



EXPLORE MOON_{to}MARS

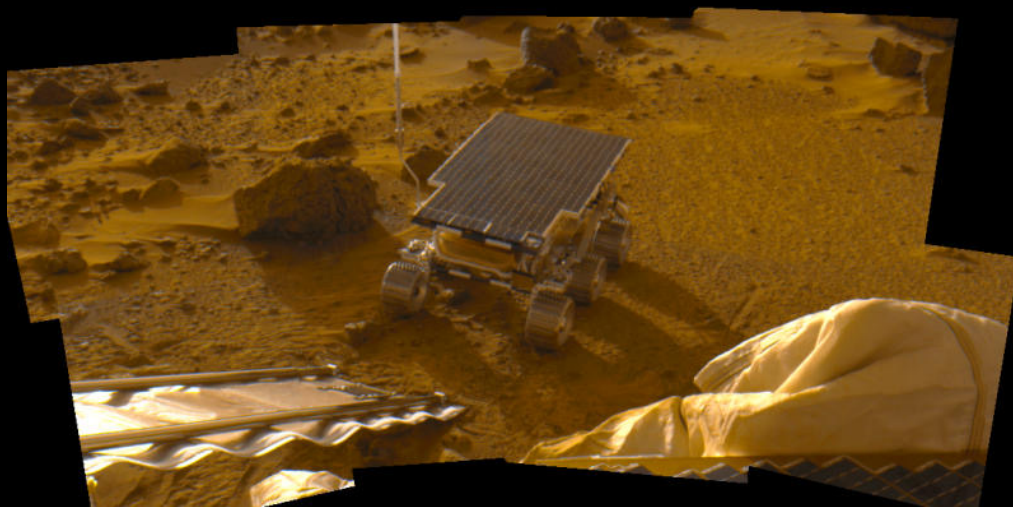
MOON LIGHTS THE WAY



Alicia Dwyer Cianciolo | NASA Langley Research Center



**January 22, 1998:
STS - 98 Launch**



Credit NASA/JPL

**July 4, 1997:
Pathfinder/Sojourner Rover
Landed on Mars**



Credit NASA



EXPLORE MARS

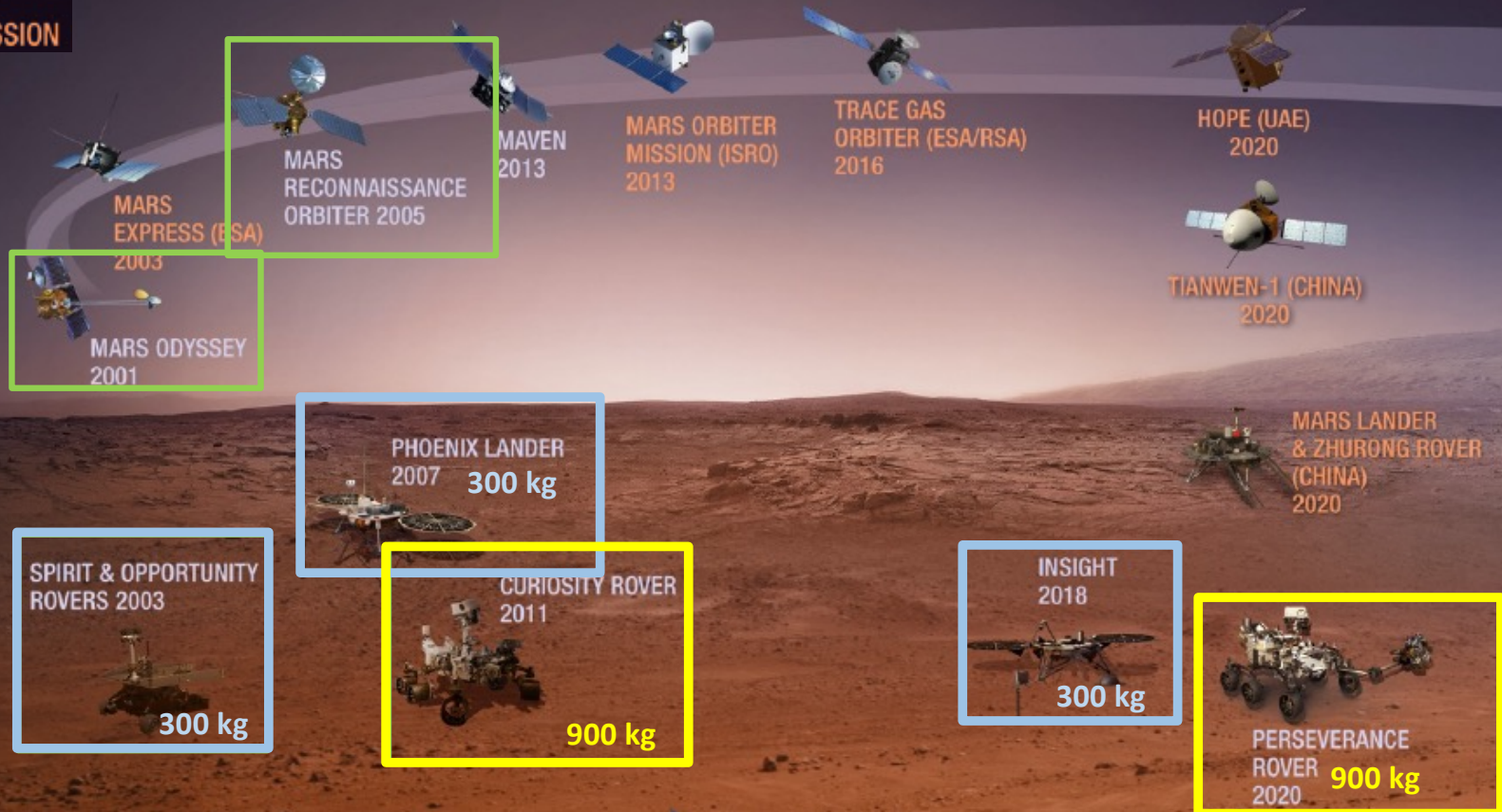


Mars Exploration In the Past 20 Years



2001–2022

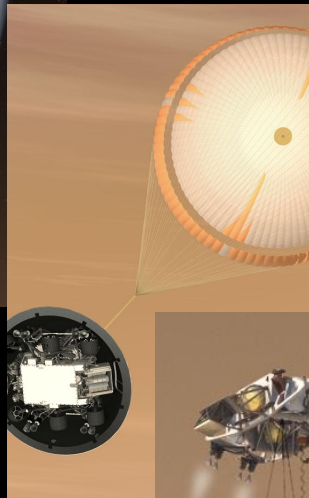
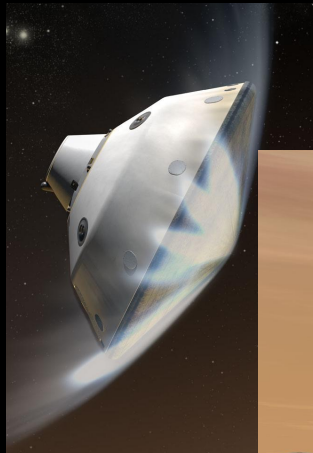
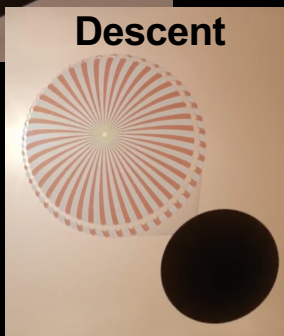
■ U.S. MISSION
■ NON-U.S. MISSION



