

National Aeronautics and
Space Administration



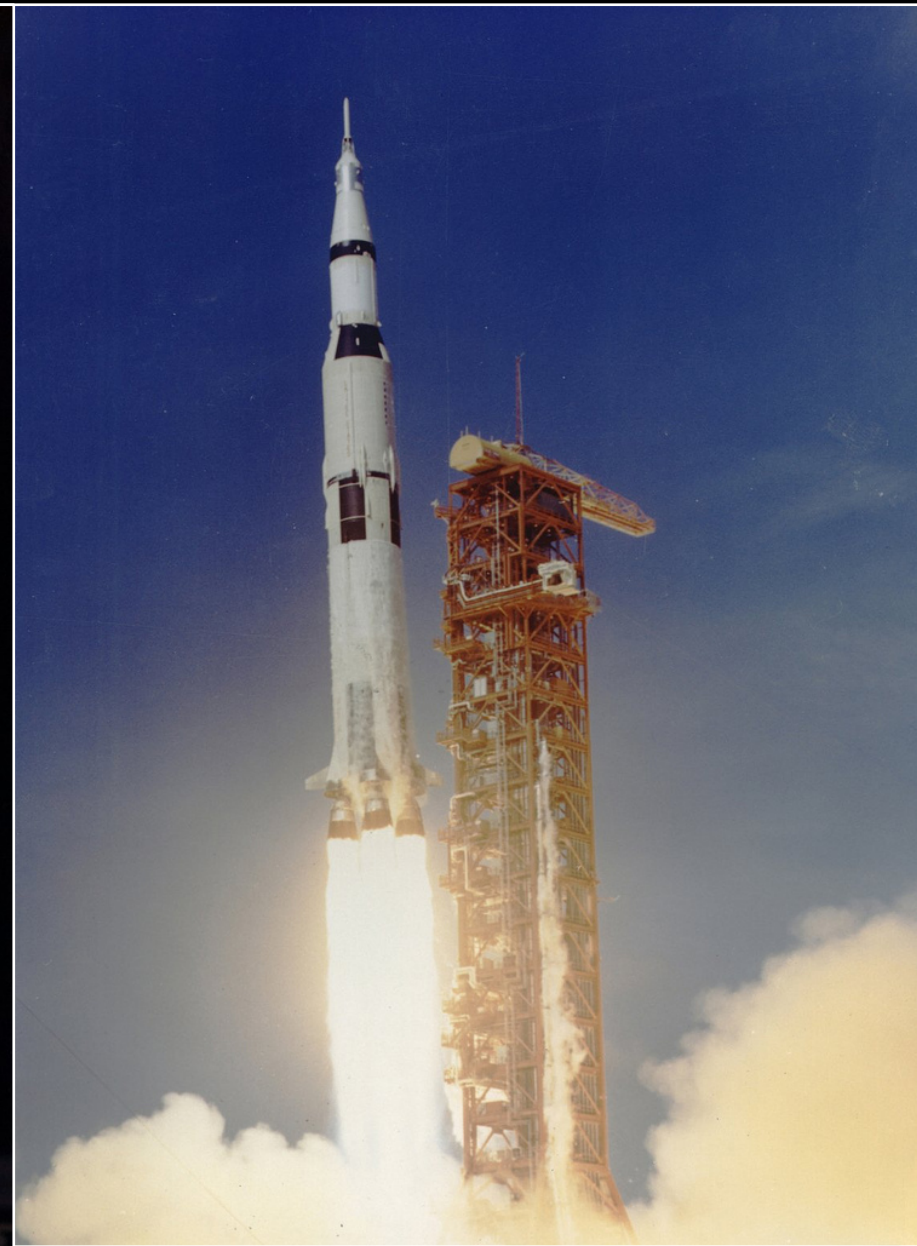
Forward to the Moon: NASA's Strategic Plan for Lunar Exploration

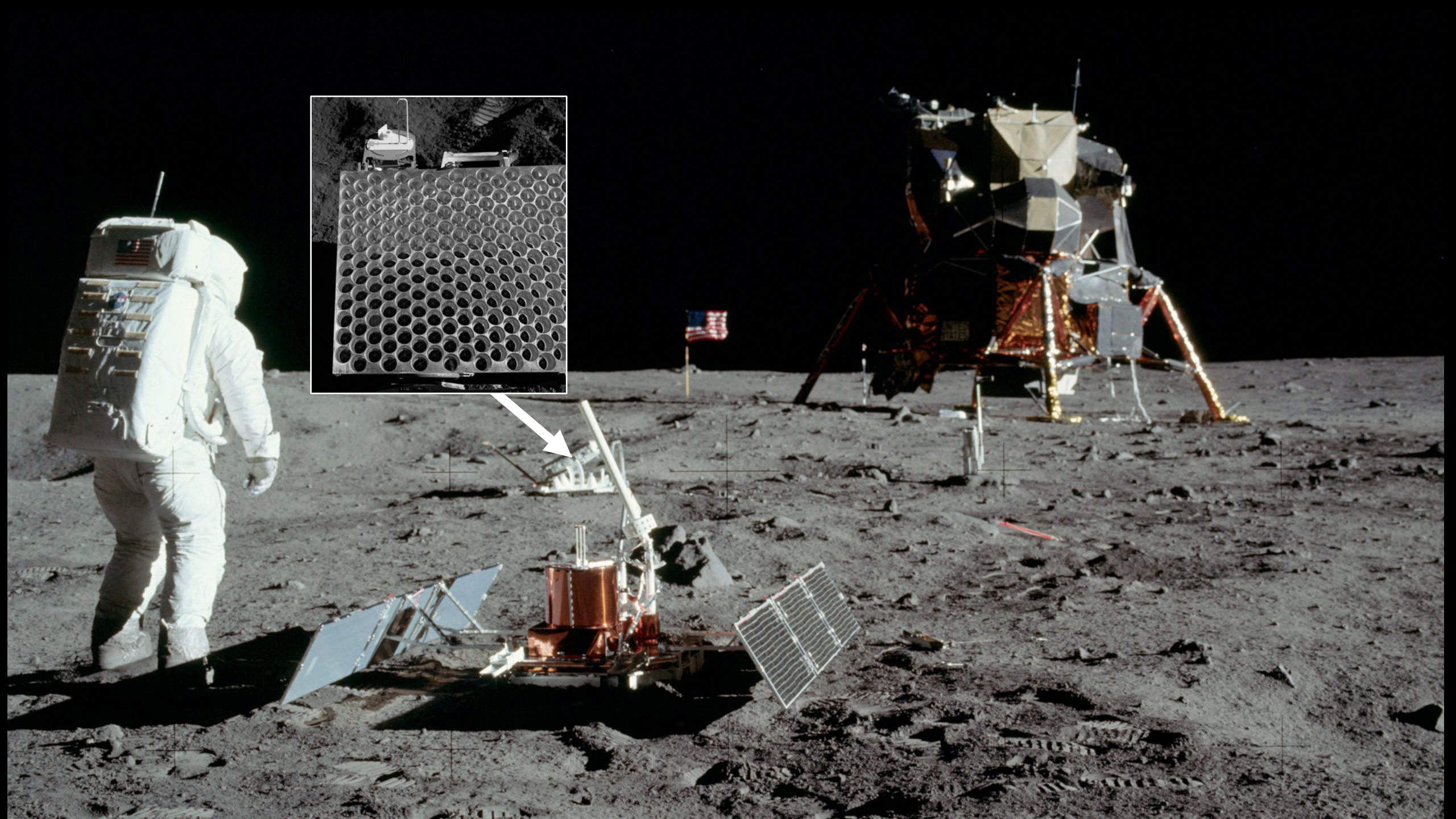
EXPLORESCIENCE

James L. Green
NASA Chief Scientist

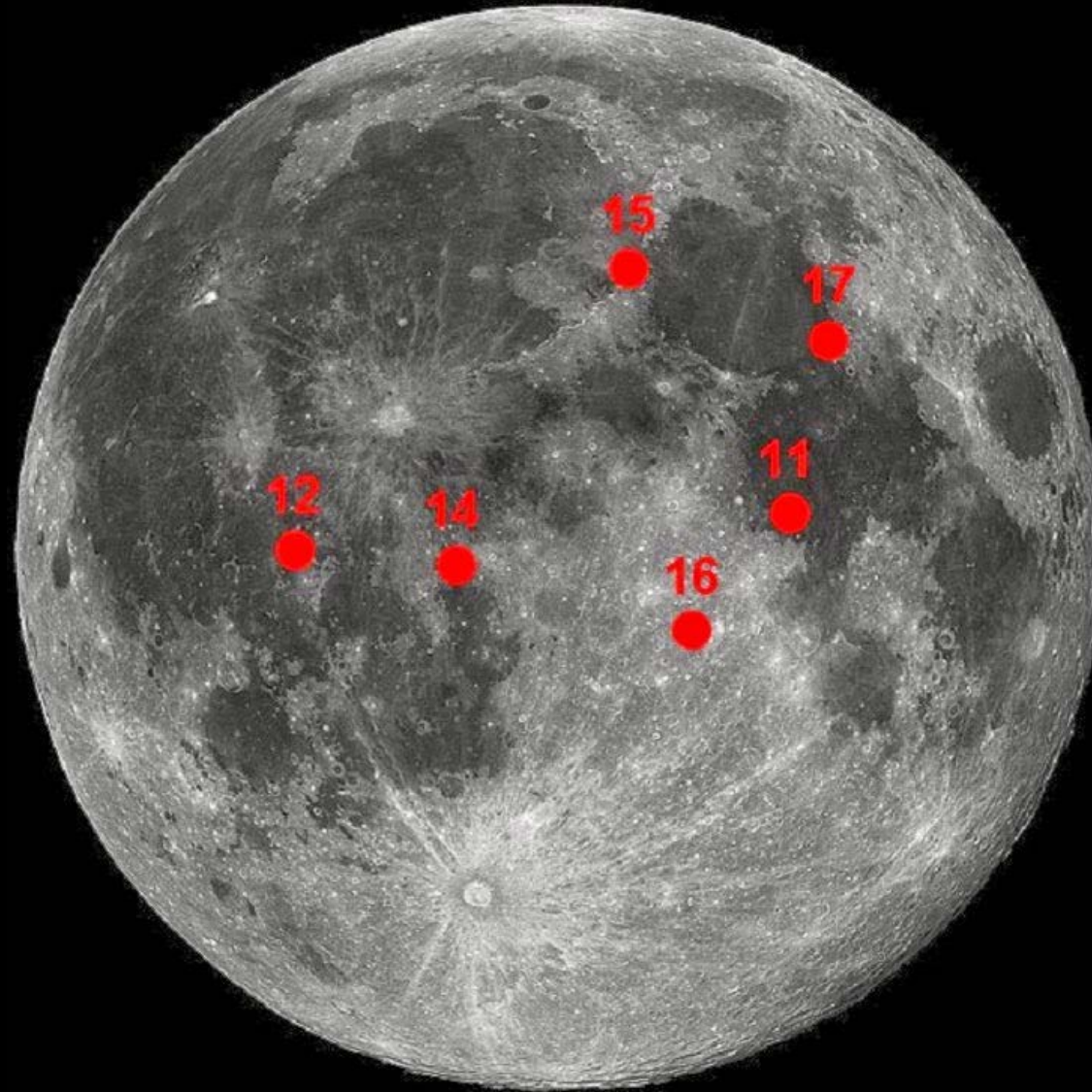
Kyoto University

October 4, 2019



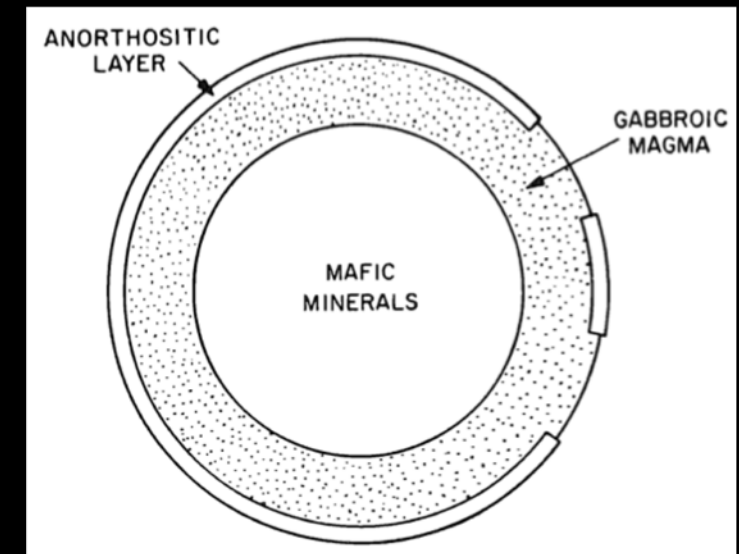


Apollo Lunar Exploration Program



What did the Apollo Lunar Samples Tell us?

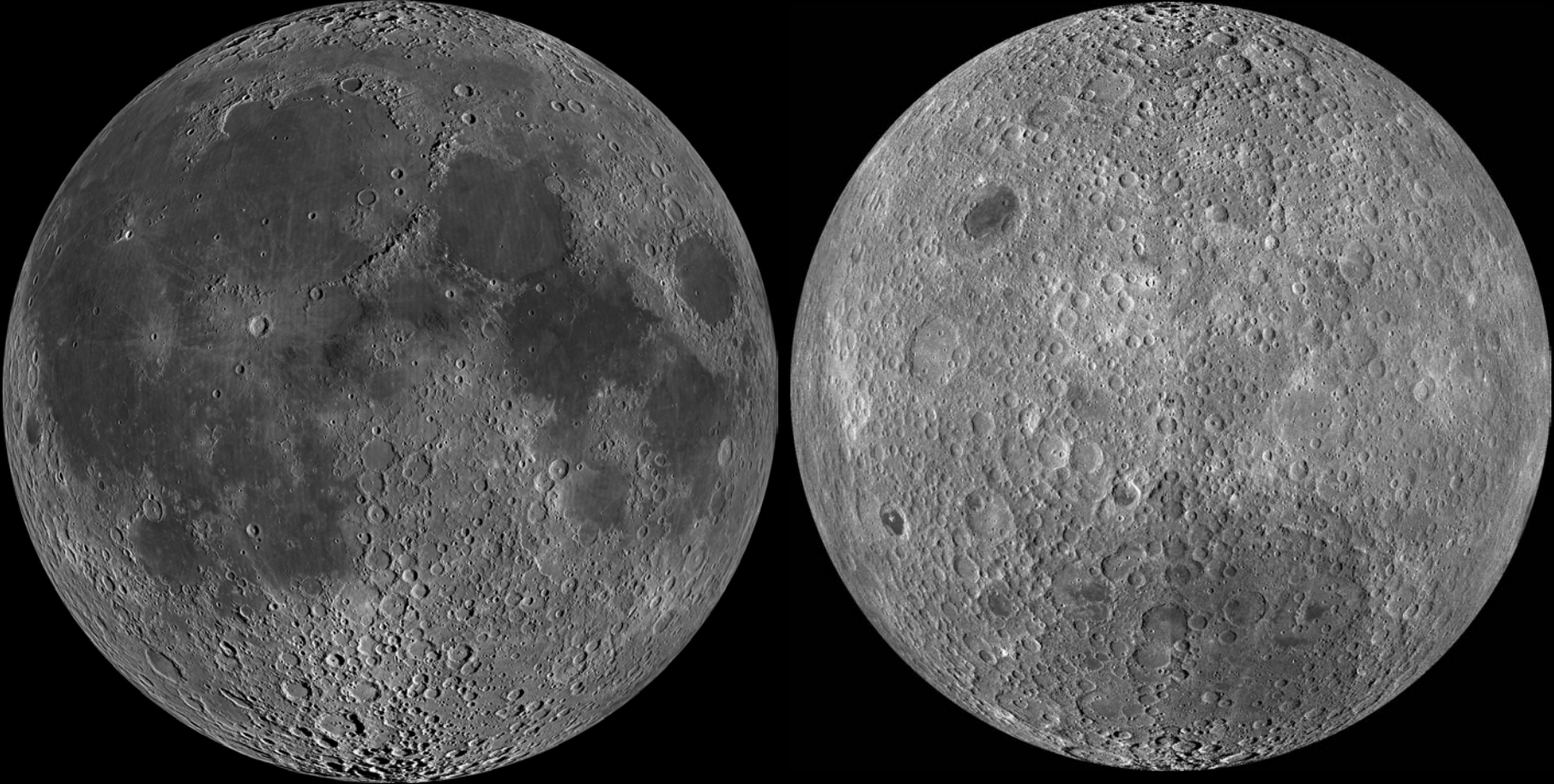
- The Moon is old (~4.6 Ga)
- Early Moon had a molten magma ocean that cooled to form the crust
- Impact cratering is a fundamental and important geologic process
- Large impacts occurred early in lunar history
- Volcanic activity occurred ~4.2-3.16 Ga
- The surface samples are “bone” dry
- Isotopic analysis told us the Moon and Earth are virtually identical



