

National Aeronautics and
Space Administration



NASA's Return to the Moon

Managing Complexity in the Artemis Program



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www.nasa.gov

“The United States will Maintain its Leadership in Space Exploration and Space Science”

“Remain a global leader in science and engineering by pioneering space research and technology that propels exploration of the Moon, Mars, and beyond.”

“U.S. human and robotic space exploration missions will land [the first woman and person of color on the Moon](#), advance a robust cislunar ecosystem, continue to leverage human presence in low-Earth orbit to enable people to live and work safely in space, and prepare for future missions to Mars and beyond.”

— The White House U.S Space Priorities Framework, Dec 2021

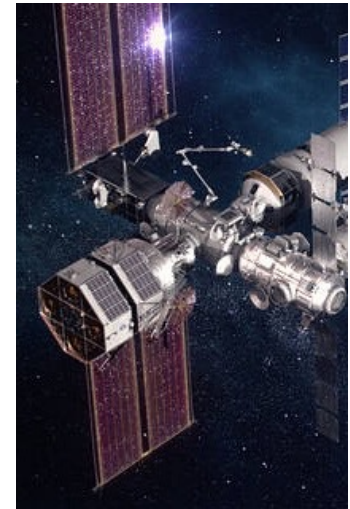
[United States Space Priorities Framework](#)
[NASA 2022 Strategic Plan](#)
[2023 NASA Budget Request](#)



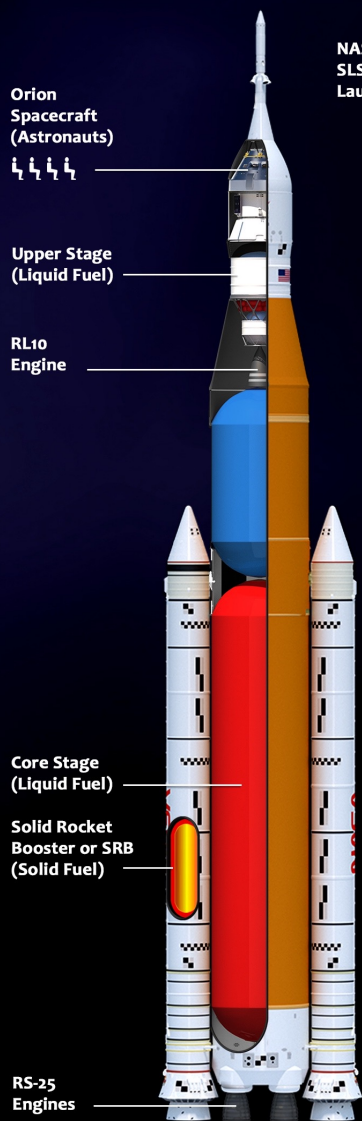
What is Artemis?



*Extravehicular
Activity and
Human Surface
Mobility Program



Combines programs into missions



NASA's
SLS Block 1
Launch Vehicle

Space Launch System



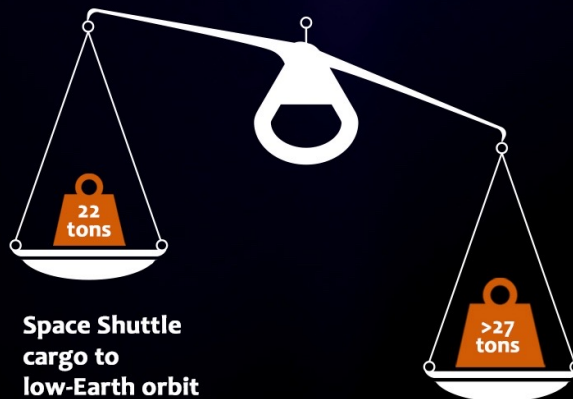
Saturn V
7.5 million
pounds



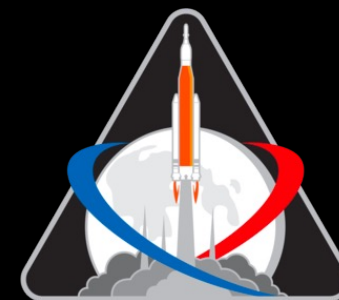
Space Shuttle
7.8 million
pounds



SLS
8.8 million
pounds

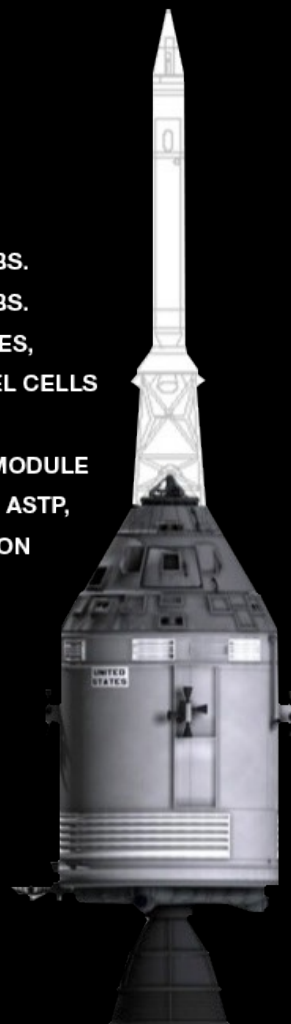


SLS cargo
to the Moon

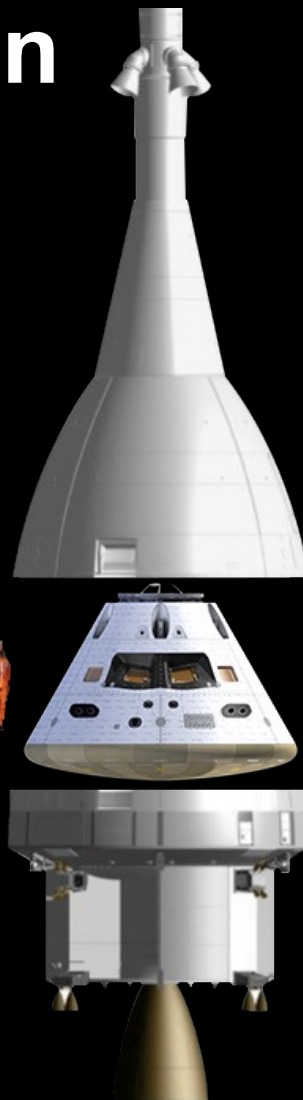


APOLLO

CREW MODULE DIAMETER: 12.8 FT.
CREW SIZE: 3
SERVICE MODULE DIAMETER: 13 FT.
SERVICE MODULE LENGTH: 24.5 FT.
SERVICE MODULE MASS: 54,000 LBS.
SERVICE MODULE THRUST: 20,500 LBS.
POWER: BATTERIES,
FUEL CELLS
LANDING: WATER
DOCKING: LUNAR MODULE
DESTINATION: SKYLAB, ASTP,
MOON



Orion



ORION

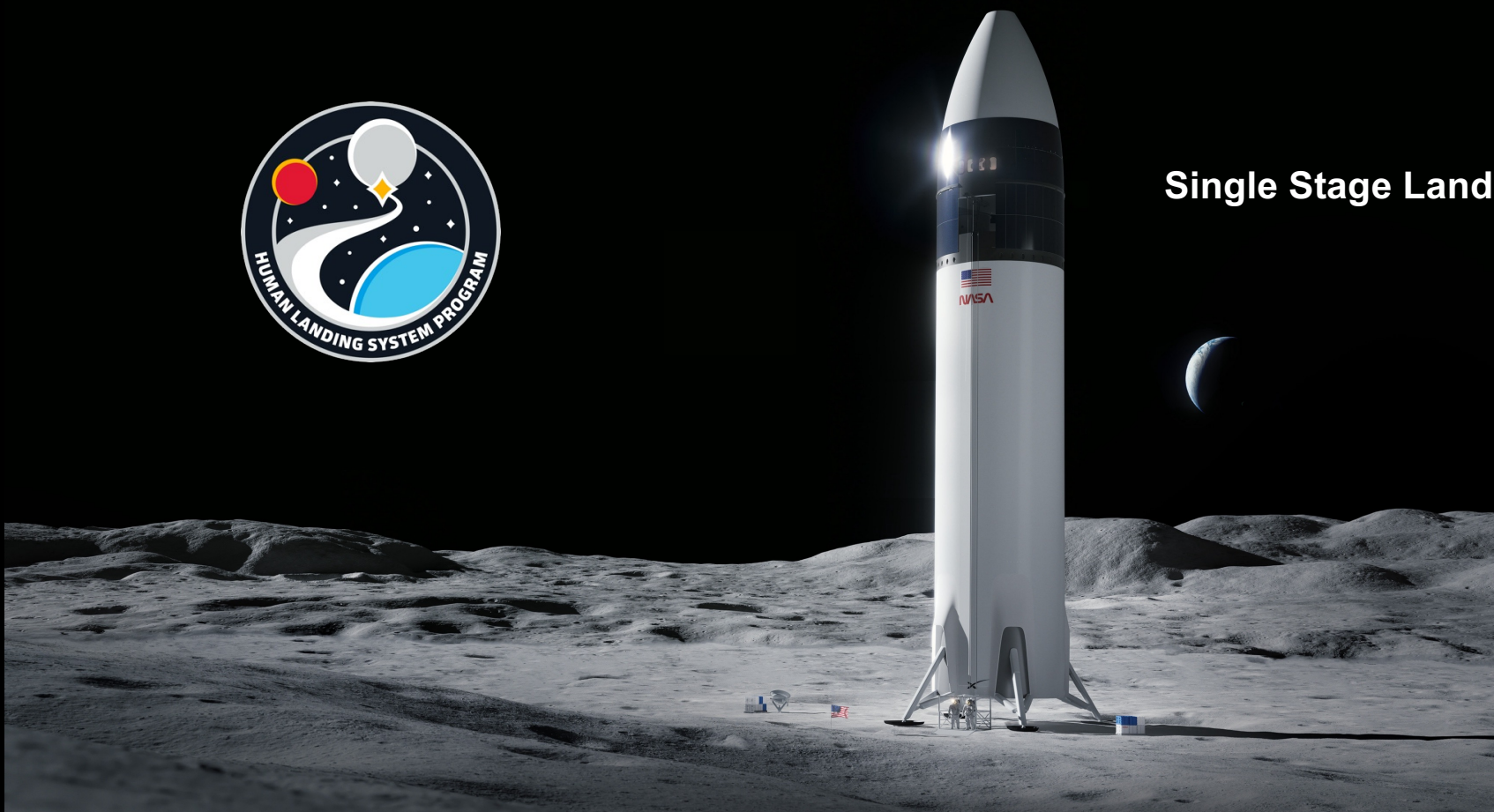
CREW MODULE DIAMETER: 16.5 FT.
CREW SIZE: 4 (6 TO ISS)
SERVICE MODULE DIAMETER: 16.5 FT.
SERVICE MODULE LENGTH: 15.7 FT.
SERVICE MODULE MASS: 27,500 LBS.
SERVICE MODULE THRUST: 7,500 LBS.
POWER: SOLAR ARRAYS,
BATTERIES
LANDING: WATER
DOCKING: MULTI PURPOSE
DESTINATION: MARS, ASTEROIDS



