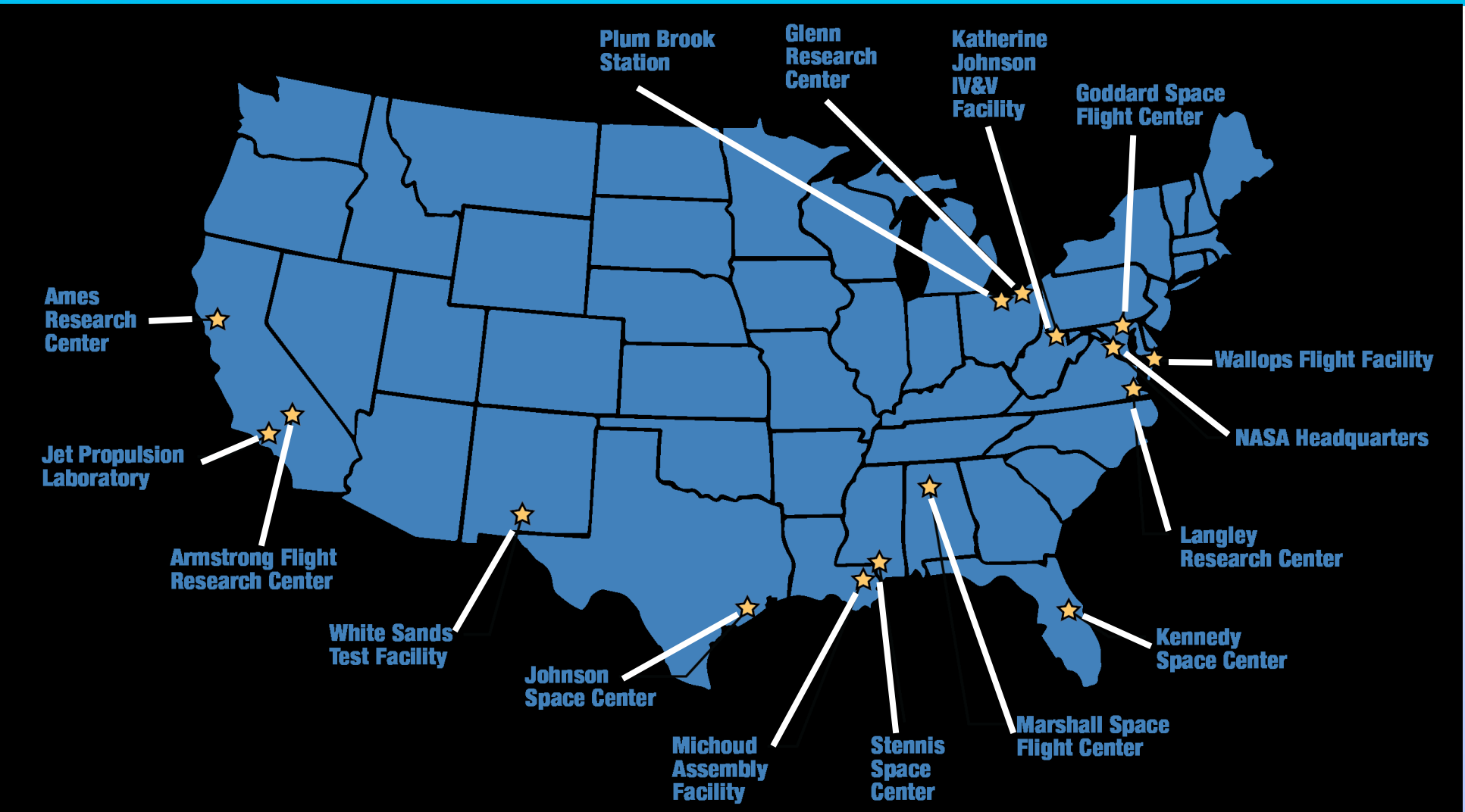
Artemis: NASA's Plan for Sustainable Lunar Exploration (c. 2024)

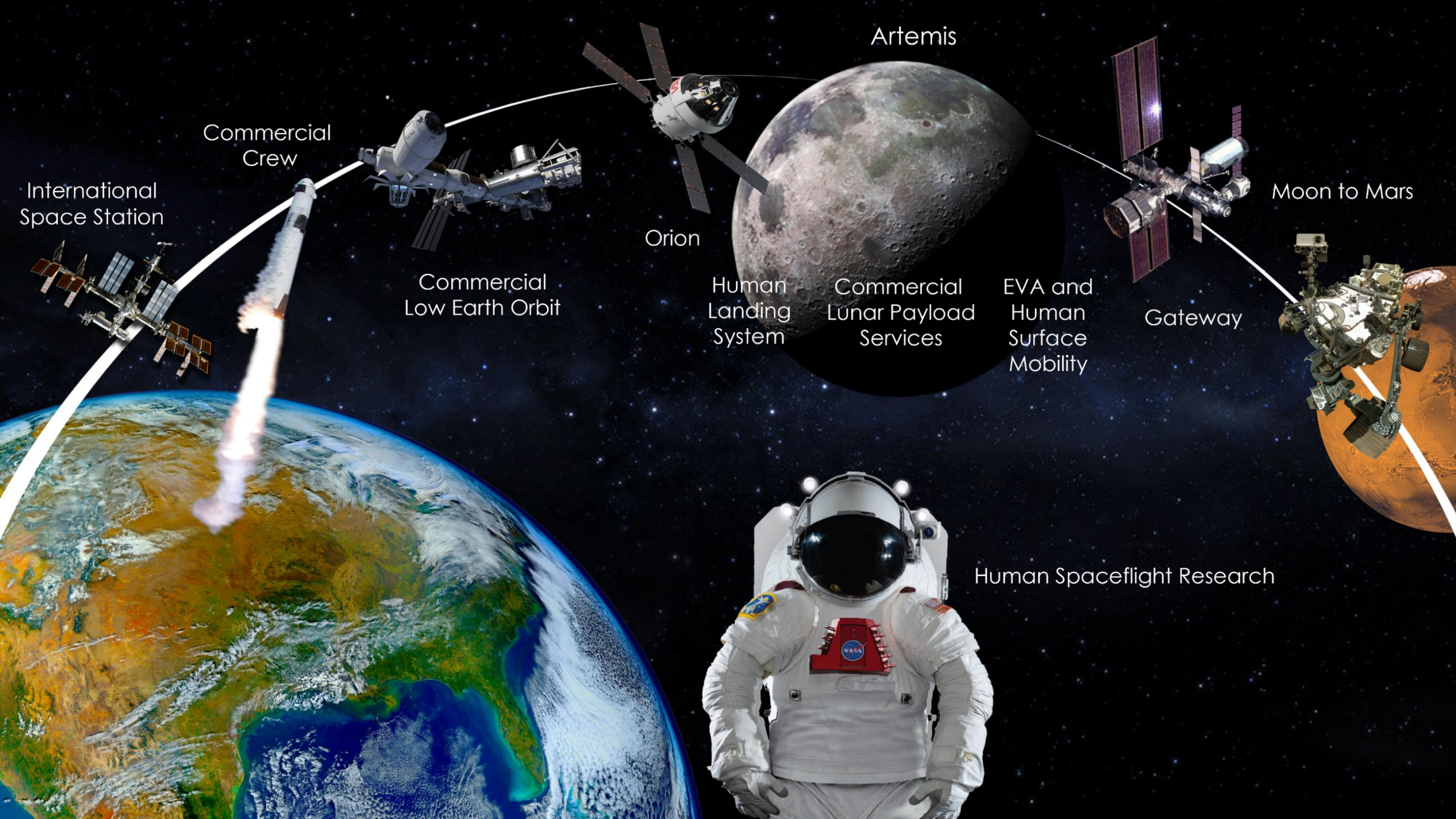
Montgomery Goforth
Assistant Director
Strategic Pursuits and Partnerships
NASA JSC Engineering

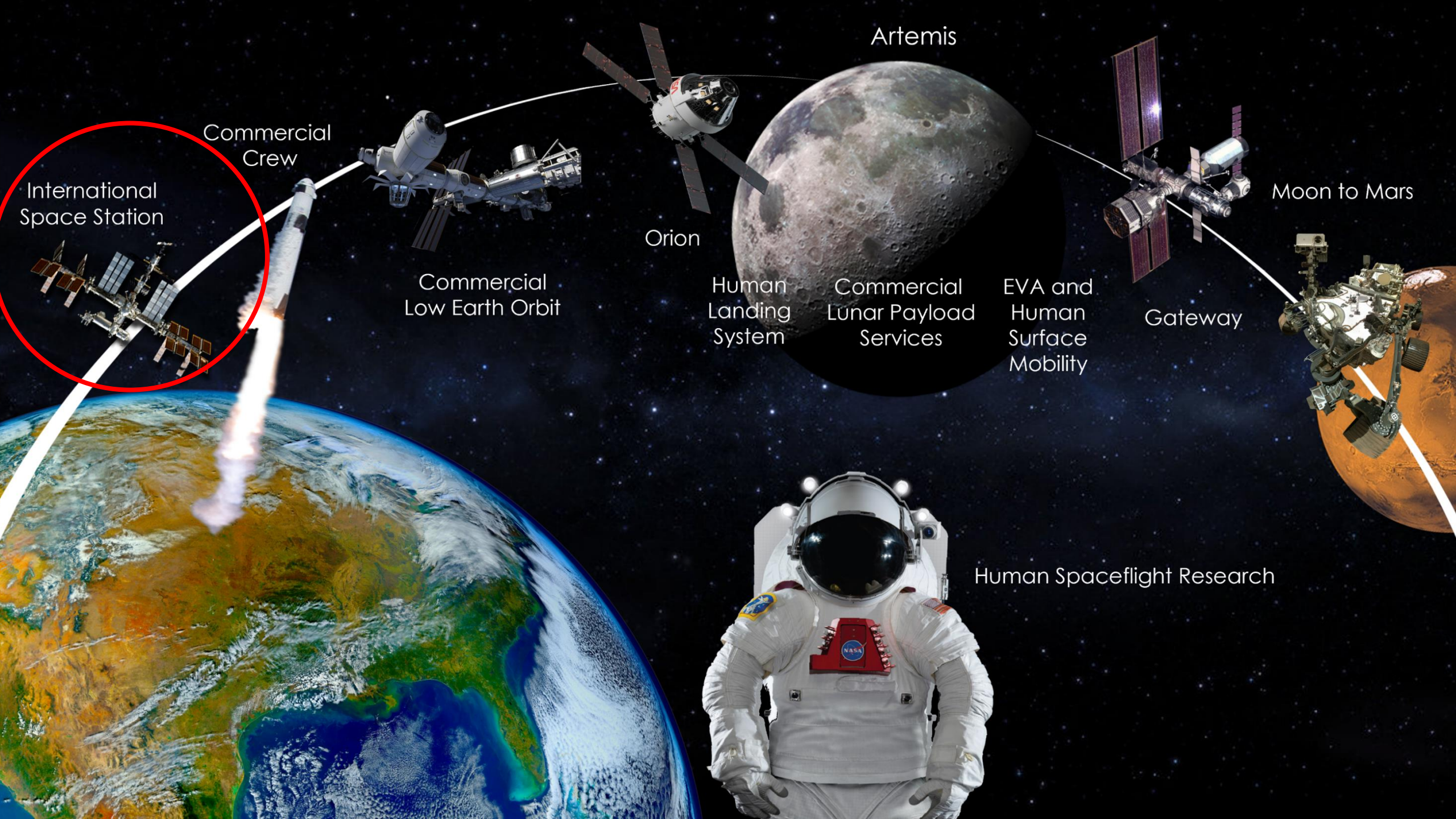
NASA Centers and Mission Directorates



Mission Directorates

- Aeronautics Research
- Science
- Space Operations
- Exploration Systems Development
- Space Technology


Artemis
Commercial Crew
International Space Station
Orion
Commercial Low Earth Orbit
Human Landing System
Commercial Lunar Payload Services
EVA and Human Surface Mobility
Gateway
Moon to Mars
Human Spaceflight Research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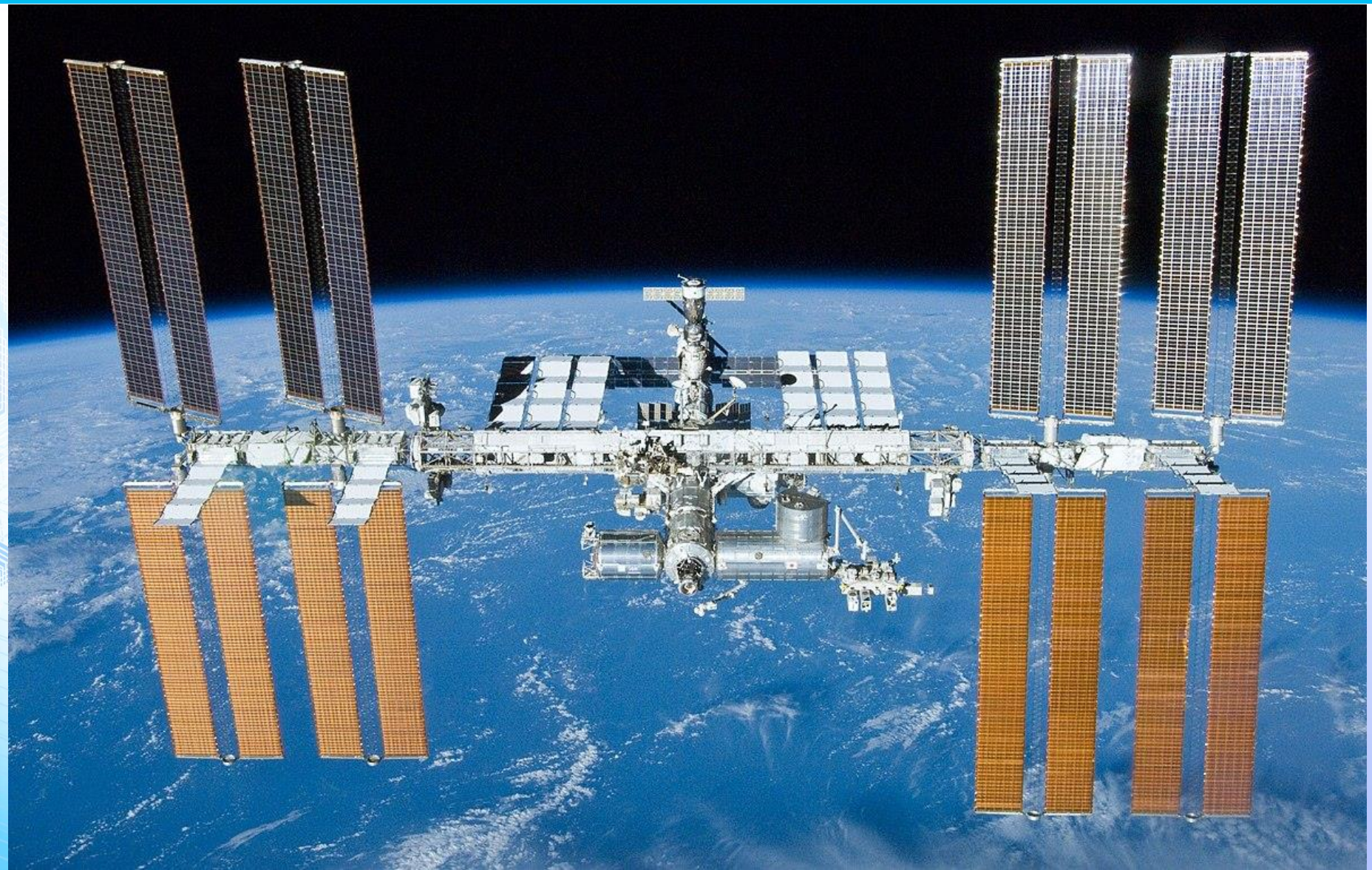
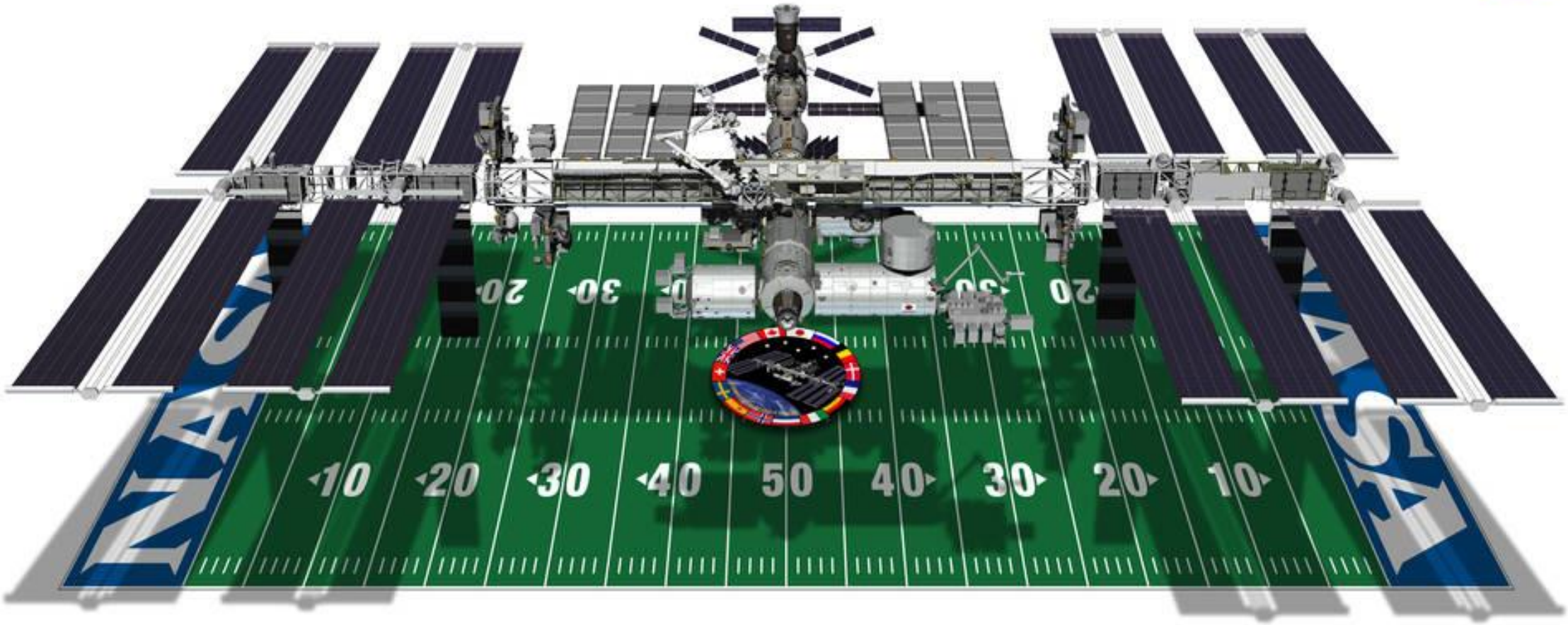
International Space Station (ISS)



