Human Missions to Mars Orbit, Phobos, and Mars Surface Using 100-kWe-Class Solar Electric Propulsion

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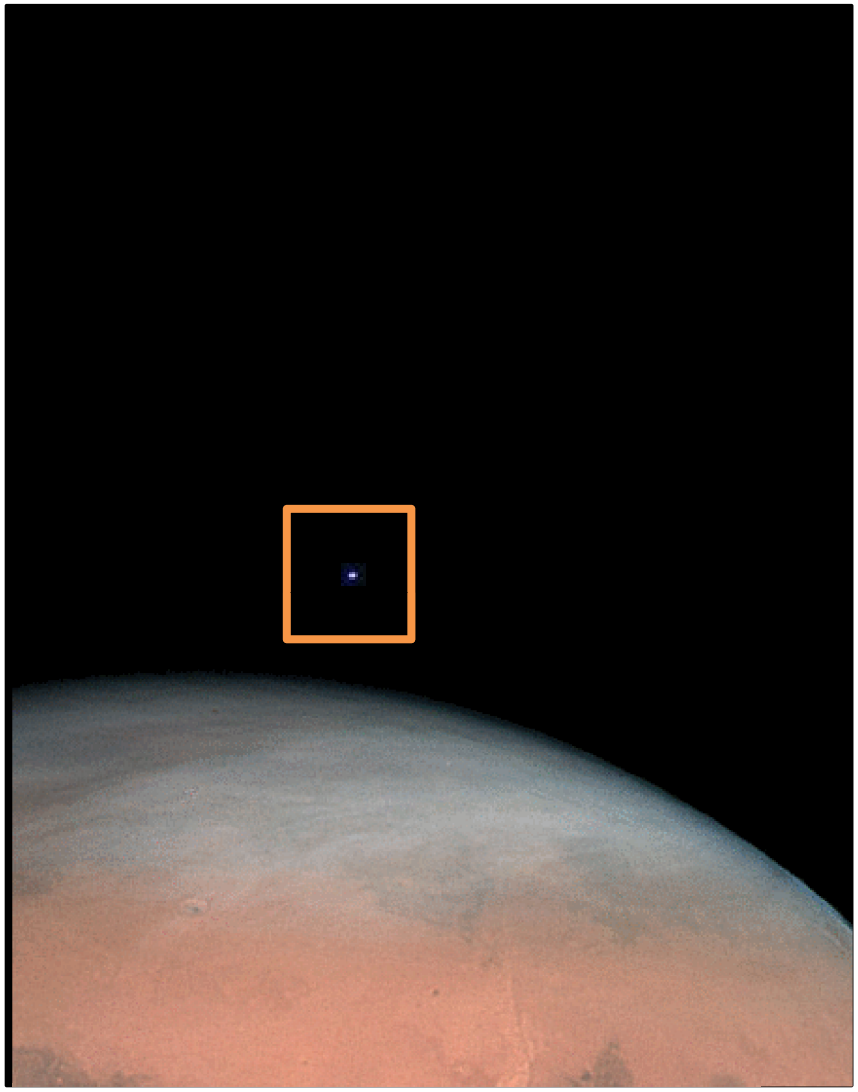
Purpose of Notional Roadmap

- To show that:
  - Sending humans to Mars orbit and Phobos could be feasible by 2033
  - Landing humans on Mars could be feasible by 2040
- To outline a possible humans to Mars program that could be implemented without a significant spike in the NASA budget
- To confirm that the key building blocks for human missions to Mars are being put in place

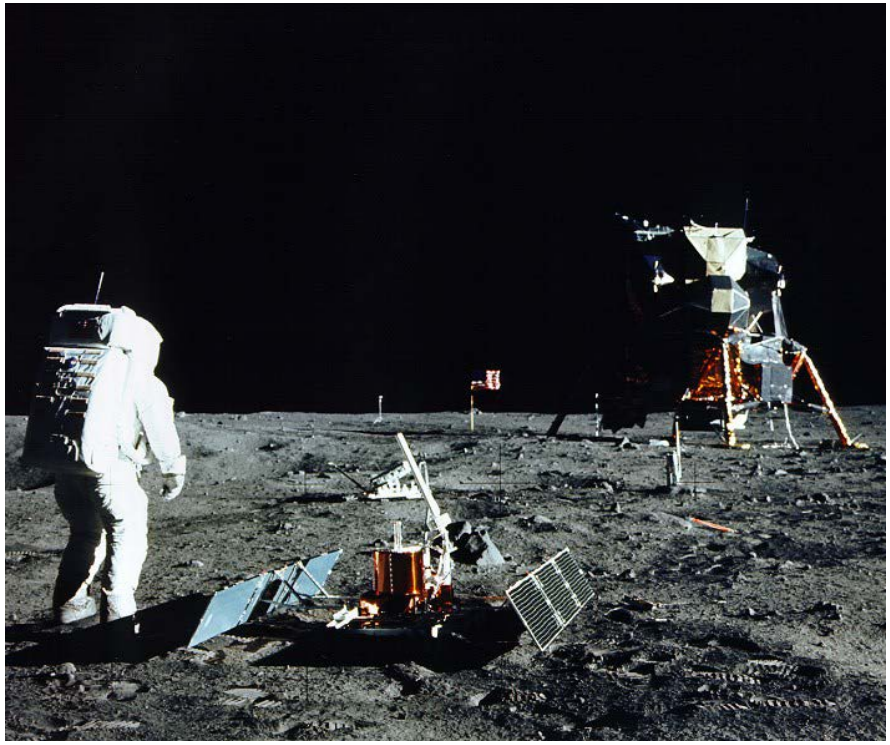
65 years later ……

The crew of Apollo 8 were the first humans to witness Earthrise, on December 24, 1968



A view of the home planet that a human crew could have from Mars orbit in 2033

71 years later ……



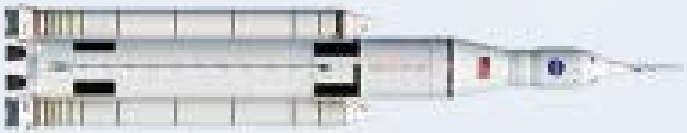
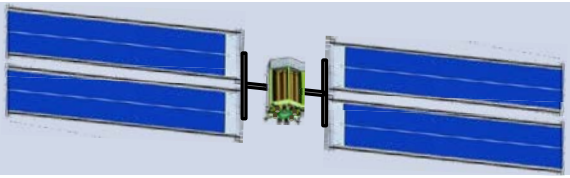
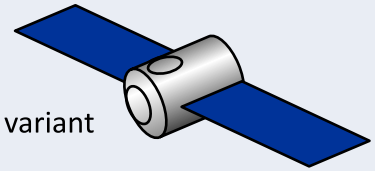
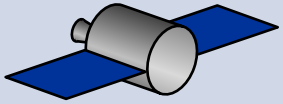
The crew of Apollo 11 landed at Tranquility Base on July 24, 1969

A U.S. led mission to land on Mars could be feasible by 2040

Basis of Feasibility Study Architecture

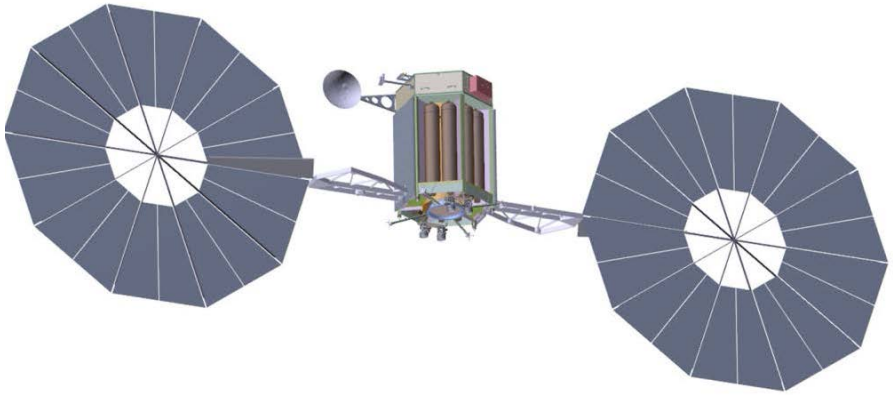
- This roadmap is intended to represent a feasible capability-driven program architecture that could be costed and scheduled
- It would be a no-frills minimal program that gets the job done
- Consistent with current NASA plans:
  - Orion/SLS capability
  - Space Station utilization to develop life support technologies
  - ARM, SEP tug(s), and long-term Habitat in Lunar orbit proving ground
    - Could potentially support commercial or international Lunar landing missions
  - Mars orbit/Phobos 2033 mission architecture is consistent with recent NASA studies (e.g. McDonald SpaceOps paper)
  - Crewed Mars landing in the 2040 time frame

Vehicles to Enable the Notional Roadmap

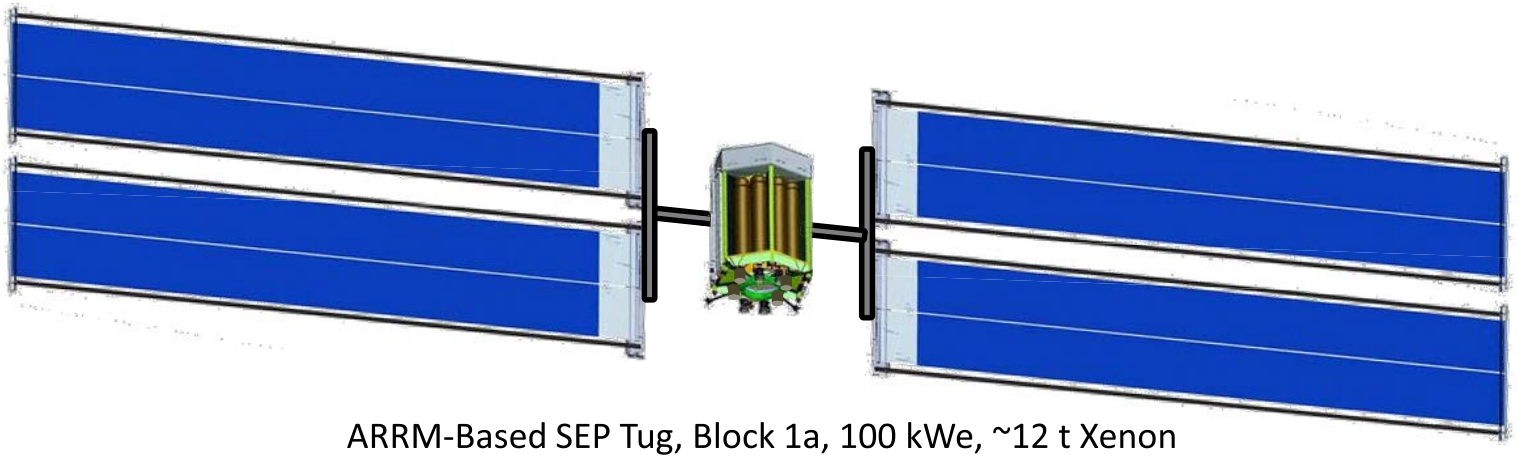
Proposed Vehicles	Notional First Launch	# Vehicles per Mission
Orion 	2014 no crew 2021 First crew	1
SLS 	2017 Block 1 2028 Block 2	7
SEP Tug 	2019	2
Deep Space Habitat • Crewed version • Uncrewed consumables resupply variant 	2024	2
In-Space Chemical Propulsion Stages (for MOI, TEI, MAV boost to HMO) 	2033	3
Mars Lander (descent and ascent stages) 	2031 Mars EDL test 2035 Crewed Lunar test 2040 Crewed Mars landing	1

