

We're going back to the Moon: Who, How, Why?

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Science on Tap – 5 September 2023

The Moon Holds a place in our Hearts

- From the Earth to the Moon: Jules Verne (1865)
- The First Men in the Moon: H.G. Wells (1901)
- The Moon is a Harsh Mistress: Robert Heinlein (1966)
- 2001 A Space Odyssey: Arthur C. Clarke (1968)
- Moonfall: Jack McDevitt (1998)
- Artemis: Andy Weir (2017)

- Space 1999
- Moon Base Alpha



Moon Colors

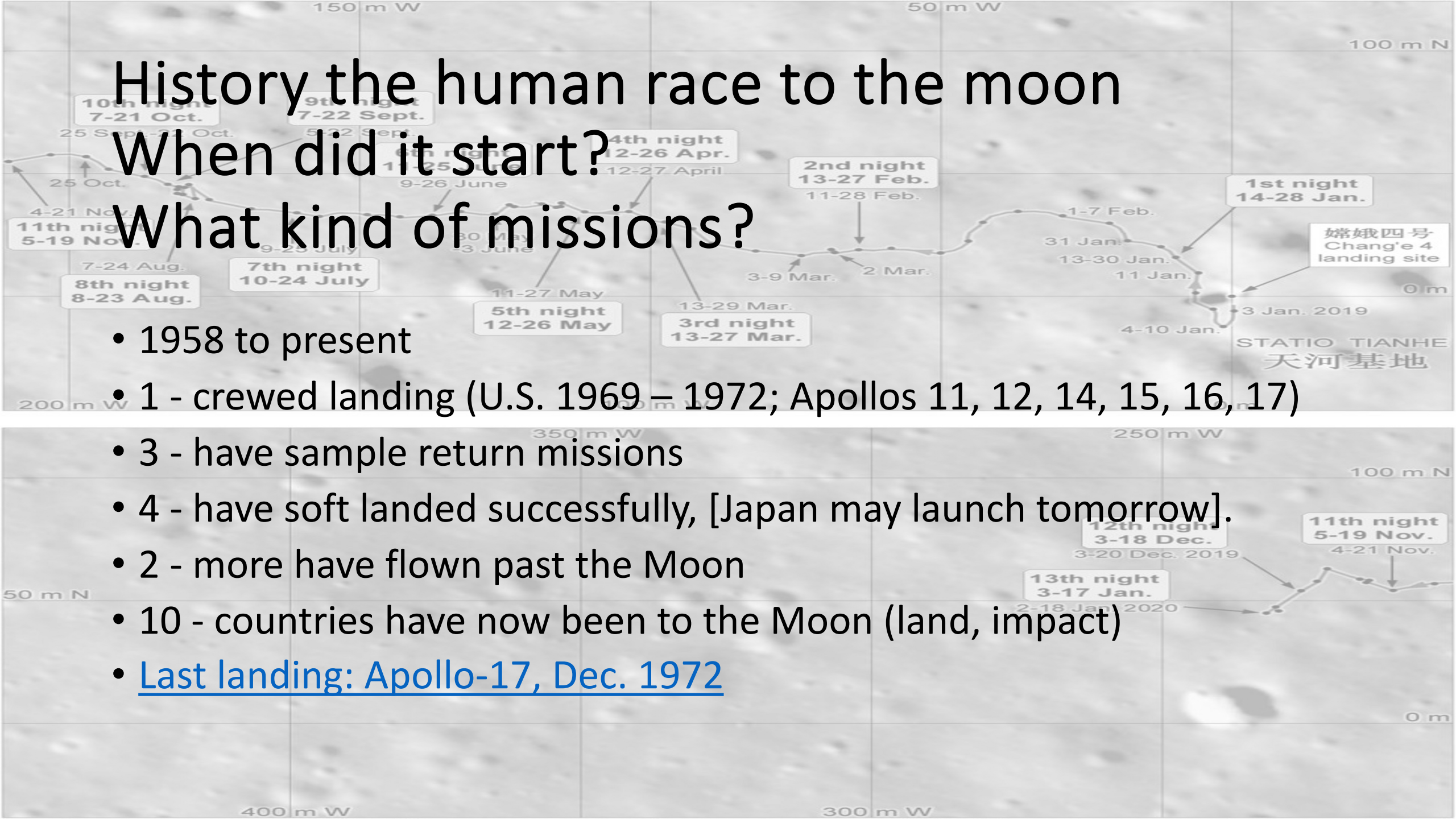


History the human race to the moon

When did it start?

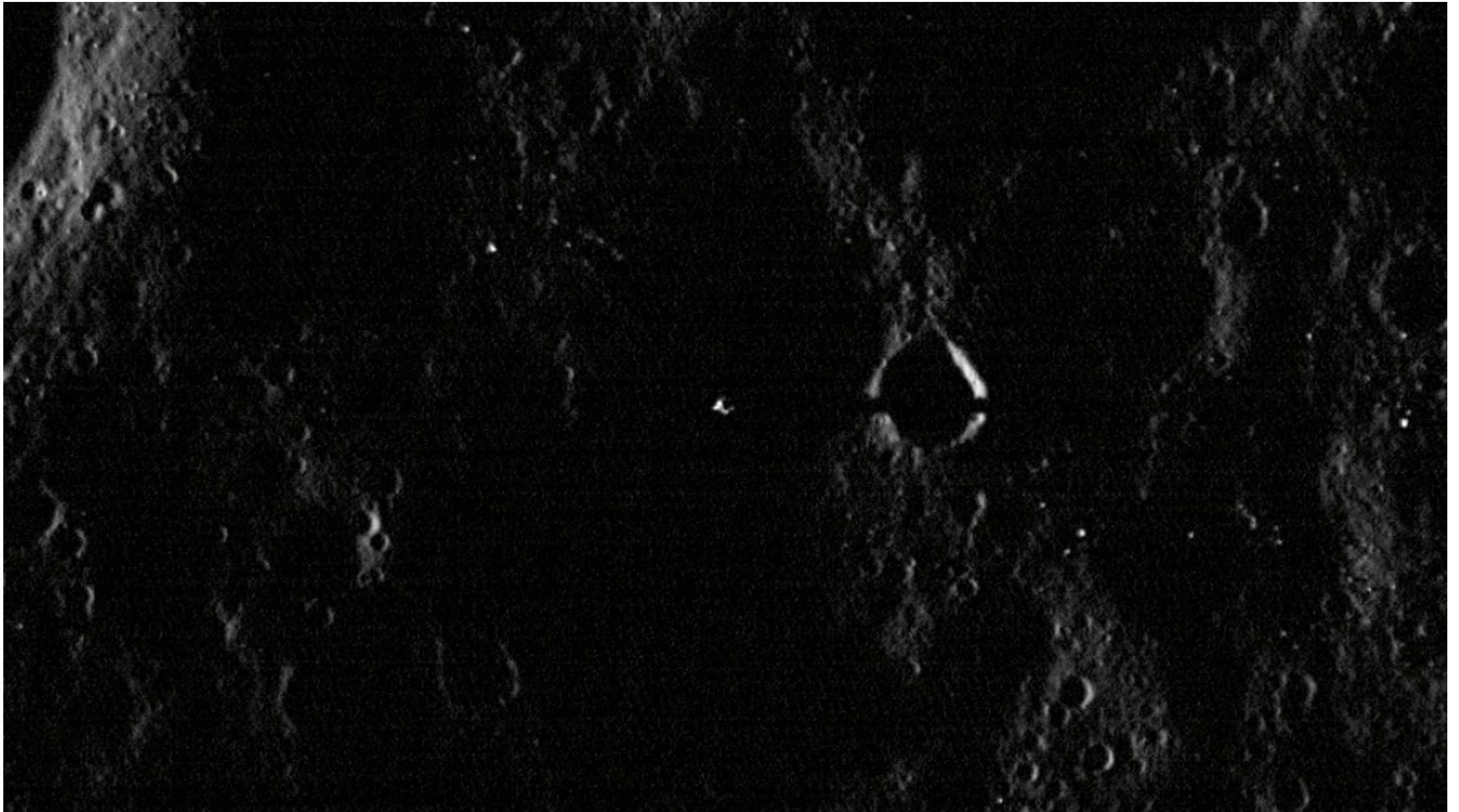
What kind of missions?

- 1958 to present
- 1 - crewed landing (U.S. 1969 – 1972; Apollos 11, 12, 14, 15, 16, 17)
- 3 - have sample return missions
- 4 - have soft landed successfully, [Japan may launch tomorrow].
- 2 - more have flown past the Moon
- 10 - countries have now been to the Moon (land, impact)
- [Last landing: Apollo-17, Dec. 1972](#)



Who – so far: Not Launch Capability

Country	Flyby	Orbit	Impact (not all intentional)	Lander	Rover	Sample Return	Crewed landing	#
United States								59
Soviet Union							—	58
China							—	5
India						—	—	3
Japan						—	—	6
Israel					—	—	—	1
Russia					—	—	—	1
UAE				—		—	—	1
ESA				—	—	—	—	1
Luxembourg		—		—	—	—	—	1
South Korea			—	—	—	—	—	1
Italy		—	—	—	—	—	—	1



Apollo-11 landing site: Dawn to Dusk: Image Credit: NASA/GSFC/Arizona State University

Why go to the Moon?