Earth's Moon

Nearside

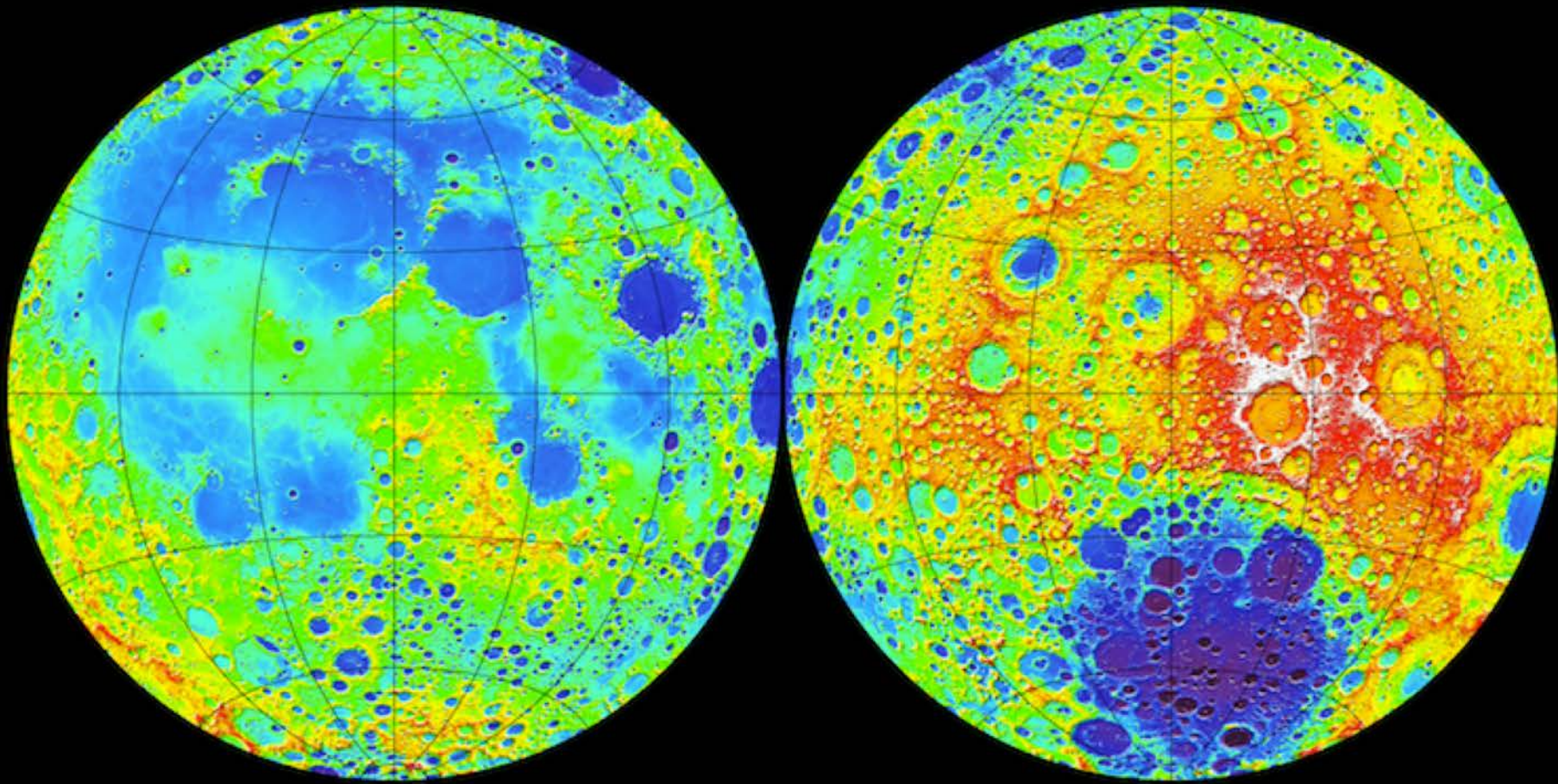
Farside



Earth's Moon
Altitude

Nearside

Farside



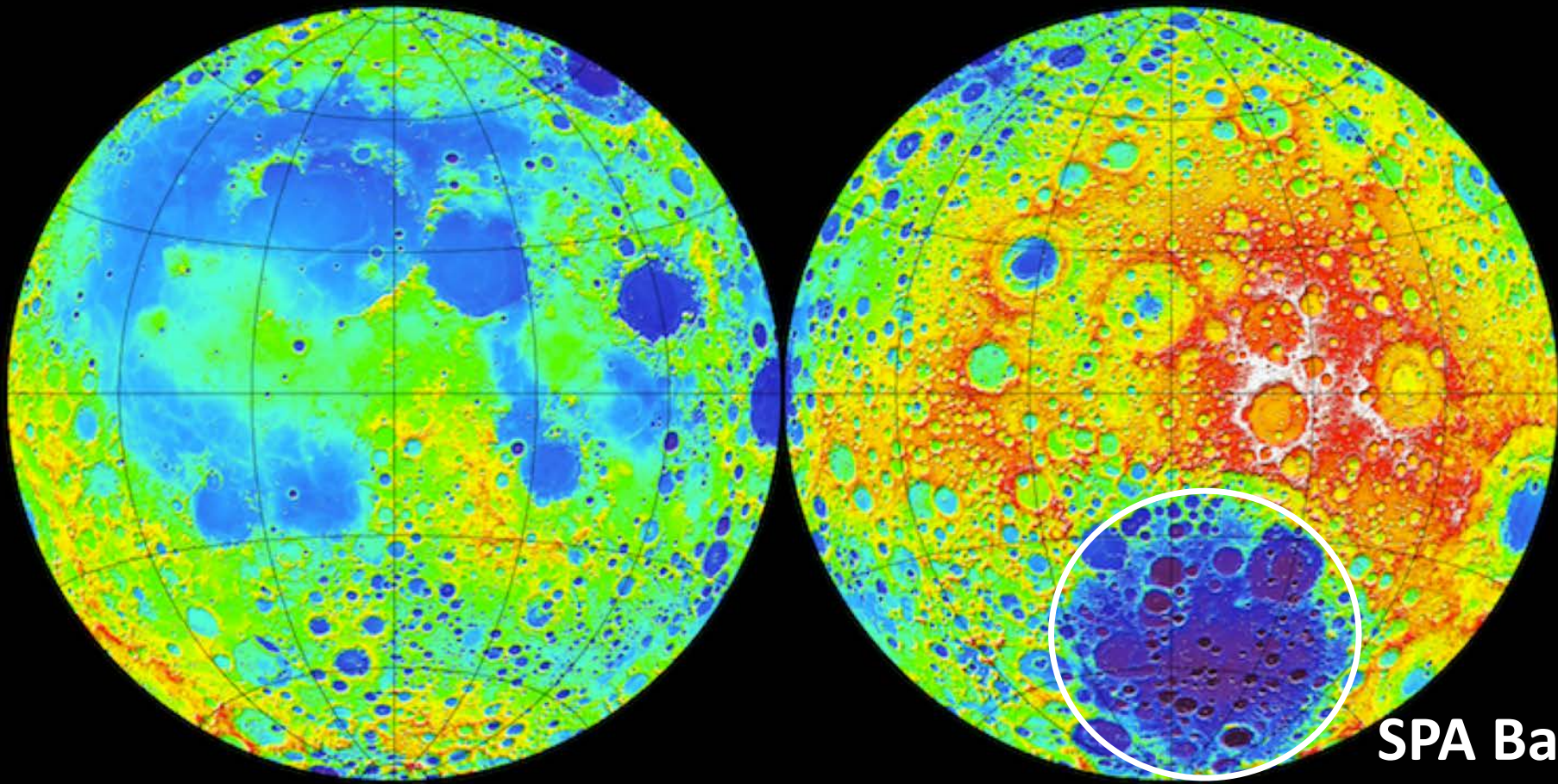
Topography (km)



Earth's Moon
Altitude

Nearside

Farside



SPA Basin

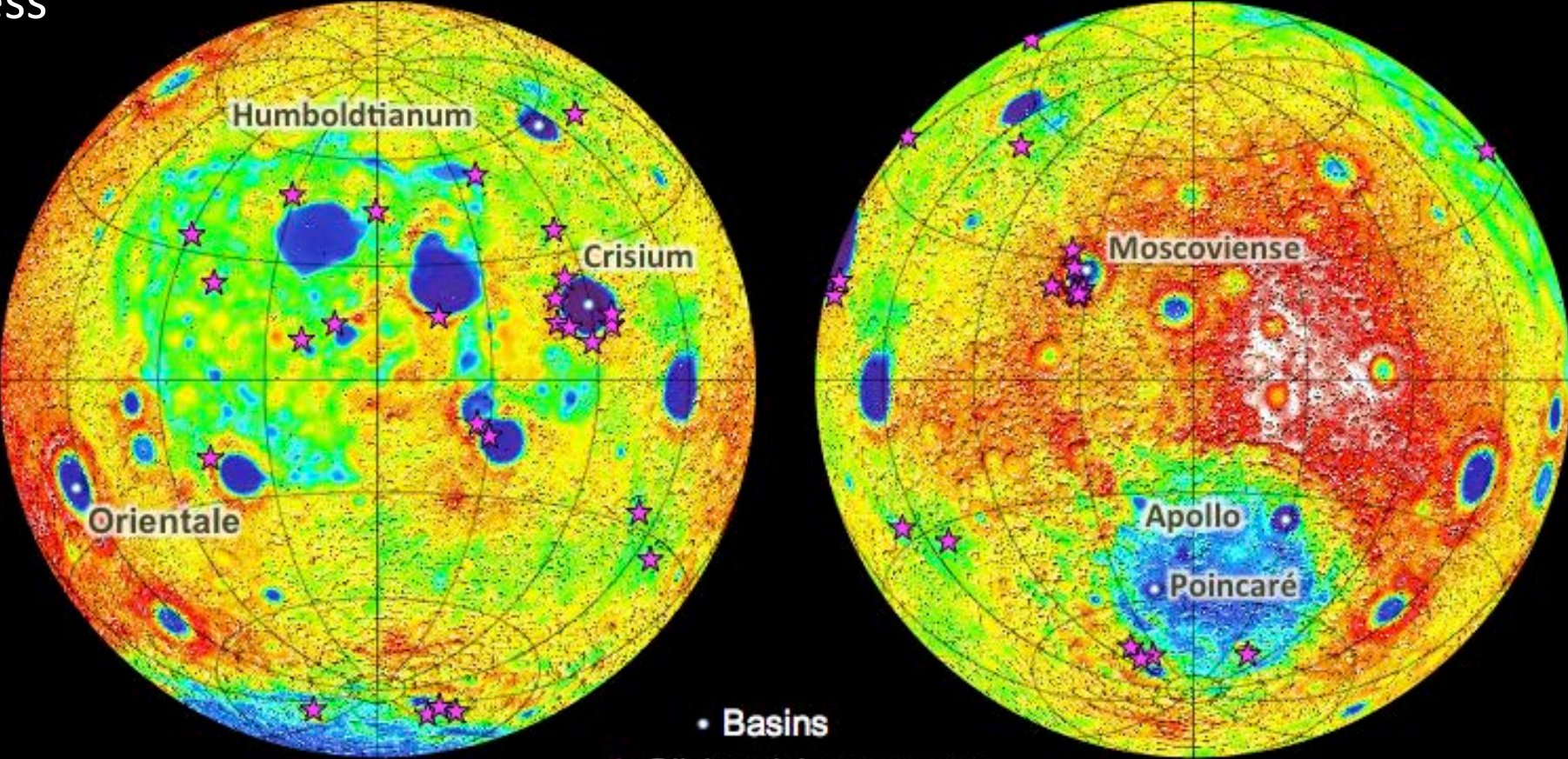
Topography (km)



Earth's Moon Crust Thickness

Nearside

Farside



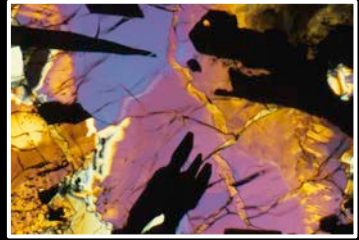
• Basins

★ Olivine-rich exposures

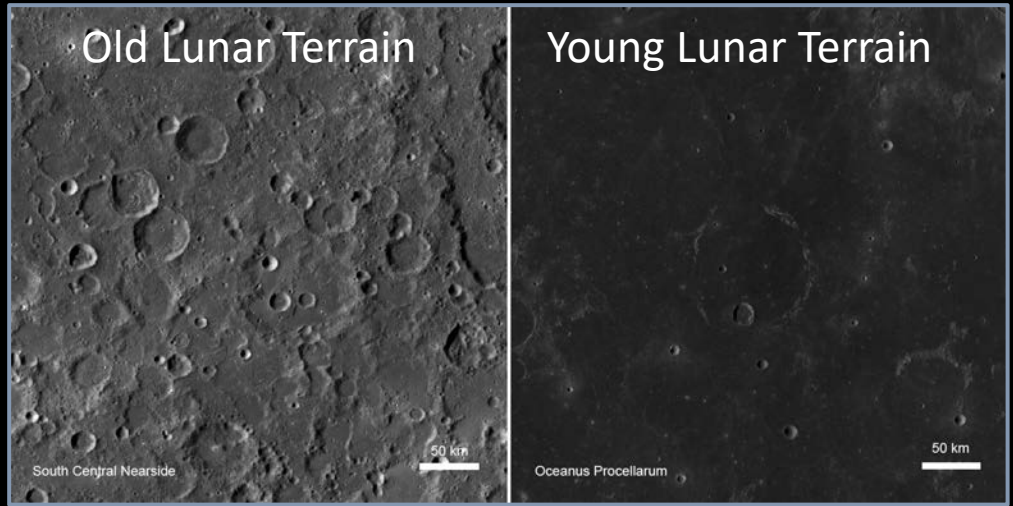


Crustal thickness (km)