Solar Electric Propulsion (SEP) Tug

- 50 kWe SEP tug is planned for ARM as a Tech Demo mission
- It is being designed to be extensible to a 100-150 kWe SEP tug to support human missions to mars by adding arrays and thrusters

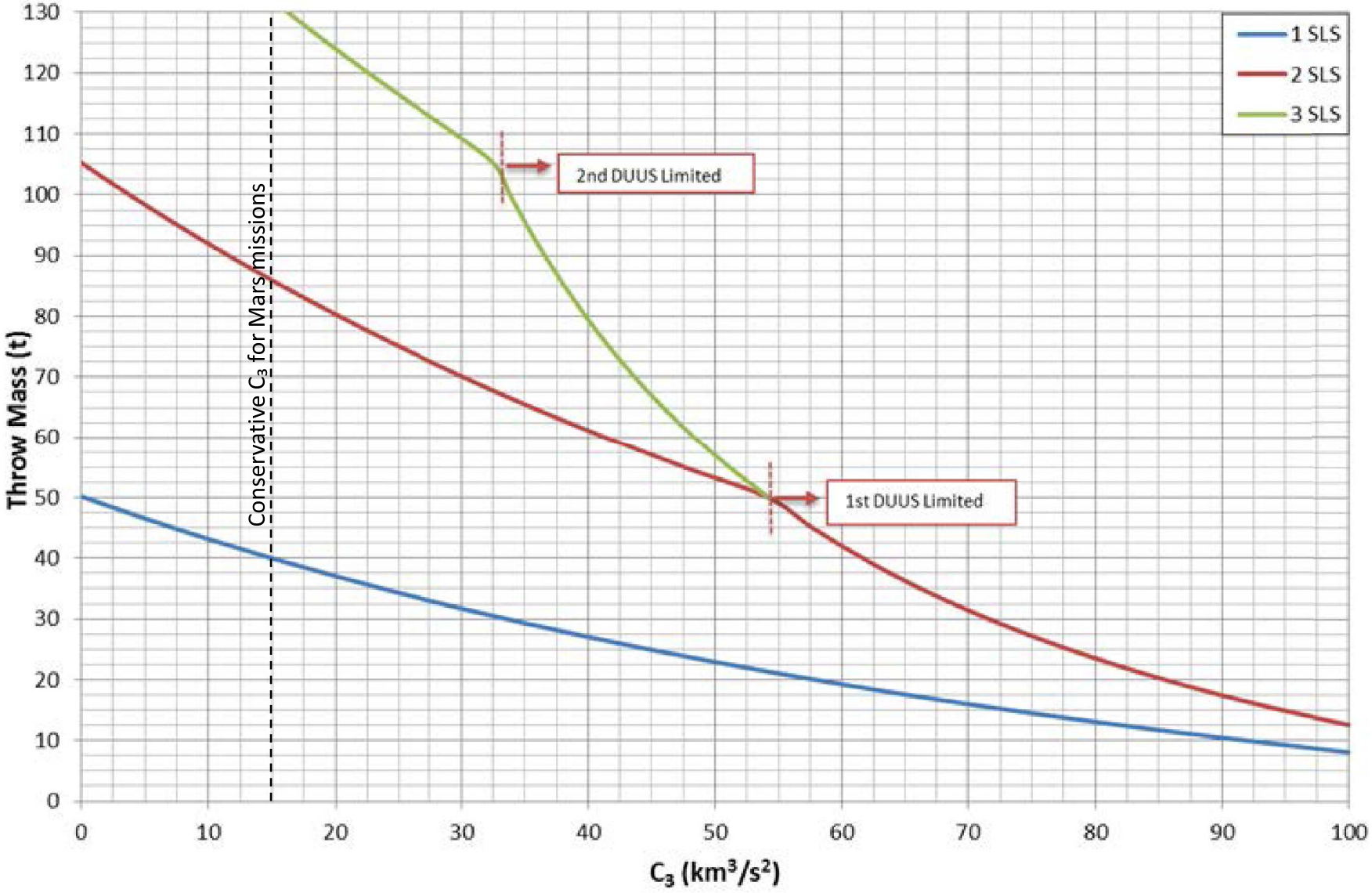


ARRM TDM SEP Tug, Block 1, 50 kWe, 10 t Xenon



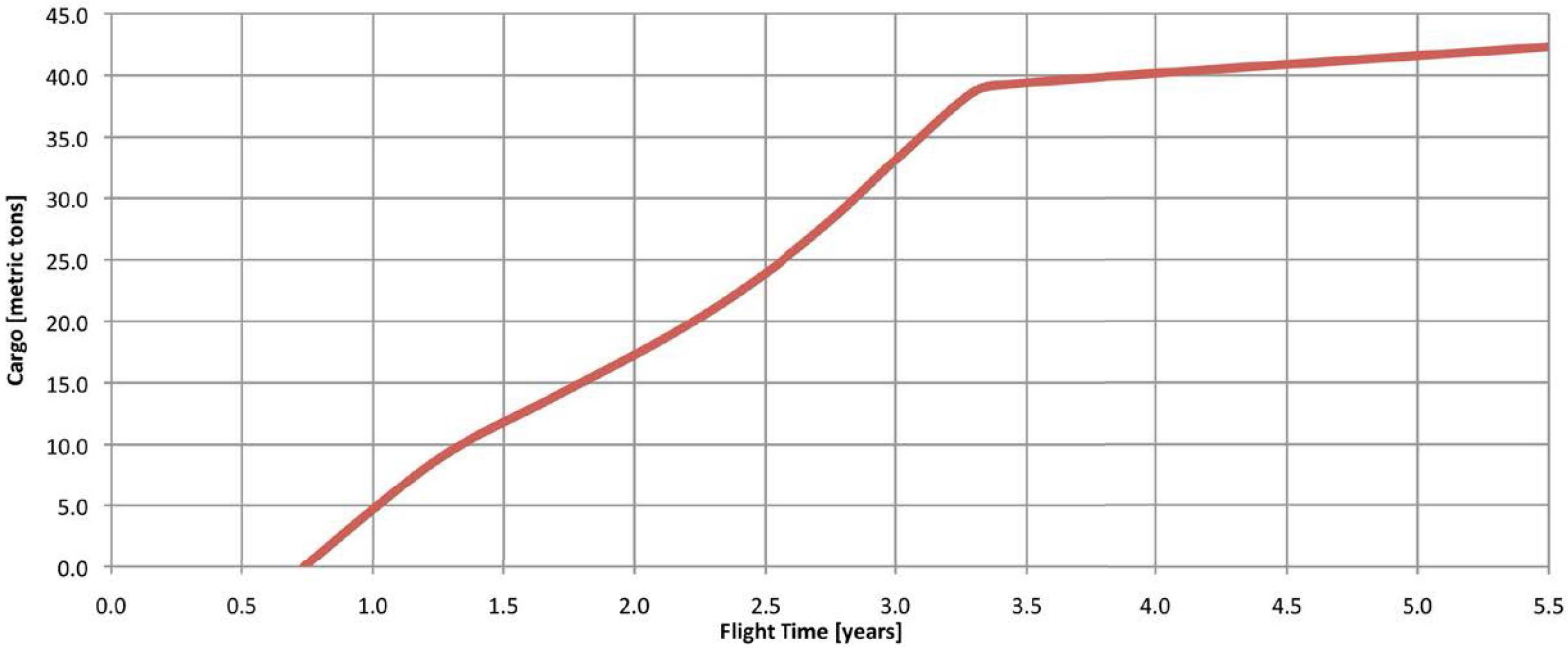
ARRM-Based SEP Tug, Block 1a, 100 kWe, ~12 t Xenon

SLS Estimated Performance for Trans-Mars Injection (TMI)



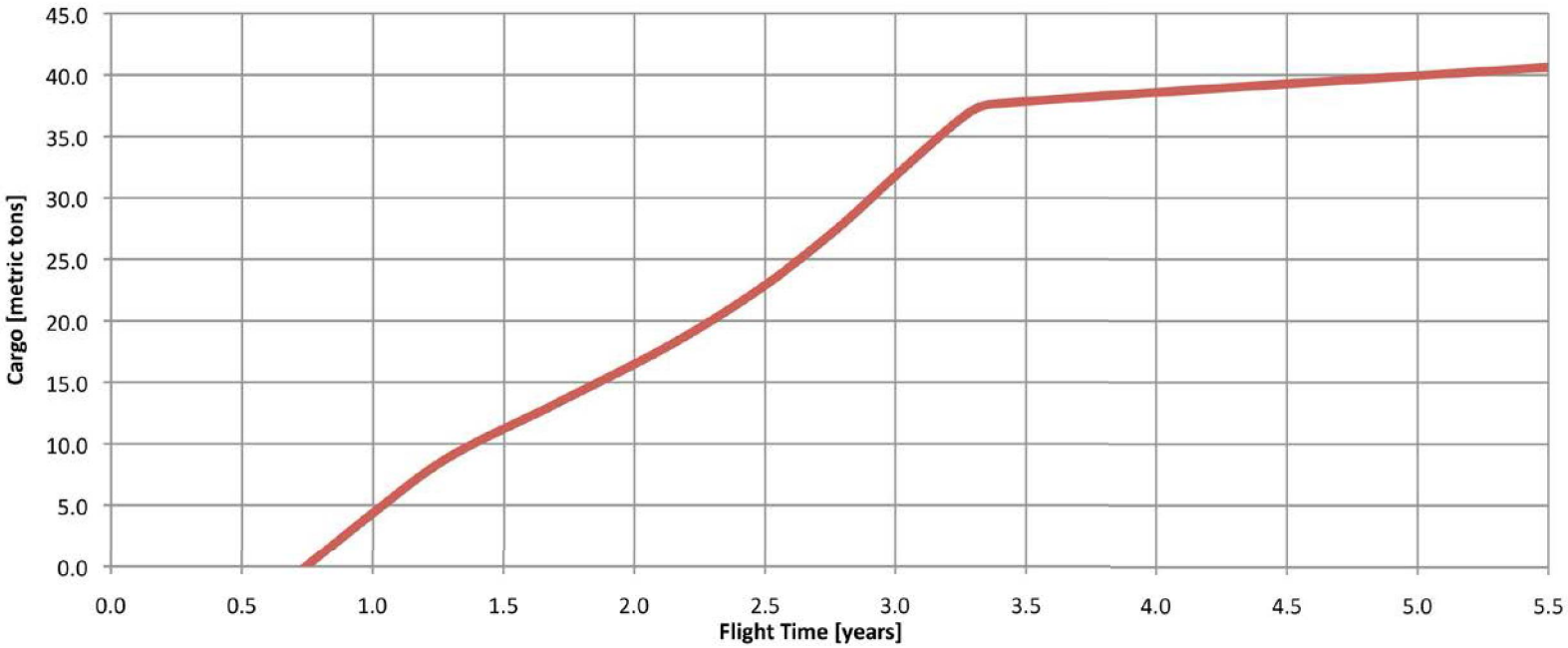
SLS Performance to High Mars Orbit with 100 kWe SEP