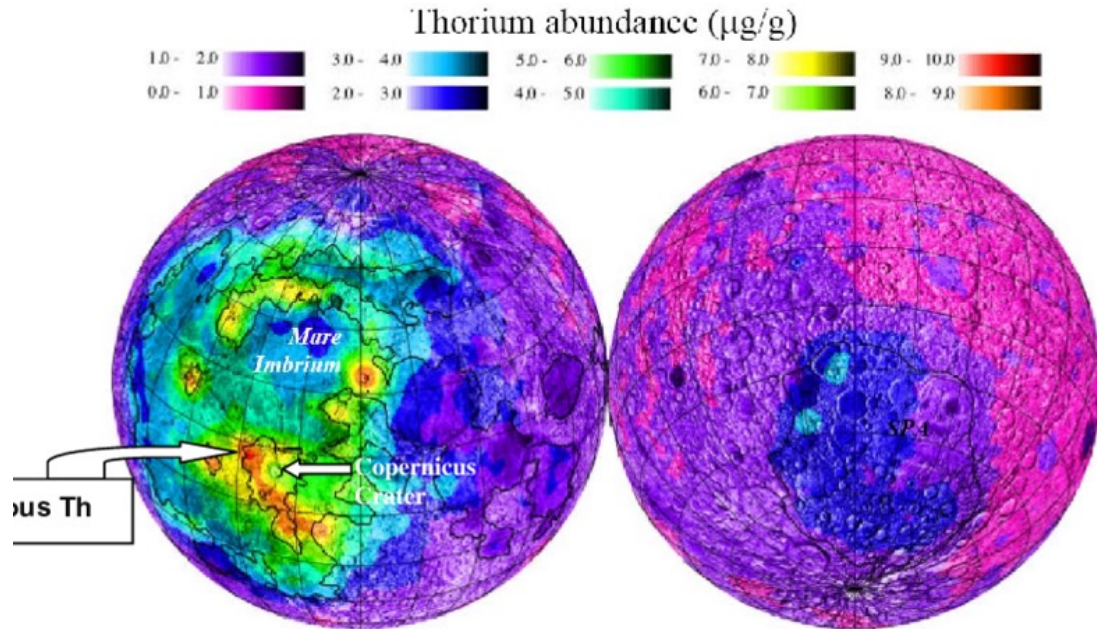
- 1960's – Politics was the driver (and political risk the killer).
- What did we get out of it?
- A bunch of rocks and more questions about lunar geology, and by extension, Earth's history than we could answer; plus solar wind data, seismographic data, and distance information.
- Technological advances (a short list of examples):
 - Teflon and non-stick surfaces
 - Rapid semi-conductor advances (hand calculators, TVs, CCDs, microwave ovens...)
 - Medical monitor equipment
 - Breathing equipment
 - Protective coverings
 - Cordless power tools
 - Athletic shoes

Why go to the Moon?



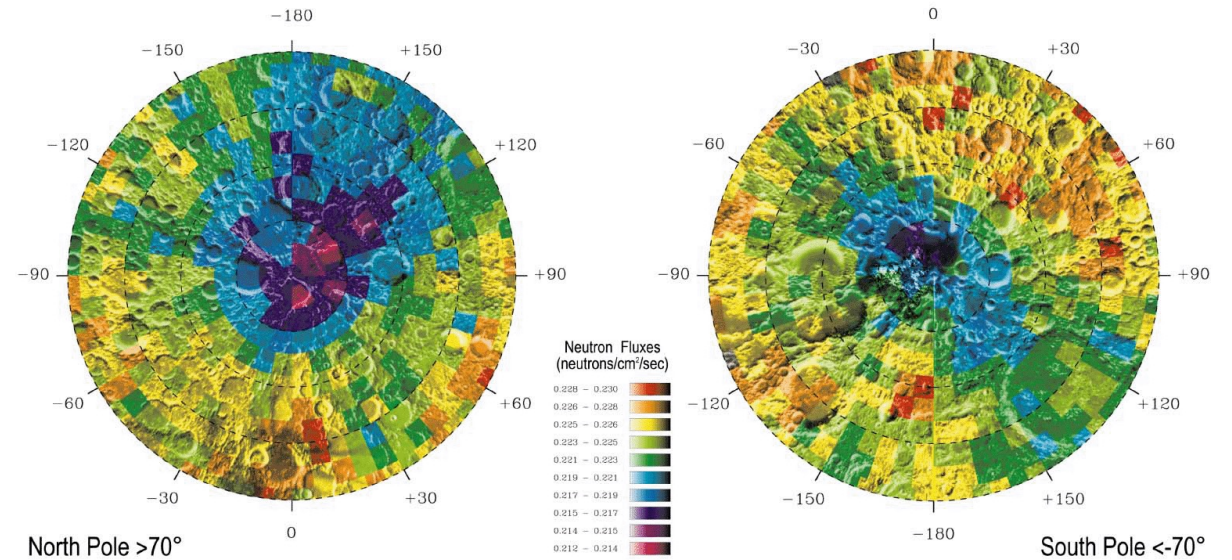
- Now? – Politics plus an actual science program; eventual expansion;
- Exploration
- Resources: He-3, Ti, Al, Si, O, H, S (according to the Indians) and others.
- Staging/Testing area for deep space missions (Mars, Jupiter moons)
- Science (optical & radio astronomy; lunar geology; formation of Earth)
- Colonization; manufacturing; tourism; food production?
- Borrowing from the Brits: penal colony? What could go wrong?

A Sampling of Lunar Resources



Campbell, Michael & King, Jeffery & Wise, Henry & Handley, Bruce & David, M.. (2009). The Role of Nuclear Power in Space Exploration and the Associated Environmental Issues: An Overview.

Possible water locations



LCROSS science. Feldman et al., Science, 281, 1496, 1998. Credit: NASA

Let's look at the (major-ish) players

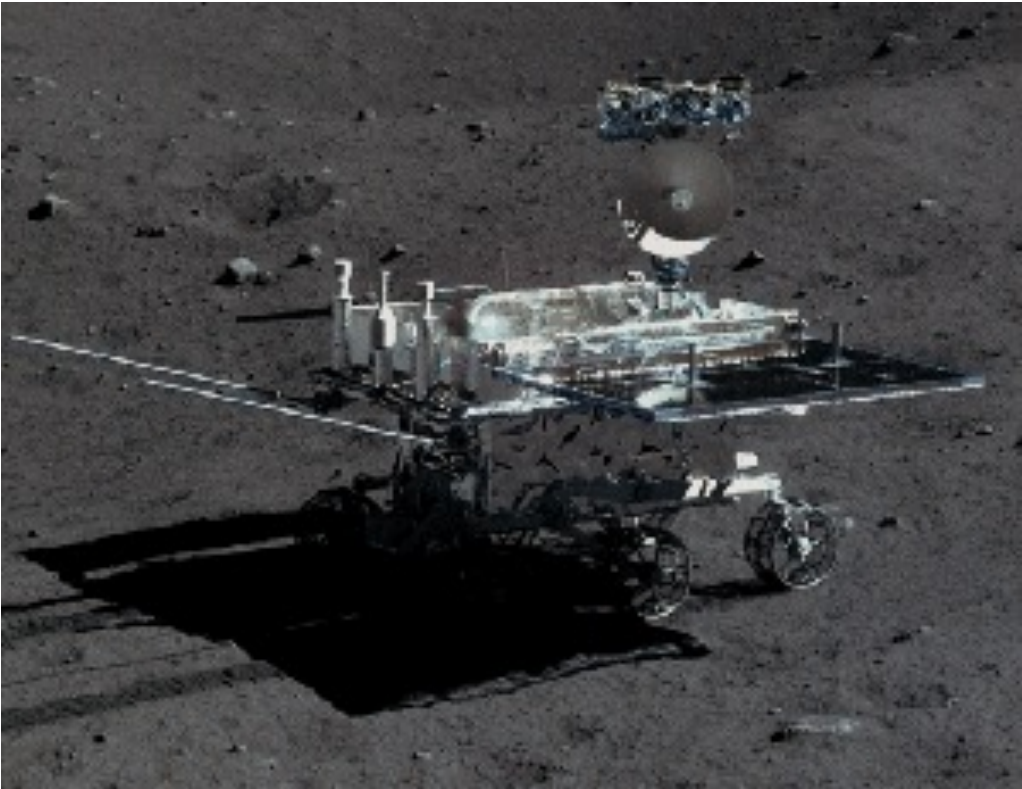
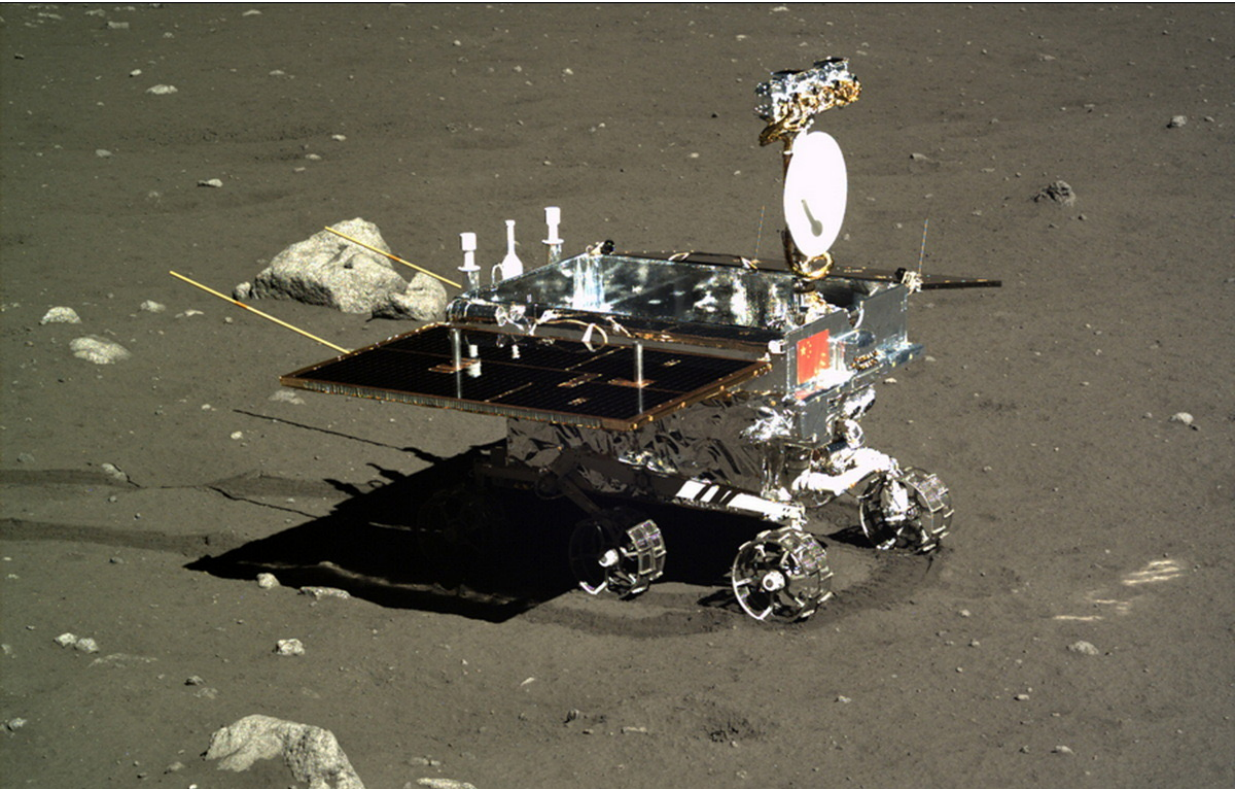
- China
- Russia – China partnership
- India
- The U.S. led coalition (The Artemis Accord)