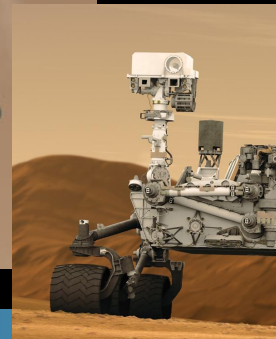
Landing on Mars



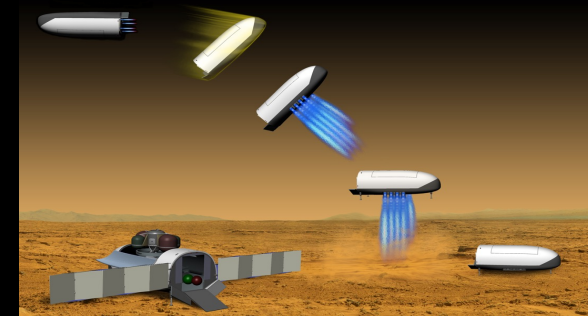
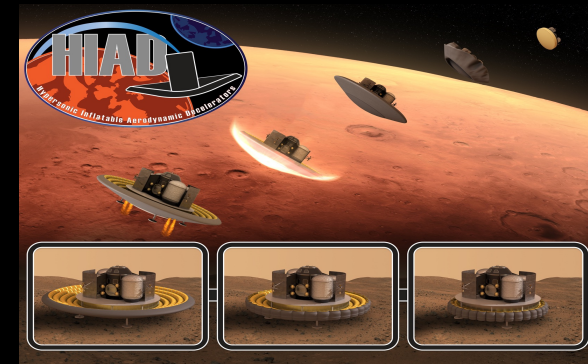
300 kg Class Payload



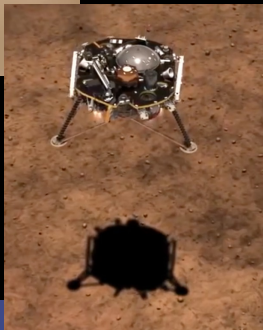
900 kg Class Payload



20,000 kg Class Payload



or



Images: NASA/JPL-Caltech



EXPLORE MOON



“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.”

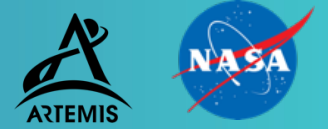
“U.S. human and robotic space exploration missions will land [the first woman and person of color on the Moon](#), advance a robust cislunar ecosystem, continue to leverage human presence in low-Earth orbit to enable people to live and work safely in space, and prepare for future missions to Mars and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

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

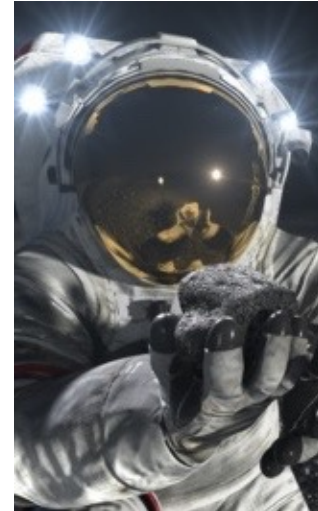
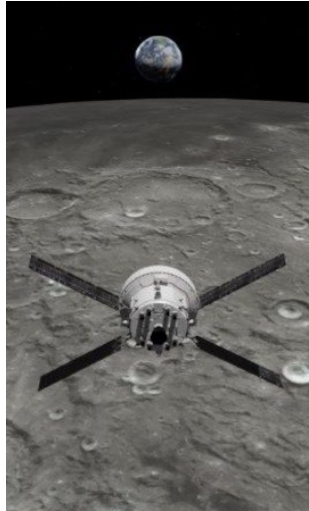
[United States Space Priorities Framework](#)
[NASA 2022 Strategic Plan](#)
[2023 NASA Budget Request](#)



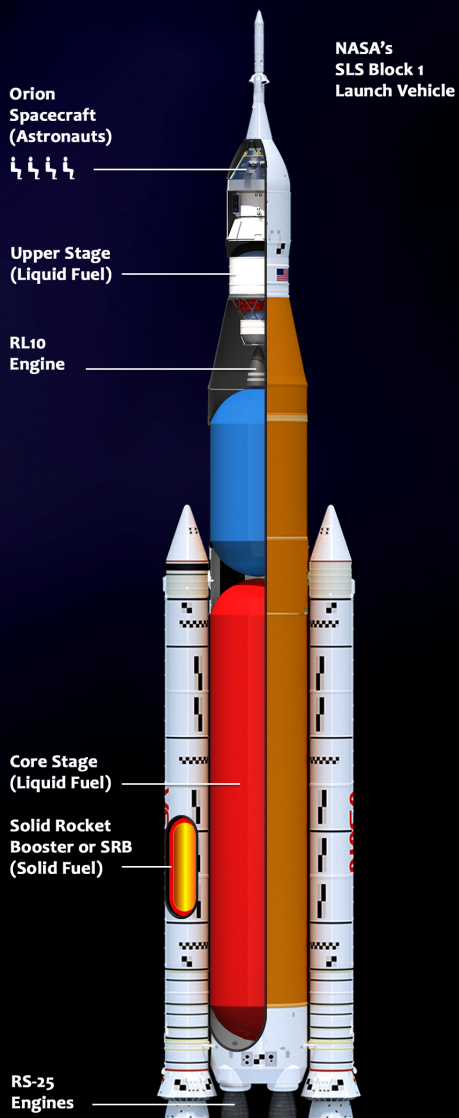
What is Artemis?



*Extravehicular
Activity and
Human Surface
Mobility Program



Combines programs into missions



Space Launch System



SLS will produce 13% more thrust at launch than the space shuttle and 15% more than Saturn V during liftoff and ascent.



Saturn V
7.5 million pounds



Space Shuttle
7.8 million pounds



SLS
8.8 million pounds

SLS will launch more cargo to the Moon than the space shuttle could send to low-Earth orbit.



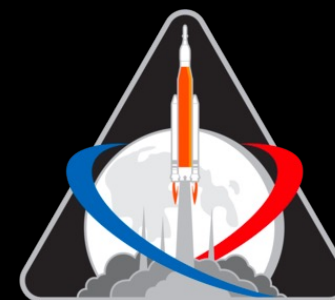
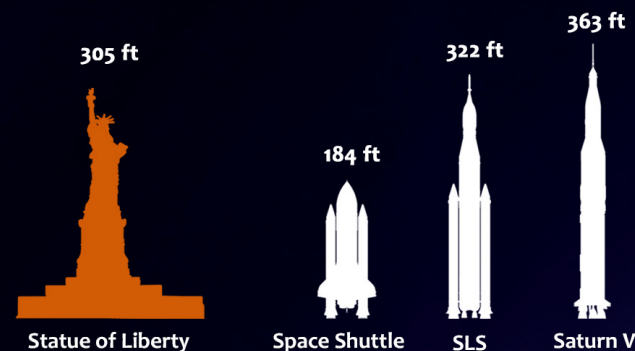
Space Shuttle
cargo to
low-Earth orbit



SLS cargo
to the Moon

www.nasa.gov/sls

If you wonder how NASA's Space Launch System, or SLS, compares to earlier generations of NASA launch vehicles:

