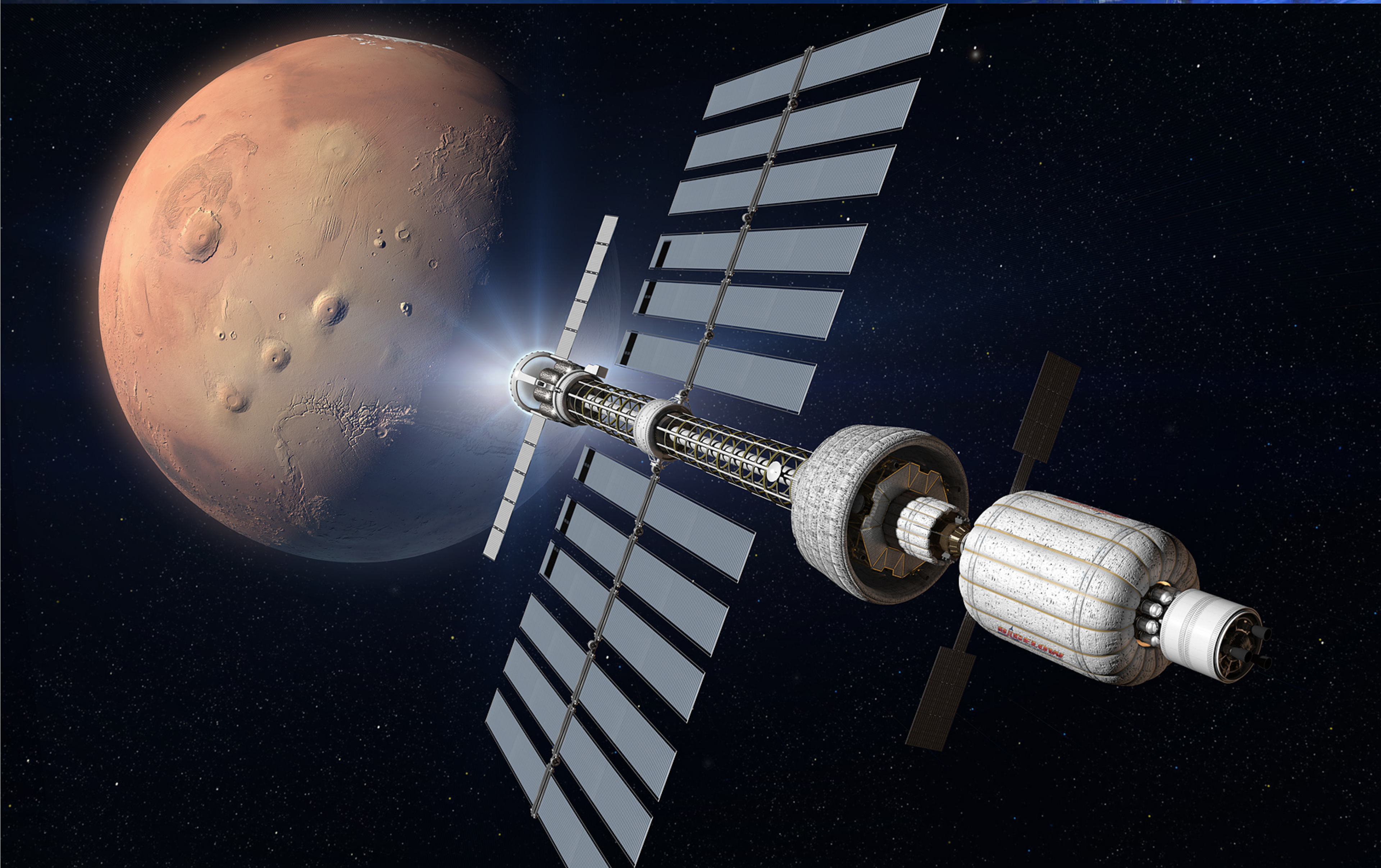
# The Space Launch System and the Pathway to Mars

**LEAG – October 24, 2014**

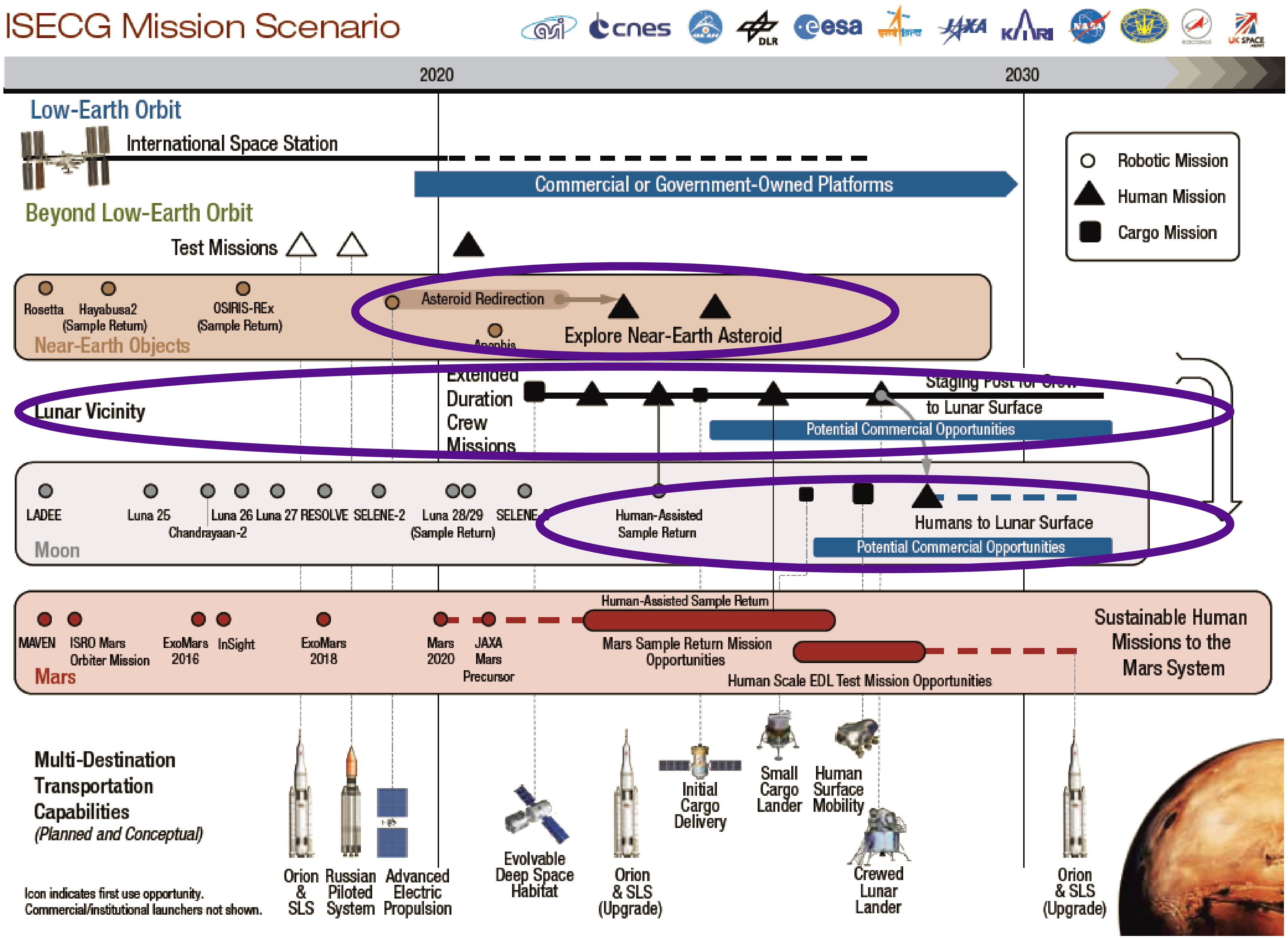
BOEING

# The Horizon Destination



# Outline

- Introduction
- The Global Exploration Roadmap
- The NRC Report – Pathways to Exploration
- SLS Configurations
- ARM
- Cislunar Habitat
- Payloads to Lunar Surface
- Mars Surface
- Final Thoughts



ISECG Mission Scenario
2020
2030
Low-Earth Orbit
International Space Station
Commercial or Government-Owned Platforms
Beyond Low-Earth Orbit
Test Missions
Robotic Mission
Human Mission
Cargo Mission
Rosetta
Hayabusa2 (Sample Return)
OSIRIS-REx (Sample Return)
Asteroid Redirection
Explore Near-Earth Asteroid
Near-Earth Objects
Lunar Vicinity
Duration
Crew
Missions
to Lunar Surface
Potential Commercial Opportunities
LADEE
Luna 25
Chandrayaan-2
Luna 26
Luna 27
RESOLVE
SELENE-2
Luna 28/29 (Sample Return)
Human-Assisted Sample Return
Humans to Lunar Surface
Potential Commercial Opportunities
Moon
MAVEN
ISRO Mars Orbiter Mission
ExoMars 2016
InSight
ExoMars 2018
Mars 2020
JAXA Mars Precursor
Human-Assisted Sample Return
Mars Sample Return Mission Opportunities
Human Scale EDL Test Mission Opportunities
Sustainable Human Missions to the Mars System
Mars
Multi-Destination Transportation Capabilities
(Planned and Conceptual)
Icon indicates first use opportunity.
Commercial/institutional launchers not shown.
Orion & SLS
Russian Piloted System
Advanced Electric Propulsion
Evolvable Deep Space Habitat
Orion & SLS (Upgrade)
Initial Cargo Delivery
Small Cargo Lander
Human Surface Mobility
Crewed Lunar Lander
Orion & SLS (Upgrade)

# From the GER Mission Scenario

- Ultimate objective is Mars
- Significant precursor activities necessary to prepare required systems
- Several interim destinations are possible
- ISS role in shaping technical basis and managerial model
- Strong partnership between human and robotic exploration programs
- International partners are prepared for and require key mission critical roles