- With a single SLS launch, the 100 kWe SEP tug could deliver a 39 t payload to High Mars Orbit in about 3.3 years
- The knee in the curve corresponds to adding Earth spiral-out to the beginning of the mission
- There is a lot of flexibility in launch dates
  - Doesn't have to fit within traditional Mars opportunities

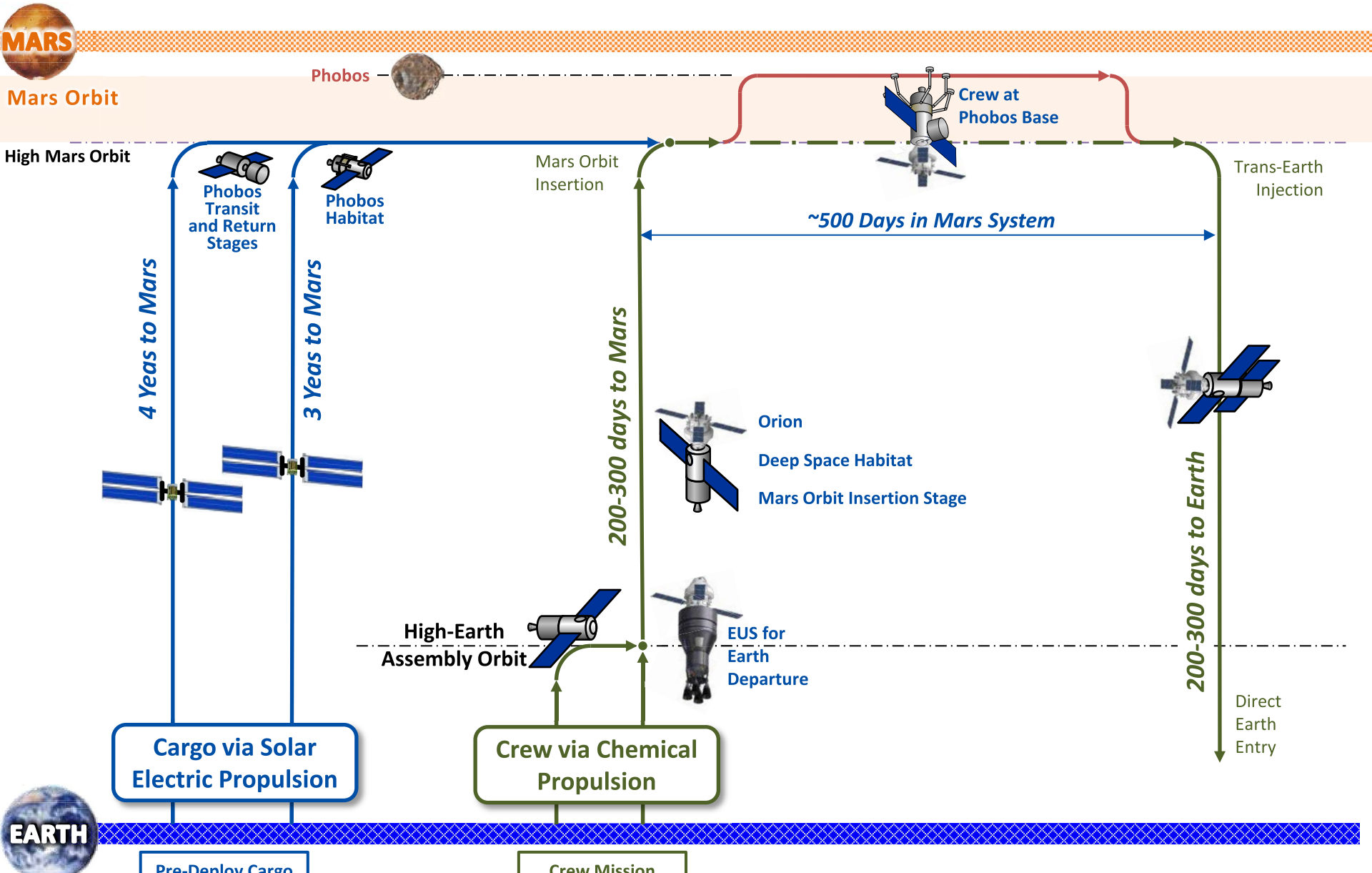


SLS Performance to Phobos with 100 kWe SEP

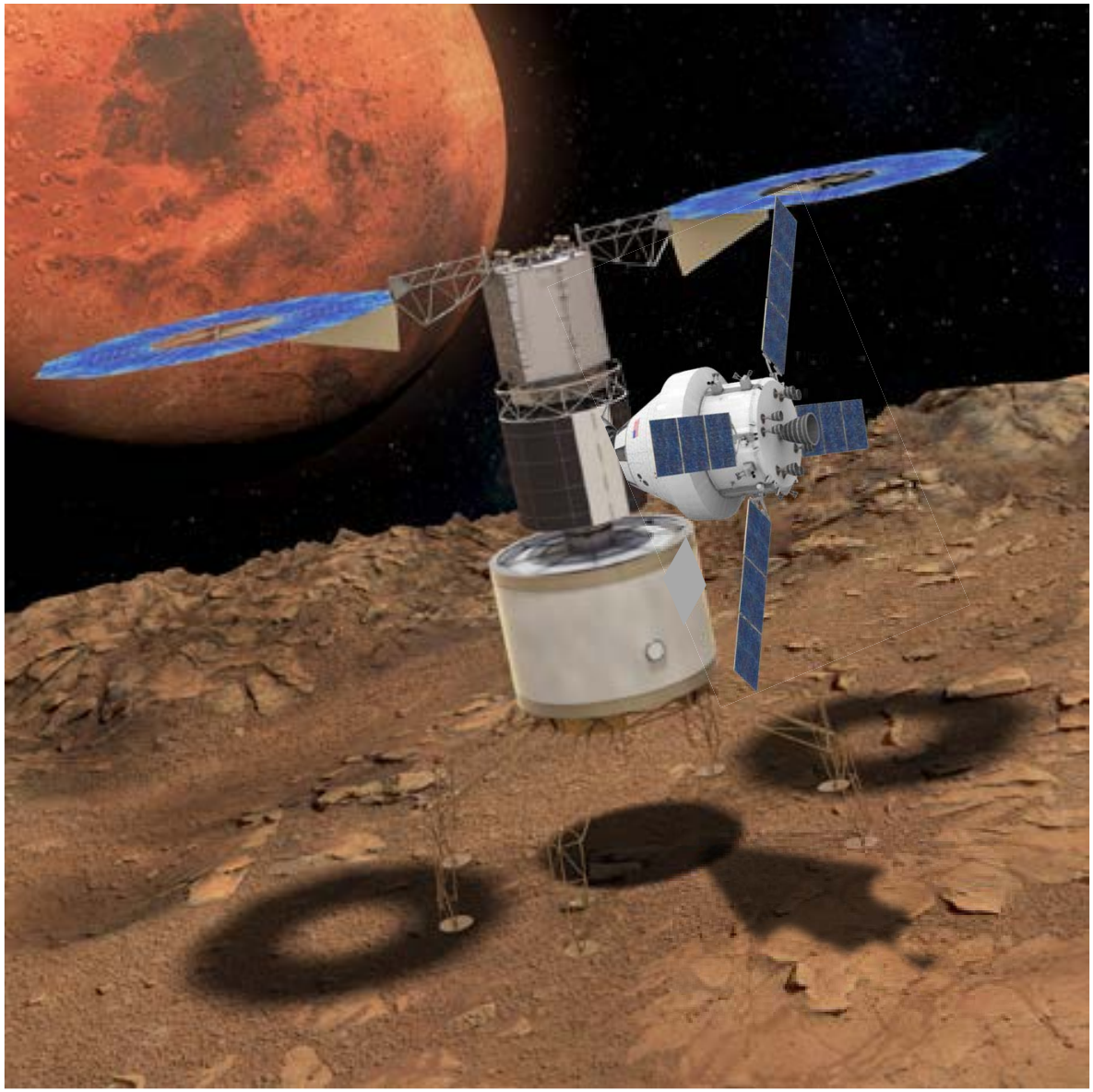
- With a single SLS launch, the 100 kWe SEP tug could deliver a 37 t payload to Phobos in about 3.3 years