National Aeronautics and Space Administration

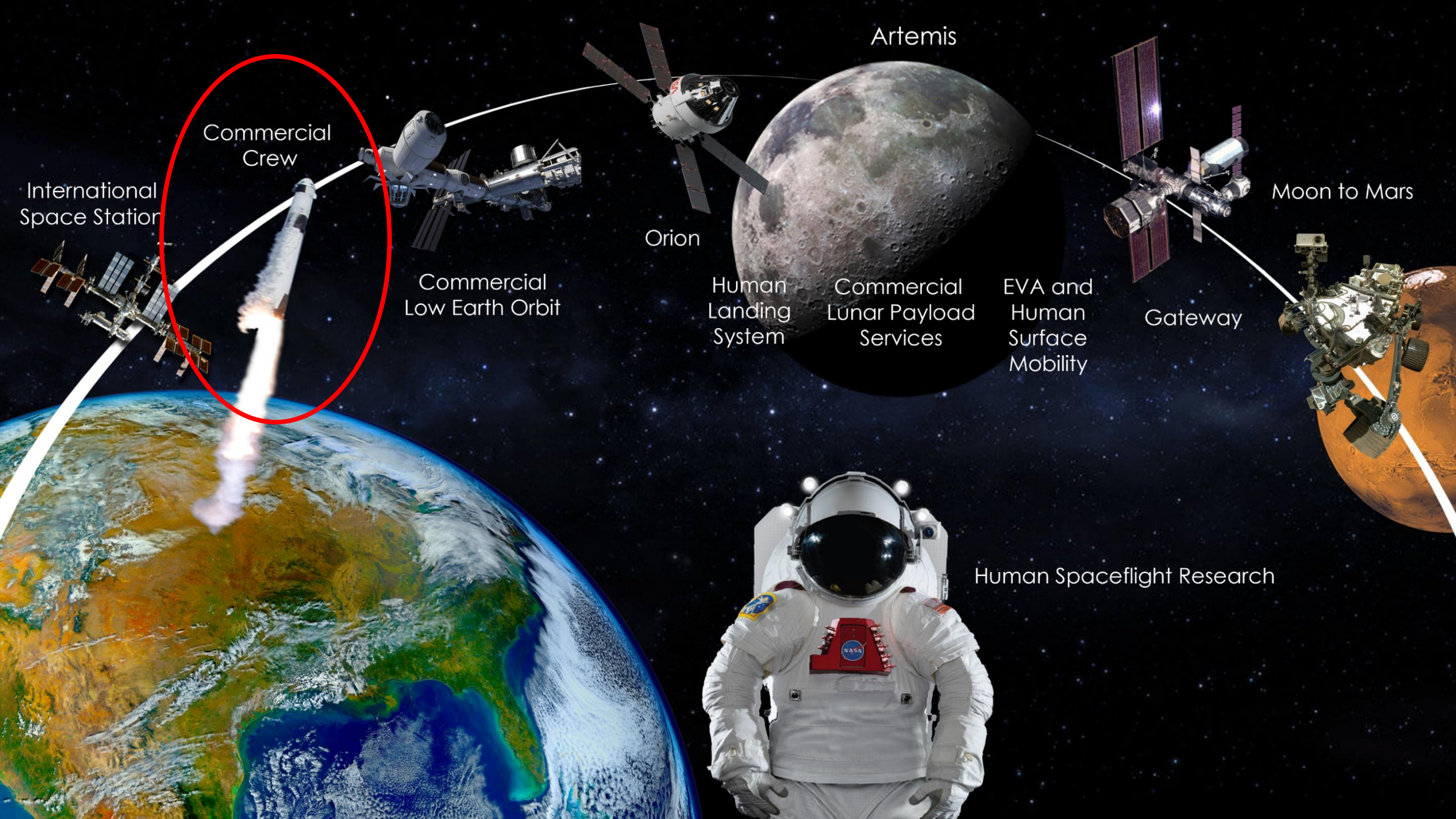


www.nasa.gov

Commercial Resupply Services

SpaceX
Falcon & Dragon

Northrup-
Grumman
Cygnus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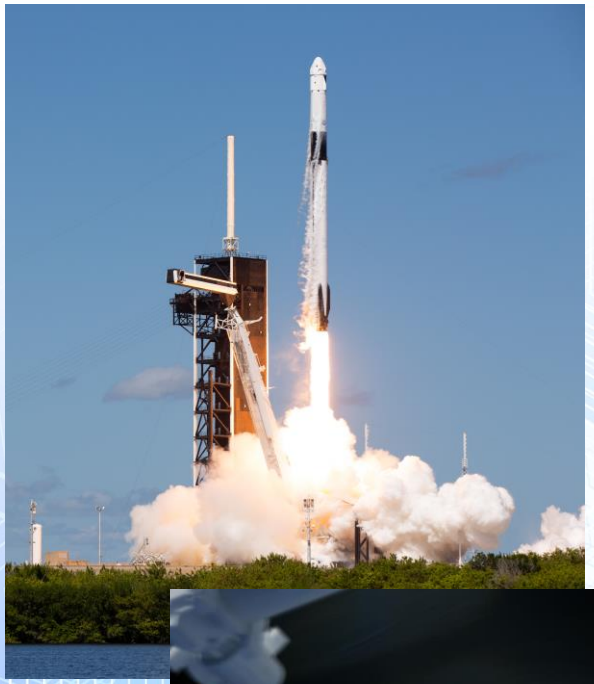
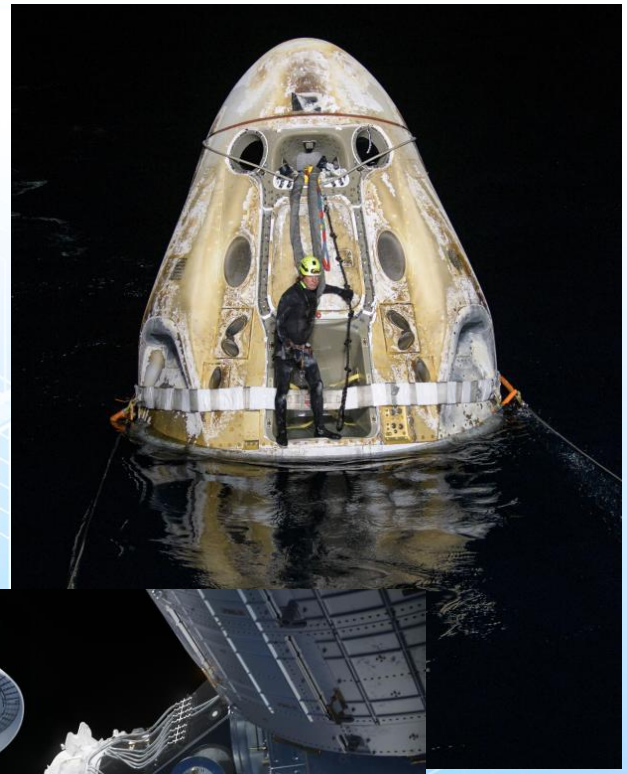
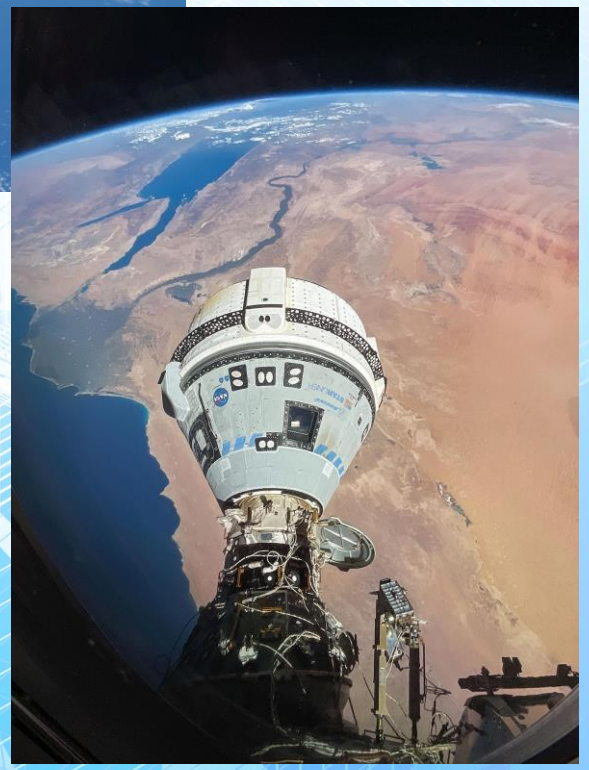
Commercial Crew
SpaceX Crewed Dragon & Deorbit Vehicle

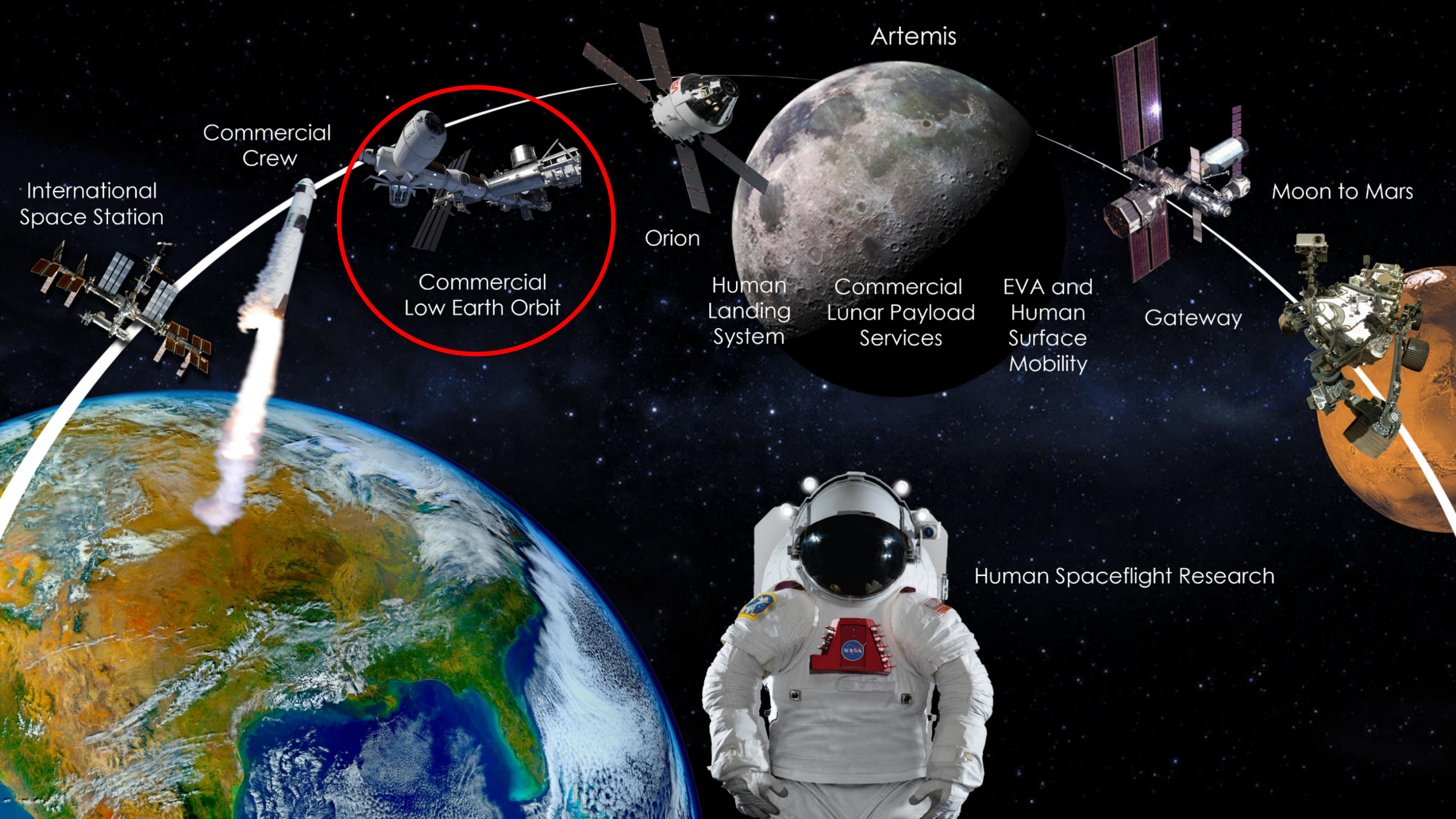




Private Astronaut Missions
“Polaris Dawn”

Commercial Crew
Boeing CST-100 Starliner

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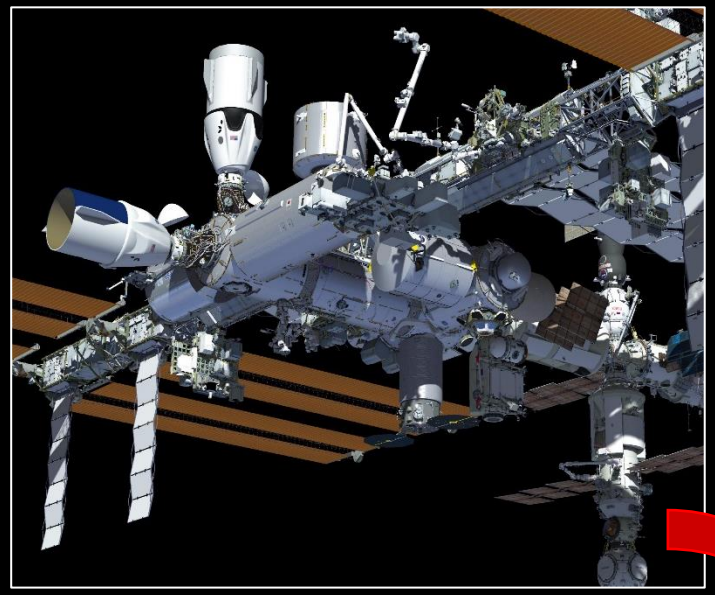
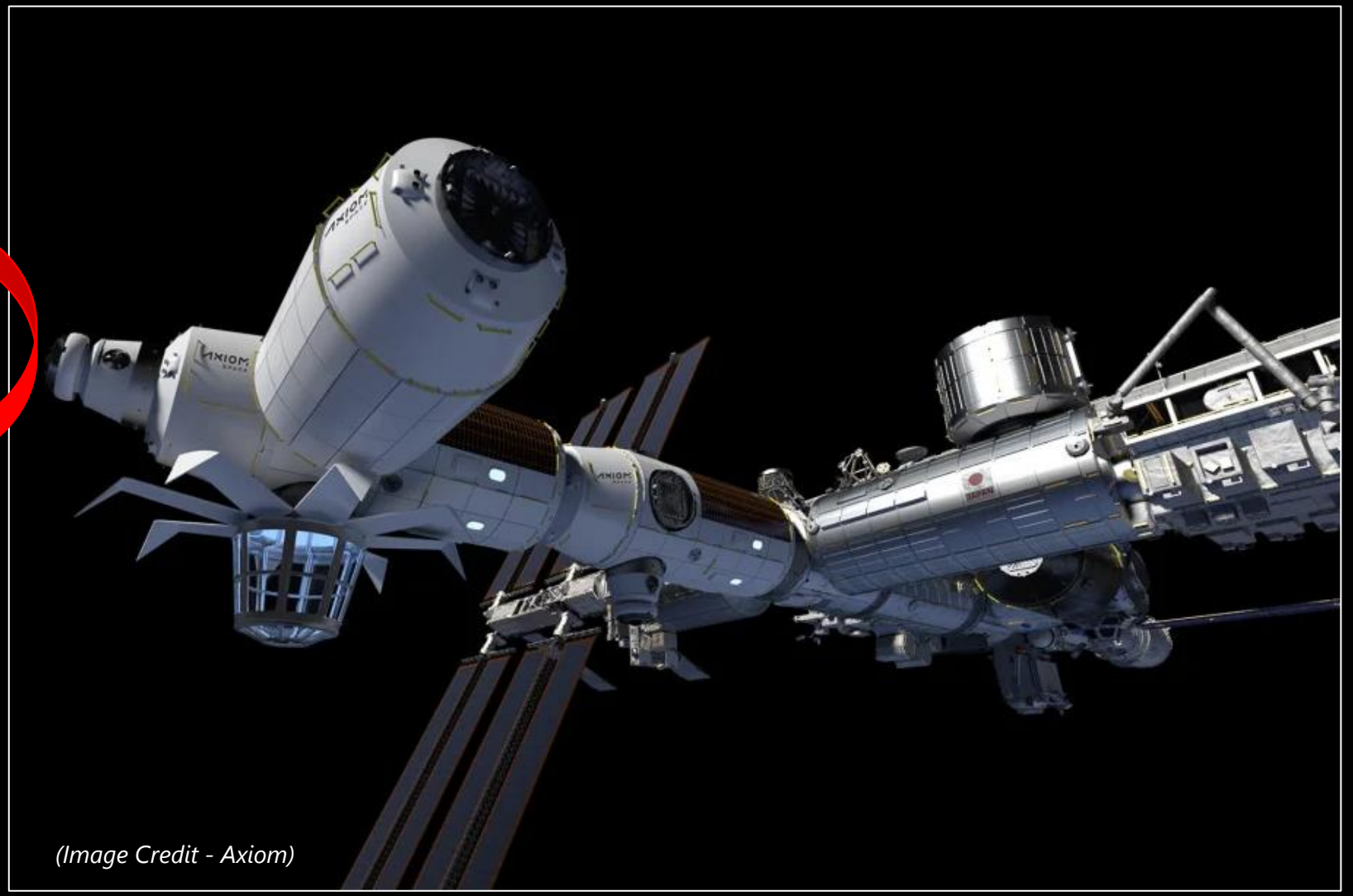
ISS In The Future...