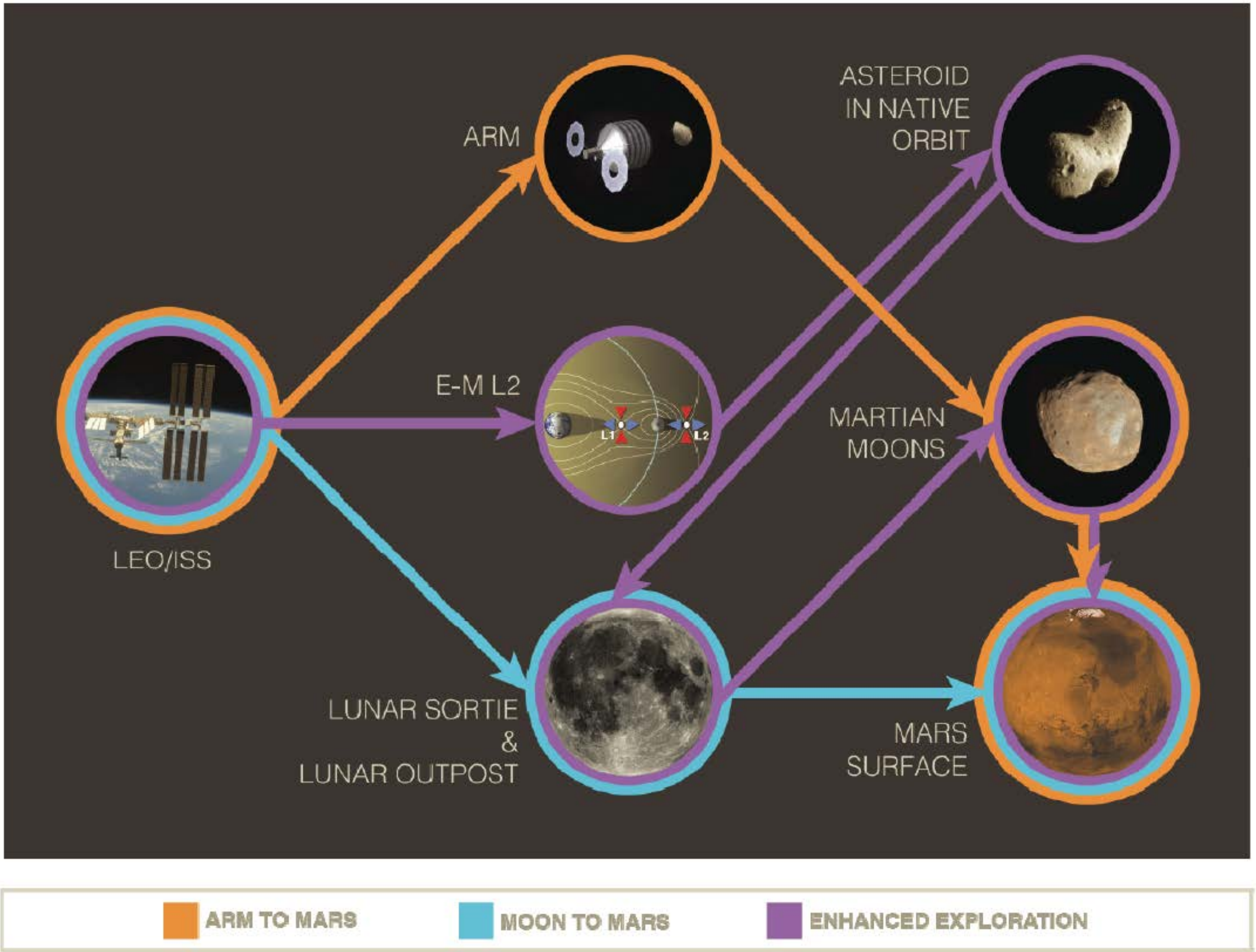
# From the NRC – Pathways to Exploration

| PATHWAY | DESIGN REFERENCE MISSION (DRM) | | | | | |
|---|---|---|---|---|---|---|
| ARM TO MARS | Asteroid Redirect Mission | Martian Moons | Mars Surface | | | |
| MOON TO MARS | Lunar Surface Sortie | Lunar Surface Outpost | Mars Surface | | | |
| ENHANCED EXPLORATION | Earth Moon L2 | Asteroid in Native Orbit | Lunar Surface Sortie | Lunar Surface Outpost | Martian Moons | Mars Surface |

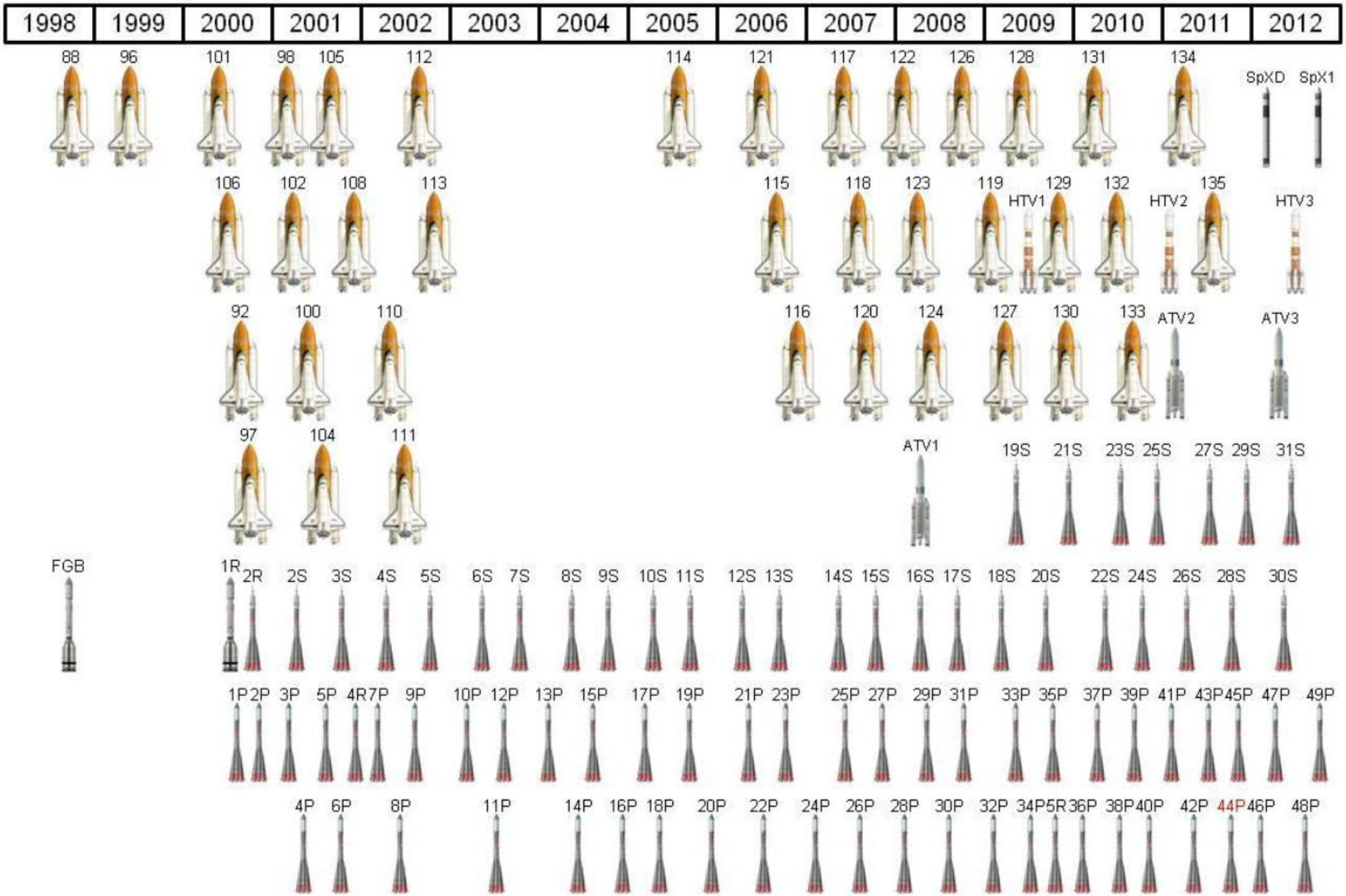
# From the NRC – Pathways to Exploration