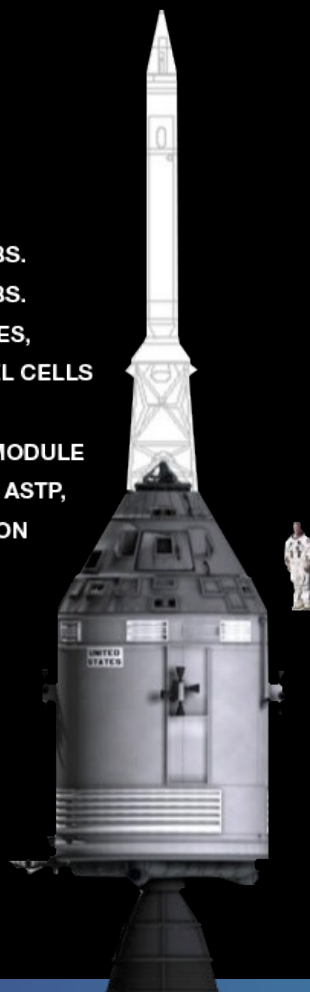


Orion



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

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



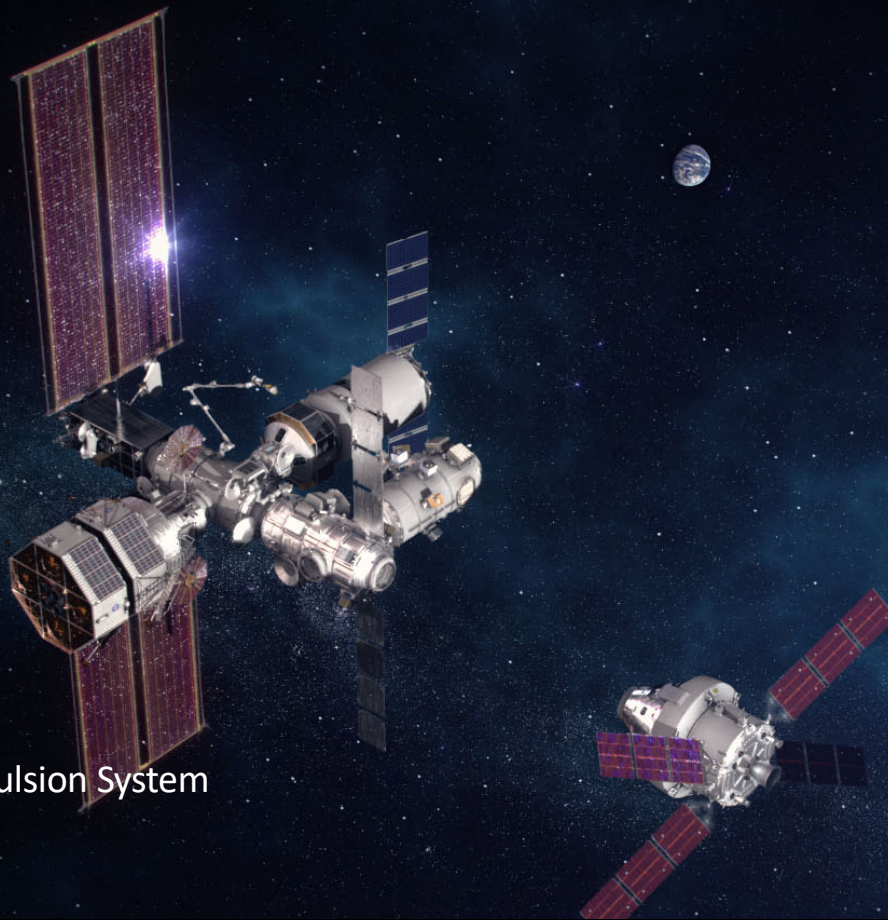
Single Stage Lander



Gateway

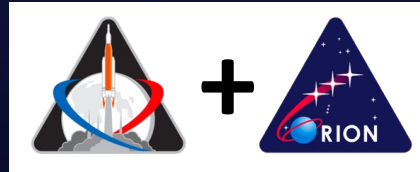


High power Solar Electric Propulsion System
And Pressurized Crew Module
Stationed in NRHO





Combine programs into missions.



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



A B C
CUBESATS DEPLOY
ICPS deploys 10
CubeSats total

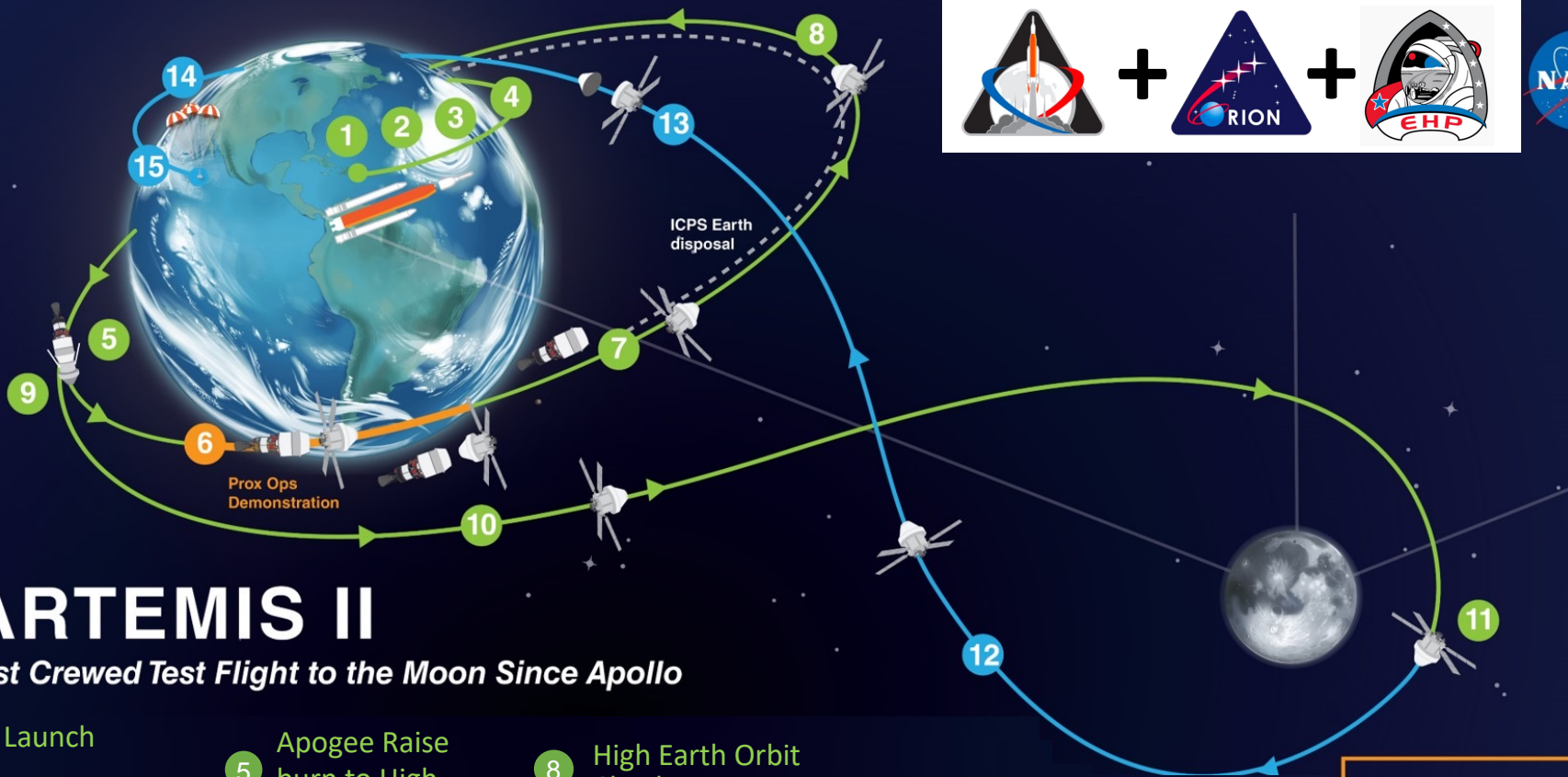
MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

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

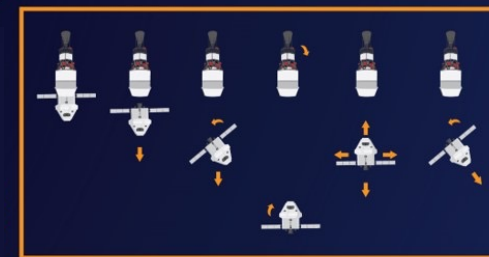


ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

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

Proximity Operations Demonstration Sequence



https://www.nasa.gov/sites/default/files/thumbnails/image/artemis_2_map_october_2021.jpg