Axiom Commercial Destination Module Concept

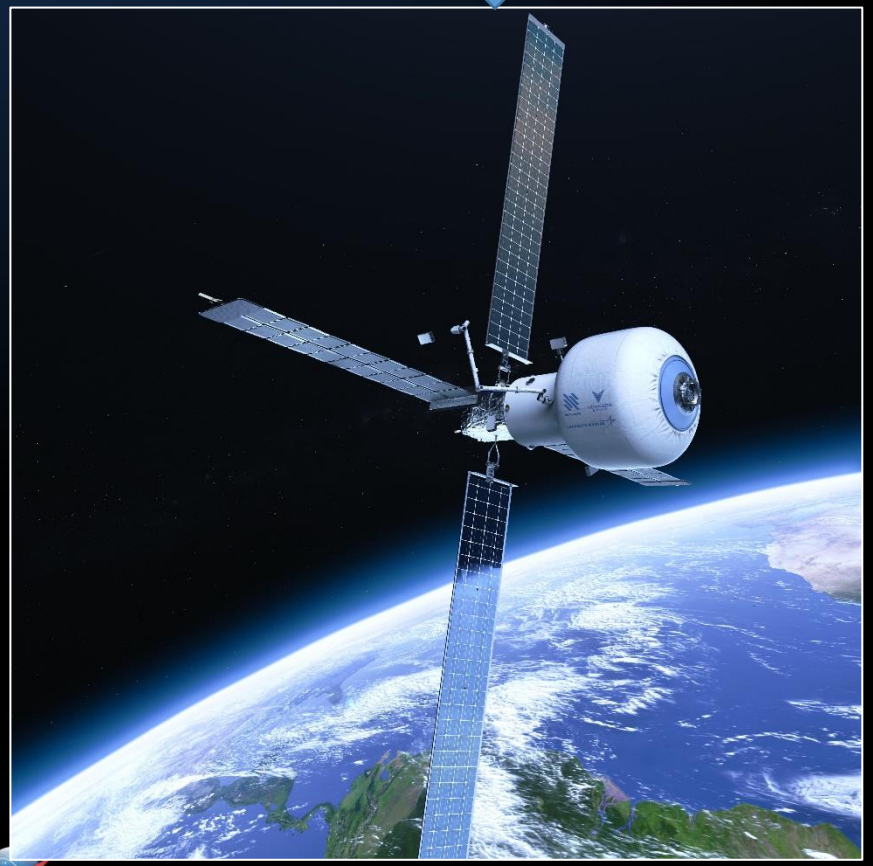




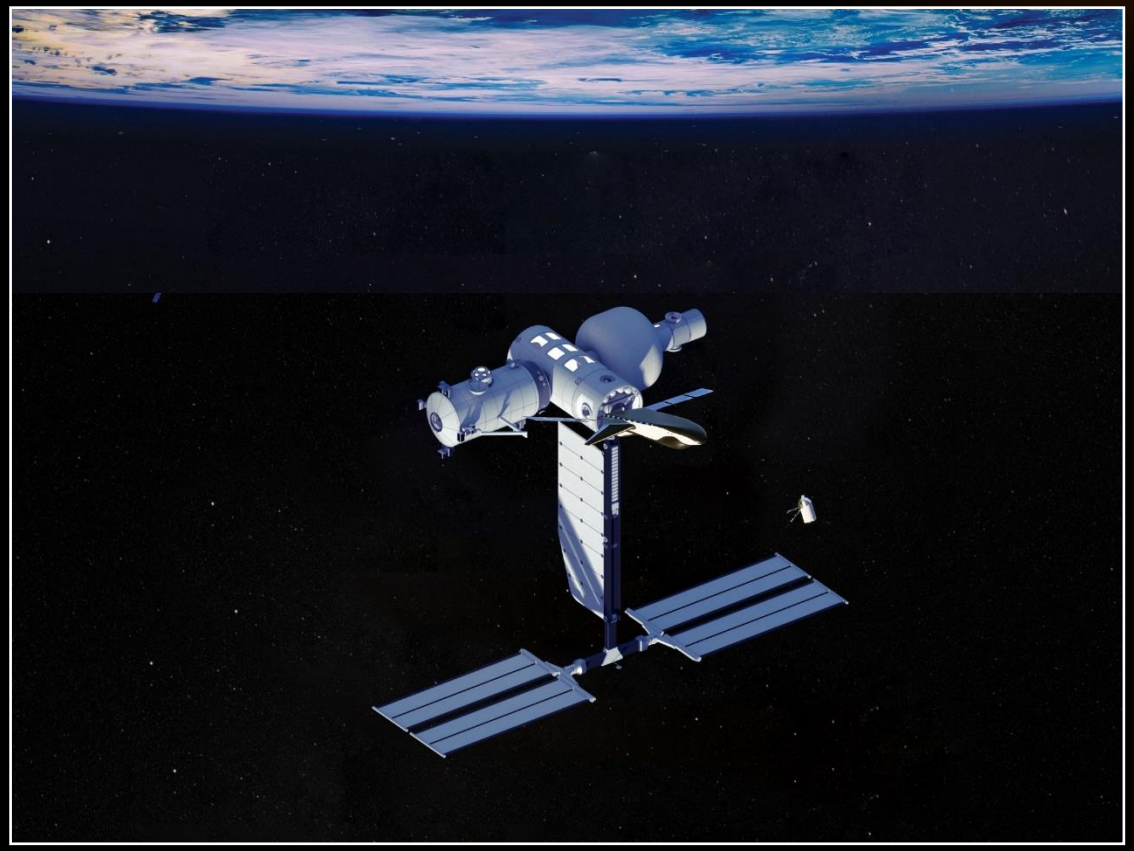
(Image Credit - Axiom)

NASA Commercial Destinations in Space

Nanoracks, Voyager Space, Northrup Grumman and Airbus "Starlab"

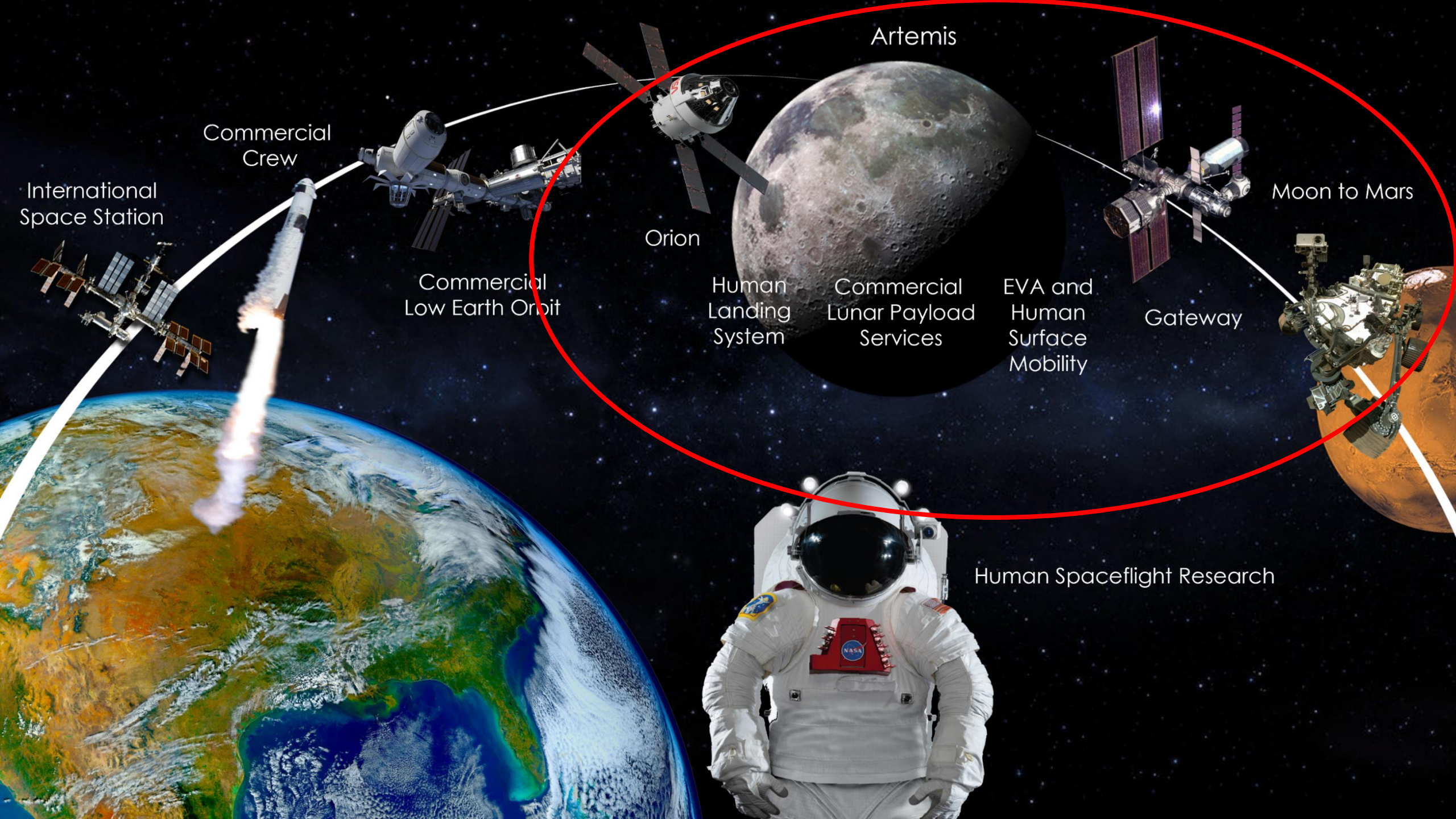


Blue Origin and Sierra Space "Orbital Reef"



Collaborations for Commercial Space Capabilities-2 (CCSC-2)

- Seven companies have been selected for Unfunded Space Act Agreements which are designed to advance commercial space-related efforts through NASA contributions of technical expertise, assessments, lessons learned, technologies, and data.
  - Blue Origin, Kent, Washington
  - Northrop Grumman Systems Corporation, Dulles, Virginia
  - Sierra Space Corporation, Broomfield, Colorado
  - Space Exploration Technologies Corporation, Hawthorne, California
  - Special Aerospace Services, Boulder, Colorado
  - ThinkOrbital Inc., Lafayette, Colorado
  - Vast Space LLC, Long Beach, California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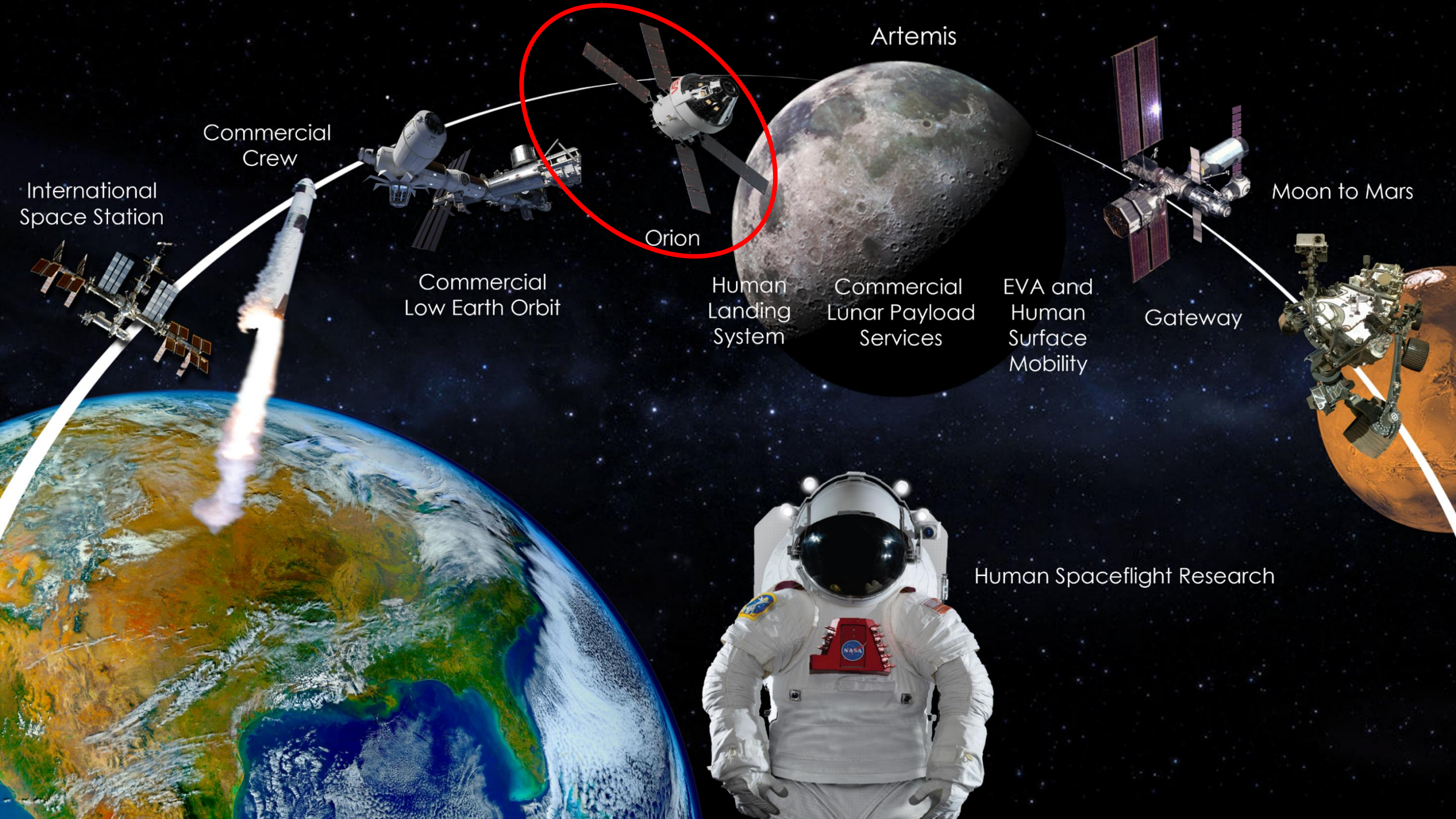
Space Policy Directive-1

"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."

Why the Moon? "Follow the Water"

- Clementine (1994)
  - Found evidence of water ice in the bottom of a permanently shadowed crater at the lunar south pole (60,000-120,000 Cubic Meters)
- Lunar Reconnaissance Orbiter (LRO) (2009-present)
  - Evidence of water ice in other permanently shadowed regions
  - "Confirmed" by observation of LCROSS impact
- Stratospheric Observatory for Infrared Astronomy (SOFIA)
  - Has detected water molecules in sunlit regions
  - Subsequent investigations appear to confirm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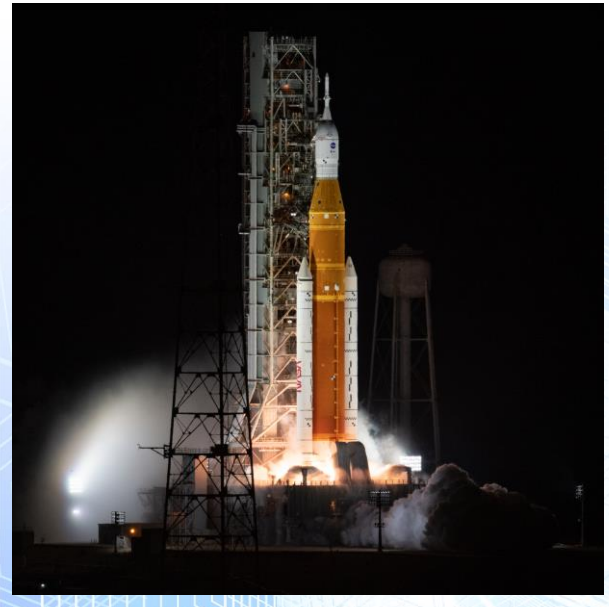
Artemis I Key Elements and Systems