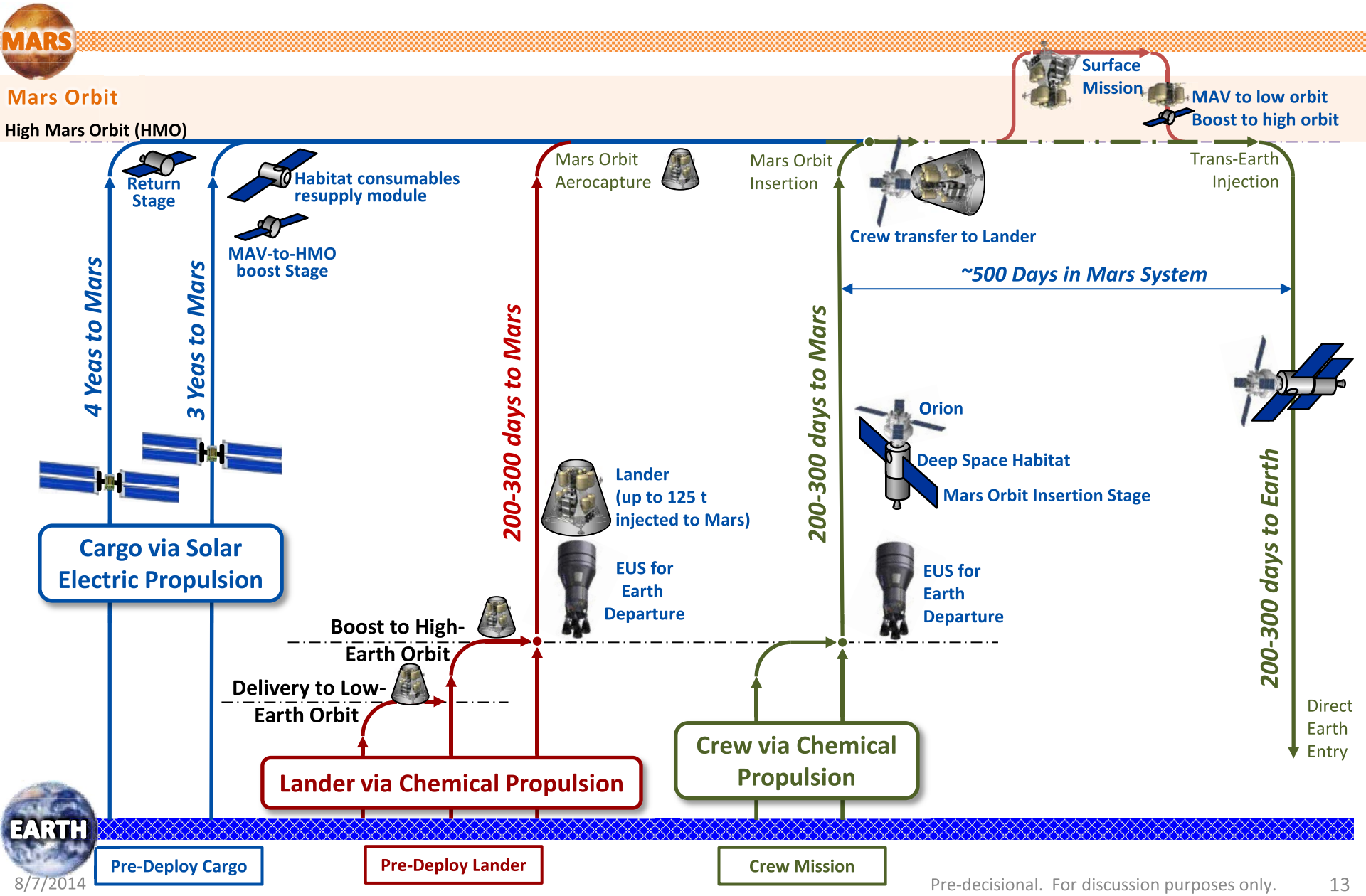
Phobos Base Mission Conceptual Architecture



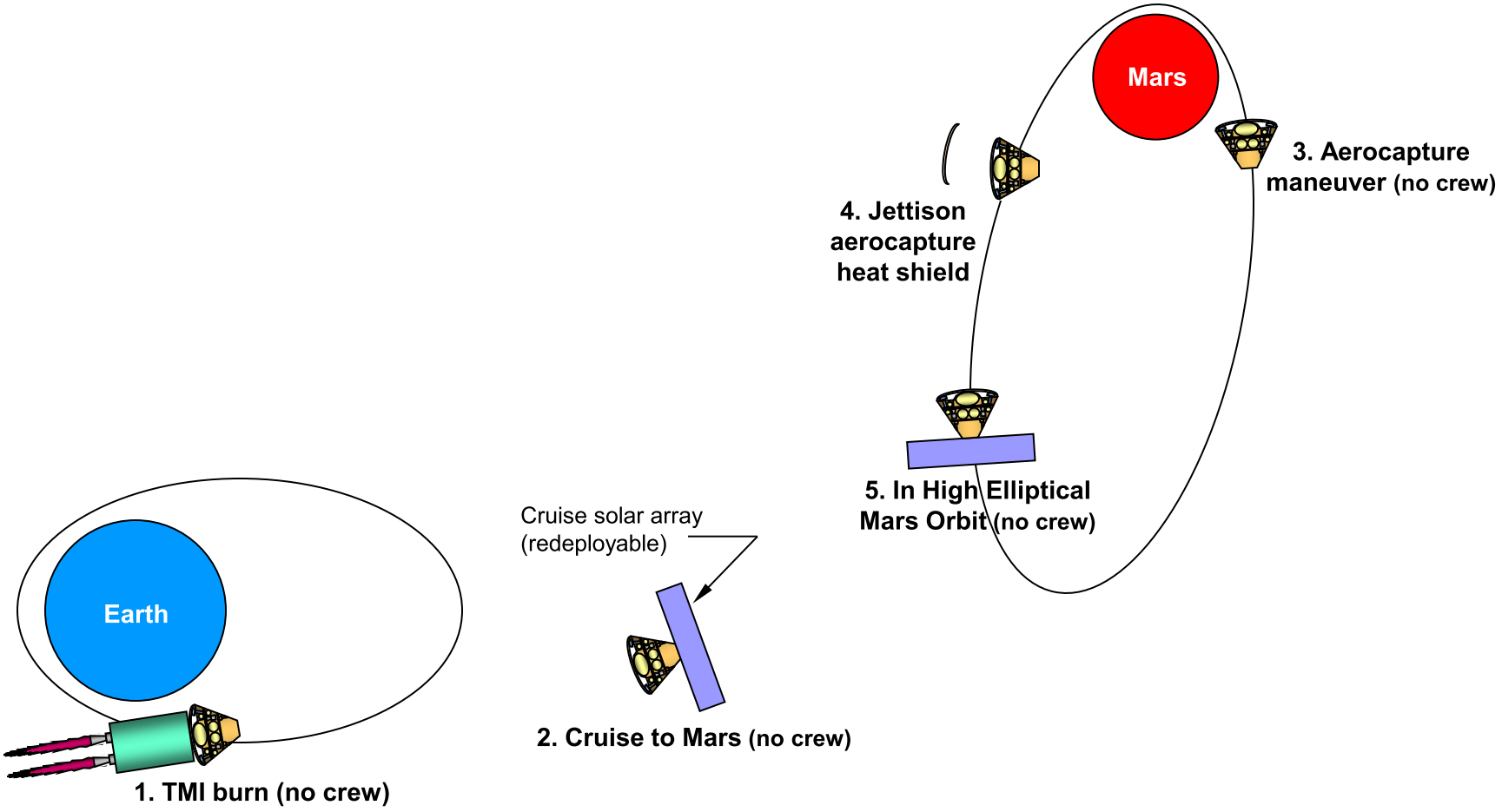
Crew at Phobos Base



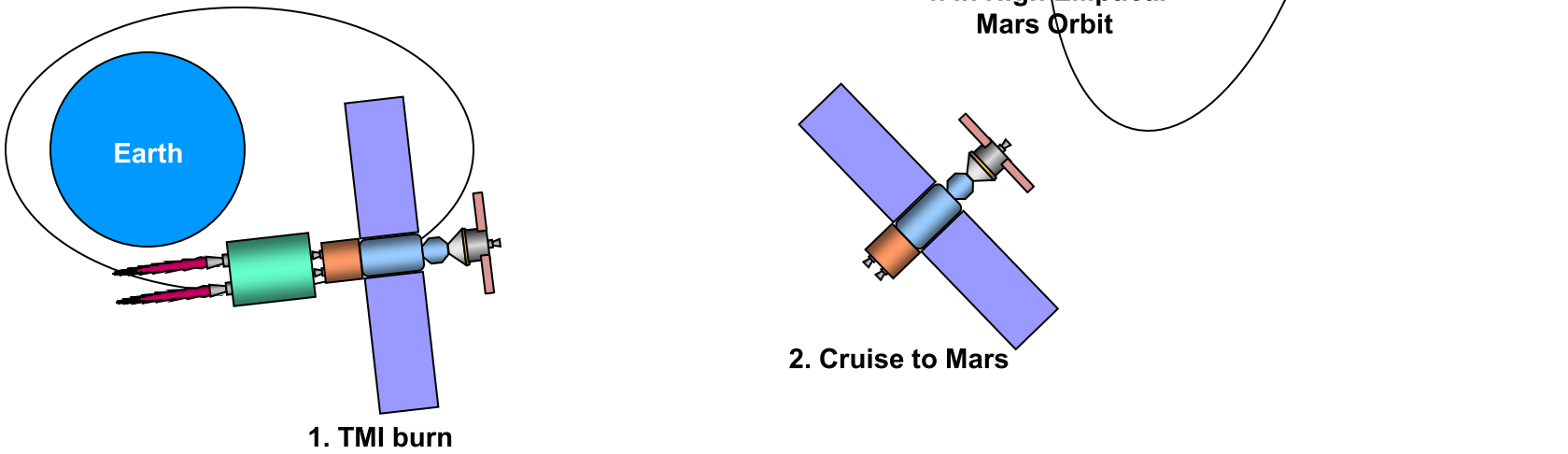
Mars Lander Mission Conceptual Architecture