Chinese lunar probes to date

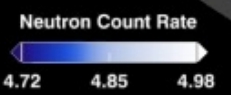
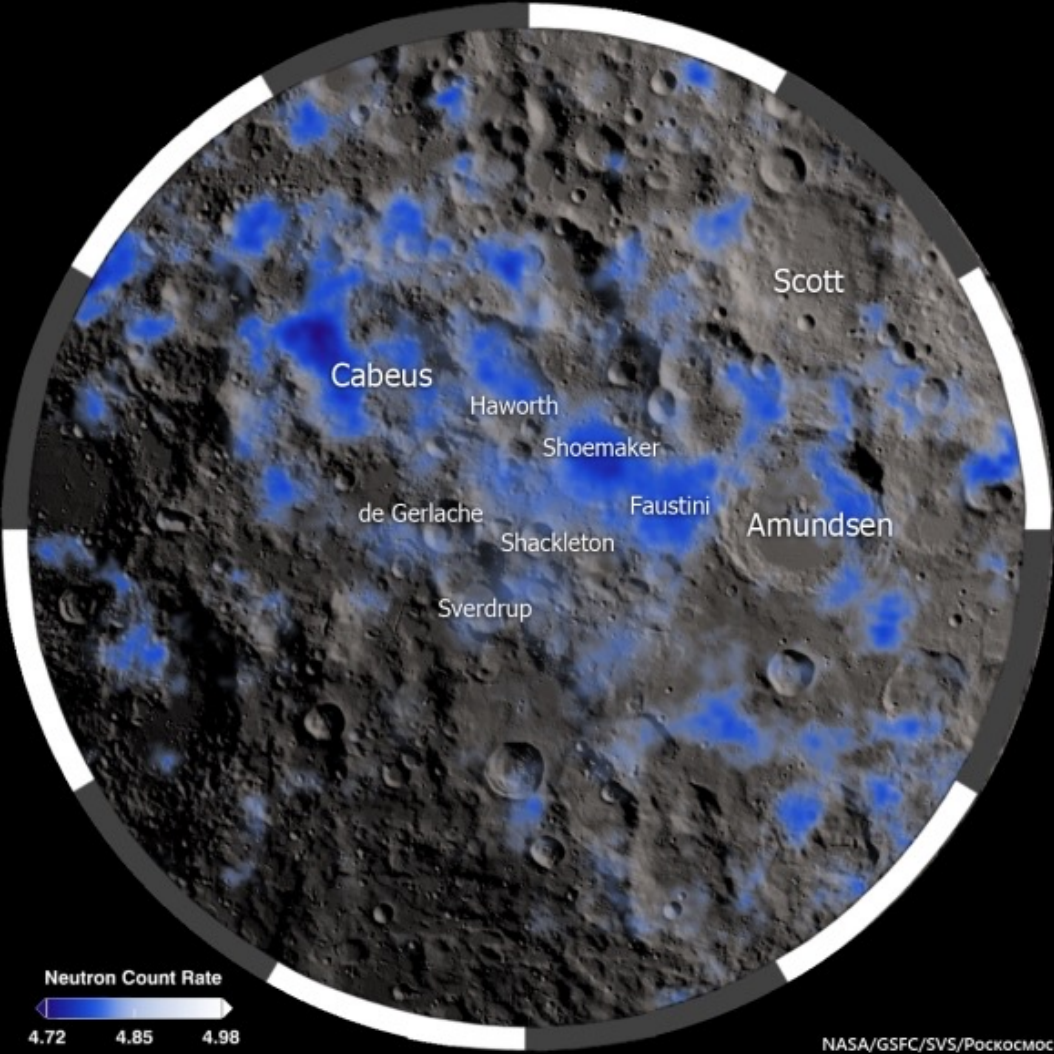
- In 2007, Chang'e-1 mapped the moon from orbit and then crashed into the lunar surface in 2009 as planned (think U.S. Ranger missions in early 1960s).
- In 2010, [Chang'e-2](#) orbited the moon, and left orbit to swing past an asteroid and then explore deeper into space.
- In 2013, [Chang'e-3 with the Yutu rover](#) became the first Chinese spacecraft to land on the moon.
- In 2019, the [Chang'e 4 mission](#), touched down on the moon's far side with a rover, Yutu-2. Still operating and returning spectacular science results.
- In 2014, the [test capsule Chang'e-5-T1](#) flew past the moon and looped back around to Earth to practice for an eventual lunar sample return mission.

Yutu-1 & Yutu-2

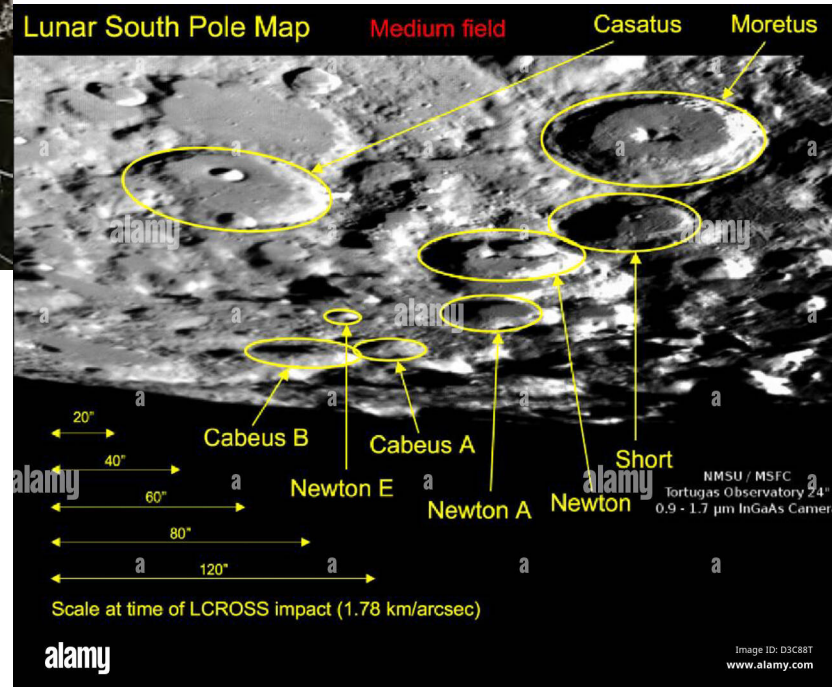
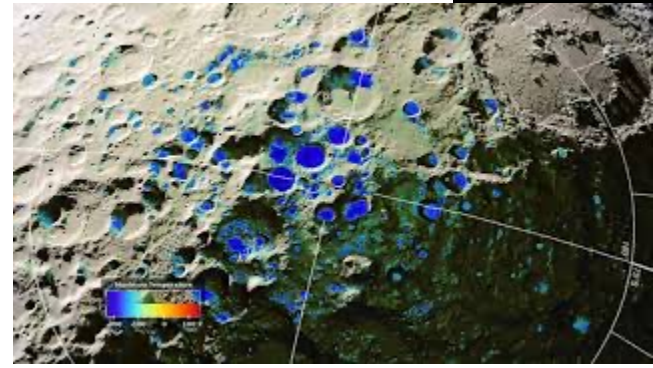
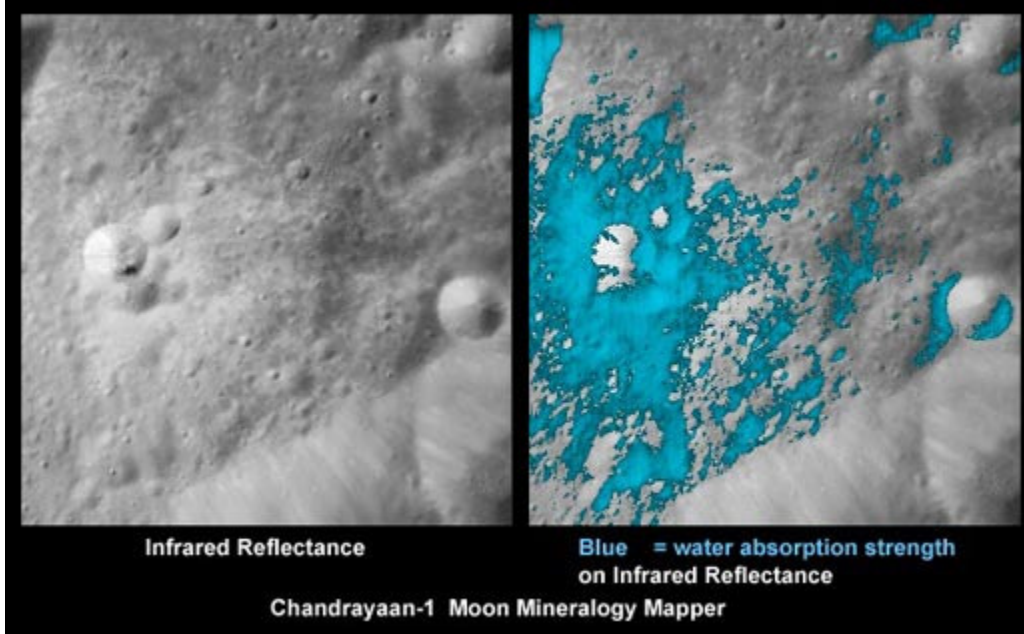


China & Russia Team

- China and Russia announced in March 2021 that they're teaming up on an ambitious project called the **International Lunar Research Station** (ILRS), which, like Artemis, aims to set up a base near the moon's south pole.
- Both projects appear to be targeting the same general patches of lunar real estate — highland regions that offer easy access to lots of sunlight as well as the water ice that's thought to be abundant on the shadowed floors of polar craters.
- Three main phases of the ILRS effort: reconnaissance, construction & utilization.
- The reconnaissance phase will continue over the next few years.
- The roughly decade-long construction stage will begin in 2026, featuring more robotic missions by China, Russia and other international partners.
- First crewed mission ~2030; two vehicles.
- If all goes according to plan, ILRS will be ready to host crewed missions by 2036 or thereabouts.