Rocket



Spacecraft

Launchpad

Communications

Orion Testing

Heatshield

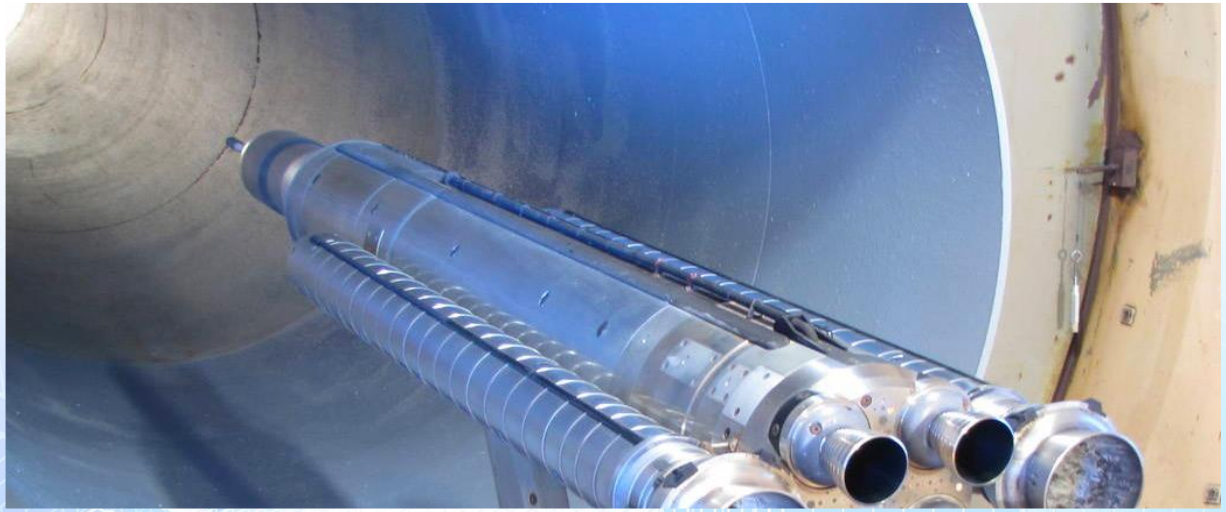
Parachute

Launch Abort System

Integrated CM & SM

Space Launch System (SLS) Testing

Wind Tunnel

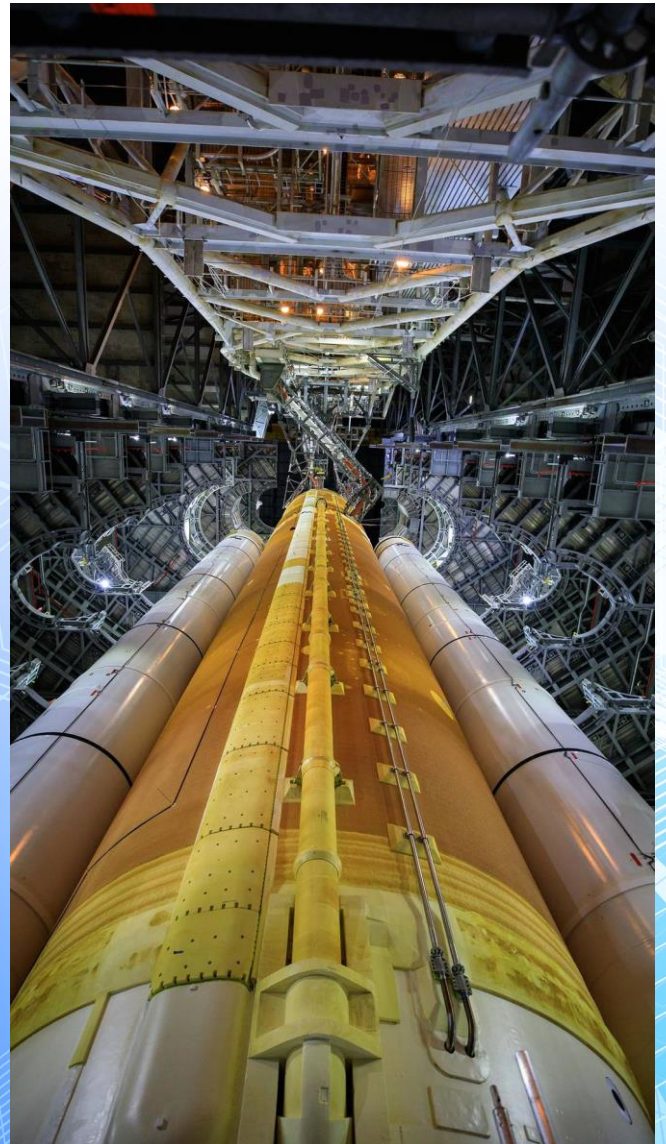


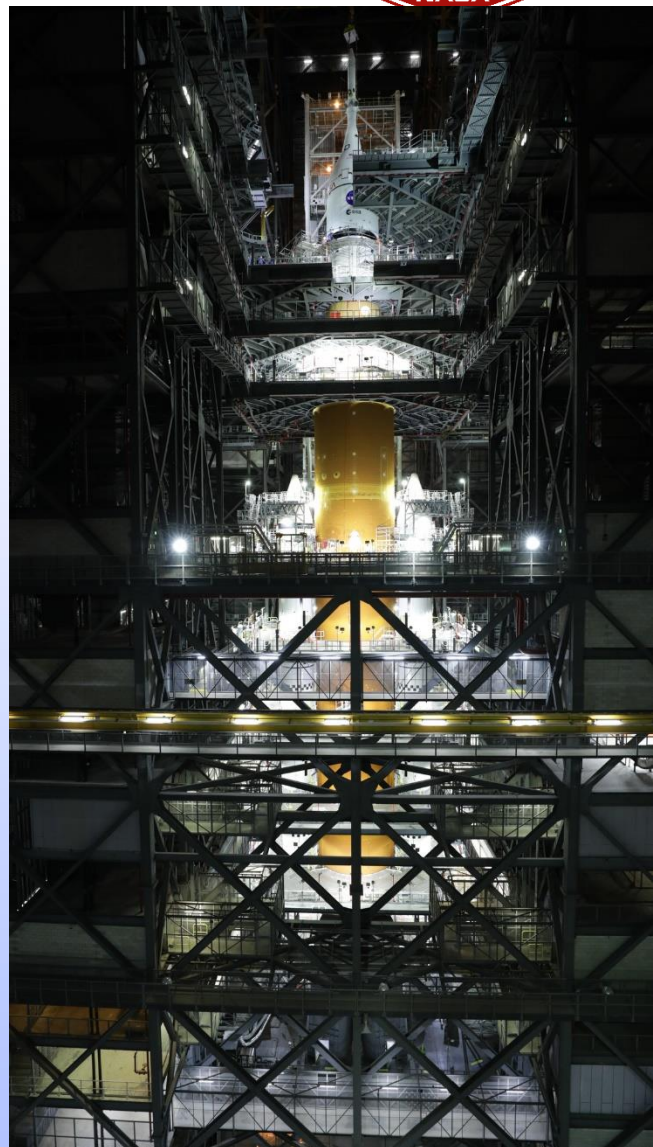
RS-25 Engine

Booster

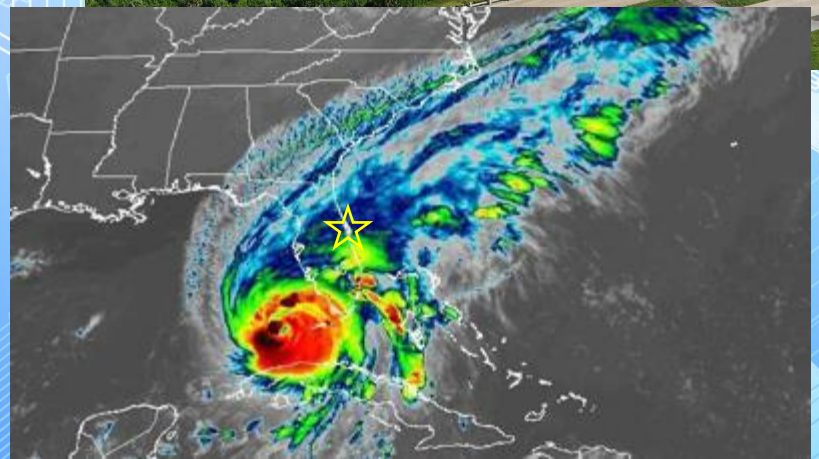
MLV & Pad 39B

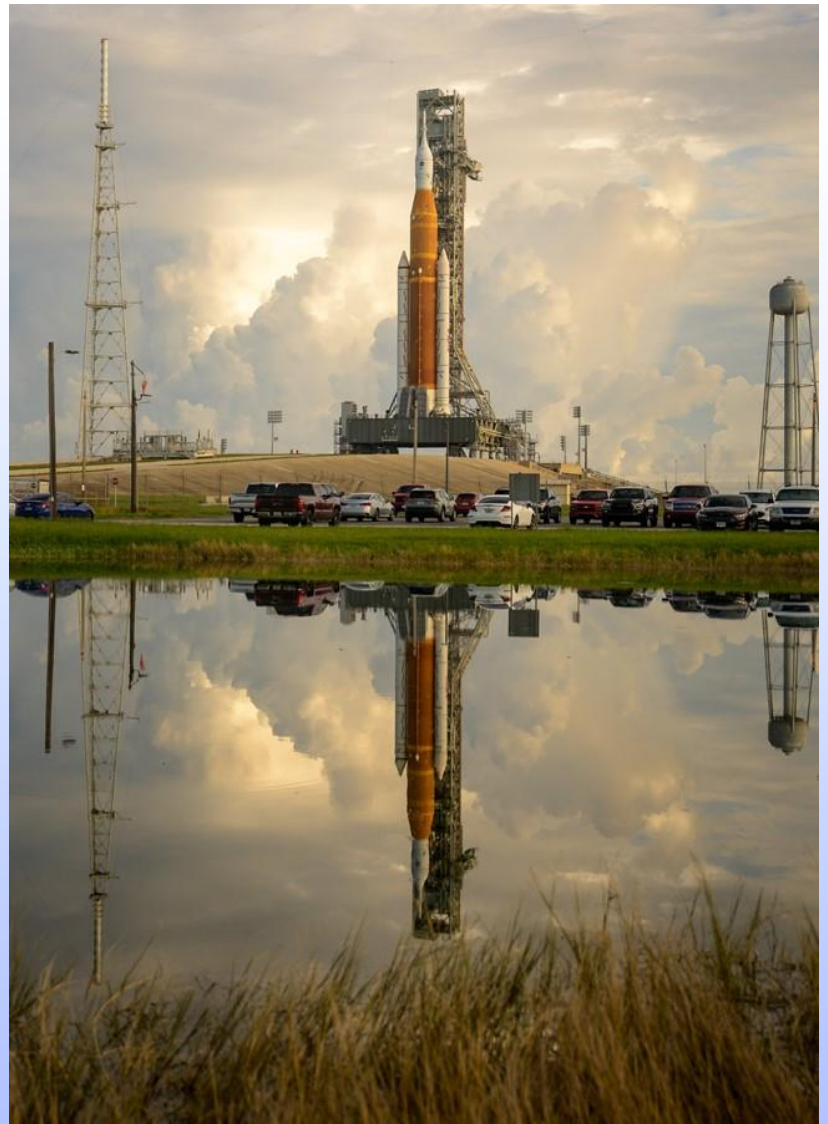
Artemis I: Stacked & Ready

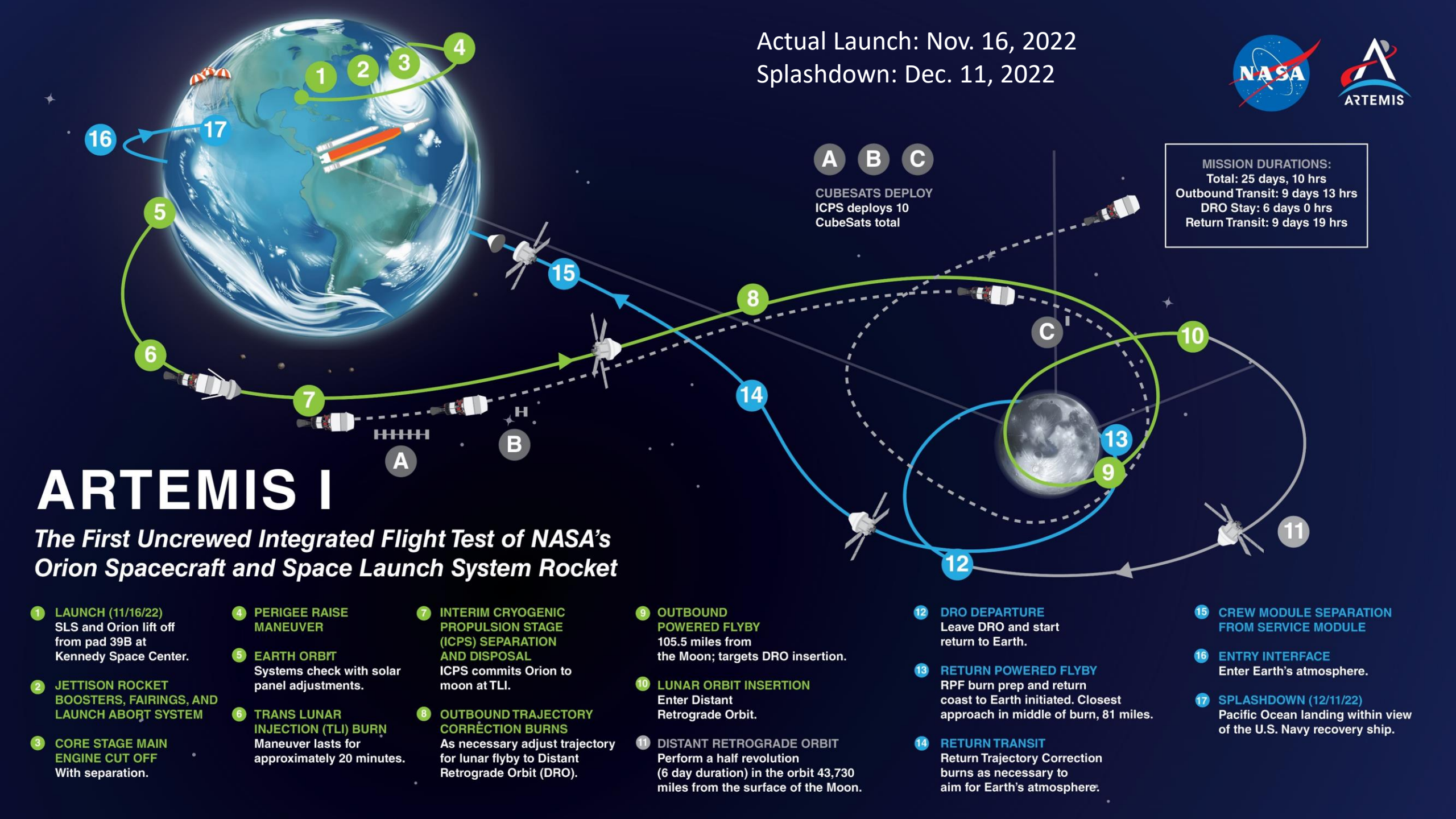




Artemis I: Launch Attempts






Actual Launch: Nov. 16, 2022
Splashdown: Dec. 11, 2022
NASA
ARTEMIS
A B C
CUBESATS DEPLOY
ICPS deploys 10
CubeSats total
MISSION DURATIONS:
Total: 25 days, 10 hrs
Outbound Transit: 9 days 13 hrs
DRO Stay: 6 days 0 hrs
Return Transit: 9 days 19 hrs
ARTEMIS I
The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket
1 LAUNCH (11/16/22)
SLS and Orion lift off from pad 39B at Kennedy Space Center.
2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM
3 CORE STAGE MAIN ENGINE CUT OFF
With separation.
4 PERIGEE RAISE MANEUVER
5 EARTH ORBIT
Systems check with solar panel adjustments.
6 TRANS LUNAR INJECTION (TLI) BURN
Maneuver lasts for approximately 20 minutes.
7 INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL
ICPS commits Orion to moon at TLI.
8 OUTBOUND TRAJECTORY CORRECTION BURNS
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9 OUTBOUND POWERED FLYBY
105.5 miles from the Moon; targets DRO insertion.
10 LUNAR ORBIT INSERTION
Enter Distant Retrograde Orbit.
11 DISTANT RETROGRADE ORBIT
Perform a half revolution (6 day duration) in the orbit 43,730 miles from the surface of the Moon.
12 DRO DEPARTURE
Leave DRO and start return to Earth.
13 RETURN POWERED FLYBY
RPF burn prep and return coast to Earth initiated. Closest approach in middle of burn, 81 miles.
14 RETURN TRANSIT
Return Trajectory Correction burns as necessary to aim for Earth's atmosphere.
15 CREW MODULE SEPARATION FROM SERVICE MODULE
16 ENTRY INTERFACE
Enter Earth's atmosphere.
17 SPLASHDOWN (12/11/22)
Pacific Ocean landing within view of the U.S. Navy recovery ship.

Artemis I: Results

- Operational Telemetry Data monitored in real-time. Additional Flight Test Data recorded and retrieved after splashdown for detailed analysis
  - Almost everything worked as good or better than expected
- Some Avionics components have been removed from the Artemis I Orion and integrated into the Artemis II Orion.
- Examples of planned Exceptions:
  - Orion ECLSS
  - Orion Crew Interfaces
  - Launchpad Emergency Egress System
  - Open water recovery of the crew

Bottom Line: We had a good test flight, and SLS, Orion, and Exploration Ground Systems will be ready for Artemis II

- A few anomalies
  - Fuel leakage problems before launch (atomic hydrogen is tricky – small and cold)
  - More damage than expected to the Mobile Launcher
  - Some latching current limiters (~circuit breakers) switched open without commanding several times throughout the mission.
  - While within margins, the heat-shield did not perform as expected.
    - We believe we now understand the cause, and can fly Artemis II safely

Planned Launch: September 2025
Planned Duration: 10 days

ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

1. **LAUNCH** Astronauts lift off from pad 39B at Kennedy Space Center.
2. **JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF** With separation.
4. **PERIGEE RAISE MANEUVER**
5. **APOGEE RAISE BURN TO HIGH EARTH ORBIT** Begin 23.5 hour checkout of spacecraft.
6. **ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO** Plus manual handling qualities assessment for up to 2 hours.
7. **ORION UPPER STAGE SEPARATION (USS) BURN** Begins high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.
8. **PERIGEE RAISE BURN**
9. **TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE** Lunar free return trajectory initiated with European service module.
10. **OUTBOUND TRANSIT TO MOON** Outbound Trajectory Correction (OTC) burns as necessary for Lunar free return trajectory; travel time approximately 4 days.
11. **LUNAR FLYBY** 6,479 miles / 10,427 km (mean) lunar farside altitude.
12. **TRANS-EARTH RETURN** Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
13. **CREW MODULE SEPARATION FROM SERVICE MODULE**
14. **ENTRY INTERFACE (EI)** Enter Earth's atmosphere.
15. **SPLASHDOWN** Ship recovers astronauts and capsule.

- Commander Reid Wiseman
- Pilot Victor Glover
- Mission Specialist Christina Hammock Koch
- Mission Specialist Jeremy Hansen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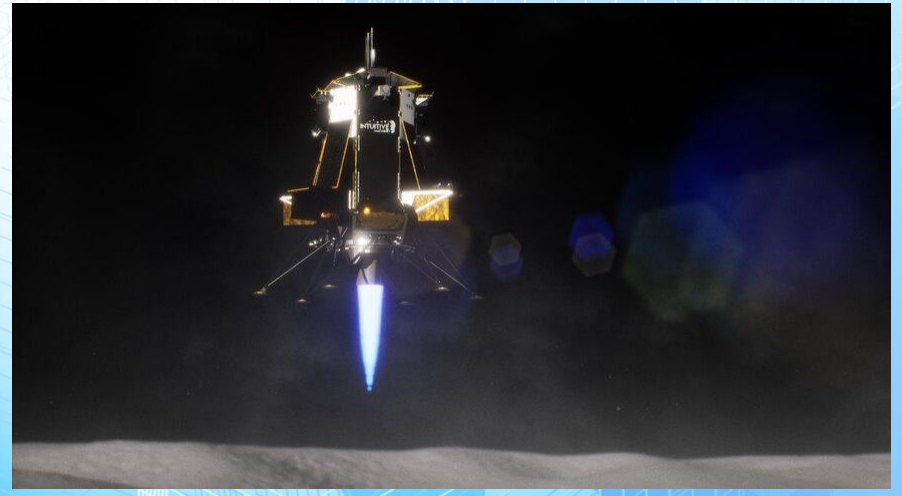
CLPS: Past Missions

Astrobotic Peregrine

Astrobotic Peregrine Mission One
Launched: 8 Jan 2024
Did not land on Moon
Re-Entered: 18 Jan 2024