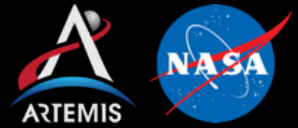
Human Landing System: Option A



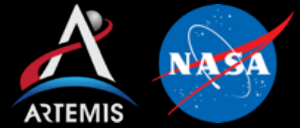
Single Stage Lander



Gateway

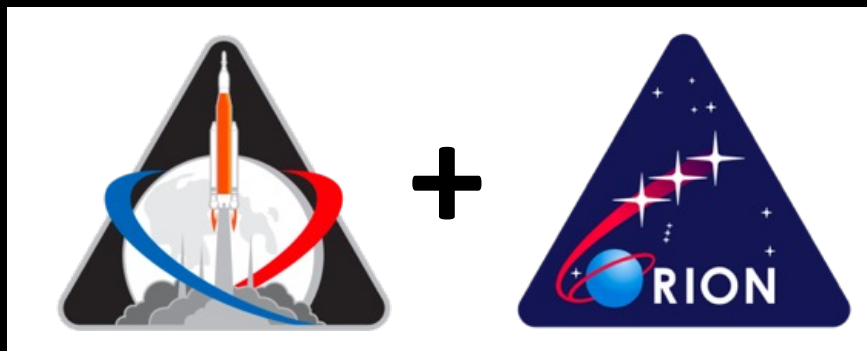


High power Solar Electric Propulsion System
And Pressurized Crew Module

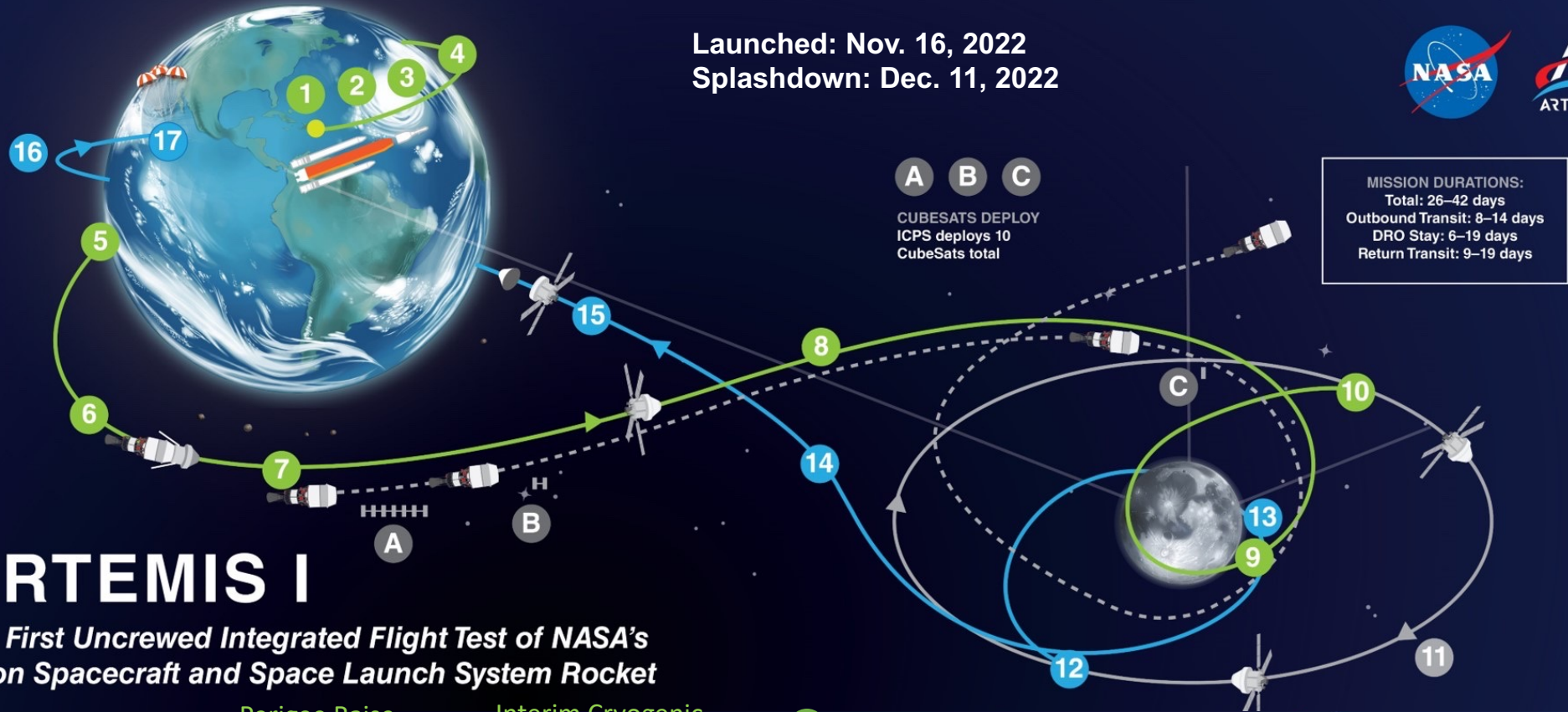


Combine programs into missions.

ARTEMIS I



Launched: Nov. 16, 2022
Splashdown: Dec. 11, 2022



MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket

- | | | | | |
|----------------------------|------------------------------|---|-----------------------------------|---------------------------|
| 1 Launch | 4 Perigee Raise Maneuver | 7 Interim Cryogenic Prop Stage Separation | 10 Lunar Orbit Insertion | 14 Return Transit |
| 2 Jettison Rocket Boosters | 5 Earth Orbit | 8 Outbound Trajectory Correction Burn | 11 Distant Retrograde Orbit (DRO) | 15 Crew Module Separation |
| 3 Main Engine Cut Off | 6 Trans Lunar Injection Burn | 9 Outbound Powered Flyby | 12 DRO Departure | 16 Entry Interface |
| | | | 13 Return Powered Flyby | 17 Splashdown |

https://appel.nasa.gov/wp-content/uploads/2021/11/artemis_1_map_october_2021.jpg

ARTEMIS II



+



+

Crew

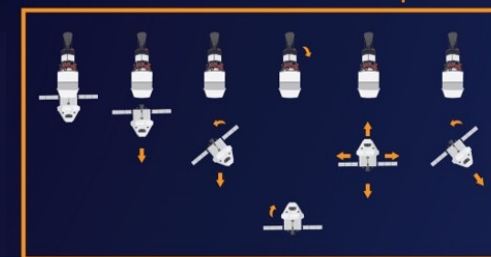


ARTEMIS II

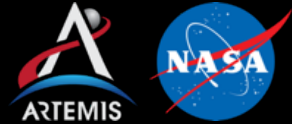
First Crewed Test Flight to the Moon Since Apollo

- | | | |
|----------------------------|---|---------------------------------|
| 1 Launch | 5 Apogee Raise burn to High Earth Orbit | 8 High Earth Orbit Checkout |
| 2 Jettison Rocket Boosters | 6 Prox Ops Demonstration | 9 Trans-Lunar Injection |
| 3 Main Engine Cut Off | 7 Interim Cryogenic Prop Stage Separation | 10 Outbound Transit to the Moon |
| 4 Perigee Raise Maneuver | | 11 Lunar Flyby |
| | | 12 Trans-Earth Return |
| | | 13 Crew Module Separation |
| | | 14 Entry Interface |
| | | 15 Splashdown |

