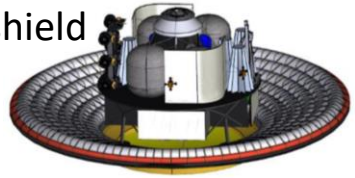


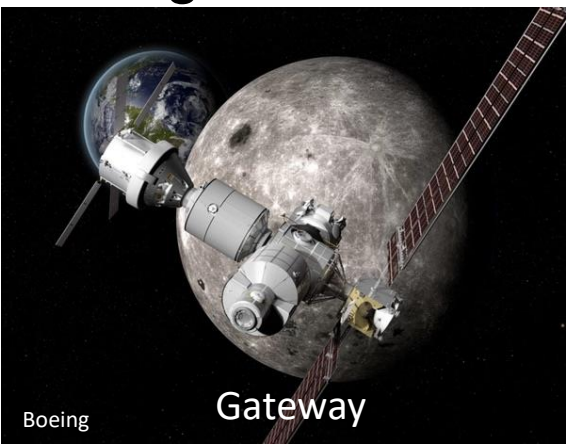
NASA Mars Architecture Concept

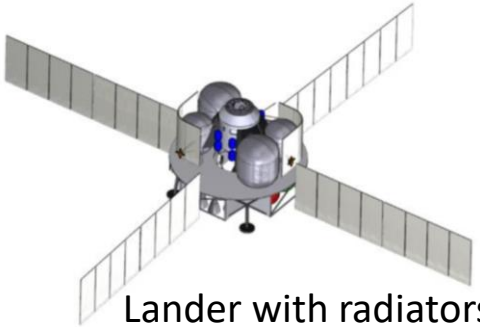
- Lunar orbiting Gateway would be used as an assembly point
- Reusable SEP/chemical Deep Space Transport (DST) would transfer crews between the Gateway and high Mars orbit
- Landers would be separately delivered to high Mars orbit by SEP tugs
- Crews would transfer from DST to lander in high Mars orbit



Lander with inflatable heat shield



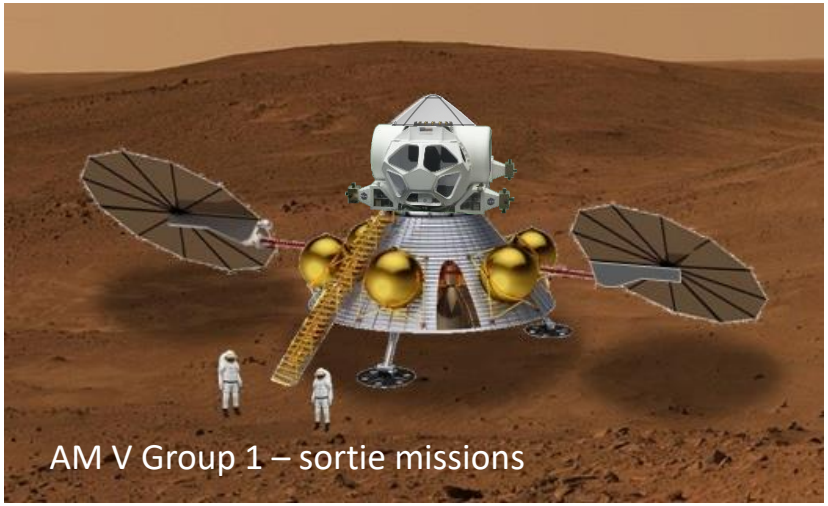




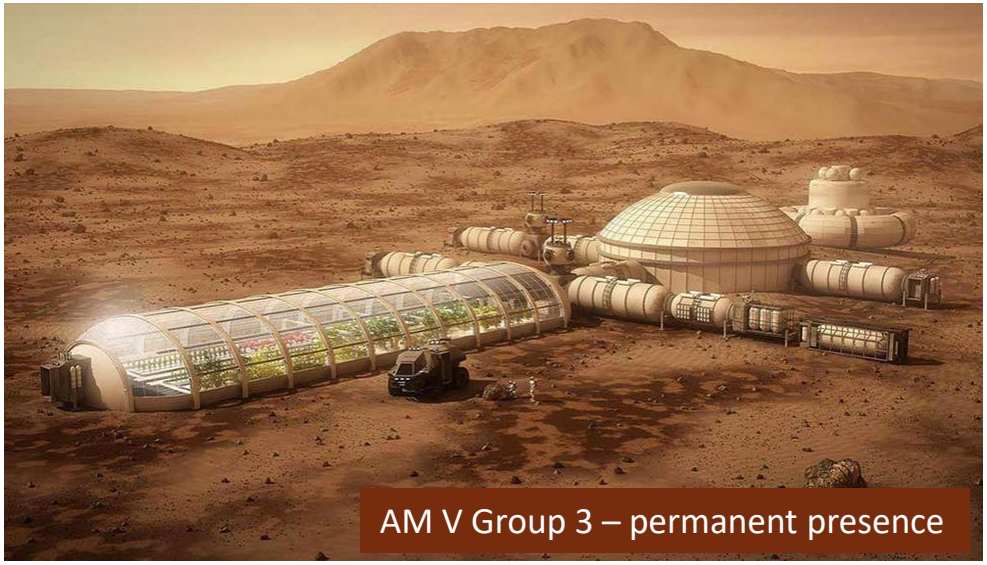
Lander with radiators for cryogenic propellant production

“Achieving Mars” Community Architectures

- Group 1 – sortie class missions
  - like Apollo plus
- Group 2 – research station
  - like Antarctic field camp
- Group 3 – permanent presence

