National Aeronautics and Space Administration

Artemis
Human Landing System
Deorbit, Descent, and Landing

Alicia Dwyer Cianciolo NASA Langley Research Center

Bryan Welch NASA Glenn Research Center

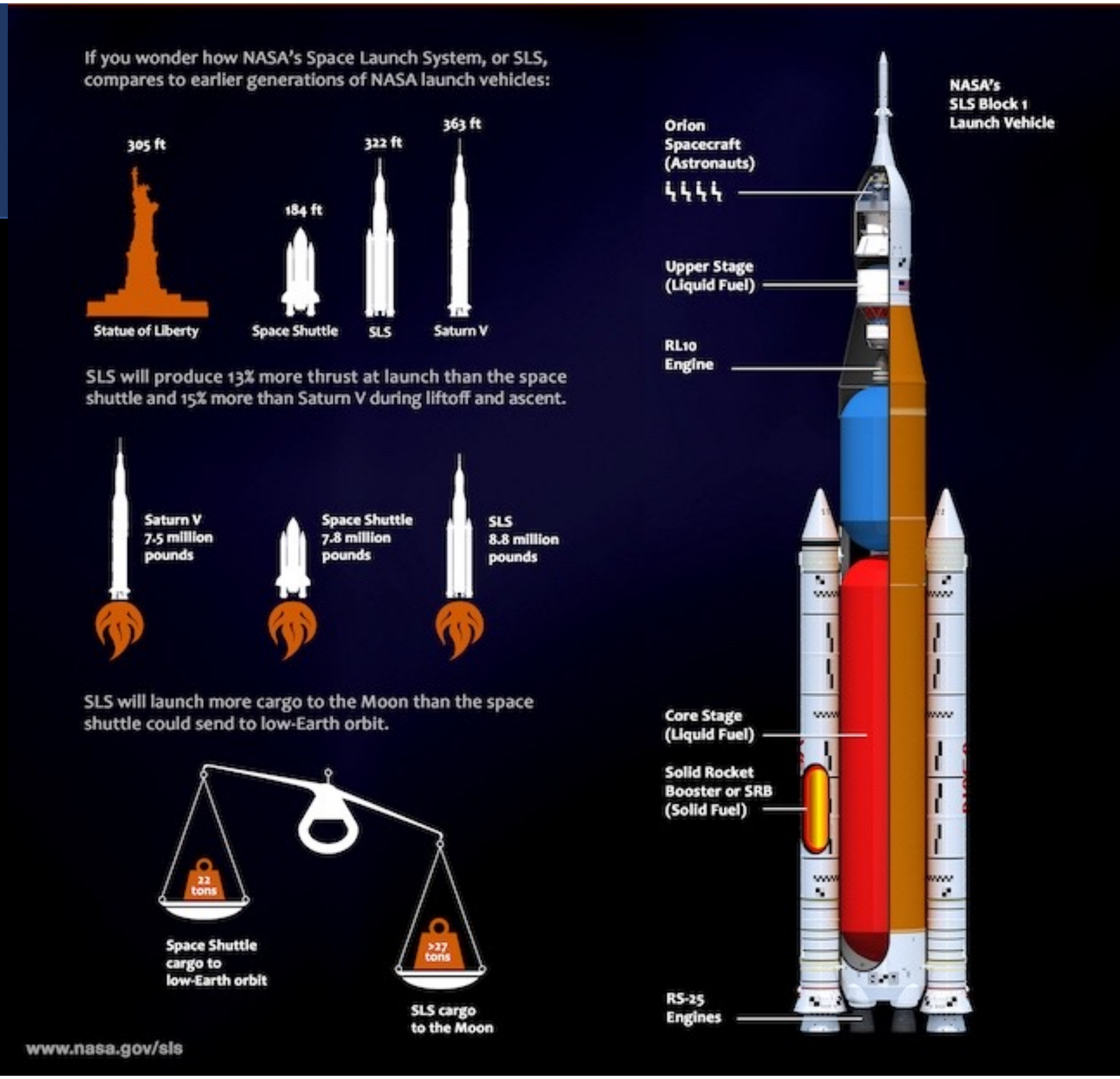
July 21, 2022

What is Artemis?

ARTEMIS = SLS + ORION + HUMAN LANDING SYSTEM PROGRAM + Extravehicular Activity and Human Surface Mobility Program (EHP) + GATEWAY

