National Aeronautics and Space Administration

Human Mars Architecture

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NASA Human Mars Study Team

15th International Planetary Probe Workshop
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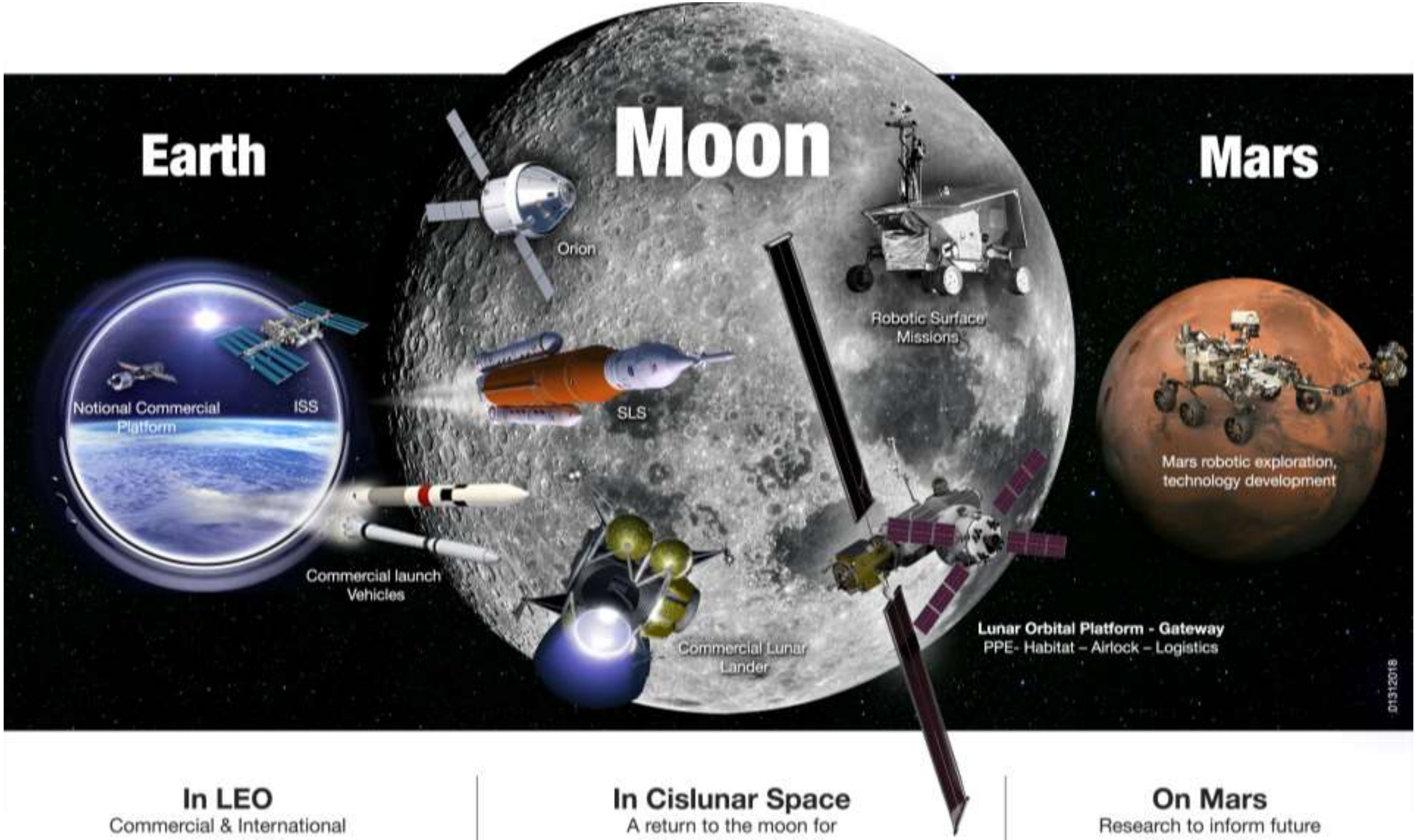
Space Policy Directive-1

"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

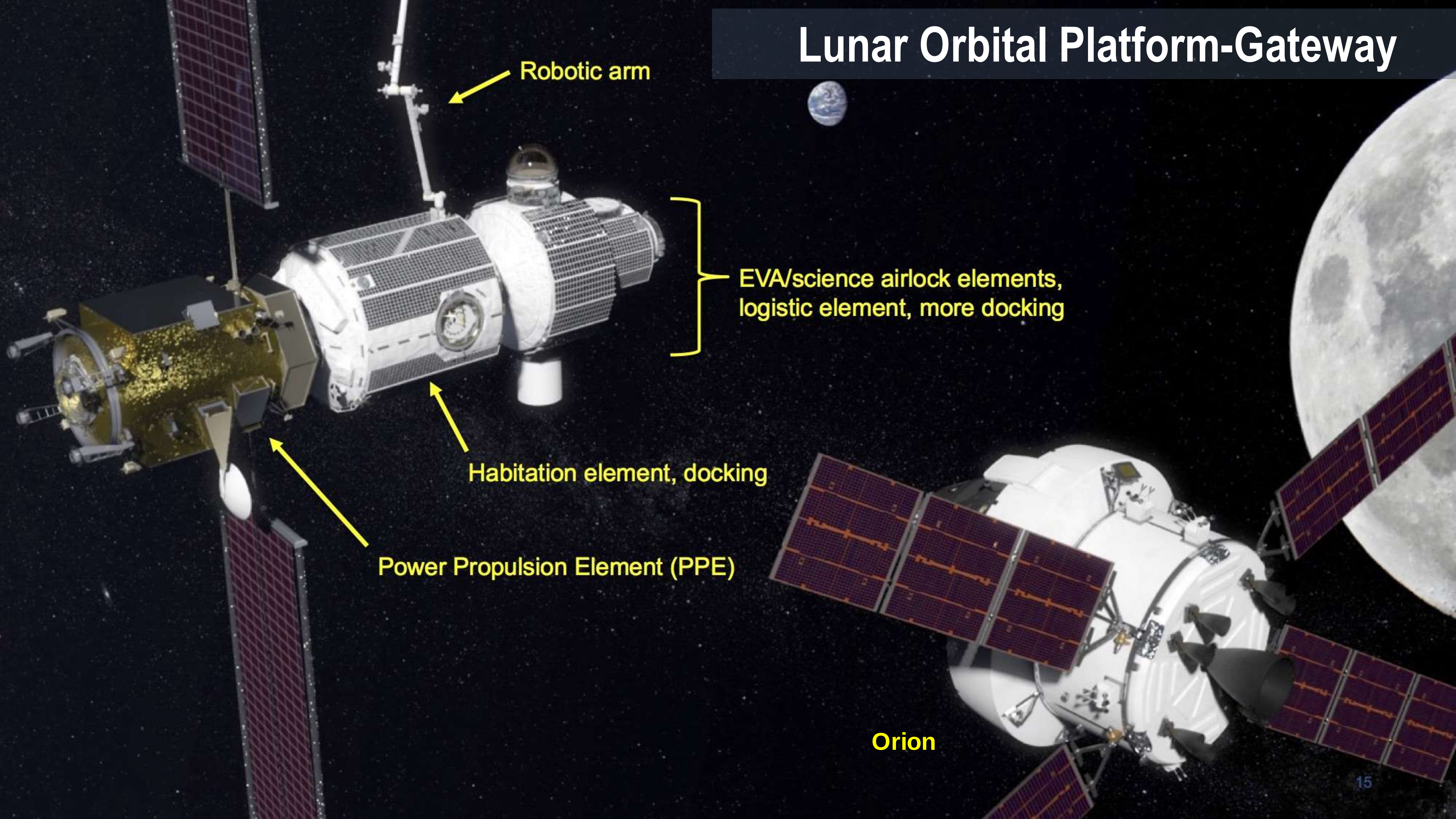


In LEO
Commercial & International partnerships

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

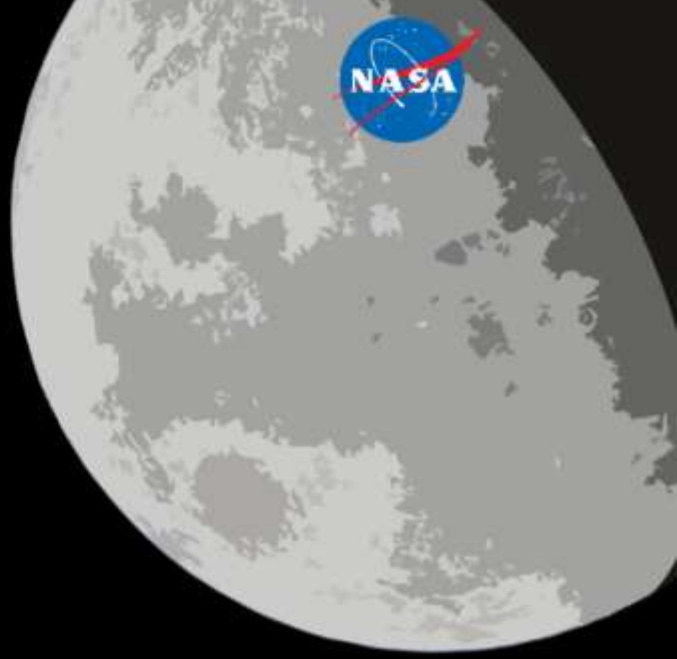
On Mars
Research to inform future crewed missions