NASA/GSFC/SVS/Роскосмос



India's Moon Plans

- Prime Minister Narendra Modi confirmed India's intention to send people to the moon in the near future as the nation celebrated the successful landing of the world's first-ever robotic mission to the lunar south pole (August 2023). The craft has been put into hibernation mode for the first lunar night.
- India has previously said it will attempt a crewed mission to low-Earth orbit by late 2024.
- Developing a whole fleet of launch vehicles.

cataddictsanony-mouse

psssst...

u awake?

ROFLBOT

Artemis Accords - 1

A rocket launch is shown through a window with a grid pattern. The rocket is in the center, ascending vertically. A large, bright plume of fire and white smoke surrounds the base of the rocket. The background is a dark, overcast sky. The window frame is visible on the left and right sides.

- The Artemis Program was officially announced on 15 May 2020; a new international agreement outlining the laws for mining on the Moon.
- It consists of a series of bilateral agreements between the governments of participating nations in the Artemis program "grounded in the Outer Space Treaty of 1967".

Artemis Accords - 2

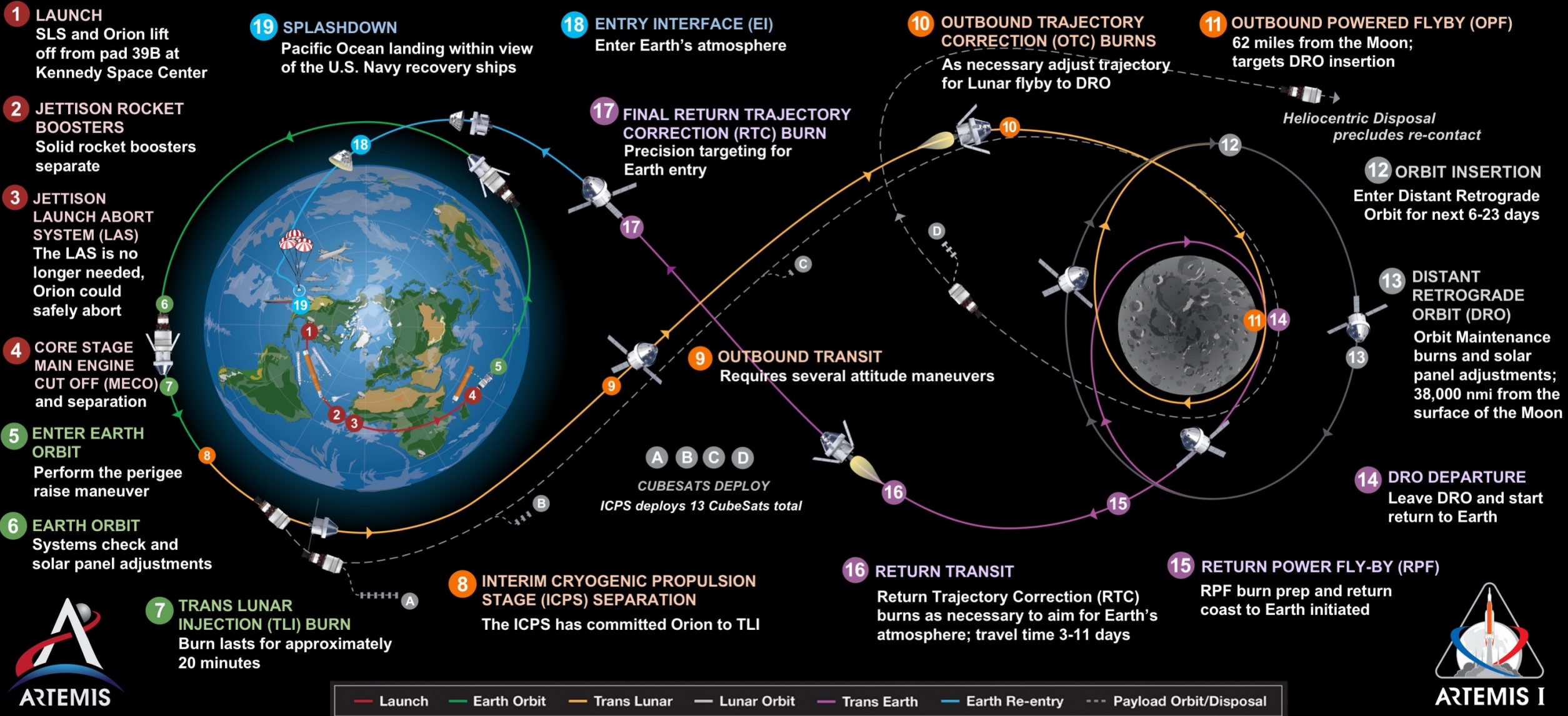
- **Peaceful Exploration of space:**
- **Transparency:**
- **Interoperability:**
- **Emergency Assistance:**
- **Registration of Space Objects:**
- **Preserving Heritage:**
- **Space Resources**
- **Deconfliction of Activities:**
- **Orbital Debris:**

This is basically the “Moon Treaty” and the “Safe Return of Astronauts Treaty” wrapped up in one document with the orbital debris disposal accord added.

ARTEMIS I



The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport



ARTEMIS I

Total distance traveled: 1.3 million miles – Mission duration: 26-42 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed



ARTEMIS ACCORDS



United for Peaceful Exploration of Deep Space

What is the Artemis program?

The Artemis program is a series of ongoing lunar missions run by NASA.

One mission has already been completed: in late 2022 [Artemis 1](#), an uncrewed test flight, orbited and flew beyond the Moon.

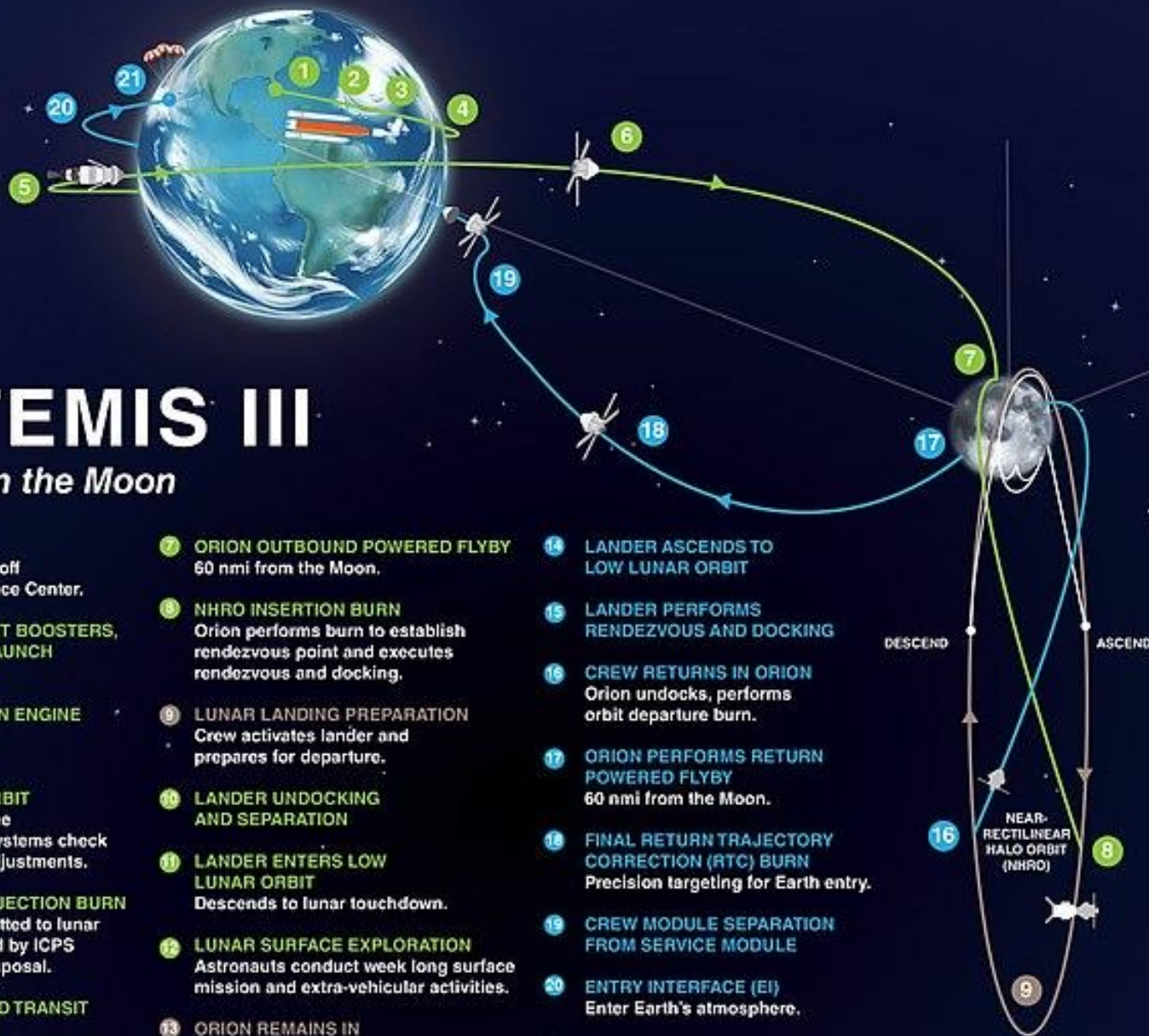
The next missions are currently in preparation:

- [Artemis 2](#) will be a crewed flight beyond the Moon which will take humans the farthest they've ever been in space. (2024)
- [Artemis 3](#) will be the first crewed Moon landing mission since Apollo 17 in 1972. NASA aims to land the first female astronaut and first astronaut of color on the lunar surface. They will spend a week on the Moon performing scientific studies, before returning to Earth. (2025)
- [Artemis 4](#) will deliver a core part of a new lunar space station (named 'Gateway') into orbit around the Moon, and land two astronauts on the Moon's surface. (2028)
- [Artemis 5](#) will add another important module to Gateway and involve a third crewed lunar landing to undertake further surface science. (2029)