Proximity Operations Demonstration Sequence



Meet the Artemis II Crew



Reid Wiseman

Commander

Victor Glover

Pilot

Christina Hammock Koch

Mission Specialist

Jeremy Hansen

Mission Specialist



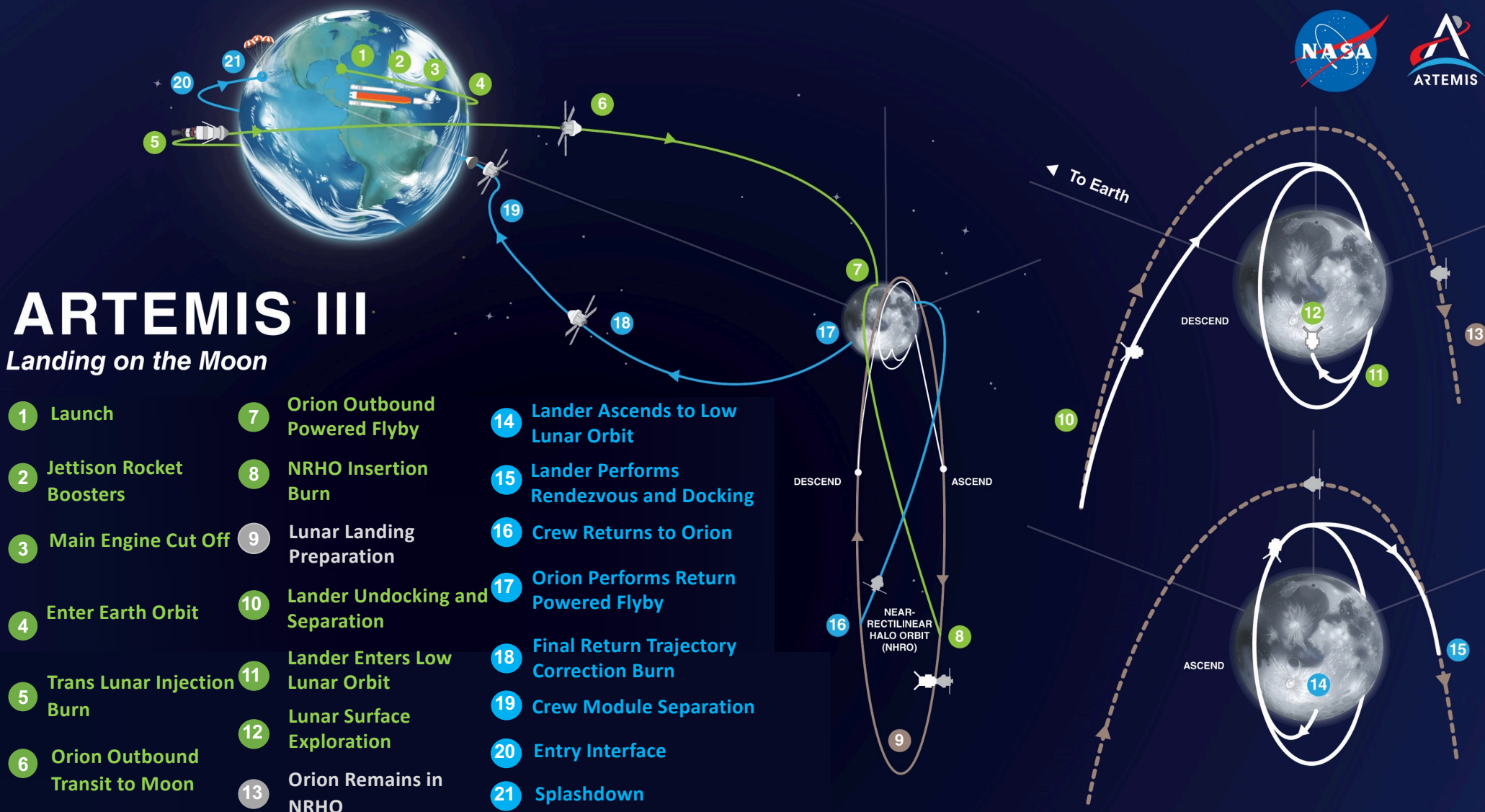
Credit: NASA

ARTEMIS III



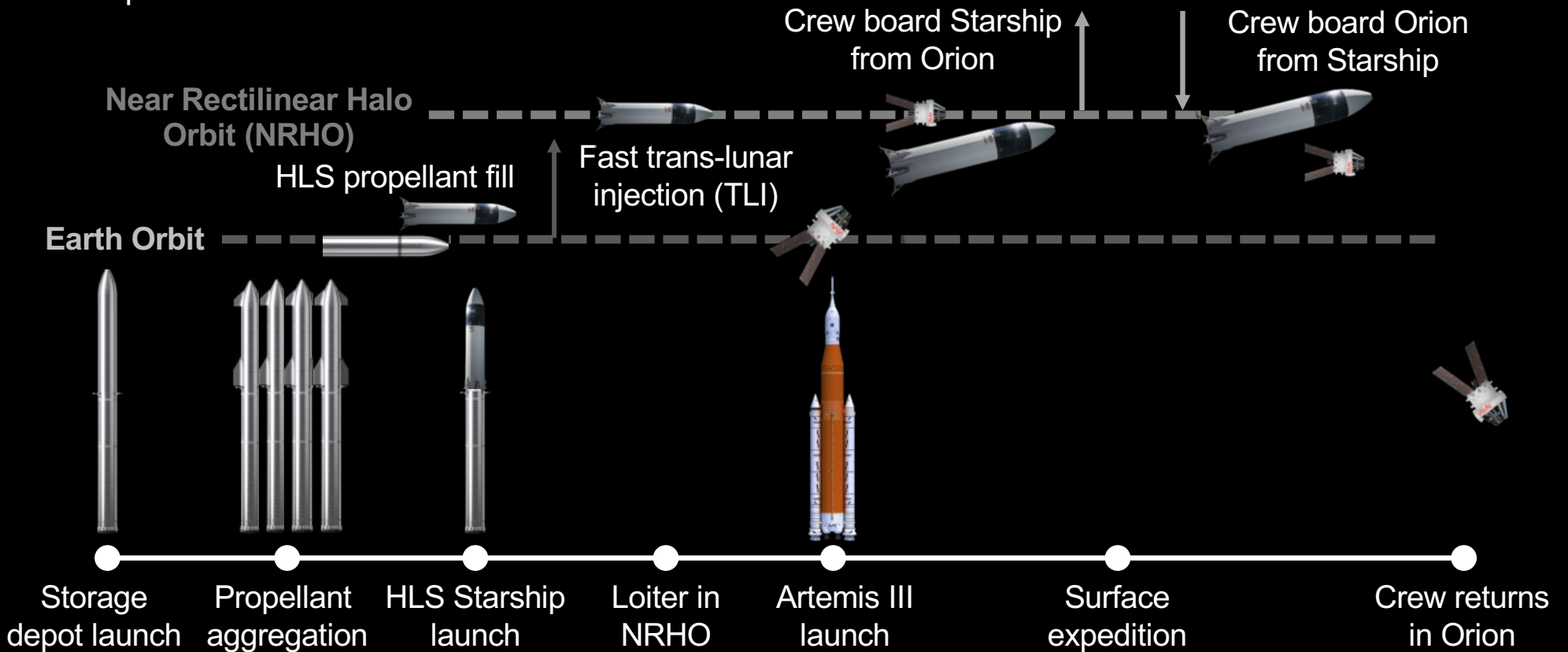
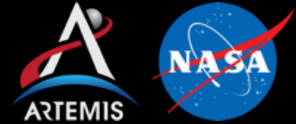
ARTEMIS III