PATHWAY STEPPING STONE DESTINATIONS

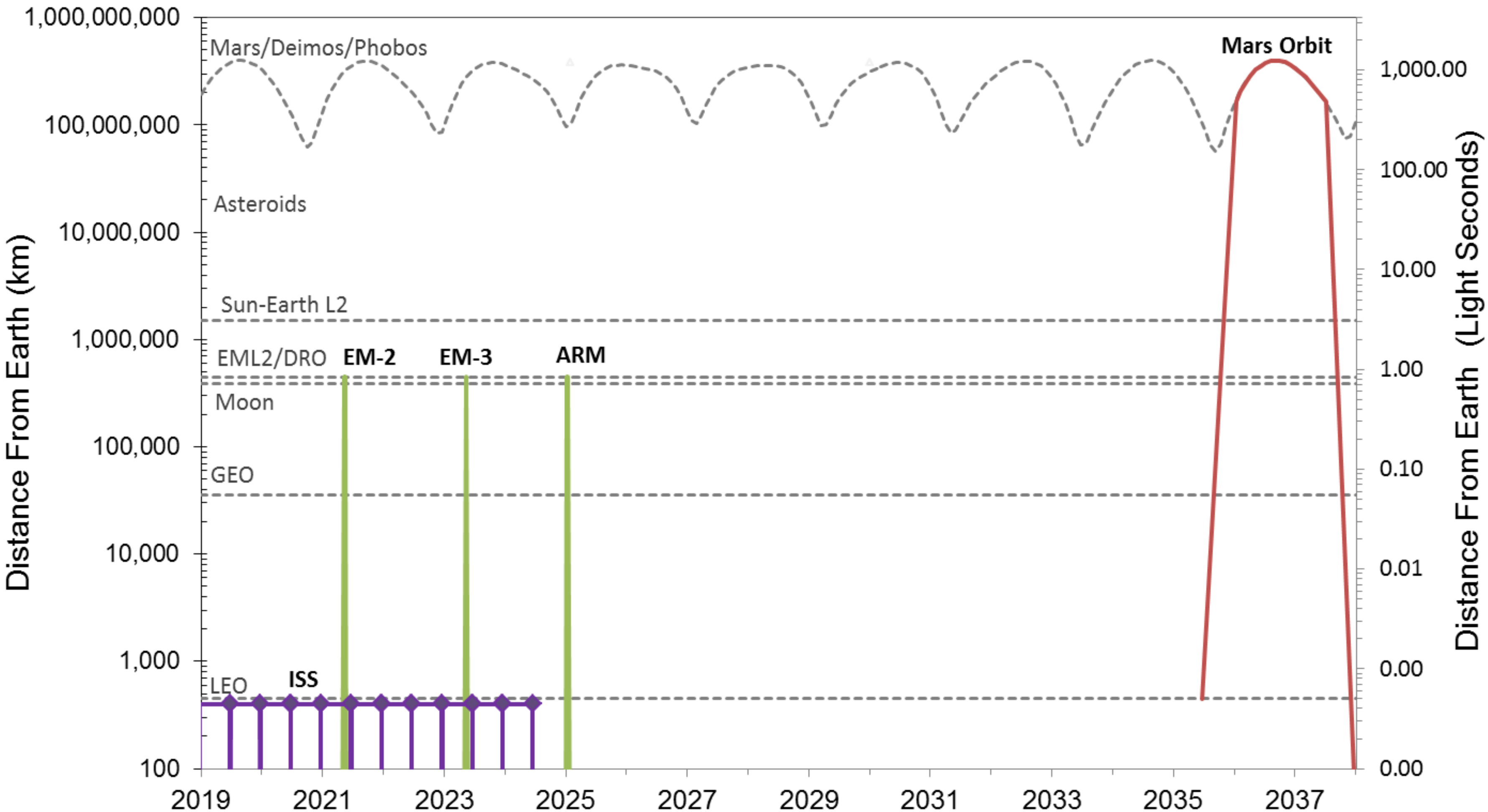


# ISS Assembly and Operations



# Mind the Gaps

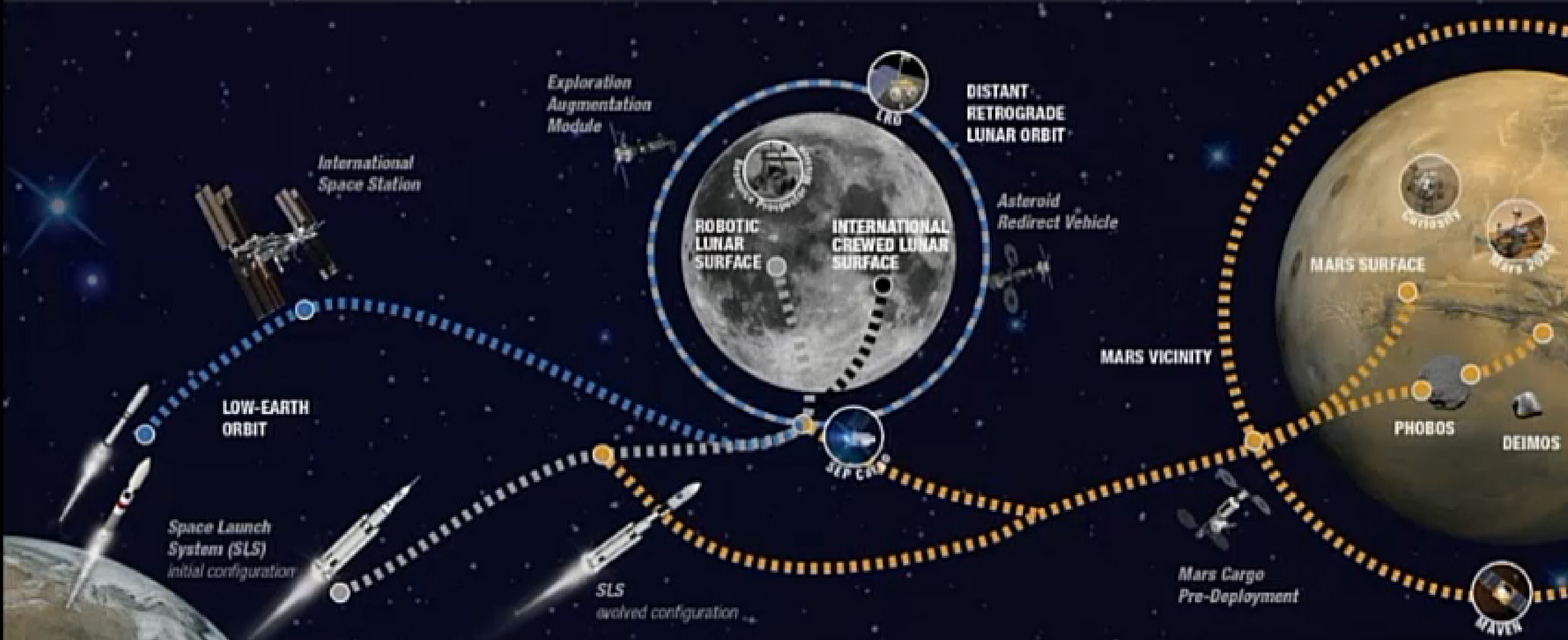
## Current NASA Human Spaceflight plan



# EVOLVABLE MARS CAMPAIGN

*A Pathways Approach to Exploration*

**EARTH DEPENDENT** | **PROVING GROUND** | **EARTH INDEPENDENT**



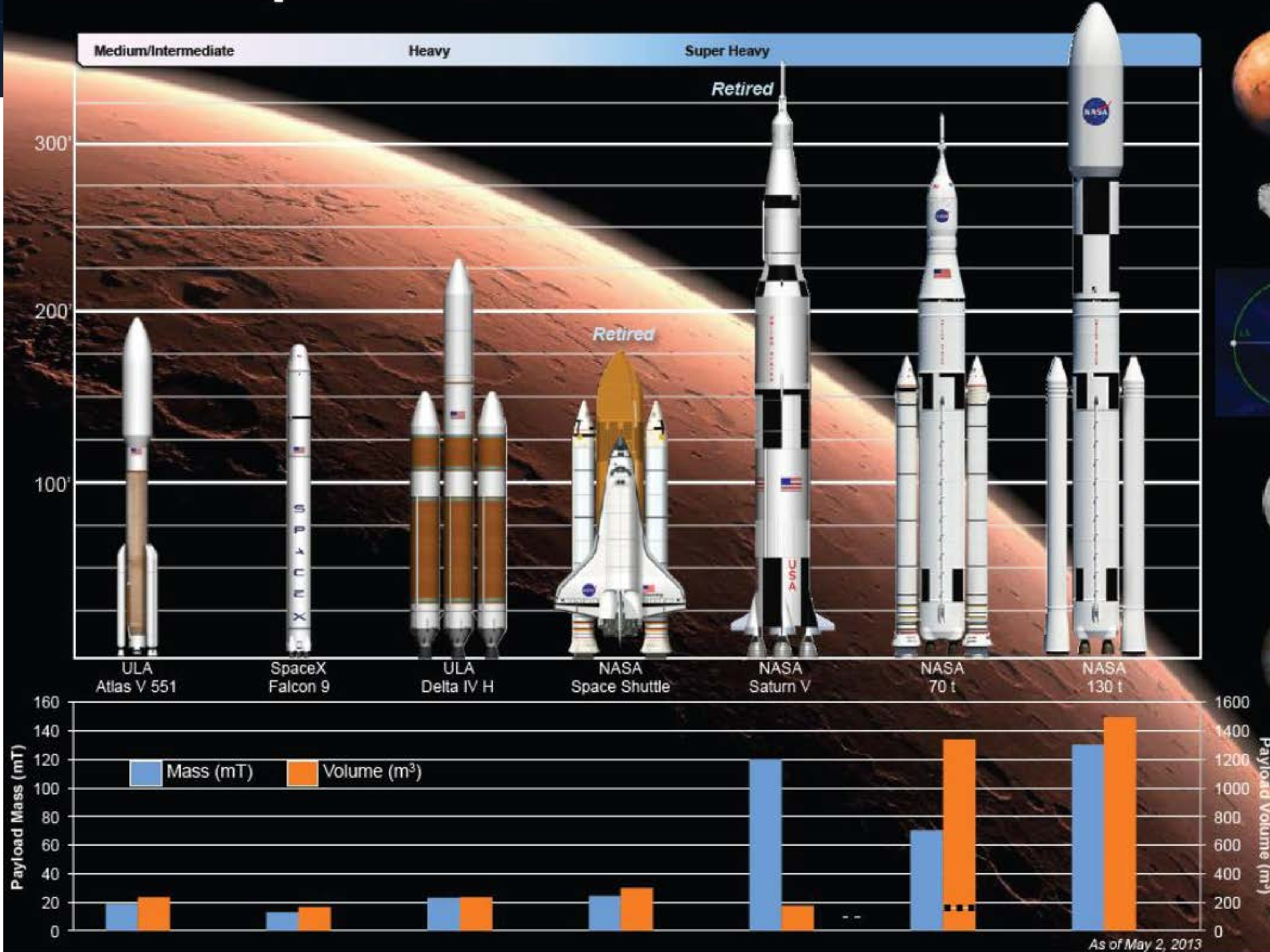

## THE TRADE SPACE

**Across the Board** | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

**Cis-lunar Trades**
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

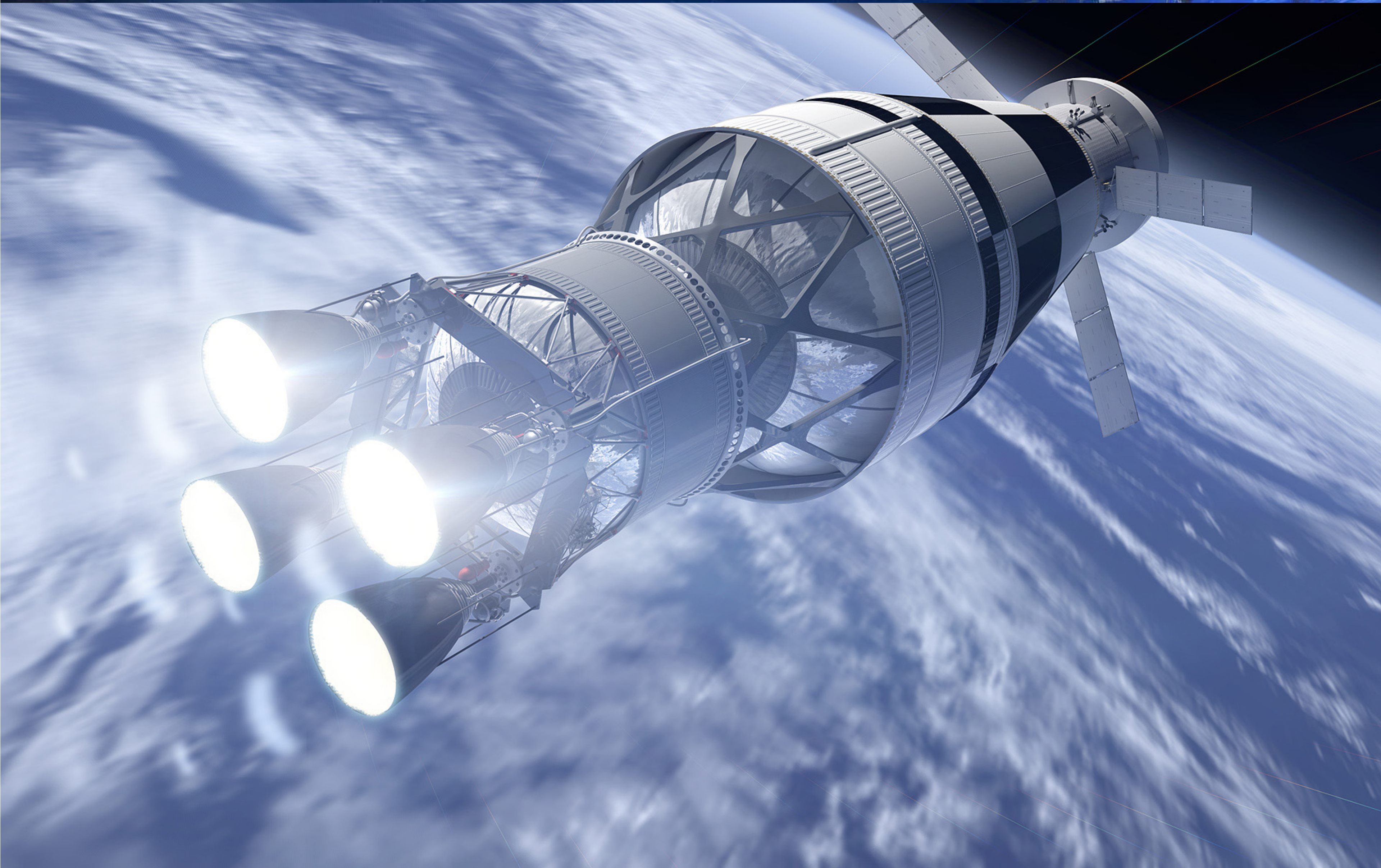
**Mars Vicinity Trades**
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

