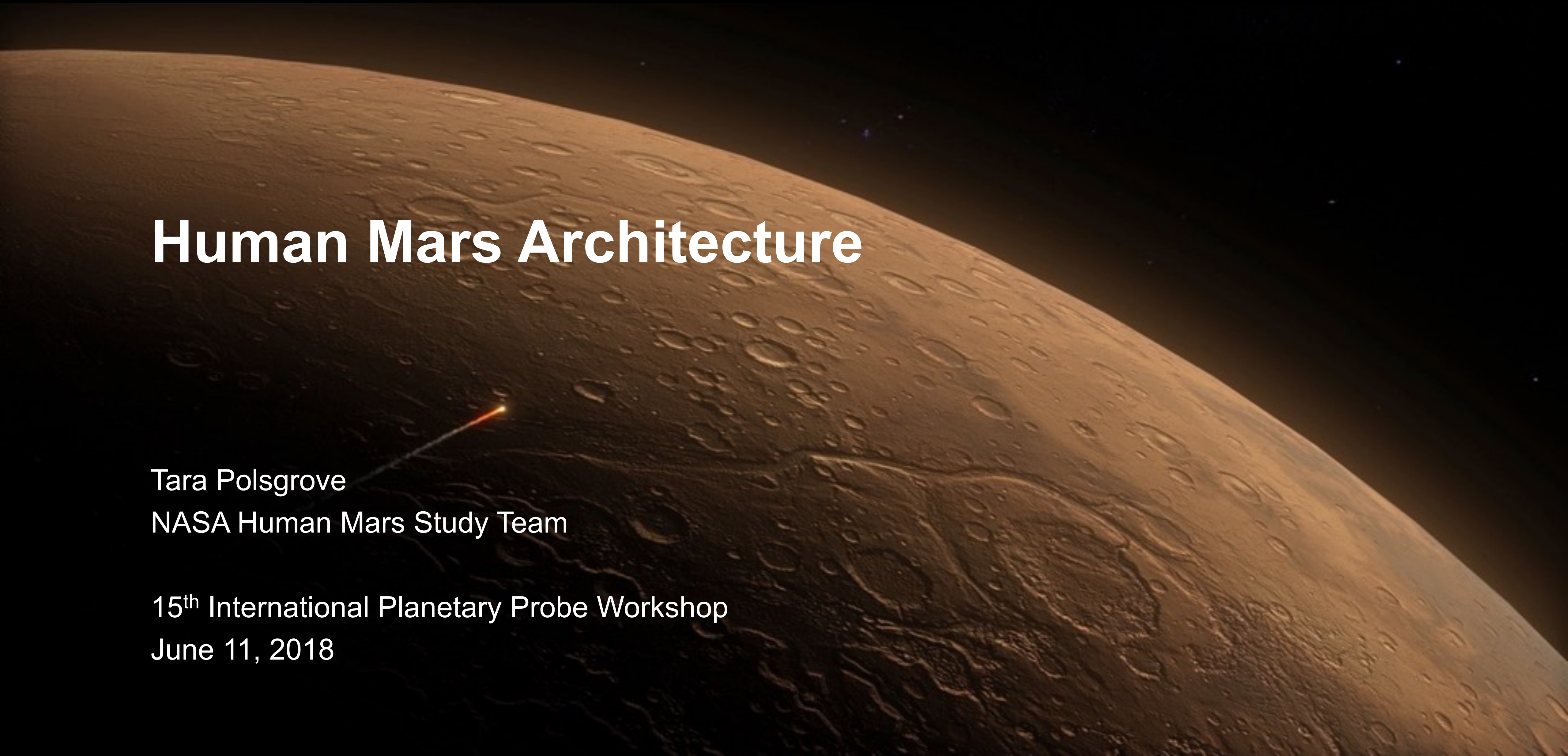
National Aeronautics and Space Administration



Human Mars Architecture

Tara Polsgrove
NASA Human Mars Study Team

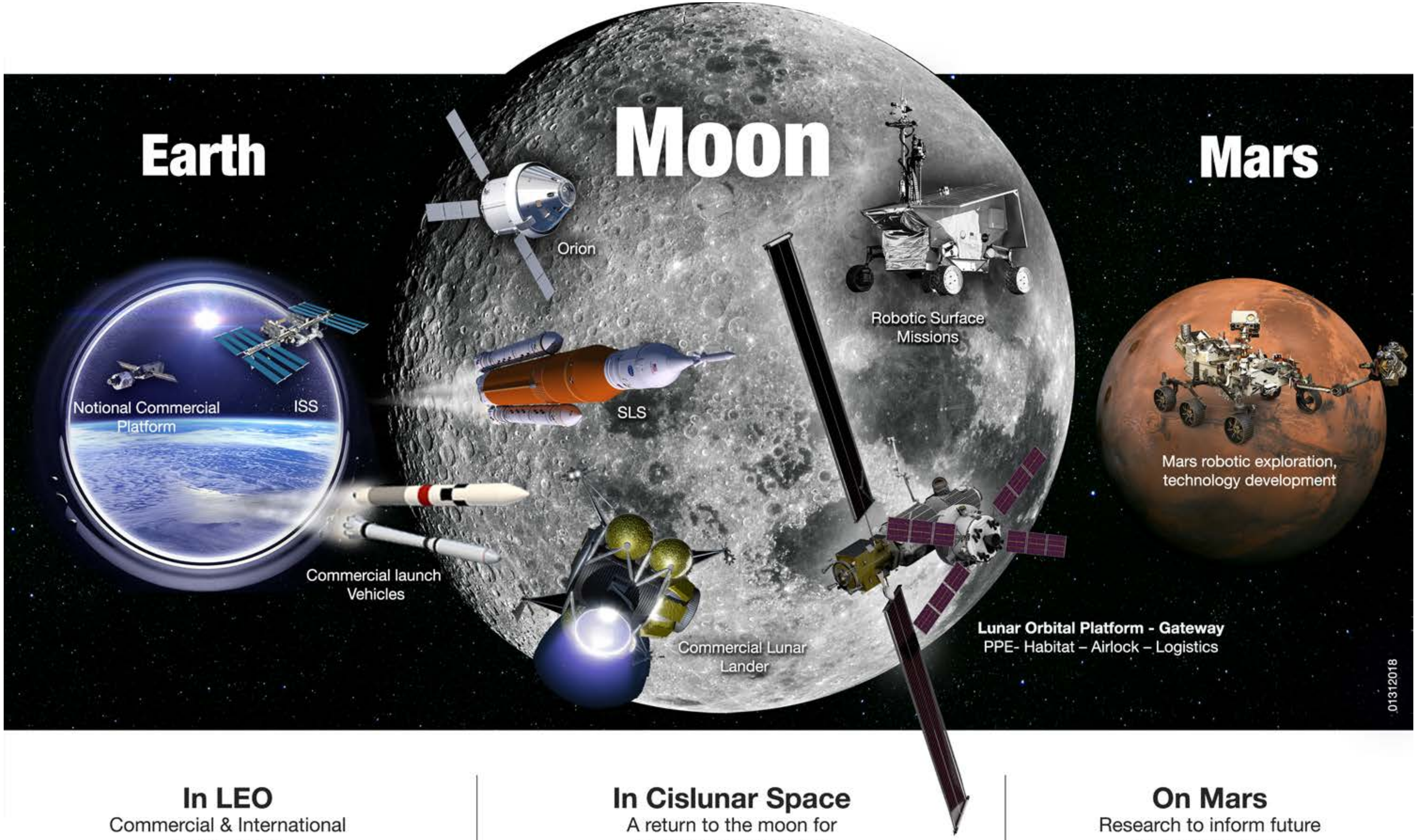
15th International Planetary Probe Workshop
June 11, 2018

Space Policy Directive-1

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.

Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

EXPLORATION CAMPAIGN

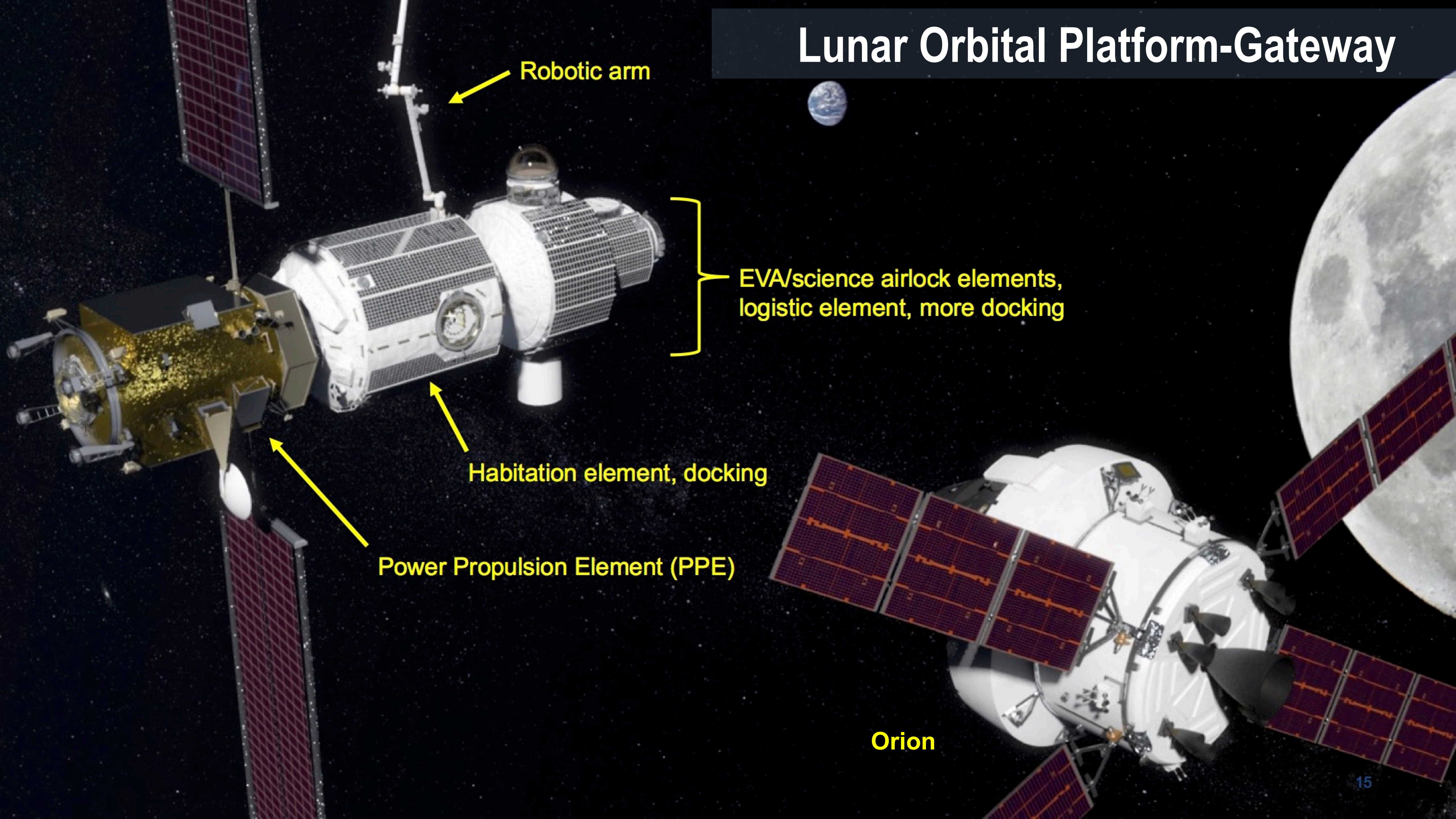


In LEO
Commercial & International partnerships

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

On Mars
Research to inform future crewed missions

Lunar Orbital Platform-Gateway



LUNAR ORBITAL PLATFORM-GATEWAY DEVELOPMENT

Establishing leadership in deep space and preparing for exploration into the solar system

FOUNDATIONAL GATEWAY ELEMENTS

2022	2023	2024+

These foundational gateway capabilities can support multiple U.S. and international partner objectives in cislunar space and beyond.

CAPABILITIES

- Supports exploration, science, and commercial activities in cislunar space and beyond
- Includes international and U.S. commercial development of elements and systems
- Provides options to transfer between cislunar orbits when uncrewed

OPPORTUNITIES

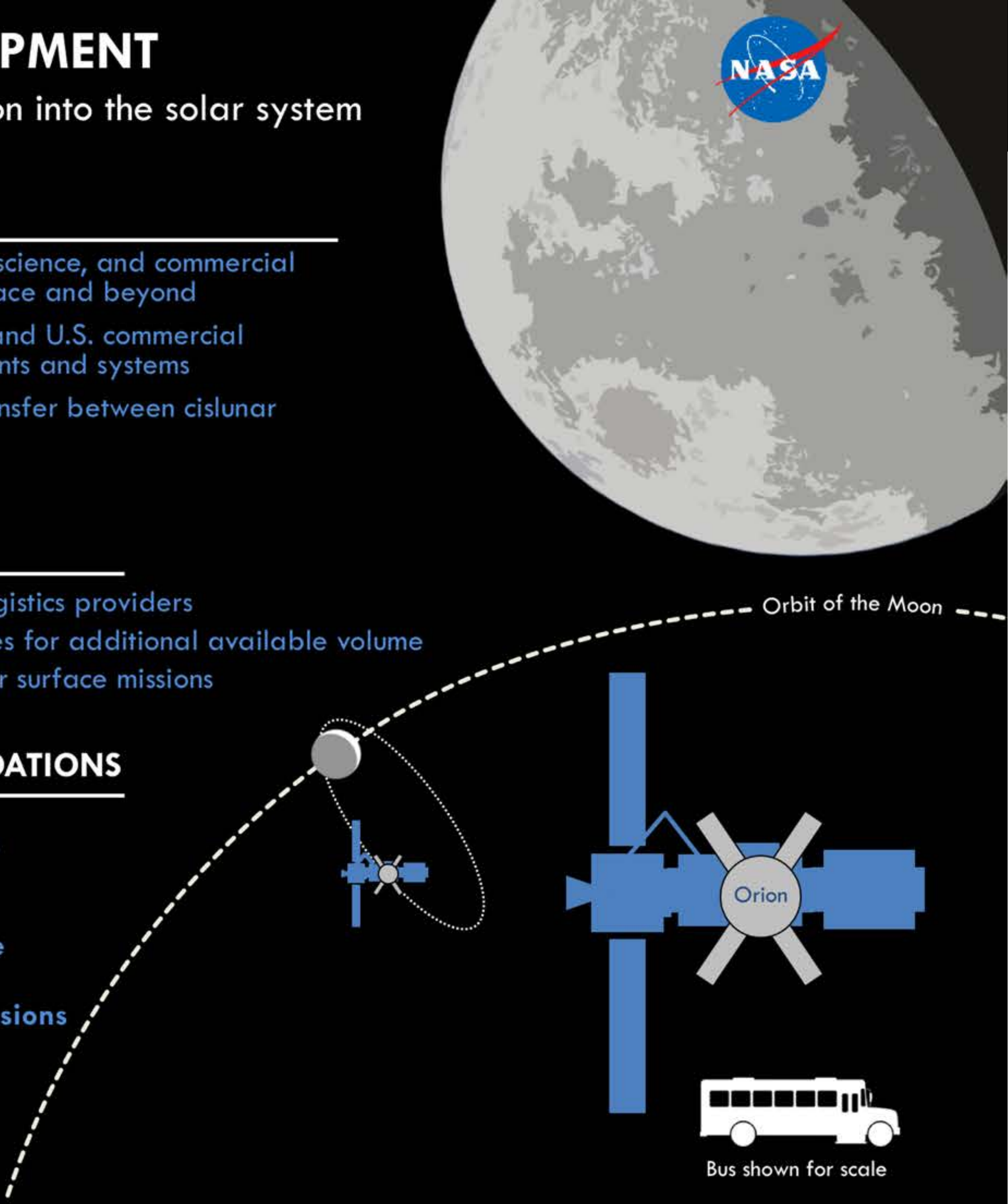
- Logistics flights and logistics providers
- Use of logistics modules for additional available volume
- Ability to support lunar surface missions