Landing on the Moon

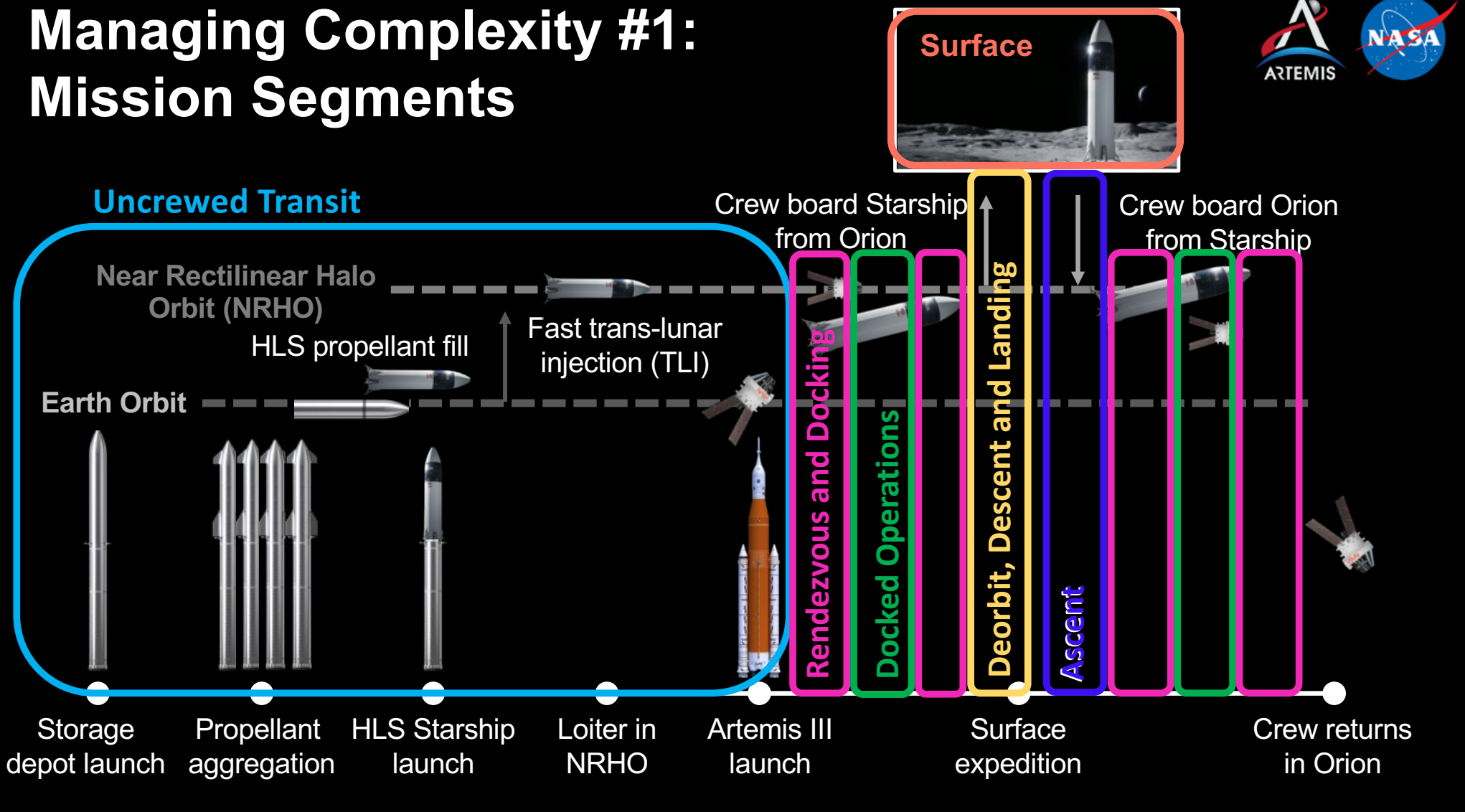


Human Landing System (HLS) Starship Artemis III Concept of Operations

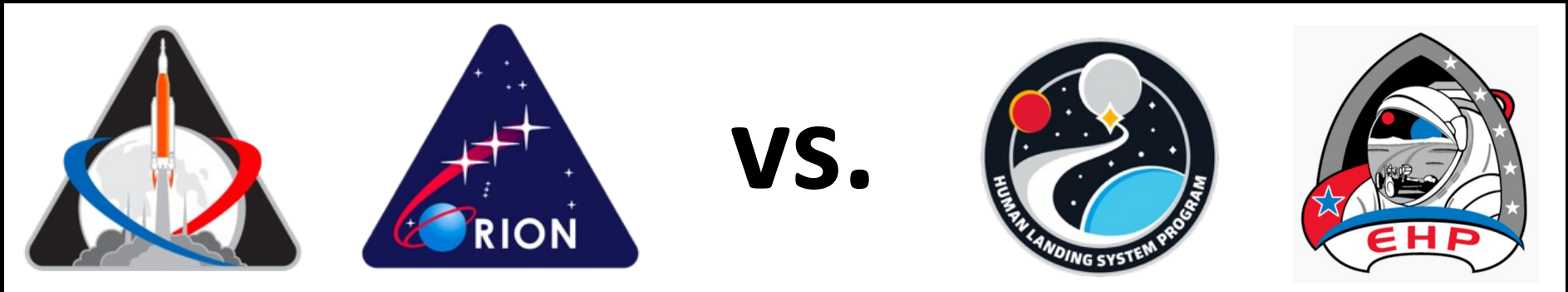
NASA has awarded SpaceX a contract to develop its HLS Starship for use on Artemis III



Managing Complexity #1: Mission Segments



Managing Complexity #2: Contracts

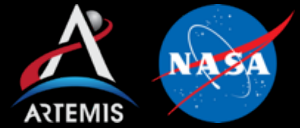


Old:

- **Cost-plus**
- **NASA owns the vehicle**
- **Began: 2011**
- **Built and operational**

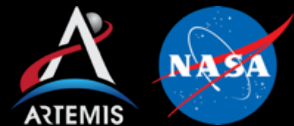
New:

- **Firm Fixed Price**
- **NASA pays for a service**
- **Began: 2021 and 2022**
- **Requirements are defined**



Why the Lunar South Pole?

Managing Complexity #3: Landing Requirements



Apollo 11 JUL 69
Mare Tranquillitatis
0.67416°N 23.47314°E
LM: 21.6 hours EVA: 2.5 hours

Apollo 12 NOV 69
Oceanus Procellarum
3.0128°S 23.4219°W
LM: 31.5 hours EVA: 7.8 hours

Apollo 14 FEB 71
Fra Mauro Highlands
3.64589°S 17.47194°W
LM: 33.5 hours EVA: 9.4 hours

Apollo 15 AUG 71
Hadley Rille
26.13239°N 3.63330°E
LM: 66.9 hours EVA: 19.1 hours

Apollo 16 APR 72
Descartes Highlands
8.9734°S 15.5011°E
LM: 71.0 hours EVA: 20.2 hours

Apollo 17 DEC 72
Taurus-Littrow Valley
20.1911°N 30.7655°E
LM: 75.0 hours EVA: 22.1 hours