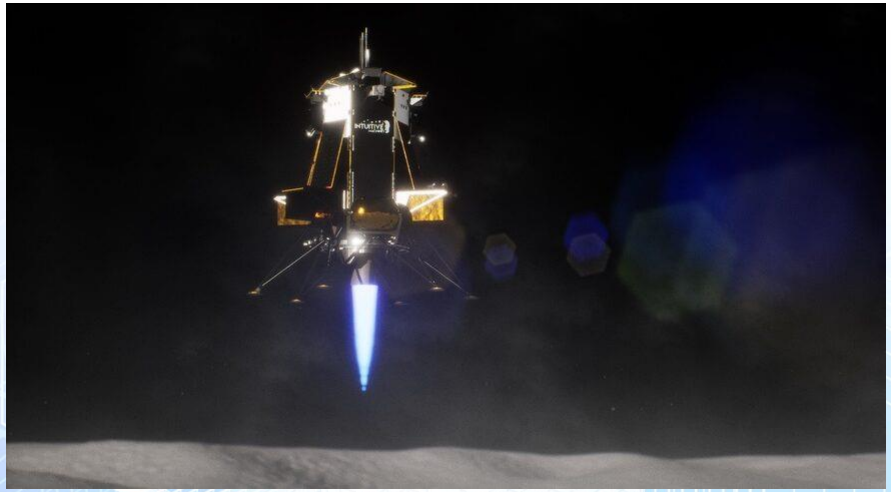
IM Nova-C

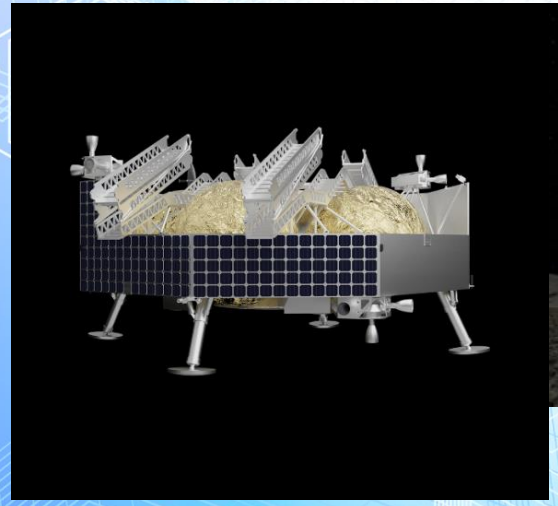


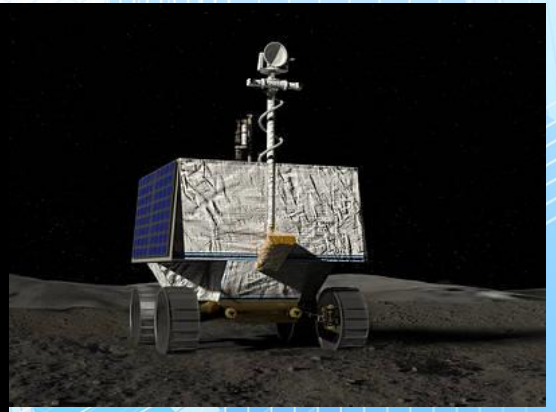
Intuitive Machines IM-1
“Odysseus”
Launched: 15 Feb 2024
Landed: 22 Feb 2024

CLPS: Planned Missions

IM Nova-C: 2024, 2025



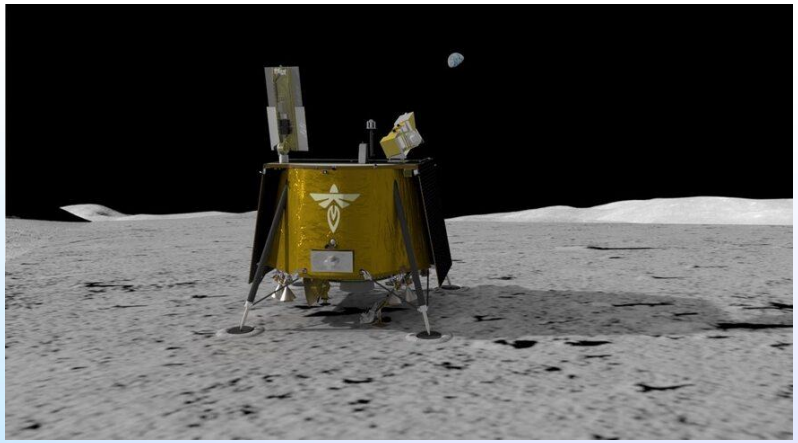


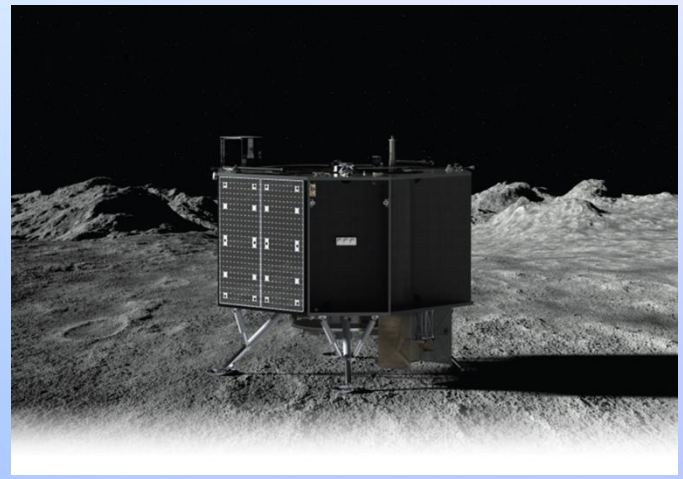


~~NASA VIPER: 2024 ??~~

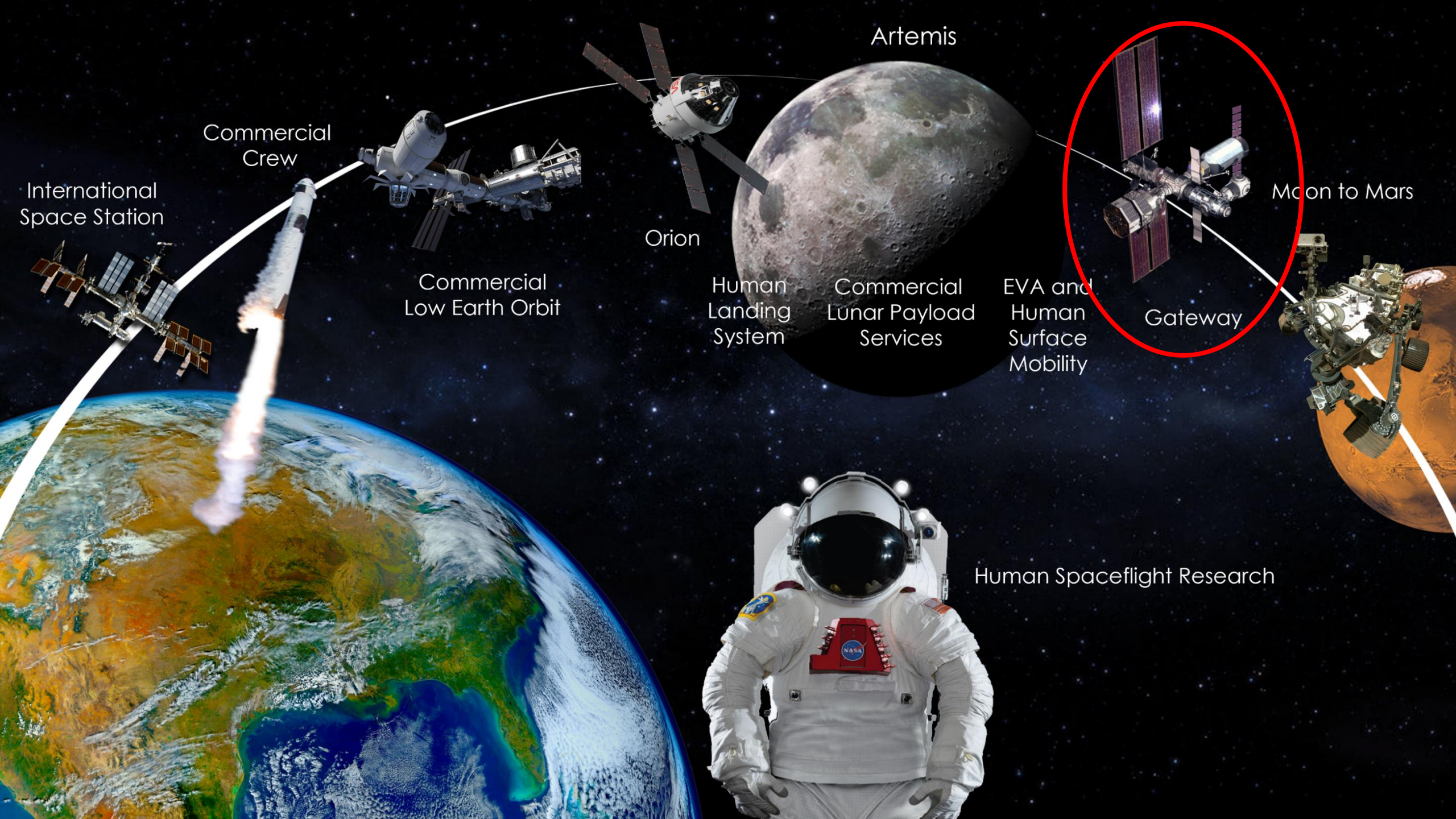
Astrobotic Griffin: NET Fall 2025

Firefly Blue Ghost: 2024, 2026





Draper SERIES-2: 2025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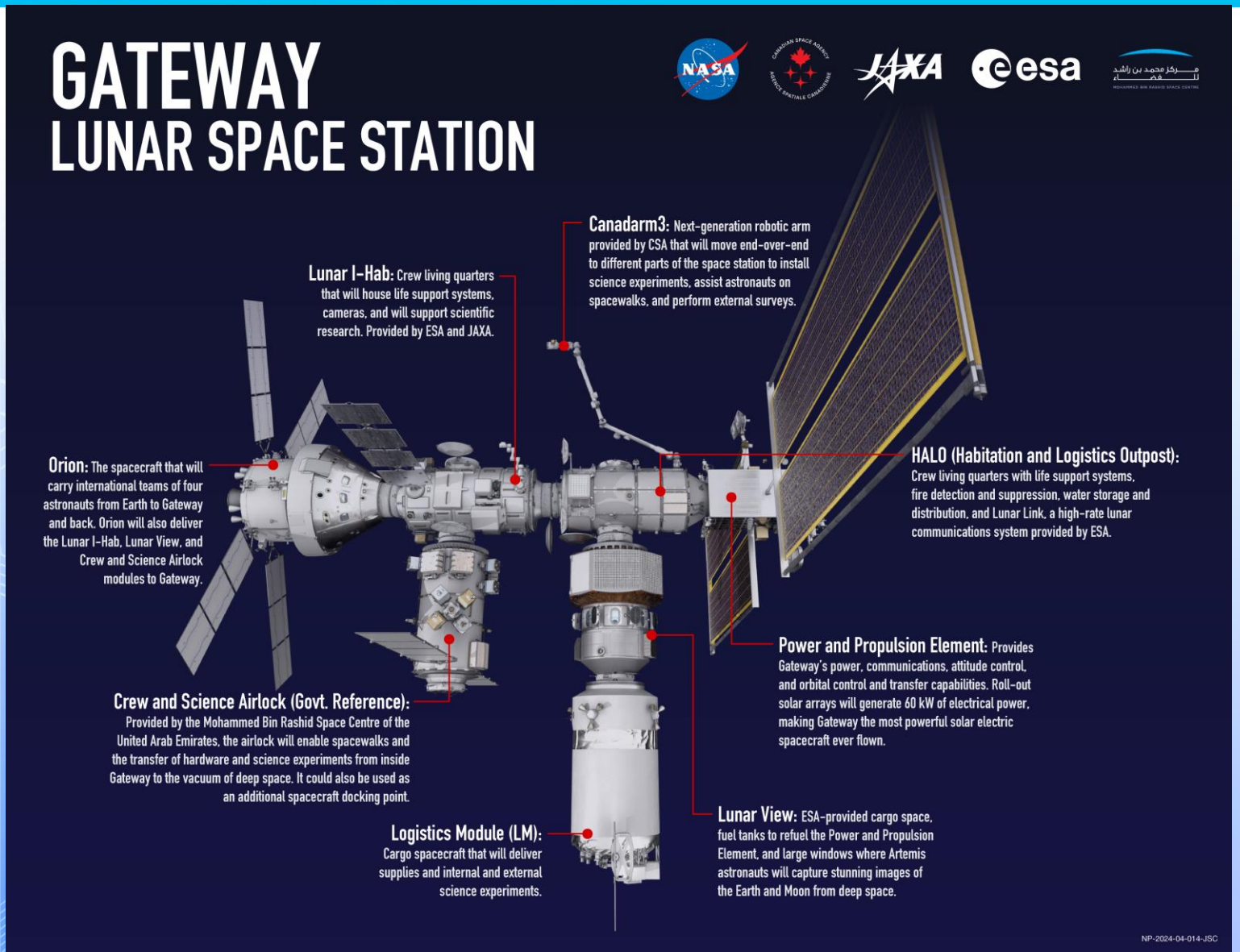
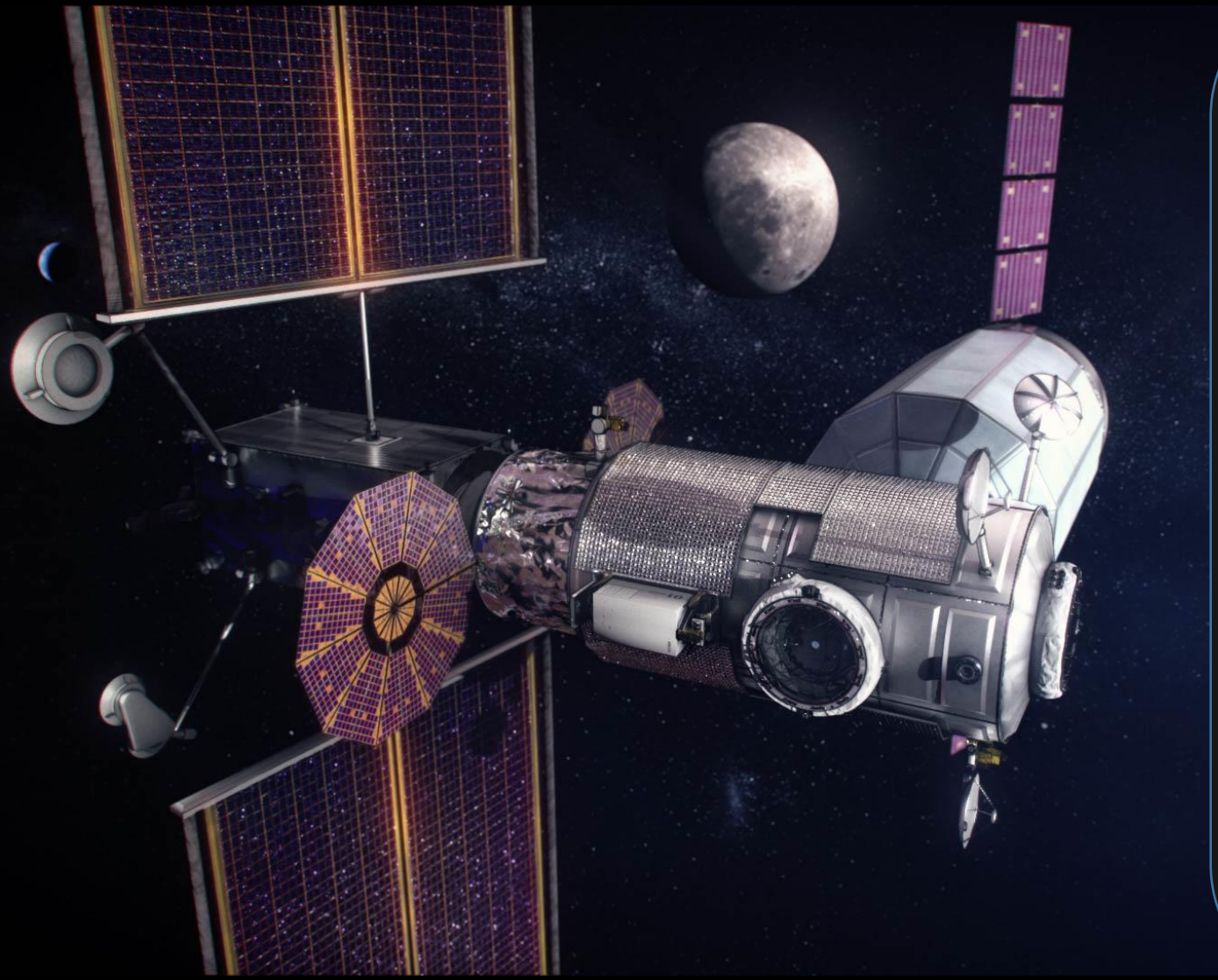
Gateway Space Station Overview



- PPE and HALO are to be launched aboard a Falcon Heavy in 2027
  - Will take ~9 months to get to Lunar Orbit
- Other elements will be added using Orion/SLS
  - Artemis IV: Habitat (ESA/JAXA)
  - Artemis V: Refueling Module (ESA)
  - Artemis VI: Airlock (UAE)
  - Artemis VII: Logistics
  - TBD (NET 2029): Canadaarm3

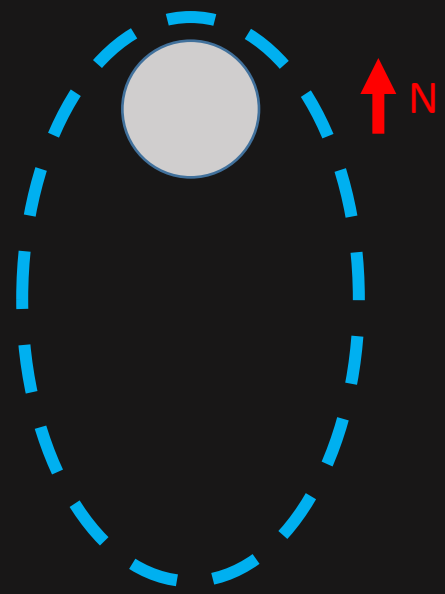
Gateway's Near-Rectilinear Halo Orbit



NRHO as viewed from Earth

Surface Operations

Access



Environment

Communications

Science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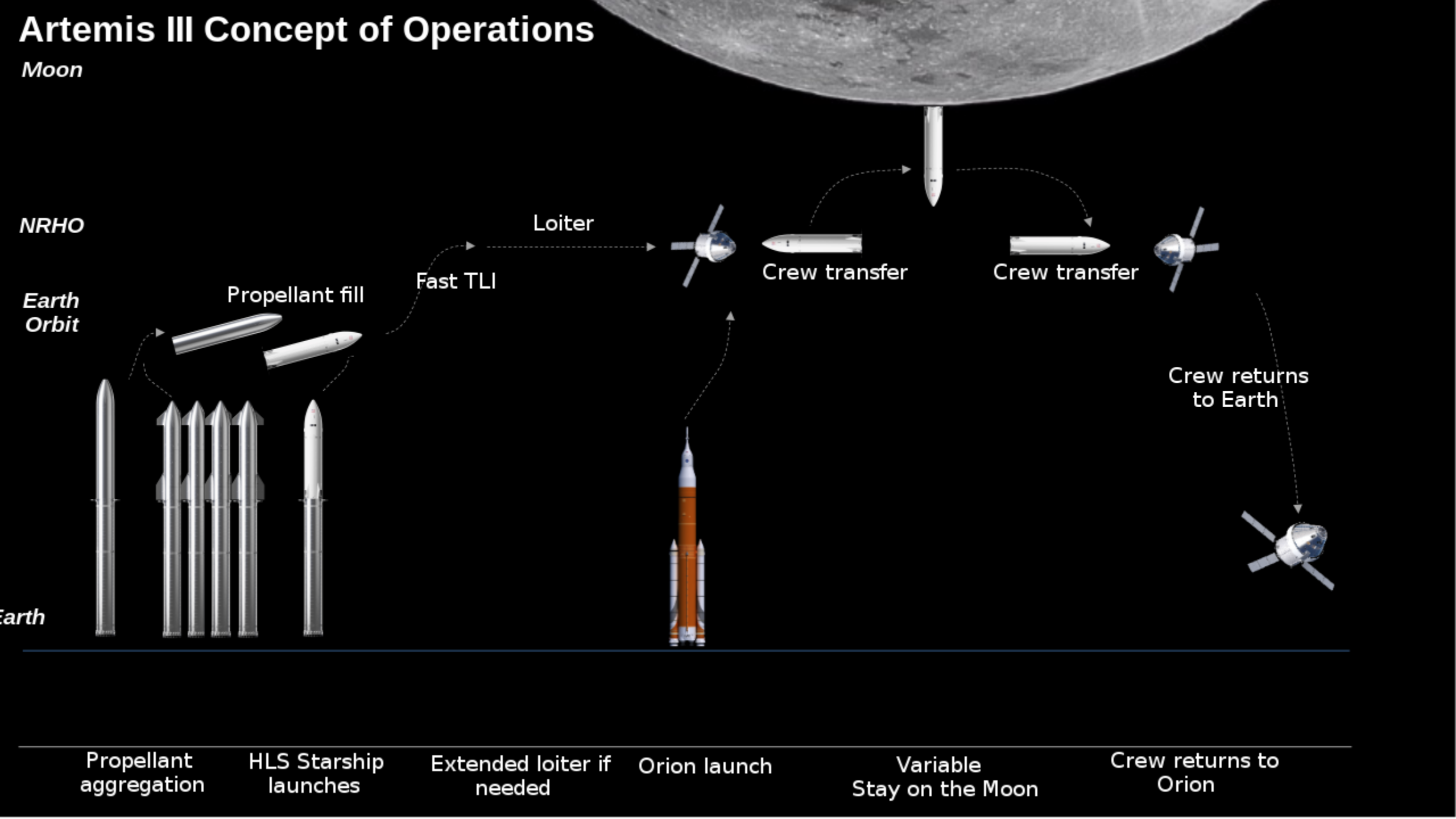
Space X Starship HLS: The next Human Lunar Lander