INITIAL ACCOMMODATIONS

4 Crew Members

At least 55 m^3 Habitable Volume

30 Day Crew Missions



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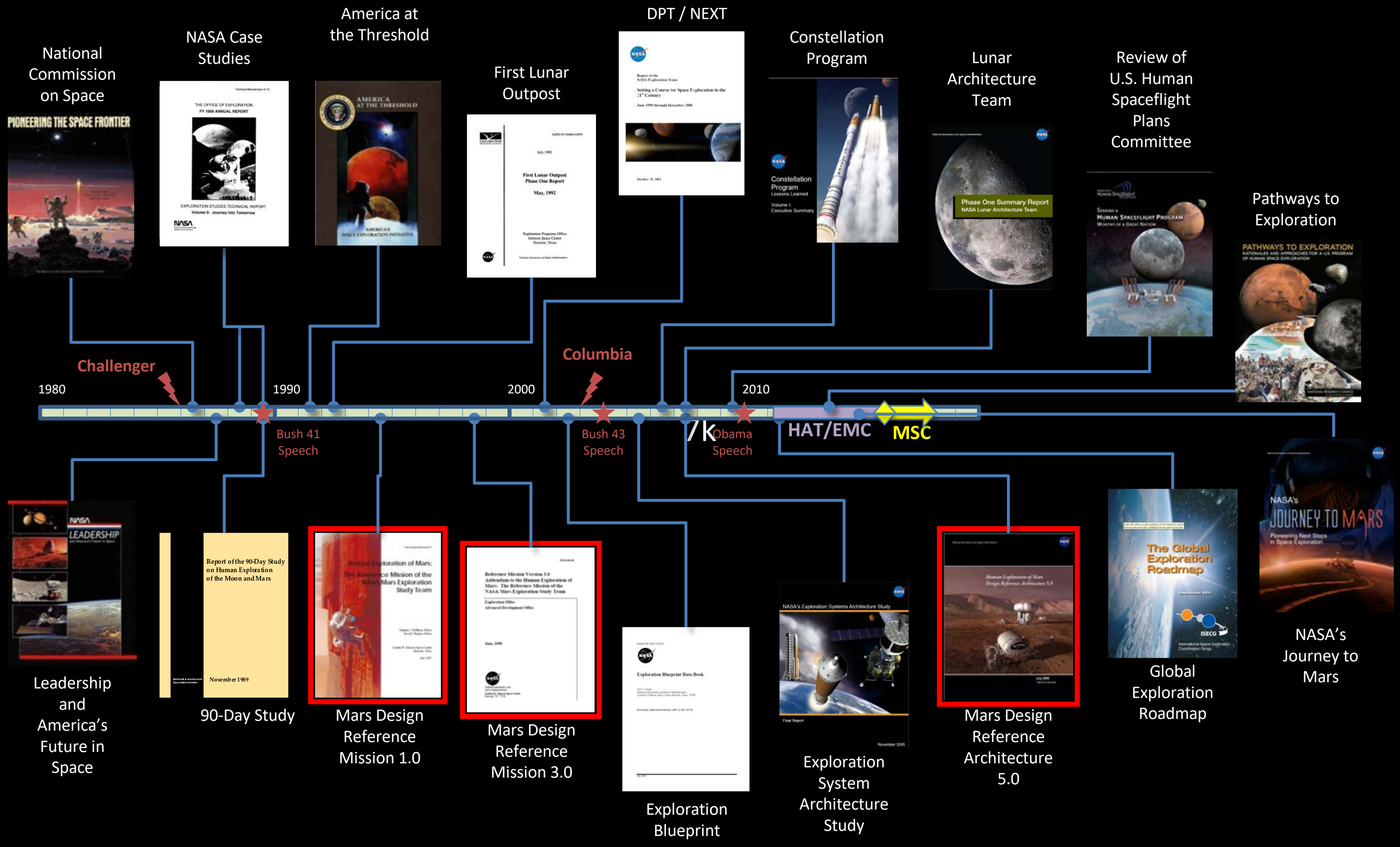
A Brief History of Human Exploration Beyond LEO



Exploring the Mars Mission Design Tradespace

- **A myriad of choices define the "Architecture" of a human Mars mission**

- **A large menu of human Mars architecture choices can be organized into three distinct segments**
  - End State: Describing long-term architecture goals and objectives
  - Transportation: Getting crew and cargo to Mars and back
  - Surface: Working effectively on the surface of Mars

- **Human exploration of Mars may represent one of the most complex systems-of-systems engineering challenges that humans will undertake**
  - Multiple systems must work seamlessly together

- **Work will continue to define the optimal human Mars architecture, and the following is ONE possible solution.**

Design Choices

Mission Architecture / End State	Transportation – Earth-to-Orbit
Primary Progra Focus	
Flags & Footprint Lewis & Clark	
Research Base / Antarctic Field Analog	
Primary Activity Science & Resear	
Primary Activity Resource Utilizati	
Primary Activity Human Expansio	

Transportation – Cis-Earth Infrastructure: Initial Orbit	Long-Term Sta	Supporting Space		In-Space	Earth Return	Cis-Lunar	Transportation – Deep Space: Mars Orbit	Chemical	In-Space	In-Space	No. of	
DRO	Cis-Lu											
Near Rectilinear Halo Orbit (NRHO)	No Ci Infrast											
LEO												
HEO												
-												

Transportation – Deep Space: Destination	Mars Parking	Mars Orbit	Mars Orbit	Mars Orbit	Mars	Ascent Vehicle	Ascent Vehicle	MAV	Earth	Earth	Mars Pre-	Earth Return: Descent to	Earth Entry
Mars Orbit													
Phobos													
Mars' Surface	50												
Combination	Are												
Lunar First													
Areosynchronous													
Mars Flyby													
Backflip													
Grand Tour													
Fast													

Human Health: Radiation	Count	Design	Surface: First Surface	Crew Surface	No. of Crew to	Lander	Landed Mass per	Lander Entry	Landing		Landing
Passive	Zero-G										
Active	Artific										
	Artific										

Surface														
ISRU	Power	Habitat Type	Life Support	Planetary Outpost	Excursion Radius/ Exploration Zone	Length of Surface Stay	Planetary Sciences	Laboratory Sciences	ECLSS	Trash	Robotics	Landing Zone Surveys	Cargo Handling	Surface Communication
None	Solar	Monolithic	Open	Different for Each Expedition	< 10 km	7 sols	Teleoperation of Instrument / Networks	None	Open	Containers	Low Latency Telerobotics	Orbital	Crane/ Hoist	Line of Sight
Demonstration Only	Nuclear	Modular	Closed	Single Outpost	10 - 100 km	14 sols	Recon Geology / Geophysiology	Basic Analysis / No Lab	50 - 75% Closed	Recycle	Autonomous	Robotic	Ramp	Relay Satellite
Atmospheric Oxygen	RTG	Inflatable		Multiple Outposts	> 100 km	30 sols	Field Work	Moderate Geochemical + Life Science	75 - 90% Closed	Combination	Crew Partnered		ATHLETE	
Water from Regolith	Combination	Rigid				90 sols	Drilling / Geophysical Tests	Full-Scale Life Science	> 90% Closed				Other	
Water from from Subsurface Ice		Local Features and Resources				300 - 500 sols								
Fabrication / Manufacturing						500 - 1000 sols								
Combination						> 1000 sols, overlapping crews								
Export														

The current big picture design choices offers up 5.3 x 10^{37} possible combinations