ARTEMIS II

First crewed flight to the Moon since Apollo

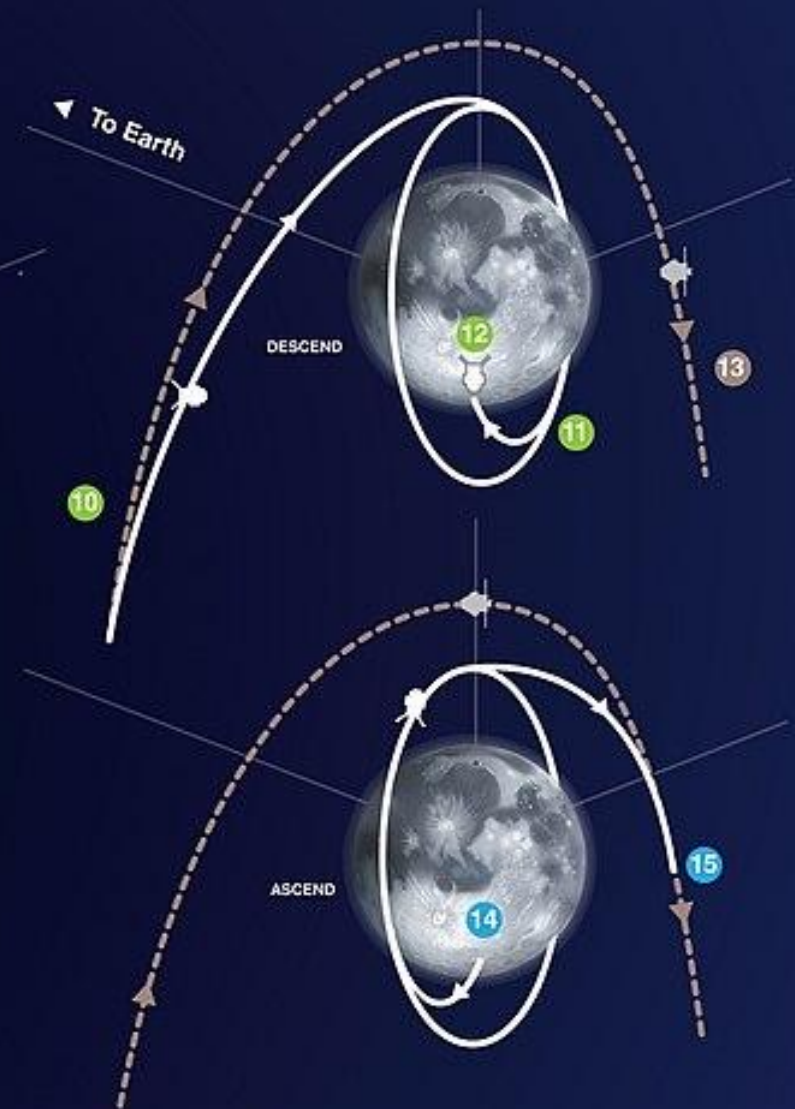




ARTEMIS III

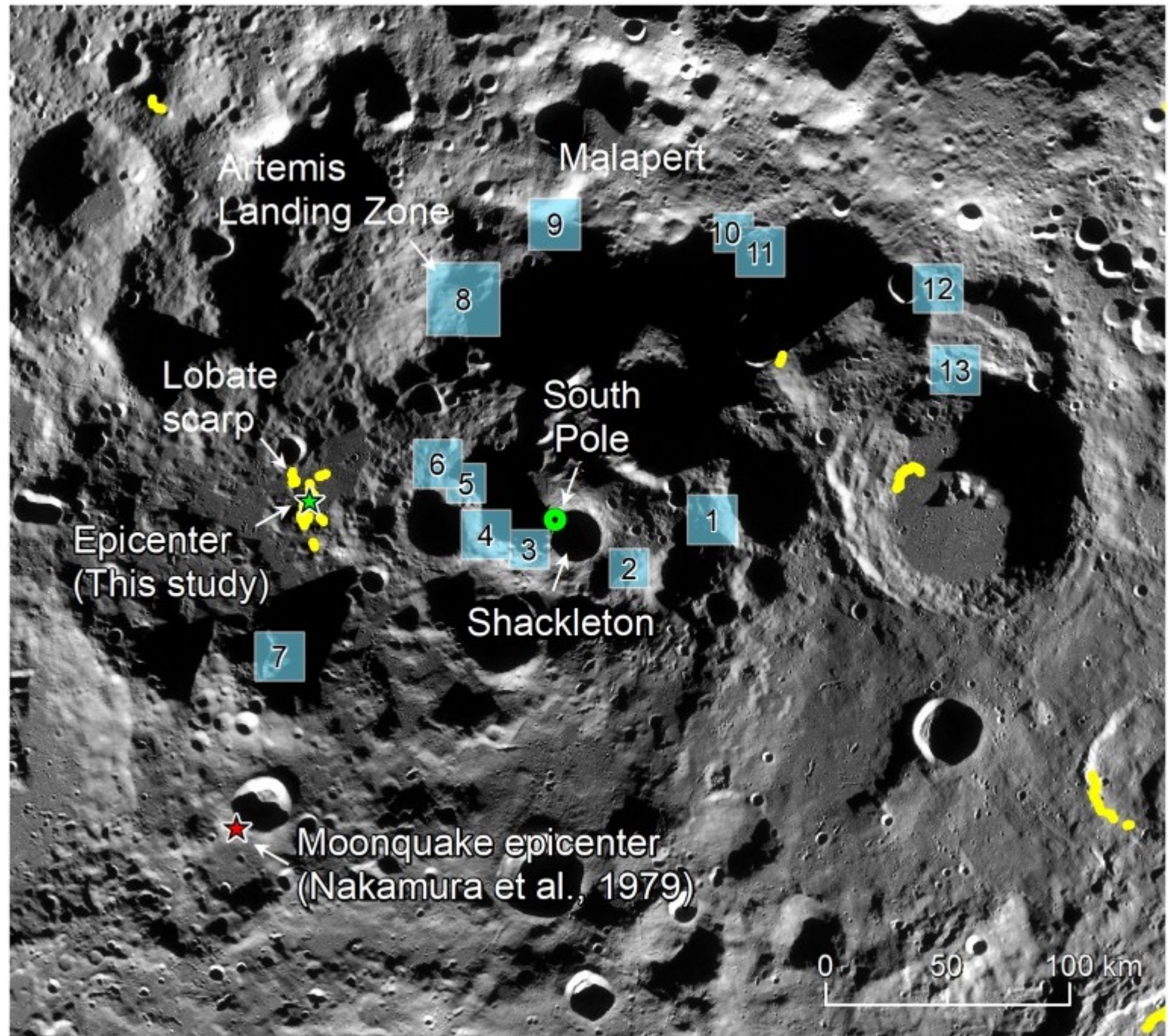
Landing on the Moon

- | | | |
|---|---|---|
| <p>1 LAUNCH
SLS and Orion lift off from Kennedy Space Center.</p> <p>2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM</p> <p>3 CORE STAGE MAIN ENGINE CUT OFF
With separation.</p> <p>4 ENTER EARTH ORBIT
Perform the perigee raise maneuver. Systems check and solar panel adjustments.</p> <p>5 TRANS LUNAR INJECTION BURN
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.</p> <p>6 ORION OUTBOUND TRANSIT TO MOON
Requires several outbound trajectory burns.</p> | <p>7 ORION OUTBOUND POWERED FLYBY
60 nmi from the Moon.</p> <p>8 NHRO INSERTION BURN
Orion performs burn to establish rendezvous point and executes rendezvous and docking.</p> <p>9 LUNAR LANDING PREPARATION
Crew activates lander and prepares for departure.</p> <p>10 LANDER UNDOCKING AND SEPARATION</p> <p>11 LANDER ENTERS LOW LUNAR ORBIT
Descends to lunar touchdown.</p> <p>12 LUNAR SURFACE EXPLORATION
Astronauts conduct week long surface mission and extra-vehicular activities.</p> <p>13 ORION REMAINS IN NHRO ORBIT
During lunar surface mission.</p> | <p>14 LANDER ASCENDS TO LOW LUNAR ORBIT</p> <p>15 LANDER PERFORMS RENDEZVOUS AND DOCKING</p> <p>16 CREW RETURNS IN ORION
Orion undocks, performs orbit departure burn.</p> <p>17 ORION PERFORMS RETURN POWERED FLYBY
60 nmi from the Moon.</p> <p>18 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN
Precision targeting for Earth entry.</p> <p>19 CREW MODULE SEPARATION FROM SERVICE MODULE</p> <p>20 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.</p> <p>21 SPLASHDOWN
Ship recovers astronauts and capsule</p> |
|---|---|---|