# Most Capable U.S. Launch Vehicle

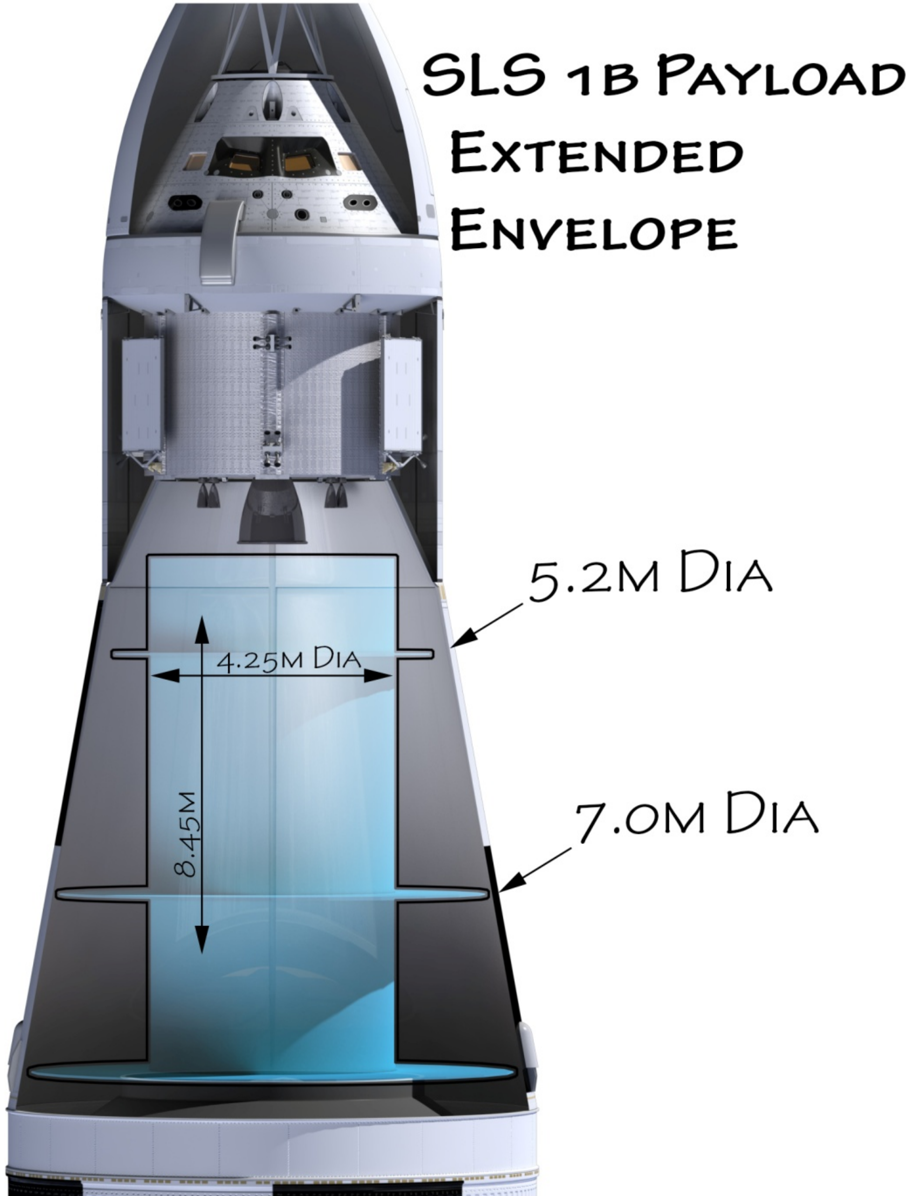


# The Space Launch System

# Exploration Upper Stage (EUS)



# SLS 1B Payload Capability



# The Next Step Beyond ISS

- **Crew tended habitat in cis-lunar space**
  - **Builds off of the Asteroid redirect mission and ISS**
    - **Allows for further study of gravity assist trajectory operations**
    - **Builds off of ISS life support with less earth support**
    - **Enables international partner and commercial lunar surface activities**
    - **Develops incremental risk management concepts to be developed and accepted**
    - **Exposure to galactic cosmic background radiation**
  - **Allows for Mars operational strategies to be developed**

# EM-2: Orion with Asteroid Retrieval Vehicle

- **Orion with ARV**
  - Asteroid Retrieval vehicle (ARV)
    - Lunar fly-by direct to Asteroid
    - Ballistic trajectory to asteroid
  - Orion mission to EAM
    - Longer duration stay (2.5 revs-35 days)?
    - Preps for next mission
      - Lunar sample return?

# EM-3: Orion with EAM to 71,000km DRO

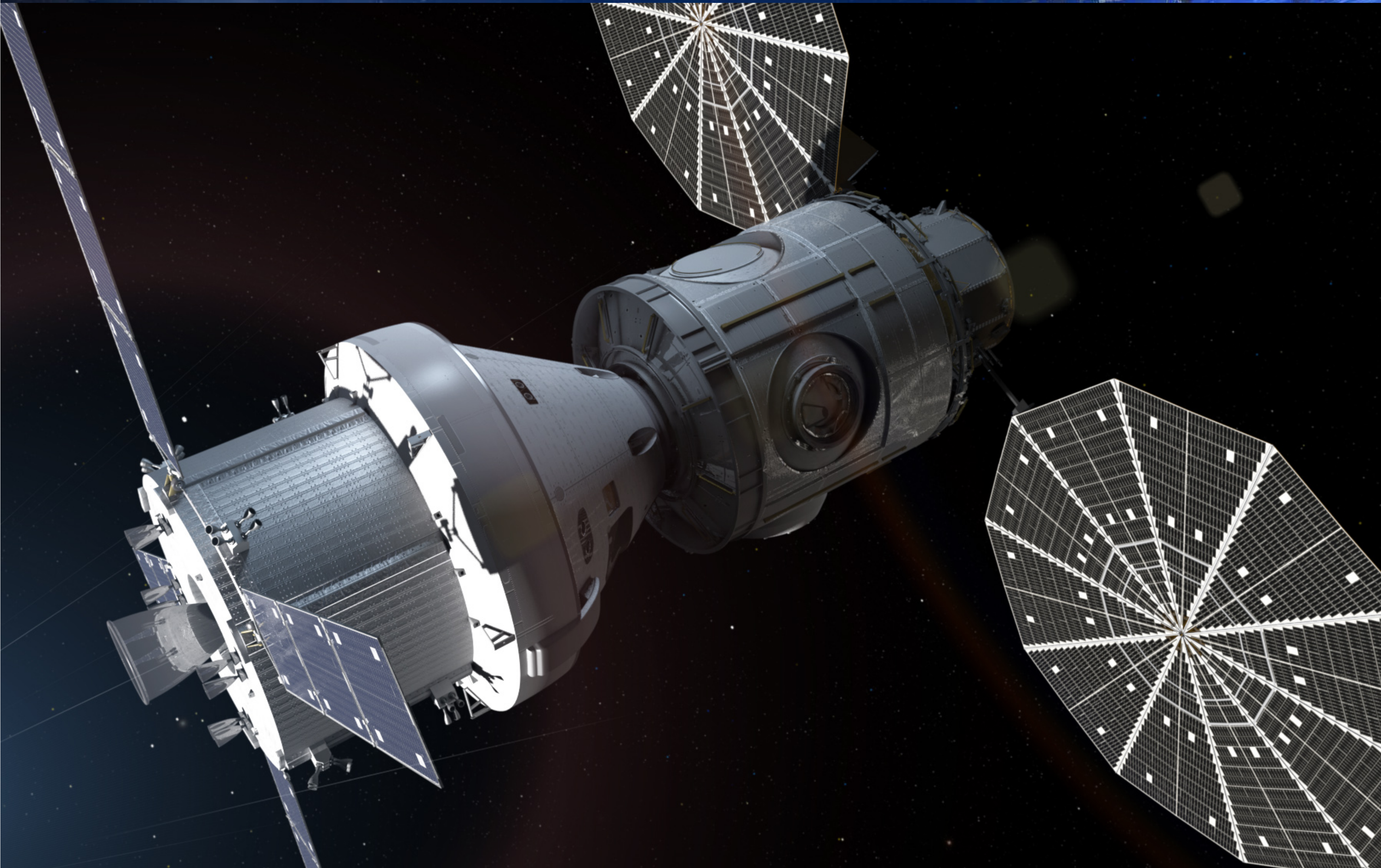
- **Orion with EAM**
  - Exploration Augmentation Module (EAM)
    - Cygnus-based bus concept
      - Larger arrays
    - "Node-like" structure
  - Current mission design assumes MSA2 & PAF are included in TLI mass
    - Orion docks to EAM after both separate
  - Orion SM performs all maneuvers into DRO while docked to EAM
  - EAM performs station keeping after Orion departure

# EM-3: Orion with EAM to 71,000km DRO

- **TLI performance:**
  - **dV = 2,707 m/s**
  - **EUS propellant used = 52,139 kg**
    - **Margin of 3,874.3 kg (56,013.3 – 52,139)**
  - **TLI performed assuming MSA2 & PAF adapter mass**
  - **Jettison of EUS, PAF, MSA2 performed after TLI complete**
  - **Payload mass delivered:**
    - **Orion**
      - **CM @ 10,387 kg**
      - **SM Inert @ 6,857.6 kg**
      - **SM Prop @ 8,602.4 kg**
    - **Payload**
      - **Assumed a 10,000 kg EAM payload (total)**
  - **Fly-By Target (includes 10t payload):**
    - **Orion Impulsive**
    - **dV: 166 m/s**
    - **Prop Used: 1,548.4 kg**
  - **DRO Insertion at 71,000 km (includes 10t payload)**
    - **Orion Impulsive**
    - **dV: 120 m/s**
    - **Prop Used: 1,072.8 kg**