Setting the Solar System's Clock

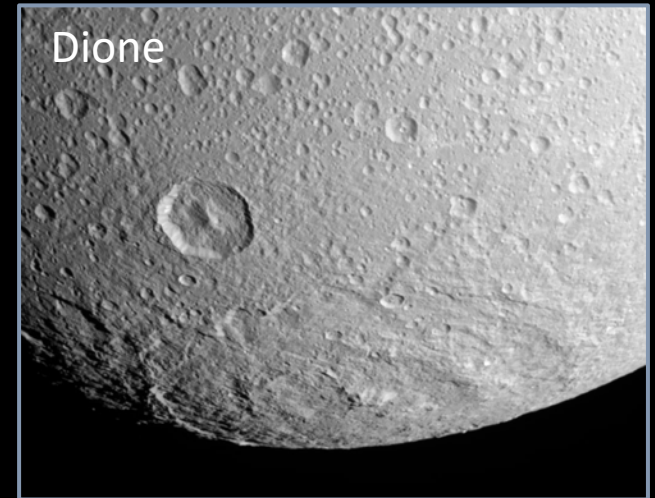


70017



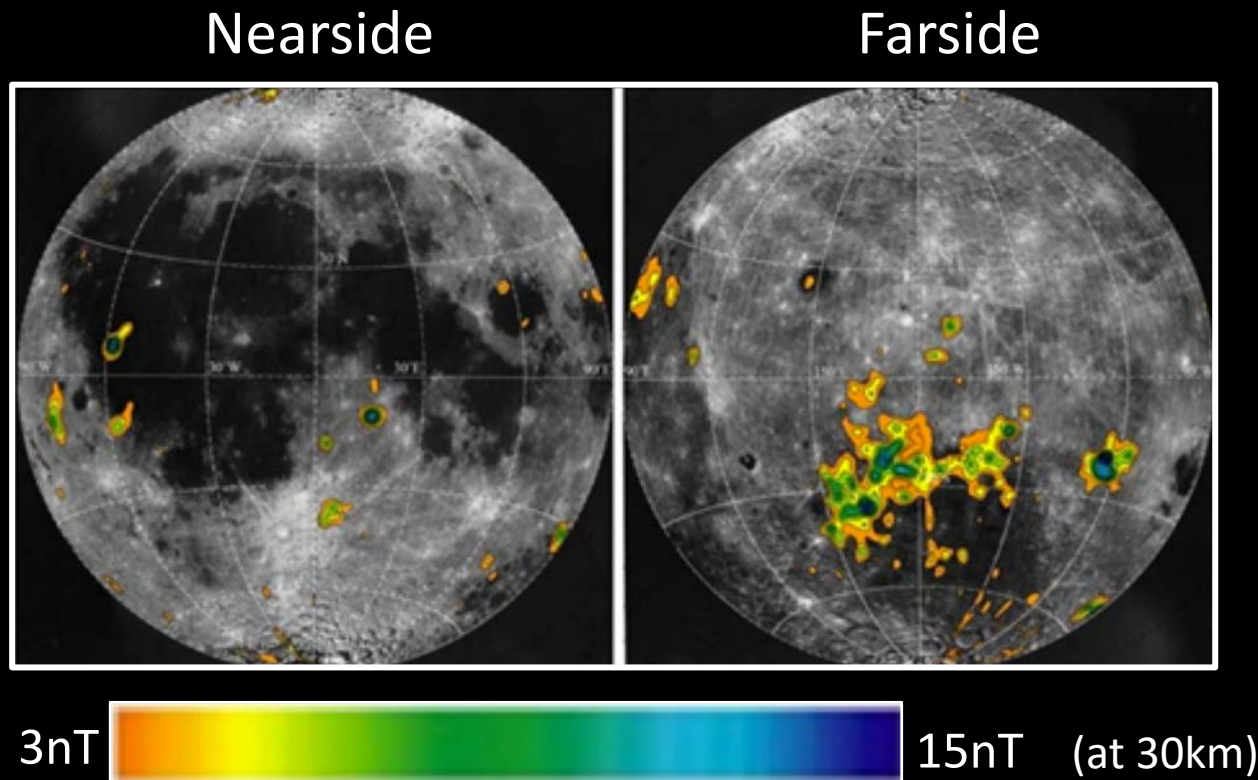
Ages of lunar surface samples calibrate the crater density "clock" used to estimate ages elsewhere on the Moon

And is used to estimate the ages of all other planetary surfaces in the Solar System



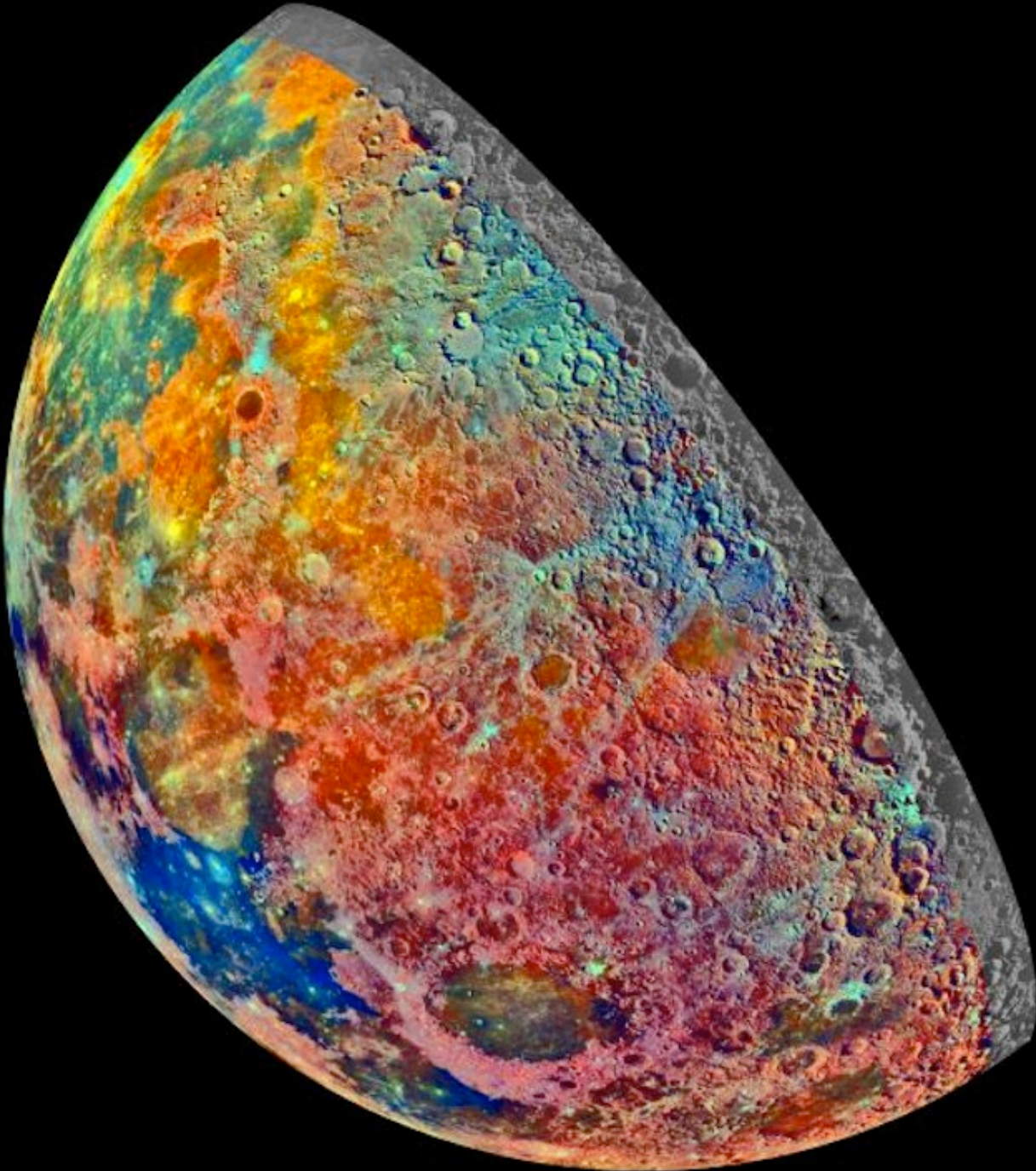
Magnetic Anomalies: Fe, Ni and PGM

- Platinum group metals (PGM) are primarily located in SPA Basin
- PGM concentration in iron meteorites can reach 200 ppm



PGM	Value per kg
Platinum	\$28,290
Palladium	\$31,860
Osmium	\$12,860
Iridium	\$45,330
Rhodium	\$72,660
Ruthenium	\$8,038.05

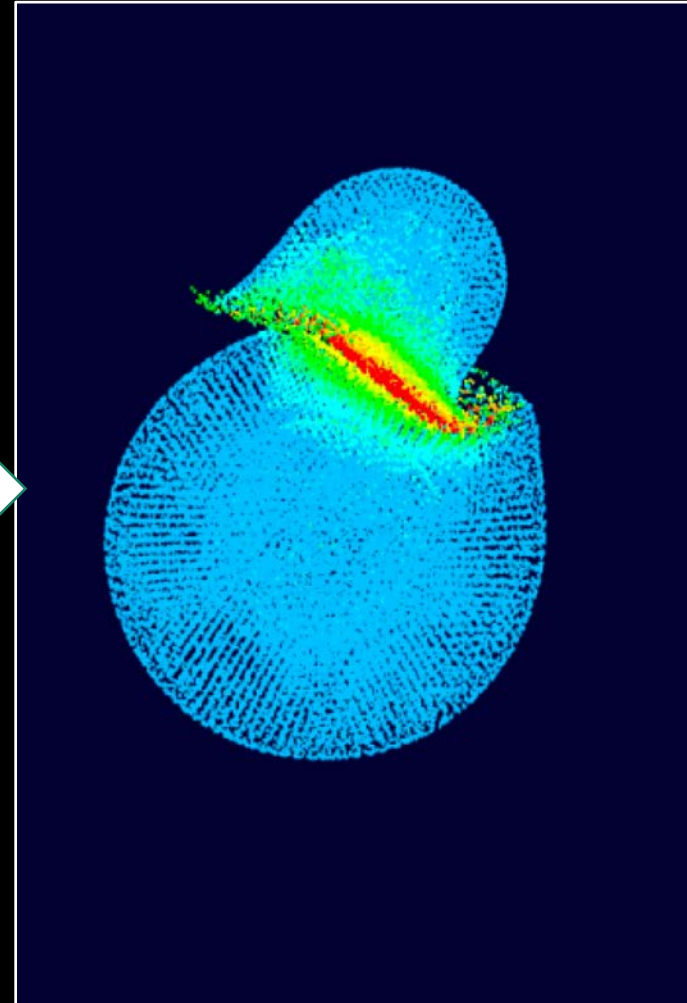
Moon's - Composition



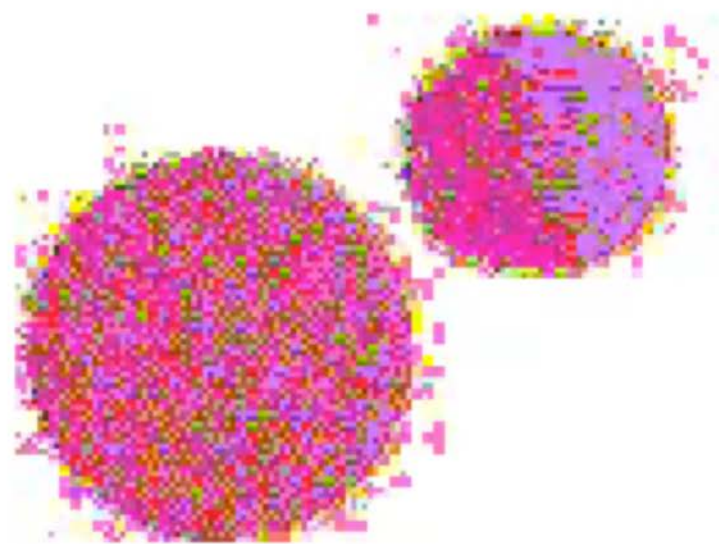
Earth-Moon Formation



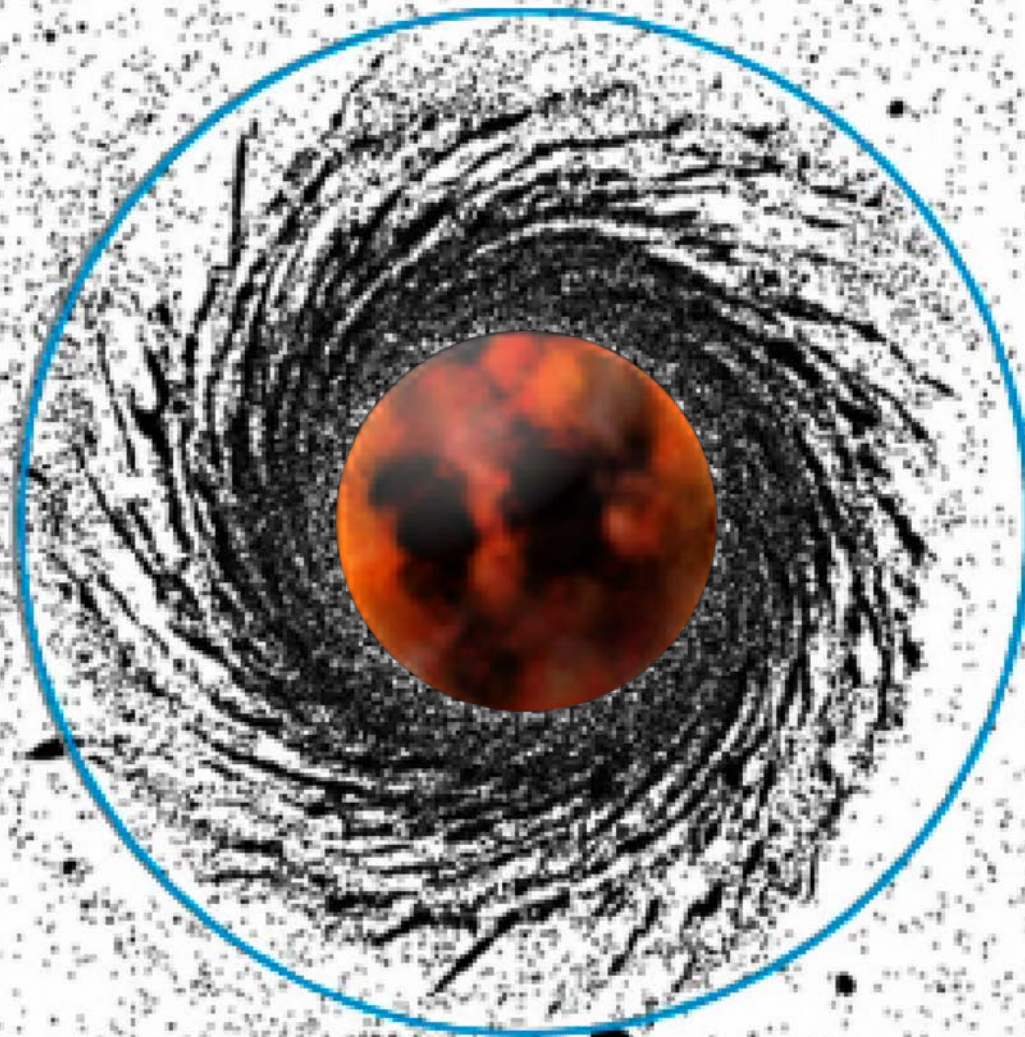
Lunar exploration can reveal how the Earth-Moon system formed