Lunar Orbital Platform-Gateway



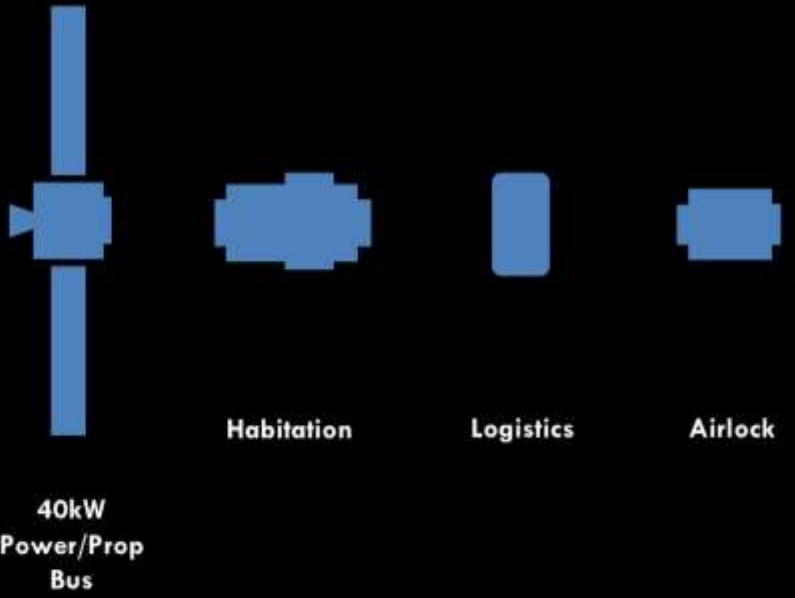
LUNAR ORBITAL PLATFORM-GATEWAY DEVELOPMENT

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

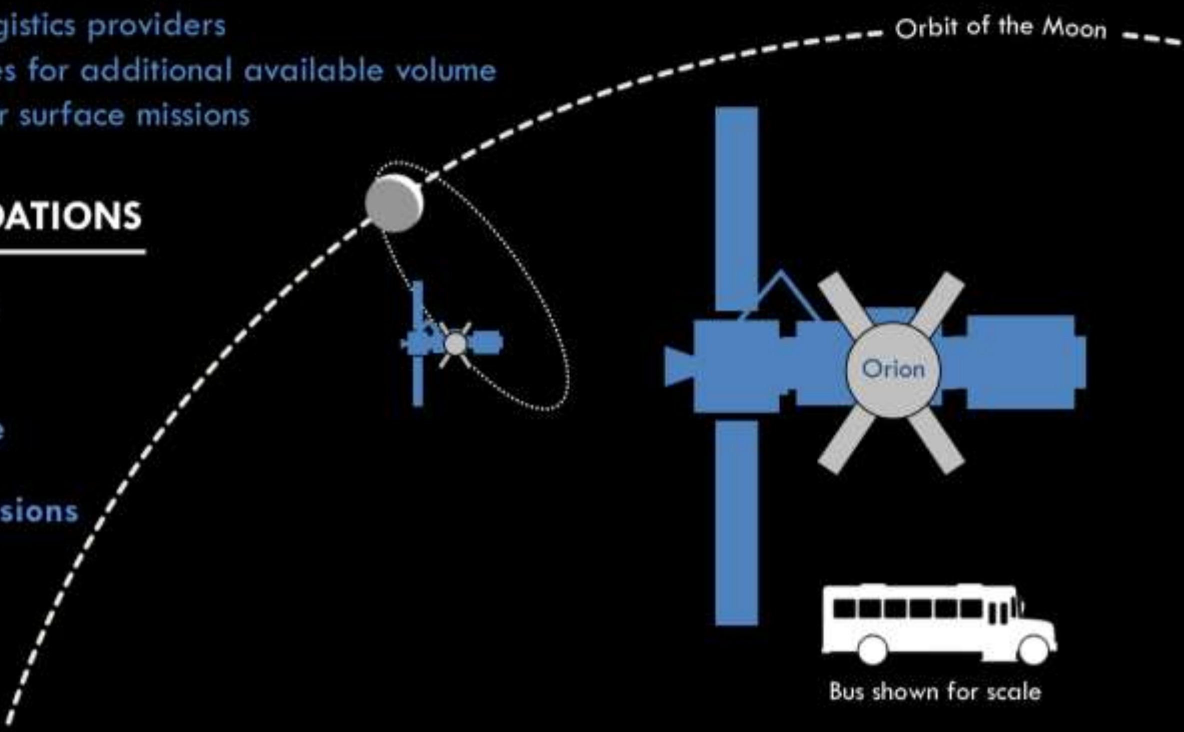
- Logistics flights and logistics providers
- Use of logistics modules for additional available volume
- Ability to support lunar surface missions

INITIAL ACCOMMODATIONS

4 Crew Members

At least 55 m^3 Habitable Volume

30 Day Crew Missions



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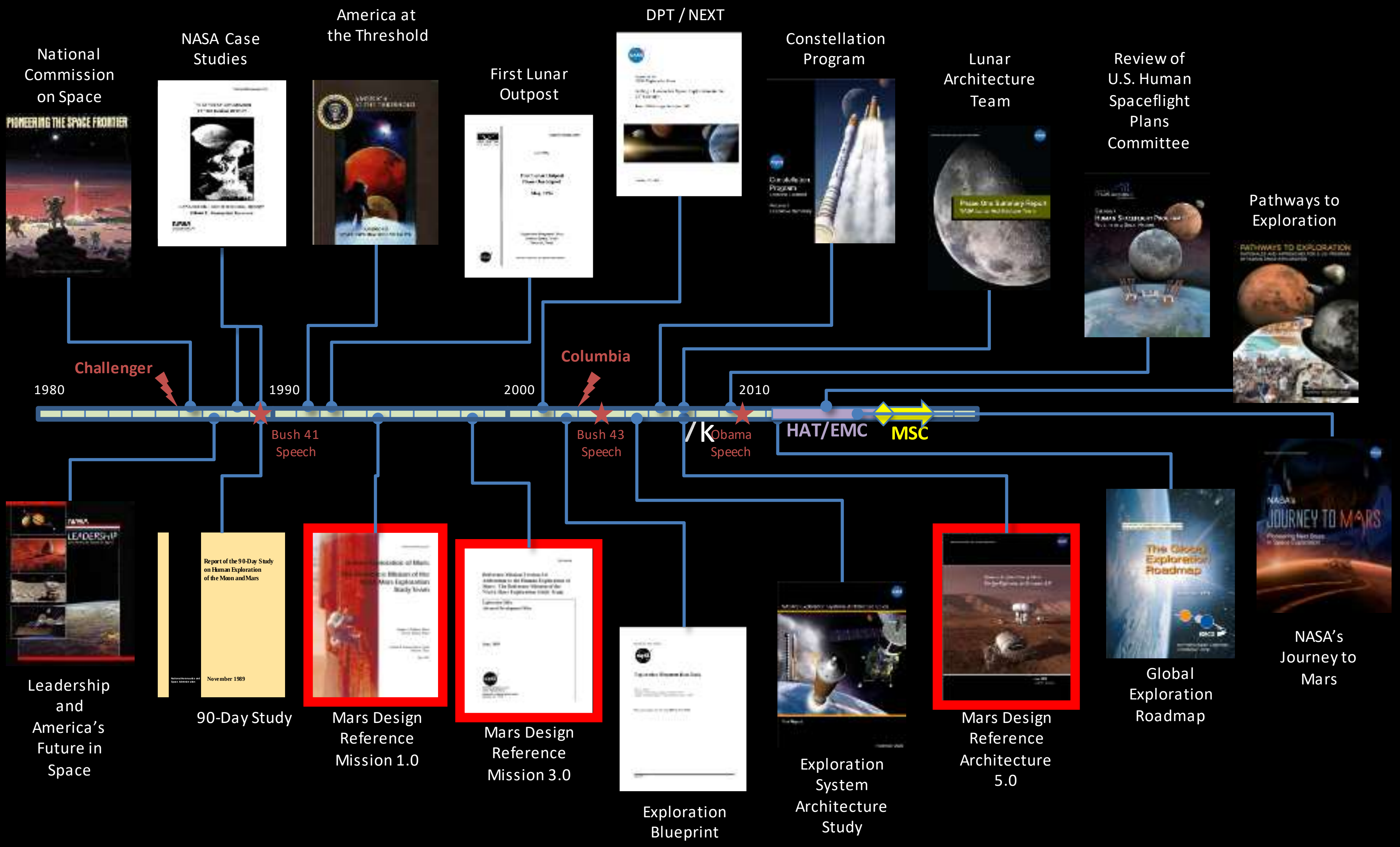
A Brief History of Human Exploration Beyond LEO



National Commission on Space

NASA Case Studies

America at the Threshold

First Lunar Outpost

DPT / NEXT

Constellation Program

Lunar Architecture Team

Review of U.S. Human Spaceflight Plans Committee

Pathways to Exploration

1980

Challenger

1990

2000

Columbia

2010

Bush 41 Speech

Bush 43 Speech

Obama Speech

HAT/EMC

MSC

Leadership and America's Future in Space

90-Day Study

Mars Design Reference Mission 1.0

Mars Design Reference Mission 3.0

Exploration Blueprint

Exploration System Architecture Study

Mars Design Reference Architecture 5.0

Global Exploration Roadmap

NASA's Journey to Mars

Exploring the Mars Mission Design Tradespace

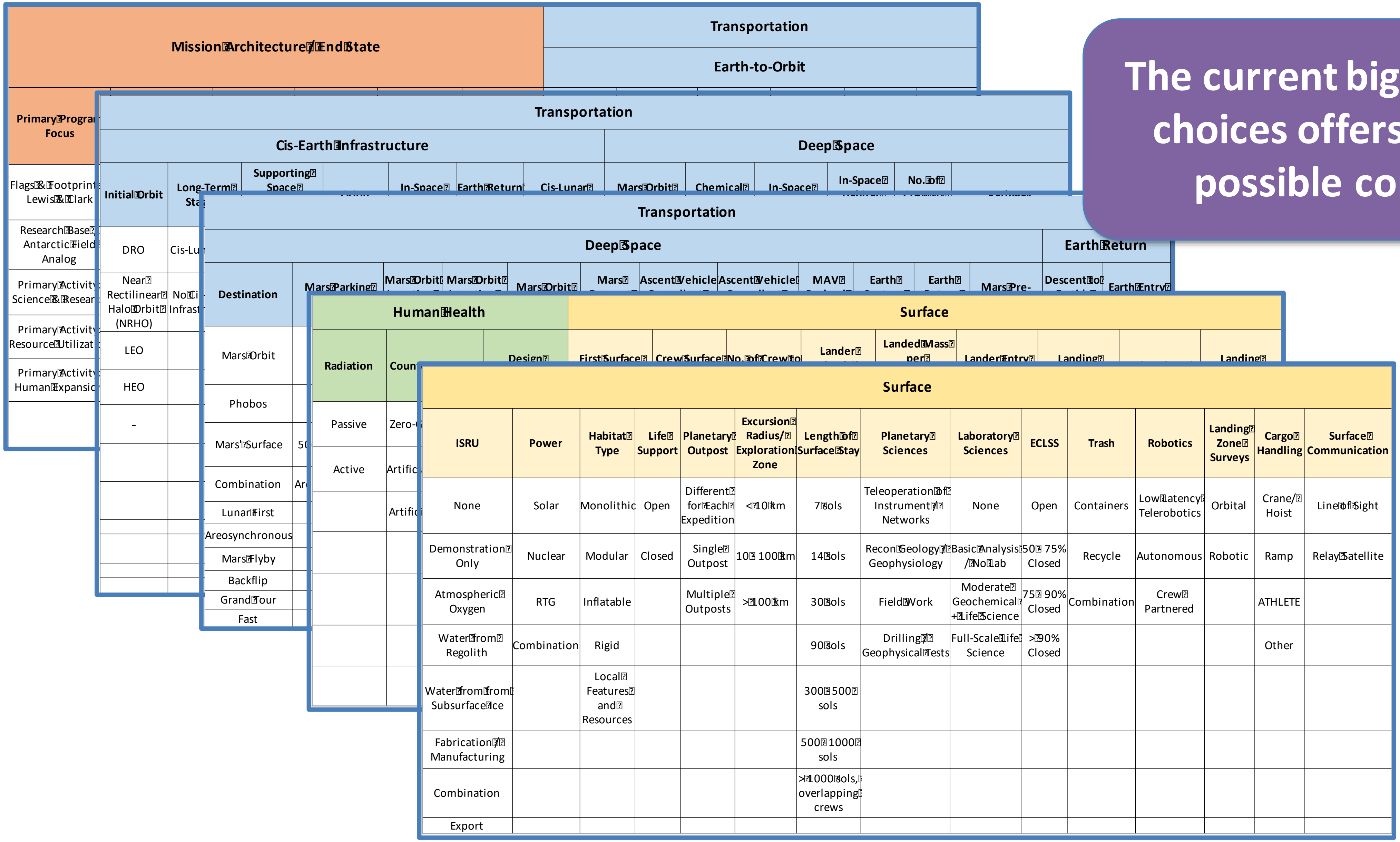
- **A myriad of choices define the “Architecture” of a human Mars mission**

- **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 Utilizat	
Primary Activity Human Expansio	