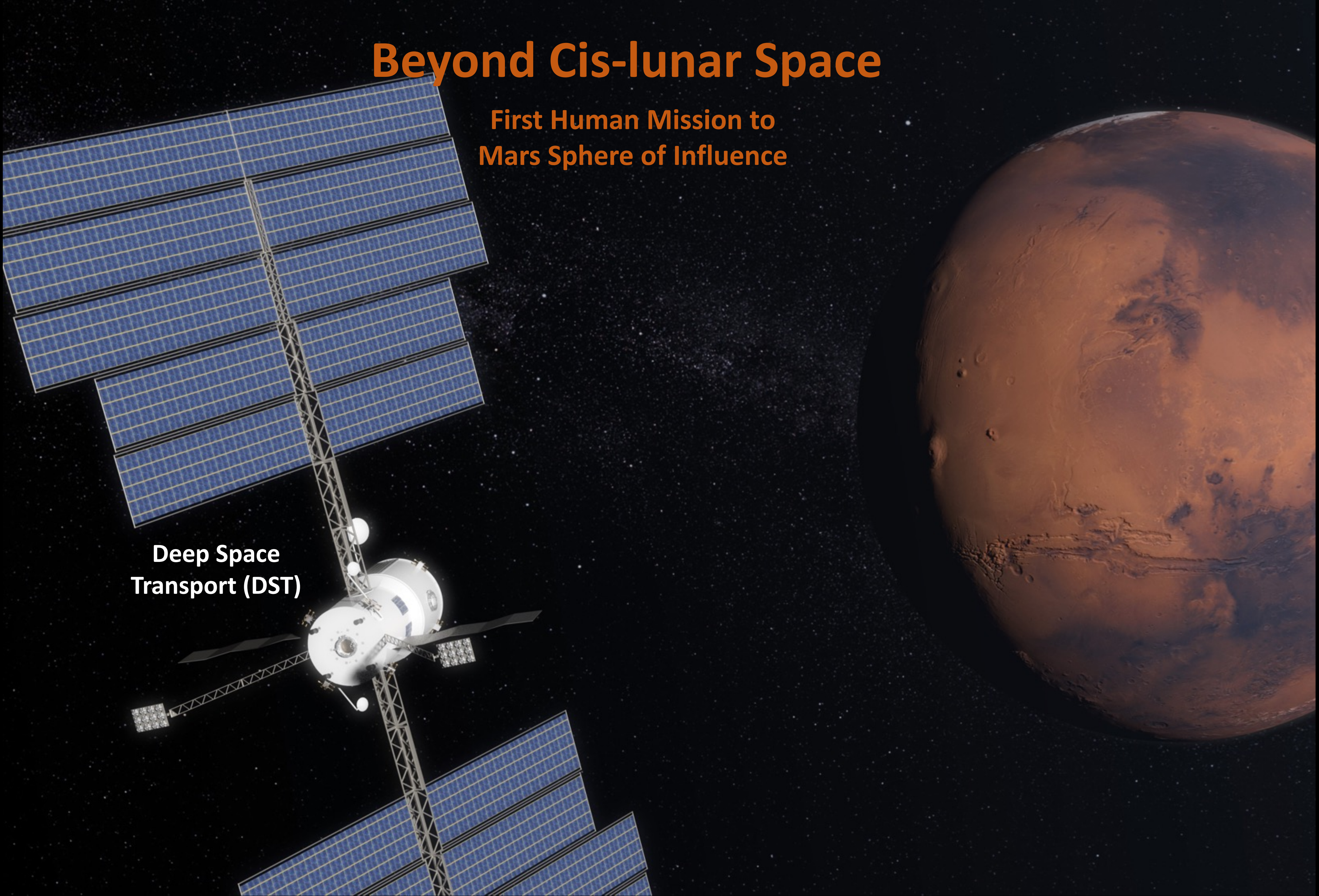
20 Questions - End State, Reusability

Mission Architecture / End State					
Primary Program Focus	**Mission Class**	**Level of Human Activity**	**Earth Based Mission Support**	**Cost Emphasis**	**Reusability**
Flags & Footprints / Lewis & Clark	Opposition Class - Short Stay (1-60 sols)	Robotic / Telerobotic	Continual Control	Low Cost / Gradual Build-Up	None
Research Base / Antarctic Field Analog	Conjunction Class - Long Stay (300+ sols)	Expeditions	Moderate Intervention	High Cost / Gradual Build-Up	In-Space Habitation
Primary Activity: Science & Research	All-Up vs. Split Mission	Human-Tended	No Daily Intervention	Low Cost / Fast Build-Up	In-Space Transportation
Primary Activity: Resource Utilization		Continuous Presence	Minimal	High Cost / Fast Build-Up	EDL and Ascent
Primary Activity: Human Expansion		Human Settlements			Surface Systems
		Human Colonization			Infrastructure for Permanent Habitation

- **A single surface site lends itself to a “field station” approach for development of a centralized habitation zone / landing site. The first mission to this site would deploy habitation, power, and other infrastructure that would be used by at least two subsequent surface missions.**
- **Reusable surface elements (first 3 landed missions)**
  - Provides some infrastructure for missions to follow
- **Reusable in-space transportation and habitation (at least 3 missions)**
  - Based in cis-lunar space
- **Cost can be spread via gradual buildup of transportation/orbital capability → short surface stay → long surface stay**

SUMMARY – NASA Example Mission

- **End State: First 3 human Mars mission visit a common "Field Station"**
  - Single landing site for first 3 (min) surface missions
  - Long-distance (100 km-class) surface mobility
- **Major decisions that "frame" this example architecture**
  - Reusable in-space transportation and habitation*
  - Split mission architecture (predeploy)
  - Conjunction-class, long-stay, minimum energy
  - Hybrid in-space propulsion
  - Use of ISRU from the very first landed mission
- **Priority elements and technological capabilities:**
  - Reusable, refuelable in-space propulsion (SEP and chemical)
  - Long-lifetime, high reliability in-space habitation
  - 20-25 mt payload to Mars surface delivery (E/D/L)
  - Surface nuclear power
  - Atmospheric ISRU, evolving to atmosphere + water
- **Affordability and sustainability: TBD**
- **Target milestones: First human orbital mission 2033, first human landed mission 2037**

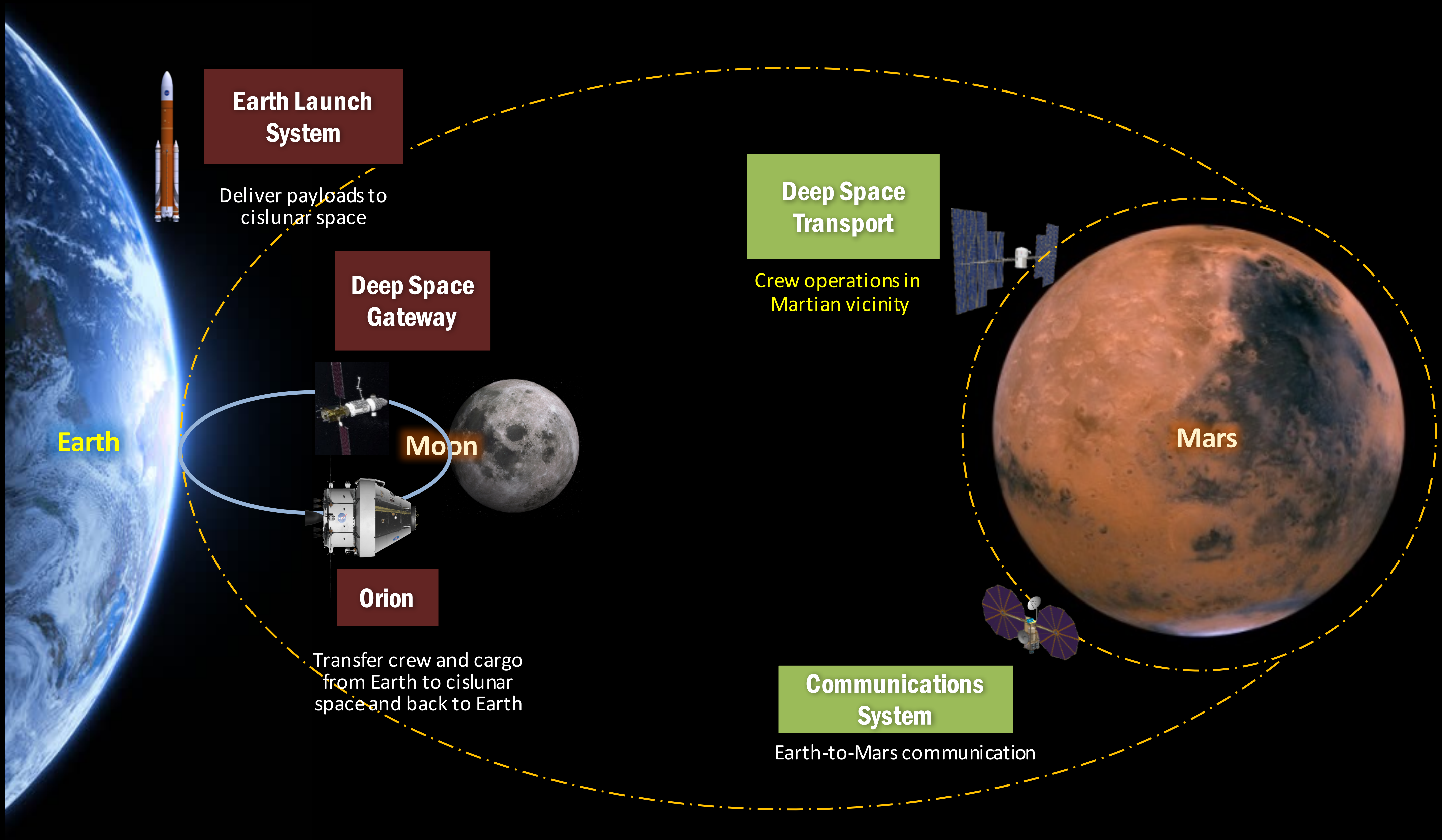

Beyond Cis-lunar Space
First Human Mission to
Mars Sphere of Influence
Deep Space
Transport (DST)

Orbital Mission to Mars Sphere of Influence

- **Emphasis on first human mission to Mars' sphere of influence**
  - First long duration flight with self sustained systems
  - Autonomous mission with extended communication delay
  - First crewed mission involving limited abort opportunities

- **Example Assumptions**
  - 8.4 m Cargo Fairing for SLS launches
  - Crew of 4 for Mars class (1000+ day) mission independent of Earth
  - Orion used for crew delivery and return to/from cislunar space
  - Re-usable DST/Habitat and Propulsion Stage
    - Hybrid (SEP/Chemical) In-Space Propulsion System
    - Gateway used for aggregation and re-fueling of DST