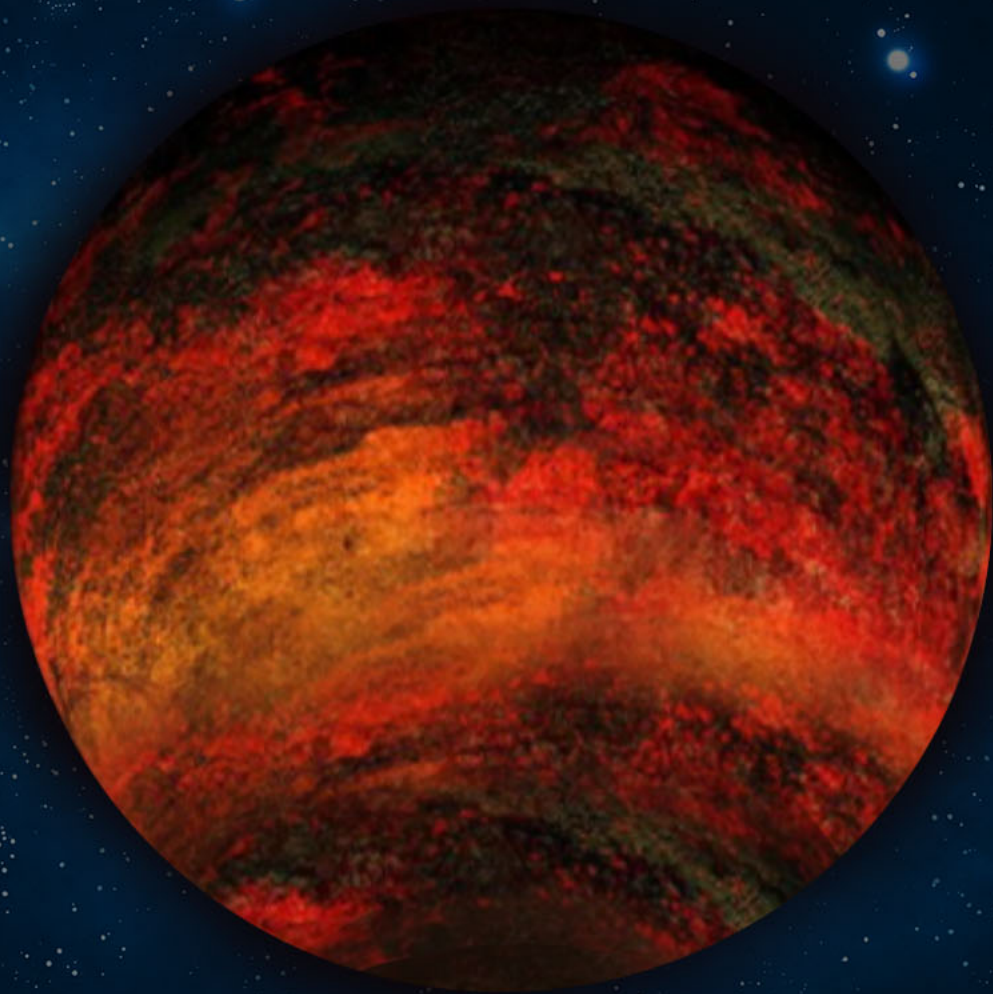
Giant impact hypothesis for origin of Moon



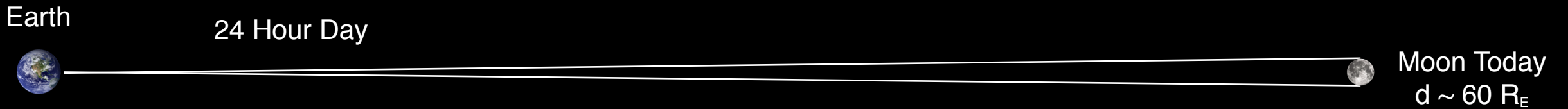
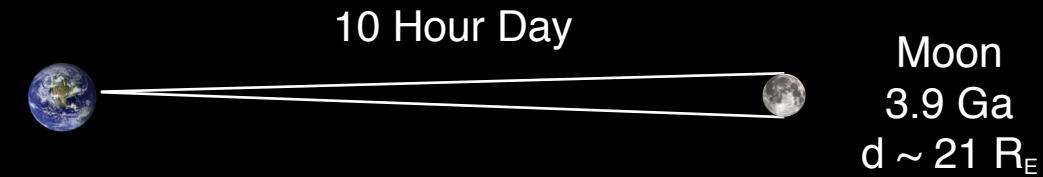
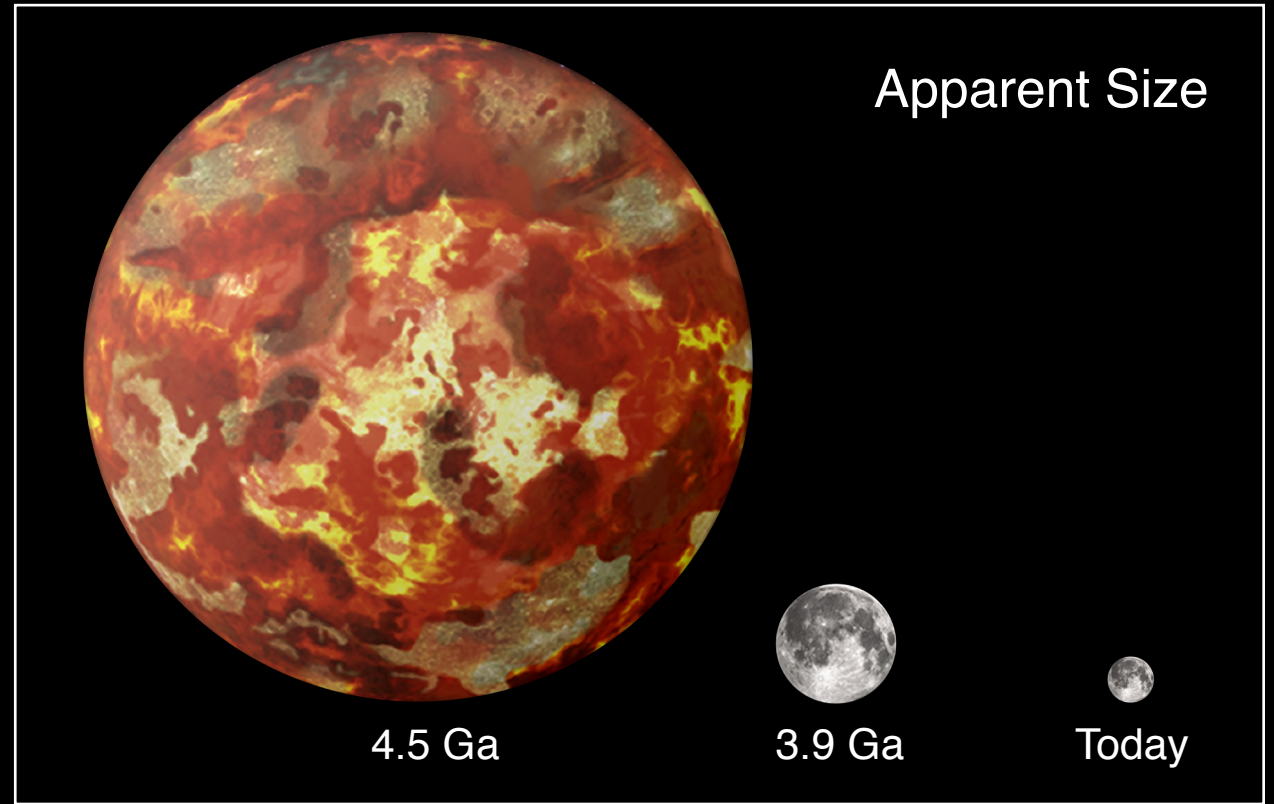
Roche limit



5-Hour Day



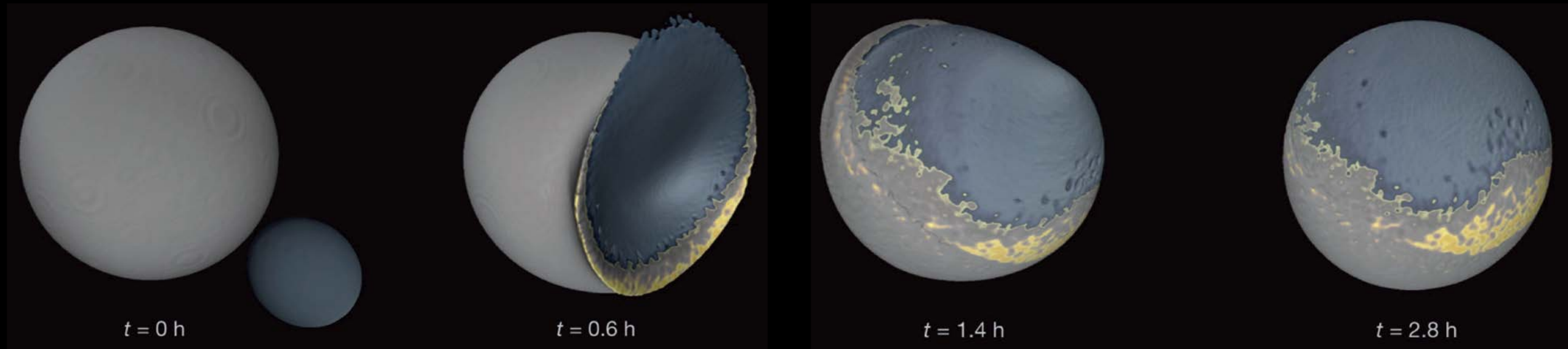
The Moon Stabilizes Our Spin Axis



Theory 1: Formation of Farside Highlands

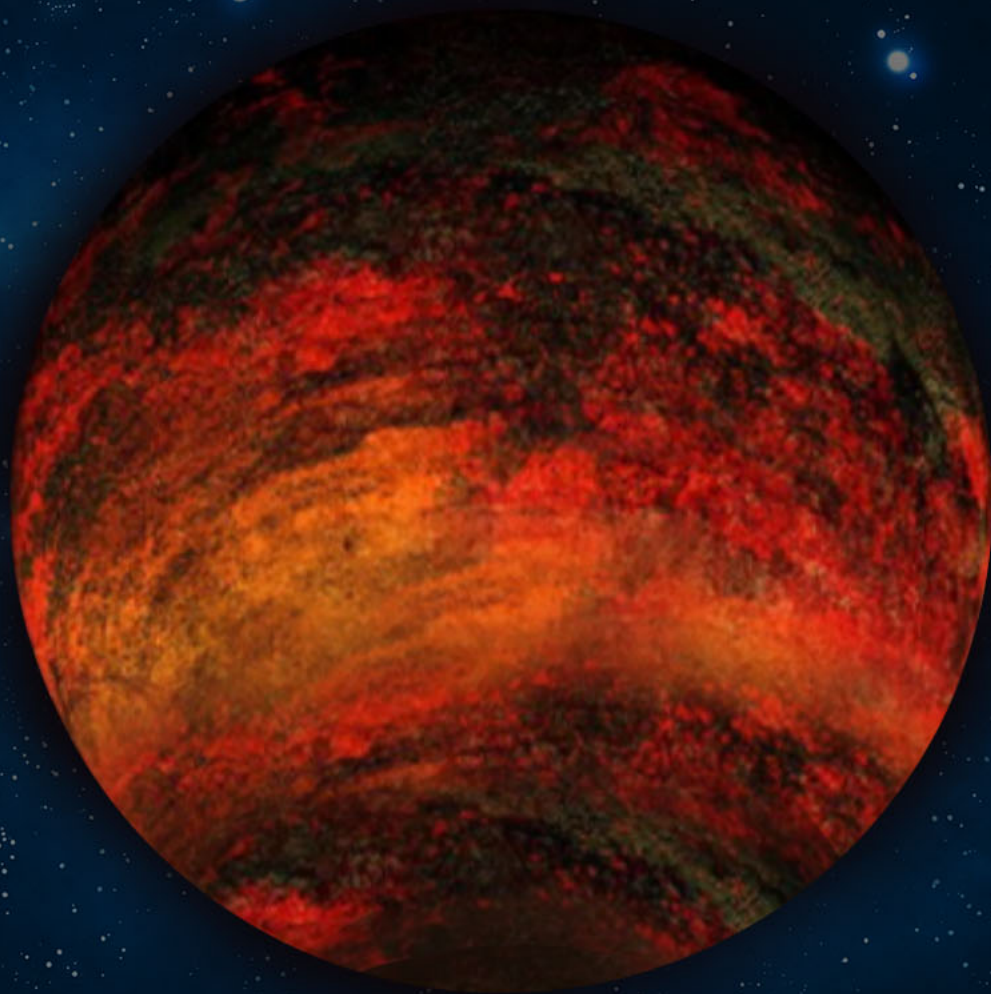


Theory 1: Formation of Farside Highlands

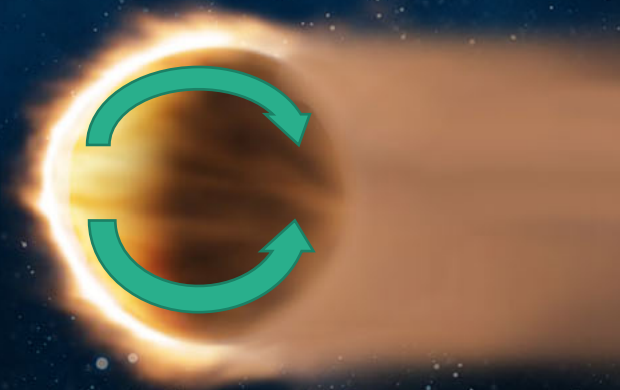
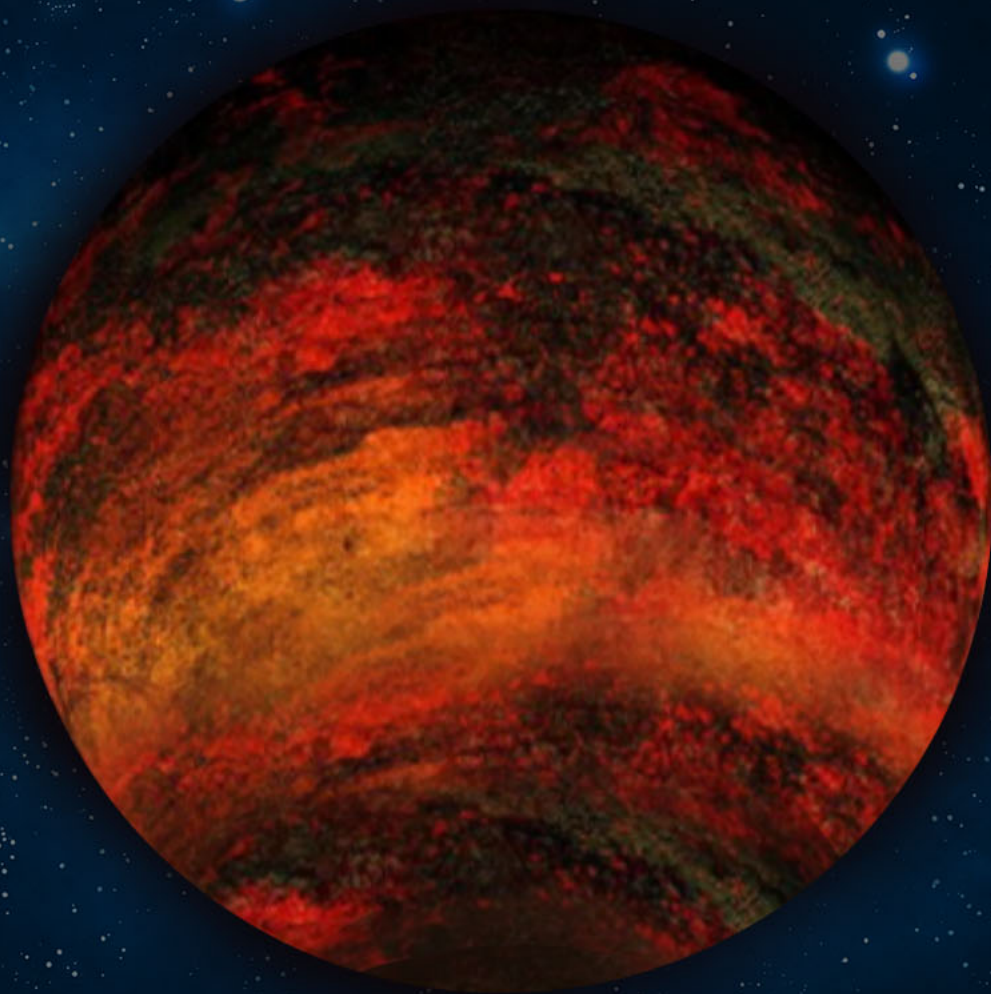