Combines programs into missions

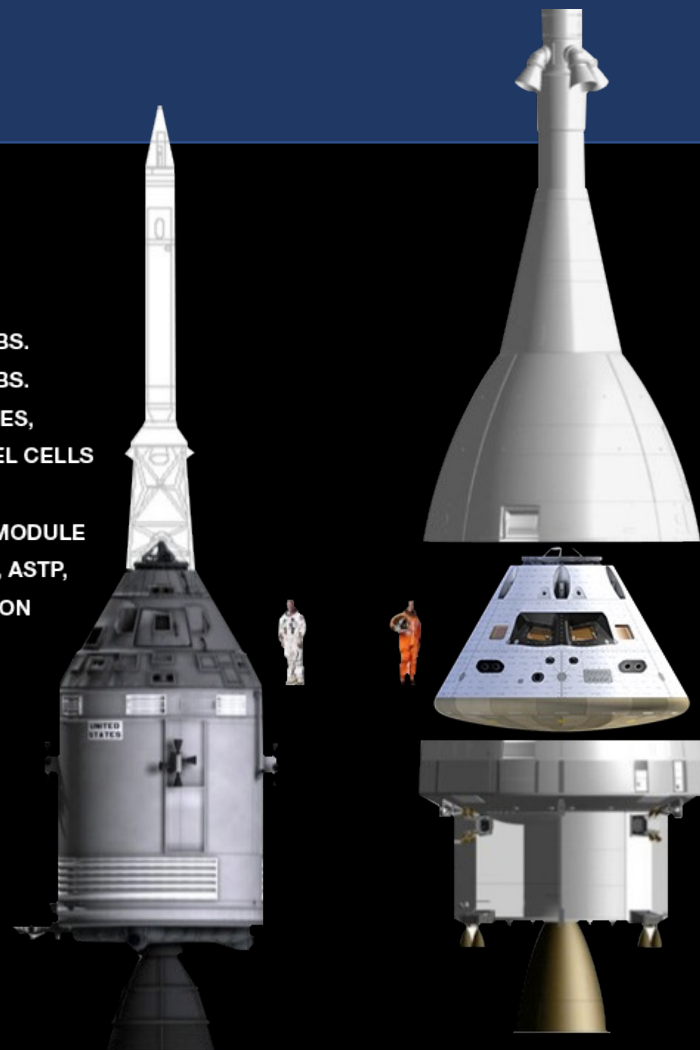
Space Launch System



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



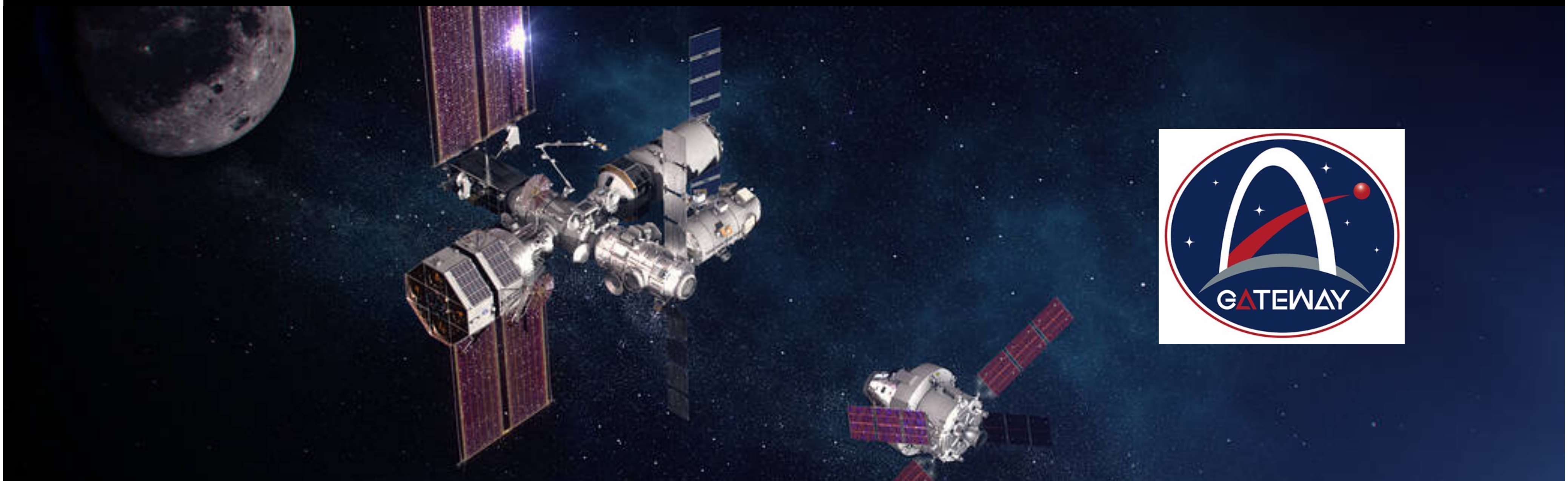
ORION

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

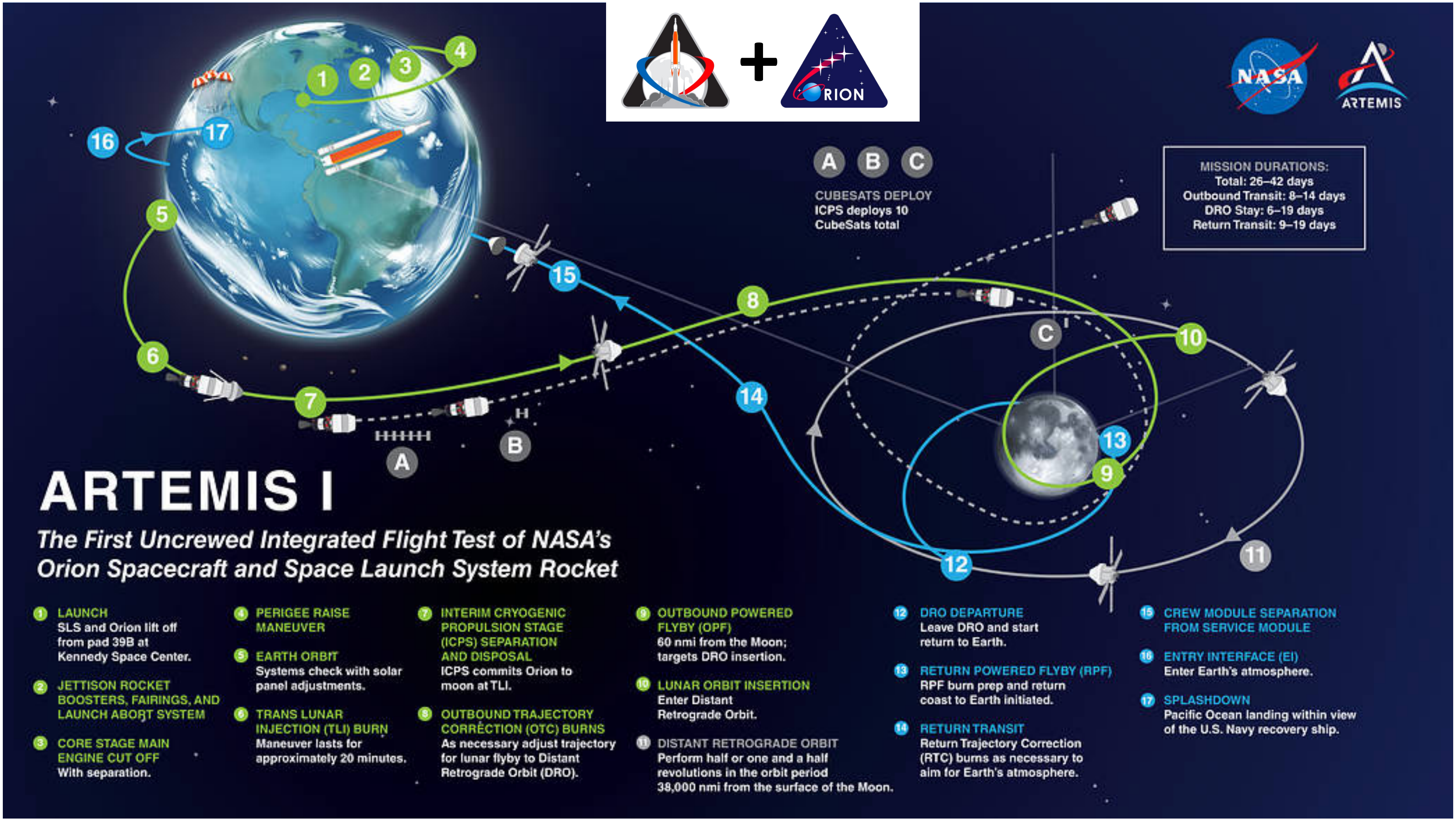
Single Stage Lander

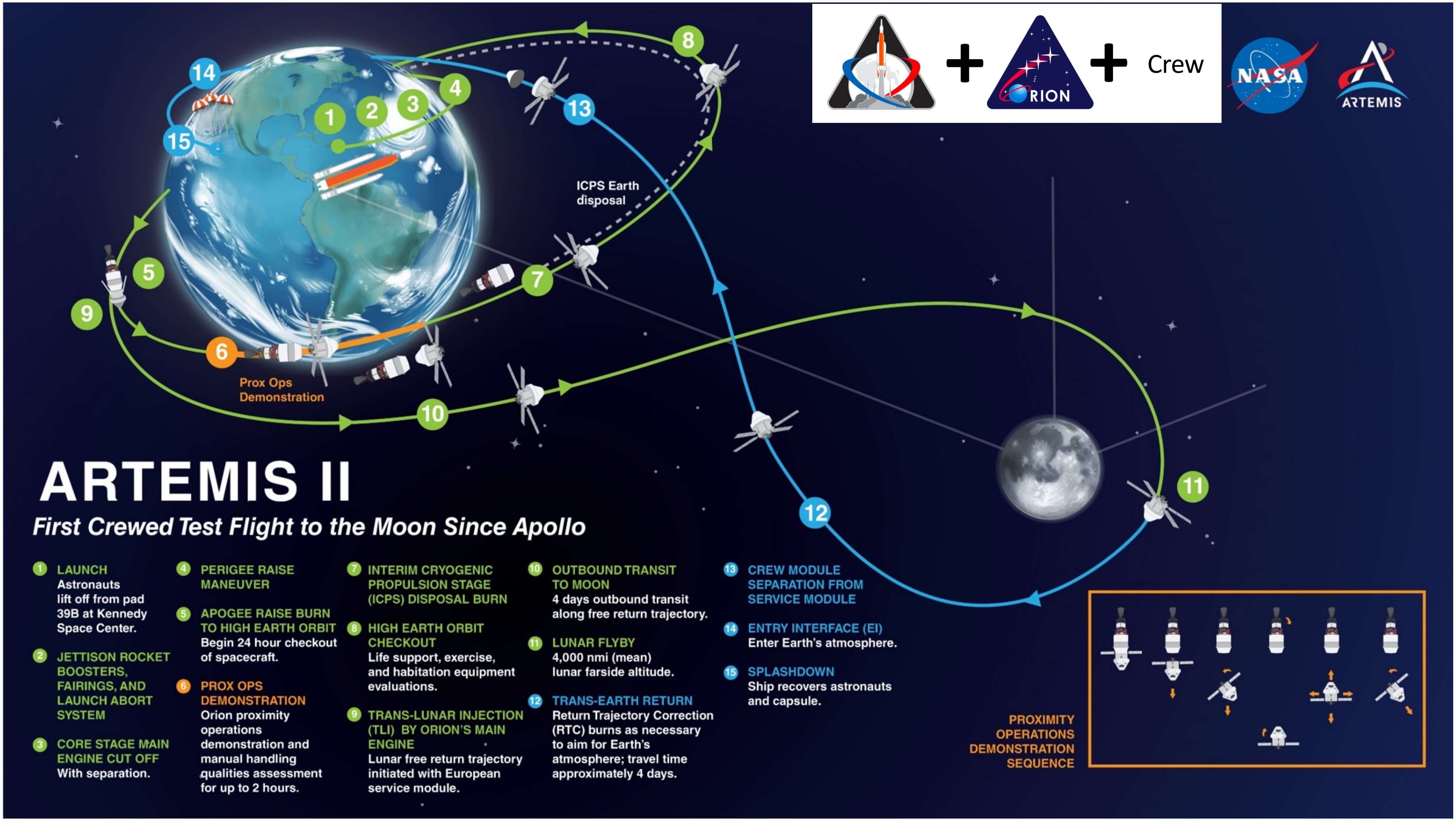
Gateway



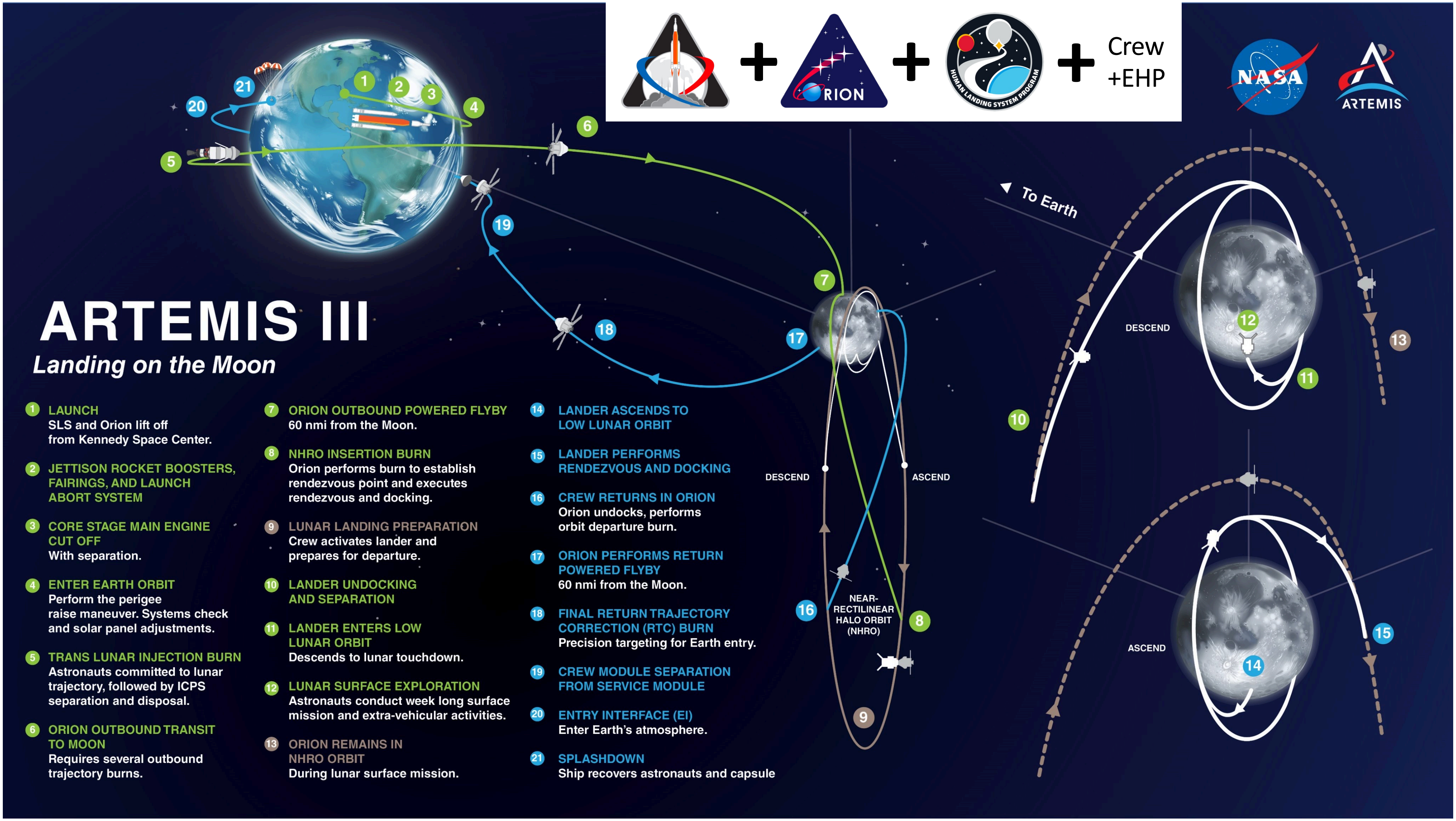
High power Solar Electric Propulsion System
And Pressurized Crew Module
Stationed in NRHO

Combine programs into missions.


ARTEMIS I
The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket
ORION
NASA
ARTEMIS
MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days
CUBESATS DEPLOY
ICPS deploys 10
CubeSats total
1 LAUNCH
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 (OTC) BURNS
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9 OUTBOUND POWERED FLYBY (OPF)
60 nmi from the Moon; targets DRO insertion.
10 LUNAR ORBIT INSERTION
Enter Distant Retrograde Orbit.
11 DISTANT RETROGRADE ORBIT
Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12 DRO DEPARTURE
Leave DRO and start return to Earth.
13 RETURN POWERED FLYBY (RPF)
RPF burn prep and return coast to Earth initiated.
14 RETURN TRANSIT
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere.
15 CREW MODULE SEPARATION FROM SERVICE MODULE
16 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.
17 SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ship.



+ + Crew
NASA
ARTEMIS
14
15
1
2
3
4
8
13
ICPS Earth disposal
5
9
6
7
Prox Ops Demonstration
10
11
12
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 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 24 hour checkout of spacecraft.
6 PROX OPS DEMONSTRATION Orion proximity operations demonstration and manual handling qualities assessment for up to 2 hours.
7 INTERIM CRYOGENIC PROPULSION STAGE (ICPS) DISPOSAL BURN
8 HIGH EARTH ORBIT CHECKOUT Life support, exercise, and habitation equipment evaluations.
9 TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE Lunar free return trajectory initiated with European service module.
10 OUTBOUND TRANSIT TO MOON 4 days outbound transit along free return trajectory.
11 LUNAR FLYBY 4,000 nmi (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.
PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE


+ + + Crew
+EHP
RION
HUMAN LANDING SYSTEM PROGRAM
NASA
ARTEMIS
ARTEMIS III
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
DESCEND
ASCEND
NEAR-RECTILINEAR HALO ORBIT (NHRO)
To Earth
DESCEND
ASCEND

ORION GATEWAY + Crew

ARTEMIS IV

International Habitation Module delivery to Gateway

1. **LAUNCH**
   SLS with I-HAB payload and crewed 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**
   Exploration Upper Stage commits Astronauts in Orion and I-HAB to lunar trajectory.
6. **ORION TUGS I-HAB TO MOON**