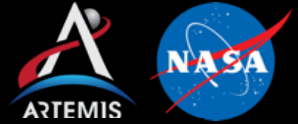


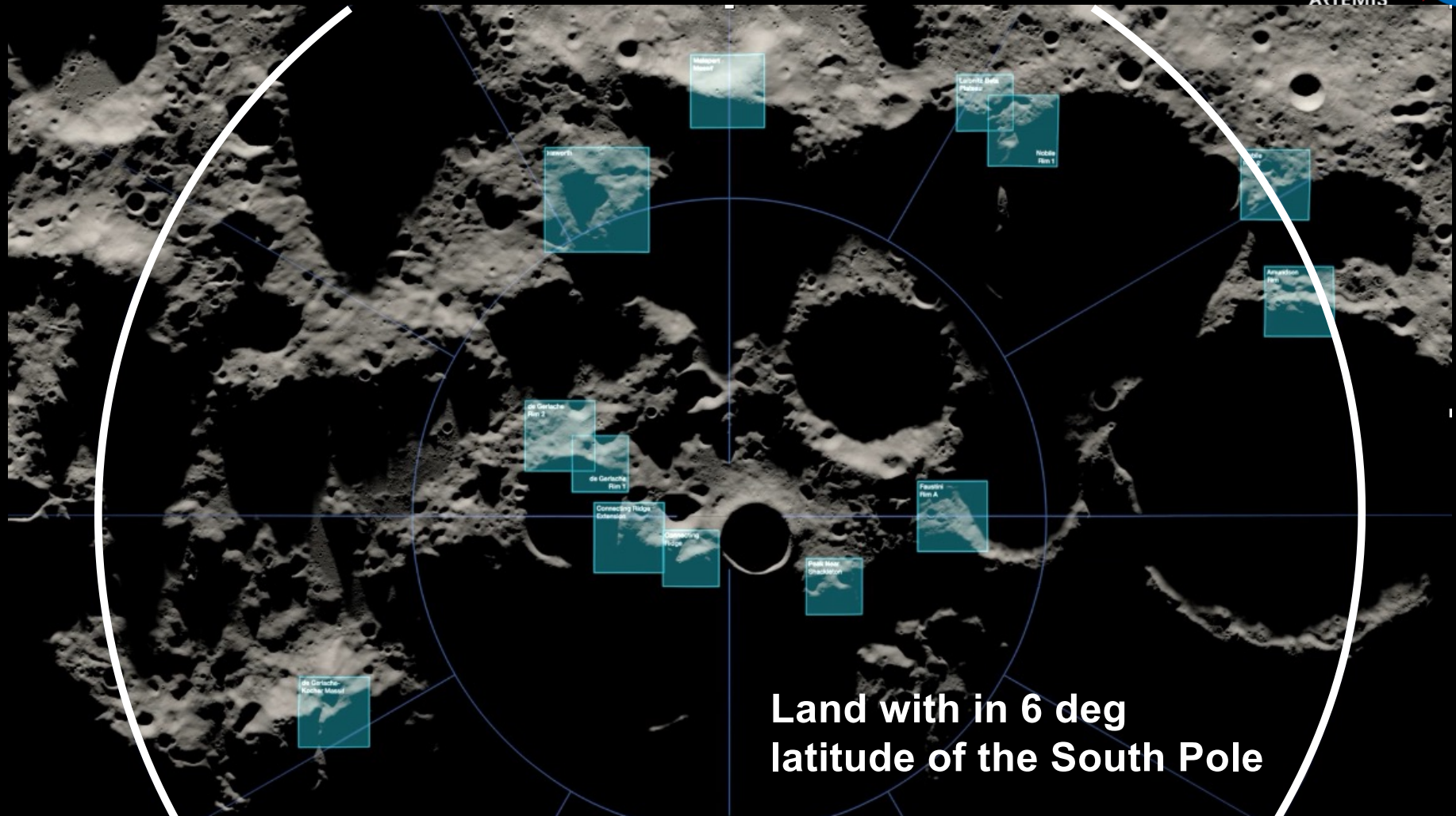
Apollo Landing Sites



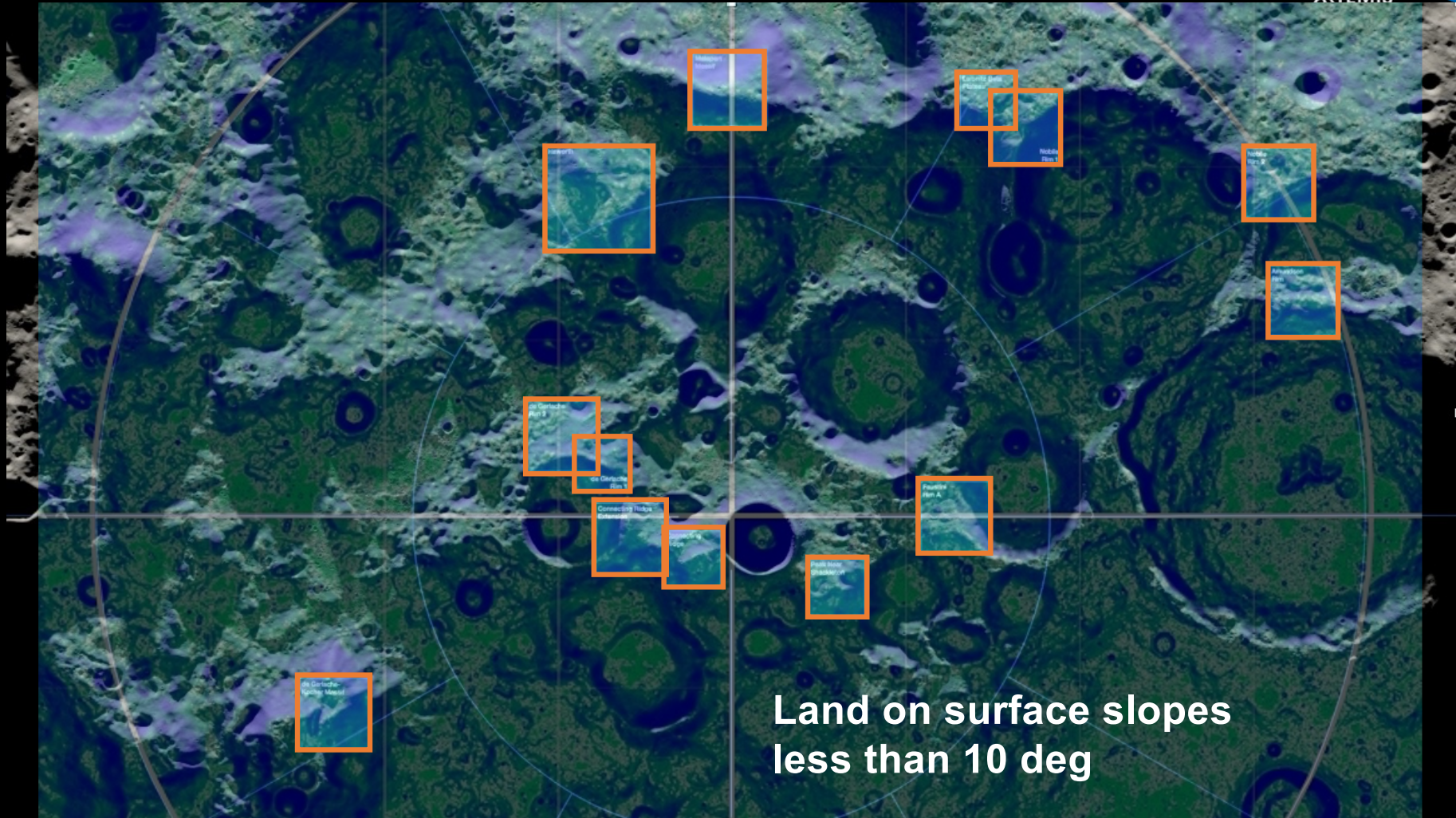
Time: 01 Jul 1969 00:00 UT
Phase: 97.8% (16d 00h 51m)
Diameter: 2002.2 arcseconds
Distance: 357960 km (28.09 Earths)
Position: 19h 56m 00s, 25° 08' 12"S
Subsolar: 1.479°N 14.482°W
Sub-Earth: 5.585°N 2.246°E
Pos. Angle: 349.630°

Managing Complexity #3: Landing Requirements

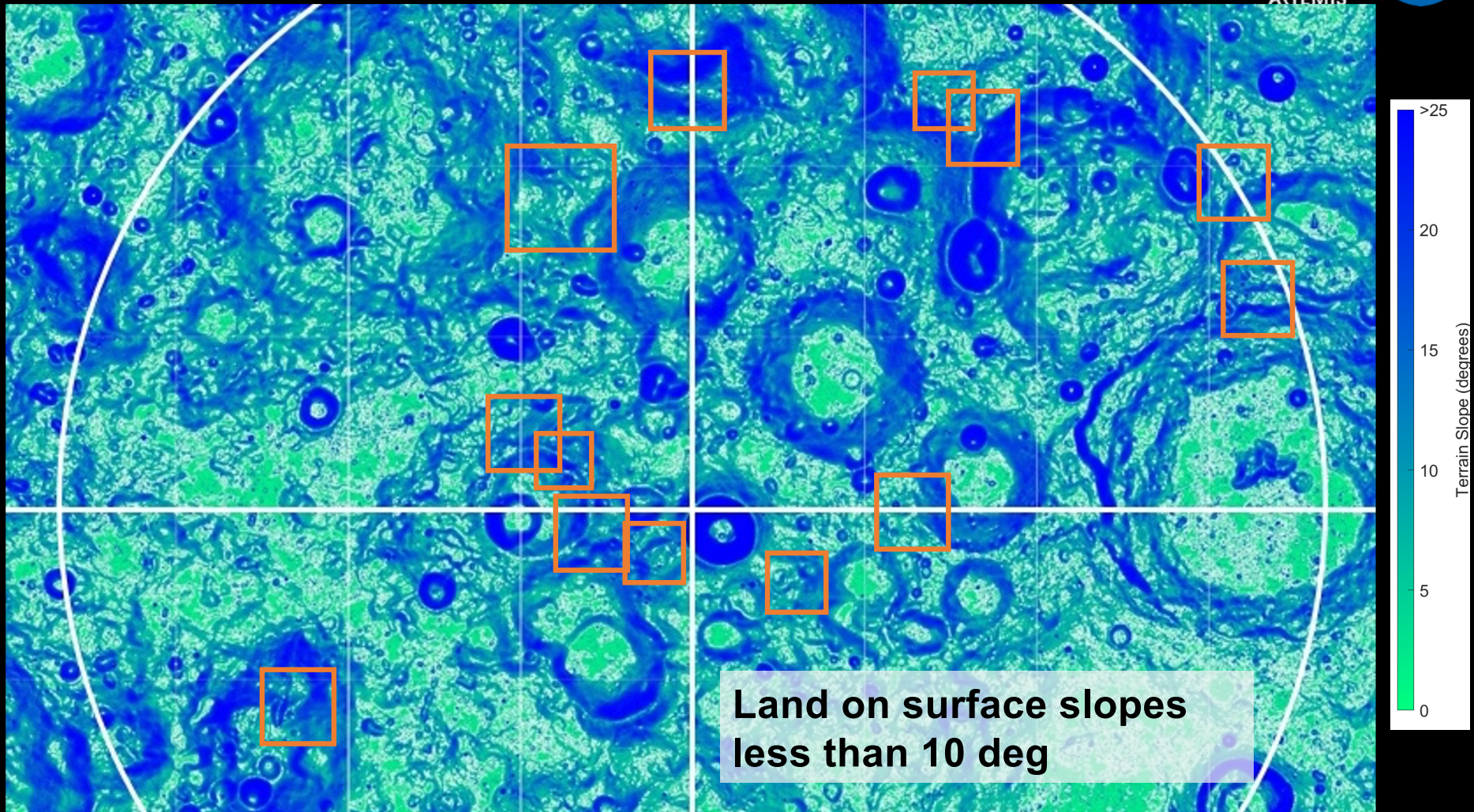
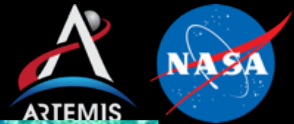