Thicker Crust on the
Far side of the Moon

Theory 2: Formation of Farside Highlands

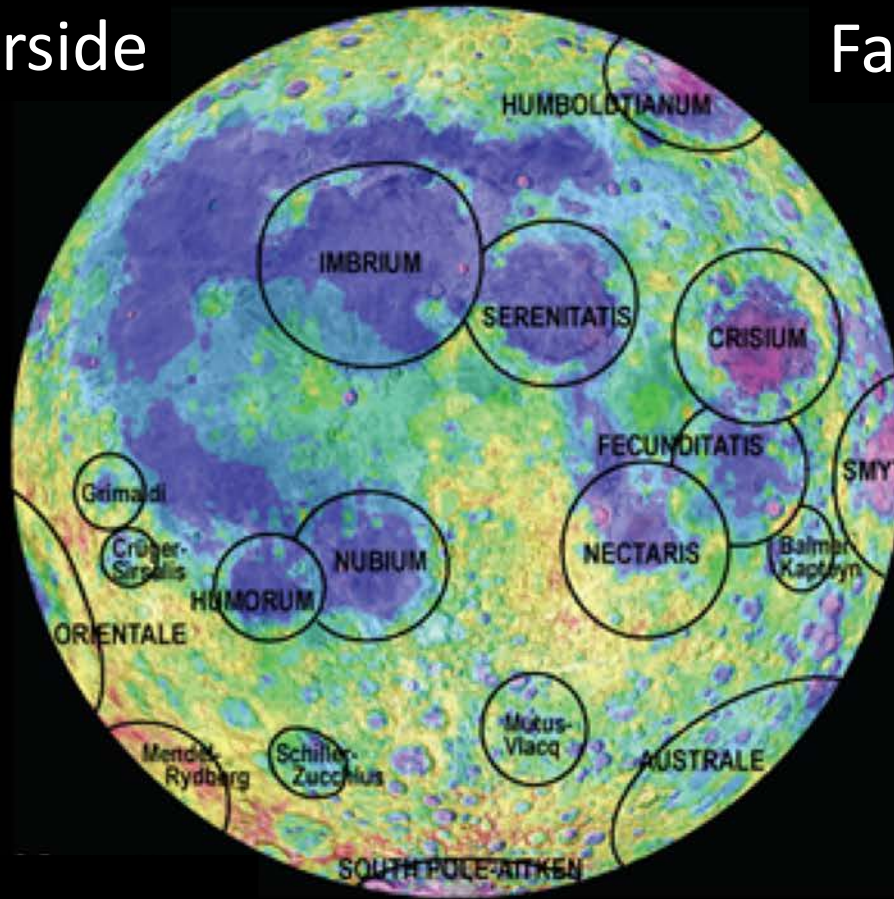


Theory 2: Formation of Farside Highlands

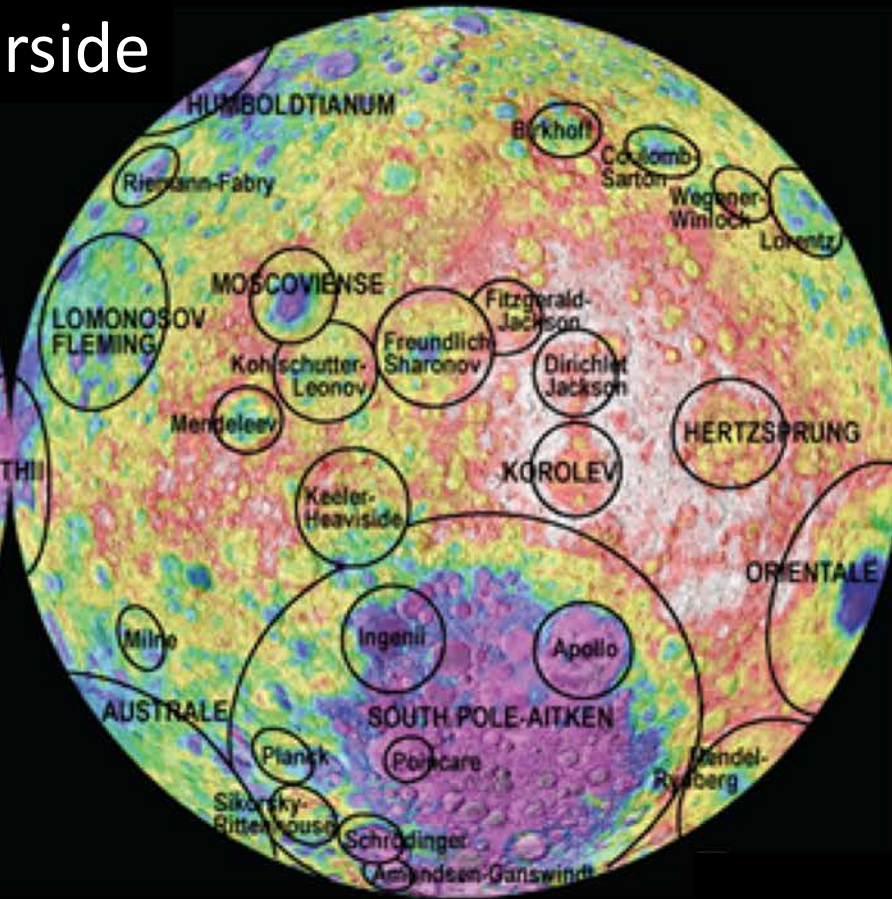


Bombardment History

Nearside



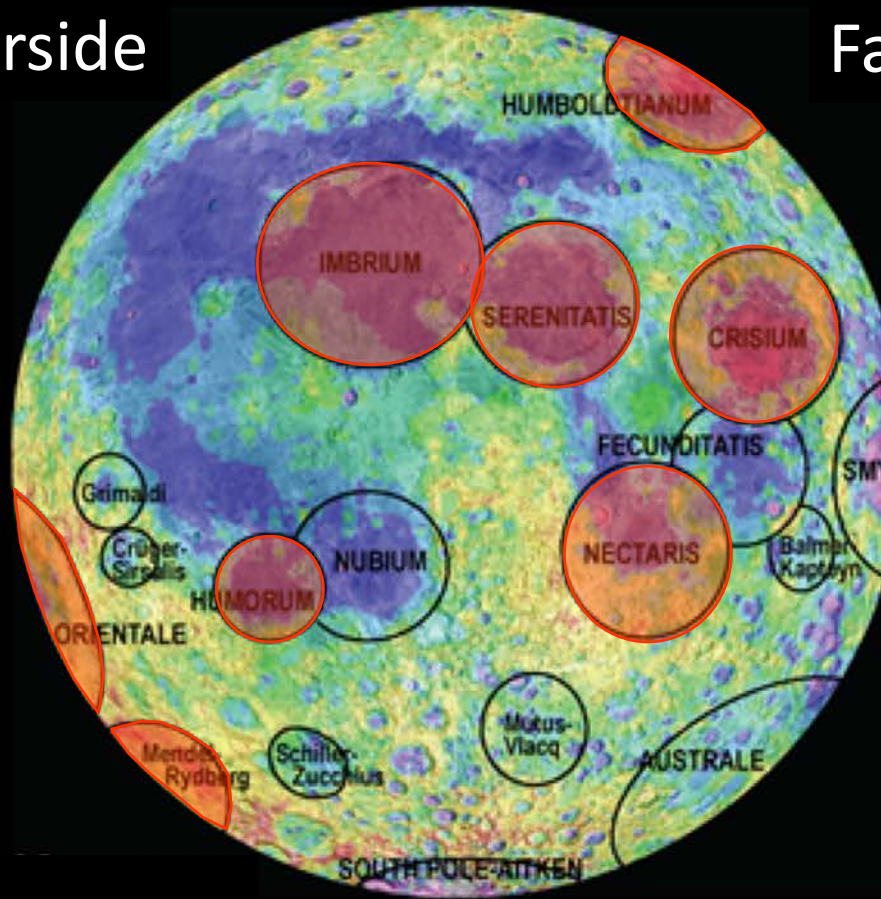
Farside



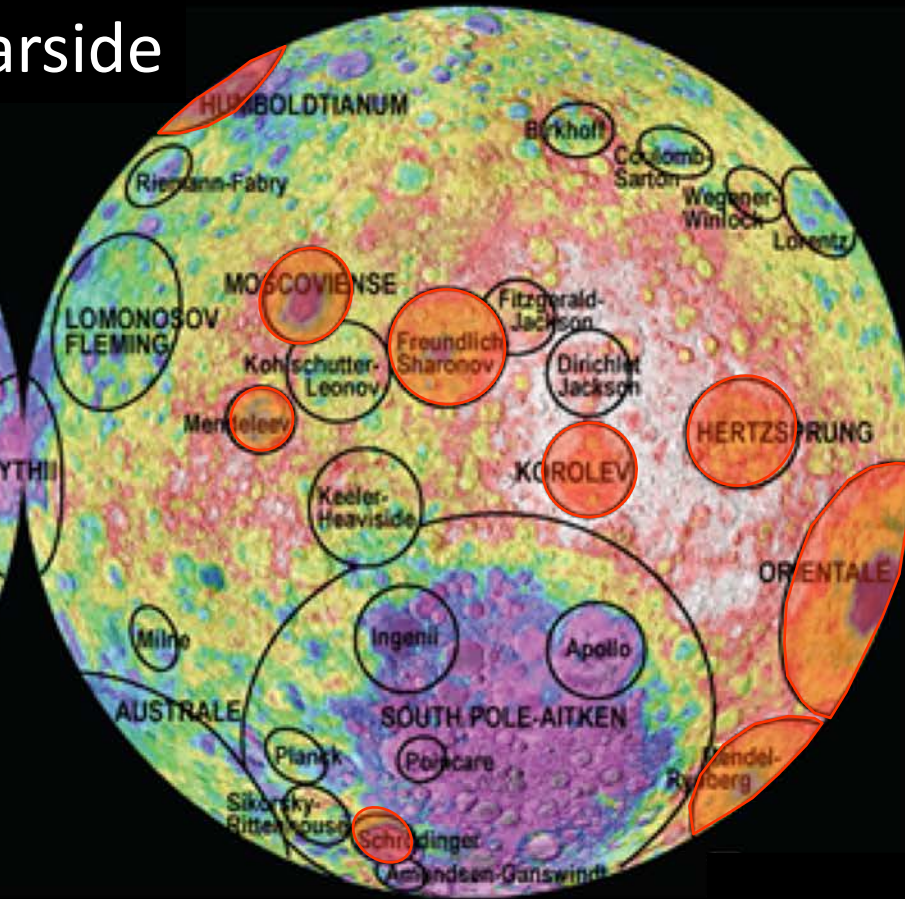
For every 1 impact on the Moon the Earth should have 20 impacts!

The Late Heavy Bombardment (4.0 - 3.8 Ga)

Nearside



Farside



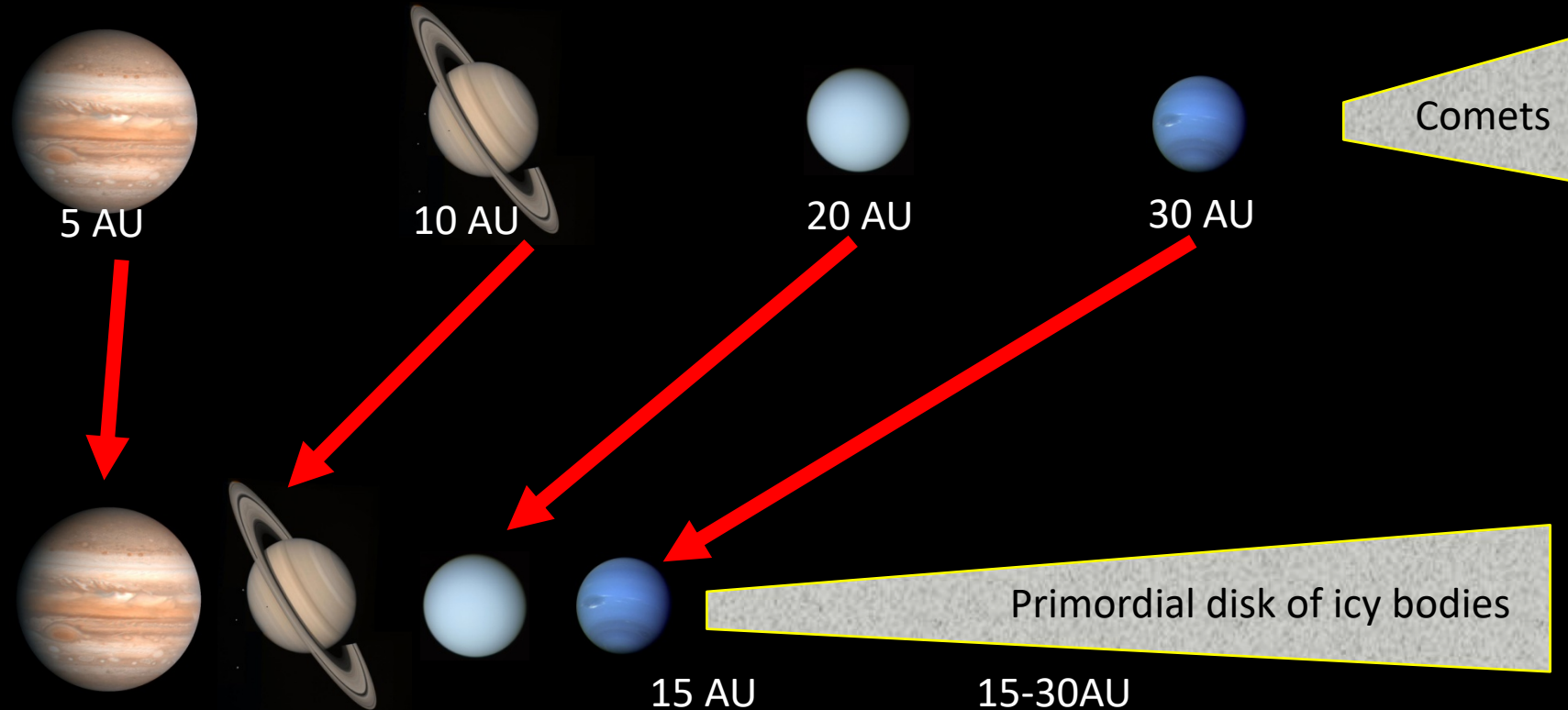
We only have reliable dates for Imbrium and Orientale Basins

Solar System Formation Models



- Planets formed near present locations
- Problem: Can't create all the outer planets even after ~4.5 By of evolution!