   Orion separation from USA, docking with I-HAB and extraction from USA followed by Orion tug of I-HAB to NRHO and EUS disposal.
7. **ORION OUTBOUND TRANSIT TO MOON**
   Requires several outbound trajectory burns.
8. **ORION OUTBOUND POWERED FLYBY**
   60 nmi from the Moon.
9. **GATEWAY ORBIT INSERTION BURN**
   Orion performs burn to establish rendezvous point and executes rendezvous and docking.
10. **INTERNATIONAL HABITATION MODULE ARRIVAL AT GATEWAY**
    I-HAB docking with Orion to Power and Propulsion Element (PPE) and Habitation and Logistic Outpost (HALO) module.
11. **I-HAB ACTIVATION AND CREW INGRESS**
    Astronauts ingress, activate and utilize I-HAB as part of larger Gateway complex.
12. **CREW RETURNS IN ORION**
    Orion undocks, performs orbit departure burn.
13. **ORION PERFORMS RETURN POWERED FLYBY**
    60 nmi from the Moon.
14. **FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**
    Precision targeting for Earth entry.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
17. **SPLASHDOWN**
    Ship recovers astronauts and capsule.

Deorbit, Descent, and Landing

Deorbit, Descent, and Landing

Orbit Loiter Phase

- DSN state with dispersions, expected time before DOI
- Mass properties with dispersions

DOI
De-orbit Insertion

- TE Engine performance characteristics with dispersions

100 km

Coast to Perilune Phase

- Plan to use high altitude TRN? Passive or active?
- How does it improve state error after DOI?
- RCS engine specifications with dispersions to calculate attitude hold DV
- Onboard TRN maps

PDI
Powered Descent Initiation

15 km

Braking Phase 1

- TE Engine performance characteristics with dispersions

TES
TE Separation

- TE & DE Engine performance characteristics with dispersions
- Transition events (transfer of GNC, etc.)
- Separation dispersions
- IMU error propagation
- Navigation filter assumptions
- Window location and view angles during descent

PDC
Powered Descent Continuation

?? km

Braking Phase 2

- Main and RCS Engine switching logic, performance characteristics (differential throttle TVC, dispersions)
- Location, pointing direction, activation time/range/altitude of descent sensors (TRN, NDL, Velocimeter, range finder, cameras. hazard detection) with performance dispersions and alignment errors
- RCS performance characteristics
- Guidance algorithms
- Nav filter assumptions and error propagation
- Onboard TRN and HD maps
- Consider different landing sites, rock fields, etc.

PU
Pitch-Up

400 m

Final Approach Phase

OUTPUT:

- Simulation Descriptions
- 8000 case Monte Carlos
- Integrated system performance w.r.t
  - Landing location
  - Sensor data available to crew
  - Vehicle performance and mas margins (DV, prop, etc.)
    - Guidance performance
      - System closure

VDI
Vertical Decent Initiation

200 m

Touchdown

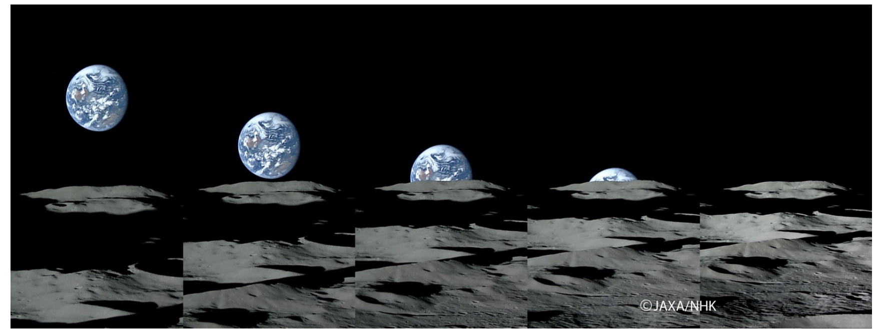
Manual Control Integration across all phases.