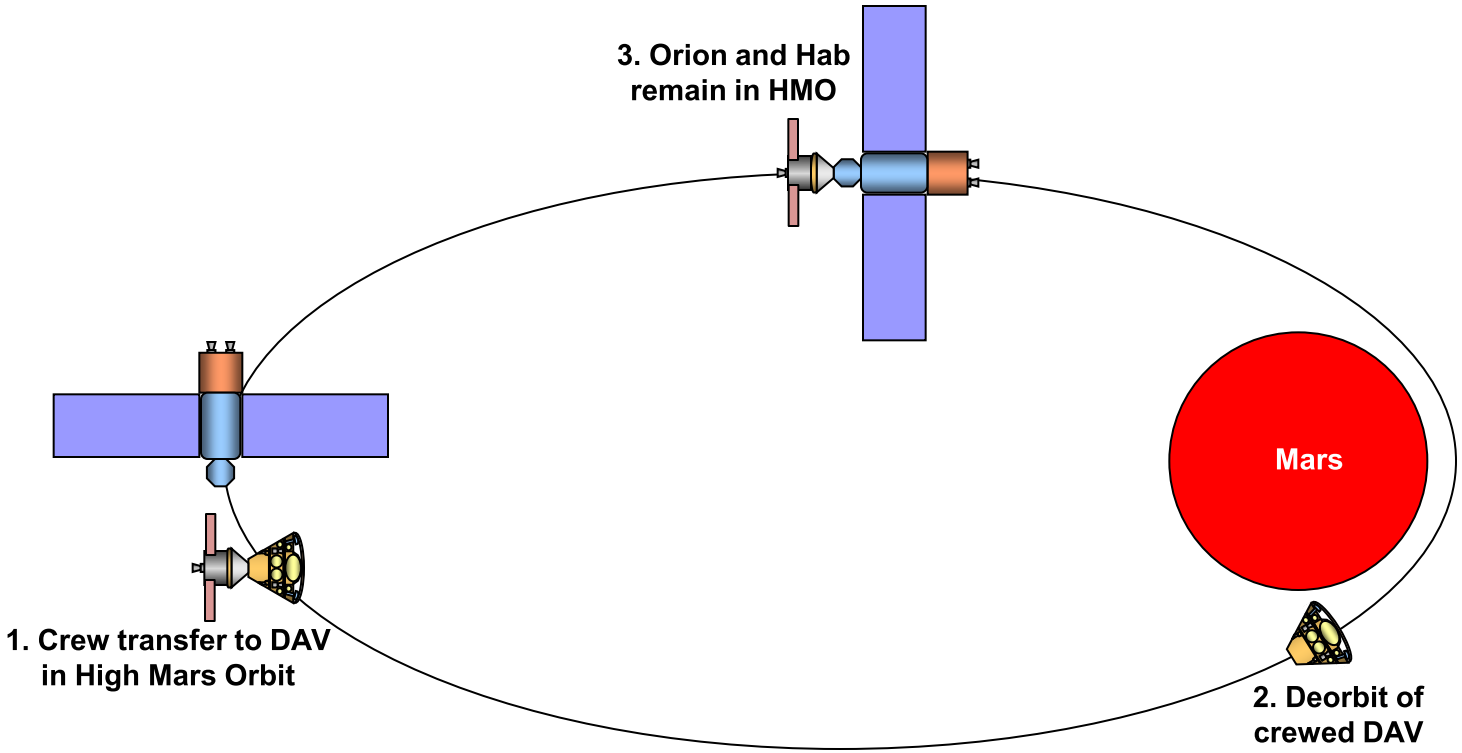
Descent/Ascent Vehicle (DAV) Transit to High Mars Orbit



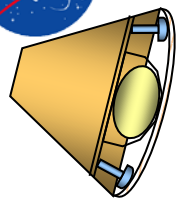
Crew Transit to High Mars Orbit



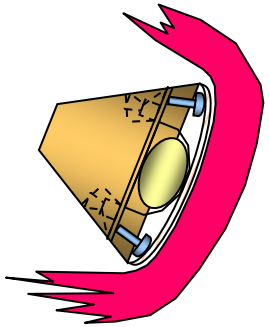
Crew Transfer from Orion to DAV



EDL Concept for Blunt Body Mars Lander

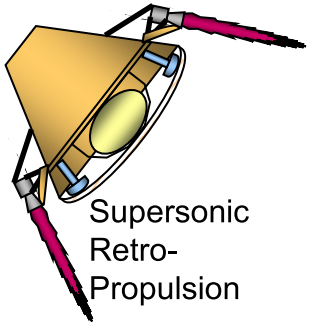


Pre-entry



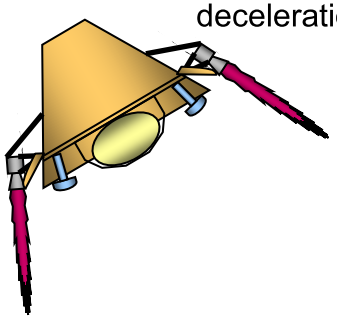
Entry and atmospheric deceleration

Note: There are no parachutes or inflatable decelerators

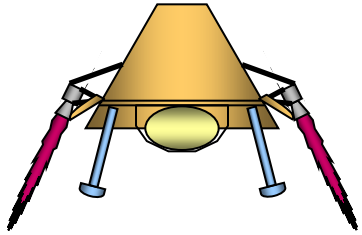


Supersonic Retro-Propulsion

Subsonic propulsive deceleration

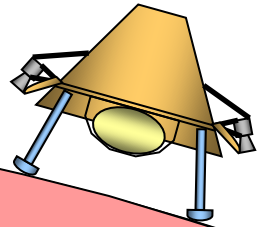


Terminal landing phase



Jettison heat shield

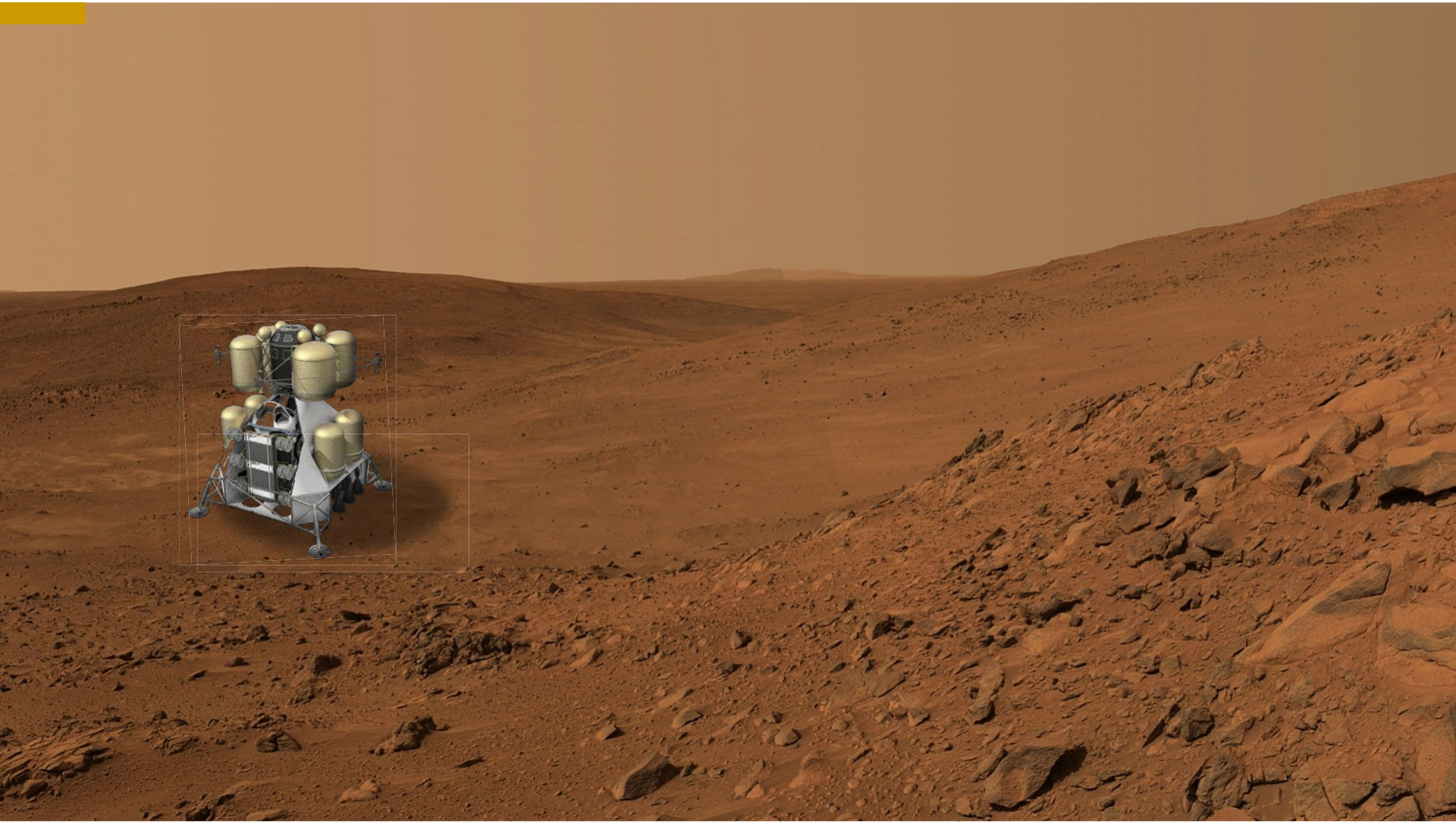
Landed!