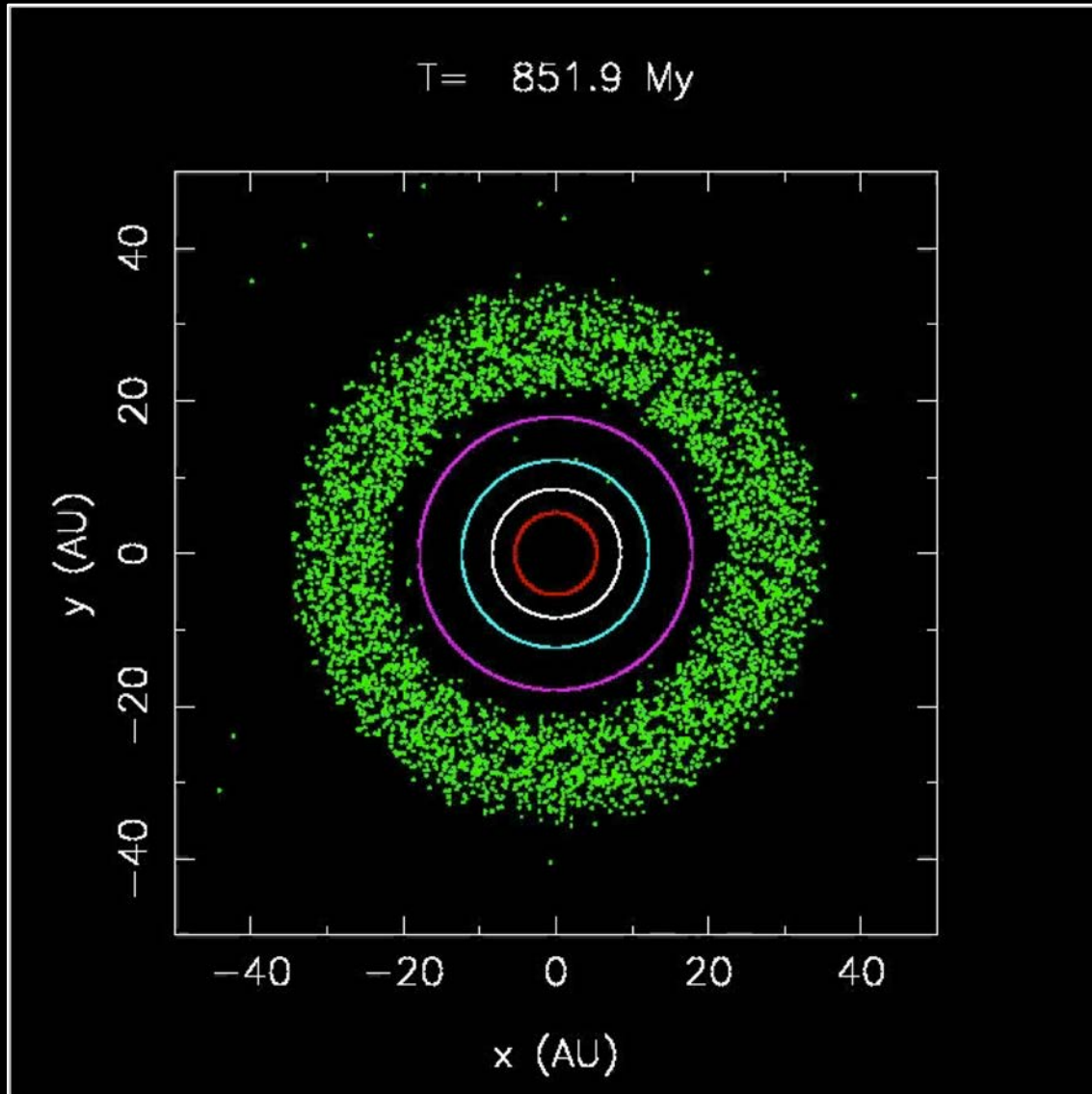
Solar System Formation Models



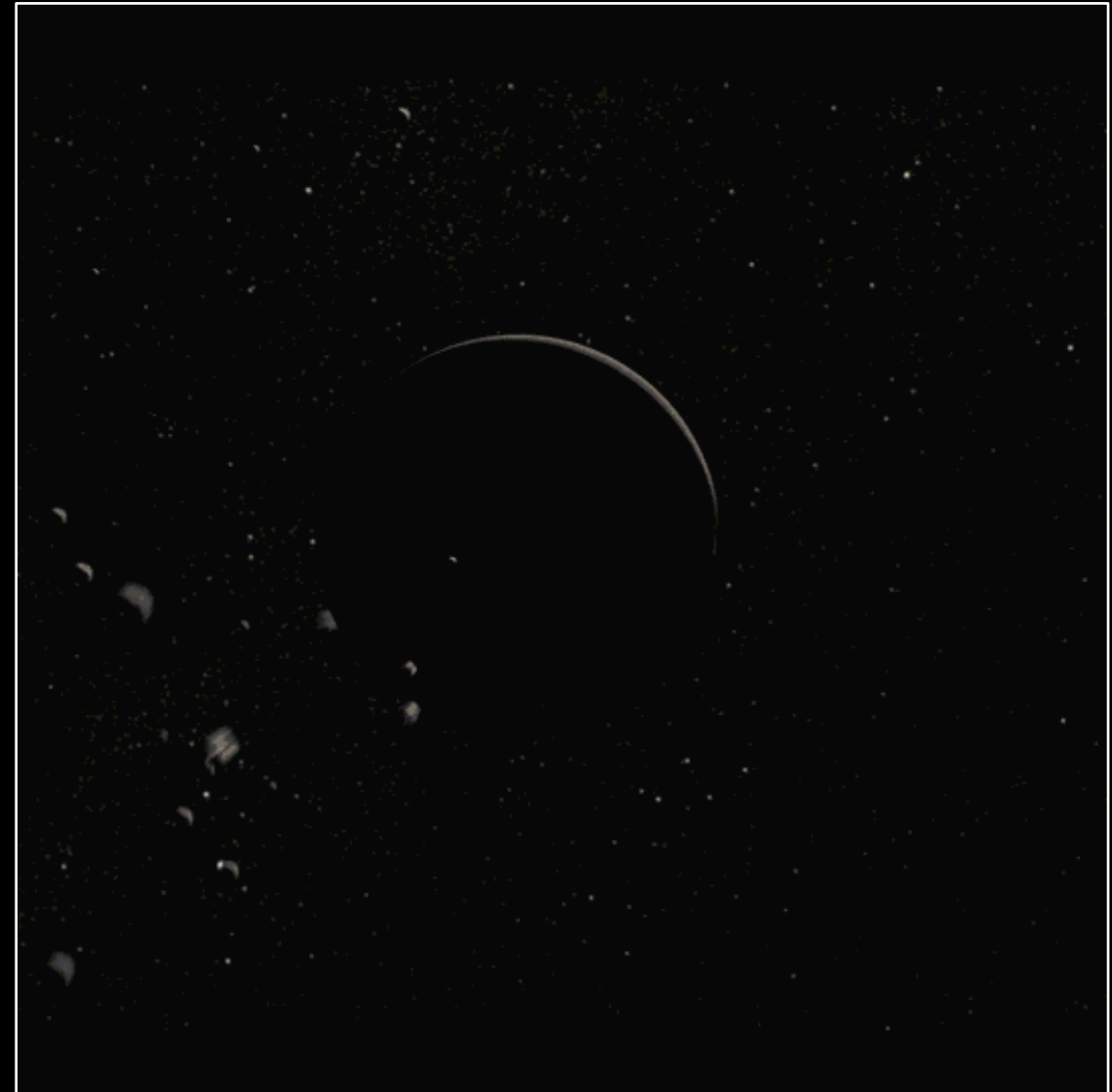
Basic Principle: Objects closer to the Sun can grow *faster*

- Gas giants must form in a compact configuration (5-15 AU)
- Massive icy body population will then exist (15-30 AU)

Destabilizing the Outer Solar System



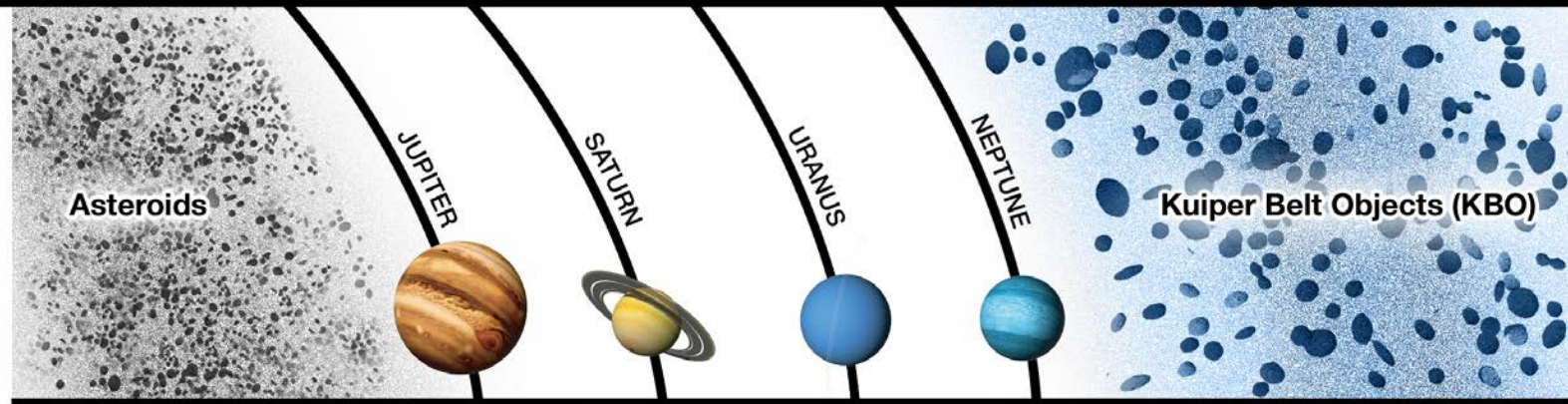
Watch what happens after 890 My



The Late Heavy Bombardment

Theory: Evolution of the Solar System

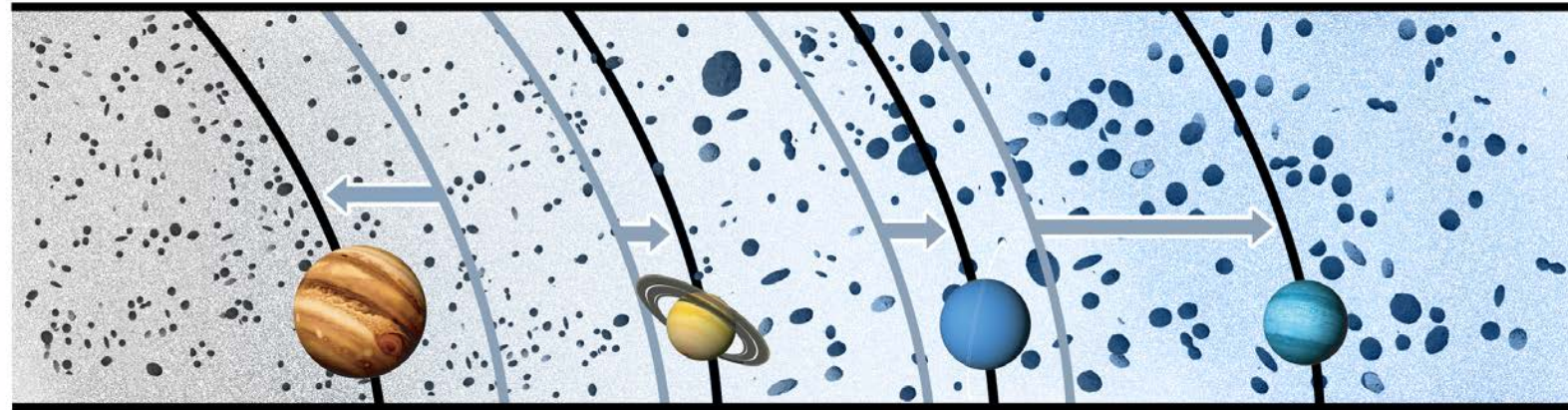
~4.2 Billion
Years



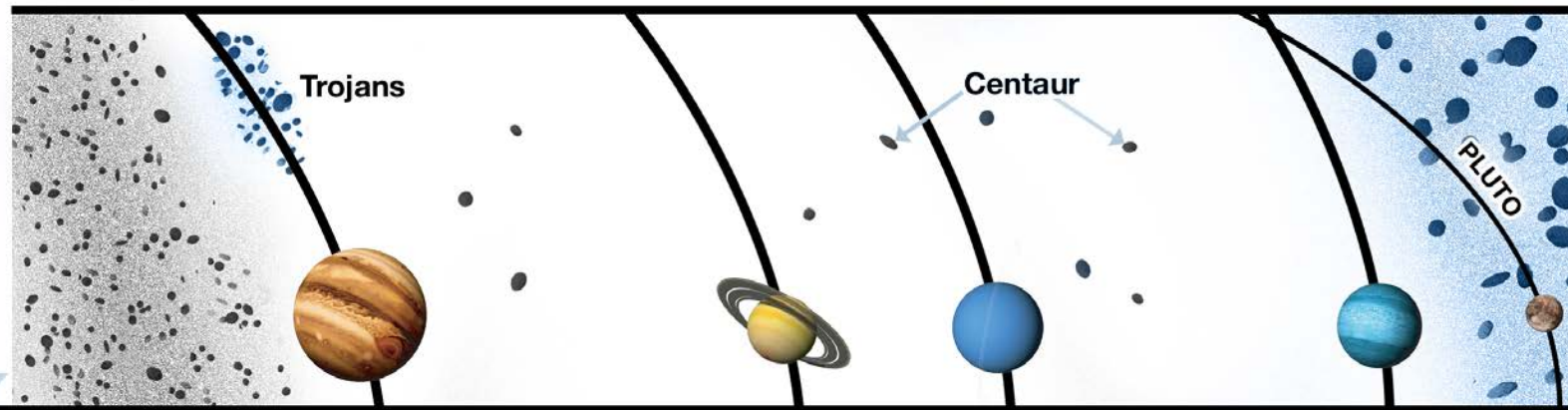
~3.8 Billion
Years

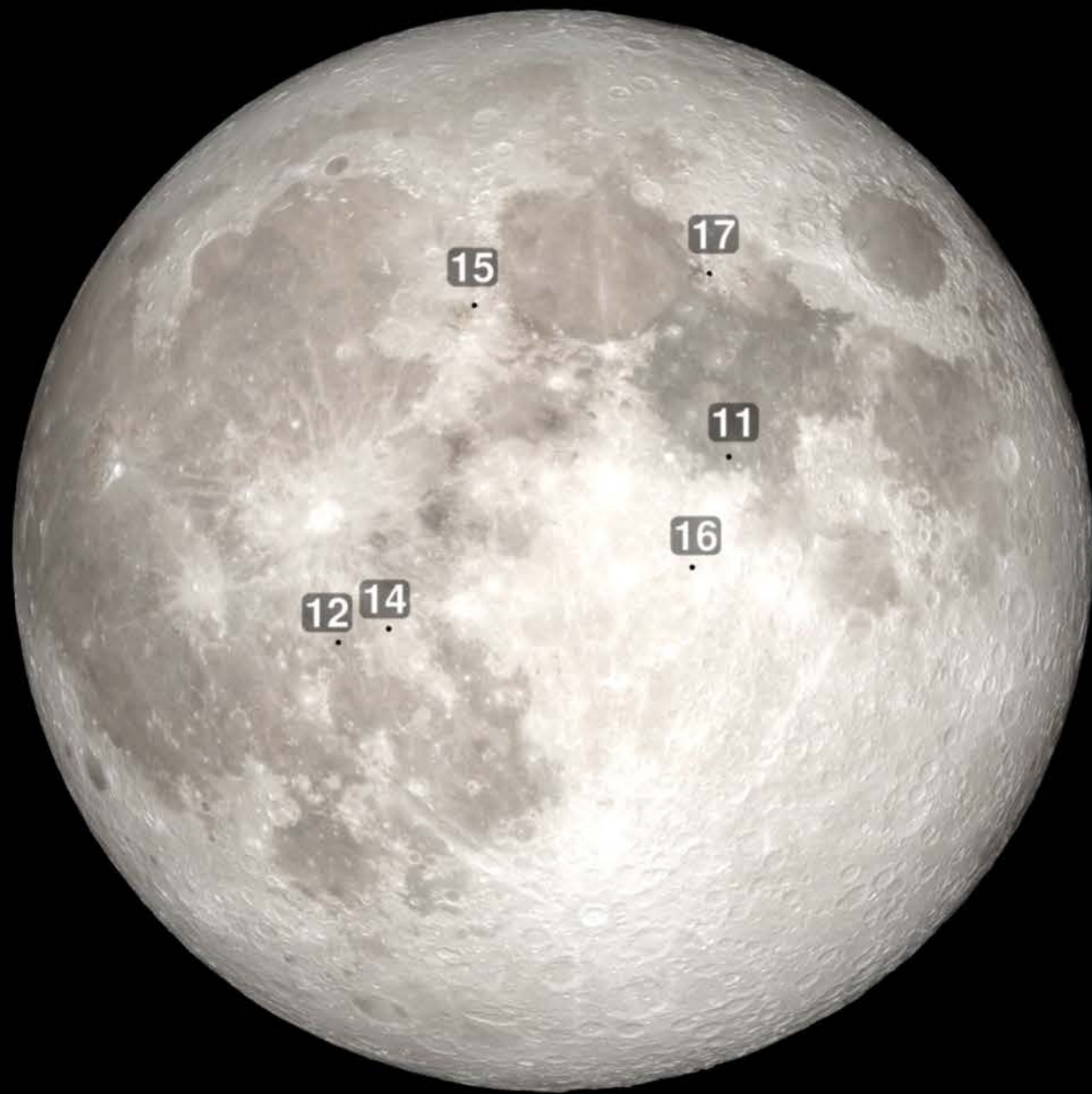
"Late Heavy
Bombardment"