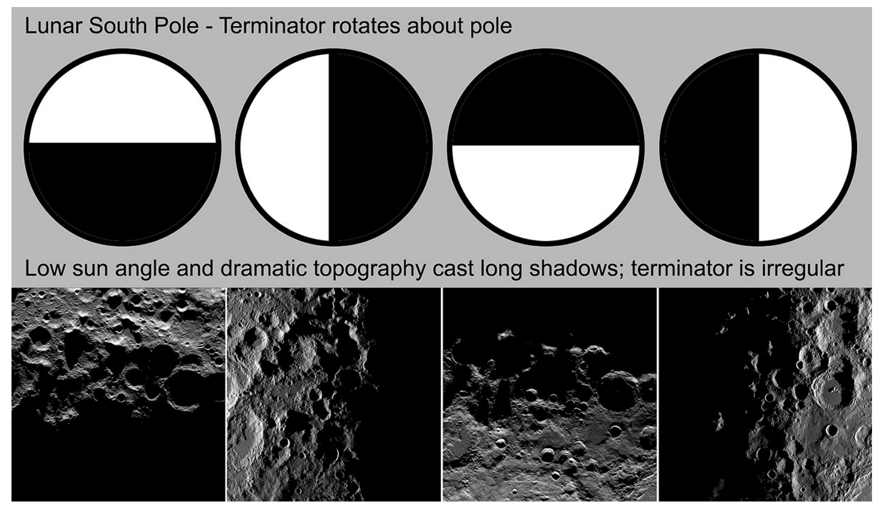
Challenges of landing at the lunar south pole

Characteristics of the South Pole

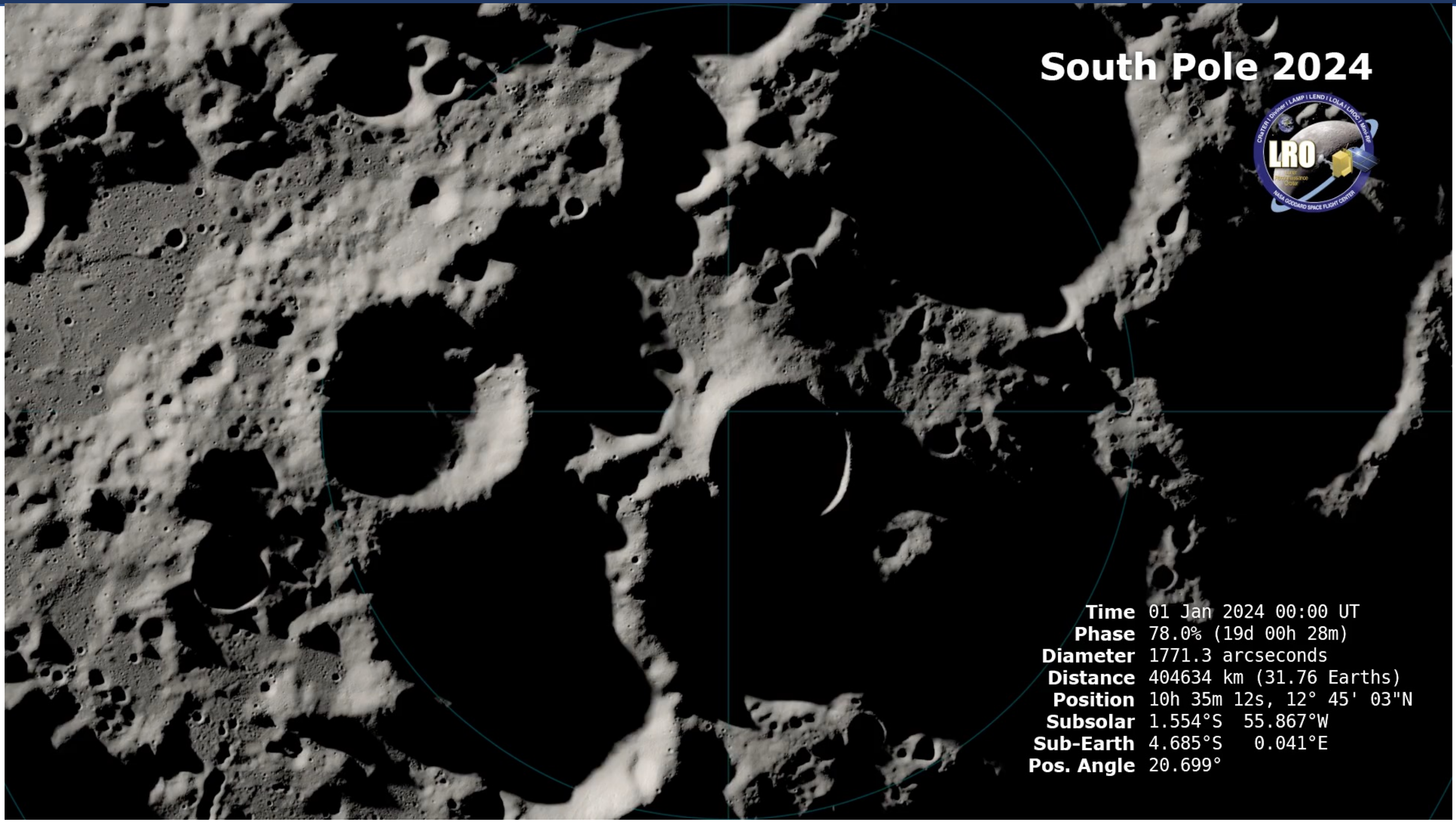
- Earth is upside down and spins backwards
- Sun and Earth only rise above the horizon ~2 to 7 deg, casting long shadows
- Same side always faces the Earth
- Earth is in a 2-week cycle: visible 2 weeks, not visible two weeks
- Terminator, where light meets darkness, is not smooth
- Constantly changing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

Kaguya "Earth-Set" from the Lunar South Pole



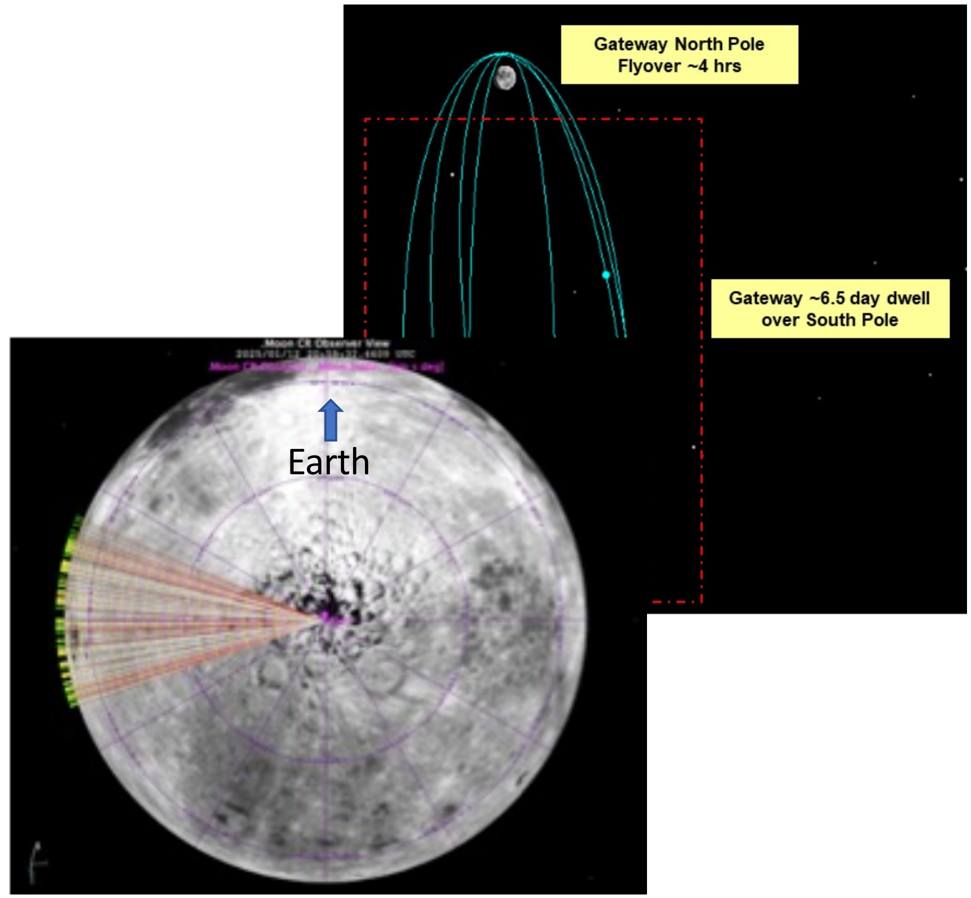


Characteristics of the South Pole



Characteristics of Near Rectilinear Halo Orbit (NRHO)