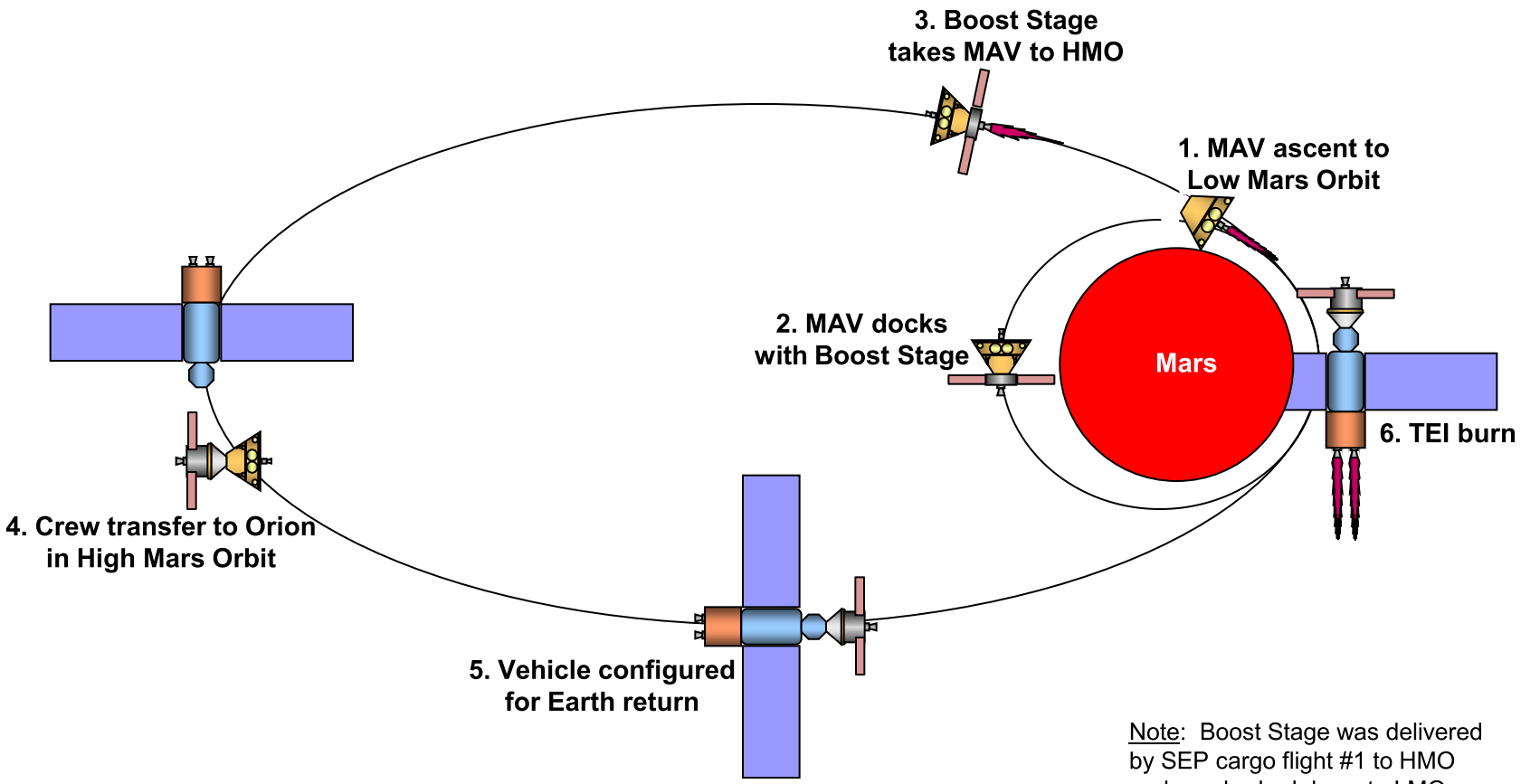
Mars

Crewed Mars Lander

Humans to Mars



MAV Ascent, DSH Docking, and Trans-Earth Injection

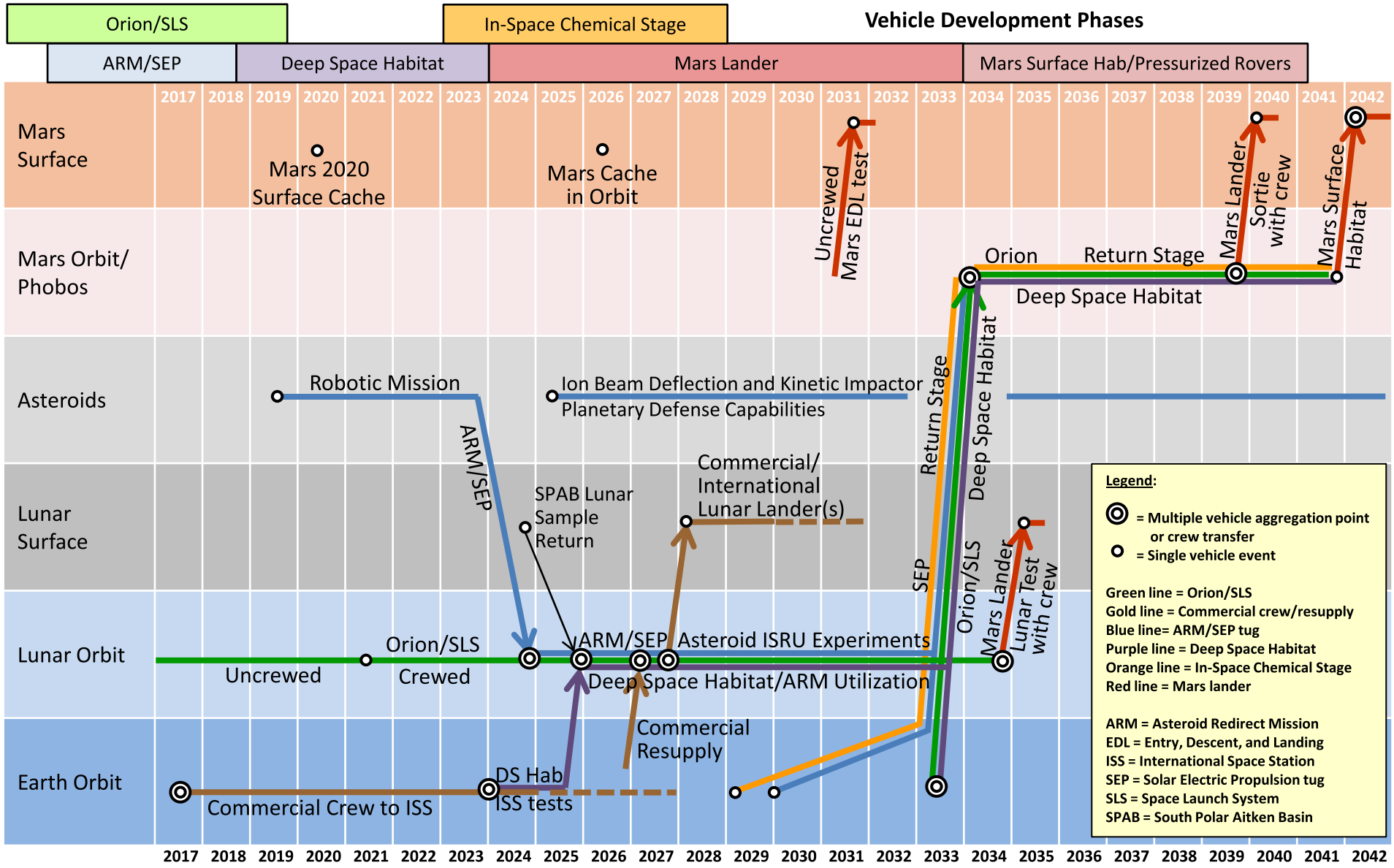


Note: Boost Stage was delivered by SEP cargo flight #1 to HMO and aerobraked down to LMO.

Advanced Technologies Onramp

- Initial human missions to Mars could be implemented using largely current technologies (e.g. traditional space-storable propellants)
- Enhancing new technologies could be on-ramped as they become available:
  - Deployable aerodynamic decelerators could reduce lander launch size and mass and/or increase landed payload
  - Zero boil-off cryogenic propulsion could reduce in-space propulsion mass and/or enable larger crew size and payloads
  - Higher powered SEP (e.g. 300-1,000 kWe) could enable larger and faster cargo delivery and enable other architectures
  - In Situ Resource Utilization (ISRU) could reduce lander mass and launch mass from Earth
- Engineering upgrades that could be on-ramped:
  - Higher throw-weight versions of the SLS could enable larger crew size, more capable crewed vehicles, and/or fewer required launches

Notional Roadmap to Mars (Feasibility Exercise)

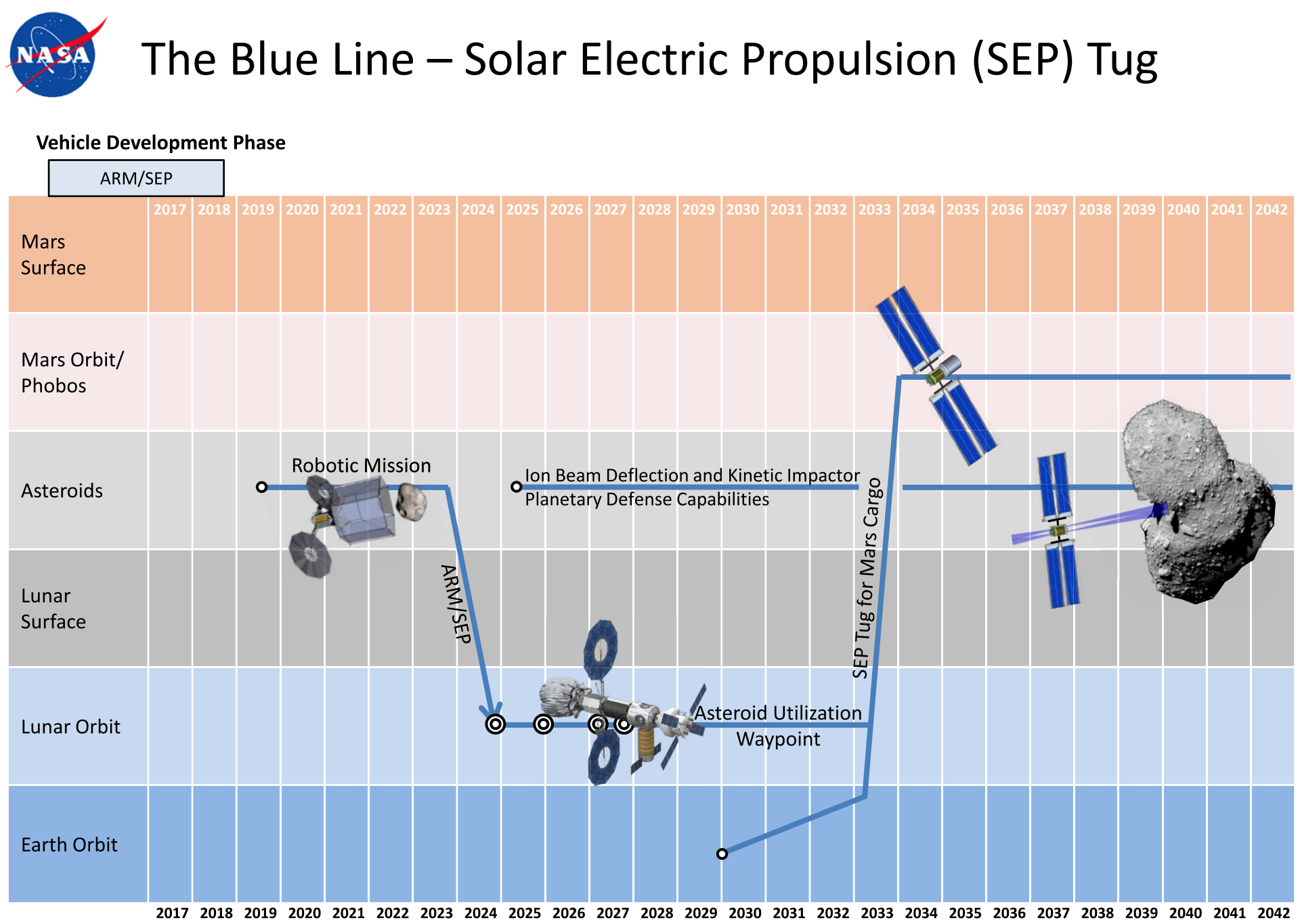


The Blue Line – Solar Electric Propulsion (SEP) Tug

Vehicle Development Phase

ARM/SEP

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Mars Surface																										
Mars Orbit/ Phobos																										
Asteroids																										
Lunar Surface																										
Lunar Orbit																										
Earth Orbit																										