TIME



Today





15

17

11

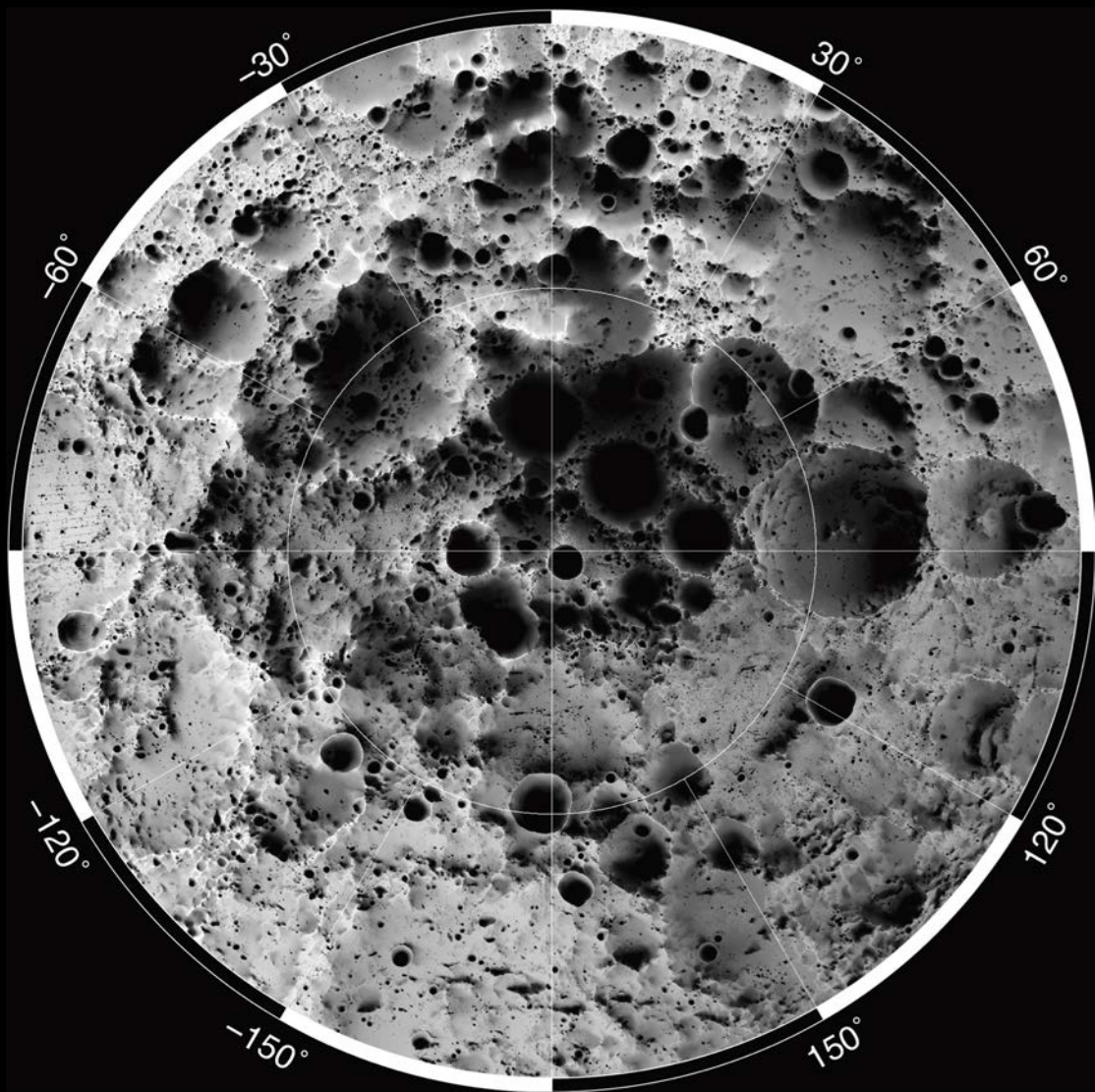
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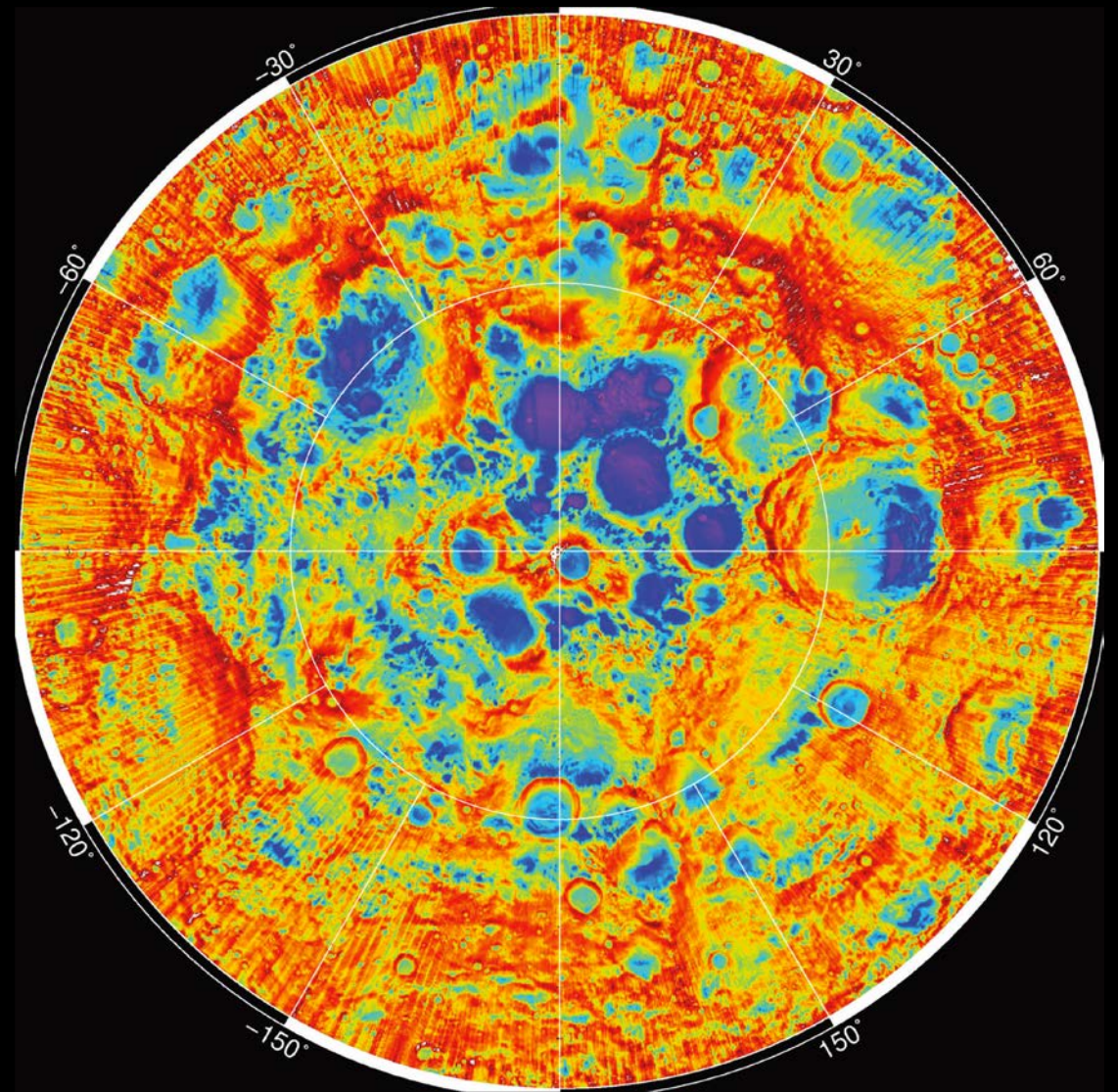
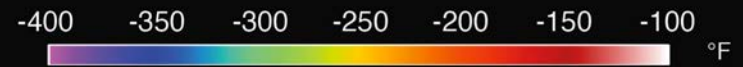
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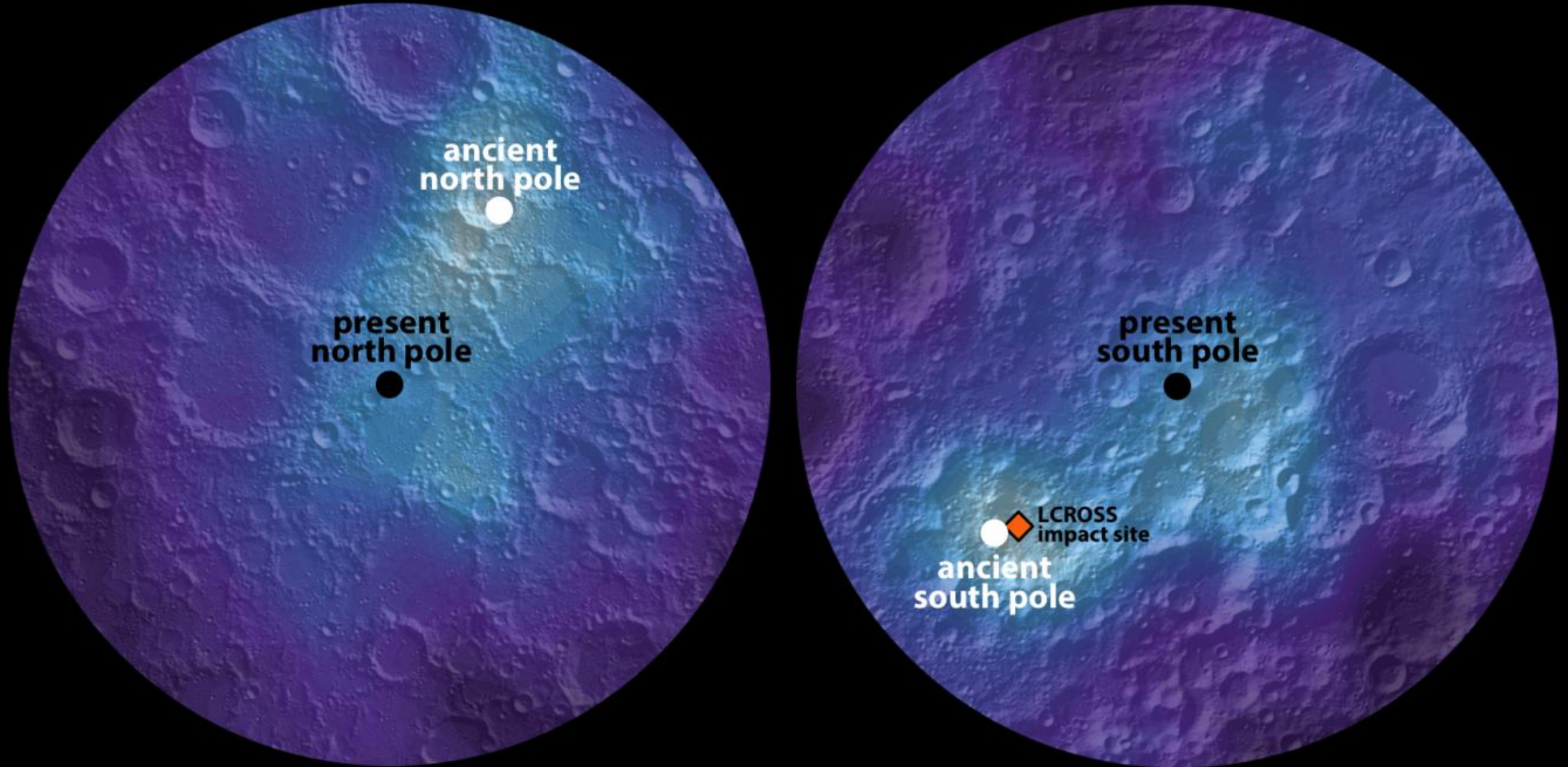
Average Illumination of the Lunar South Pole