Meet the Artemis II Crew



Reid Wiseman
Commander

Victor Glover
Pilot

Christina Hammock Koch
Mission Specialist

Jeremy Hansen
Mission Specialist

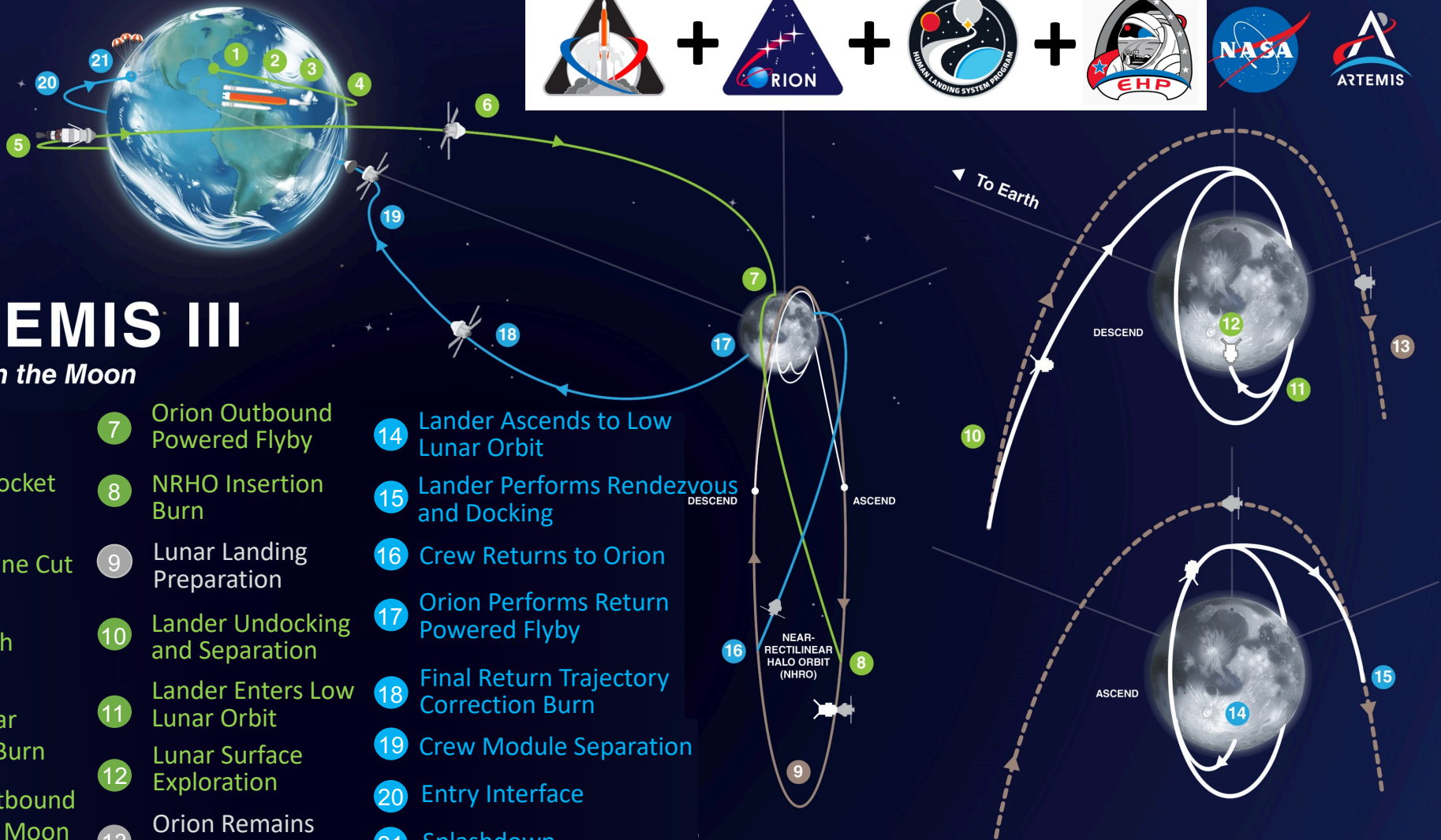


Credit: NASA

ARTEMIS III

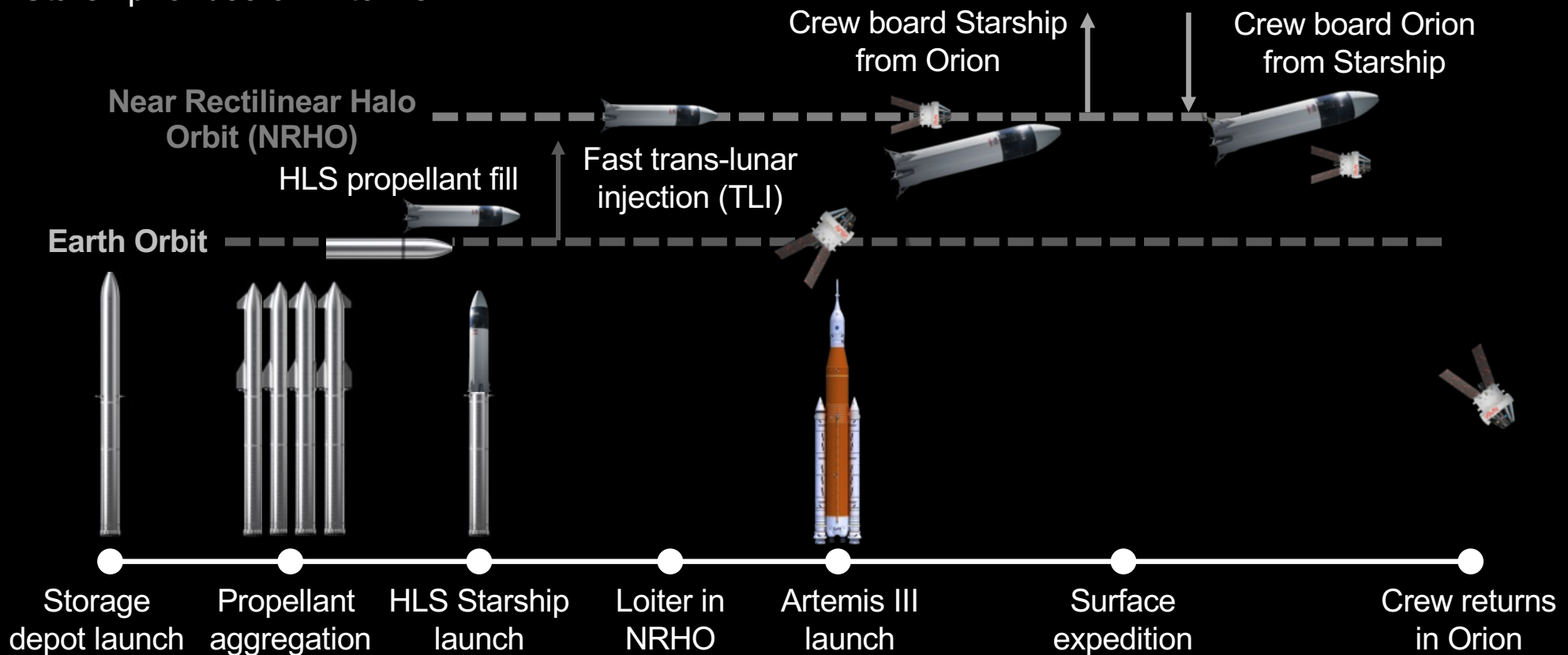
Landing on the Moon

- 1 Launch
- 2 Jettison Rocket Boosters
- 3 Main Engine Cut Off
- 4 Enter Earth Orbit
- 5 Trans Lunar Injection Burn
- 6 Orion Outbound Transit to Moon
- 7 Orion Outbound Powered Flyby
- 8 NRHO Insertion Burn
- 9 Lunar Landing Preparation
- 10 Lander Undocking and Separation
- 11 Lander Enters Low Lunar Orbit
- 12 Lunar Surface Exploration
- 13 Orion Remains in NRHO
- 14 Lander Ascends to Low Lunar Orbit
- 15 Lander Performs Rendezvous and Docking
- 16 Crew Returns to Orion
- 17 Orion Performs Return Powered Flyby
- 18 Final Return Trajectory Correction Burn
- 19 Crew Module Separation
- 20 Entry Interface
- 21 Splashdown