The Green Line – Orion/SLS

Vehicle Development Phase

Orion/SLS

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Mars Surface																										
Mars Orbit/ Phobos																										
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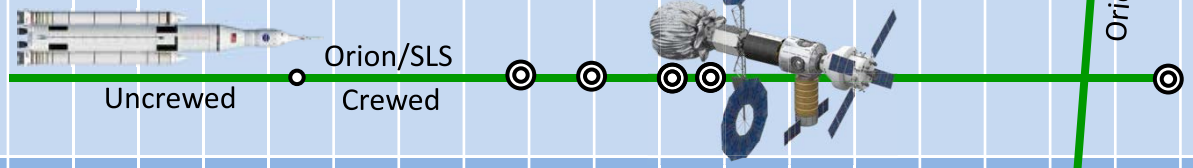
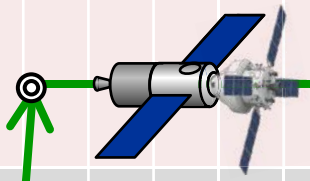
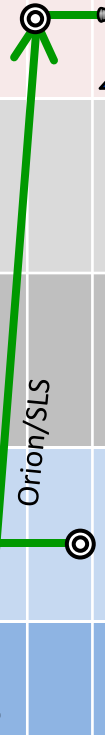
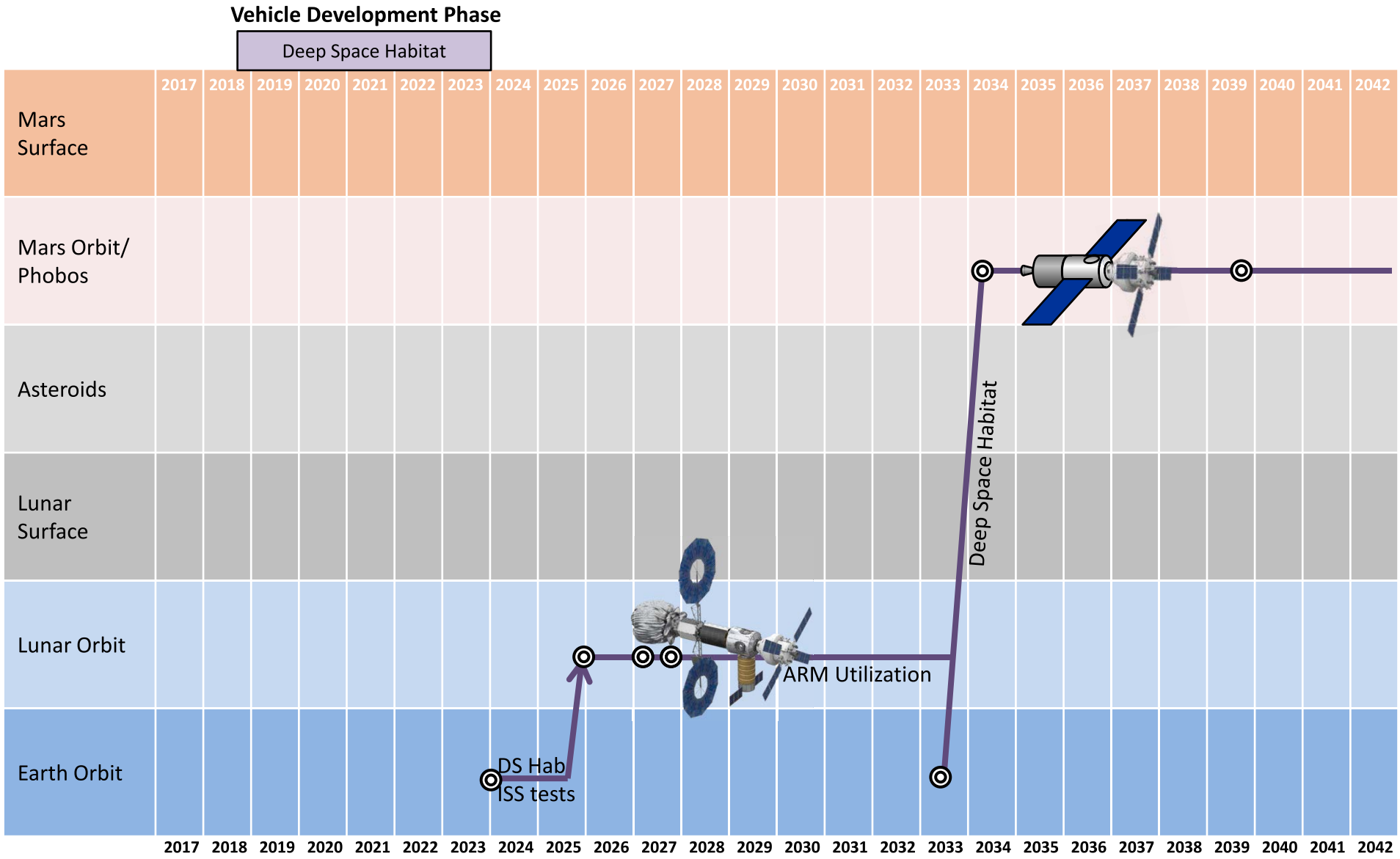
Earth Orbit																										