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

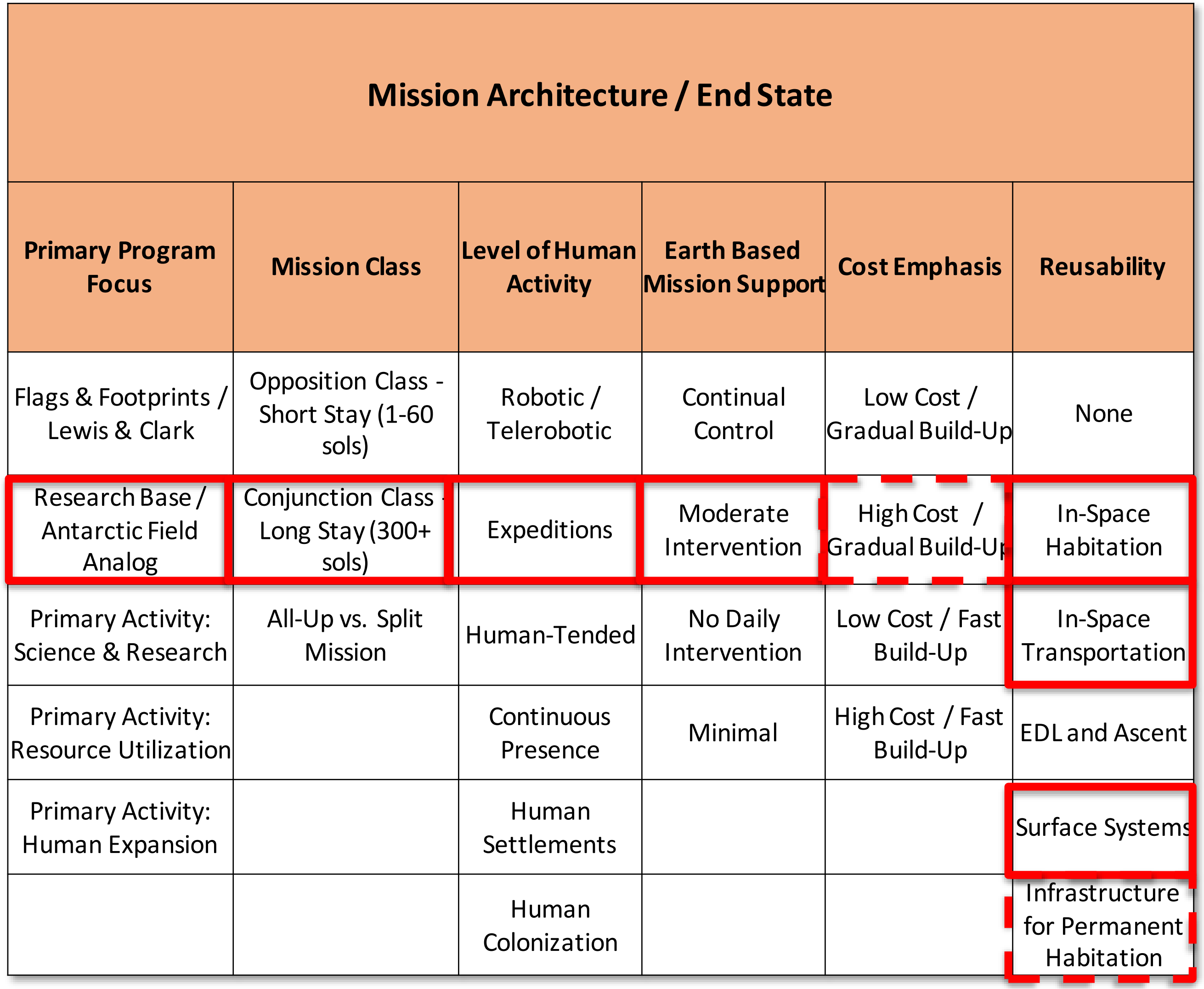
Transportation													
Deep Space												Earth Return	
Destination	Mars Parking	Mars Orbit	Mars Orbit	Mars Orbit	Mars	Ascent Vehicle	Ascent Vehicle	MAV	Earth	Earth	Mars Pre-	Descent to	Earth Entry
Mars Orbit													
Phobos													
Mars' Surface	50												
Combination	Ar							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

Human Health			Surface								
Radiation	Count	Design	First Surface	Crew Surface	No. of Crew	Lander	Landed Mass per	Lander Entry	Landing		Landing
Passive	Zero-(										
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

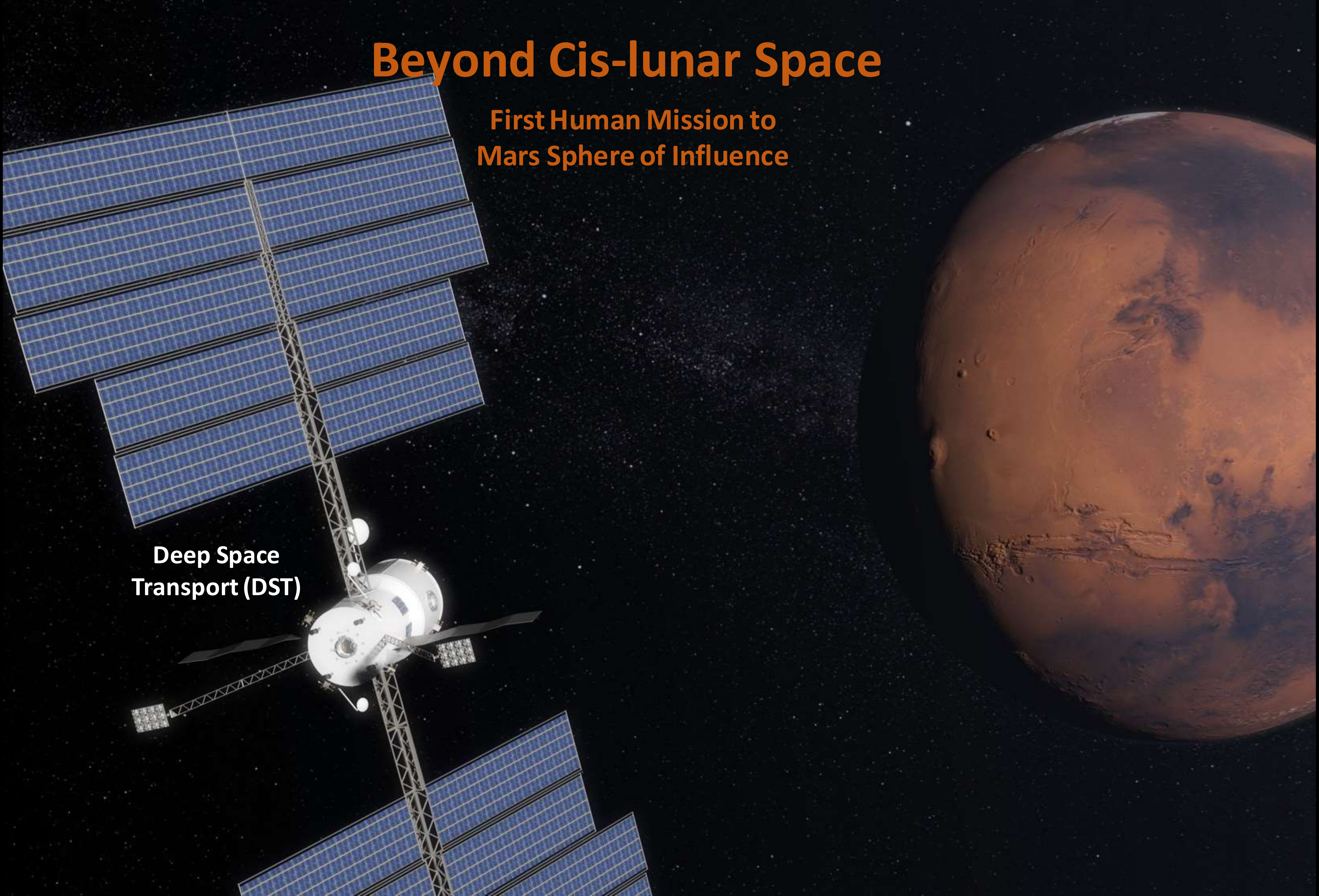
- **A single surface site lends itself to a “field station” approach for development of a centralized habitation zone / landing site. The first mission to this site would deploy habitation, power, and other infrastructure that would be used by at least two subsequent surface missions.**
- **Reusable 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