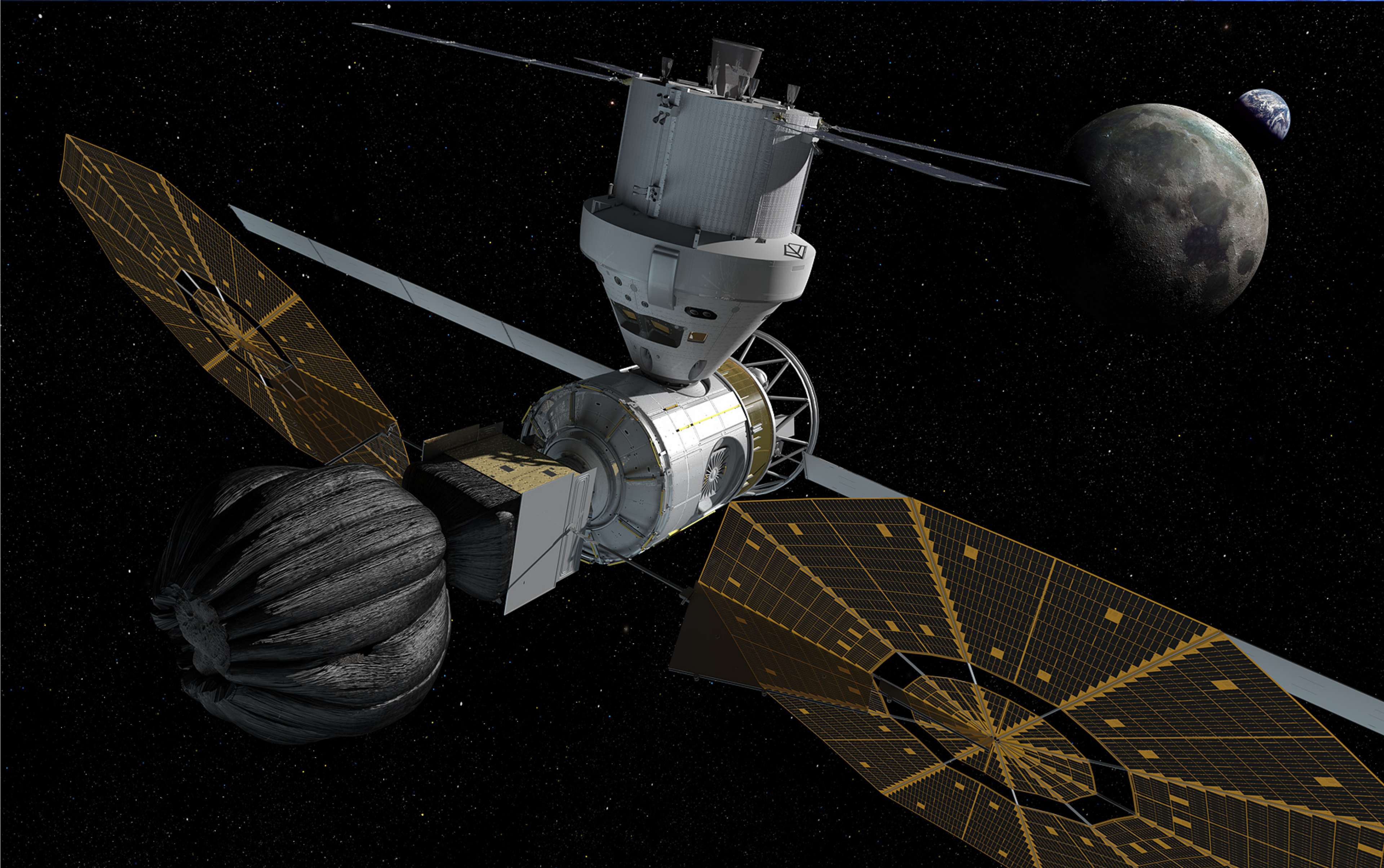
**SLS Performance suggests that EAM mass could be up to 12,000Kg**

# Orion docked to EAM



# Mission concept including EAM and ARV





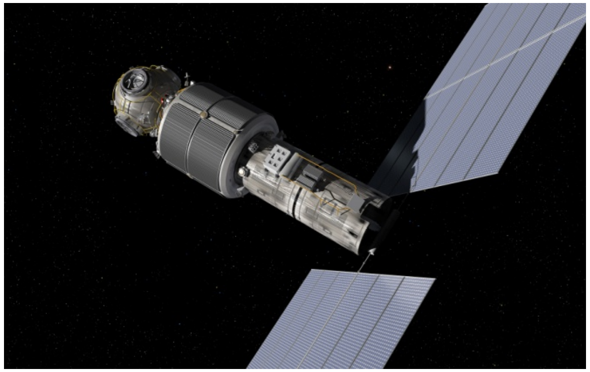
# Comparison of Orion and EAM

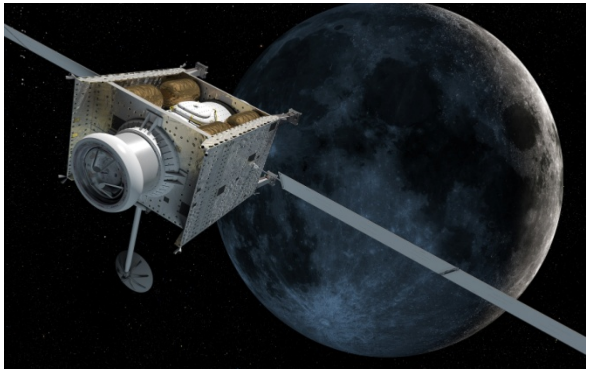
| Capability | Orion | EAM + Orion |
|---|---|---|
| **Exobody Interaction**<br>• Characterize geology and topography at destinations and collect samples<br>• Test tools and technologies to extract, process, and utilize resources | ✓ | ✓ |
| **Science**<br>• Earth observation, heliophysics, and astrophysics and other applied research | ✓ | ✓ |
| **Crew Health**<br>• Evaluate human health and risk mitigation in the deep space environment<br>• Test radiation countermeasures and mitigation technologies and strategies<br>• Monitor and predict radiation | ✓ | ✓ |
| **Spacecraft Systems and Operations**<br>• Space power generation and storage<br>• High-performance mobility and extravehicular activity capabilities<br>• Autonomous robots to supplement crew activities<br>• Advanced in-space propulsion capabilities<br>• Automated rendezvous and docking and on-orbit assembly capabilities<br>• Space communications and navigation capabilities<br>• Protocols for deep space operations at a large distance from Earth | **Partial** | ✓ |
| **Cooperation**<br>• Opportunities for integrating commercial elements<br>• Opportunities for international space agency cooperation | | ✓ |
| **Extend Orion mission duration in translunar space** | | ✓ |
| **Long duration habitability in deep space** | | ✓ |
| **Provide a local abort destination for Orion missions** | | ✓ |
| **Extensible architecture for future exploration missions** | | ✓ |

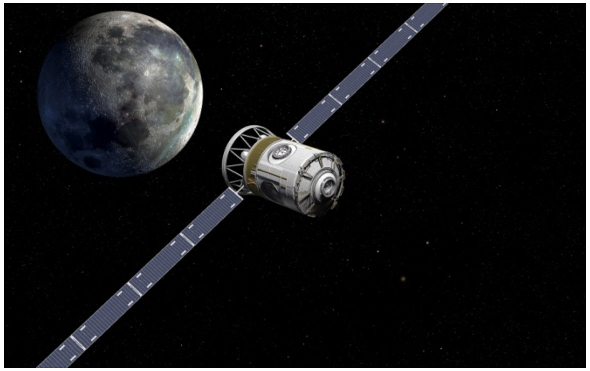
# Asteroid Exploration Module

- Crew operations at a redirected asteroid could be significantly enhanced by providing additional systems and EVA capabilities beyond those available from Orion only missions.

- Placing an Asteroid Exploration Module (AEM) at the redirected asteroid would :
  - Extend mission duration – Reduce EVA and consumables mass requirements on Orion
  - Increase capability – Supply additional EVA functions and crew volume
  - Reduce risk - Provide an abort location for Orion







# Risk Reduction for Exploration

- **EAM increases science return of the Asteroid Redirect Mission**

- **EAM demonstrates many core capabilities needed for deep space missions**
  – Electric propulsion
  – EVA
  – Deep space navigation and communications
  – Long duration operations beyond low earth orbit
  – Commercial/international interaction
  – Long duration radiation countermeasures and mitigation

- **<u>EAM benefits Exploration as a residual asset</u>**

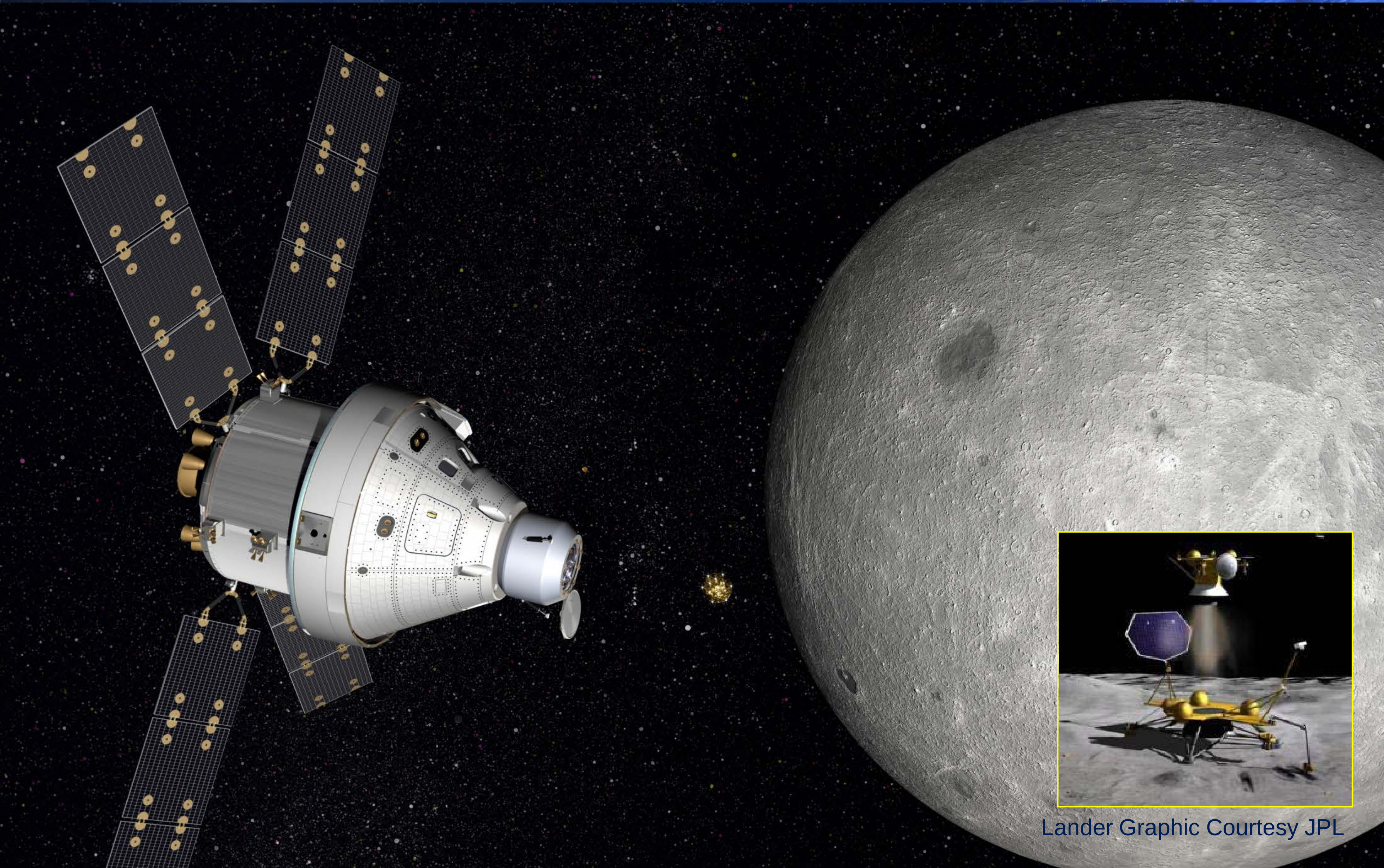
# EM-4: Orion with Robotic Lander

- **Orion with Lander**

  Lander derived from Morpheus
  - Lander injects into a lunar phasing orbit
  - Target Schrödinger Basin on Lunar farside (example)
  - Phase to time landing at the beginning of the lunar day
  - Lander Payload: Ascent Vehicle and option for Rover
  - Sample returned to crew at the end of the Lunar day