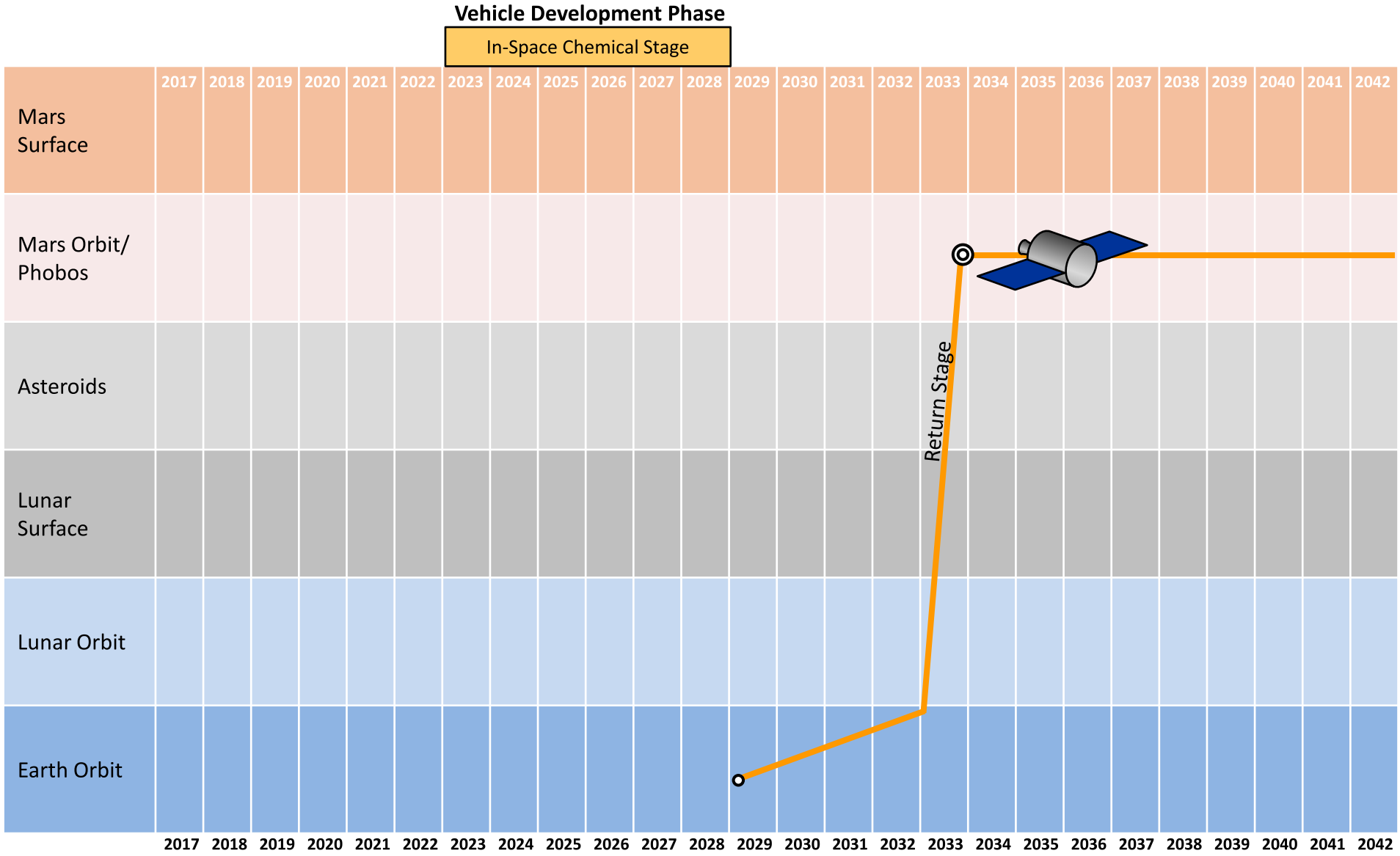




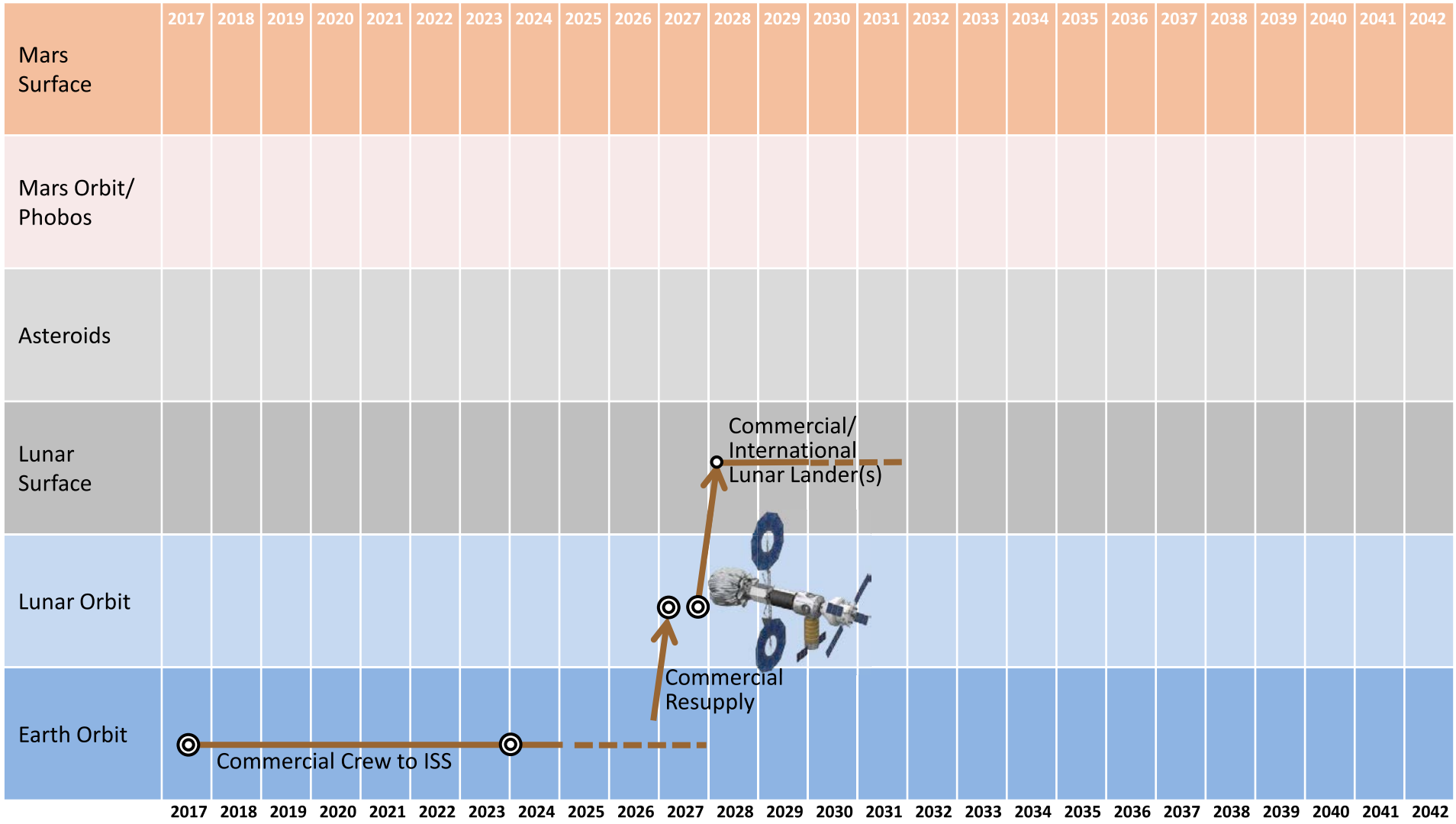
The Purple Line – Deep Space Habitat



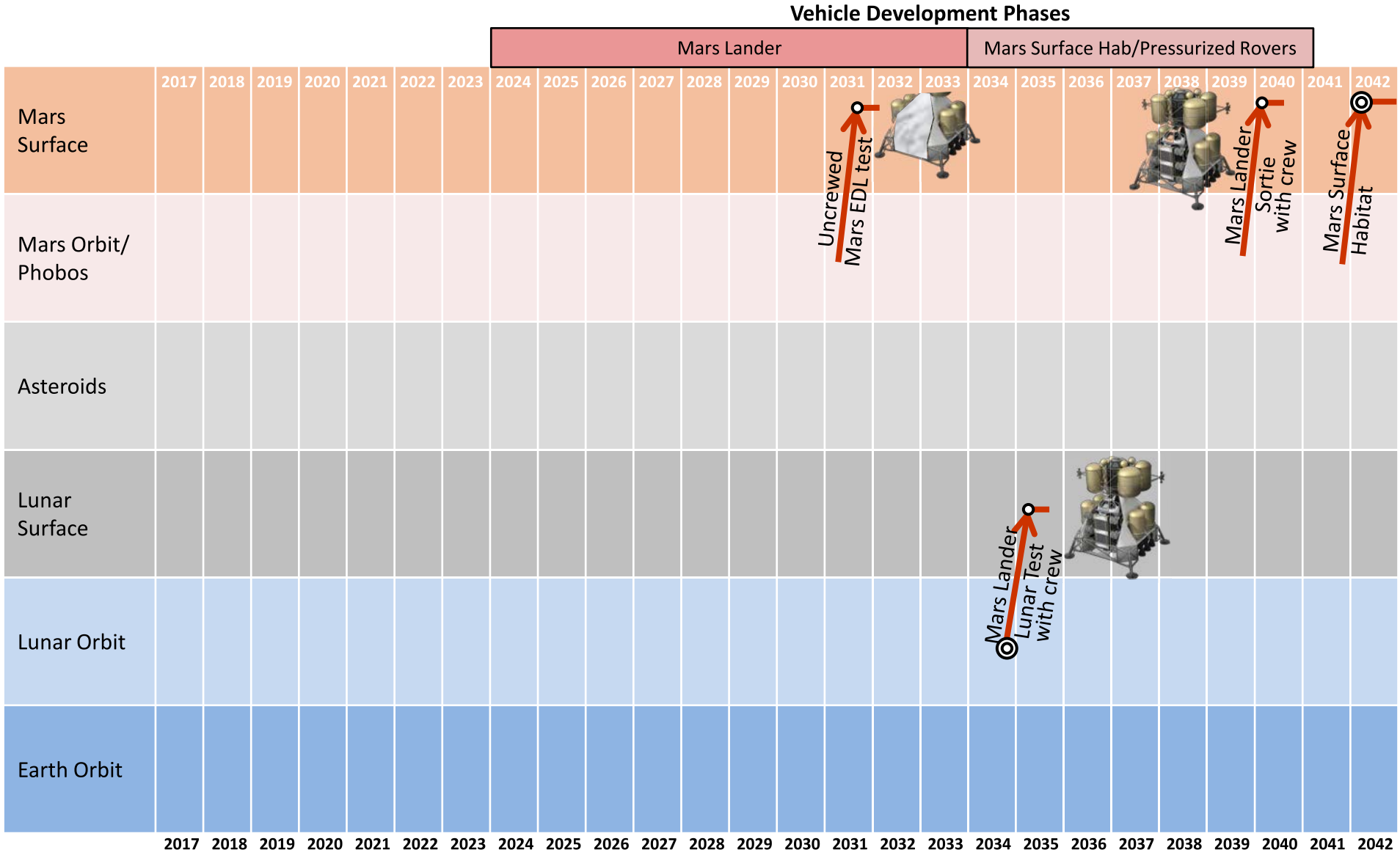
The Orange Line – In-Space Chemical Propulsion Stage



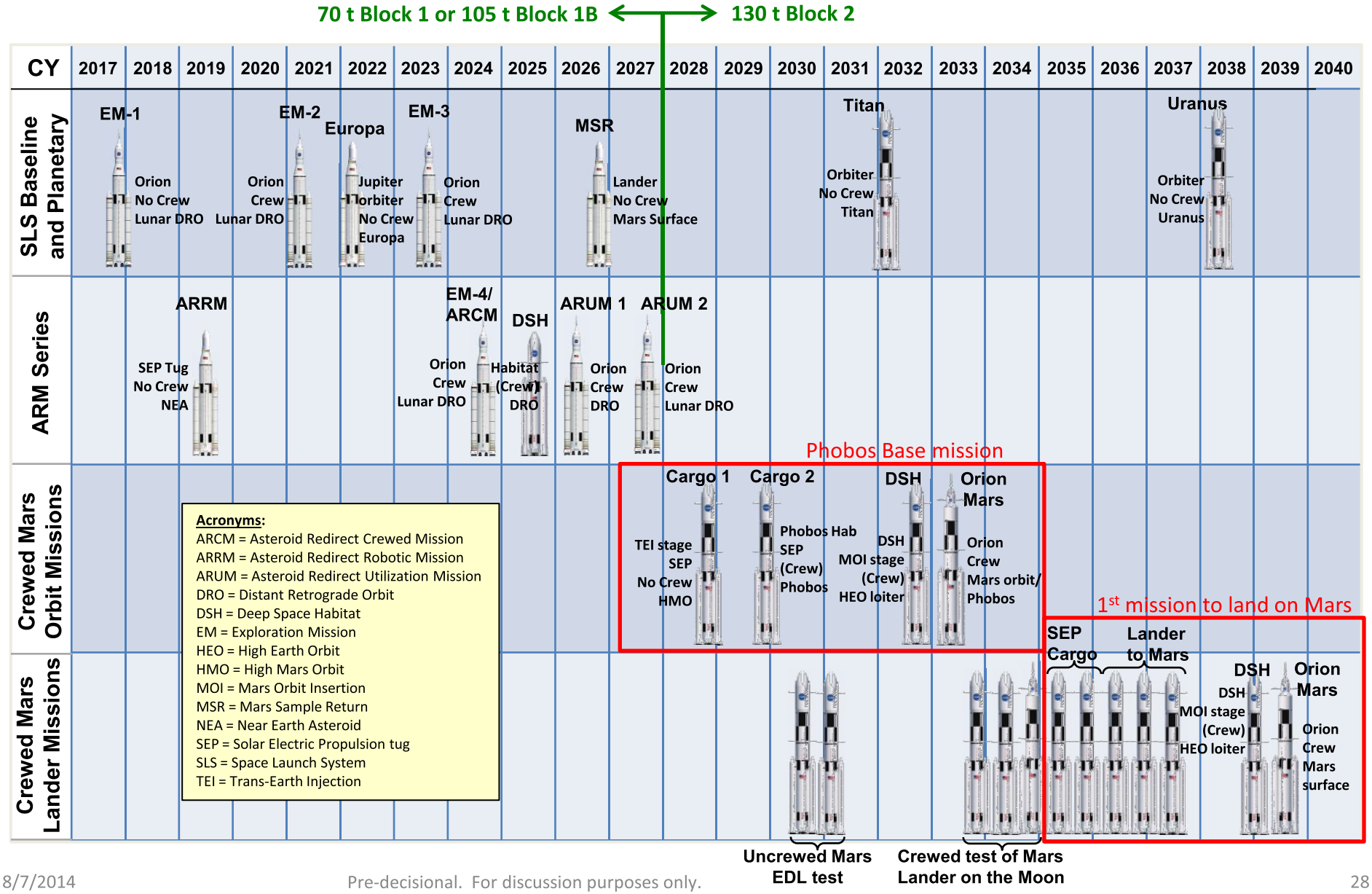
The Gold Line – Commercial/International Vehicles



The Red Line – Crewed Mars Lander



Notional SLS Launch Sequence



Conclusions

- This notional roadmap could be a feasible approach for NASA to send astronauts to Mars orbit and Phobos by 2033 and land on Mars by 2040
- The program would require a few key new technologies, and they are not viewed as being high risk developments:
  - Long duration life support systems
  - Low gravity and radiation support strategies
  - Advanced 100 kWe class Solar Electric Propulsion (SEP)
  - 500 kN class throttleable MMH/NTO rocket engine with high I_{SP} (~328 s)
    - Modified Proton 3rd stage engine or Dnepr 2nd stage engine might work
      - A modified version of the Titan II 2nd stage engine would need higher I_{SP}
    - Could be used for in-space propulsion, lander descent stage, and MAV
  - Supersonic Retro-Propulsion for Mars Entry, Descent, and Landing (EDL)
- The program might be implementable within NASA's current budget, taking advantage of the funds that would free up when Orion and SLS developments are completed
  - Development time and cost might be similar in scope to ISS