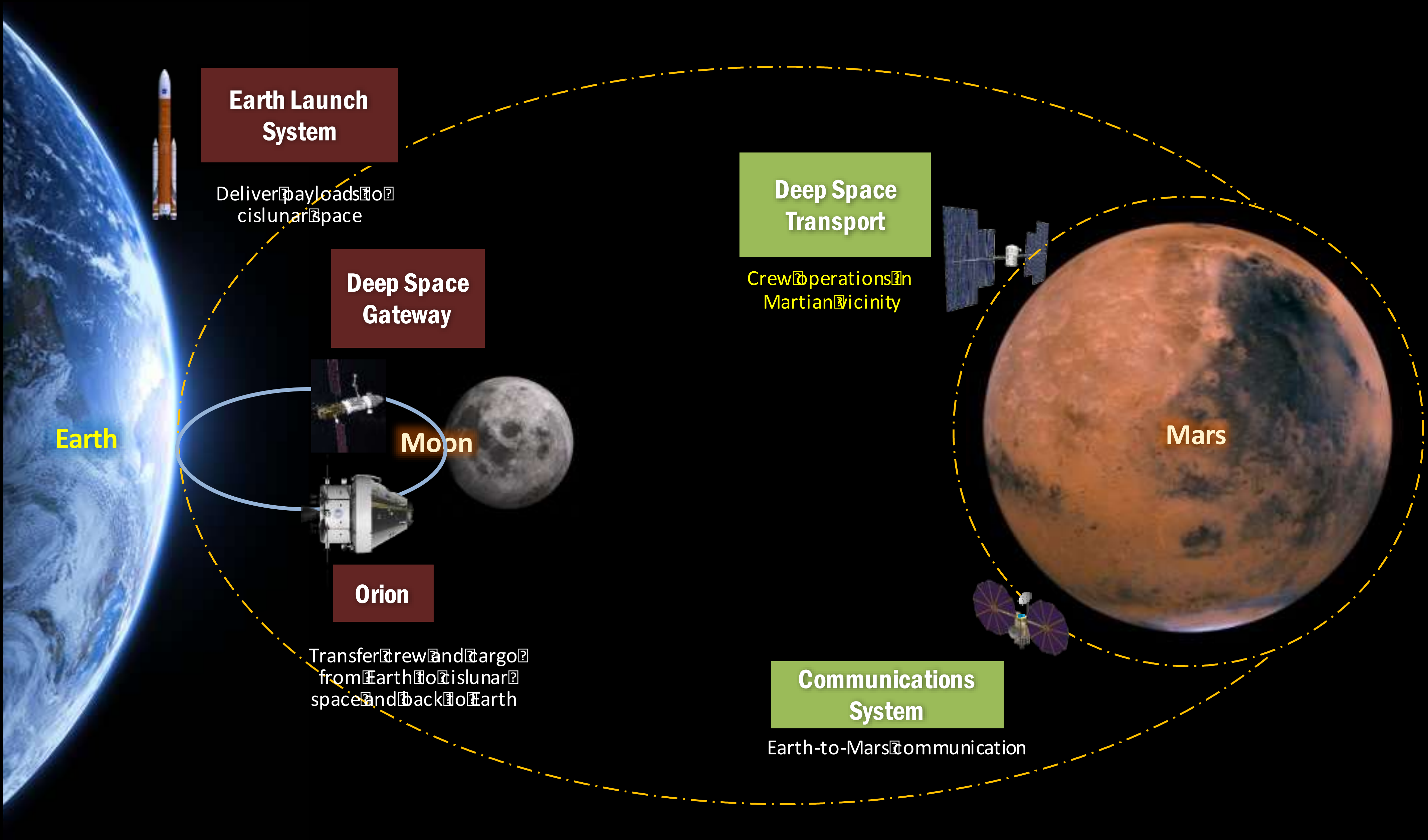


Orbital Mission to Mars Sphere of Influence

- **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



Earth Launch System

Deliver payloads to cislunar space

Deep Space Gateway

Orion

Transfer crew and cargo from Earth to cislunar space and back to Earth

Deep Space Transport

Crew operations in Martian vicinity

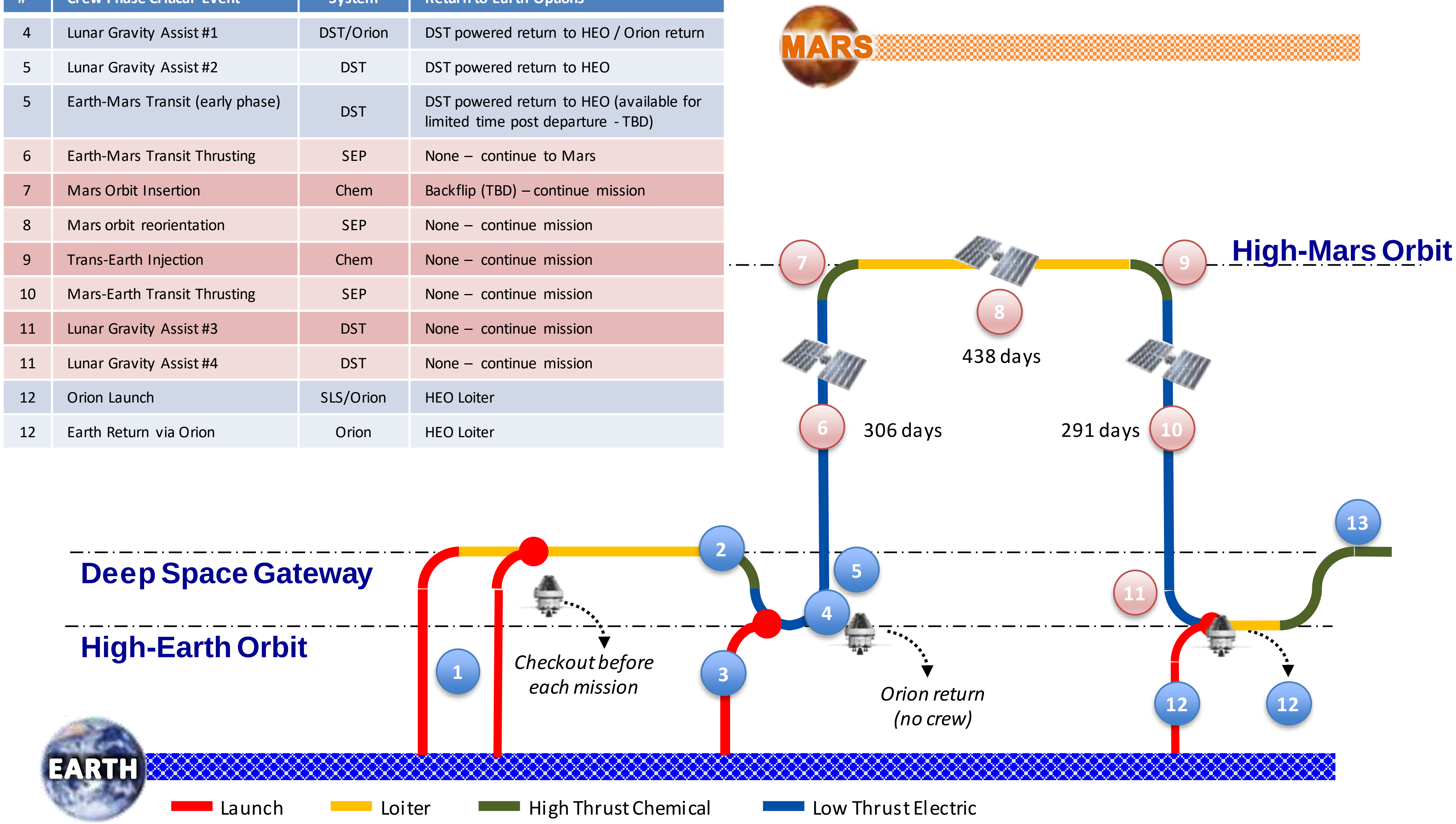
Communications System

Earth-to-Mars communication

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

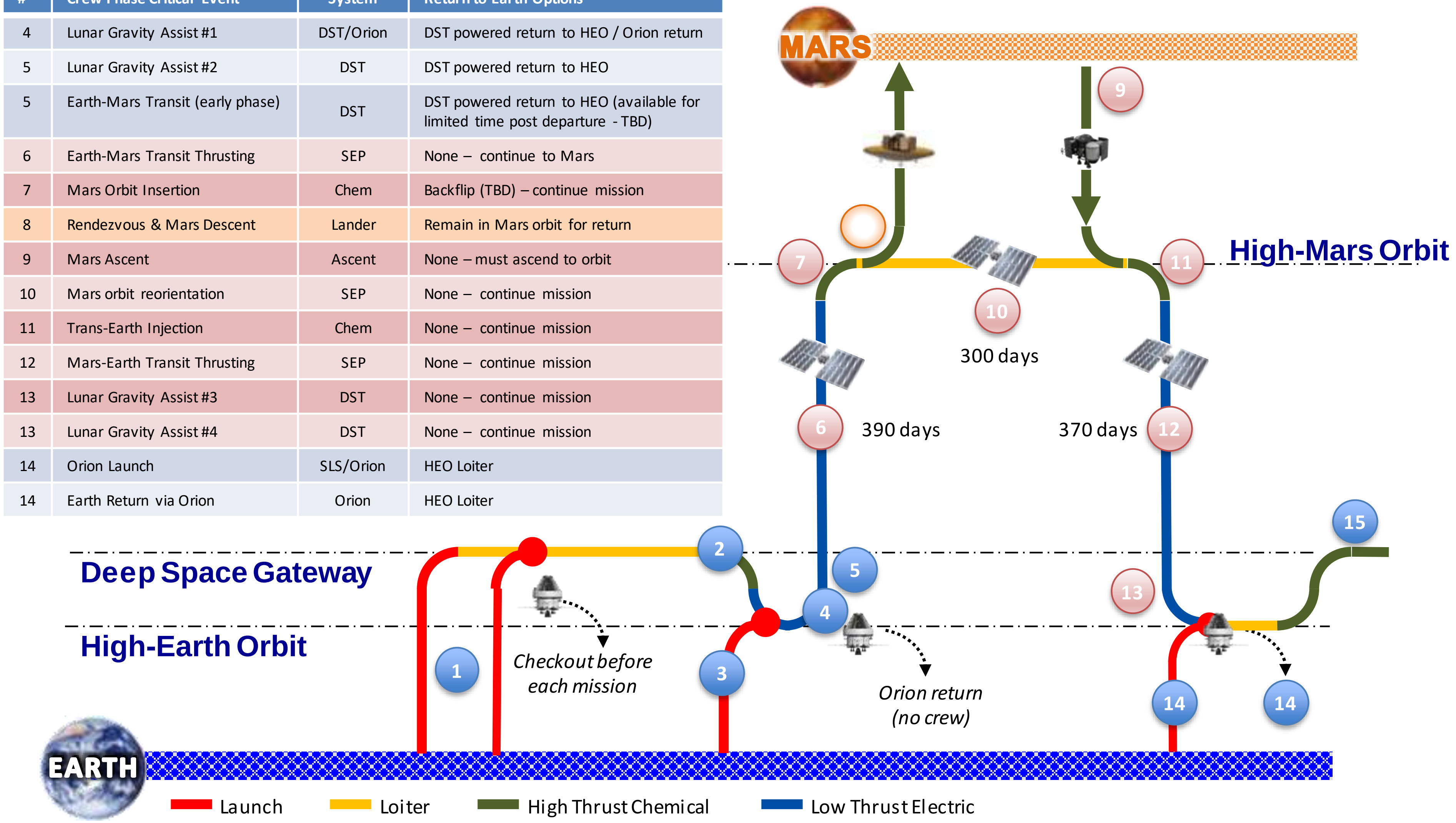
- **Emphasis on establishing Mars surface field station**
  - First human landing on Mars' surface
  - First three missions revisit a common landing site

- **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

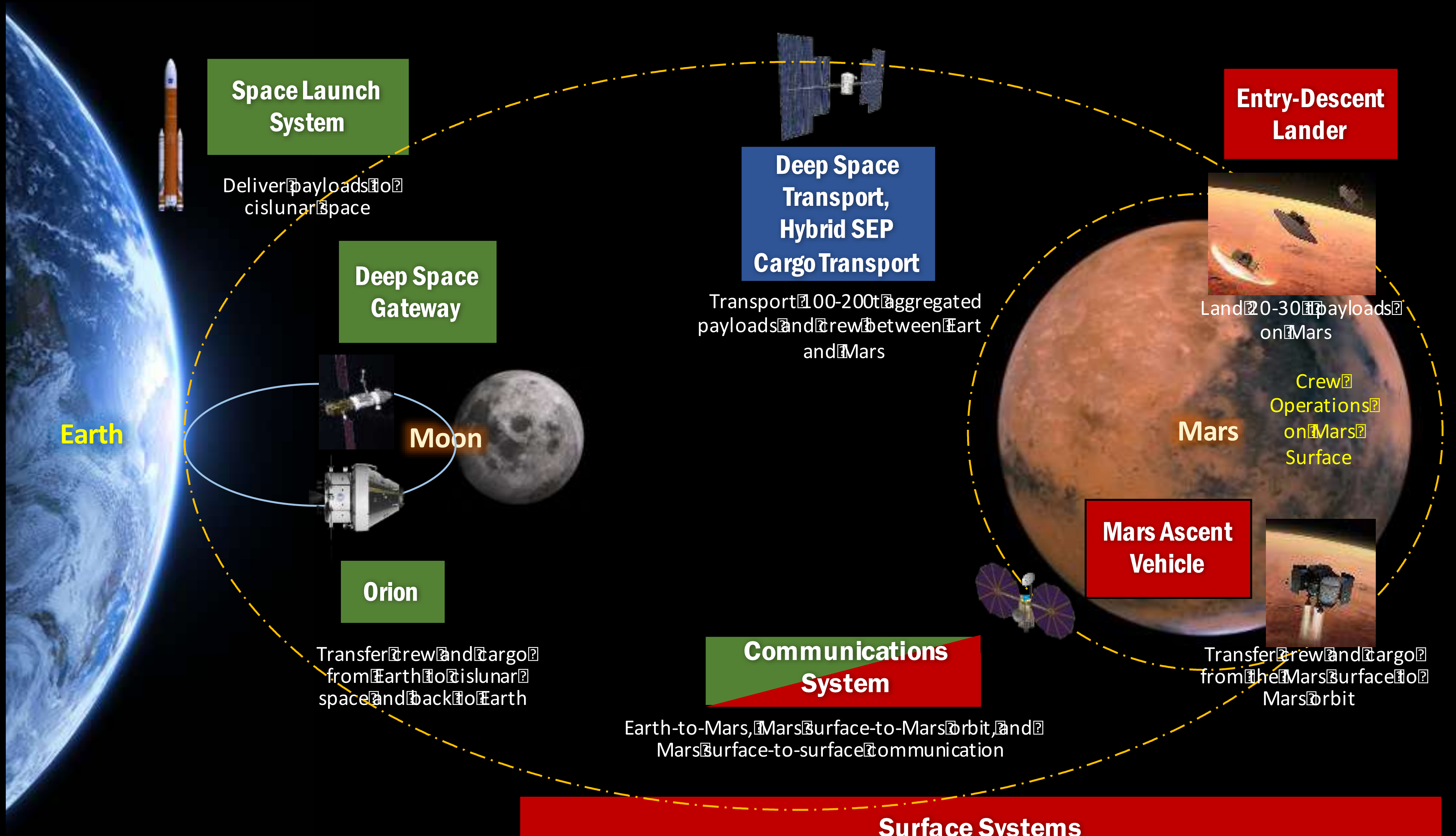


Checkout before each mission

Orion return (no crew)