Space X Starship Test Flights

Artemis III Concept of Operations

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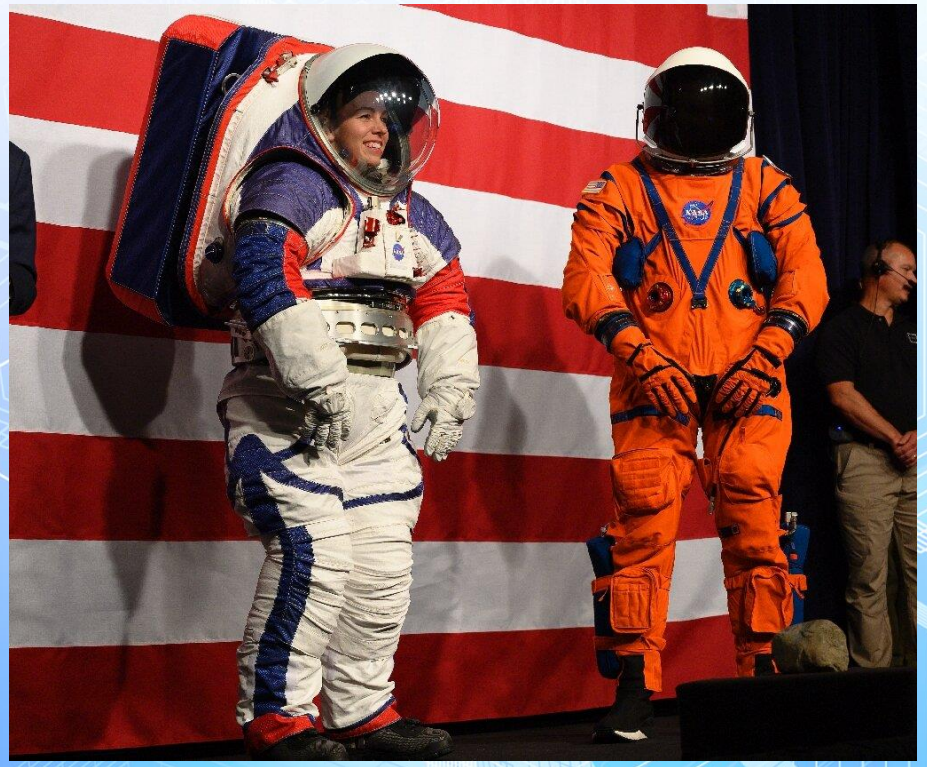
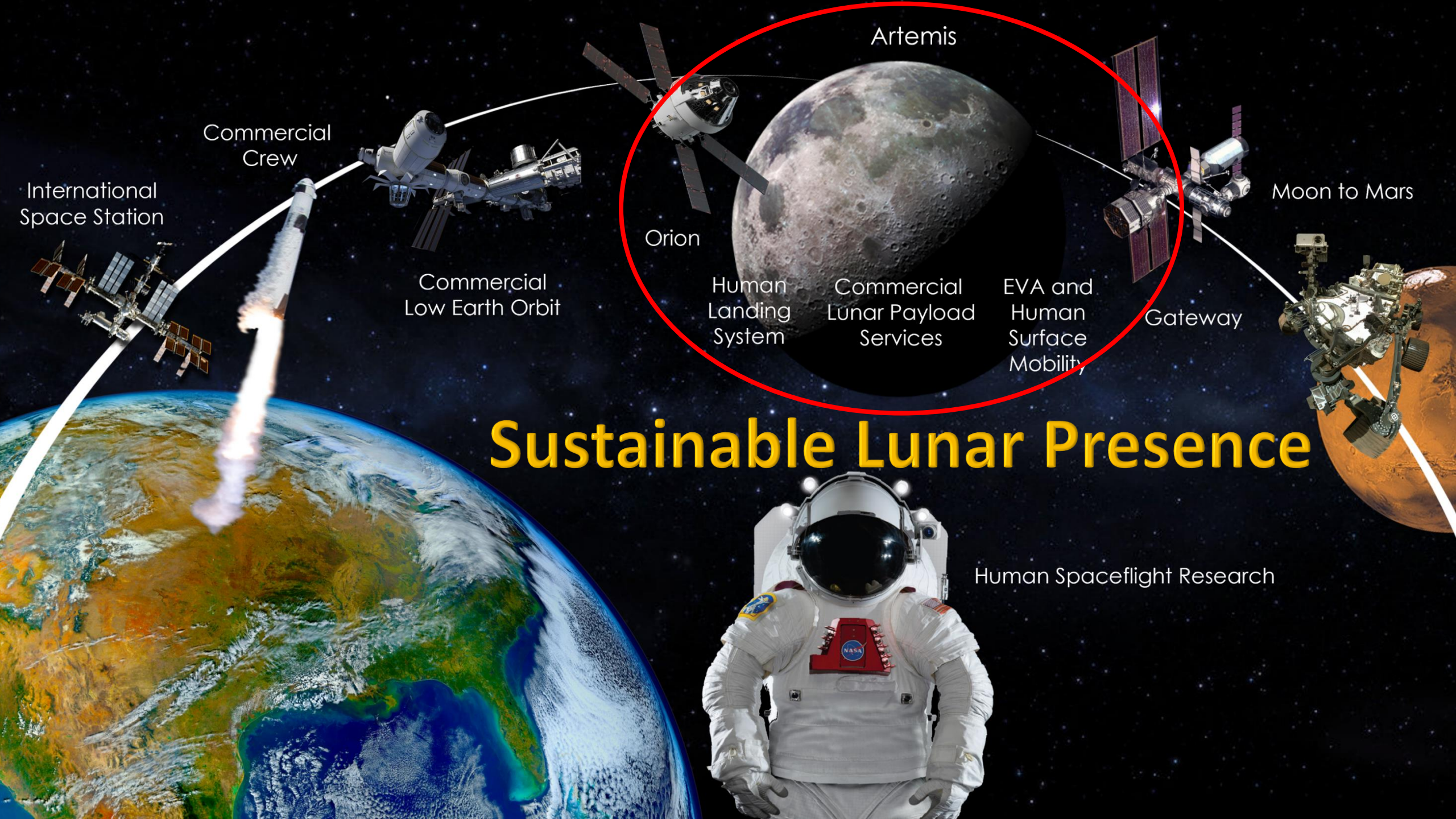
Exploration Extravehicular Activity Services (xEVAS)

NASA xEMU (precursor)



Collins

Axiom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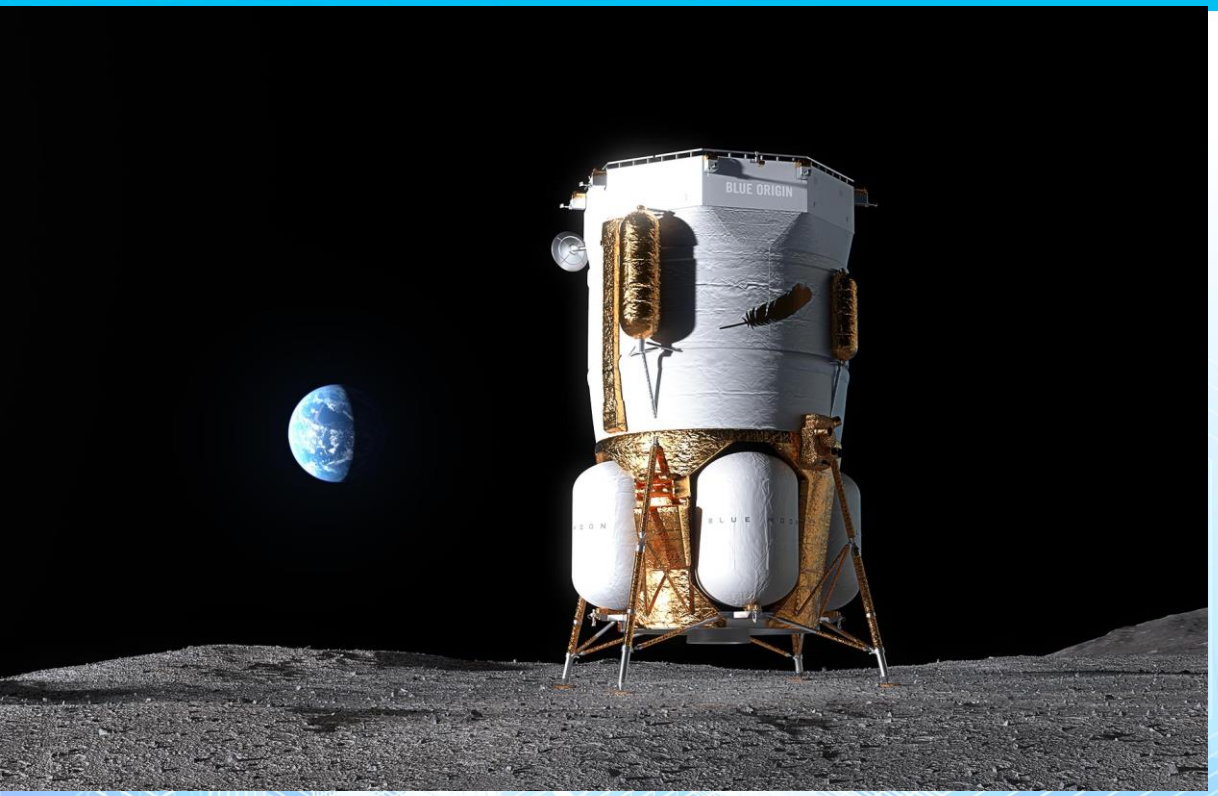
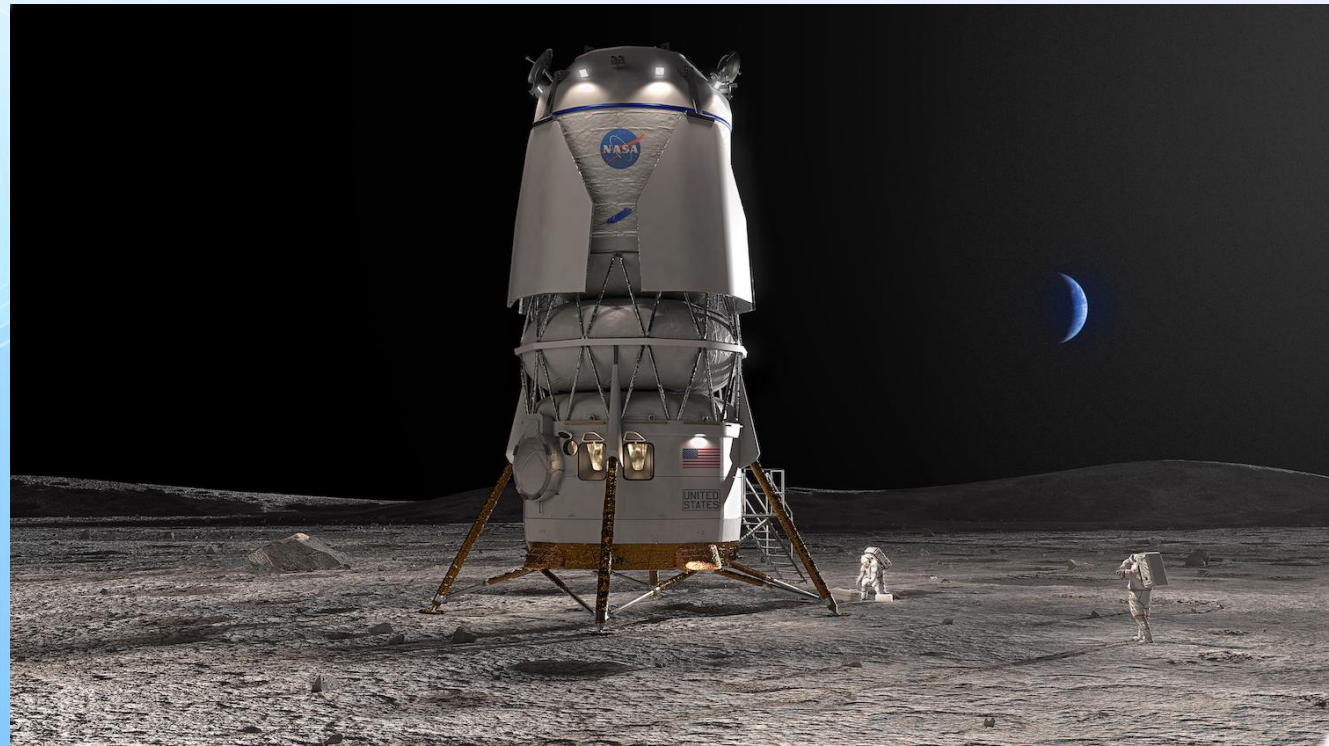
Blue Origin: Blue Moon



Mk-1: Cargo Lander

Human Lander



ARTEMIS III → V

Landing on the Moon

1 LAUNCH
SLS and Orion lift off from Kennedy Space Center.

2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

3 CORE STAGE MAIN ENGINE CUT OFF
With separation.

4 ENTER EARTH ORBIT
Perform the perigee raise maneuver. Systems check and solar panel adjustments.

5 TRANS LUNAR INJECTION BURN
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.

6 ORION OUTBOUND TRANSIT TO MOON
Requires several outbound trajectory burns.

7 ORION OUTBOUND POWERED FLYBY
60 nmi from the Moon.

8 NHRO INSERTION BURN
Orion performs burn to establish rendezvous point and executes rendezvous and docking.

9 LUNAR LANDING PREPARATION
Crew activates lander and prepares for departure.

10 LANDER UNDOCKING AND SEPARATION

11 LANDER ENTERS LOW LUNAR ORBIT
Descends to lunar touchdown.

12 LUNAR SURFACE EXPLORATION
Astronauts conduct week long surface mission and extra-vehicular activities.

13 ORION REMAINS IN NHRO ORBIT
During lunar surface mission.

14 LANDER ASCENDS TO LOW LUNAR ORBIT

15 LANDER PERFORMS RENDEZVOUS AND DOCKING

16 CREW RETURNS IN ORION
Orion undocks, performs orbit departure burn.

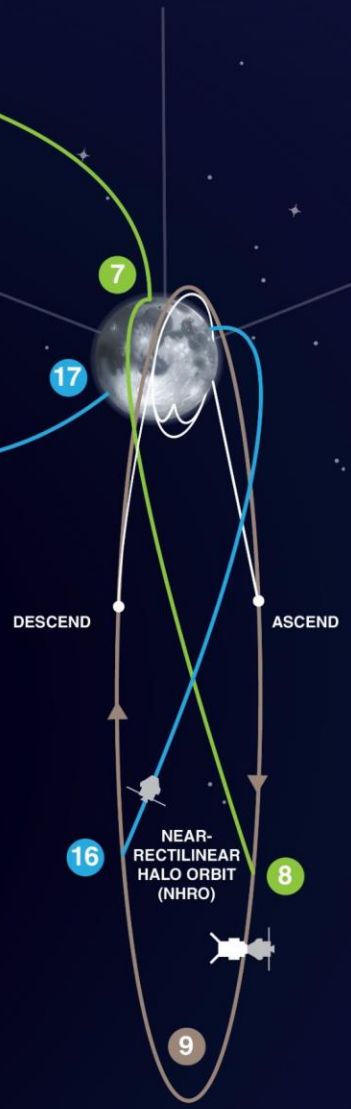
17 ORION PERFORMS RETURN POWERED FLYBY
60 nmi from the Moon.