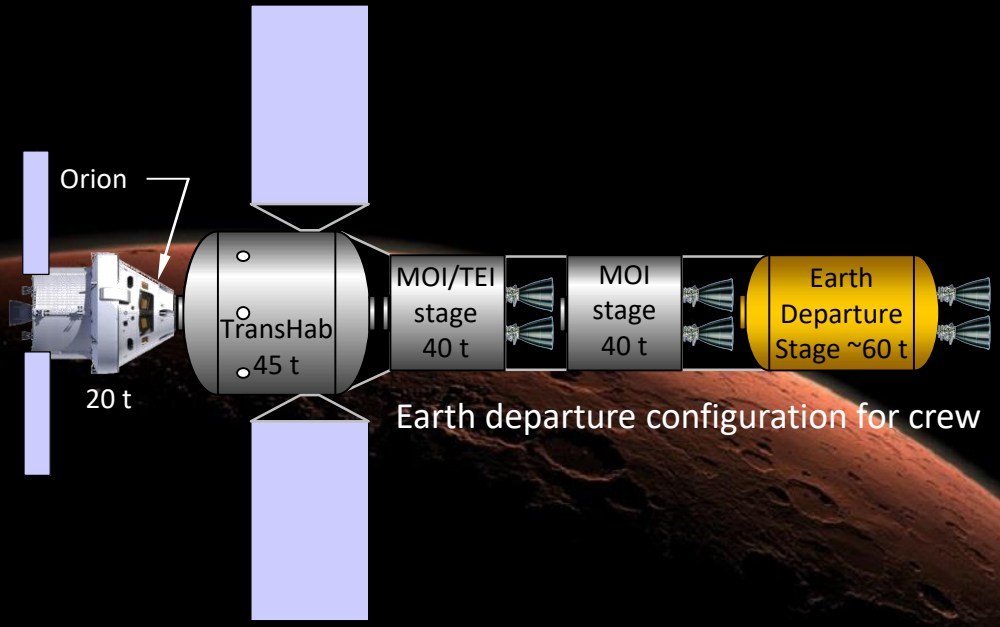

AM V Group 1 – sortie missions


AM V Group 2 – research station


AM V Group 3 – permanent presence

Going to Mars in 2033: Starting Small

- The Explore Mars AM V Group 1 sortie mission architecture offers an example of a near-term affordable approach for human exploration of Mars
- Design would first be tested in lunar orbit (e.g. Gateway)
- Launched in segments by SLS and commercial rockets
- Assembled in high Earth orbit
- Crew would return to Earth in Orion capsule

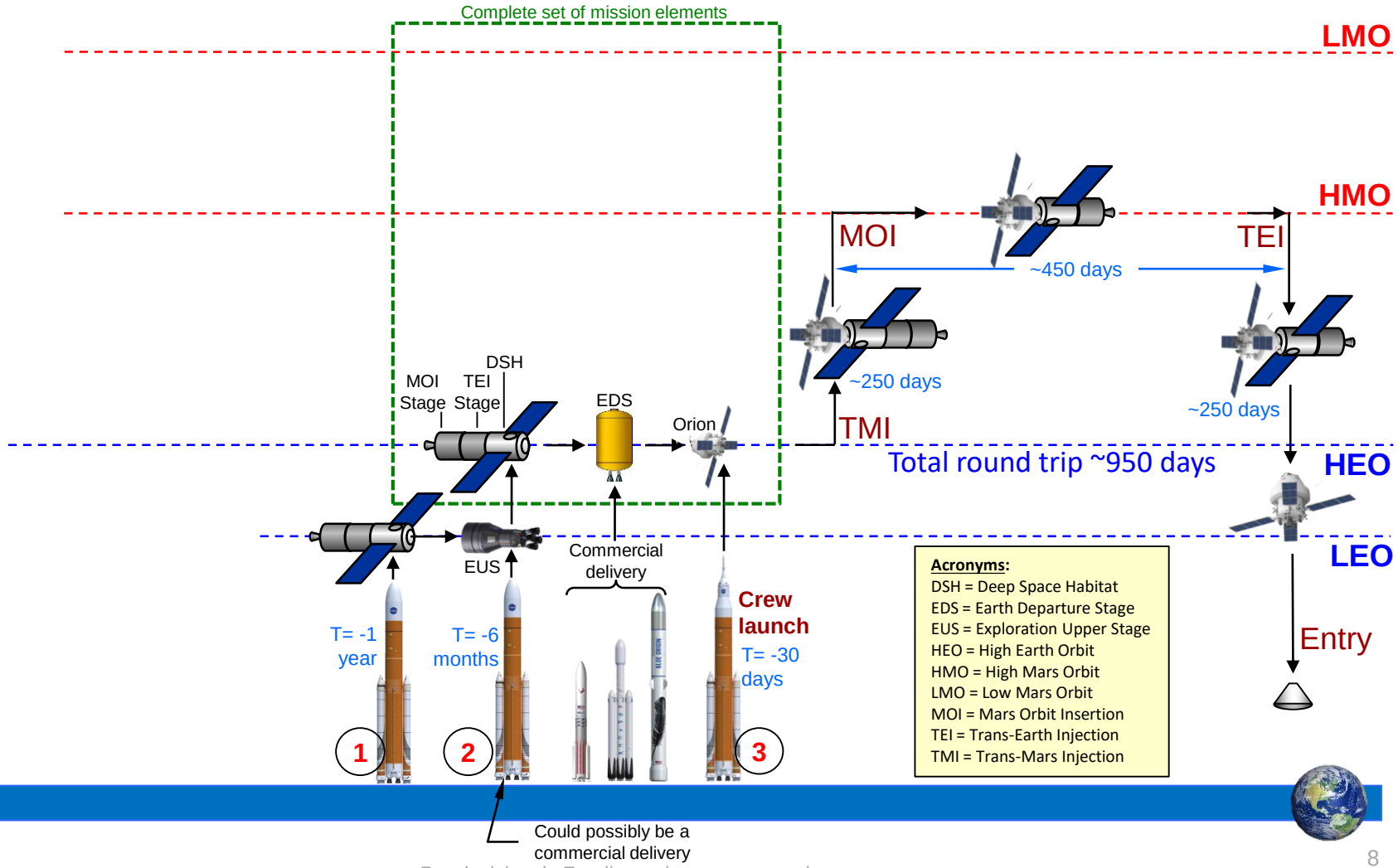


Earth departure configuration for crew

- The focus of the first missions would be exploration and science
  - Search for life
  - Identification of resources
- Later missions could build upon a modest start with these vehicles and on-ramp greater capabilities