🟥 Launch 🟨 Loiter 🟩 High Thrust Chemical 🟦 Low Thrust Electric

Mars Surface Mission Key Elements and Systems



Space Launch System

Deliver payloads to cislunar space

Deep Space Gateway

Orion

Transfer crew and cargo from Earth to cislunar space and back to Earth

Deep Space Transport, Hybrid SEP Cargo Transport

Transport 100-200t aggregated payloads and crew between Eart and Mars

Communications System

Earth-to-Mars, Mars surface-to-Mars orbit, and Mars surface-to-surface communication

Entry-Descent Lander

Land 20-30t payloads on Mars

Crew Operations on Mars Surface

Mars Ascent Vehicle

Transfer crew and cargo from the Mars surface to Mars orbit

Surface Systems


Surface Habitat and Laboratory


Surface Mobility


Surface Utilities

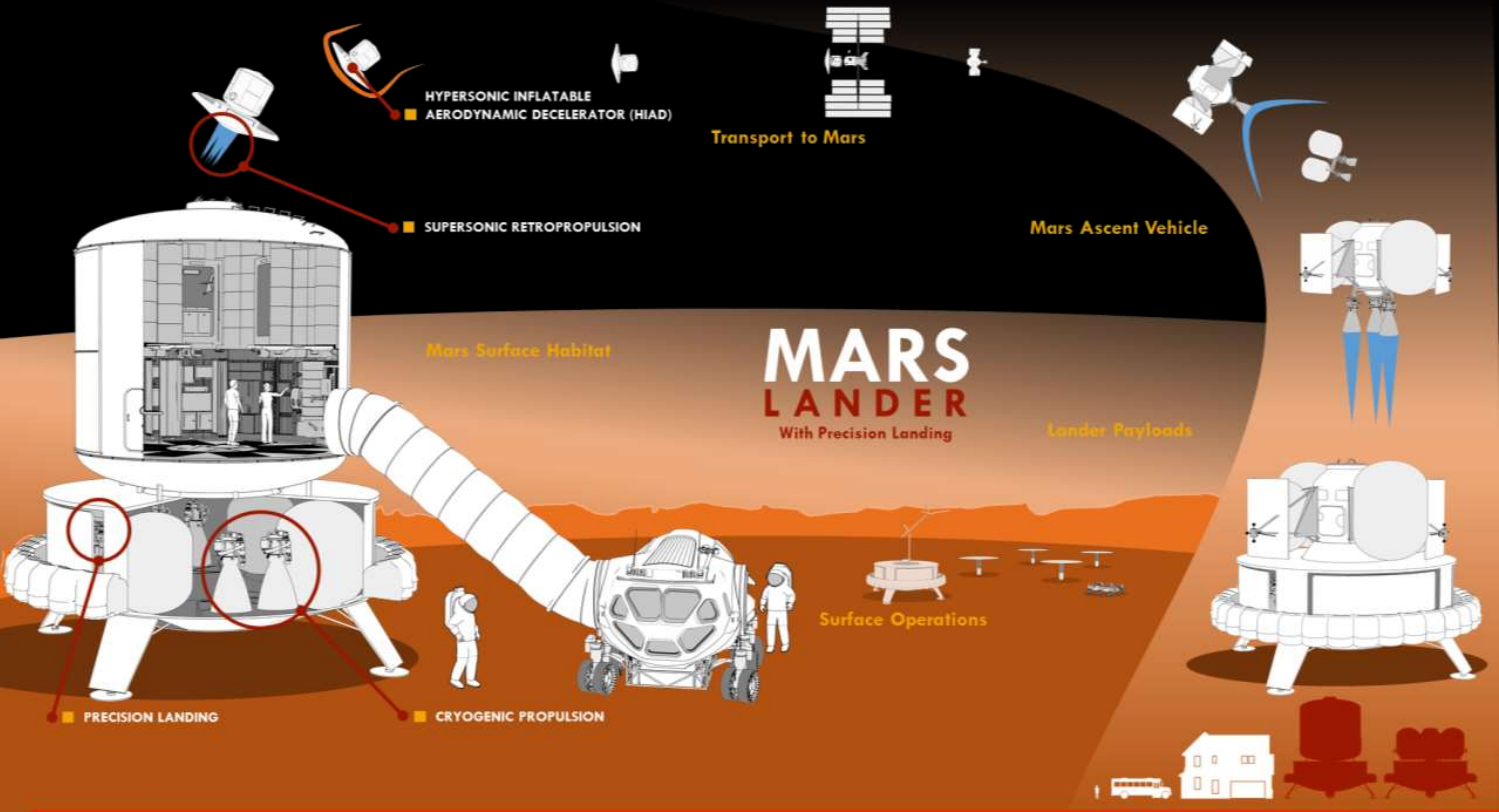

Logistics Carrier

Legend:

- 🟩 Phase 1 elements
- 🟦 Phase 2/3 elements
- 🟥 Phase 4 elements

MARS
LANDER

With Precision Landing



HYPERSONIC INFLATABLE AERODYNAMIC DECELERATOR (HIAD)

SUPERSONIC RETROPROPULSION

PRECISION LANDING

CRYOGENIC PROPULSION

Transport to Mars

Mars Ascent Vehicle

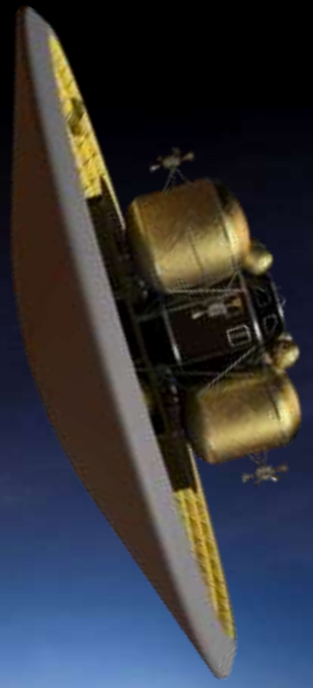
Mars Surface Habitat

Lander Payloads

Surface Operations

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

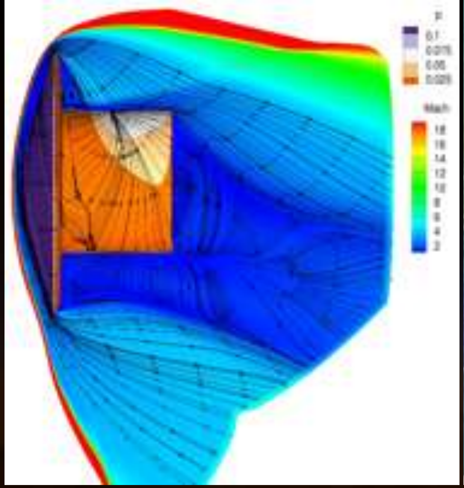


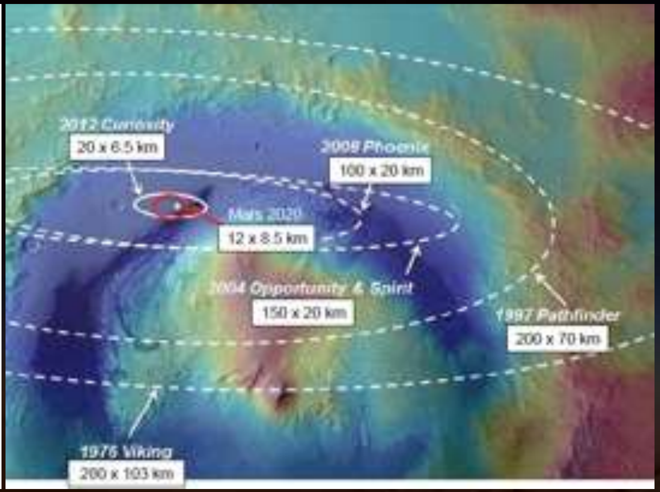
Steady progression of “in family” EDL

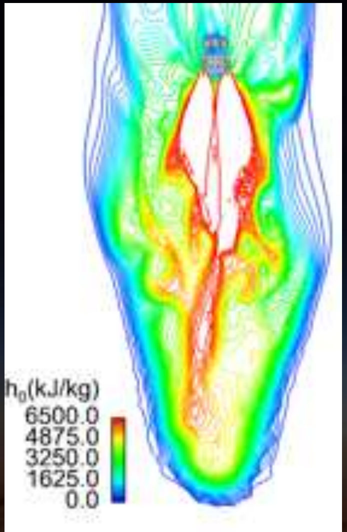
New Approach Needed for Human Class Landers

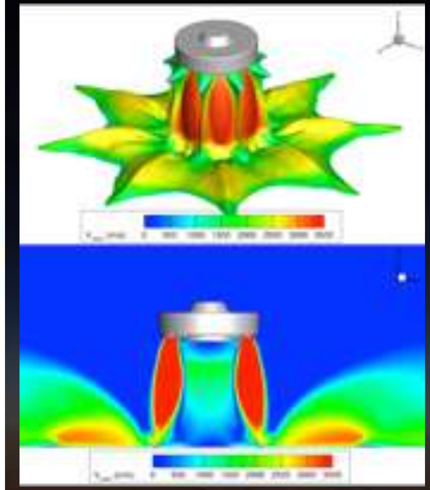
Human Mars Lander Challenges

- 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



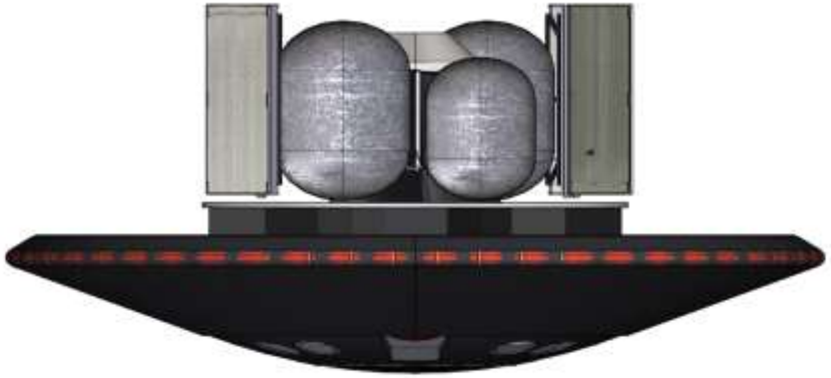




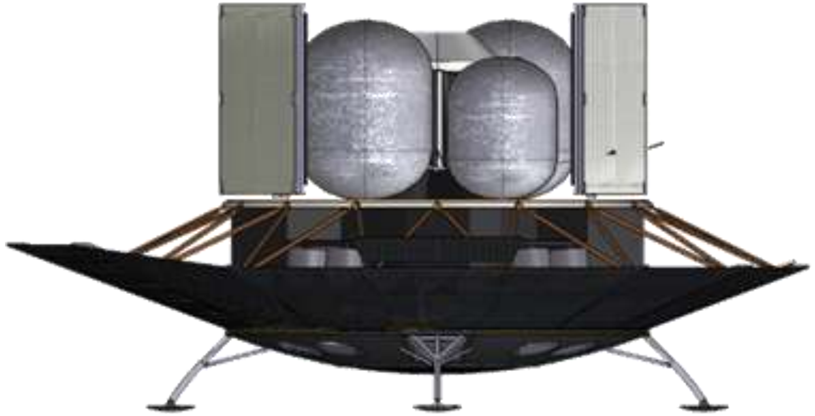


Concept Quad Chart

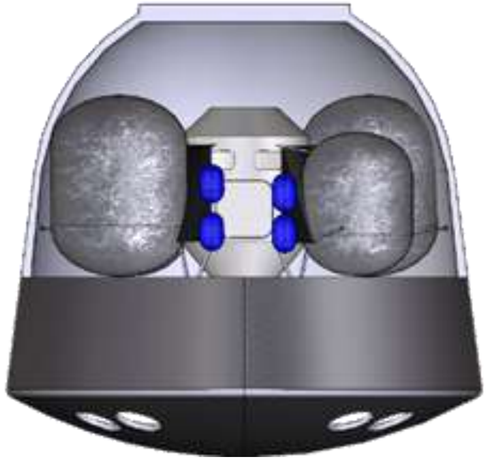
HIAD: Hypersonic Inflatable Aerodynamic Decelerator