- ~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 descent to the surface once every 6.5 days (~55 opportunities to land per year)
  - Earth/Moon orbital mechanics limit and SLS limits reduce ability to get to NRHO to ~28 NRHO departure opportunities per year

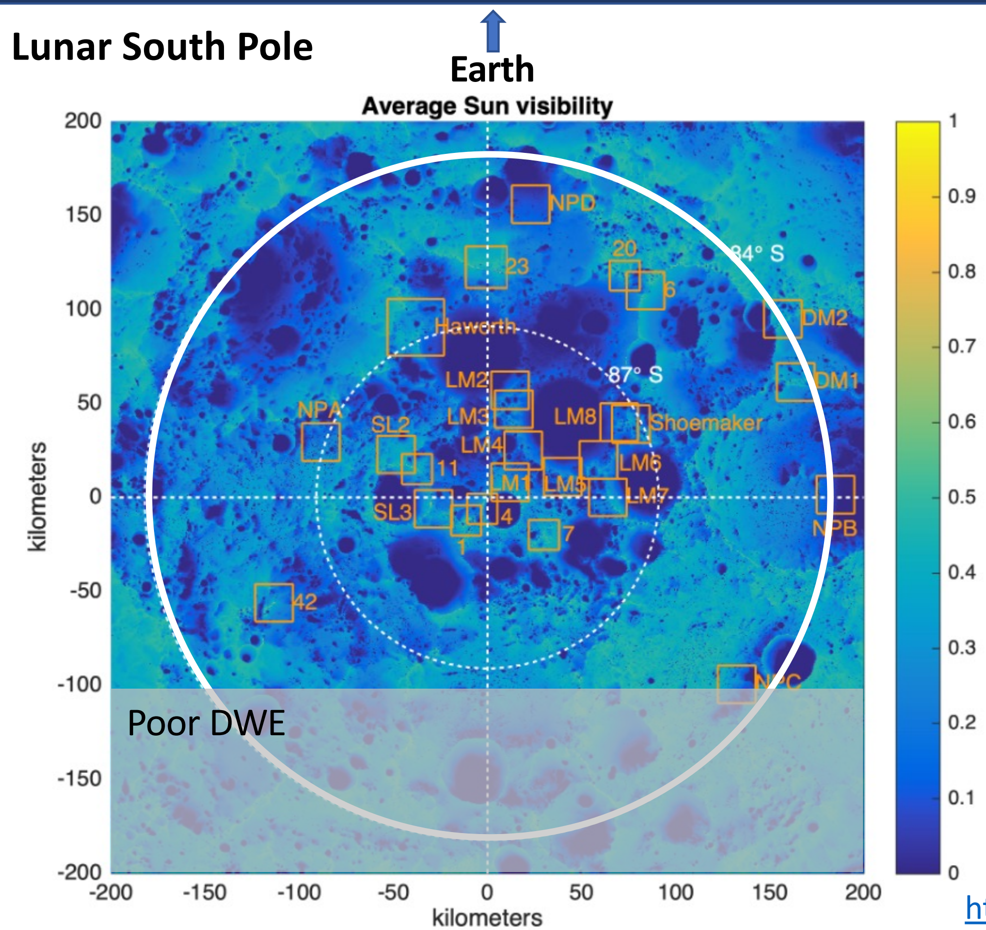
Key Artemis 3 Landing Requirements

1. Land within 6 deg latitude of the South Pole
2. Surface slope for landing: <10 deg
3. Surface slope limit for EVA: <20 deg
4. Direct with Earth (DWE) communication; assume no comm relay is available
5. Surface must be lit for whole surface stay duration: ~6.5 days
6. Land within 100 m of a target
   - Gateway phased NRHO approach from “left”
   - Passive TRN requires lit approach trajectory
   - Unknown how much of the trajectory needs to be illuminated

One strategy: Start by looking for the locations that are not available for landing

1. Land within 6 deg latitude of the pole

Orange boxes represent locations with highest fidelity resolution data with uncertainty datasets