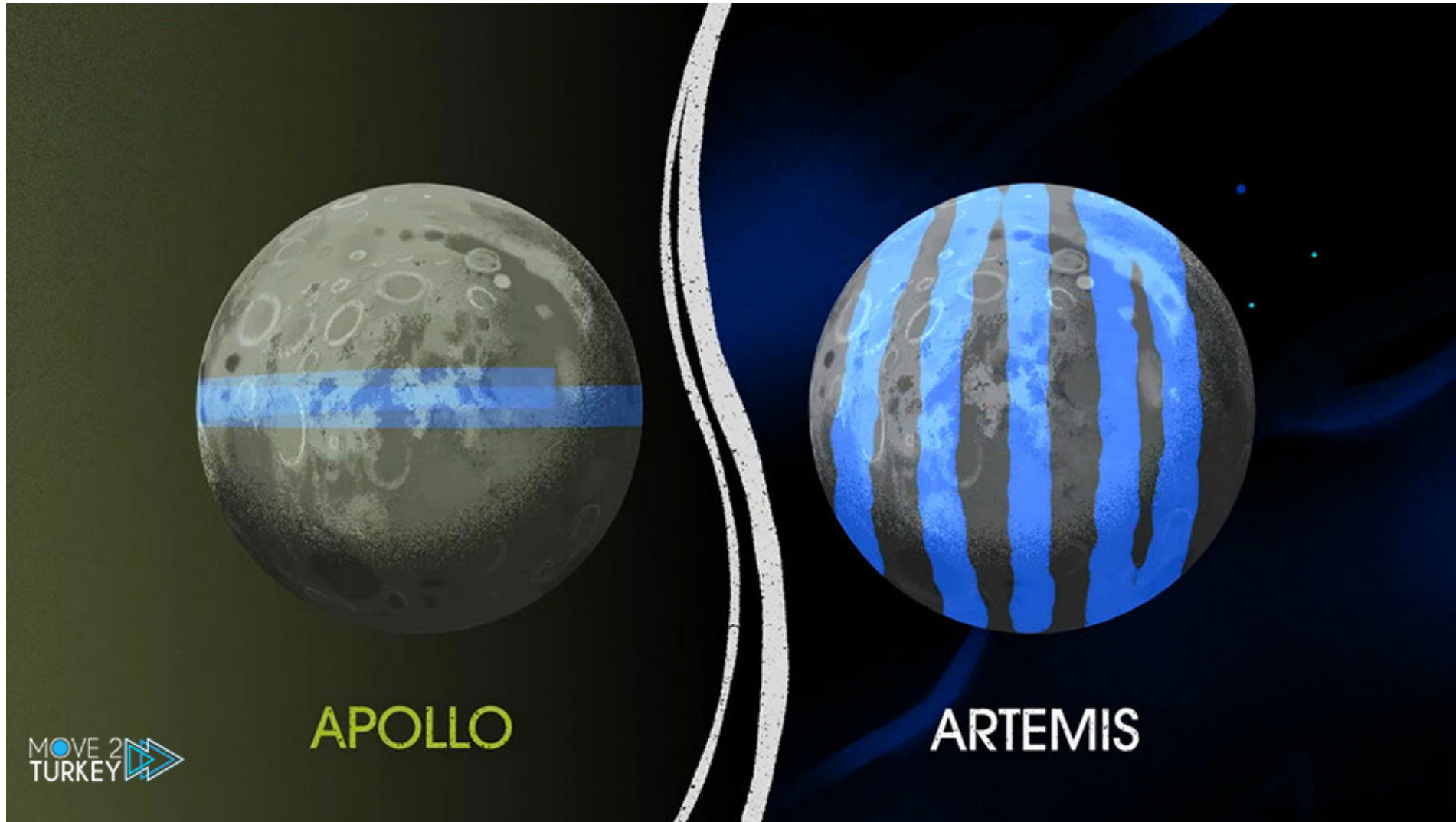


Potential Artemis Landing Zones

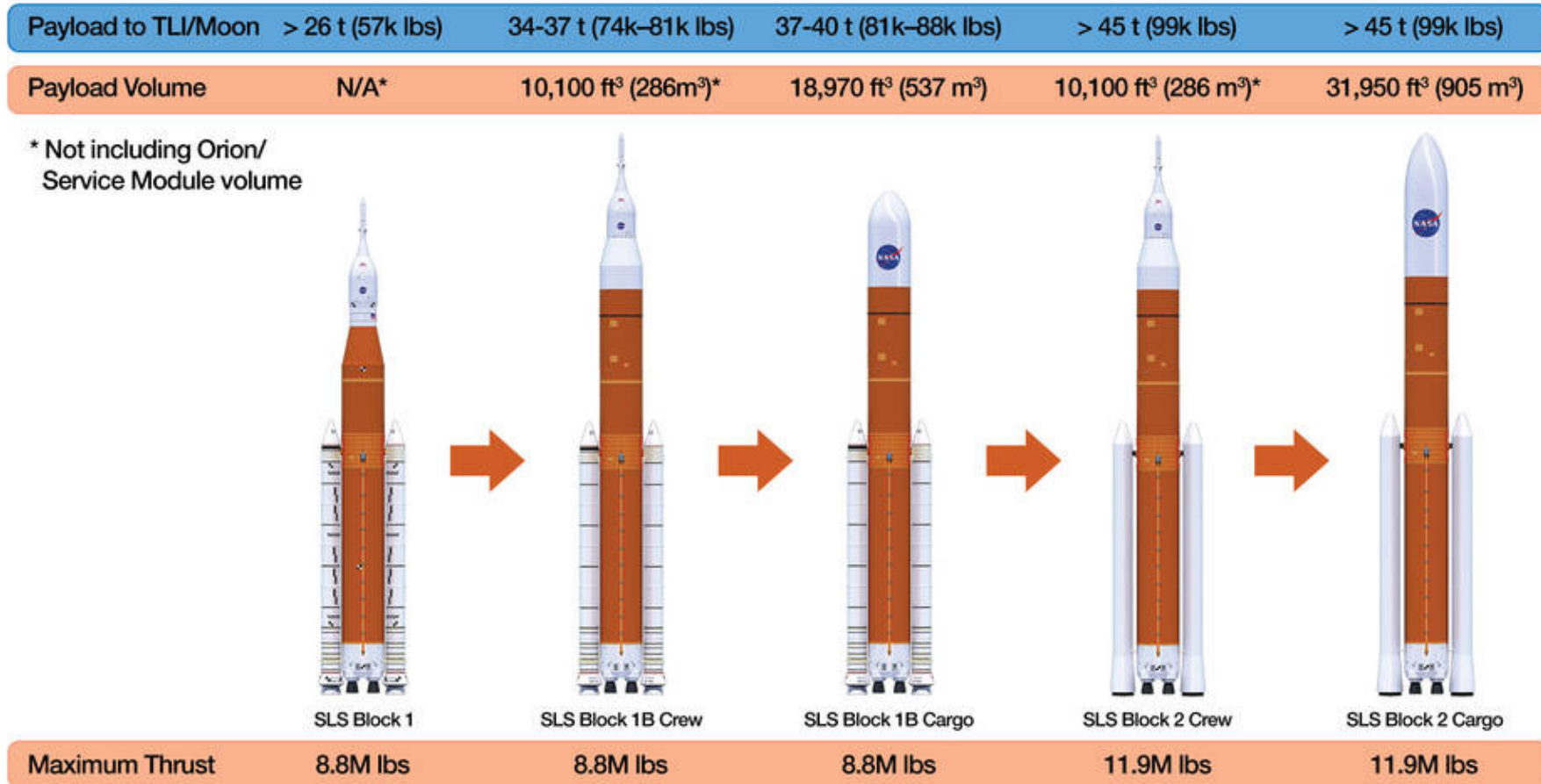
Technical Challenge:
Orbital Plane Change



What a polar vs. equatorial orbit gets you



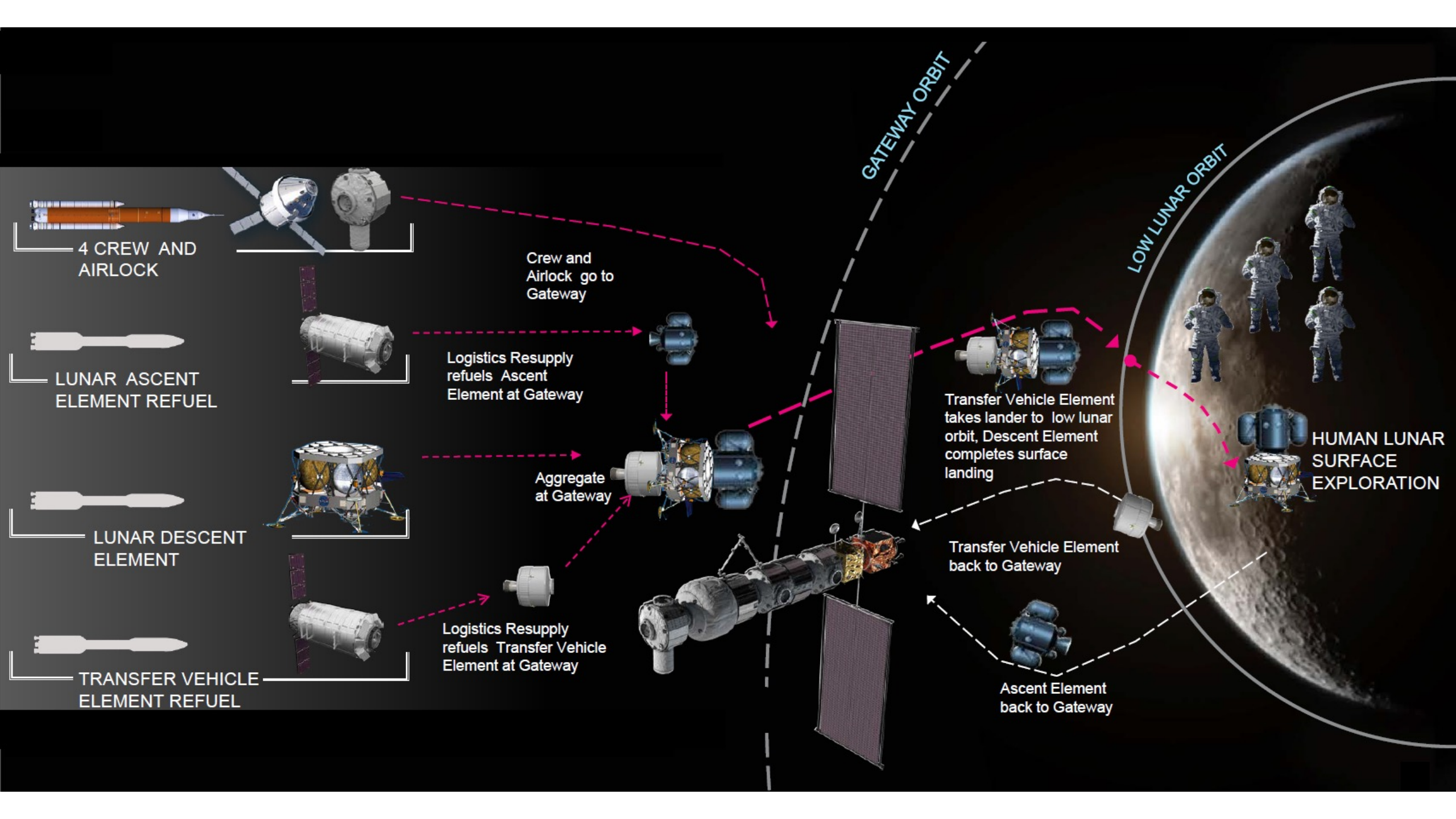
The Artemis family



Orion Spacecraft

- Originally the Constellation S/C
- Solar powered
- 4-6 person crew
- 21 day “free flying” flight
- 6 months “tethered” flight
- Intended for “deep space missions”
- Lockheed-Martin is prime contractor
- Partially reusable