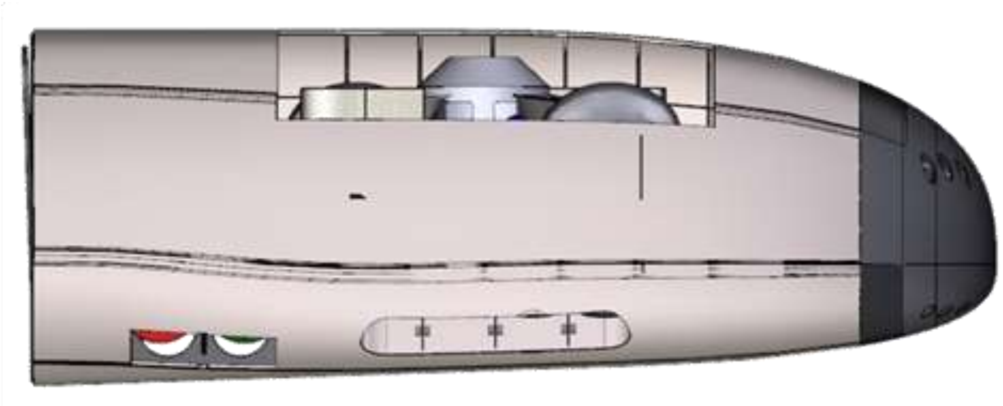
ADEPT: Adaptable Deployable Entry & Placement Technology