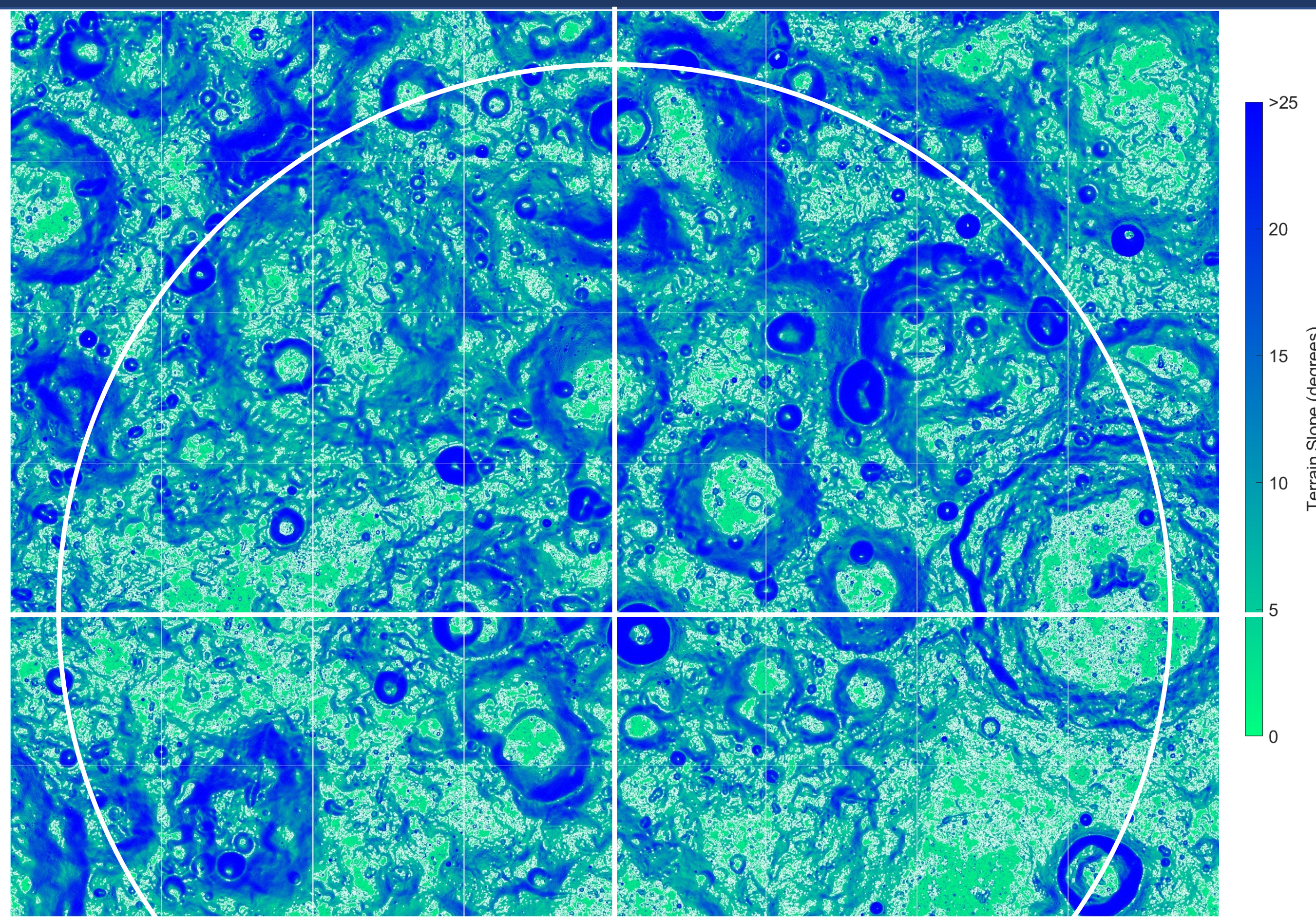


https://pgda.gsfc.nasa.gov/products/78

2. Surface slope for landing: <10 deg

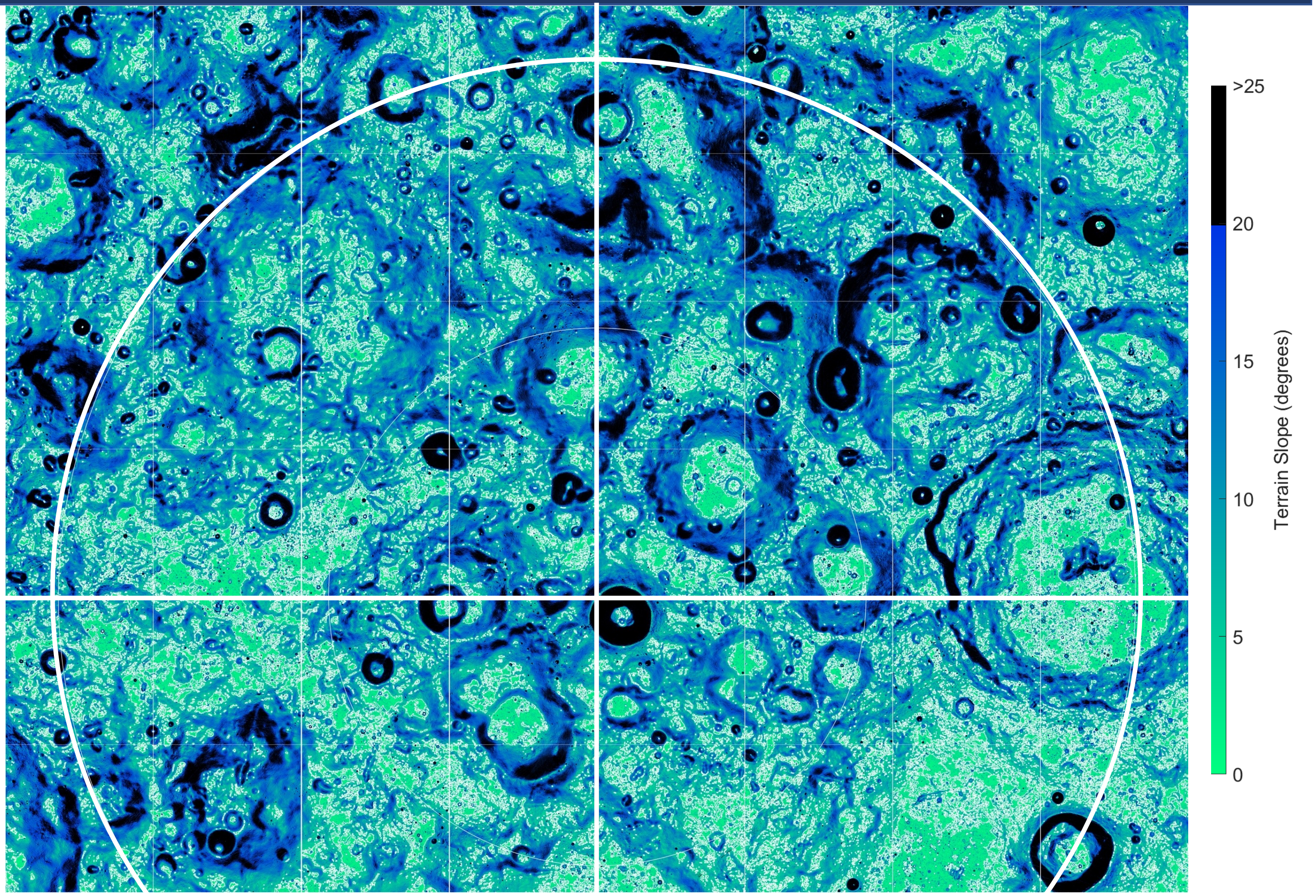
Green areas = slopes <10 deg

White contours show continuous regions of 8 deg slope



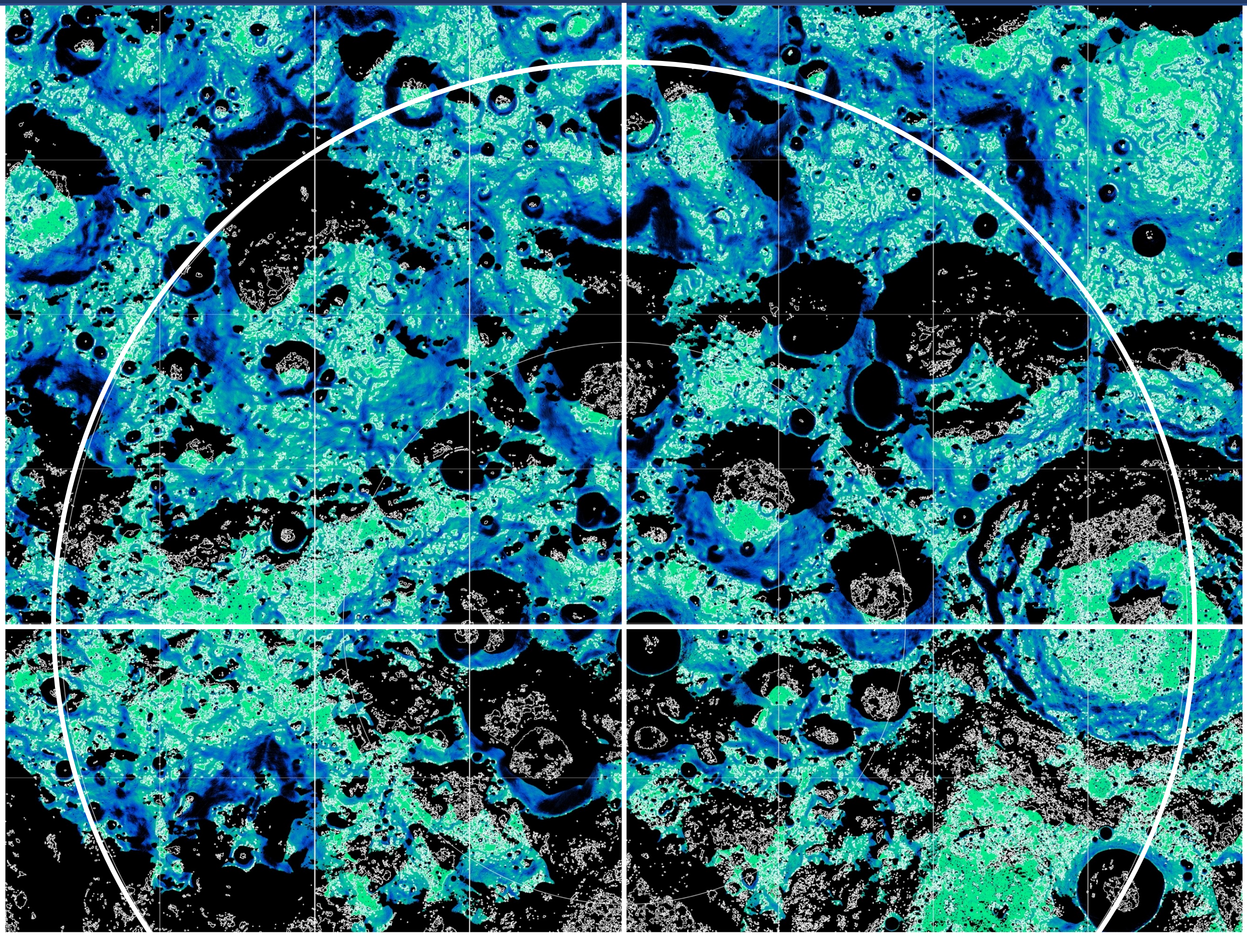
3. EVA limited to slopes less than 20 deg