  – Orion mission to EAM
  - Longer duration stay (3.5 revs-50 days)?
  - Farside comm considerations
  - Several options for sample retrieval:
    - OSCAR integrated into EAM
    - Grapple arm on EAM;  EVA sample retrieval
    - NDS for ascent vehicle;  EVA sample retrieval
    - NDS ascent (pressurized );  IVA sample retrieval

# Moonrise Mission



Lander Graphic Courtesy JPL


# Sample Return Lander

## Lander Summary Table

| Description | Morpheus | Hosted Lander |
|---|---|---|
| Engine Thrust | 22,000 N | 22,000 N |
| Propellant | LOX/CH4 | LOX/CH4 |
| Specific Impulse (Isp) | 321 | 321 |
| Propellant Mass | 2,900 kg | 5,900 kg |
| Dry Mass | 1,100 kg | 2,600 kg |
| Payload | 500 kg | 1,500 kg |
| Diameter | 3.7 m | 5.5 m |
| Height | 3.7 m | 5.5 m |
| Total Est. Mass | 4,500 kg | 10,000 kg |
| | | |
| | | |

# Sample Return Example – Schrödinger Crater



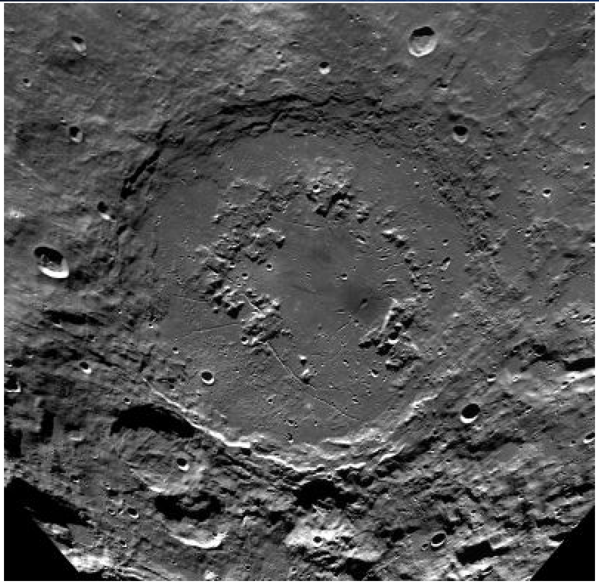
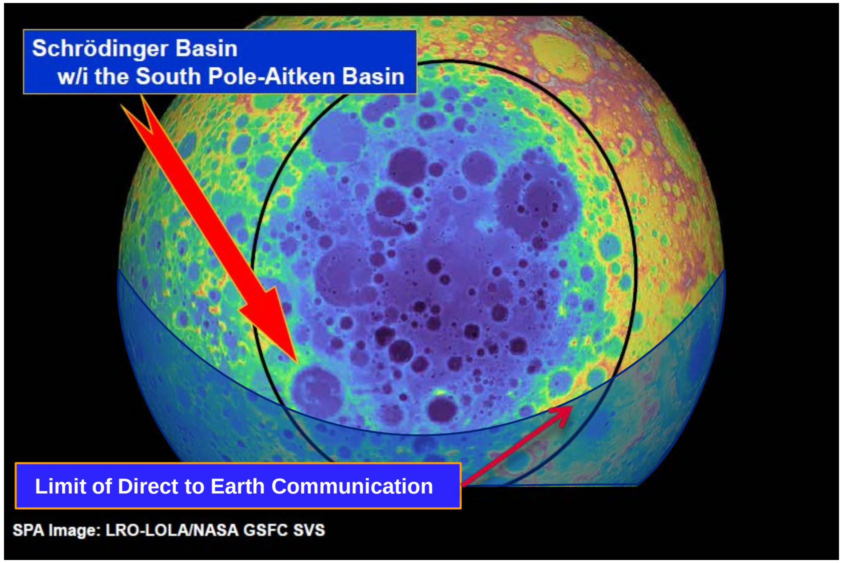


Image Courtesy of NASA – Clementine mission



SPA Image: LRO-LOLA/NASA GSFC SVS

- Why Schrödinger?
  - Large Impact Crater Within South Pole-Aitken Basin
    - Lat: 75.0°S, Long: 132.4°E, Main ring diam.: 320 km, Depth: 4.8 km
  - Sample return from SPA high priority from 2012 NRC Decadal Survey
  - Meets many goals of NRC 2007 Study
  - Access to Amundsen and Shackelton
  - ISRU Potential
    - Lunar regolith
    - Pyroclastic deposits
    - Polar Volatiles?
  - Many other prospective landing sites
    - Ex: 50 Constellation regions of interest
    - Recognition that target would be selected with community input

# Sample Return Example – Schrödinger Crater con't

- Payload
- Lander with Ascent Vehicle
- Long lived teleoperated prospecting rover with sample caching mechanism (Find, Characterize, Document, Return Samples)
  - Model payload
    - Caching mechanism (modeled after Mars 2020)
    - Drill
    - Mineralogy
      - X-Ray Diffraction
      - Multispectral (UV-VIS-NIR) reflectance spectrometer
    - Elemental Abundance
      - Gamma-Ray spectrometer
      - Laser-induced Breakdown Spectroscopy (LIBS)
    - Lunar Environment
      - Magnetometer
      - Handlens camera
      - Electrical charge detection
- Ability to traverse beyond Schrödinger when primary mission complete
  - Amundsen
  - Shackleton
- Rover could be modeled after Curiosity


**Image Courtesy of Zacny– 2013**

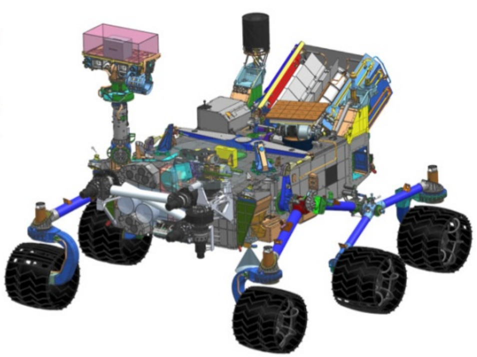


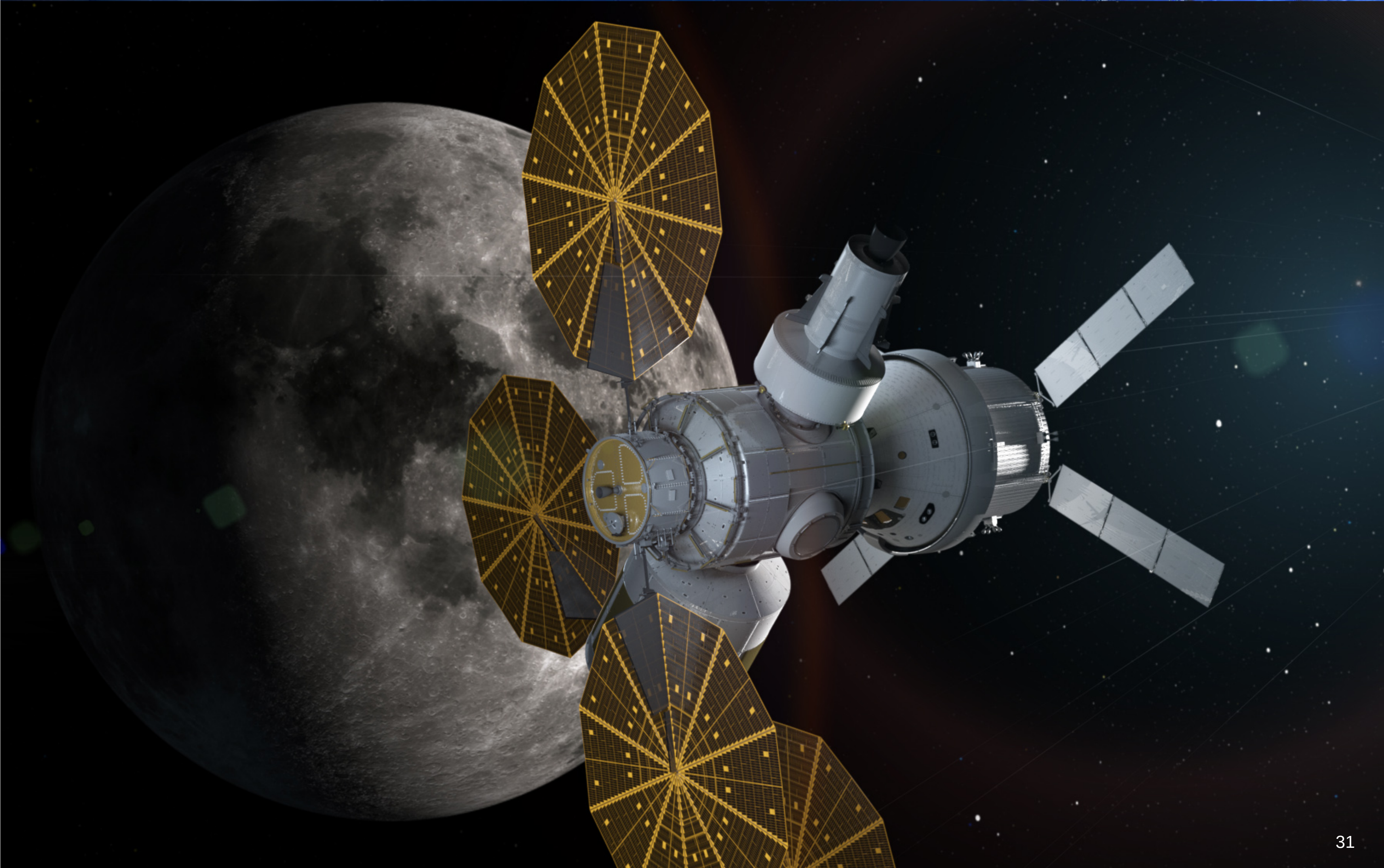
**Image Courtesy of NASA**

# Orion/Sample Carrier docked to EAM

# EM-5: Orion with Commercial Re-Supply

- **Orion with Commercial Cargo**
  - Cargo Module based on enlarged Cygnus
    - Larger diameter canister?
  - Orion mission to EAM
    - Longer duration stay (5.5 revs-80 days)?
    - Supplies for Asteroid mission?