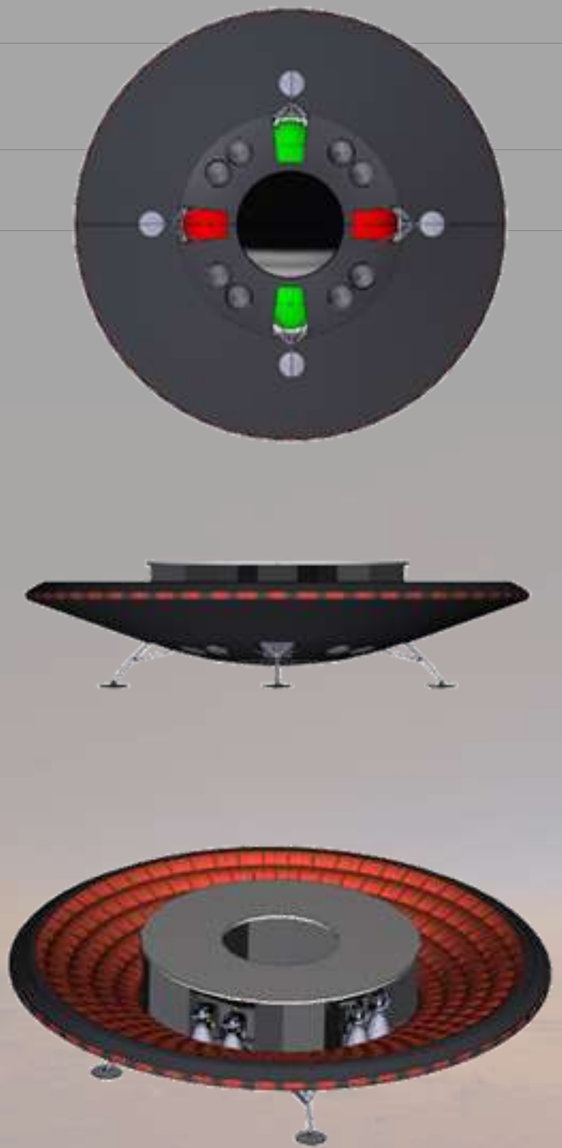
Capsule

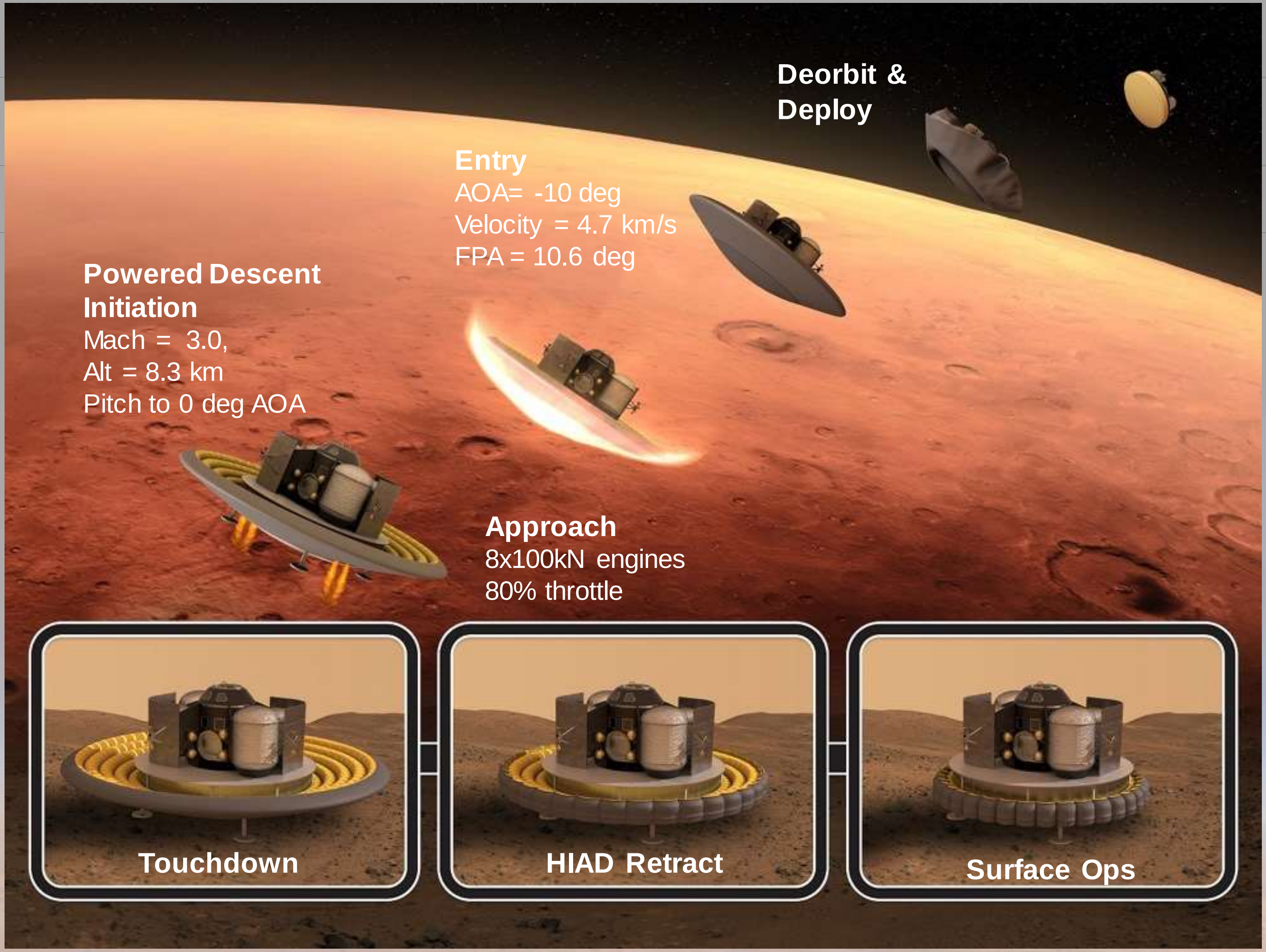


Mid L/D



HIAD EDL Sequence





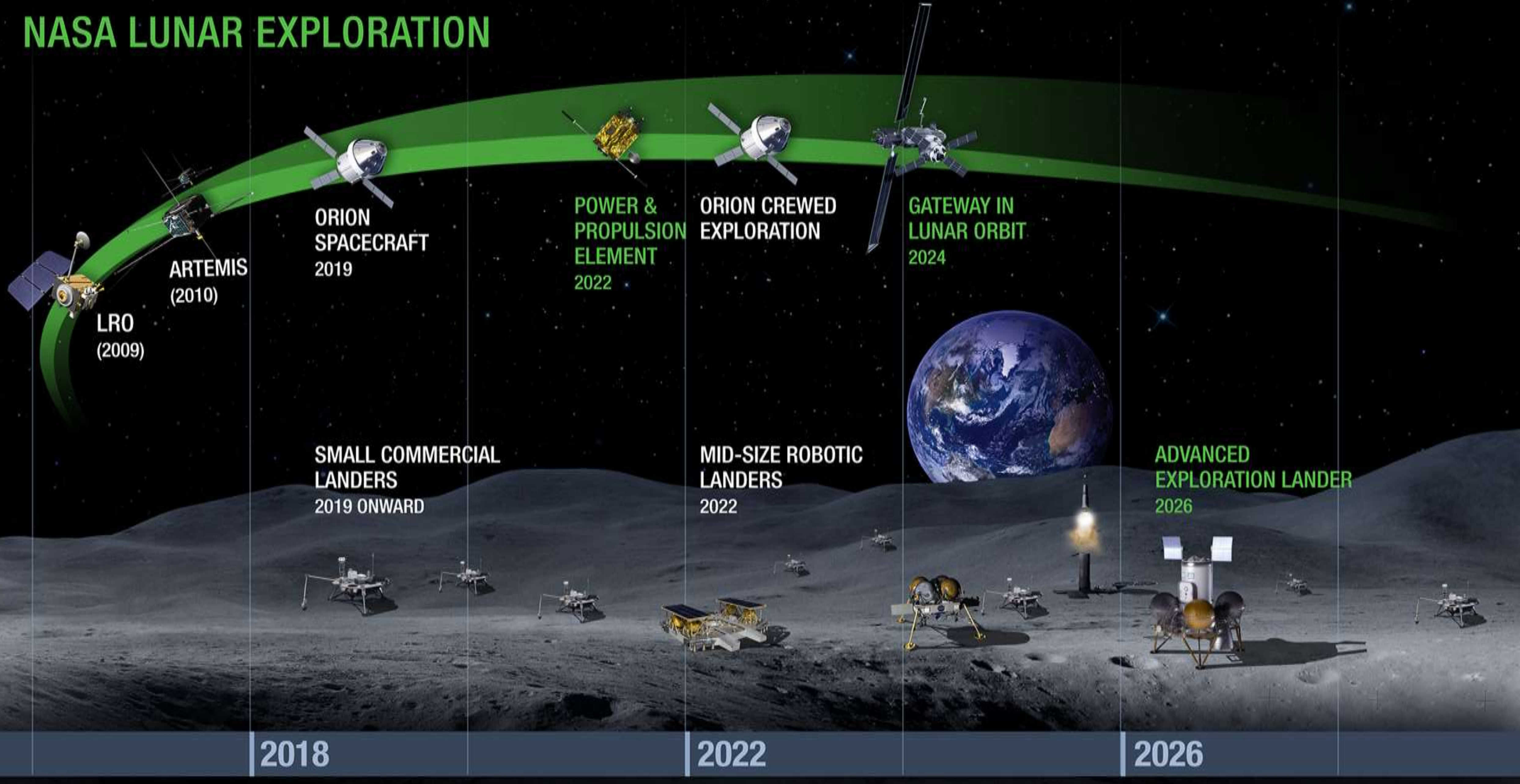
Deorbit & Deploy

Entry
AOA= -10 deg
Velocity = 4.7 km/s
FPA = 10.6 deg

Powered Descent Initiation
Mach = 3.0,
Alt = 8.3 km
Pitch to 0 deg AOA

Approach
8x100kN engines
80% throttle

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

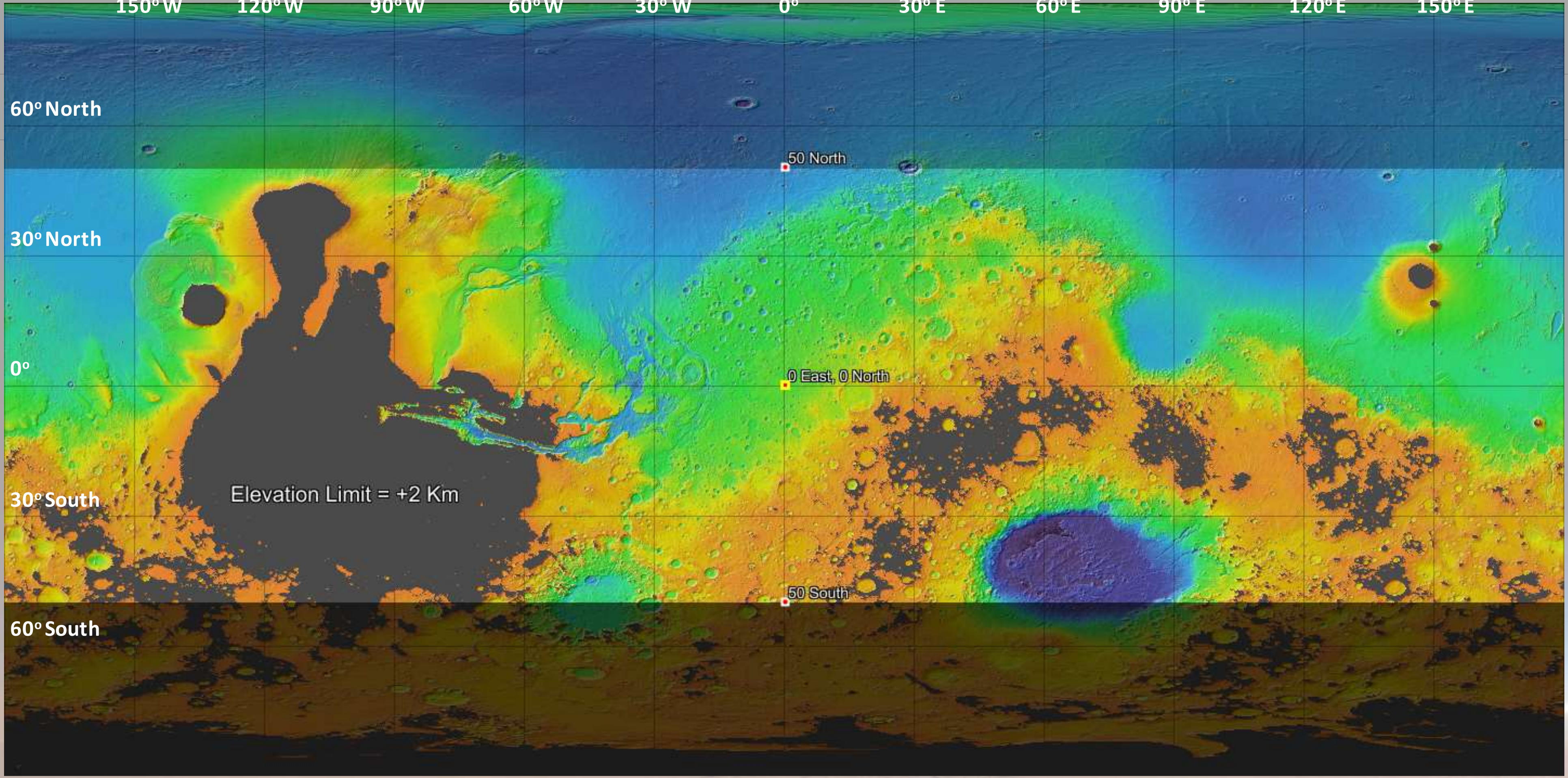
MID-SIZE ROBOTIC
LANDERS
2022

ADVANCED
EXPLORATION LANDER
2026

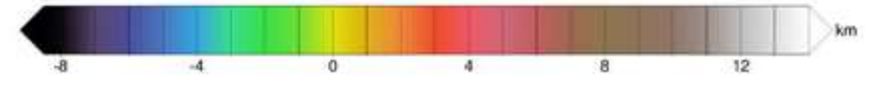

NASA

Preliminary Mars Surface Location Constraints

Elevation Limit = +2 km   Latitude Limits = +/- 50º

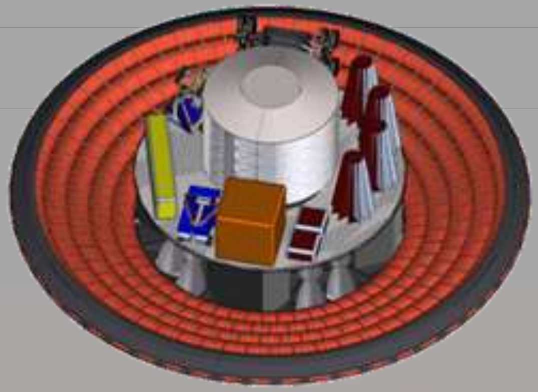


MOLA Color Legend



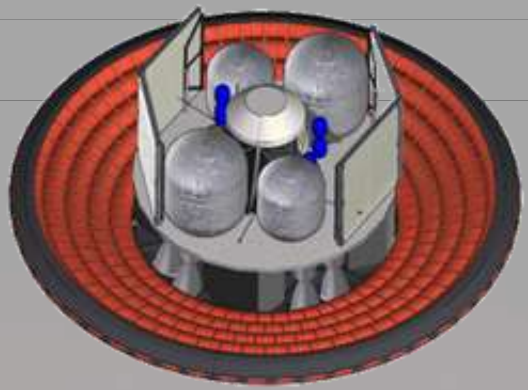
What Do We Need to Land?

10 m diameter SLS fairing; 300 day stay; Crew of 4; Four 20 t payloads



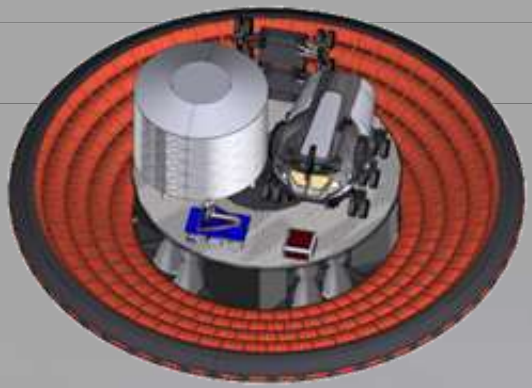
Lander 1

- Surface Power Units
- Unpressurized Rovers
- Cargo Off-loading
- Logistics Module
- Science Payloads



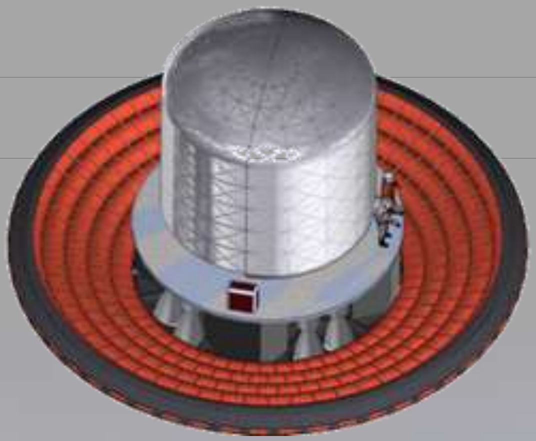
Lander 2

- Mars Ascent Vehicle
- Atmosphere ISRU
- Crew Access Tunnel



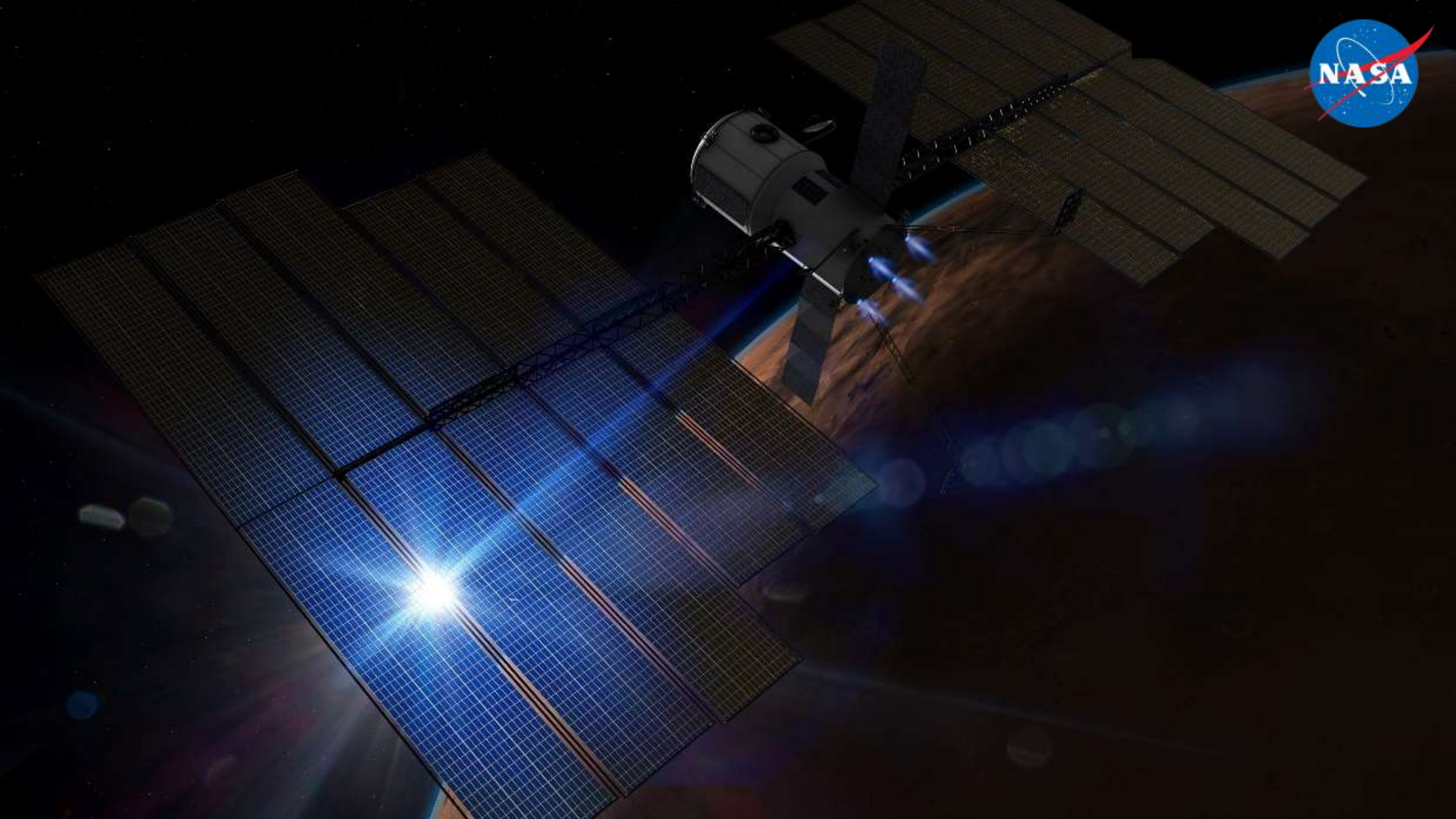
Lander 3

- Pressurized Rover
- Logistics module
  - Crew consumables
  - Fixed system spares
  - Mobile system spares
  - EVA spares
- Surface Mobility