4 CREW AND AIRLOCK

LUNAR ASCENT ELEMENT REFUEL

LUNAR DESCENT ELEMENT

TRANSFER VEHICLE ELEMENT REFUEL

Crew and Airlock go to Gateway

Logistics Resupply refuels Ascent Element at Gateway

Aggregate at Gateway

Logistics Resupply refuels Transfer Vehicle Element at Gateway

Transfer Vehicle Element takes lander to low lunar orbit, Descent Element completes surface landing

HUMAN LUNAR SURFACE EXPLORATION

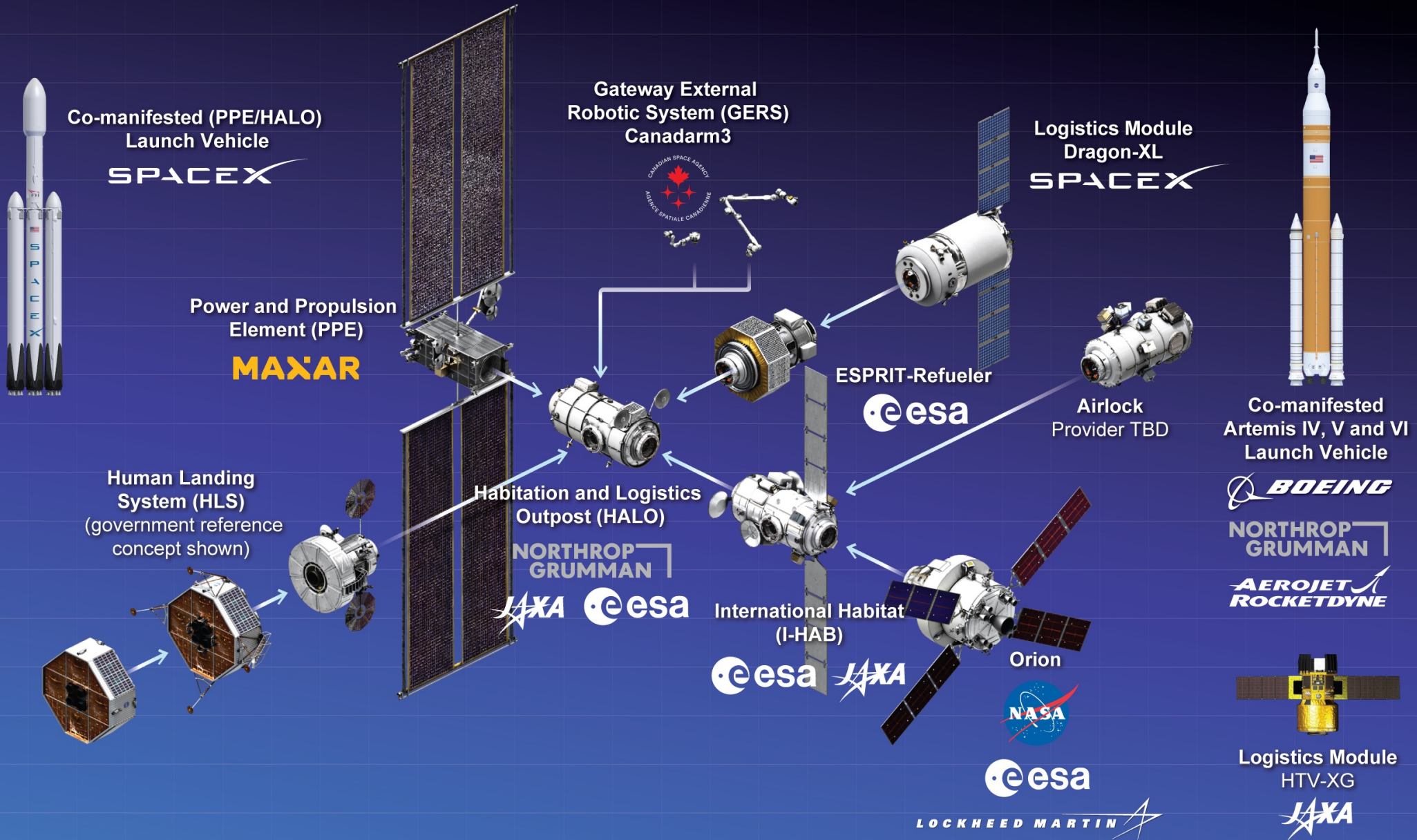
Transfer Vehicle Element back to Gateway

Ascent Element back to Gateway

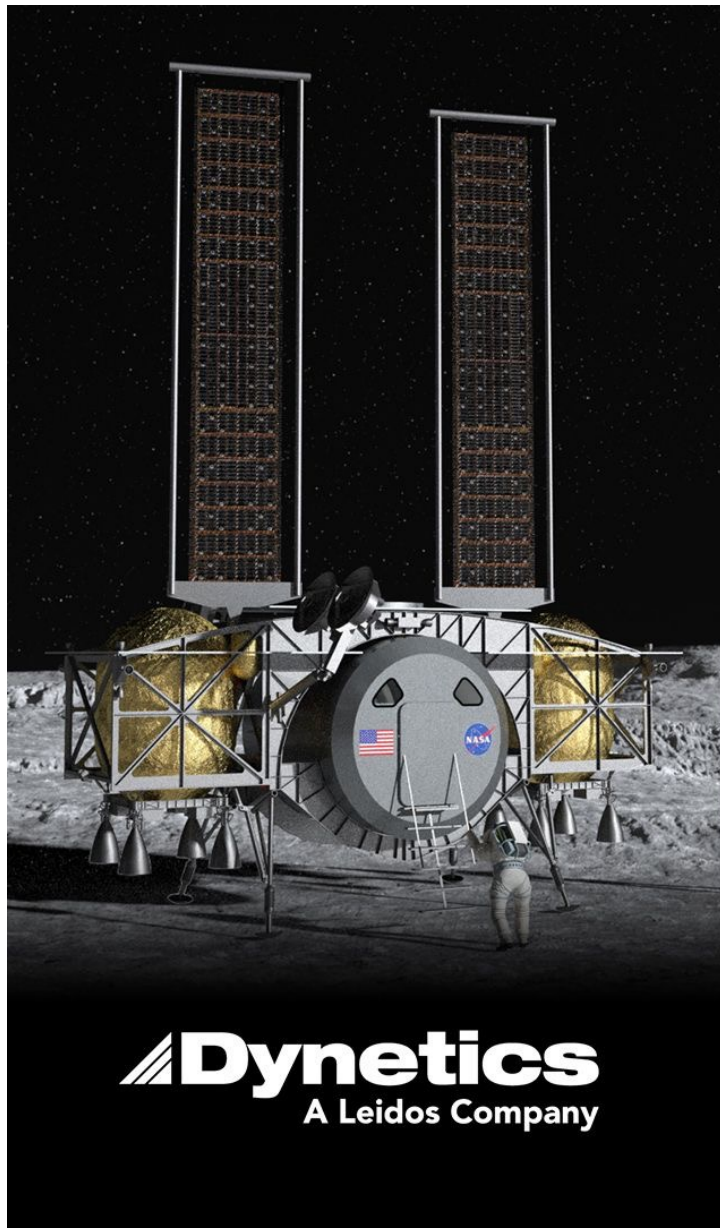
GATEWAY ORBIT

LOW LUNAR ORBIT

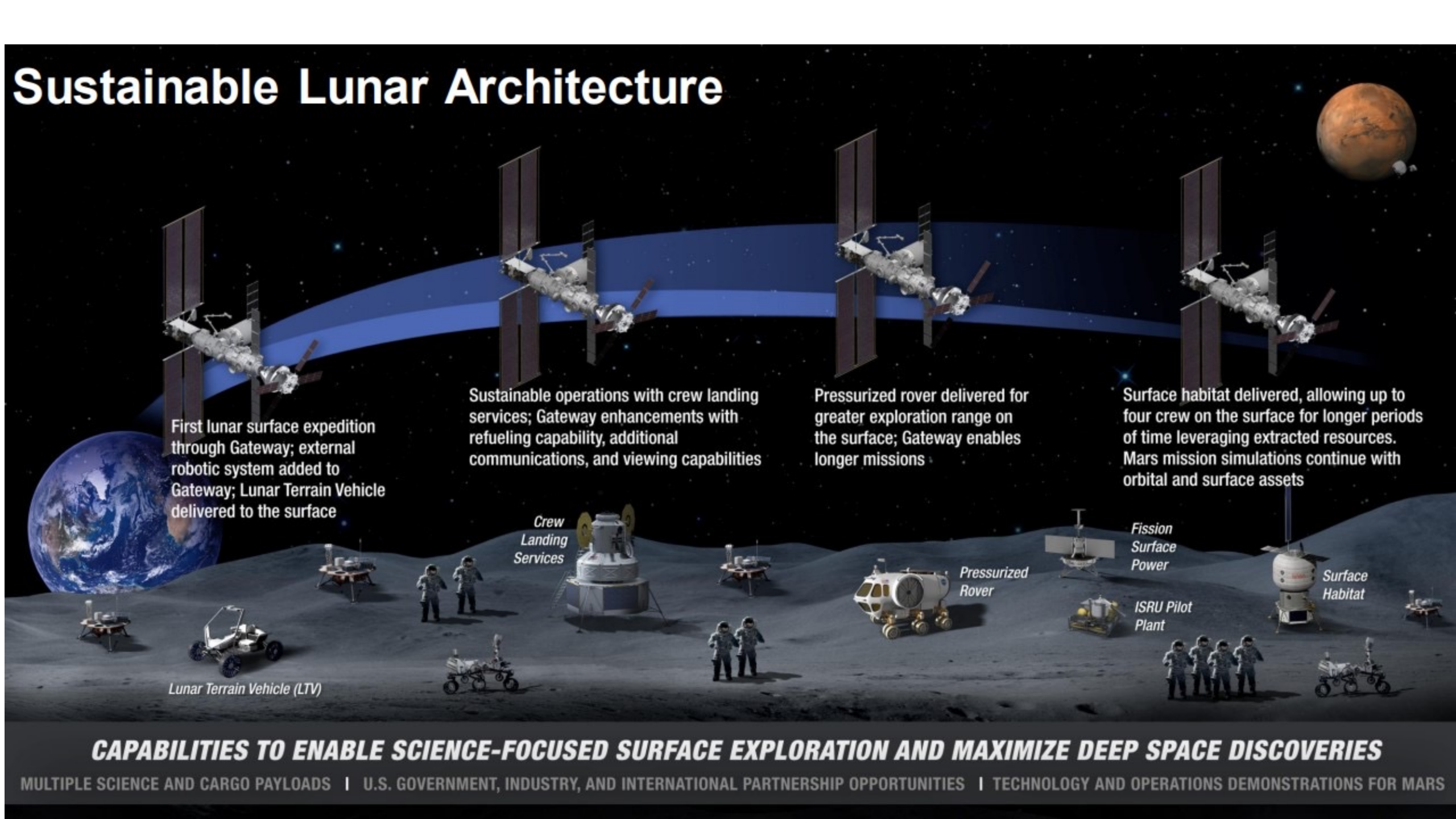
GATEWAY Integrated Spacecraft Configuration