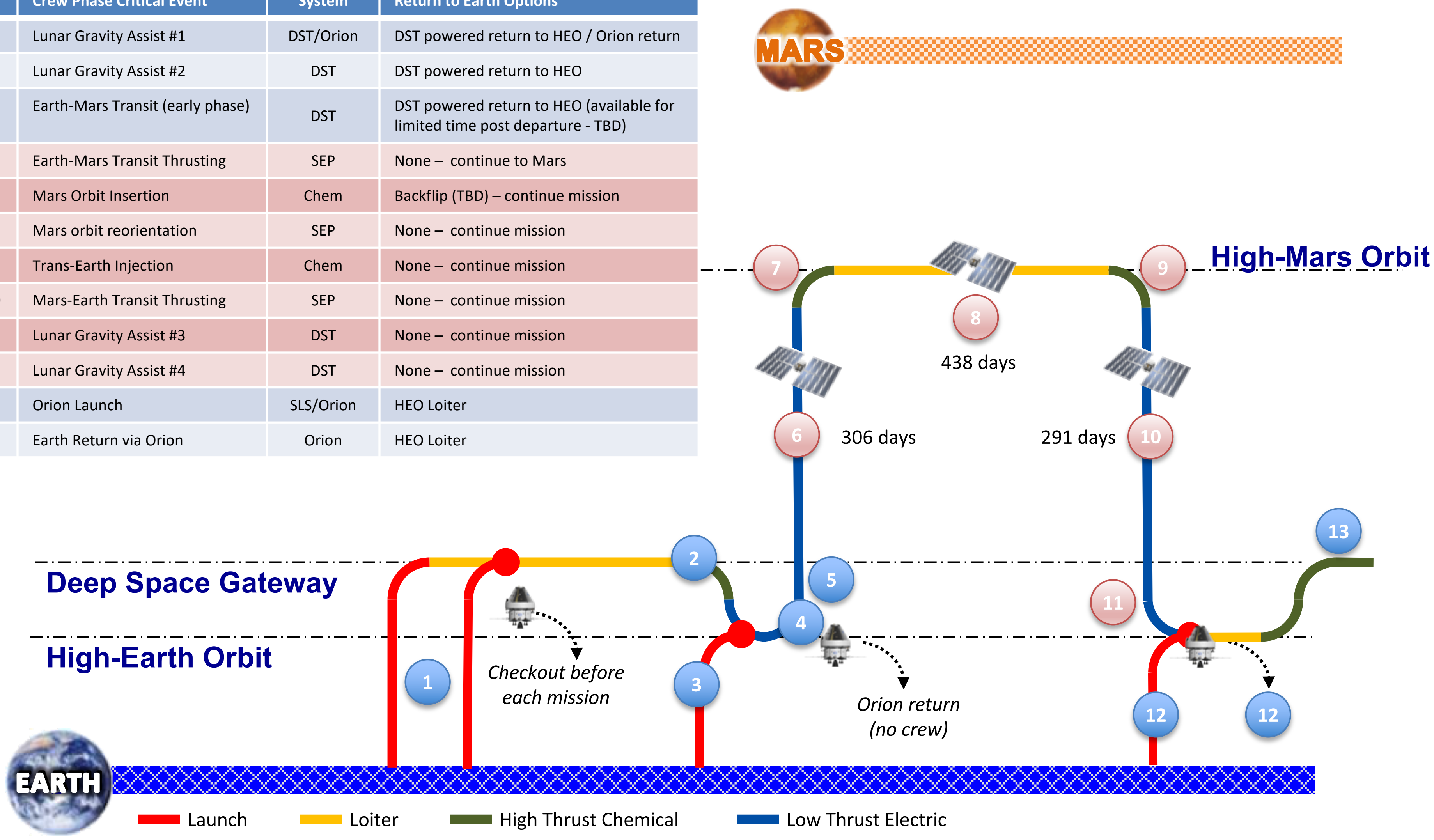
Mars Orbital Mission Elements and Systems



Mars Orbital Mission

Example Operational Concept

#	Crew Phase Critical Event	System	Return to Earth Options
4	Lunar Gravity Assist #1	DST/Orion	DST powered return to HEO / Orion return
5	Lunar Gravity Assist #2	DST	DST powered return to HEO
5	Earth-Mars Transit (early phase)	DST	DST powered return to HEO (available for limited time post departure - TBD)
6	Earth-Mars Transit Thrusting	SEP	None – continue to Mars
7	Mars Orbit Insertion	Chem	Backflip (TBD) – continue mission
8	Mars orbit reorientation	SEP	None – continue mission
9	Trans-Earth Injection	Chem	None – continue mission
10	Mars-Earth Transit Thrusting	SEP	None – continue mission
11	Lunar Gravity Assist #3	DST	None – continue mission
11	Lunar Gravity Assist #4	DST	None – continue mission
12	Orion Launch	SLS/Orion	HEO Loiter
12	Earth Return via Orion	Orion	HEO Loiter



Mars Surface Mission

Mars Surface Mission

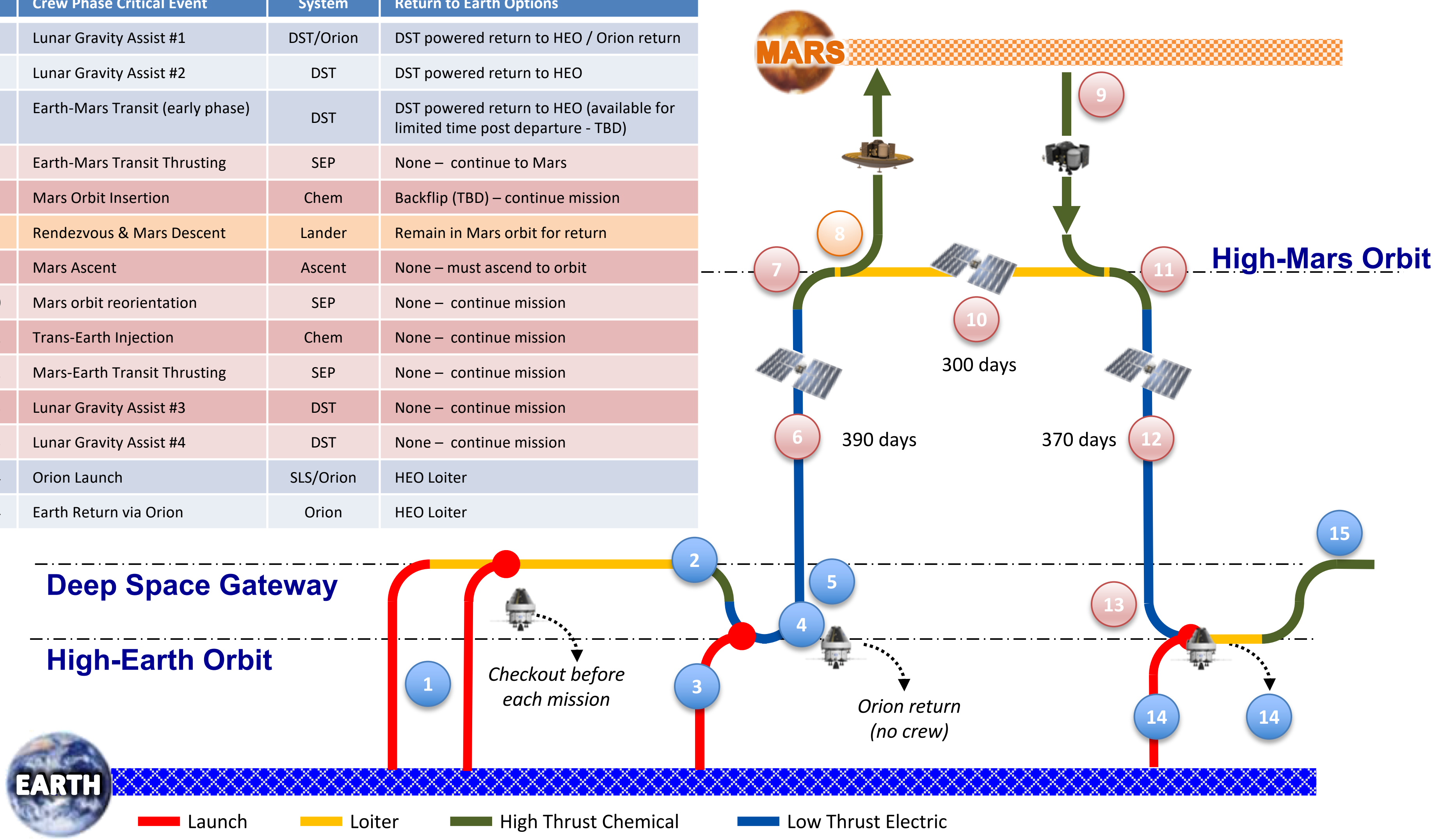
- **Emphasis on establishing Mars surface field station**
  - First human landing on Mars’ surface
  - First three missions revisit a common landing site

- **Example Assumptions**
  - Re-use of Deep Space Transport for crew transit to Mars
  - 4 additional, reusable Hybrid SEP In-Space Propulsion stages support Mars cargo delivery
  - 10 m cargo fairing for SLS Launches
  - Missions to Mars’ surface include the following:
    - Common EDL hardware with precision landing
    - Modular habitation strategy
    - ISRU used for propellant (oxidizer) production
    - Fission Surface Power
    - 100 km-class Mobility (Exploration Zone)