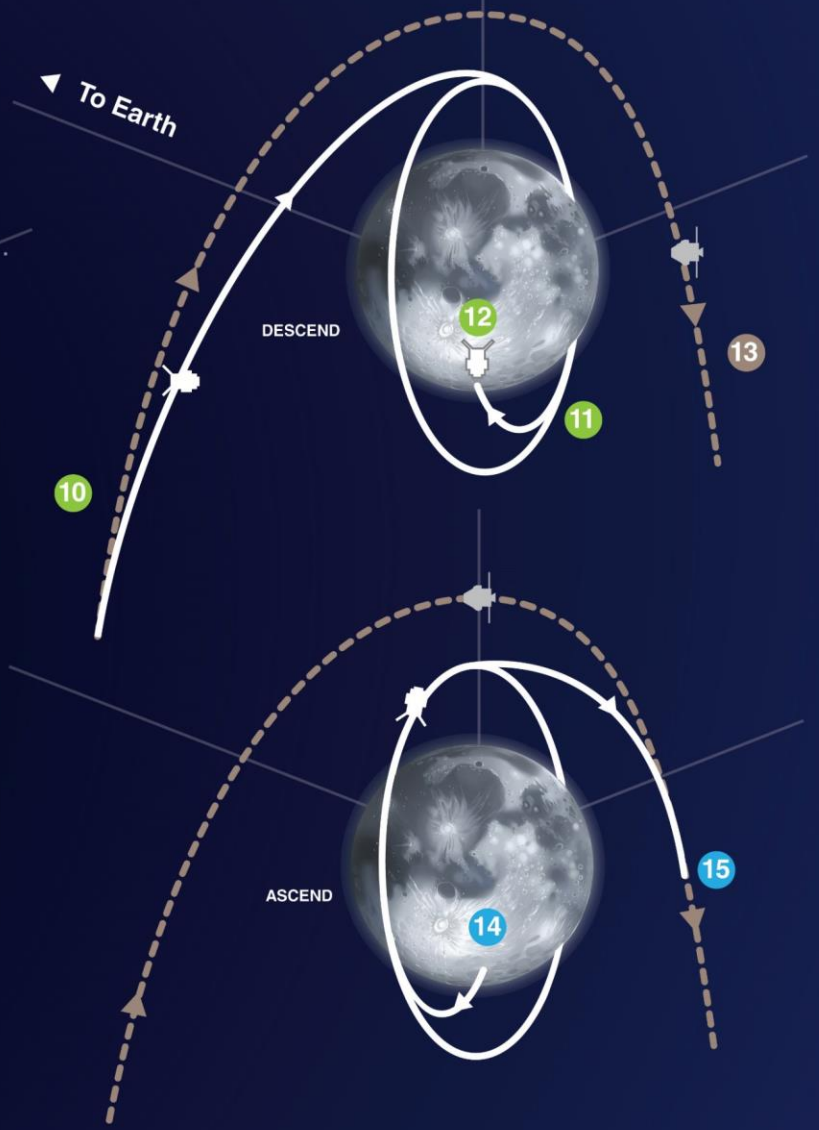
18 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN
Precision targeting for Earth entry.

19 CREW MODULE SEPARATION FROM SERVICE MODULE

20 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.

21 SPLASHDOWN
Ship recovers astronauts and capsule





Lunar Terrain Vehicle Services (LTVS)

Moon Racer

- Intuitive Machines
- AVL, Boeing, Michelin, Northrup-Grumman

Lunar Dawn

- Lunar Outpost
- Lockheed-Martin, GM, Goodyear, MDA

FLEX

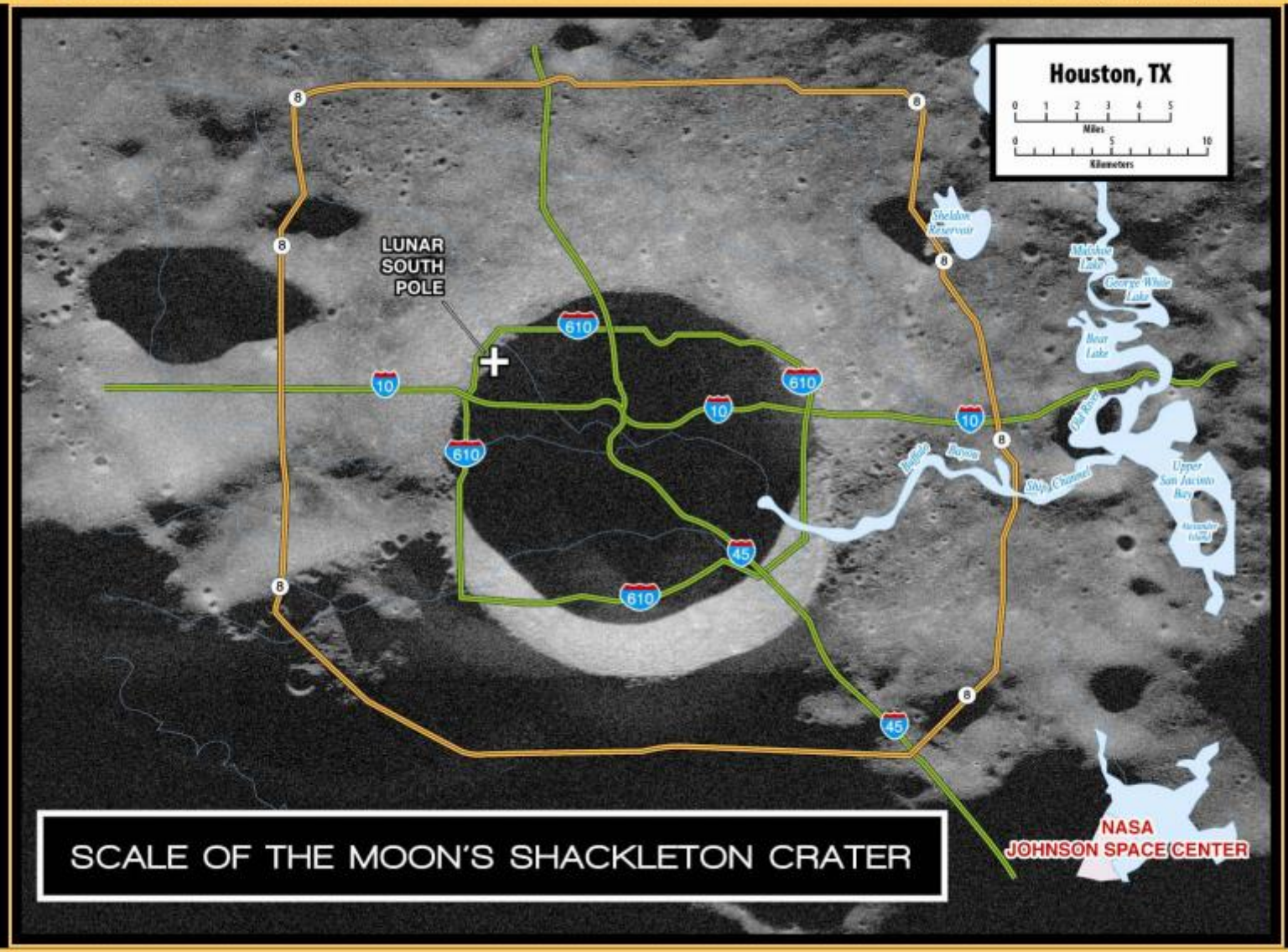
- Astrolab
- Axiom Space, Odyssey Space Research

JAXA Pressurized Rover (PR)

LUNAR CRUISER

- **Toyota**
- **Mitsubishi Heavy Industries**

Enhanced Mobility



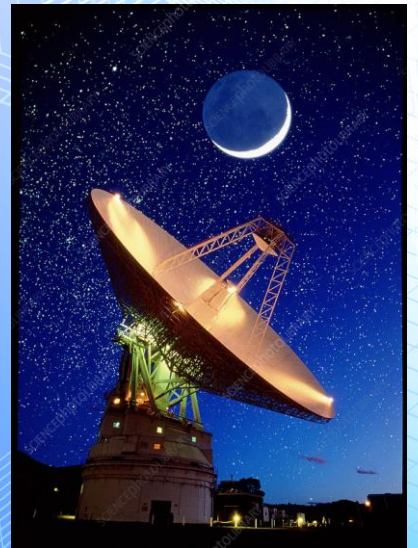
Shackleton Crater vs. Houston

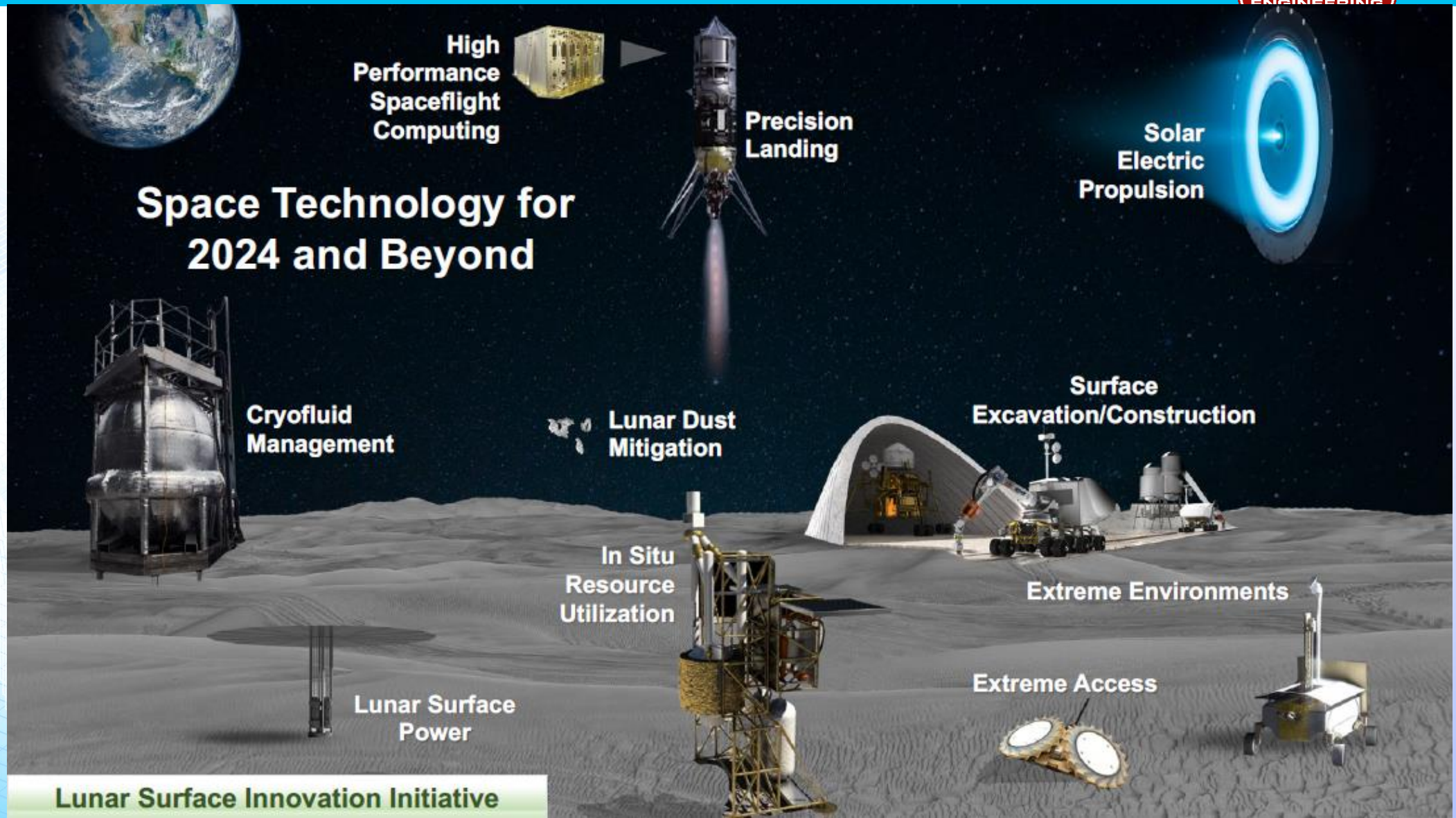
Dr. David A. Kring (USRA - http://www.lpi.usra.edu/science/kring/)

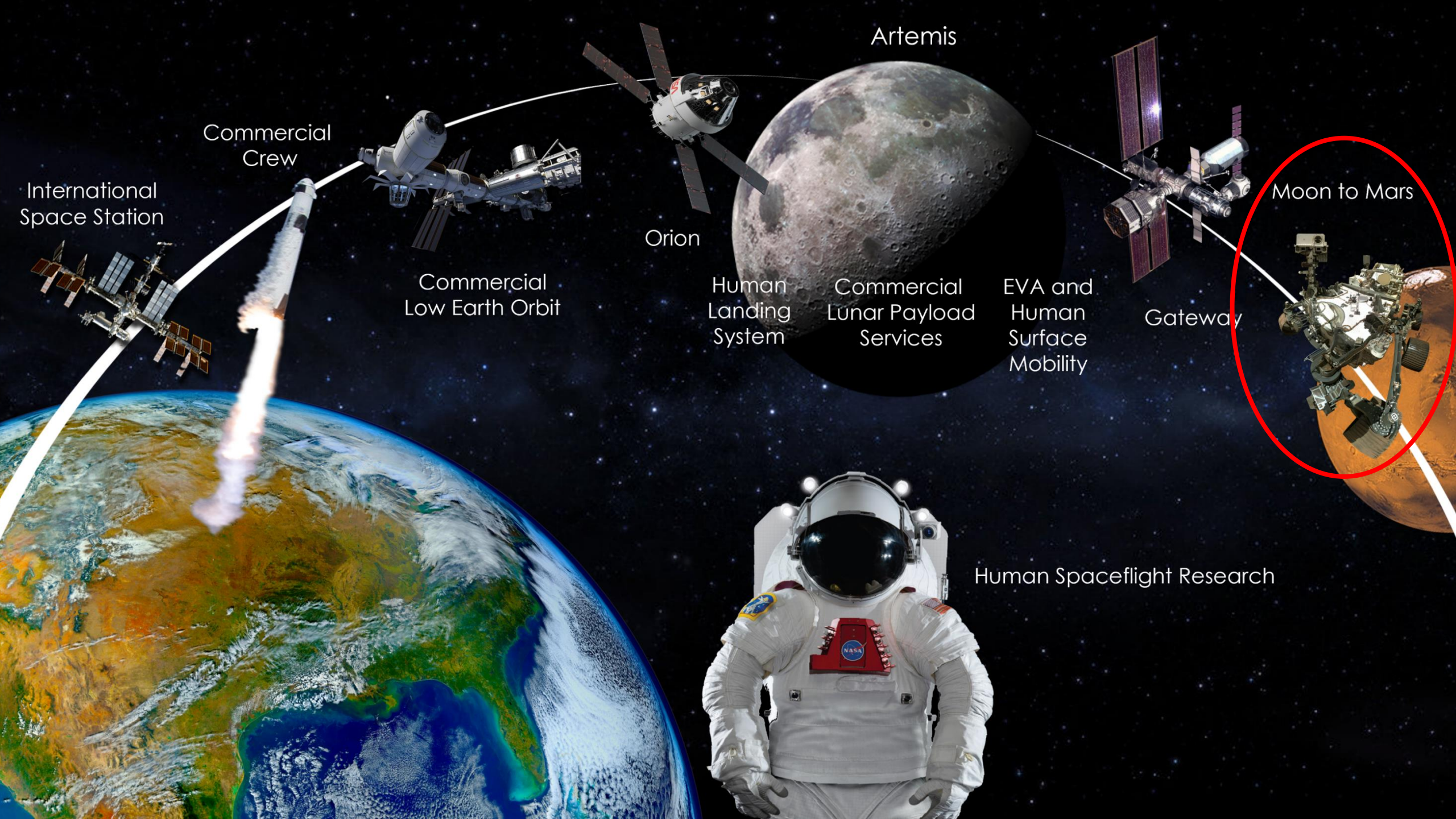
Artemis Base Camp

Habitat

Enhanced Communication

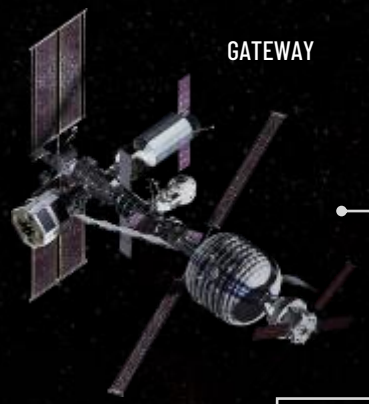





Artemis
Commercial Crew
International Space Station
Orion
Commercial Low Earth Orbit
Human Landing System
Commercial Lunar Payload Services
EVA and Human Surface Mobility
Gateway
Moon to Mars
Human Spaceflight Research

MOON AND MARS EXPLORATION

Campaign elements and systems have common applications, enabling versatility across missions



GATEWAY

Long Durations in Zero Gravity

Deep Space Aggregation

Crew Size

Mobile Expedition Duration

Suitport EVA Operations

Mobile Exploration Range

Fission Surface Power

In-Situ Resource Utilization

Partial Gravity Operations

Autonomous Robotics Systems & Contingency Crew Transportation

TRANSIT HABITAT AND MARS TRANSIT

SURFACE HABITAT

PRESSURIZED ROVER

HUMAN LANDING SYSTEM AND HLS ASCENT ELEMENT

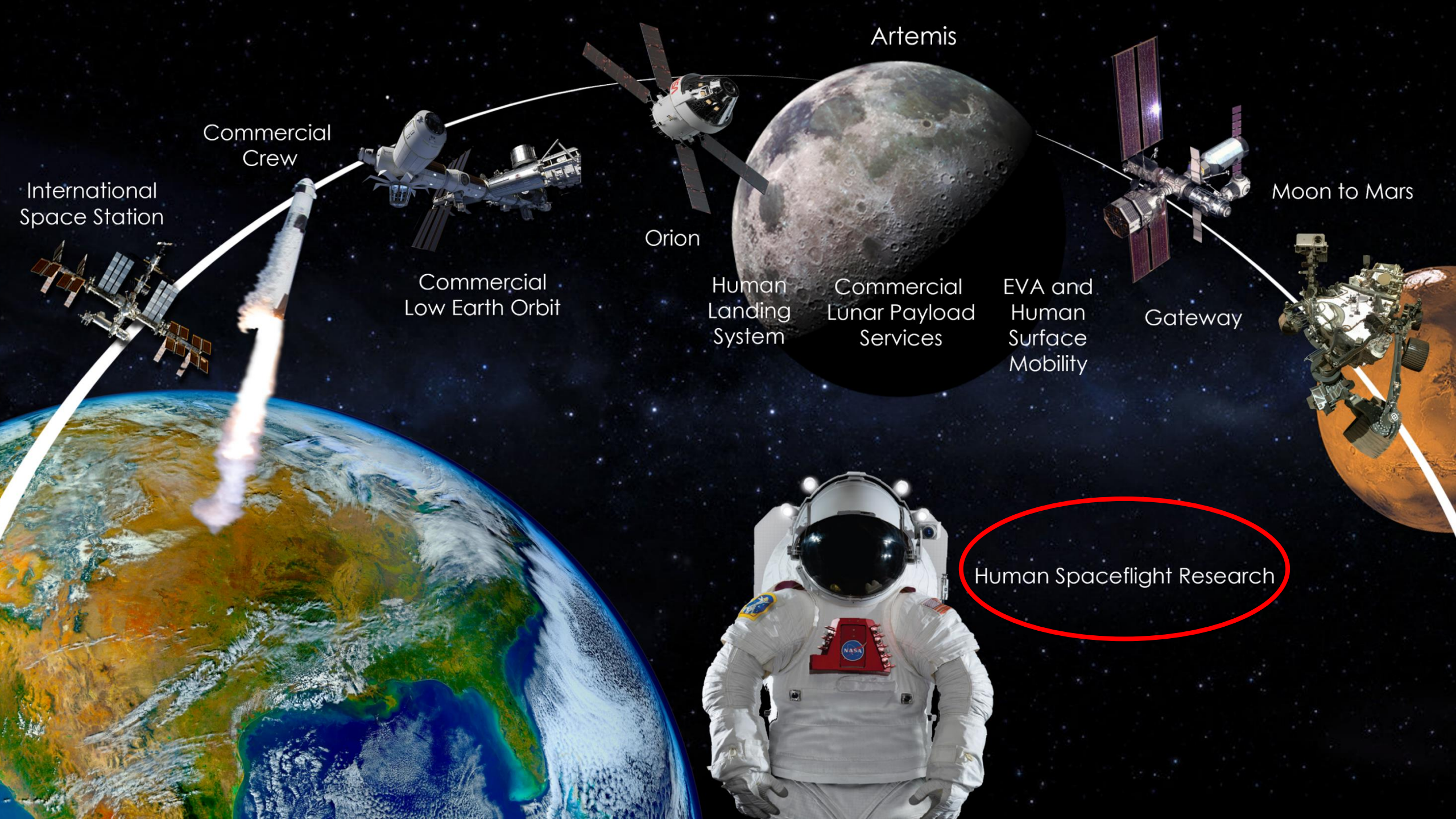
LUNAR TERRAIN VEHICLE

PRESSURIZED ROVER

SUITPORT BASED EXPLORATION

MARTIAN TERRAIN VEHICLE

MARS ASCENT VEHICLE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HERA and CHAPEA Analogs