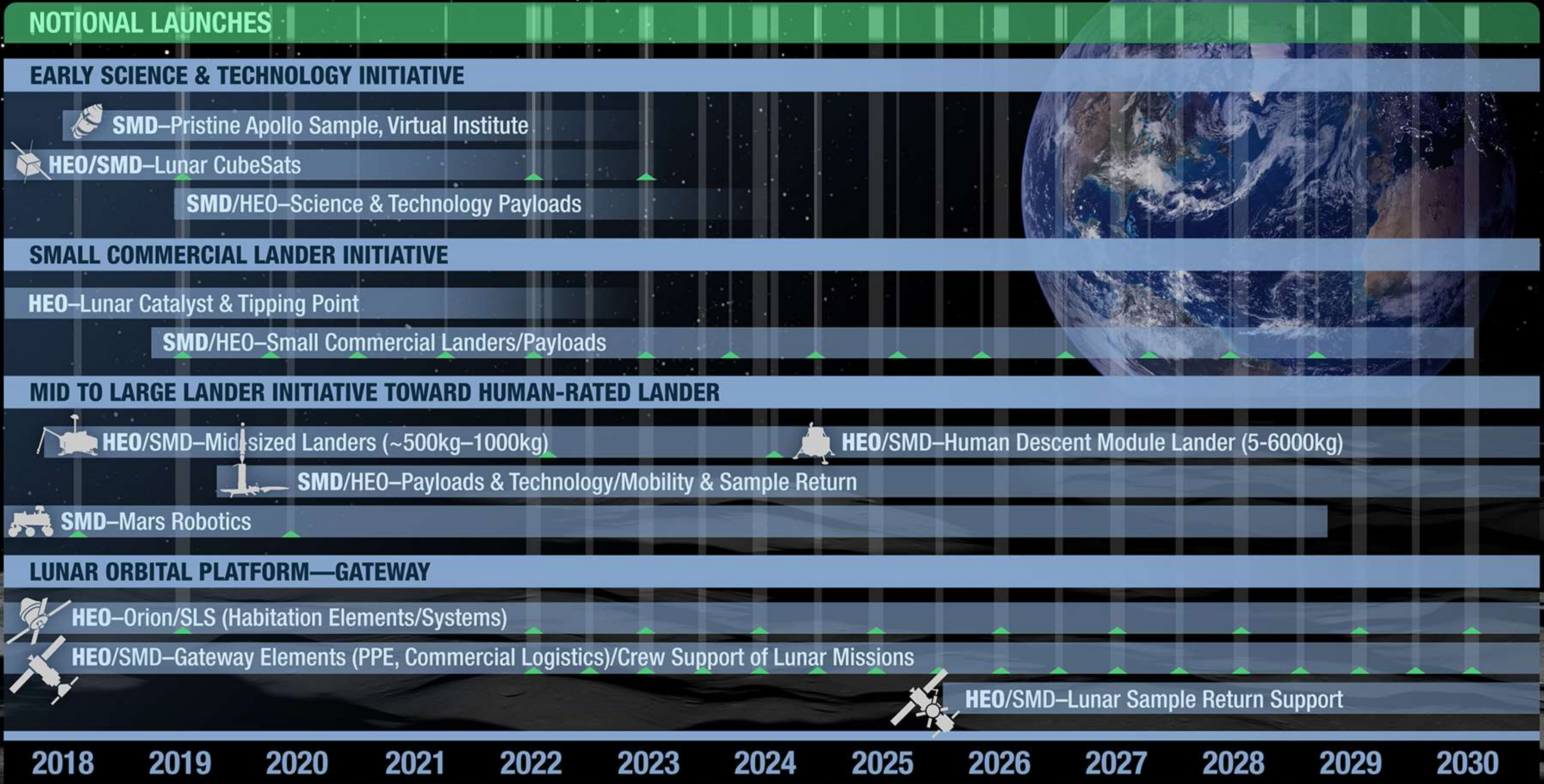


Lander 4

- Habitation
- Crew



NASA Exploration Campaign



NOTIONAL LAUNCHES

EARLY SCIENCE & TECHNOLOGY INITIATIVE

SMD–Pristine Apollo Sample, Virtual Institute

HEO/SMD–Lunar CubeSats

SMD/HEO–Science & Technology Payloads

SMALL COMMERCIAL LANDER INITIATIVE

HEO–Lunar Catalyst & Tipping Point

SMD/HEO–Small Commercial Landers/Payloads

MID TO LARGE LANDER INITIATIVE TOWARD HUMAN-RATED LANDER

HEO/SMD–Mid-sized Landers (~500kg–1000kg)

HEO/SMD–Human Descent Module Lander (5-6000kg)

SMD/HEO–Payloads & Technology/Mobility & Sample Return

SMD–Mars Robotics

LUNAR ORBITAL PLATFORM—GATEWAY

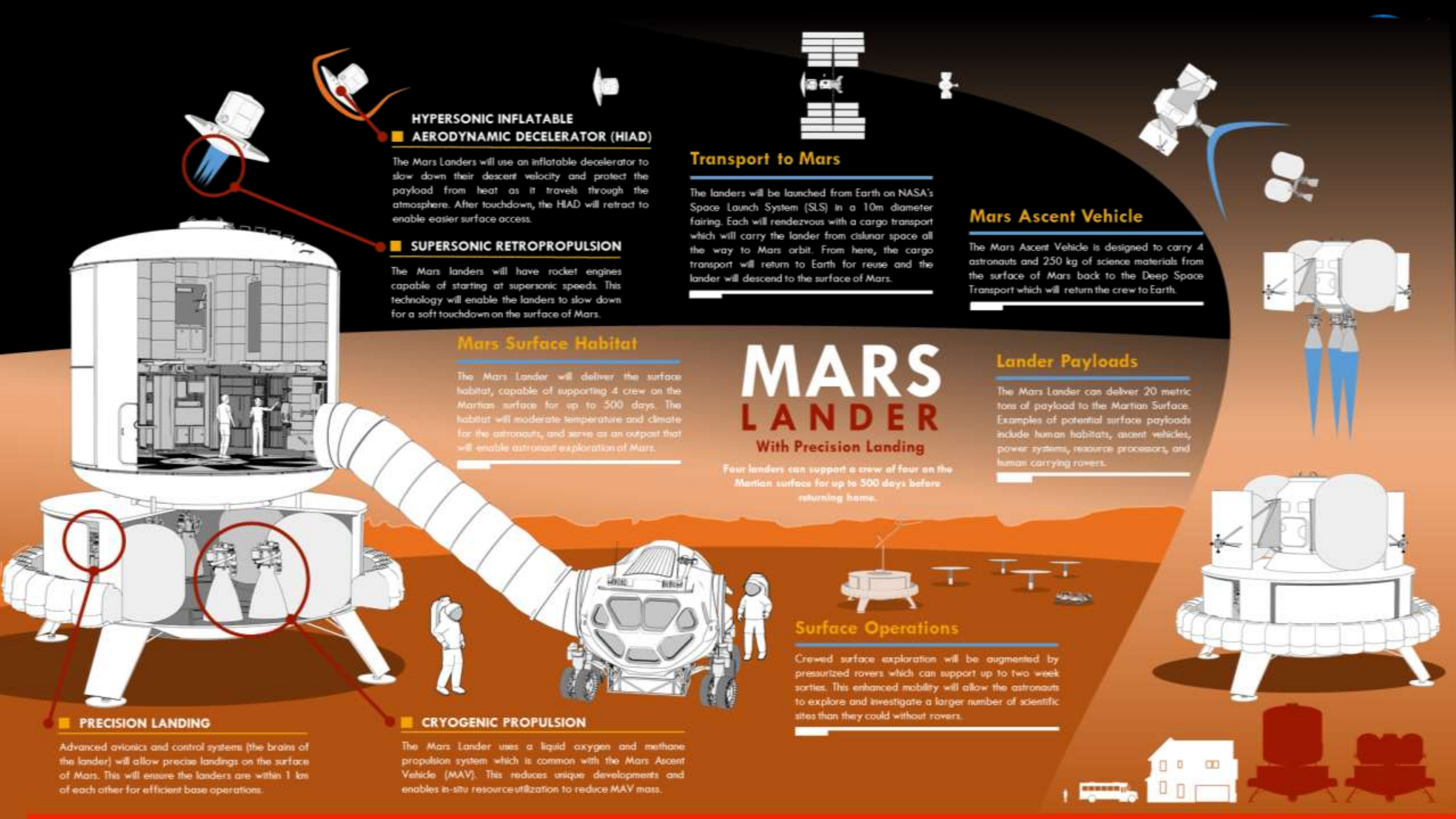
HEO–Orion/SLS (Habitation Elements/Systems)

HEO/SMD–Gateway Elements (PPE, Commercial Logistics)/Crew Support of Lunar Missions

HEO/SMD–Lunar Sample Return Support

Timelines are tentative and will be developed further in FY 2019

MARCH 2018



MARS
LANDER
With Precision Landing

Four landers can support a crew of four on the Martian surface for up to 500 days before returning home.

HYPERSONIC INFLATABLE AERODYNAMIC DECELERATOR (HIAD)

The Mars Landers will use an inflatable decelerator to slow down their descent velocity and protect the payload from heat as it travels through the atmosphere. After touchdown, the HIAD will retract to enable easier surface access.

SUPERSONIC RETROPROPULSION

The Mars landers will have rocket engines capable of starting at supersonic speeds. This technology will enable the landers to slow down for a soft touchdown on the surface of Mars.

Transport to Mars

The landers will be launched from Earth on NASA's Space Launch System (SLS) in a 10m diameter fairing. Each will rendezvous with a cargo transport which will carry the lander from cislunar space all the way to Mars orbit. From here, the cargo transport will return to Earth for reuse and the lander will descend to the surface of Mars.

Mars Ascent Vehicle

The Mars Ascent Vehicle is designed to carry 4 astronauts and 250 kg of science materials from the surface of Mars back to the Deep Space Transport which will return the crew to Earth.

Mars Surface Habitat

The Mars Lander will deliver the surface habitat, capable of supporting 4 crew on the Martian surface for up to 500 days. The habitat will moderate temperature and climate for the astronauts, and serve as an outpost that will enable astronaut exploration of Mars.

Lander Payloads

The Mars Lander can deliver 20 metric tons of payload to the Martian Surface. Examples of potential surface payloads include human habitats, ascent vehicles, power systems, resource processors, and human carrying rovers.

Surface Operations

Crewed surface exploration will be augmented by pressurized rovers which can support up to two week sorties. This enhanced mobility will allow the astronauts to explore and investigate a larger number of scientific sites than they could without rovers.

PRECISION LANDING

Advanced avionics and control systems (the brains of the lander) will allow precise landings on the surface of Mars. This will ensure the landers are within 1 km of each other for efficient base operations.

CRYOGENIC PROPULSION

The Mars Lander uses a liquid oxygen and methane propulsion system which is common with the Mars Ascent Vehicle (MAV). This reduces unique developments and enables in-situ resource utilization to reduce MAV mass.