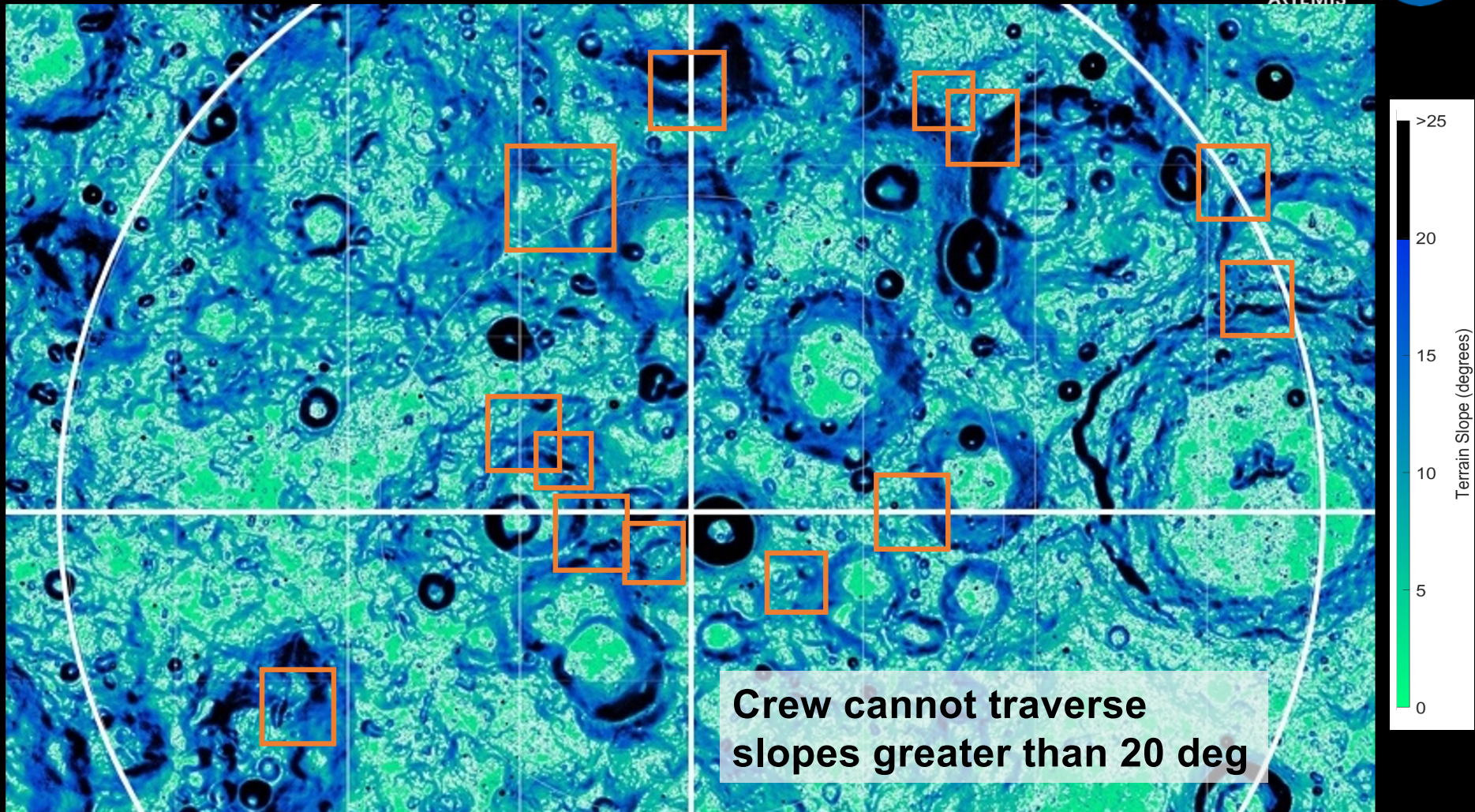
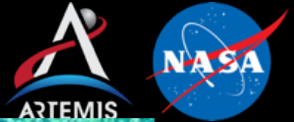
Managing Complexity #3: Landing Requirements



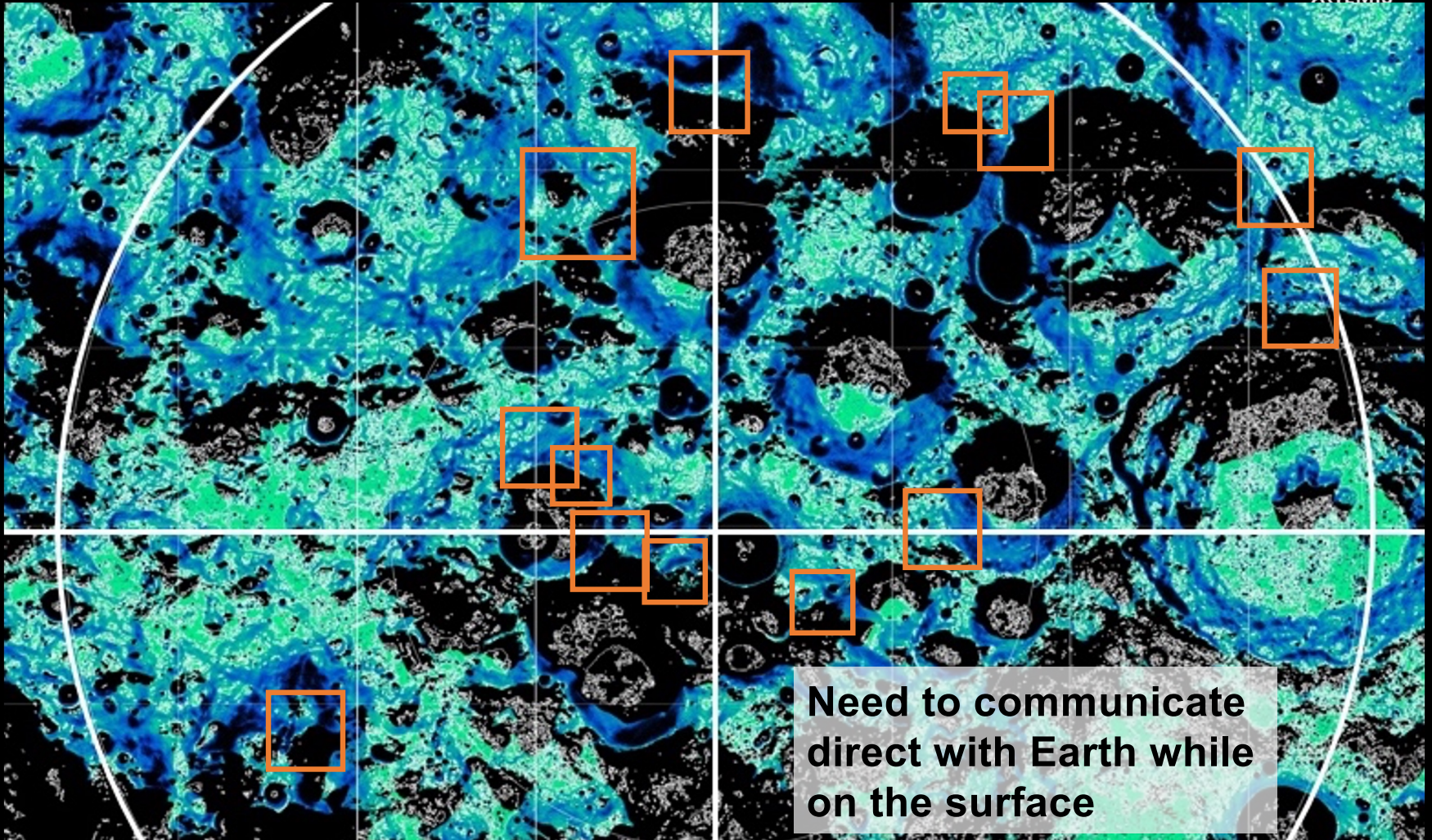
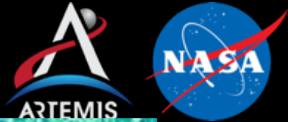
Managing Complexity #3: Landing Requirements