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





Challenges of Landing at the Lunar South Pole

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°

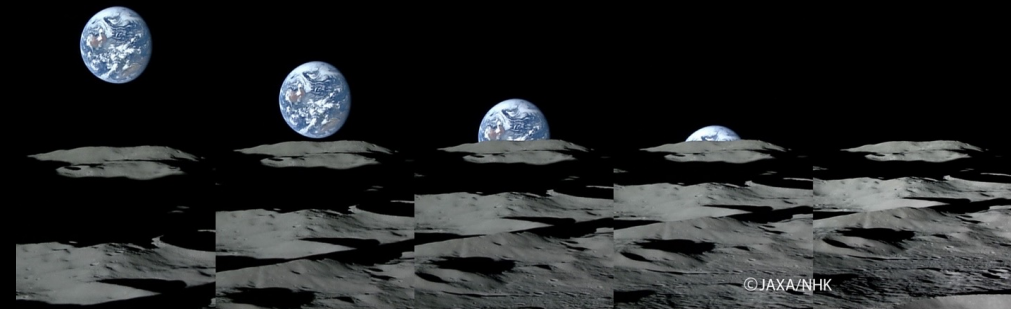
Characteristics of the South Pole



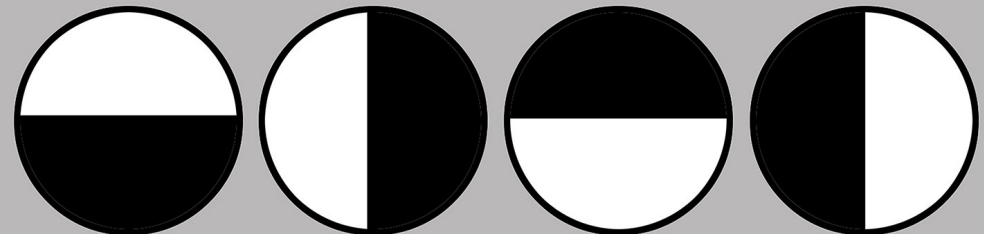
Characteristics of the South Pole



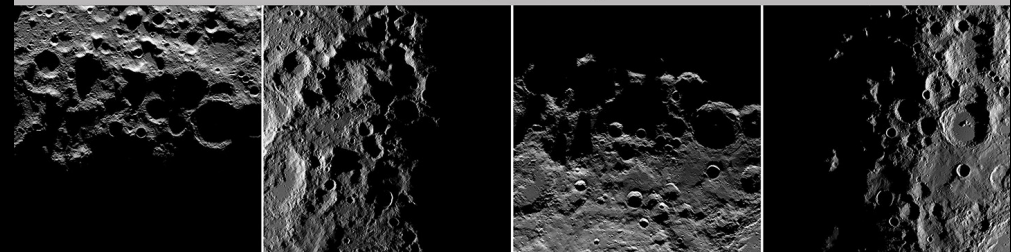
- Earth is upside down and spins backwards
- Same side of the moon always faces the Earth
- Sun and Earth only rise above the horizon ~2 to 7 deg
- Sun casts long shadows
- Earth is in a 2-week cycle: visible two weeks, not visible two weeks
- Terminator, where light meets darkness, is not smooth
- Constantly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



Lunar South Pole terminator rotates around the pole.



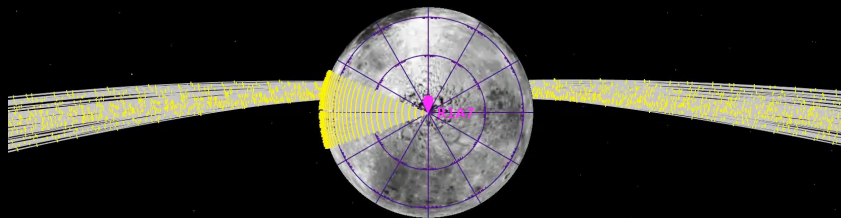
Low sun angle and dramatic topography cast long shadows; terminator is irregular



Characteristics of Near Rectilinear Halo Orbit

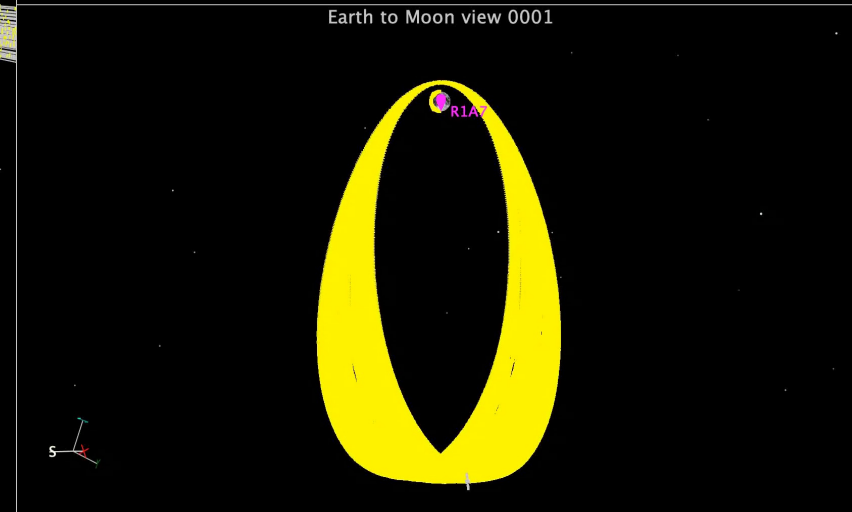
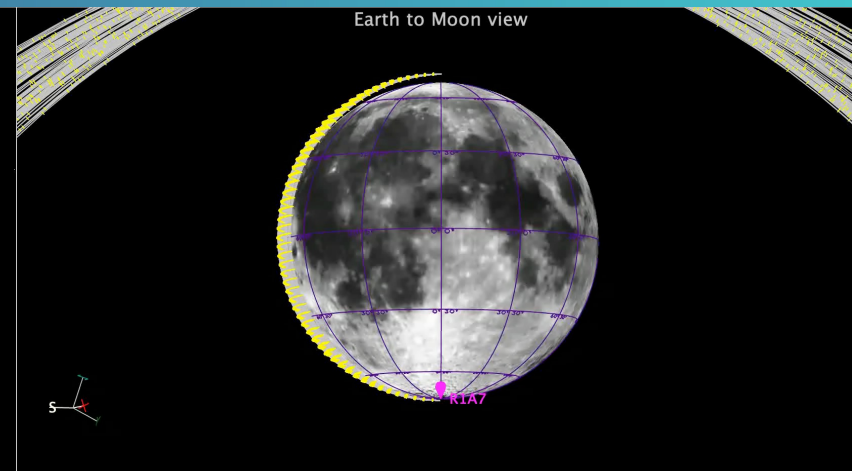


- ~6.5 day period
- Visible from Earth 100%
- Periapsis of ~1500 km and apoapsis nearly 70,000 km
- Due to variations in Moon and NRHO, approach path varies orbit-to-orbit but has general left to right direction



- 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

.Moon CR Observer View
2024/01/01 04:16:00.0000 UTC
.Moon CR Observer, .Moon Nadir, [km s deg]