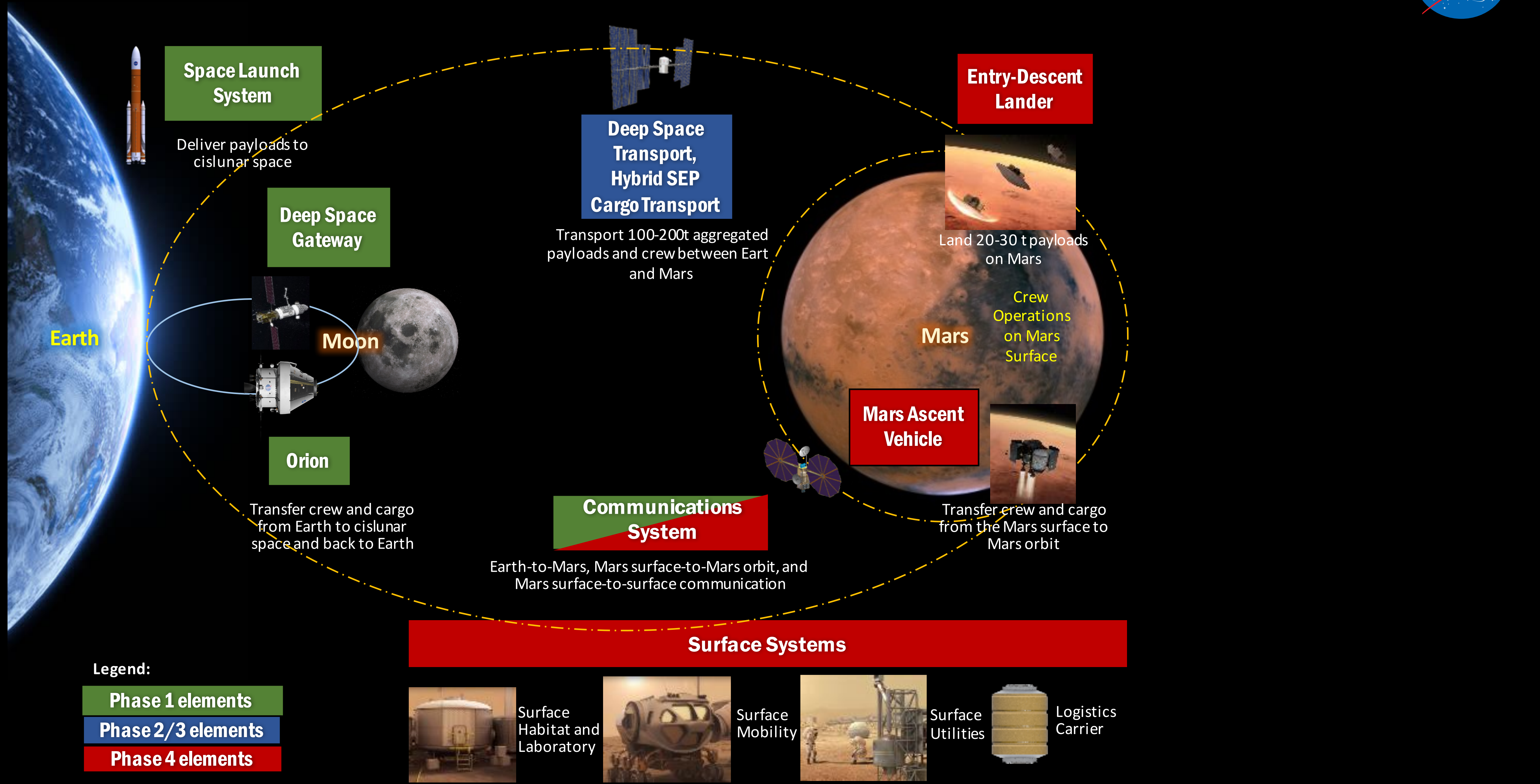
Mars Surface Mission

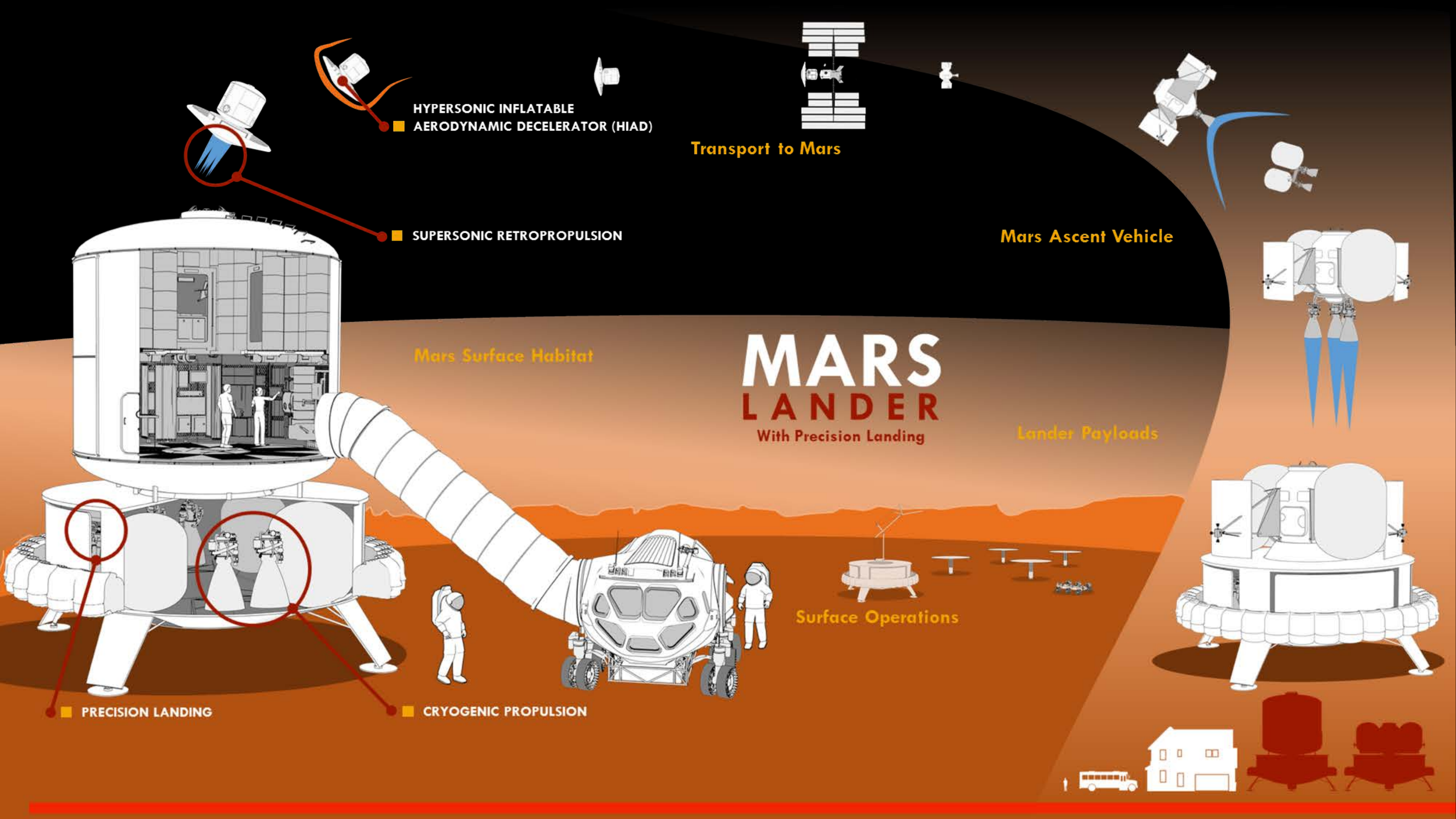
Example Operational Concept

#	Crew Phase Critical Event	System	Return to Earth Options
4	Lunar Gravity Assist #1	DST/Orion	DST powered return to HEO / Orion return
5	Lunar Gravity Assist #2	DST	DST powered return to HEO
5	Earth-Mars Transit (early phase)	DST	DST powered return to HEO (available for limited time post departure - TBD)
6	Earth-Mars Transit Thrusting	SEP	None – continue to Mars
7	Mars Orbit Insertion	Chem	Backflip (TBD) – continue mission
8	Rendezvous & Mars Descent	Lander	Remain in Mars orbit for return
9	Mars Ascent	Ascent	None – must ascend to orbit
10	Mars orbit reorientation	SEP	None – continue mission
11	Trans-Earth Injection	Chem	None – continue mission
12	Mars-Earth Transit Thrusting	SEP	None – continue mission
13	Lunar Gravity Assist #3	DST	None – continue mission
13	Lunar Gravity Assist #4	DST	None – continue mission
14	Orion Launch	SLS/Orion	HEO Loiter
14	Earth Return via Orion	Orion	HEO Loiter



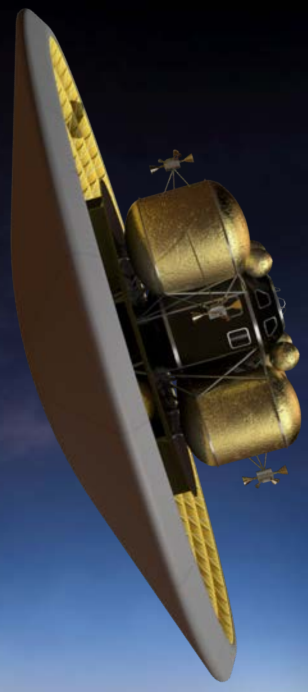
Mars Surface Mission Key Elements and Systems




HYPERSONIC INFLATABLE AERODYNAMIC DECELERATOR (HIAD)
Transport to Mars
SUPERSONIC RETROPROPULSION
Mars Ascent Vehicle
Mars Surface Habitat
MARS
LANDER
With Precision Landing
Lander Payloads
Surface Operations
PRECISION LANDING
CRYOGENIC PROPULSION