Managing Complexity #3: Landing Requirements

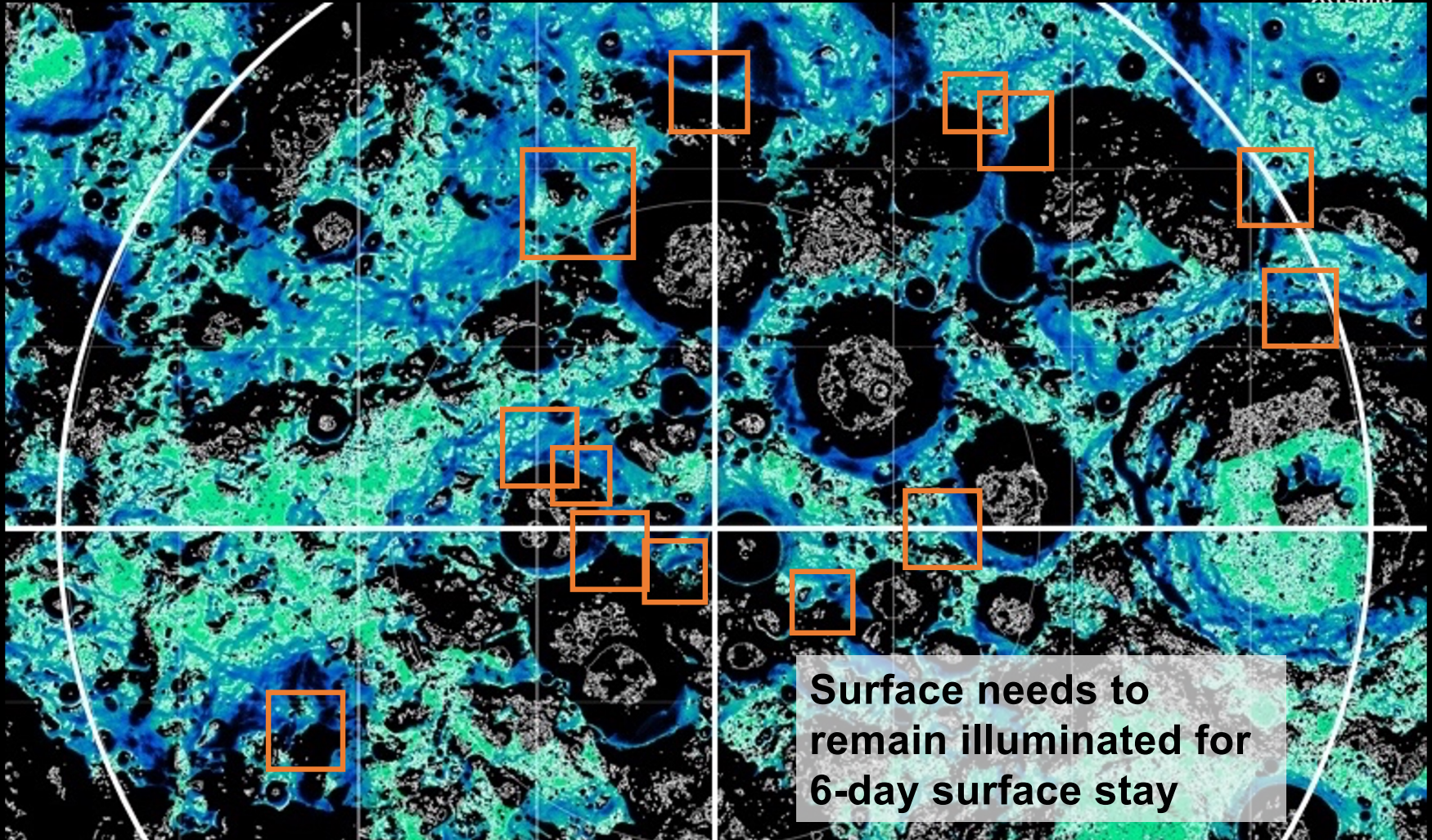
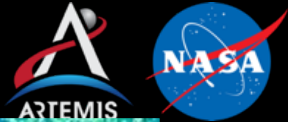


Managing Complexity #3: Landing Requirements

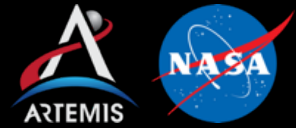


**Need to communicate
direct with Earth while
on the surface**

Managing Complexity #3: Landing Requirements



Oh and...



- The ground track will be different each orbit
- Land within 100 m of a target designated before the flight
- The lighting at the south pole is different each landing opportunity
- Etc., etc.,

Impact:

- Each landing opportunity will need different approach maps
- The approach maps must be accurate, and the approach path must be illuminated
- The same location may not be available on consecutive landing opportunities