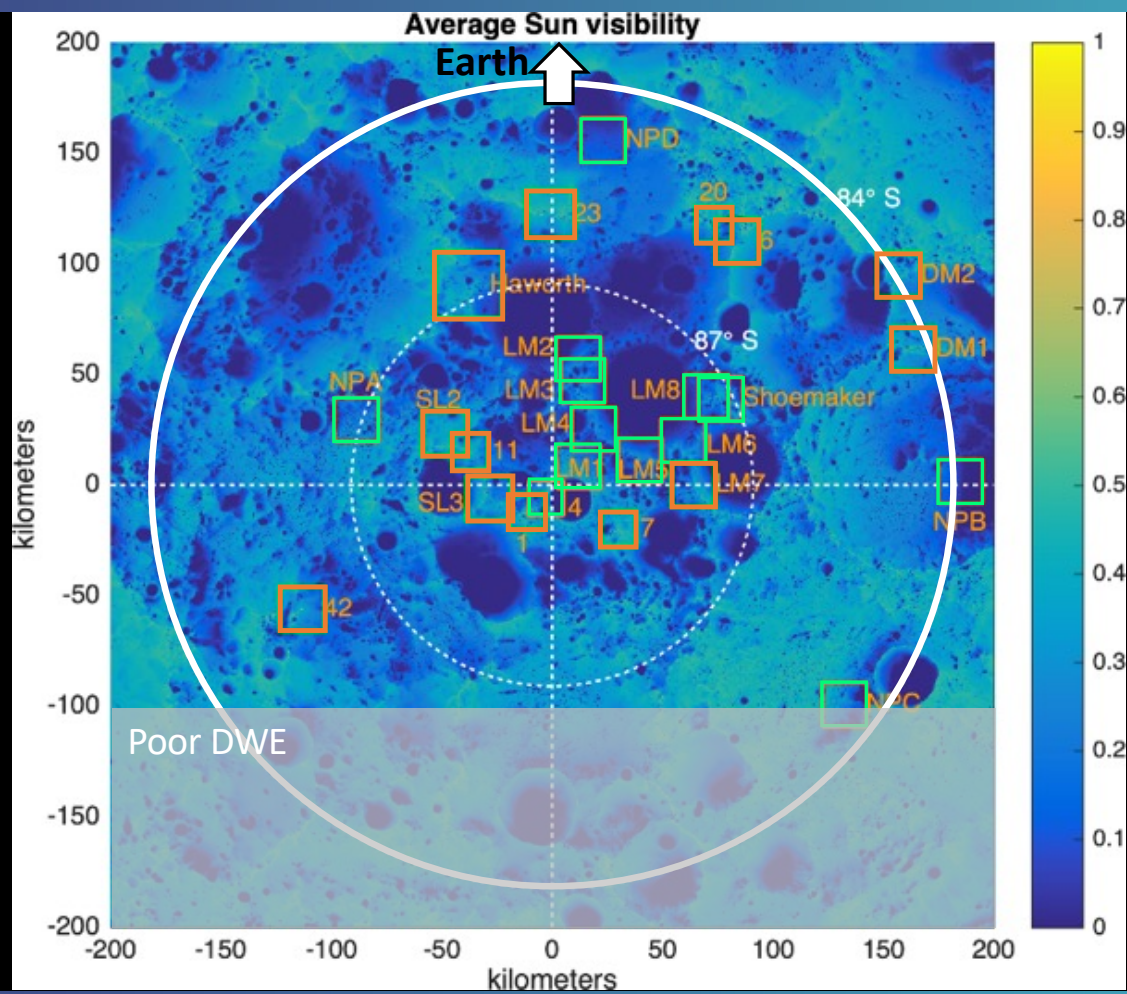
Key Artemis III Landing Requirements



1. Land within 6 deg latitude of the South Pole
2. Surface slope for landing (100m): <10 deg
3. Surface slope limit for EVA (2km): <20 deg
4. Direct with Earth (DWE) communication; assume no comm relay is available
5. Lighting
 - a. Surface Lighting
 - b. Approach lighting
6. Land within 100 m of a target

Objective: Identify locations that are viable for landing and meet all requirements and constraints