Black designates slopes that exceed 20 deg



4. Direct With Earth Communication; no relay

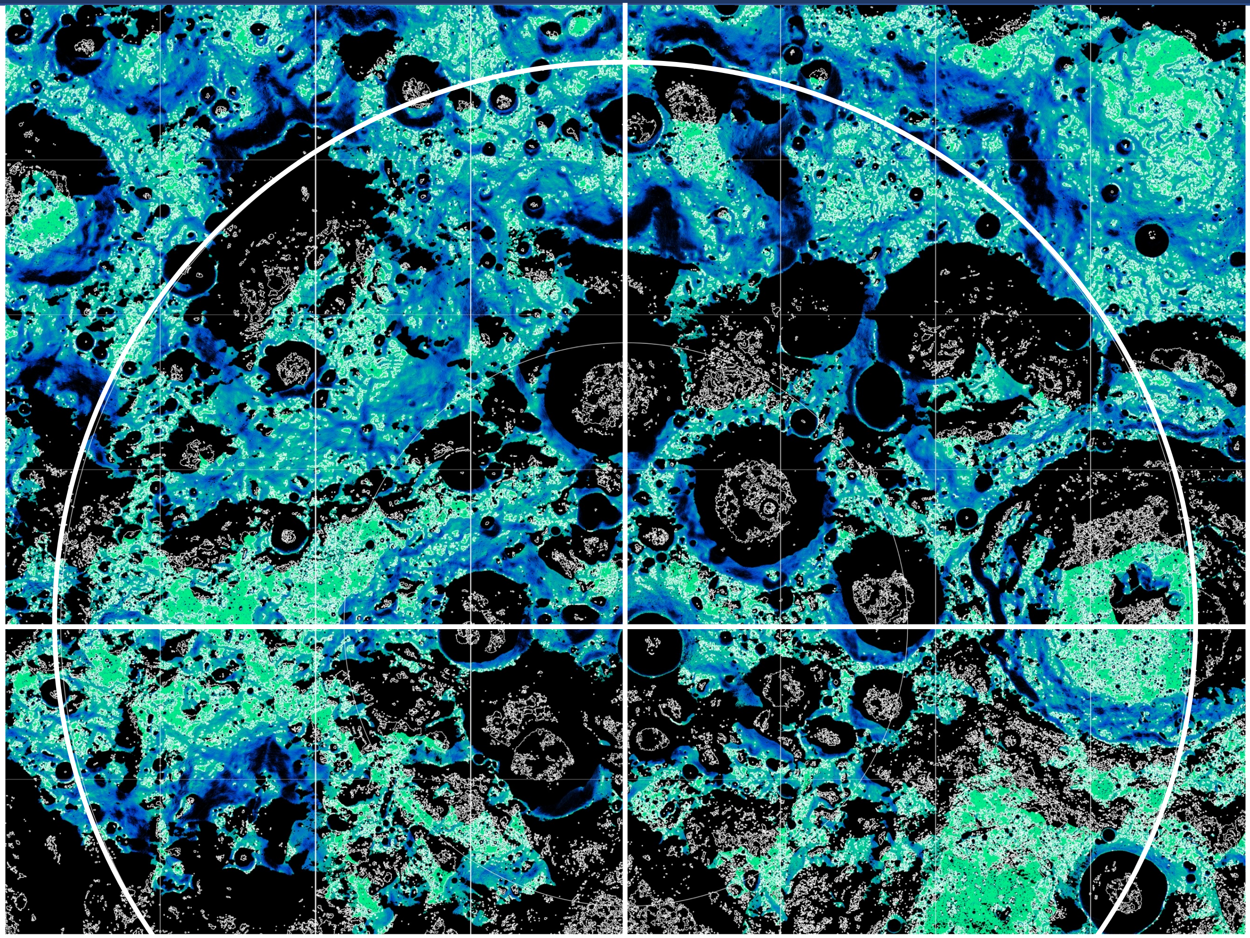
Black designates slopes
that exceed 20 deg
+ Earth visibility less 25%



5. Surface lighting for ~6.5 days

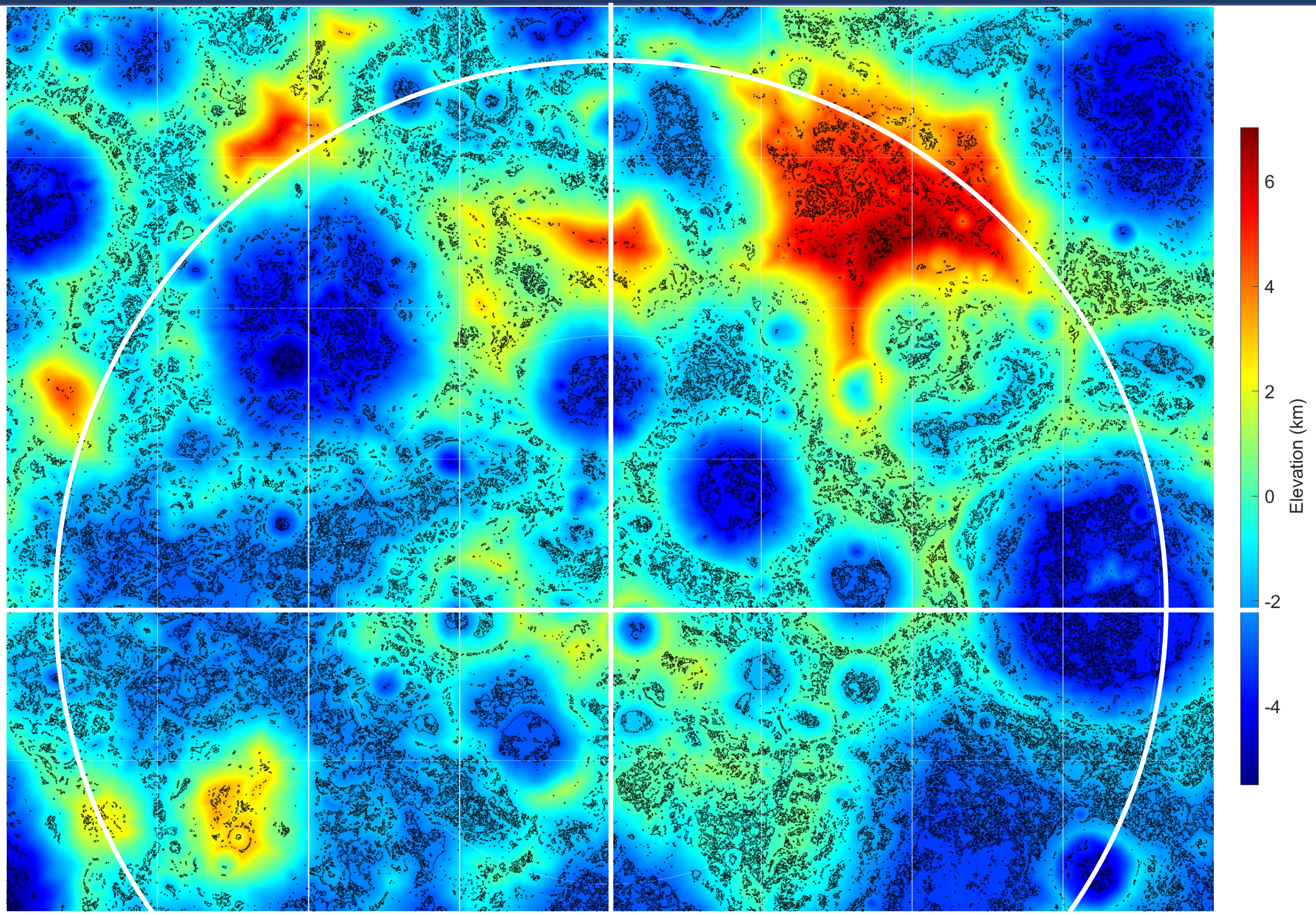
Black designates slopes
that exceed 20 deg
+ Earth visibility less 25%
+ solar visibility less 5%

Green areas in white
contours are viable areas
for initial site screening



In general, higher elevations are better

Higher elevations don't block Sun or Earth visibility and are less prone to dynamic shadows.