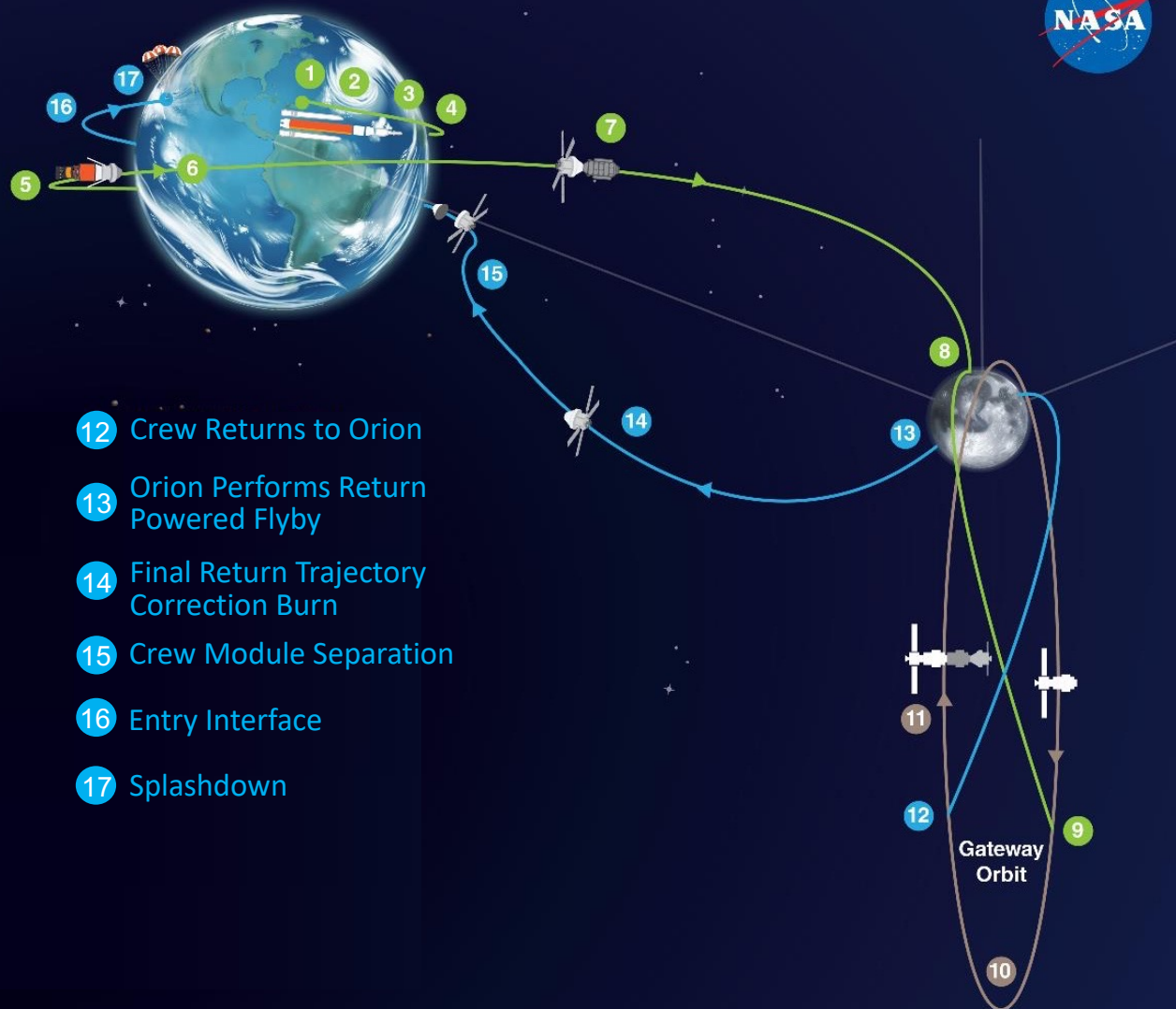
ARTEMIS IV



ARTEMIS IV

International Habitation Module delivery to Gateway

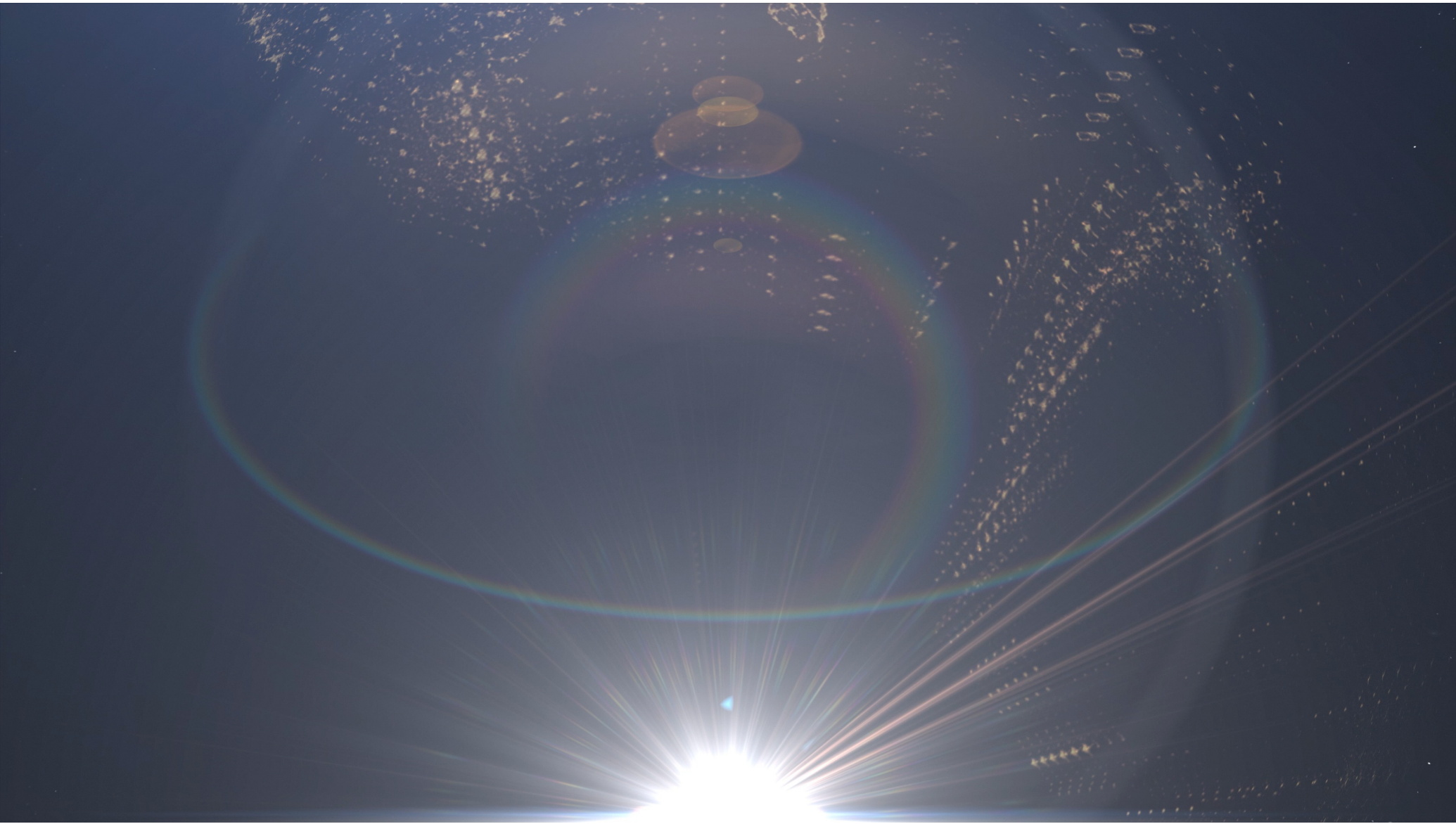
- 1 Launch
- 2 Jettison Rocket Boosters
- 3 Main Engine Cut Off
- 4 Enter Earth Orbit
- 5 Trans Lunar Injection Burn
- 6 Orion Tugs I-HAB to Moon
- 7 Orion Outbound Transit to Moon
- 8 Orion Outbound Powered Flyby
- 9 Gateway Orbit Insertion Burn
- 10 I-HAB Arrives at Gateway
- 11 I-HAB Activation and Crew Ingress
- 12 Crew Returns to Orion
- 13 Orion Performs Return Powered Flyby
- 14 Final Return Trajectory Correction Burn
- 15 Crew Module Separation
- 16 Entry Interface
- 17 Splashdown





WE GO



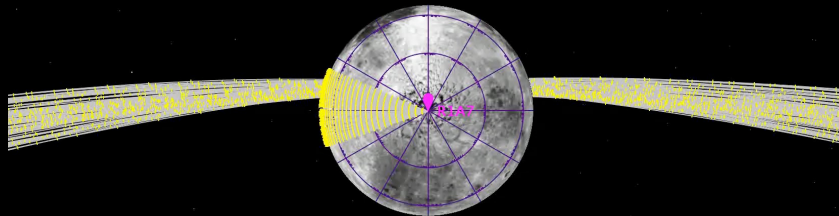




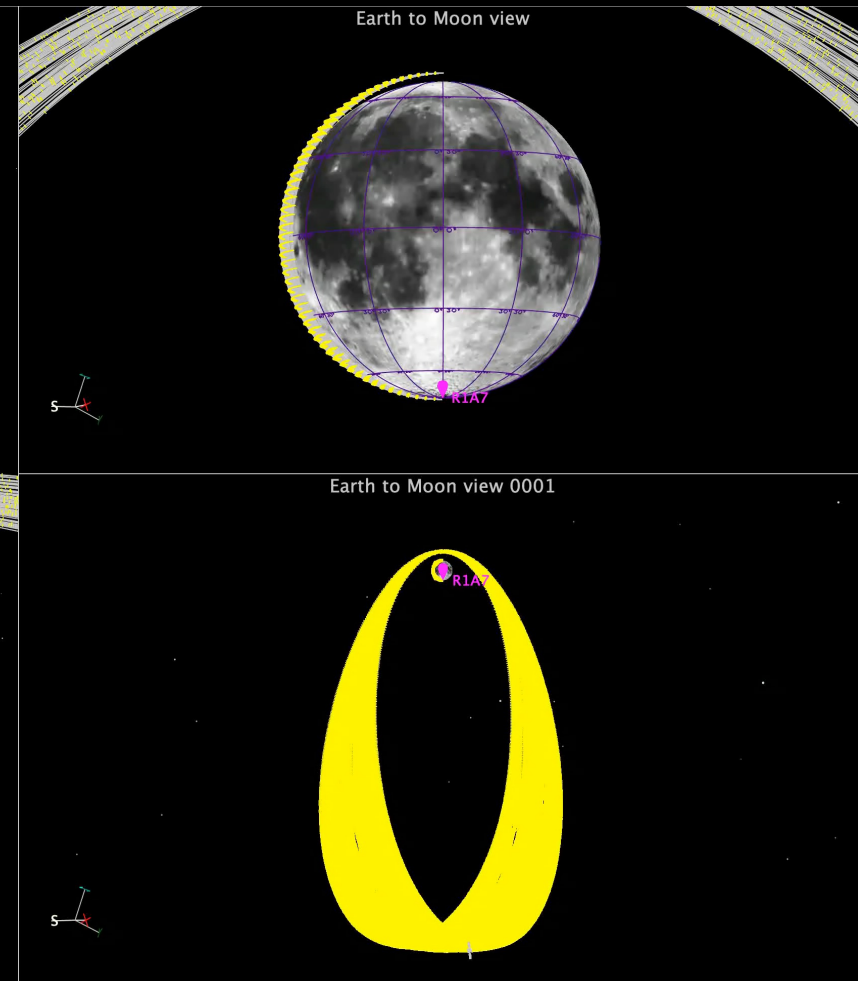
Characteristics of Near Rectilinear Halo Orbit



- ~6.5 day period
- Visible from Earth 100%
- Periapsis of ~1500 km and apoapsis nearly 70,000 km
- Due to variations in Moon and NRHO, approach path varies orbit-to-orbit but has general left to right direction



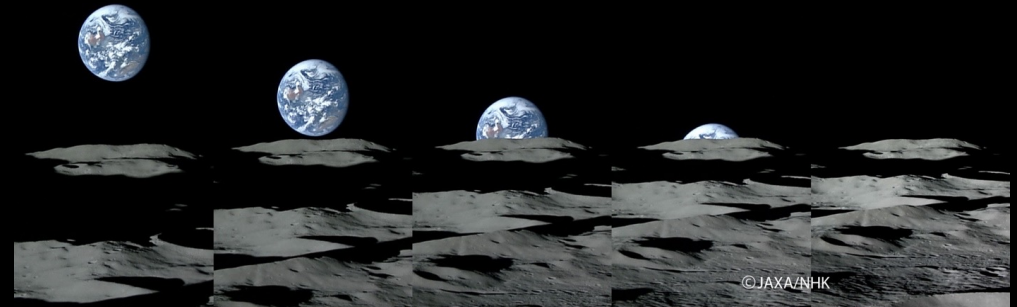
- Other Considerations:
 - Assumes Gateway fixed NRHO, so can only descend to the surface once every 6.5 days (~55 opportunities to land per year)
 - Earth/Moon orbital mechanics and SLS/Orion limitations reduce ability to get to NRHO to ~28 NRHO departure opportunities per year



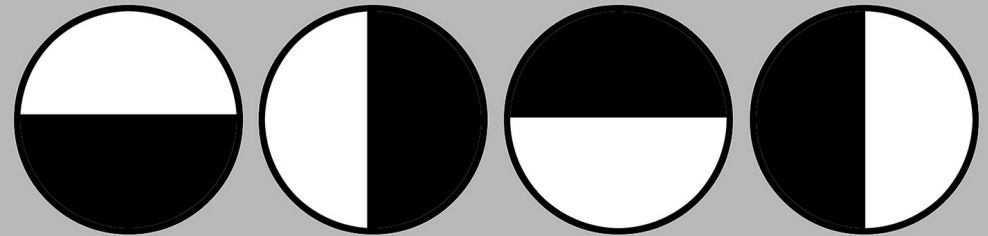
Characteristics of the South Pole



- Earth is upside down and spins backwards
- Same side of the moon always faces the Earth
- Sun and Earth only rise above the horizon ~2 to 7 deg
- Sun casts long shadows
- Earth is in a 2-week cycle: visible two weeks, not visible two weeks
- Terminator, where light meets darkness, is not smooth
- Constantly changing lighting effects at the pole



Lunar South Pole terminator rotates around the pole.



Low sun angle and dramatic topography cast long shadows; terminator is irregular