1. Land within 6 deg latitude of the pole



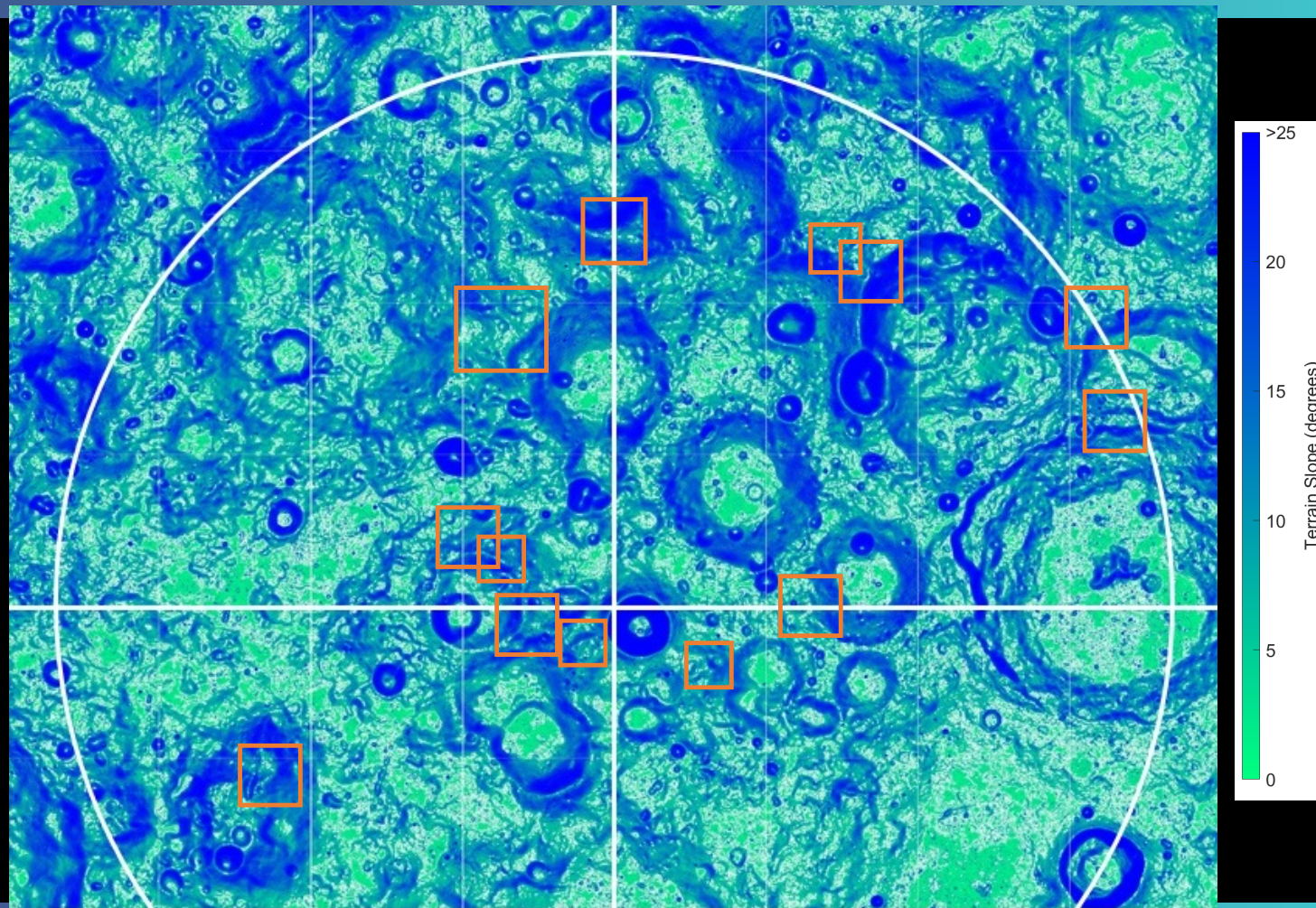
2. Surface slope for landing: <10 deg



Slopes for landing must be less than 10 deg

Green areas show slopes less than 10 deg

White contours show regions of continuous 8 deg slope



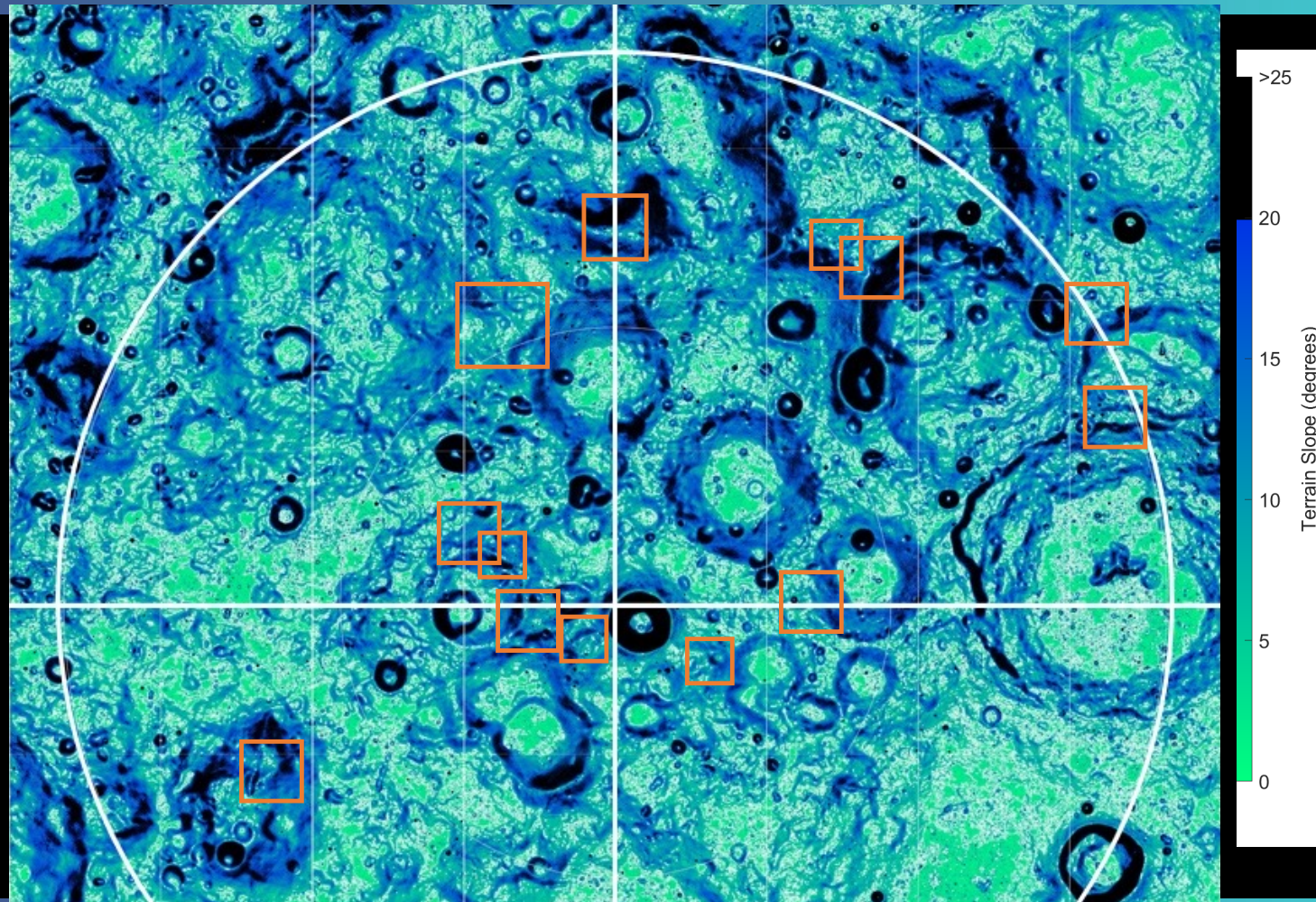
3. Surface slope for EVA: <20 deg



Slopes for
Extravehicular Activity
(EVA) must be less
than 20 deg

Black designates areas
of slope > 20 deg

No EVAs can occur in
black areas



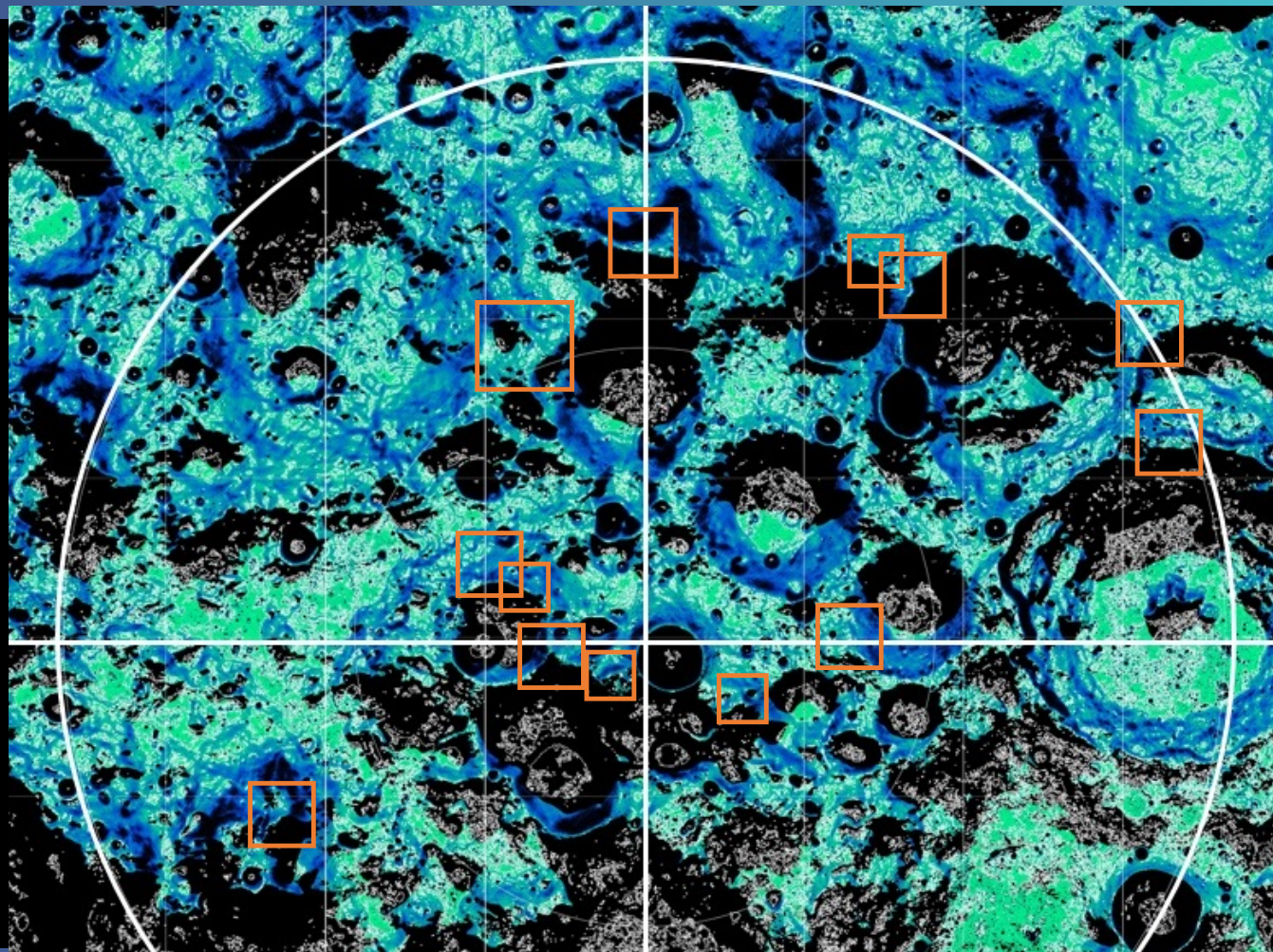
4. Direct with Earth Communication



Artemis III will require
Earth to be visible for
communications

Black designates areas
of slope > 20 deg
+
Earth visibility $< 25\%$

Reduces areas suitable
for landing.



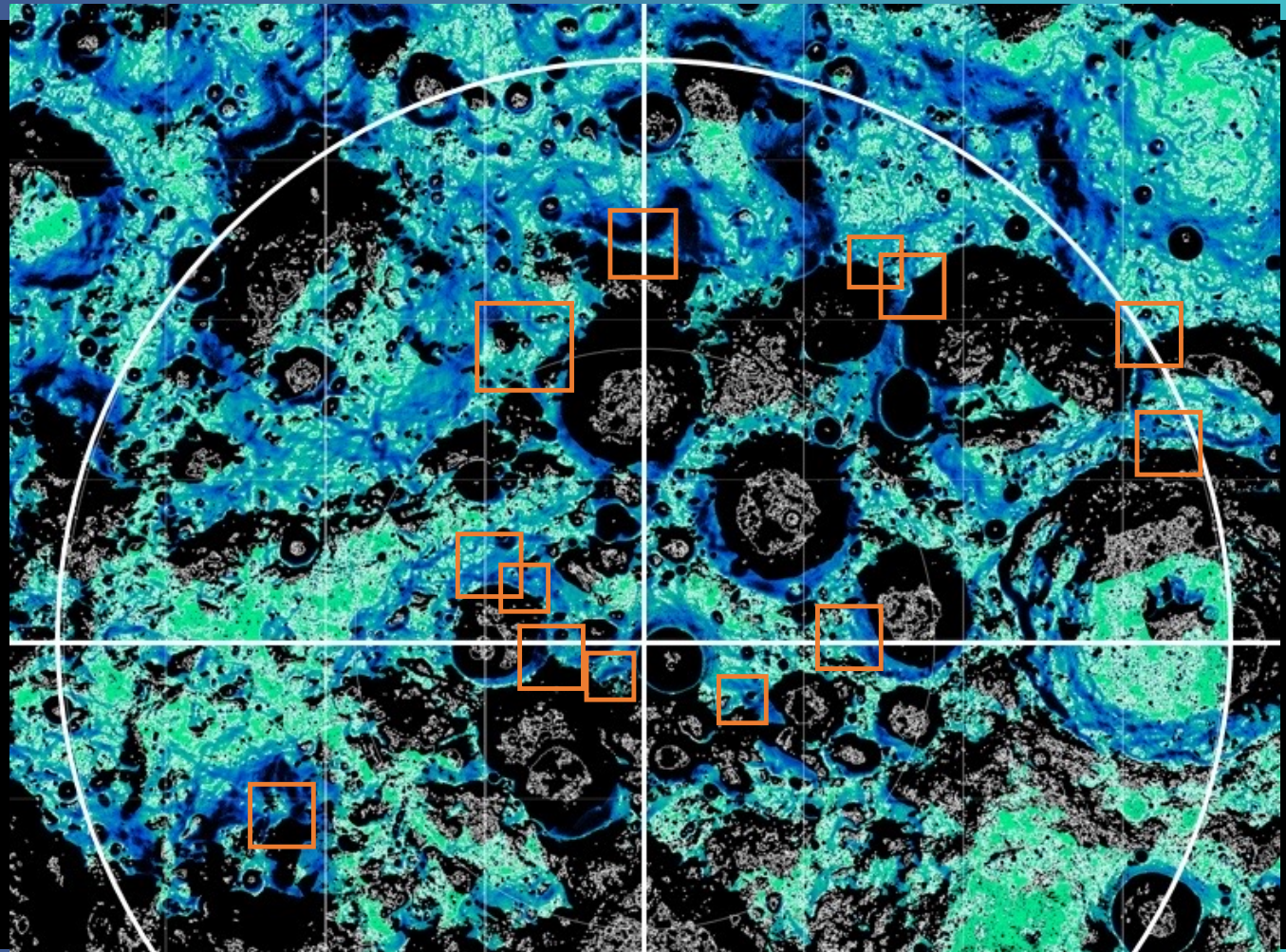
5a. Surface Lighting



Artemis III will require
the surface to be lit for
the duration of the
surface stay