# EAM Ports…



# EM-6 - Lunar Surface Mission

## Lunar Surface Mission

**Mission Objective**

Launch astronauts and a reusable lunar lander to the moon's surface

**Mission Rationale**

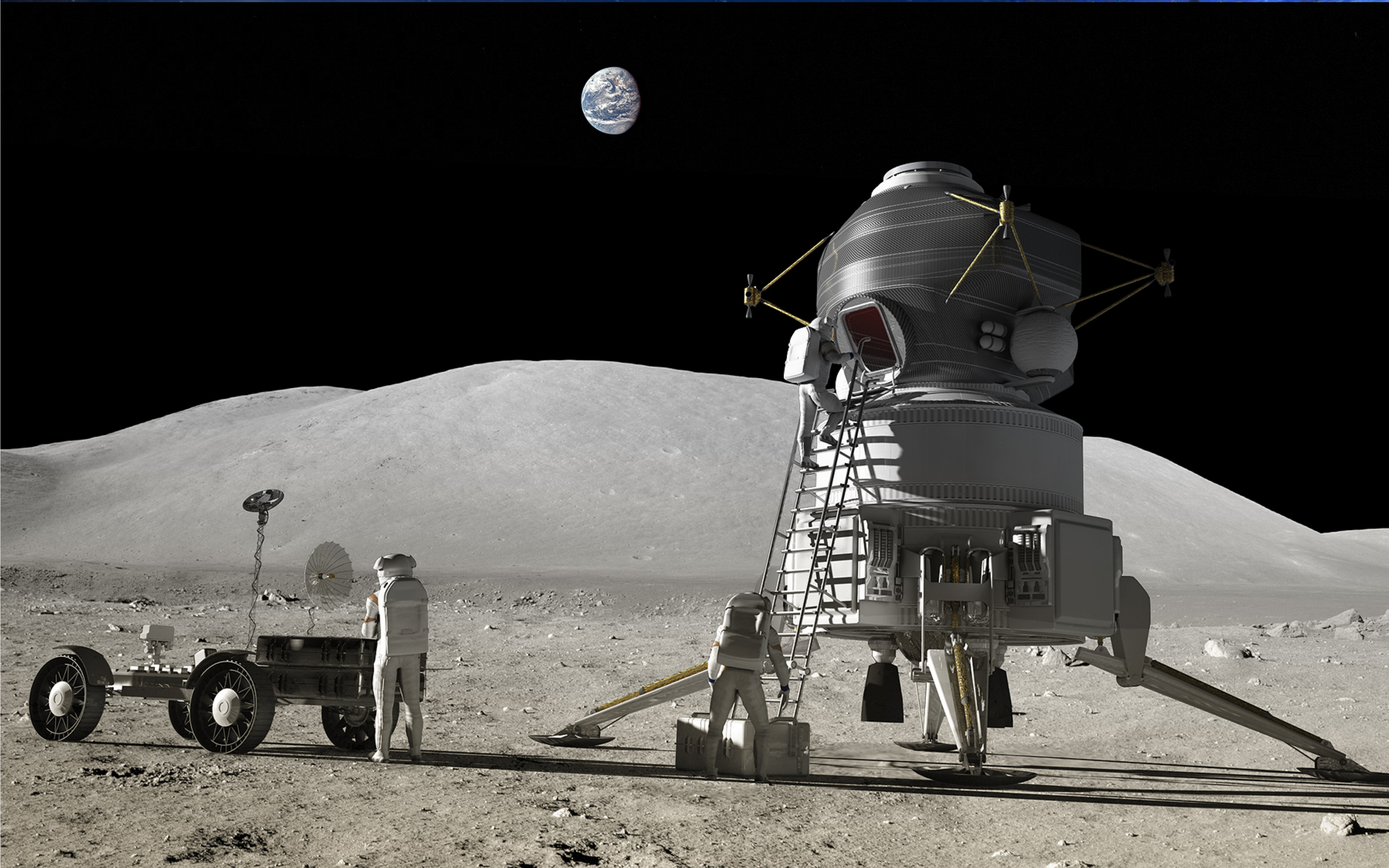
Unlike Earth, the moon remains largely unchanged since the formation of the solar system. Through study of our only natural satellite, scientists can look billions of years into the past for geologic clues while engineers can test systems necessary for future Mars missions. Lunar exploration challenges strengthen international partnerships critical to ambitious deep space endeavors.

**SLS Capabilities**

SLS enables human return to the moon. The intermediate SLS capability allows both crew and cargo to fly to translunar orbit at the same time which will simplify mission design and reduce launch costs.

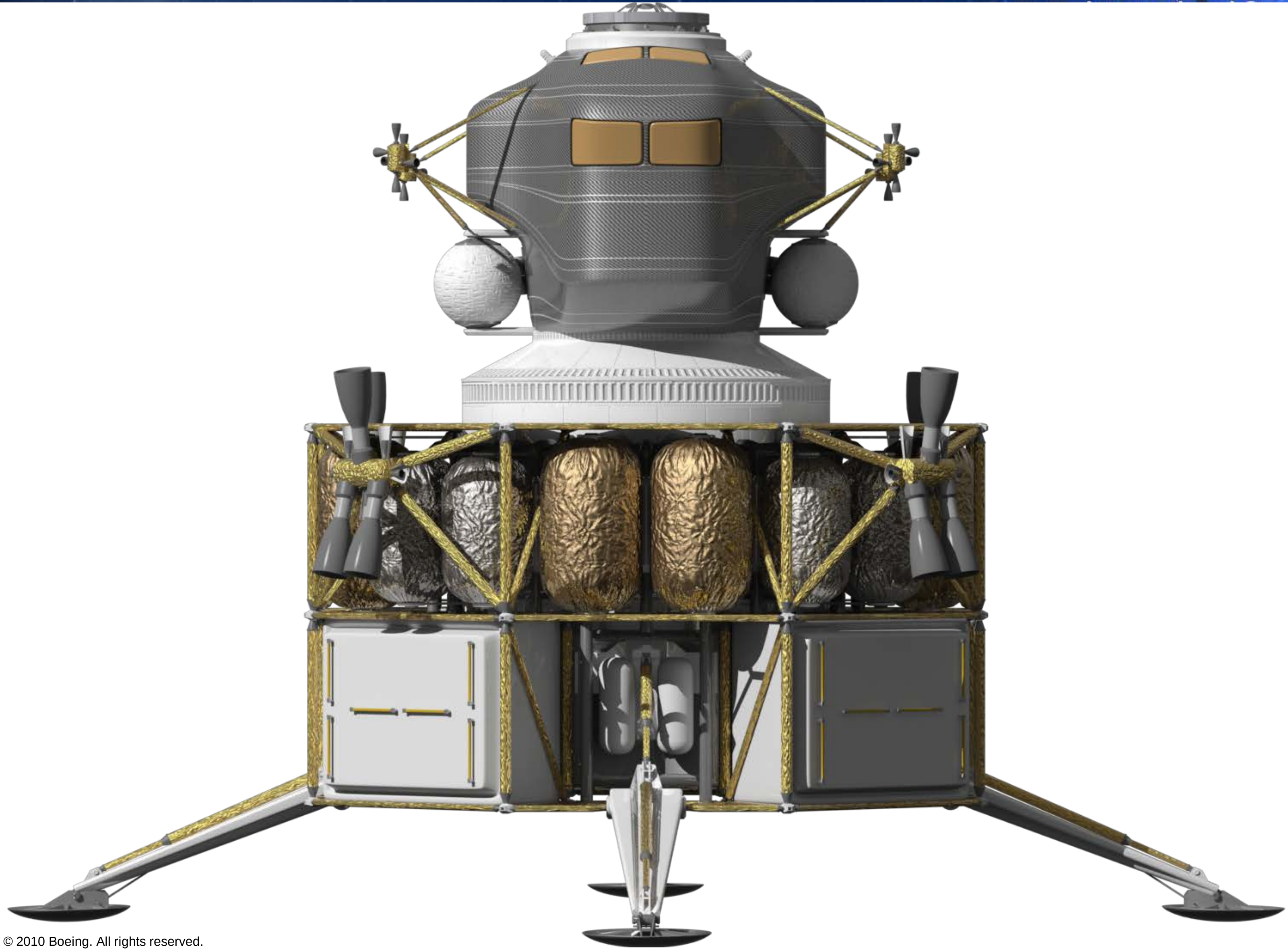
# EAM with Lander System

# Crew on the Lunar Surface



# Leaving the Moon

# Reusable Lander



# Deep Space Habitat: Bigelow BA 330




## Deep Space Habitat: Bigelow BA 330

**Mission Objective**

Deliver expandable BA 330 module to cislunar space

**Mission Rationale**

SLS supports commercial launch requirements and operations enabling a deep space human presence while extending Orion mission duration. The BA 330 is a stand-alone, self-sufficient module with crew support necessary to sustain long duration human habitation and may serve as a base element for future expansion. It can house up to six people on a long-term basis.