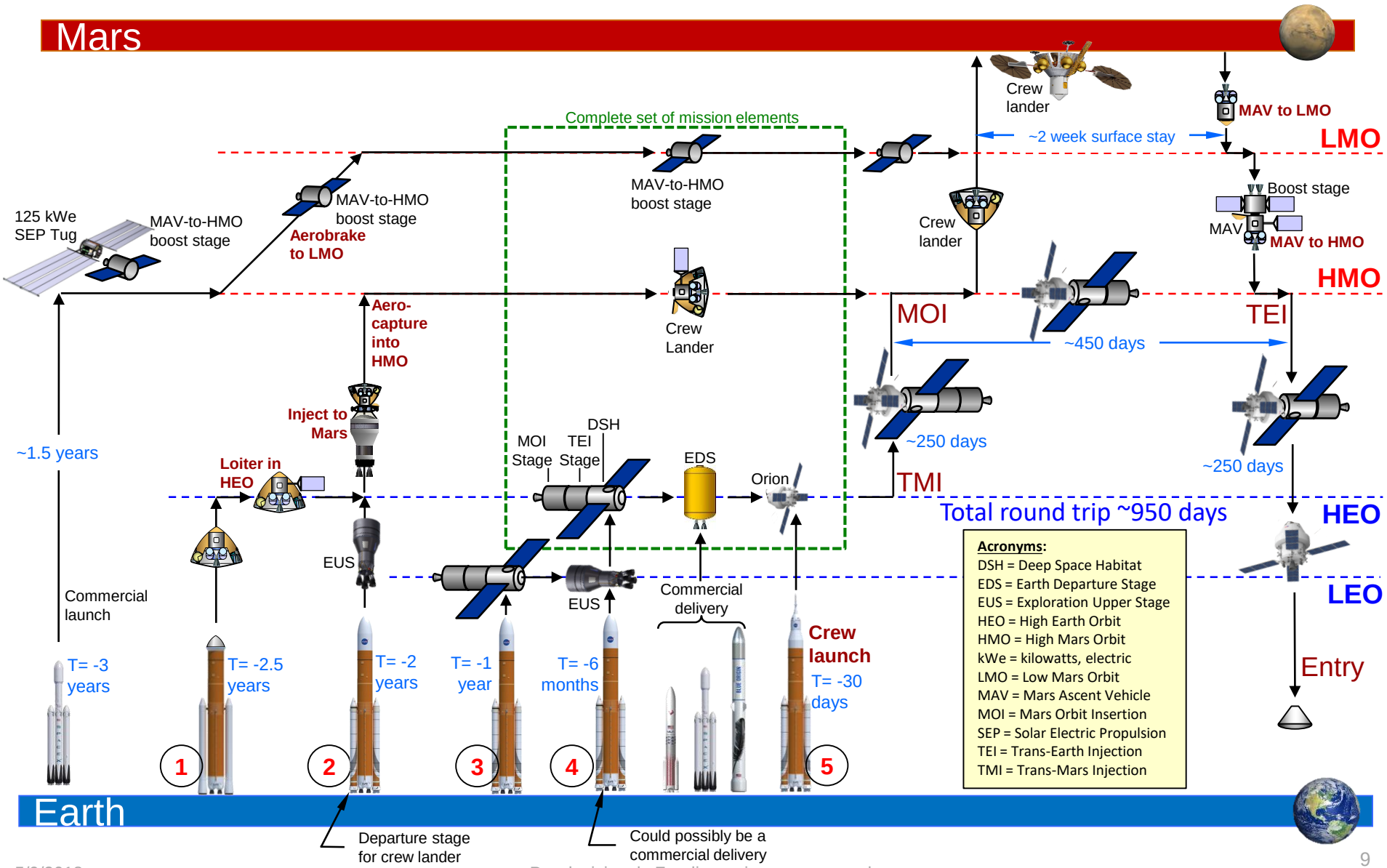
Mars Orbit Mission Concept

crew of 4; 3 SLS launches; ~4 commercial launches

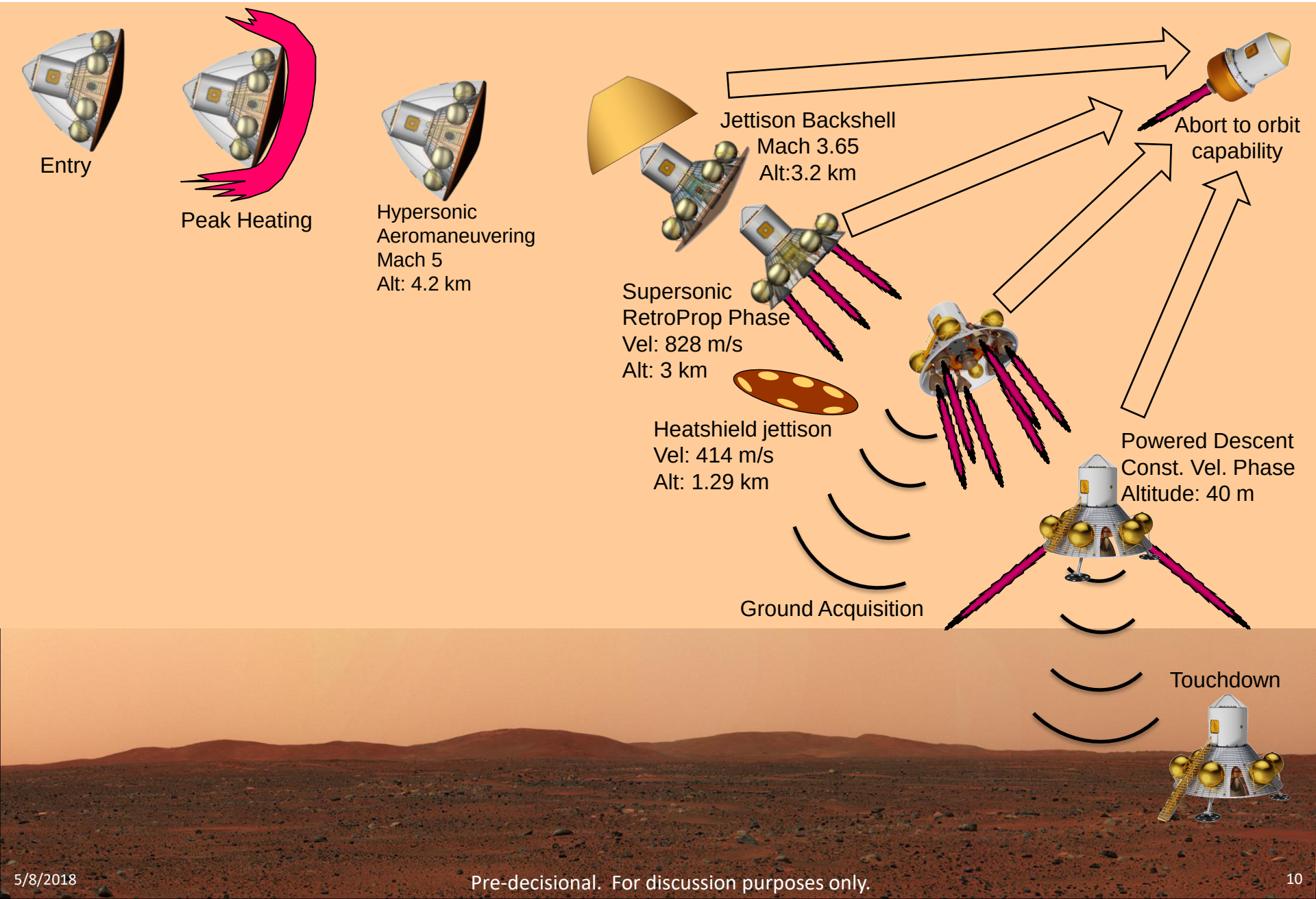


Two-Week Mars Surface Sortie Mission Concept

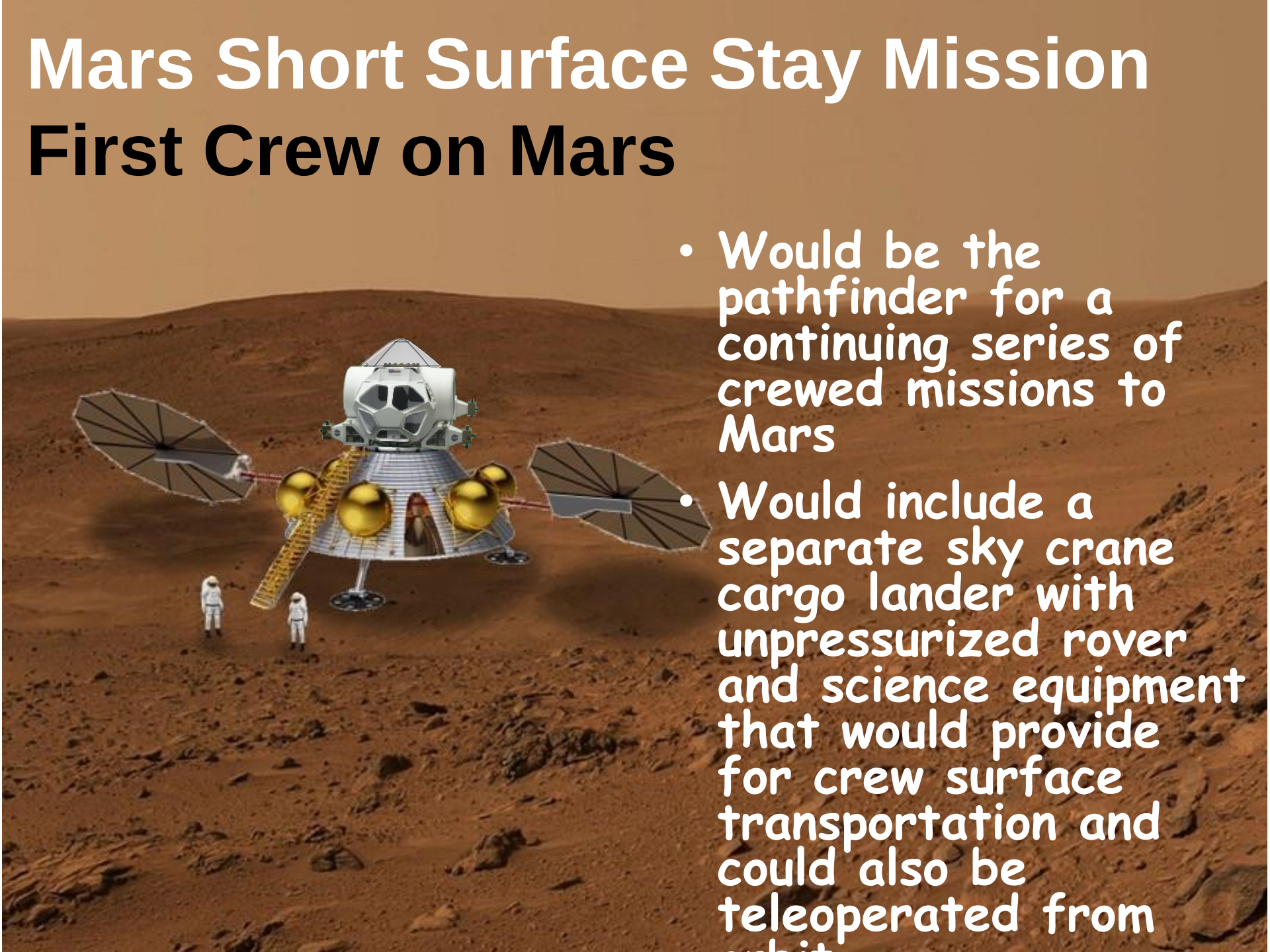
crew of 4; 5 SLS launches; ~5 commercial launches



Entry, Descent, and Landing (EDL) Concept for Crewed Mars Lander



Mars Short Surface Stay Mission
First Crew on Mars

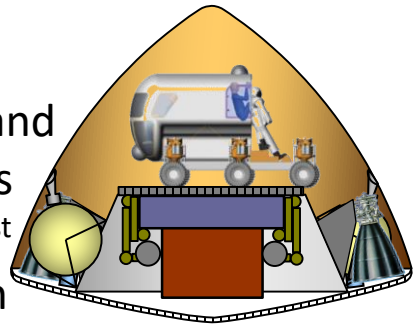


- Would be the pathfinder for a continuing series of crewed missions to Mars
- Would include a separate sky crane cargo lander with unpressurized rover and science equipment that would provide for crew surface transportation and could also be teleoperated from

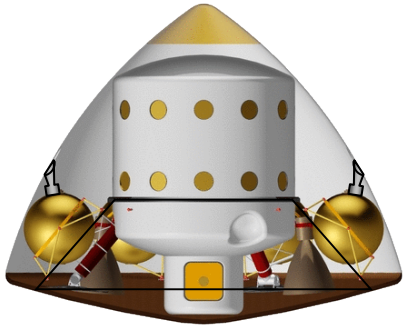
Going Bigger: One-Year Surface Mission

- Would build on the short-stay architecture by adding a surface habitat
  - A cargo lander would carry the surface habitat
  - Crew lander with MAV would carry a crew of 4 to the surface
  - Could re-use pressurized rover and other equipment from first mission