Black designates areas
of slope > 20 deg
+
Earth visibility $< 25\%$
+
Solar visibility less 5%

Reduces areas suitable
for landing.



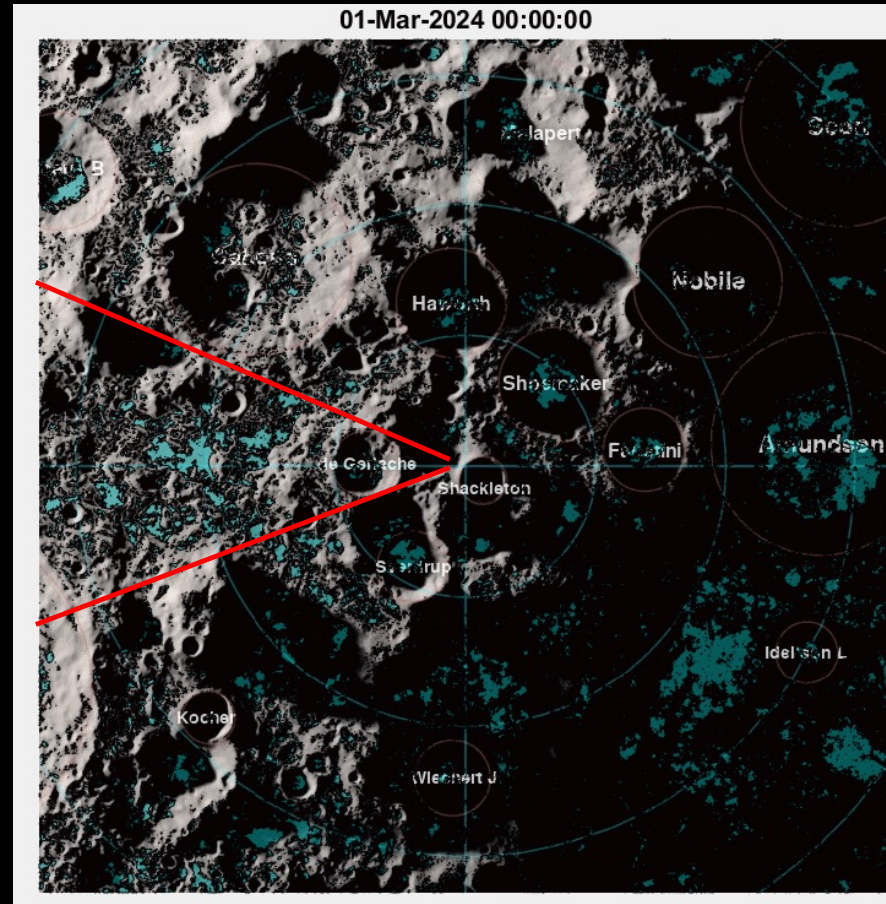
5b. Approach Lighting



Illumination along the approach trajectory is beneficial.

The approach trajectory is different for each landing opportunity.

Notional range designated in red



Peak lighting conditions are periodic and shift 2-3 weeks earlier each year, where by 2030, peak solar illumination occurs around the month of August

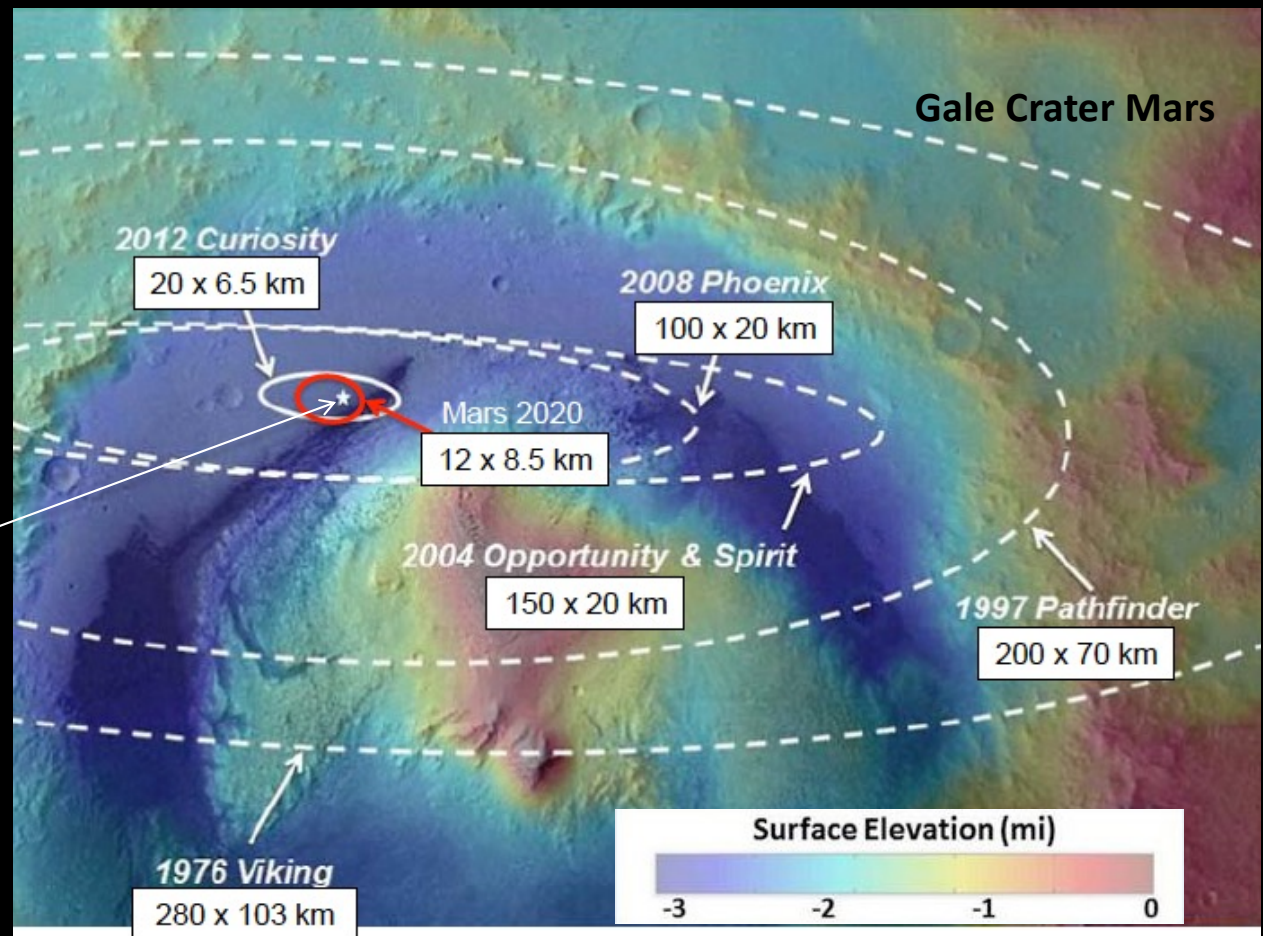
6. Land within 100m of a target



Past Robotic mission
landing performance at
Mars

Apollo 11 landing ellipse:
17 x 5 km

Human Landing
Accuracy Requirements
100 m x 100 m





Looking Forward



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