Human Landers: A Leap in Scale

	Viking 1 & 2	Pathfinder	MER A/B	Phoenix	MSL	Human Scale Lander (Projected)
Diameter, m	3.505	2.65	2.65	2.65	4.5	16-19
Entry Mass, kg	930	585	840	602	3151	47-62 t
Landed Mass, kg	603	360	539	364	1541	36-47 t
Landing Altitude, km	-3.5	-1.5	-1.3	-3.5	-4.4	+ 2
Peak Heat Rate, W/cm^2	24	106	48	56	~120	~120-350
Landing Ellipse, km	280x130	200x70	150x20	100x20	20x6.5	0.1x0.1

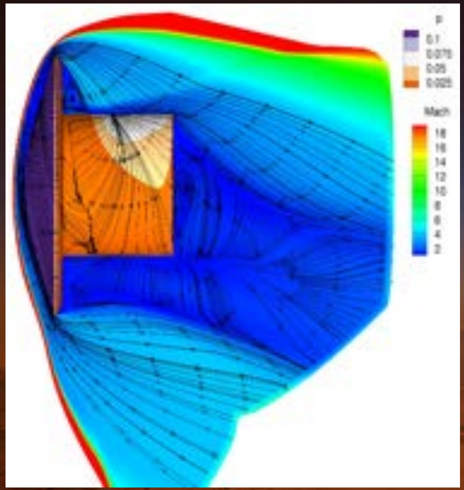


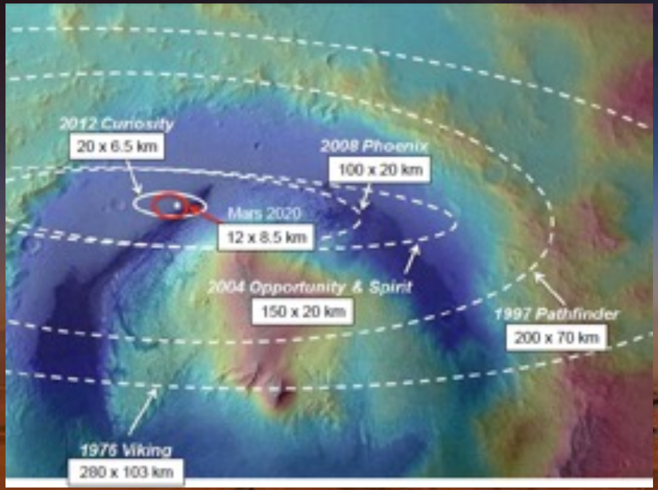
Steady progression of “in family” EDL

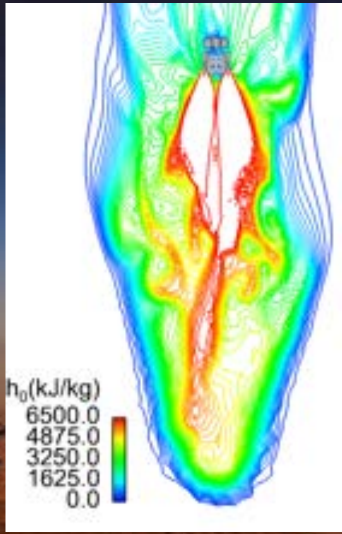
New Approach Needed for Human Class Landers

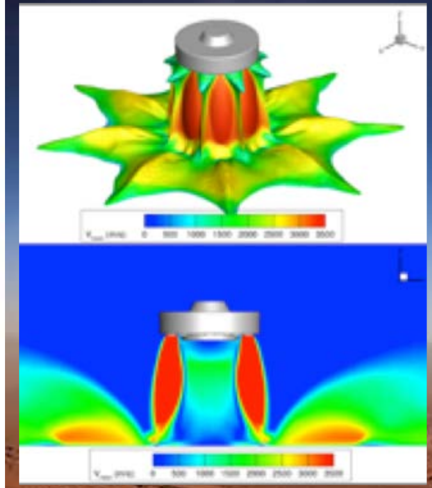
Human Mars Lander Challenges

- **20x more payload to the surface**
- **200x improvement in precision landing**
- **Dynamic atmosphere; poorly characterized**
- **New engines; performing Supersonic RetroPropulsion**
- **Terrain hazard detection - improving, but not perfect**
- **Surface plume interaction - debris ejecta could damage vehicles**









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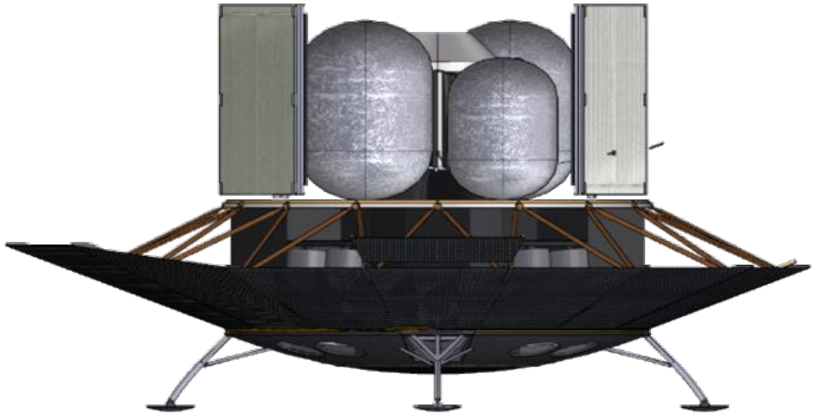
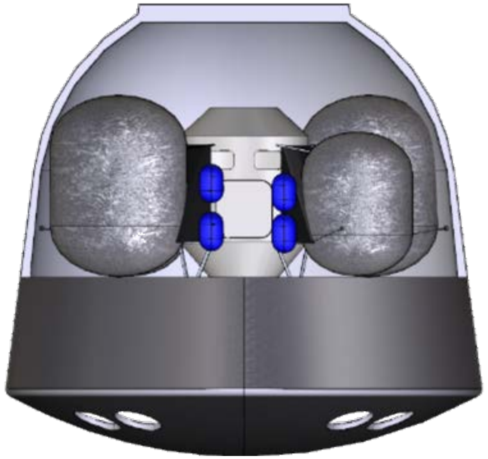
Concept Quad Chart

HIAD: Hypersonic Inflatable Aerodynamic Decelerator

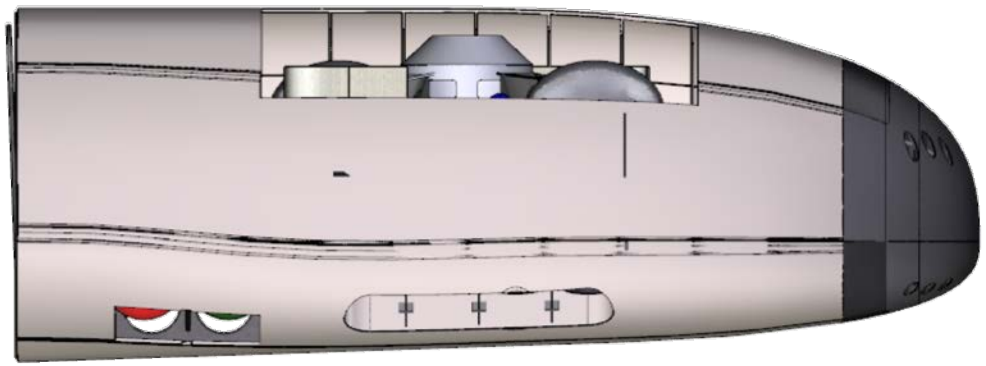
ADEPT: Adaptable Deployable Entry & Placement Technology