Cargo and logistics from 1st mission

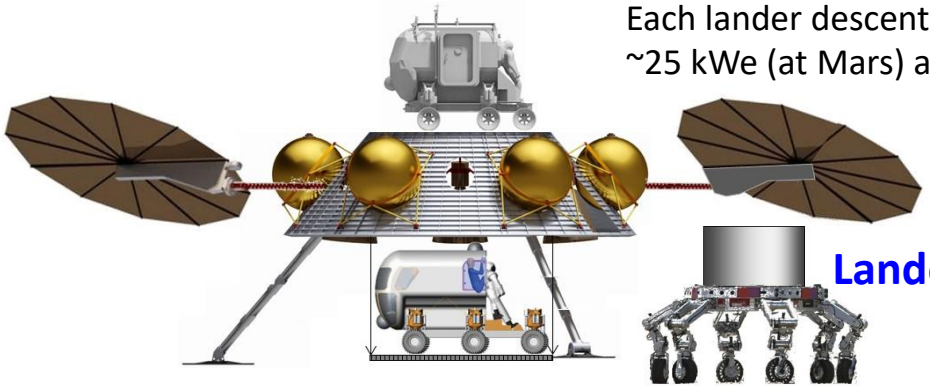


Entry Configurations

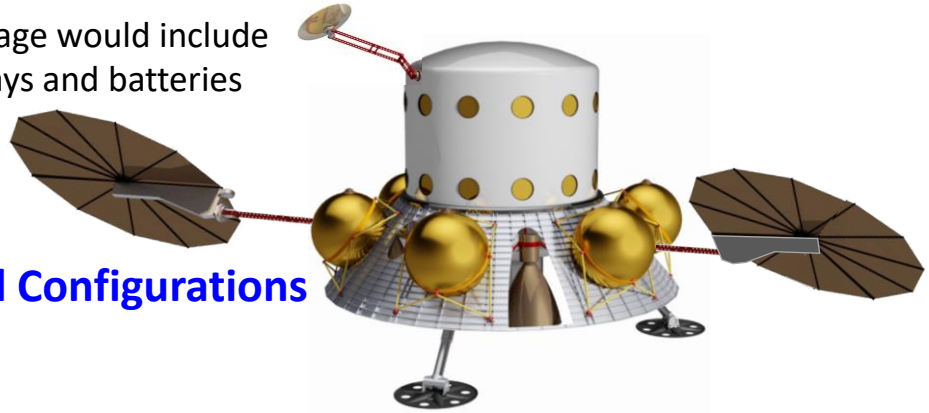


Surface habitat

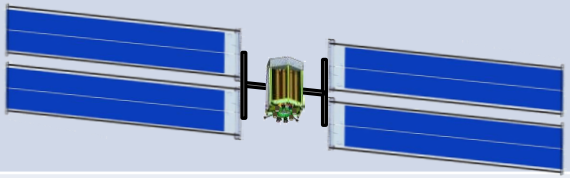
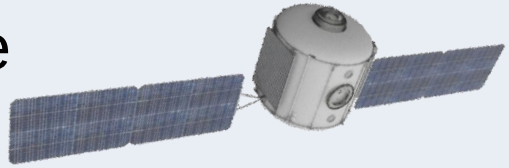
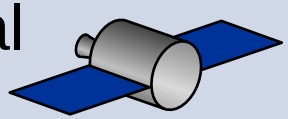
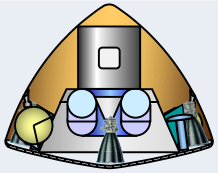
Each lander descent stage would include ~25 kWe (at Mars) arrays and batteries



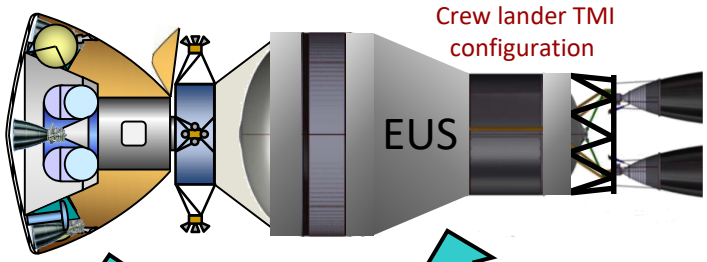
Landed Configurations

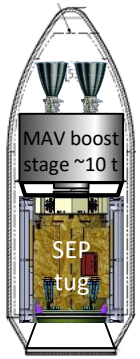


Six Vehicles to Enable Crewed Missions to Mars

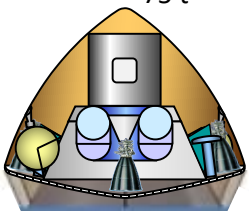
Vehicles	# Vehicles per Mission	
Orion 	1	In development
SLS 	5	In development
SEP Tug ~125 kWe 	1	Studies are on contract
Deep Space Habitat 	1	Studies are on contract
In-Space Chemical Propulsion Stage 	4	Could be an international contribution
Mars Lander 	1	Development would need to start

SLS Block 2 and Commercial Launch Concepts



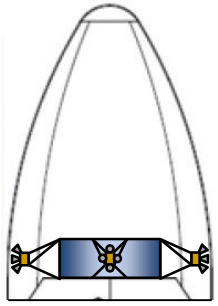


Commercial launch of 125 kWe SEP tug and MAV boost stage to $C_3 = 0$



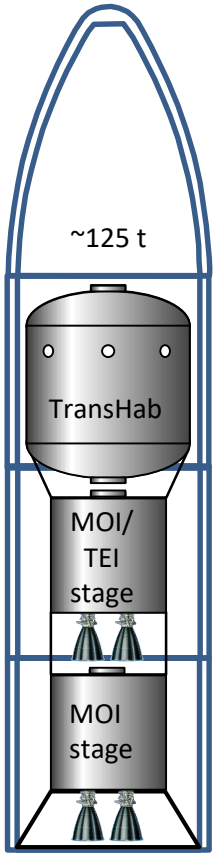
Crew lander to HEO using back-shell as payload fairing

SLS Launch #1



Docking kit for EUS to use as departure stage

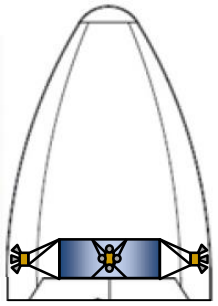
SLS Launch #2



MOI & TEI stages and TransHab launch to LEO

SLS Launch #3

Boost to HEO could alternatively be performed by commercial stage(s)