Current Lander Concepts: The last unknown



Sustainable Lunar Architecture



The diagram illustrates a four-stage mission sequence for sustainable lunar operations. A blue orbital path curves across the top of the image, with four Gateway stations positioned along it. Below the path, the lunar surface is shown with various assets and astronauts. The Earth is visible on the left, and Mars is in the upper right corner. The mission stages are described by text blocks: 1. First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface. 2. Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities. 3. Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions. 4. Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets. Labels for surface assets include: Lunar Terrain Vehicle (LTV), Crew Landing Services, Pressurized Rover, Fission Surface Power, ISRU Pilot Plant, and Surface Habitat.

First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets

Lunar Terrain Vehicle (LTV)

Crew
Landing
Services

Pressurized
Rover

Fission
Surface
Power

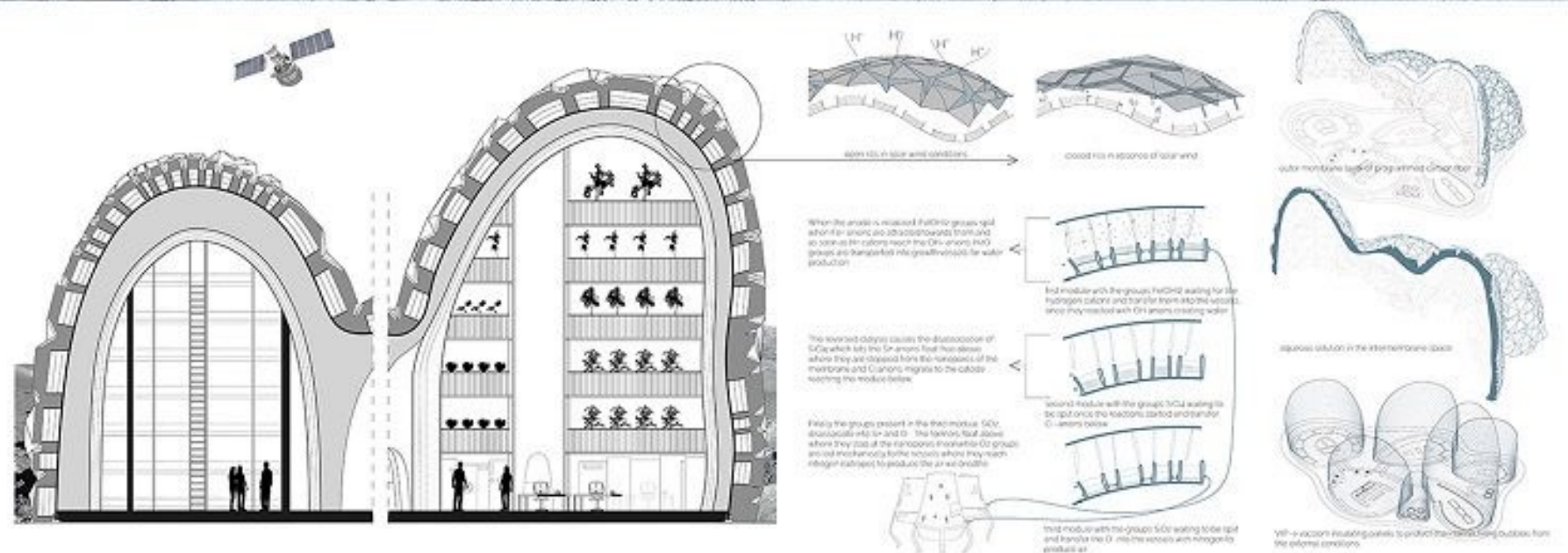
ISRU Pilot
Plant

Surface
Habitat

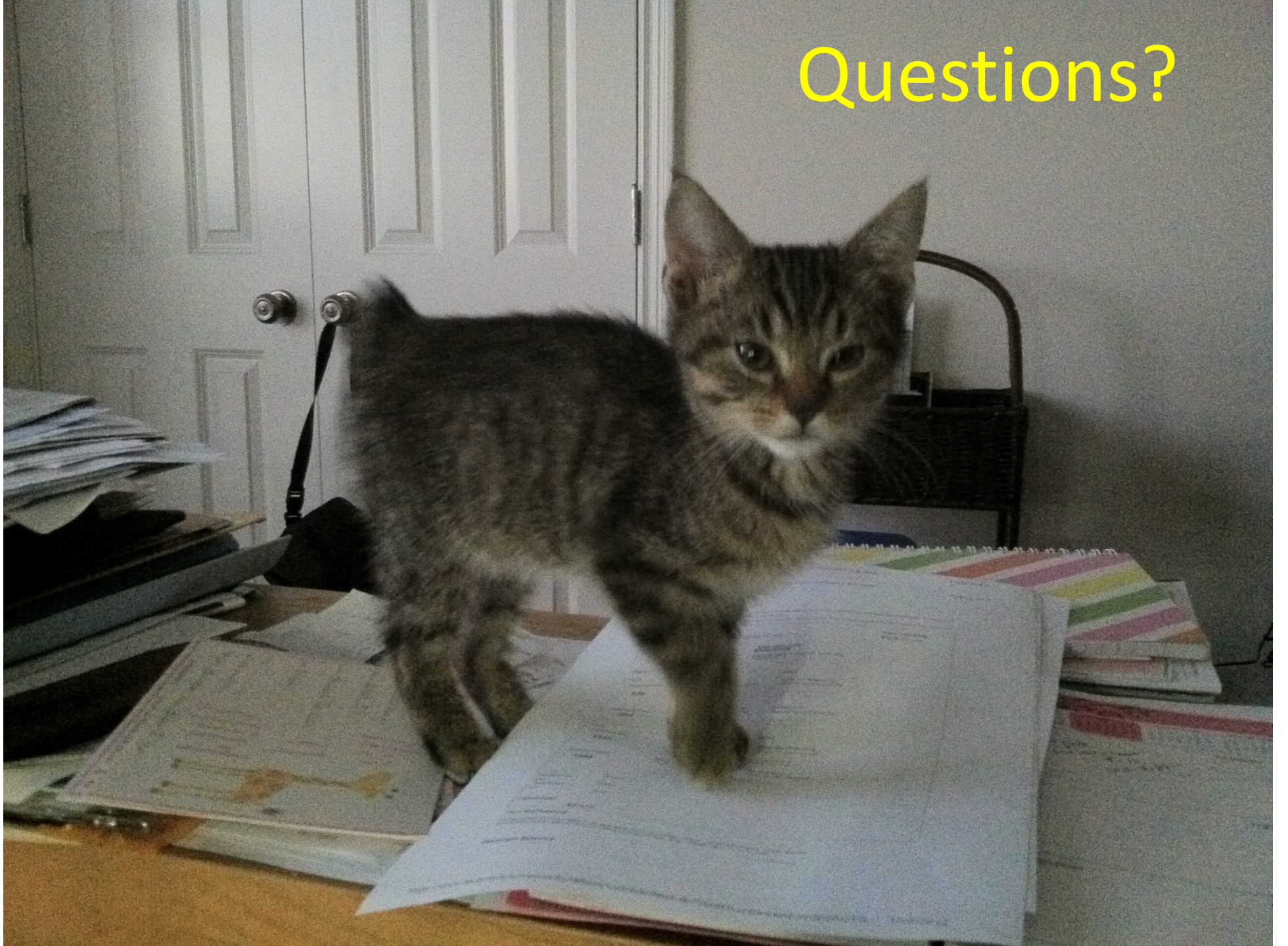
CAPABILITIES TO ENABLE SCIENCE-FOCUSED SURFACE EXPLORATION AND MAXIMIZE DEEP SPACE DISCOVERIES

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

European Moon Base Design Concept



Questions?



China's Plans as of now

- In 2019, China sent a rover to the far side of the moon – a historic first. Then in 2020, it became only the third country to successfully collect rock samples from the moon.
- In July, 2023; new details were revealed about their plans for a manned lunar mission.
- The first mission, expected before 2030, is part of an effort to establish a lunar research station. It will investigate how best to build the facility, and carry out moon exploration tasks.
- Two launch vehicles will send a moon surface lander and manned spacecraft into lunar orbit, before they dock with each other. After docking, the Chinese astronauts on board the spacecraft will enter the lander, which is used to descend to the moon's surface.
- While on the moon, they will collect samples and carry out “scientific exploration,” before leaving on the lander and reuniting with the spacecraft waiting in orbit – which will return them to Earth.
- In preparation for the mission, Chinese researchers are busy developing all the necessary equipment including moon suits, manned lunar rovers, manned spaceships and moon landers. This includes a whole new fleet of reusable, heavy-lift launchers.

Costs

- Apollo program
- \$25.8 Billion 1960-1973
- ~\$257B in 2020 dollars
- Artemis Program
- \$93B 2012-2025 (2020 dollars)
- In contrast:
- Vietnam \$168B (1963-1974)
- ~\$1T+ in current year