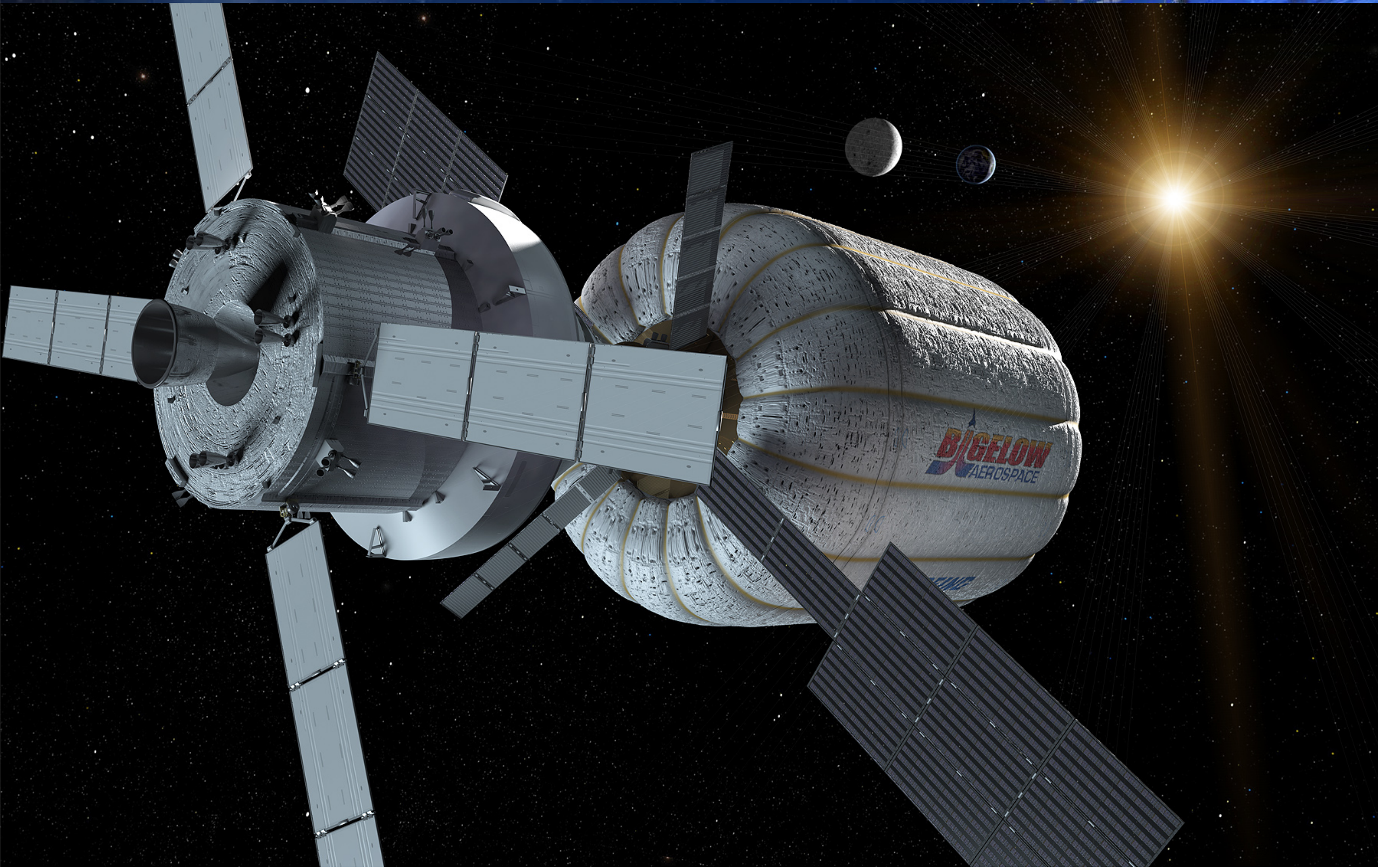
**SLS Capabilities**

SLS is the only launch vehicle capable of delivering the BA 330 to EML2. The heavy-lift vehicle will transport the habitation module beyond the moon and back to cislunar space via a low-energy transfer that reduces required propellant mass. SLS mass margin allows additional consumables, radiation protection or a secondary payload.

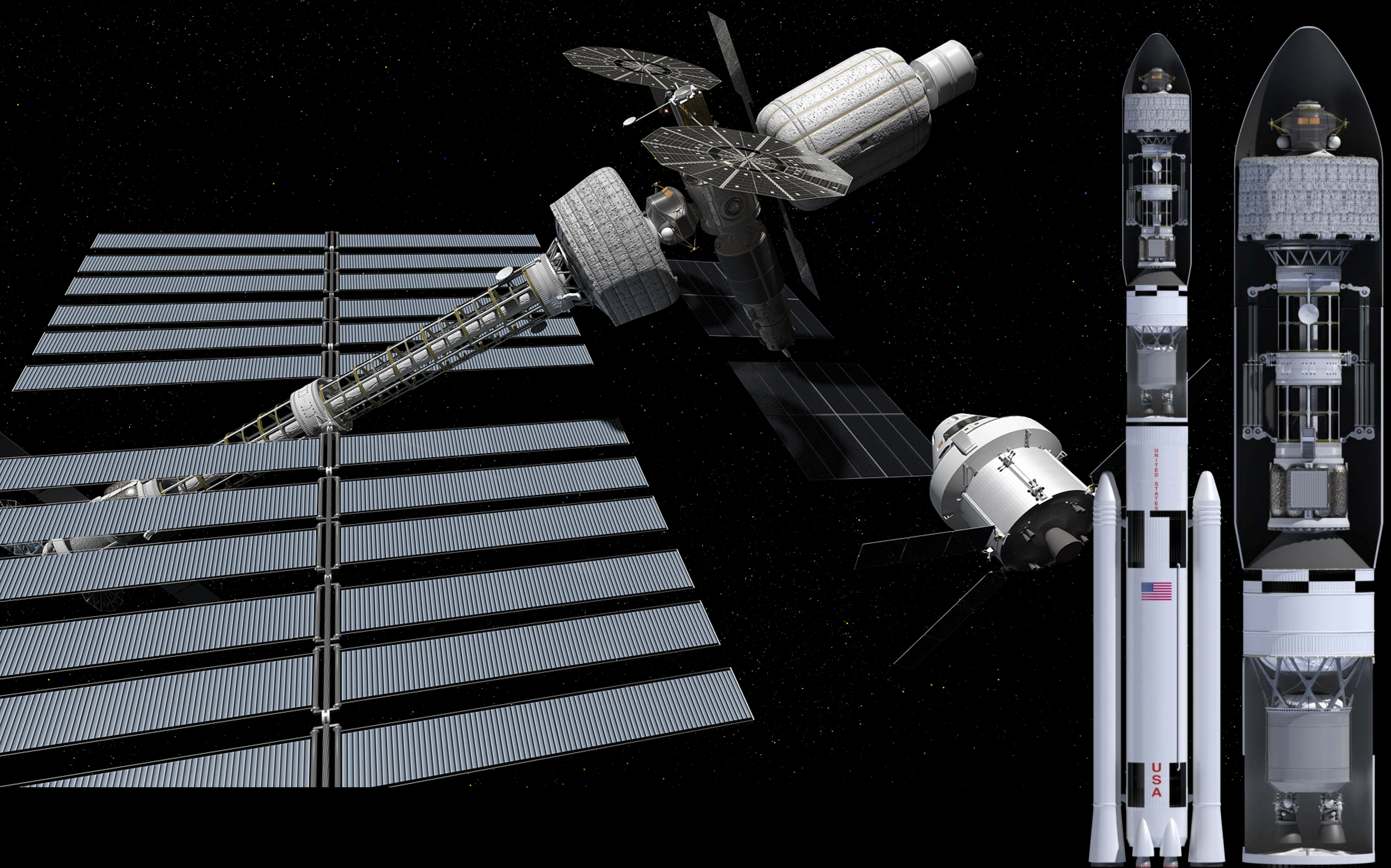
SLS Lift Capacity | 25t to EML2

PUBLIC-PRIVATE PARTNERSHIPS

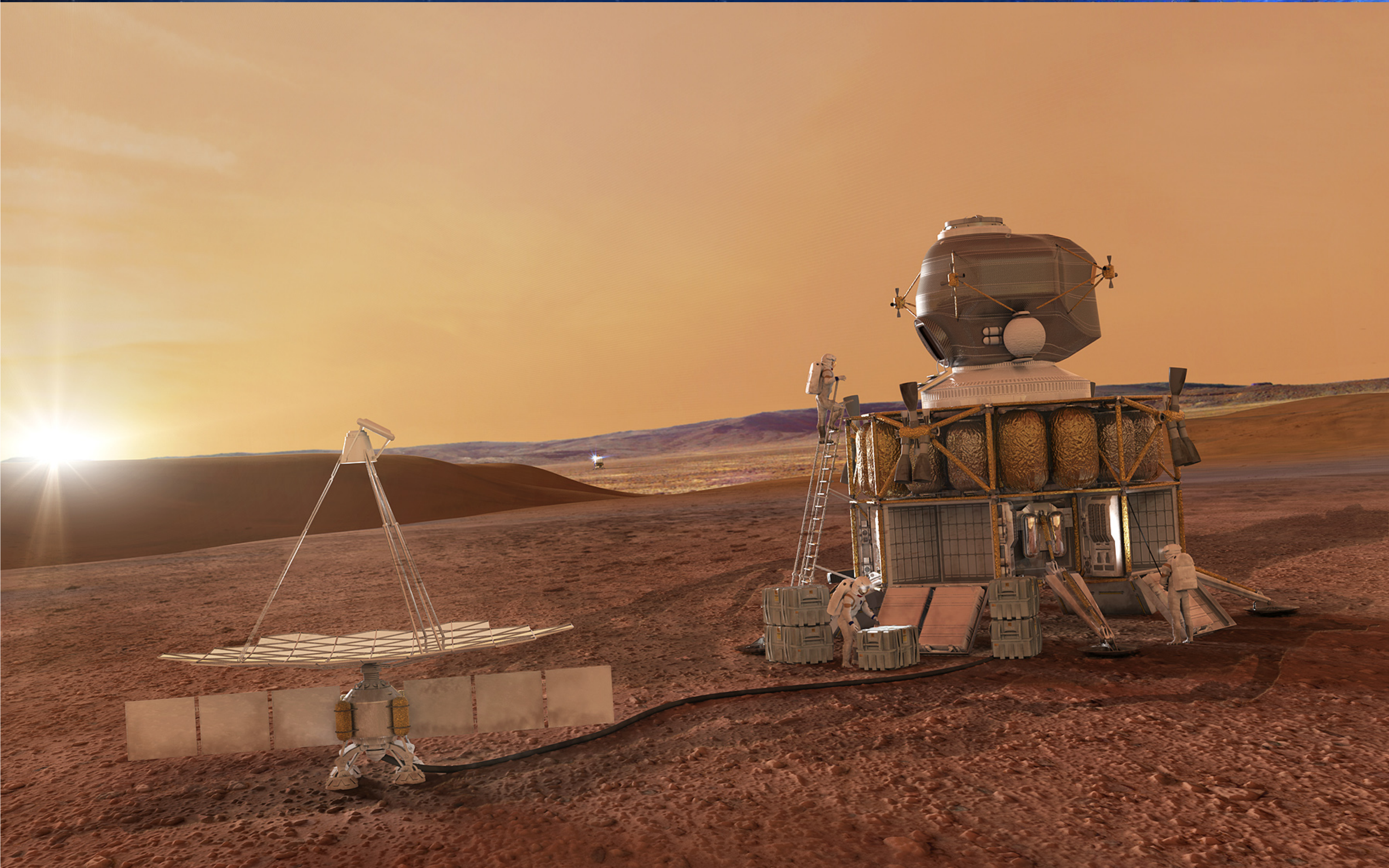
# Bigelow Deep Space Habitat Deployed



# Beyond the Proving Ground



# On Mars



# International Cooperation

- ISS has established a firm basis for a vibrant exploration program with a proven management model and proven existing designs

- A Deep Space capability based on ISS technology provides flexibility and is an enabling capability for key cost-reducing strategies:
  - Mobility within the libration system
  - Reuse of expensive spaceflight hardware
  - Base for assembly of complex, deep space mission systems

- International collaboration has been proven effective on ISS and could be improved and expanded for exploration
  - Embrace the International Space Exploration Coordination Group (ISECG) Global Exploration Roadmap (GER)
  - Apply the lessons learned from the International Space Station program and the experiences of the current partnership
  - Strong coordinated support from the associated transportation programs (Shuttle, Soyuz, Arianne, H2B)
  - International partnership with strong political support
  - Adequate funding to accomplish the objective
  - Agreements on hardware/software interface and construction standards

# From NASA's Emerging Space Report 2014

Looking ahead to 2044

"Exploration of the lunar surface was supplemented by privately financed expeditions with NASA partnerships enabling renewed American activities on the lunar surface."

# Questions?