Docking kit for EUS to use for TransHab boost to HEO

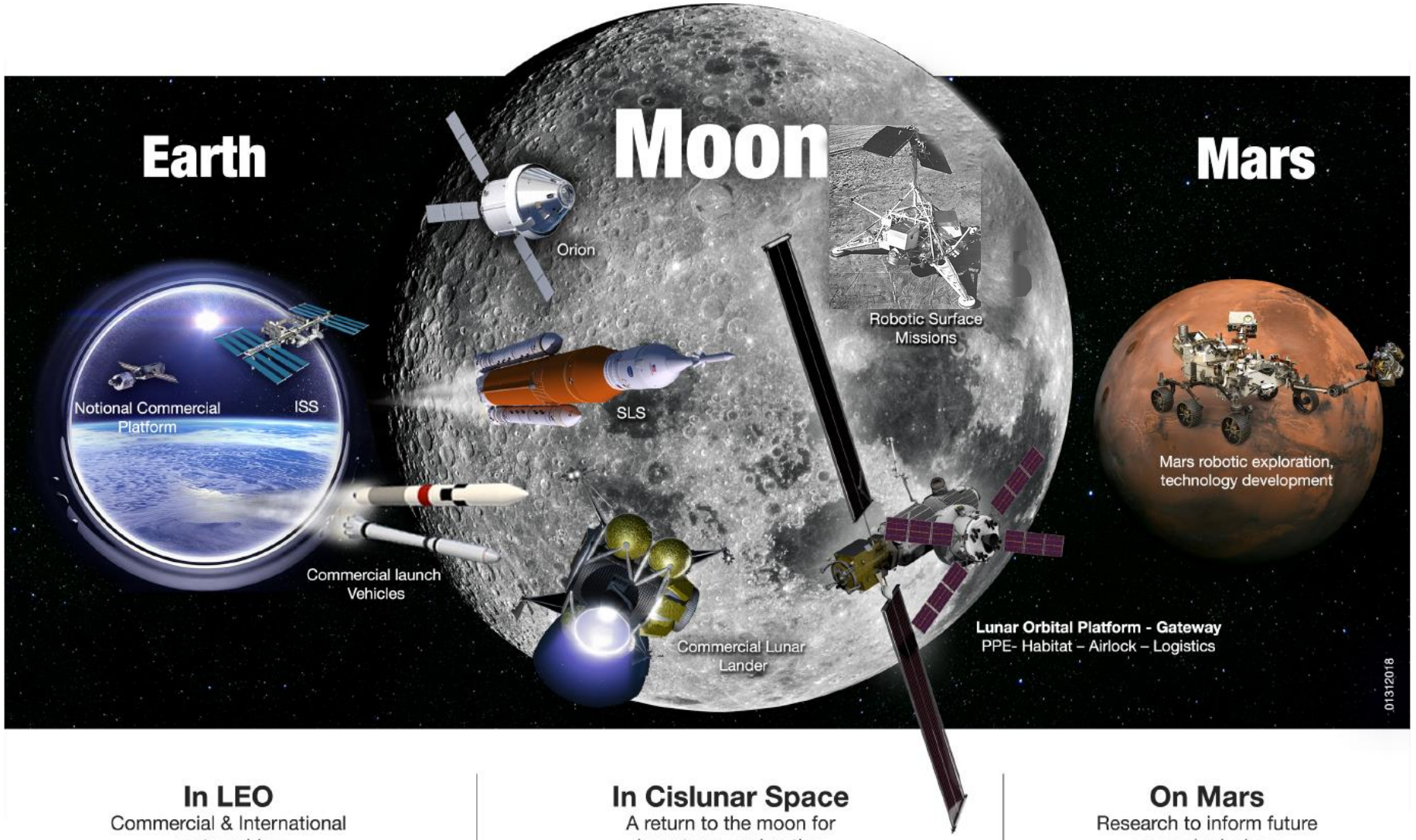
SLS Launch #4

Orion with crew for docking with stack

SLS Launch #5

Launches #2 and #5 have limited launch periods. The other launches have flexible launch dates.

NASA's Current Plans for Human Exploration



In LEO
Commercial & International partnerships

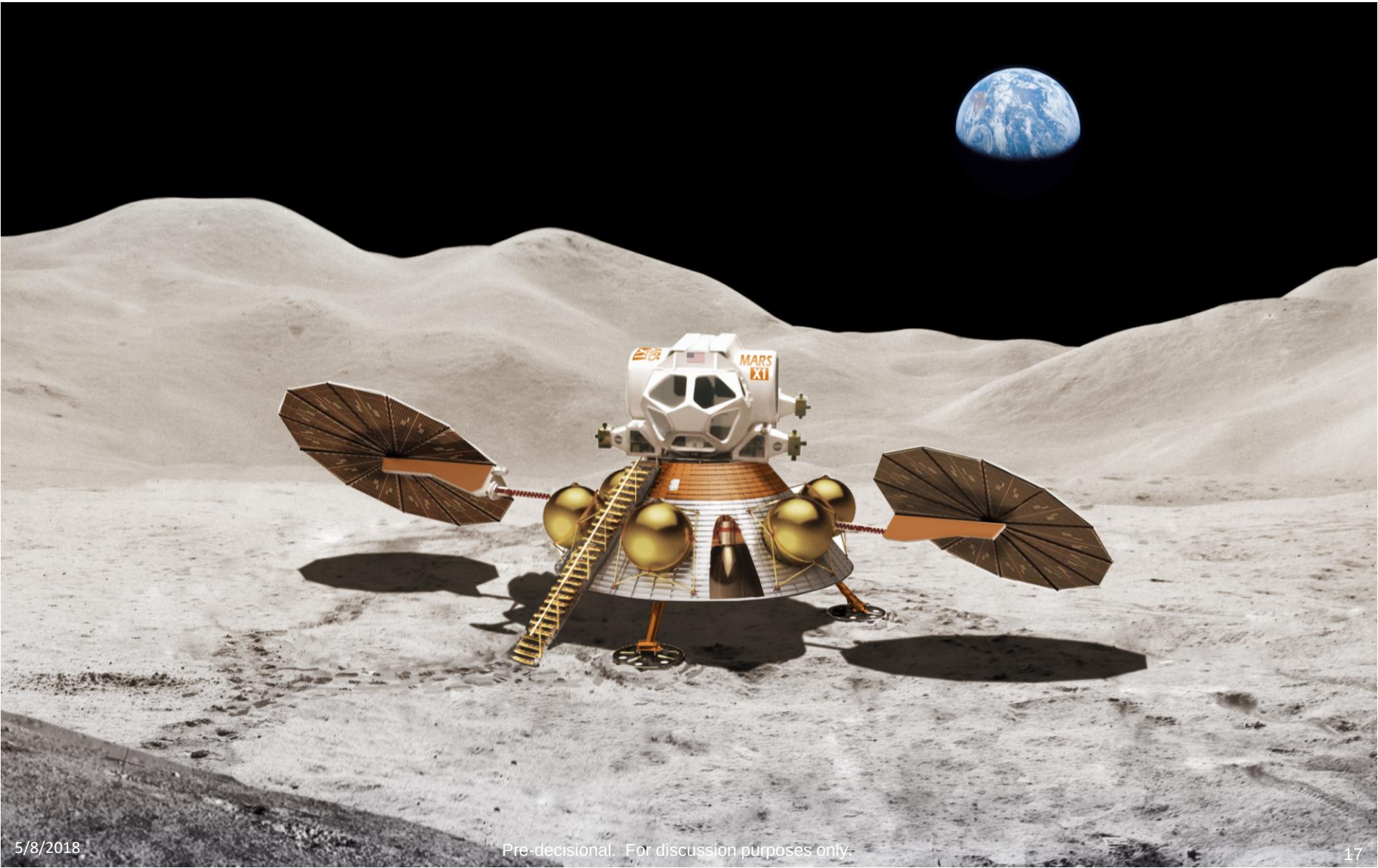
In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions

The Moon on the Path to Mars

- The Moon could provide important testing and qualification of the vehicles to conduct successful missions to Mars
  - Orion
  - Deep Space Habitat
  - Mars lander and Mars Ascent Vehicle (MAV) system checkout
  - Mars orbital and surface operations and Earth ground operations
- The Moon could provide a shakedown test of the lander design
  - Qualify design in crewed flight-like environment
  - System qualification, space operations, terminal descent and landing, surface deployments, crew surface operations, and MAV operations

Concept for Crewed Test of Mars Lander on the Moon



After Starting Small…Going Big

- Would use results from the early Mars sortie missions to select location for a more permanent presence
  - Accessibility (latitude, terrain)
  - Resources (water ice, minerals)
  - Access to scientific areas of interest
- Would build up surface infrastructure and capability
- Could expand crew sizes and durations of stay

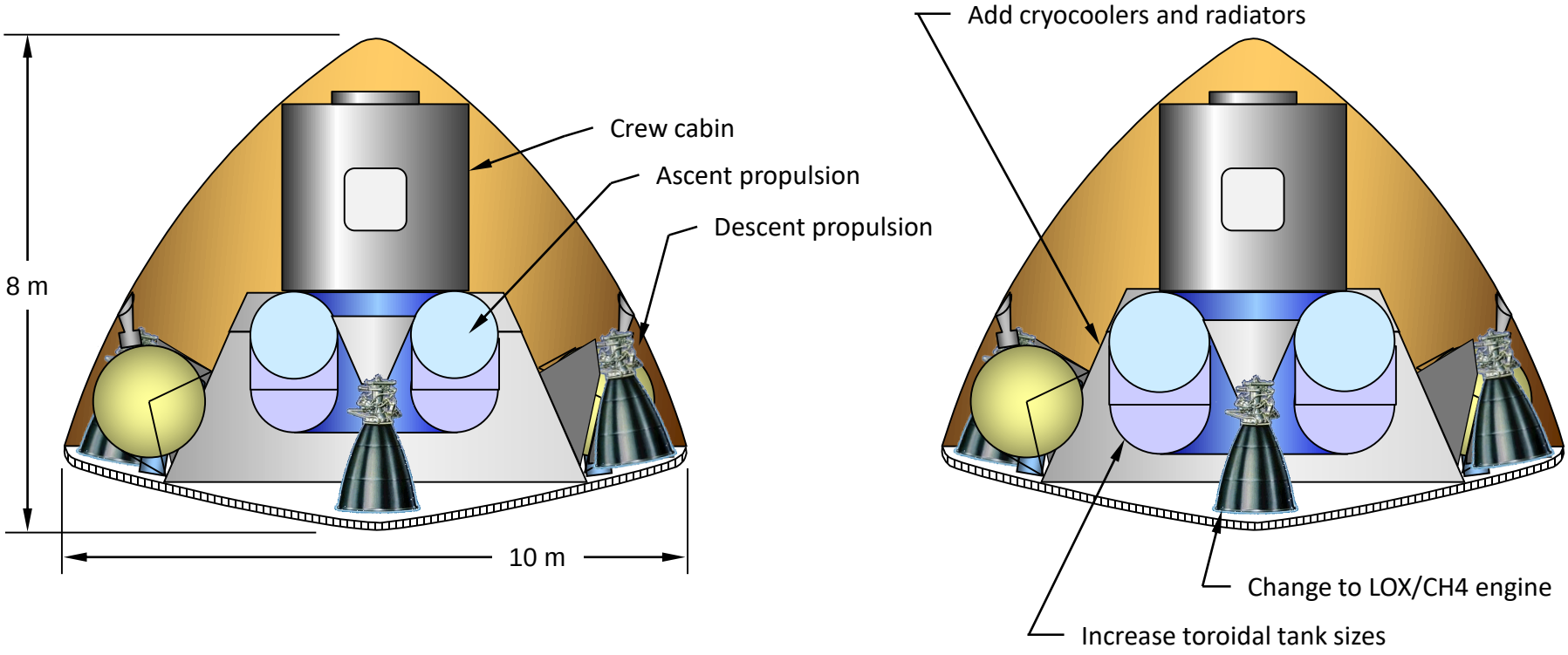
Notional Progression of Missions

This example is slightly more aggressive than the AM V Group 1 scenario:

- Crewed lunar landing test (2031)
- Mars orbit (2033)
- First crewed Mars landing sortie mission with rover (2037)
- Select location for habitat and perform long surface stay (2041)
- Build up surface systems and on-ramp food production (2045)
- On-ramp large nuclear power systems and ISRU (2050)
- Revamp transportation infrastructure (2054)
  - Re-usable MAV (e.g. LaRC Hercules concept, Lockheed Martin lander concept)
  - Possibly convert transit hab and SEP tug vehicles to Aldrin cyclers
  - SpaceX BFR type transportation system (would require Mars surface infrastructure in place)