Human Exploration Research Analog (HERA)

- 4 Missions per Campaign
- Missions are ~45 days
- Have completed 6 Campaigns since 2014

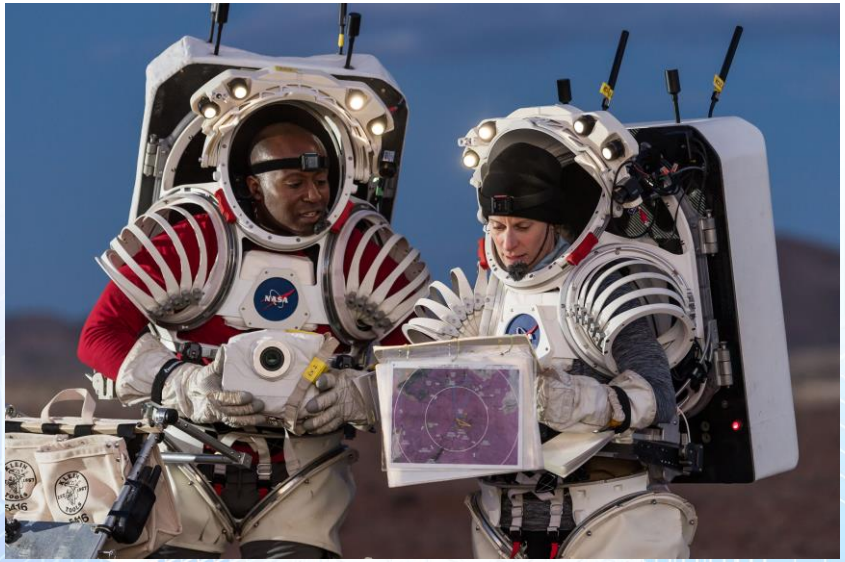
Crew Health and Performance Exploration Analog (CHAPEA)

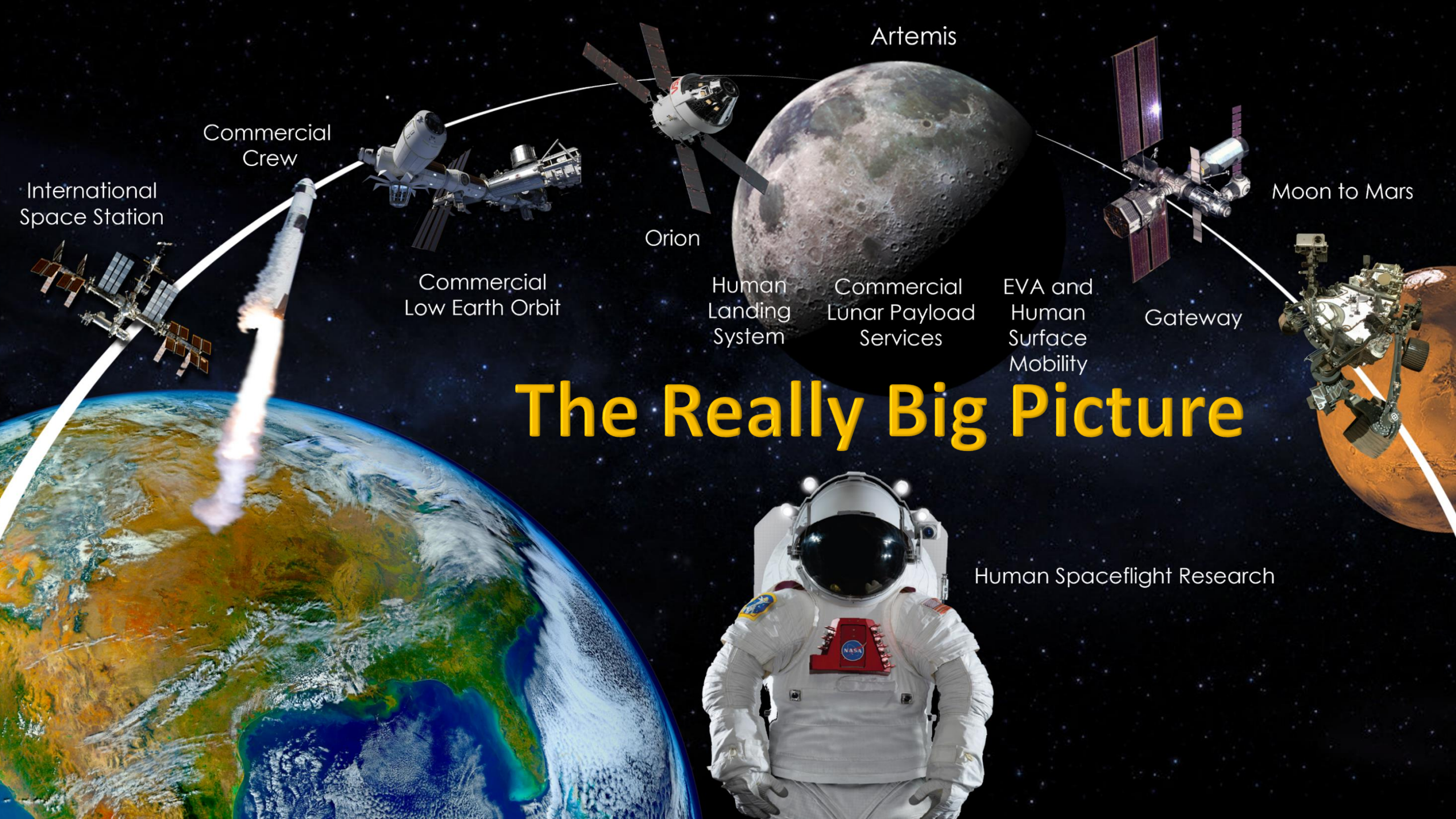
- Missions are ~1 year
- Analog mission 1 – “Landed” 7/6/24
- Analog mission 2 – “Launches” Spring 2025

Similarities to Space

- Daily tasks
- Schedule
- Supported by Mission Control
- Communication Delays
- Isolation
- Confinement
- Space Food
- Daily Exercise
- All Maintenance done by Inhabitants
- Weekly Housekeeping

Joint EVA and Human Surface Mobility Test Team (JETT5) -2024

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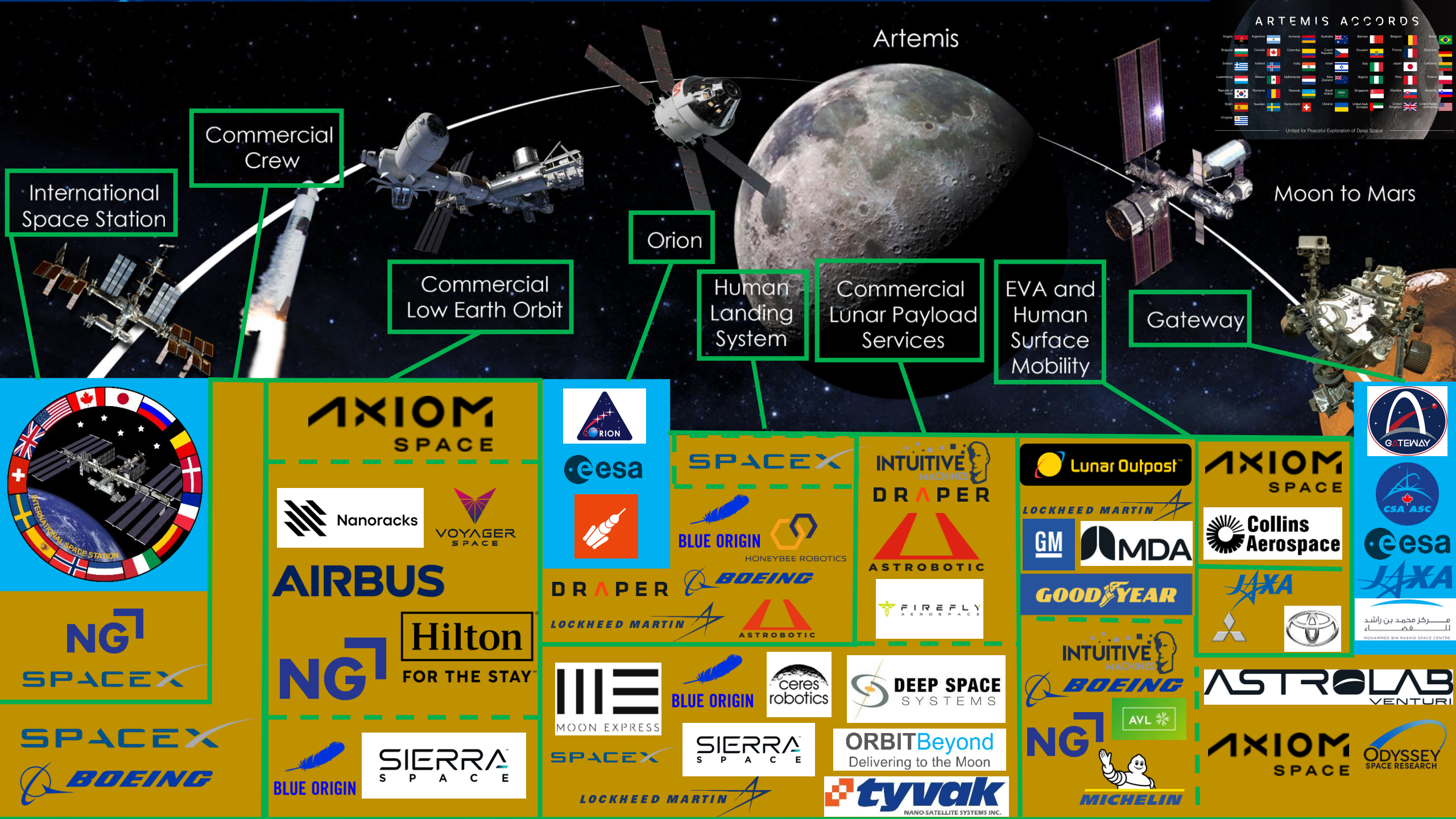
The Really Big Picture
Human Spaceflight Research


Artemis
ARTEMIS ACCORDS
United for Peaceful Exploration of Deep Space
International Space Station
Commercial Crew
Commercial Low Earth Orbit
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Human Landing System
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INTERNATIONAL SPACE STATION
NG
SPACEX
AXIOM SPACE
Nanoracks
VOYAGER SPACE
AIRBUS
Hilton
FOR THE STAY
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SPACEX
BOEING
BLUE ORIGIN
SIERRA SPACE
ORION
esa
DRAPER
LOCKHEED MARTIN
SPACEX
BLUE ORIGIN
HONEYBEE ROBOTICS
BOEING
ASTROBOTIC
INTUITIVE MACHINES
DRAPER
ASTROBOTIC
FIREFLY AEROSPACE
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DEEP SPACE SYSTEMS
SPACEX
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Delivering to the Moon
LOCKHEED MARTIN
tyvak
NANO-SATELLITE SYSTEMS INC.
Lunar Outpost
LOCKHEED MARTIN
GM
MDA
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INTUITIVE MACHINES
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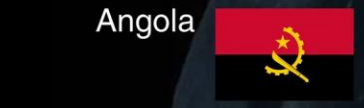
MICHELIN
AXIOM SPACE
Collins Aerospace
JAXA
ASTROLAB
VENTURI
AXIOM SPACE
ODYSSEY SPACE RESEARCH
GATEWAY
CSA ASC
esa
JAXA
MOHAMMED BIN RASHID SPACE CENTRE

ARTEMIS ACCORDS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Armenia


Australia


Bahrain


Belgium


Brazil


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Lithuania


Luxembourg


Mexico


Netherlands


New Zealand


Nigeria


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Poland


Republic of Korea


Romania


Rwanda


Saudi Arabia


Singapore


Slovakia


Slovenia


Spain


Sweden


Switzerland


Ukraine


United Arab Emirates


United Kingdom


United States of America


Uruguay

United for Peaceful Exploration of Deep Space

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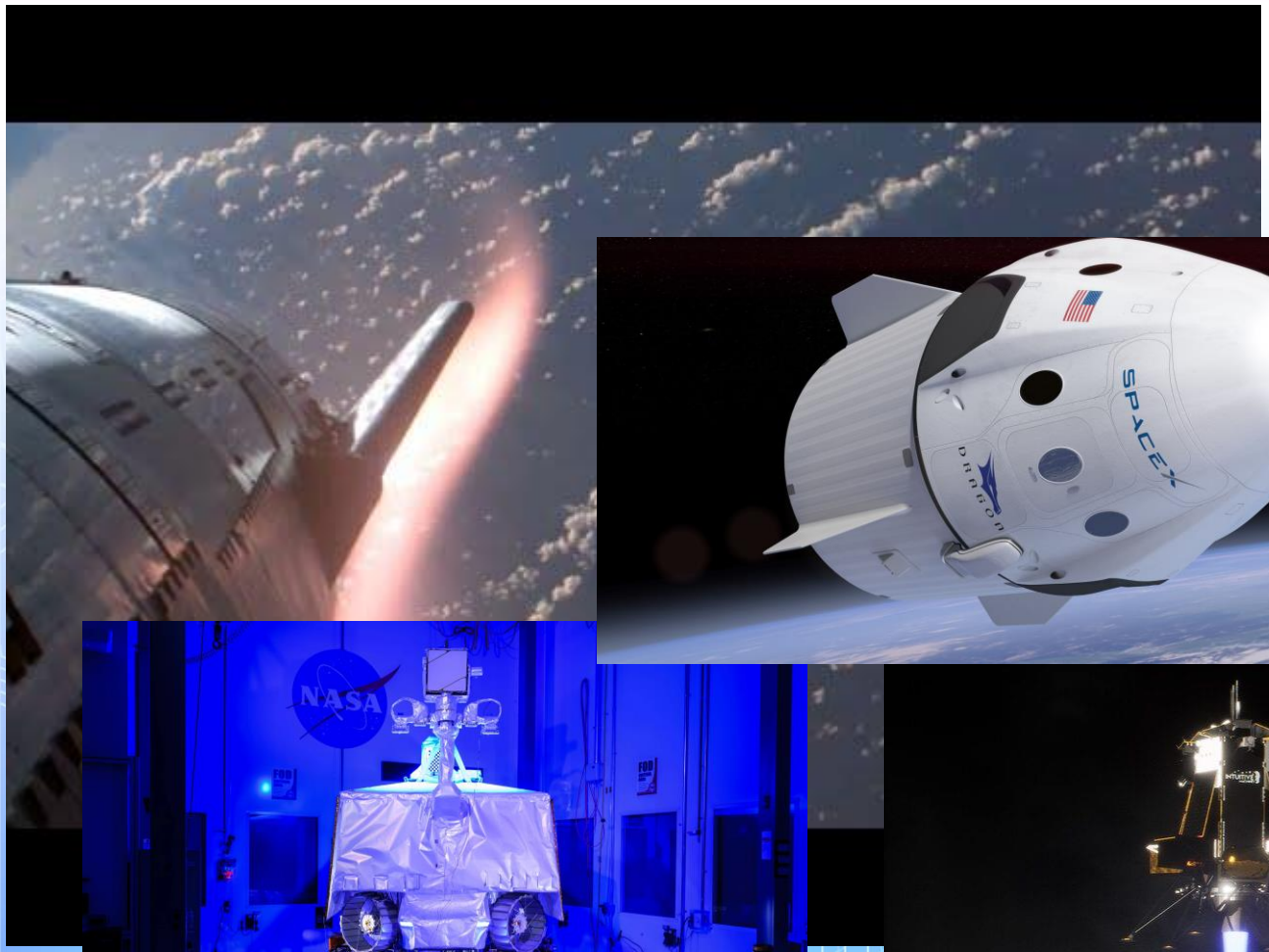
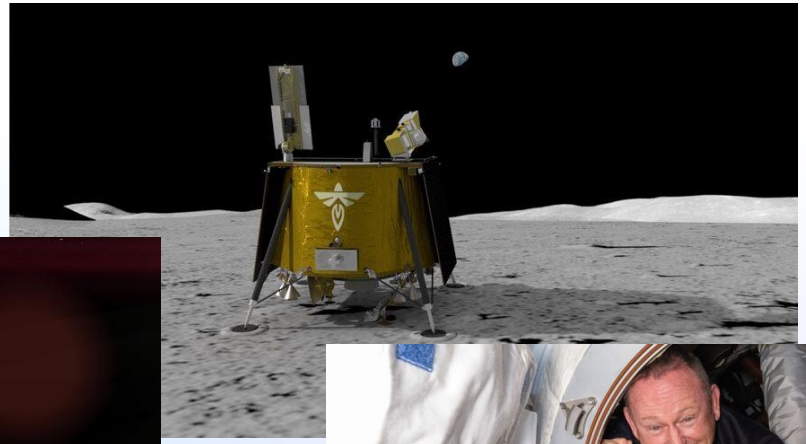
Upcoming Artemis Events






NASA
*Concept image