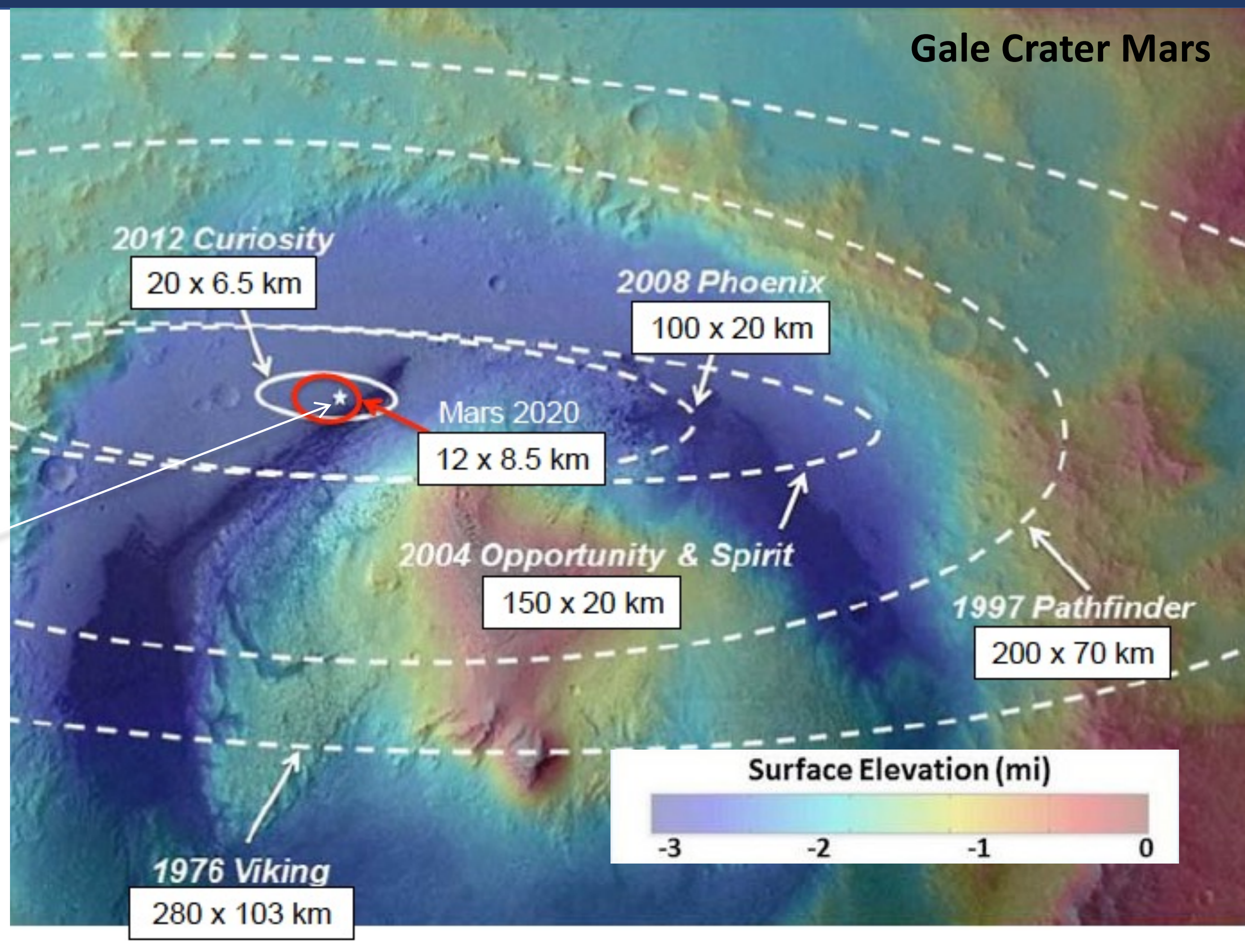


6. Land within 100m of a target

Past Robotic mission landing performance at Mars

Apollo 11 landing ellipse: 17 x 5 km

Human Landing Accuracy Requirements 100 m x 100 m

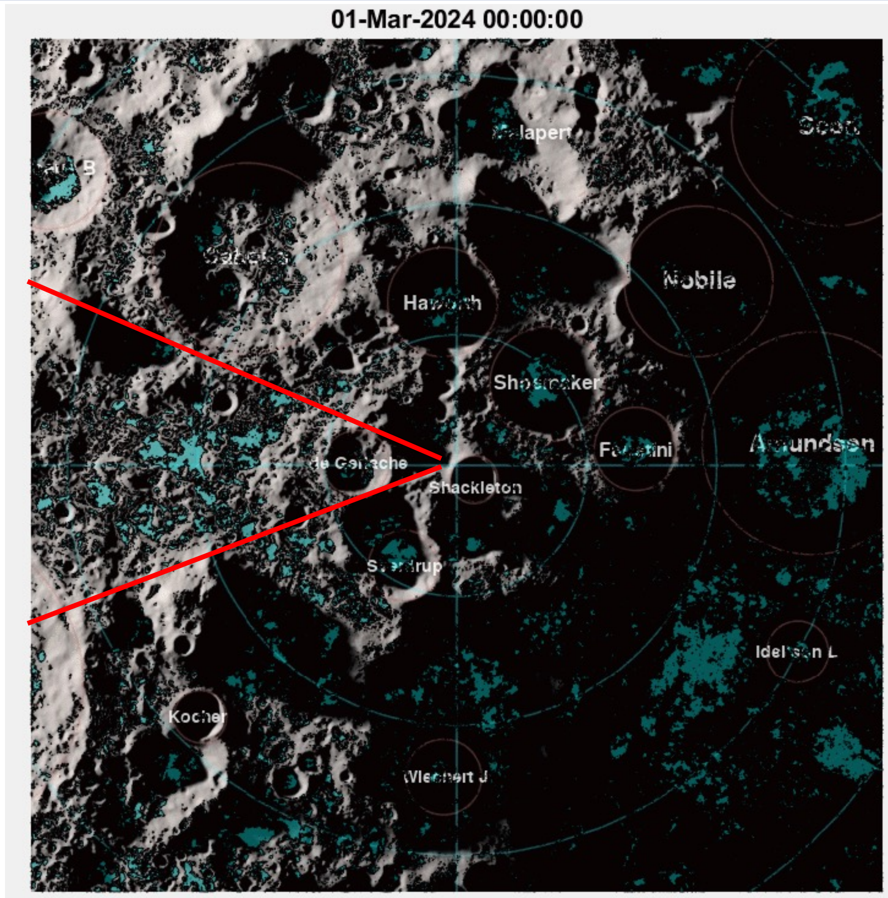


Challenges of landing at the South Pole: Lighting

One way to ensure 100 m landing accuracy is to use Terrain Relative Navigation (TRN)

Passive TRN requires lit approach trajectory

Unknown how much of the trajectory needs to be illuminated



June 2024 minimum lighting

December 2024 maximum lighting*

*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

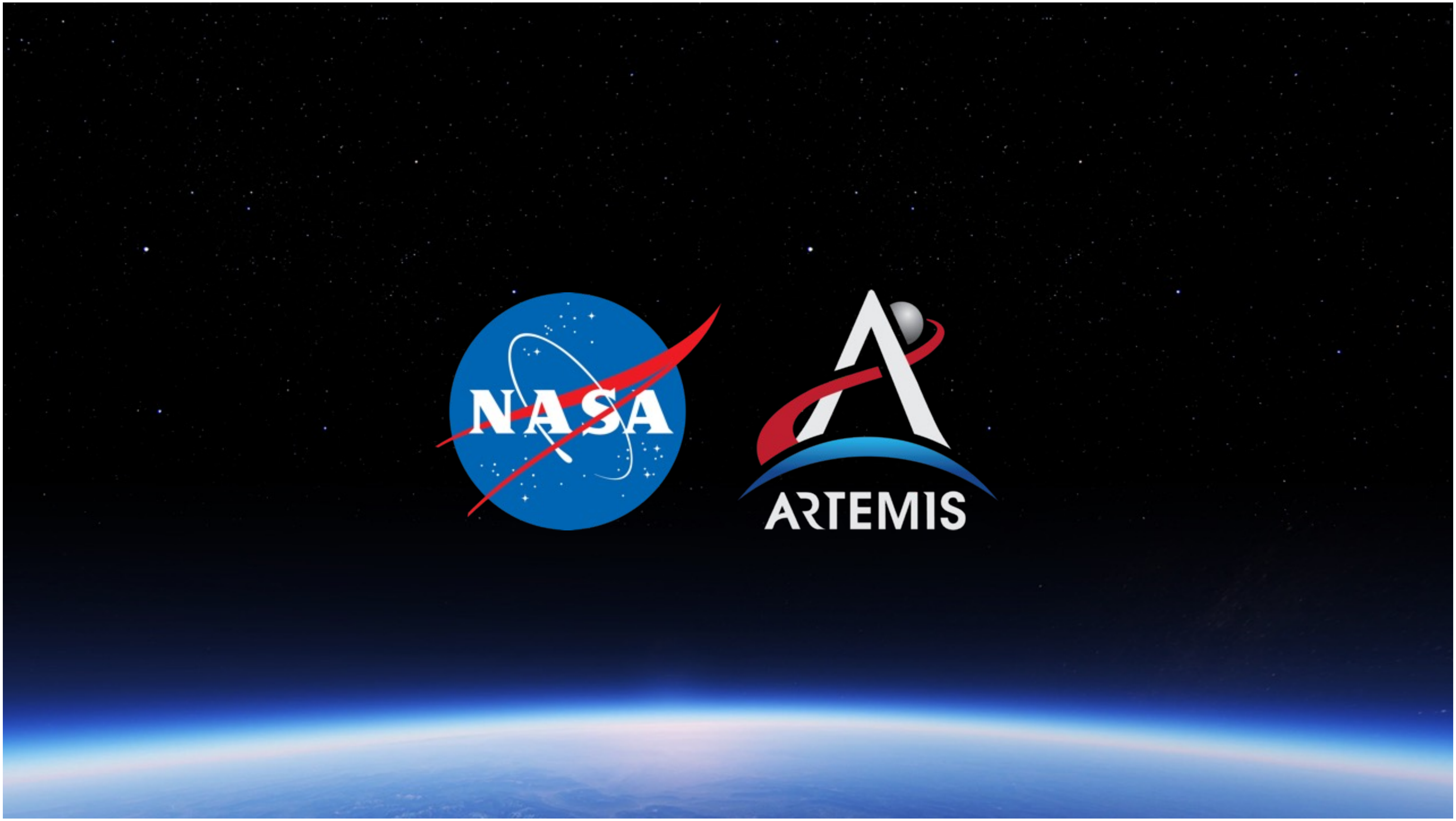
Summary

- No landing site has been selected for Artemis III
- Landing at the lunar south pole pose many challenges and has many constraints not experienced during Apollo missions
- We continue to work to determine a safe and interesting place to land

Summary

- Described Artemis I, II, III, IV
  - Go to Florida to see a launch!
  - Artemis I launch window opens August: Aug. 29, Sept. 2 and Sept. 5.***
  - https://www.space.com/artemis-1-moon-rocket-launch-date-august-2022
- Described Human Landing System: Option A
- Described Deorbit, Descent and Landing
- Described the challenges and Artemis III requirements for landing at the lunar south pole

*** “pending repairs and tweaks”


NASA
ARTEMIS