Going ISRU: Concept for Converting MAV from MMH/MON-15 to LOX/CH4

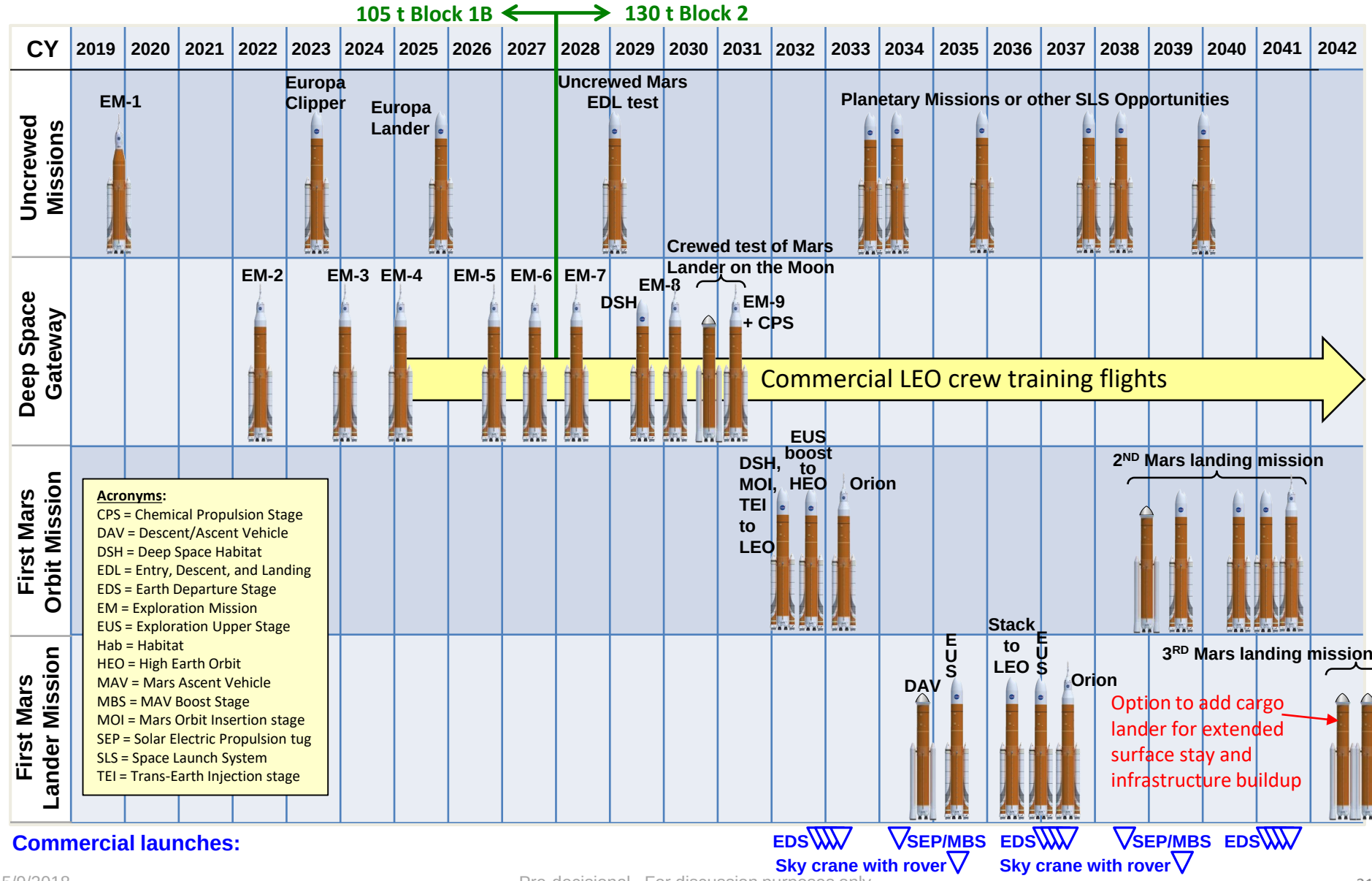
MMH/MON-15 → LOX/CH4



Note: Keep descent propulsion the same – MMH/MON-15

Notional SLS Flight Scenario

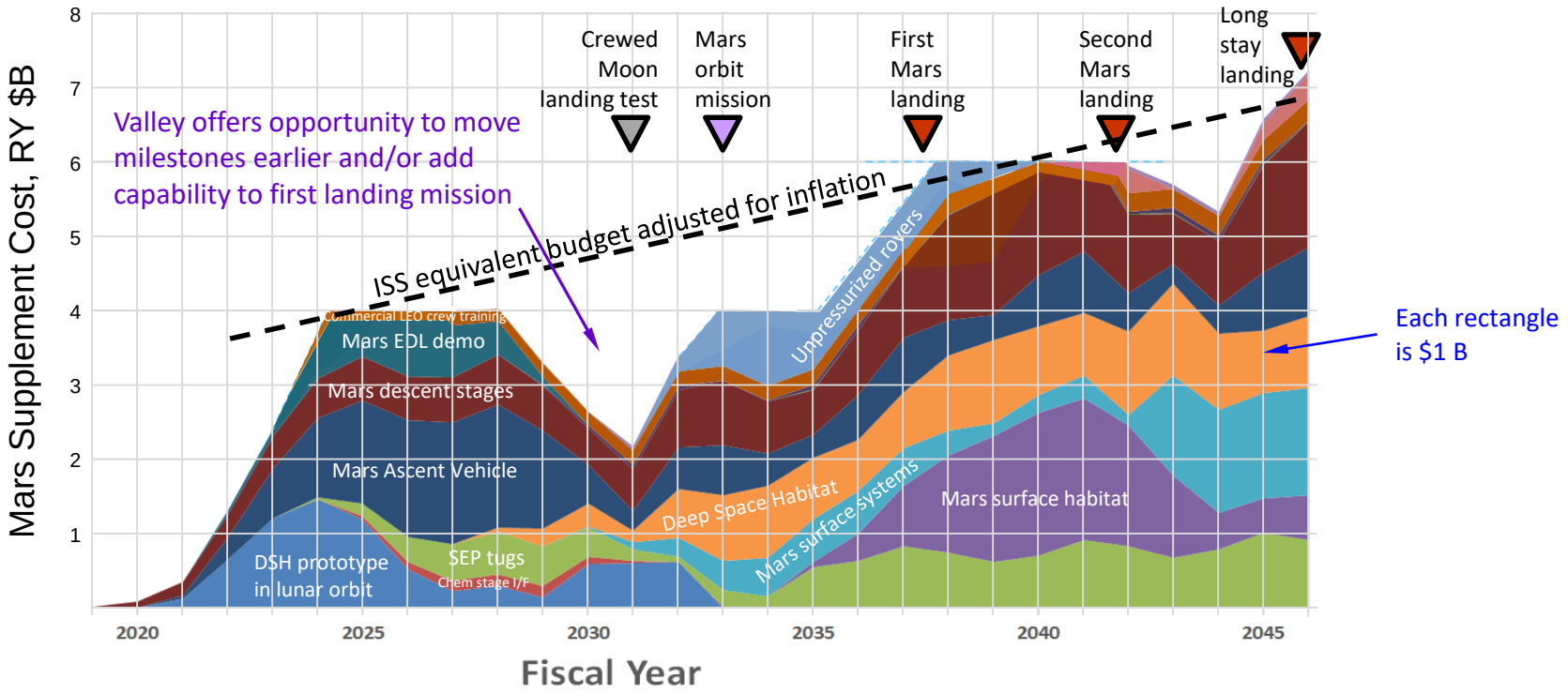
for AM V Group 1 Concept



AM V Group 1 Program Cost Estimate

Mars budget supplement only, in real year dollars (includes 2.6% inflation)
Assumes SLS, Orion, and Gateway funded as separate budget items
Assumes international partners provide in-space chemical propulsion stages

- Cost methodology developed by the Aerospace Corporation
- Same methodology as 2014 NRC “Pathways” and 2017 OIG report
- Results suggest a similar annual cost and total cost as ISS, over ~25 years, adjusted for inflation



Humans to Mars could be implemented in our lifetime.