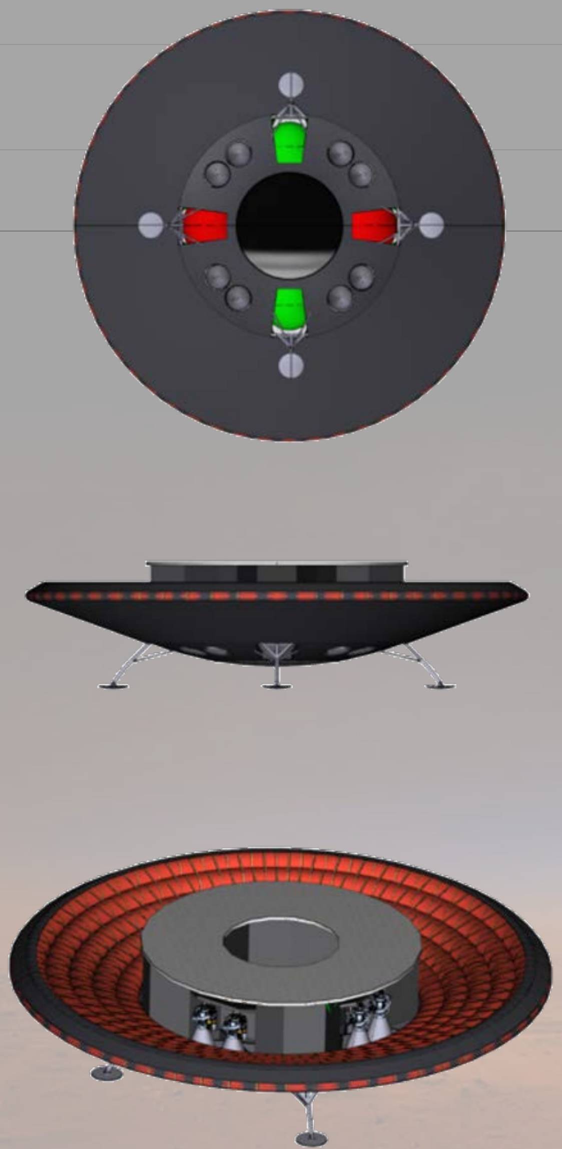
Capsule

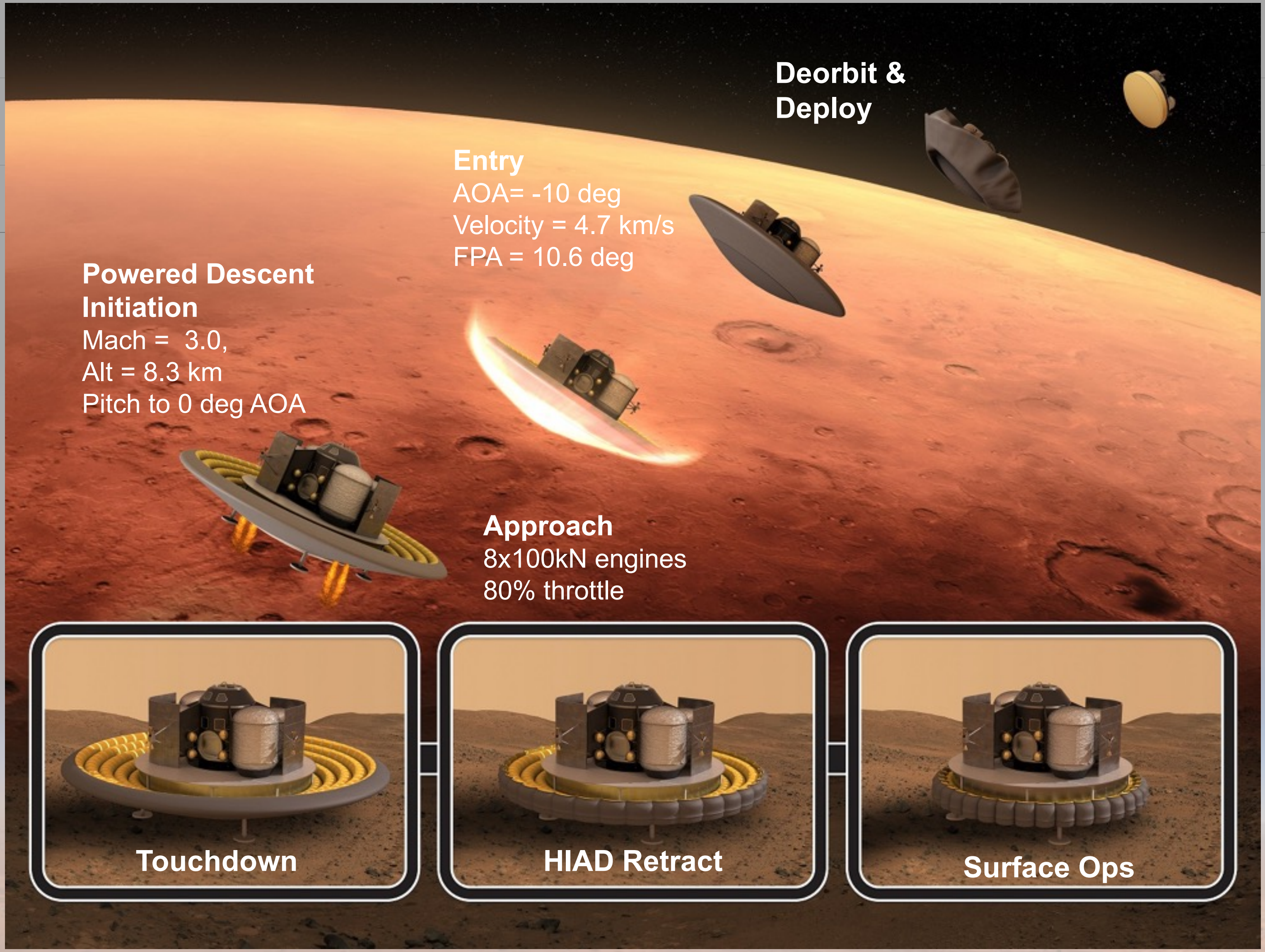


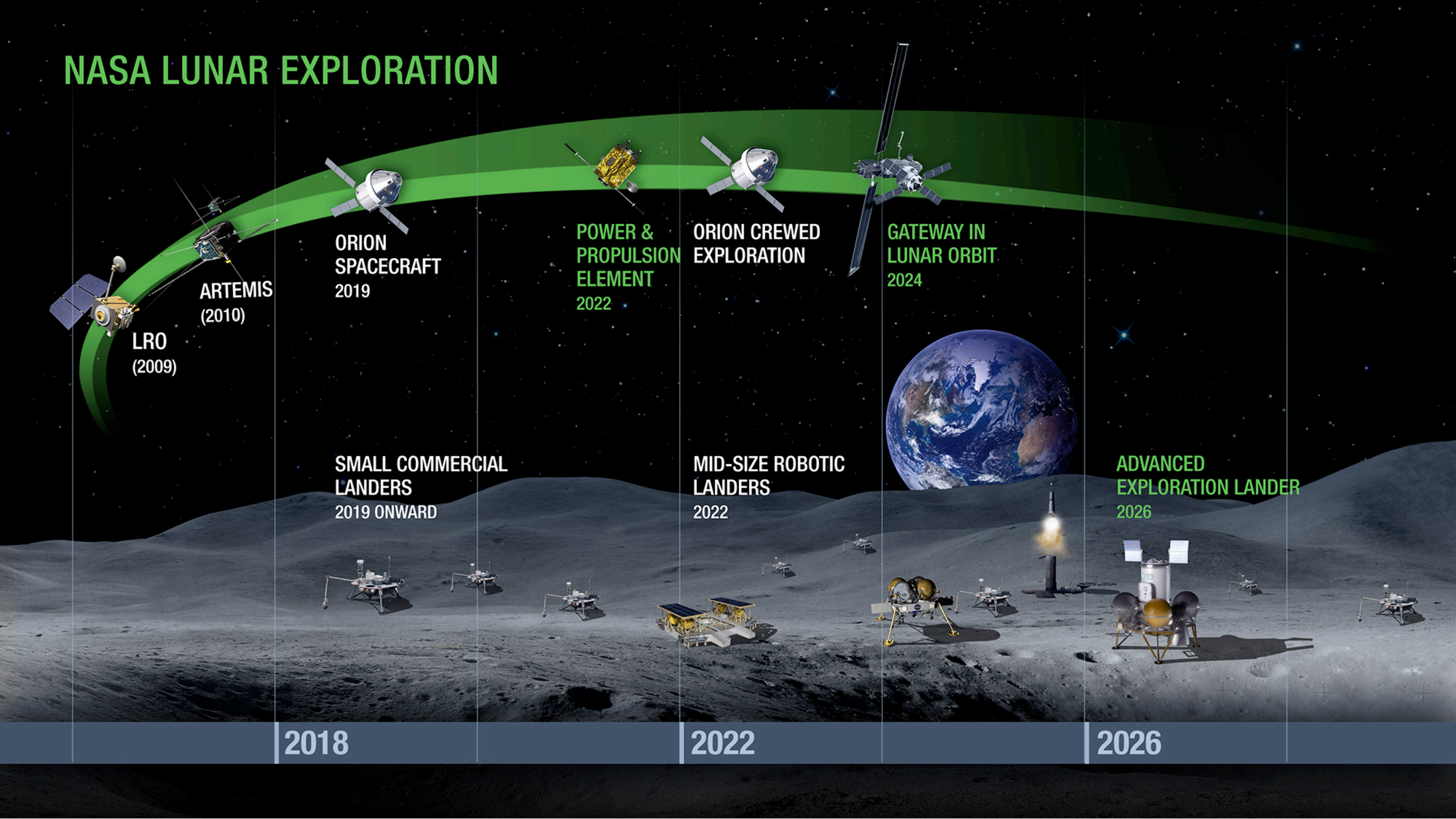
Mid L/D



HIAD EDL Sequence






NASA LUNAR EXPLORATION
LRO
(2009)
ARTEMIS
(2010)
ORION
SPACECRAFT
2019
POWER &
PROPULSION
ELEMENT
2022
ORION CREWED
EXPLORATION
GATEWAY IN
LUNAR ORBIT
2024
SMALL COMMERCIAL
LANDERS
2019 ONWARD
MID-SIZE ROBOTIC
LANDERS
2022
ADVANCED
EXPLORATION LANDER
2026
2018
2022
2026

NASA