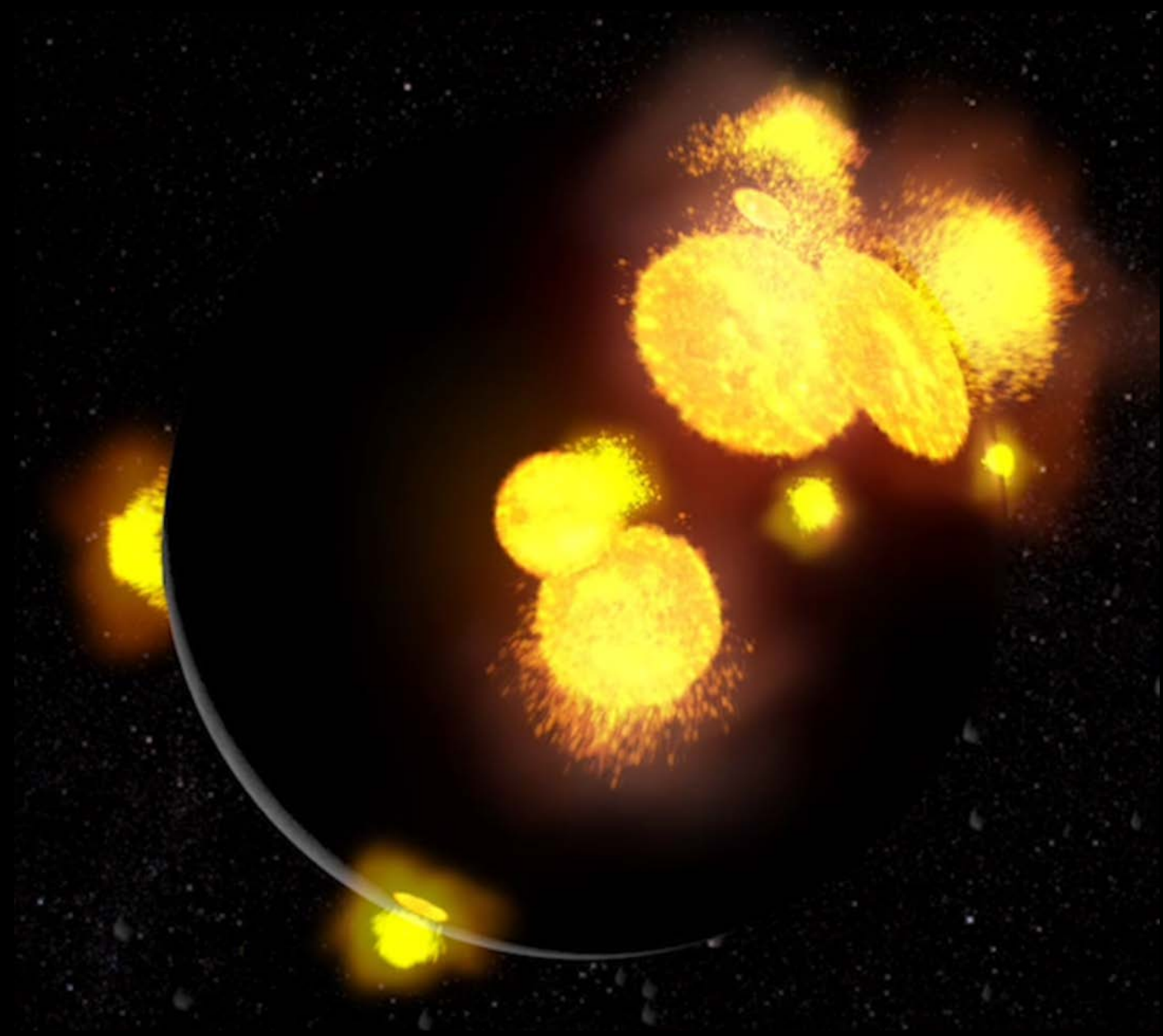


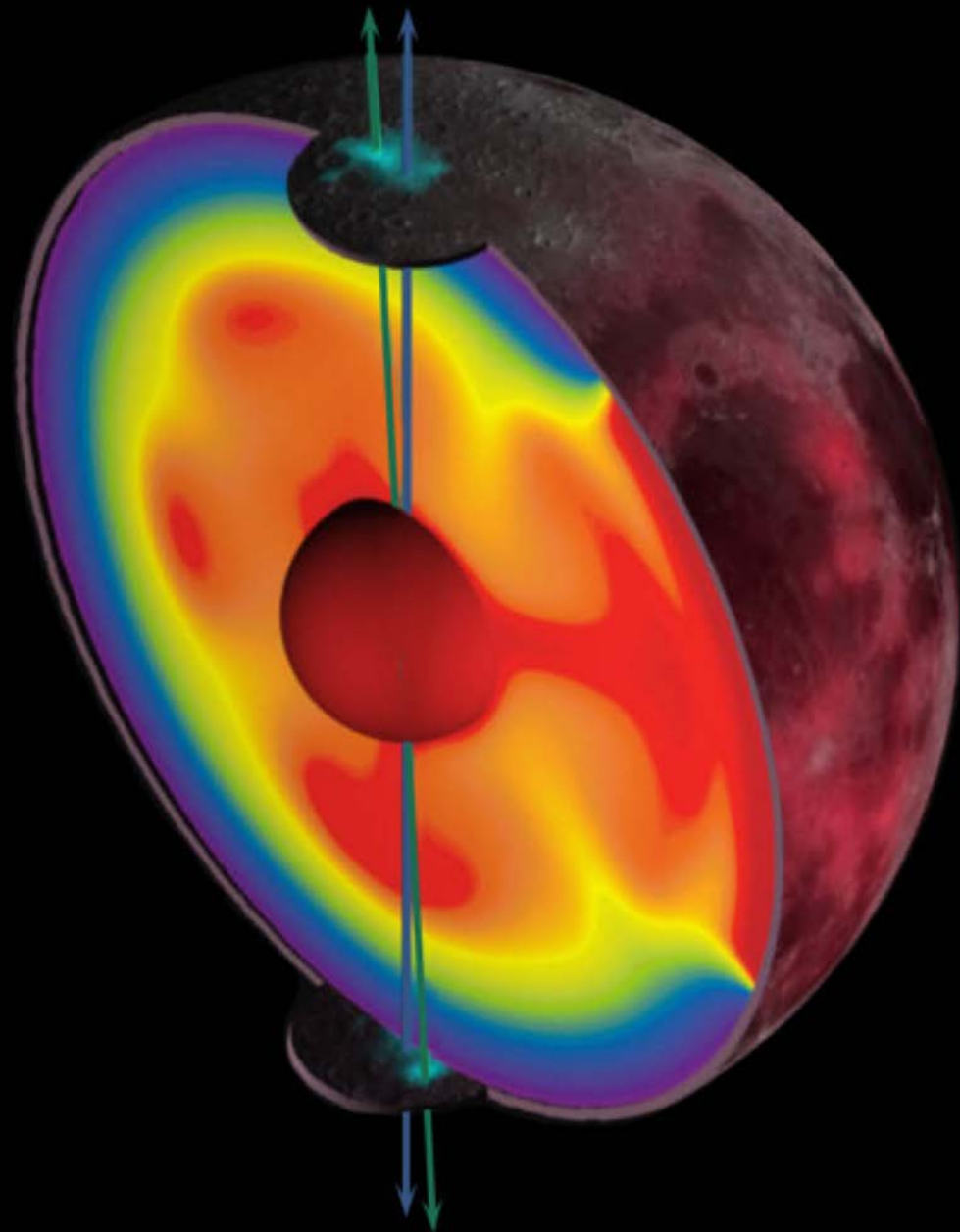
Average Daytime Temperature at the Lunar South Pole

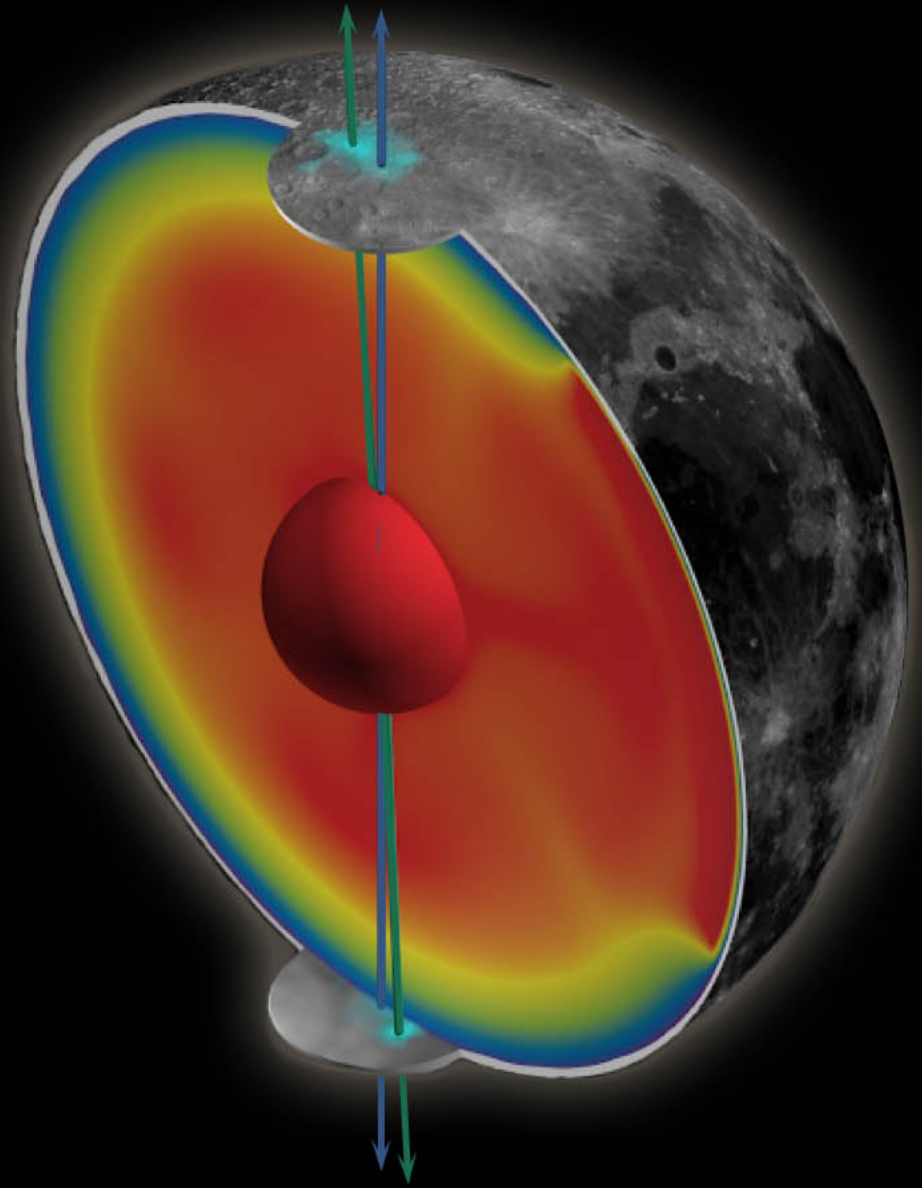
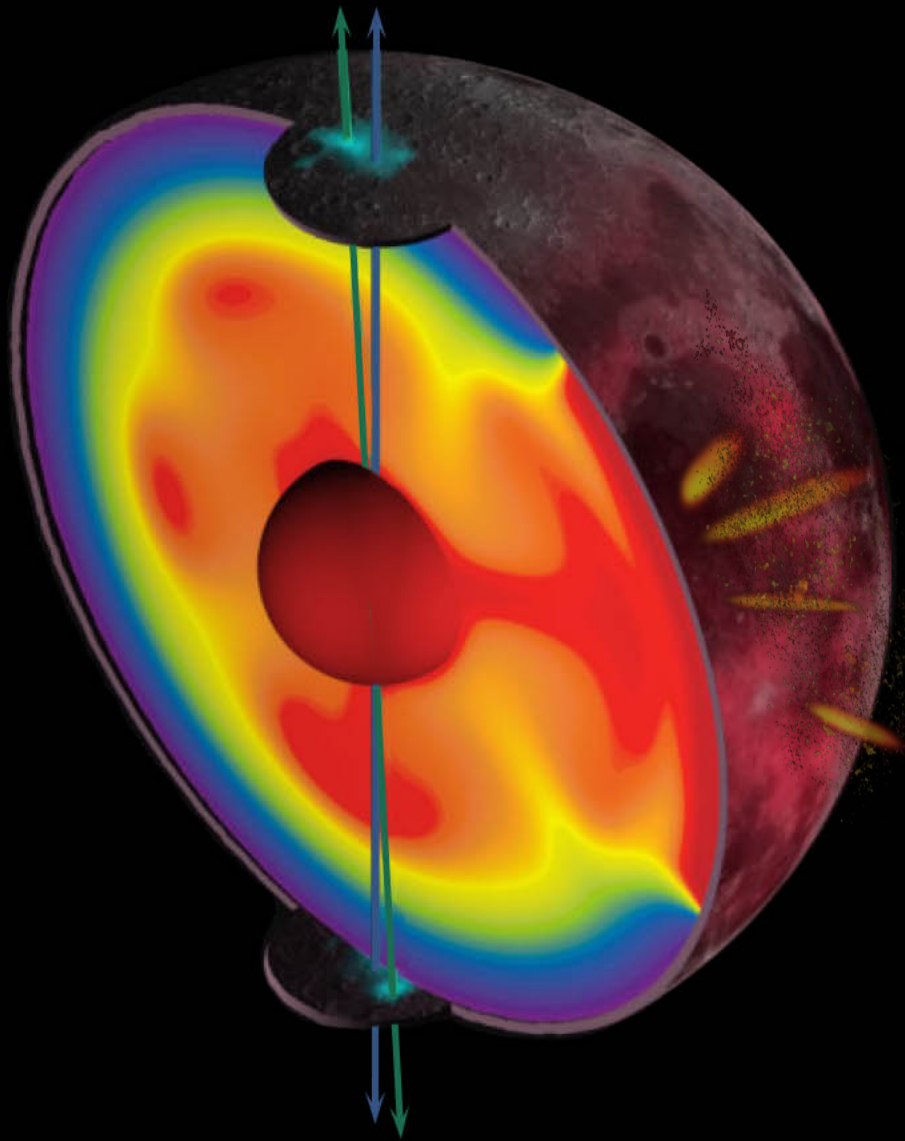


Lunar Polar Water

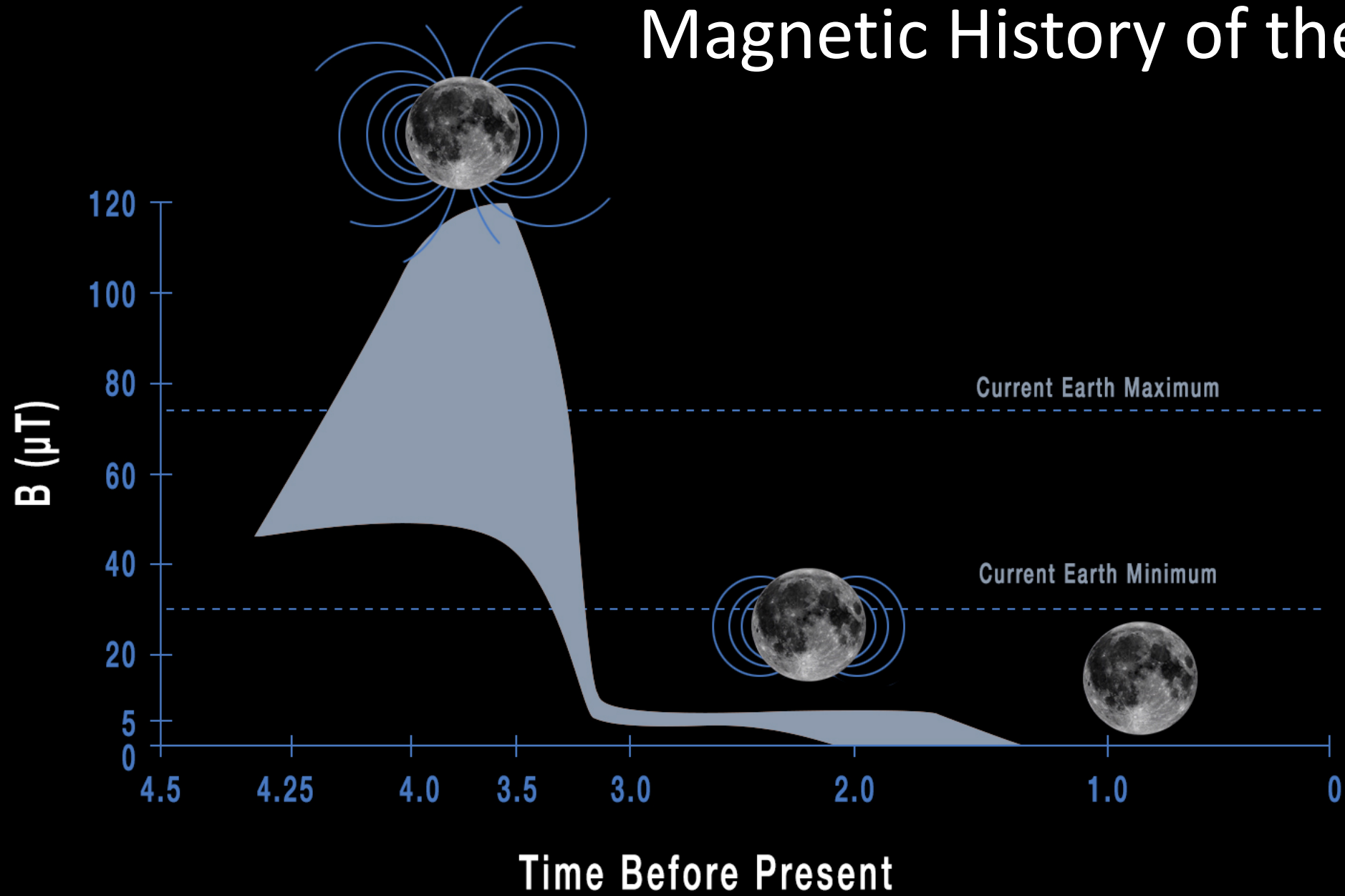


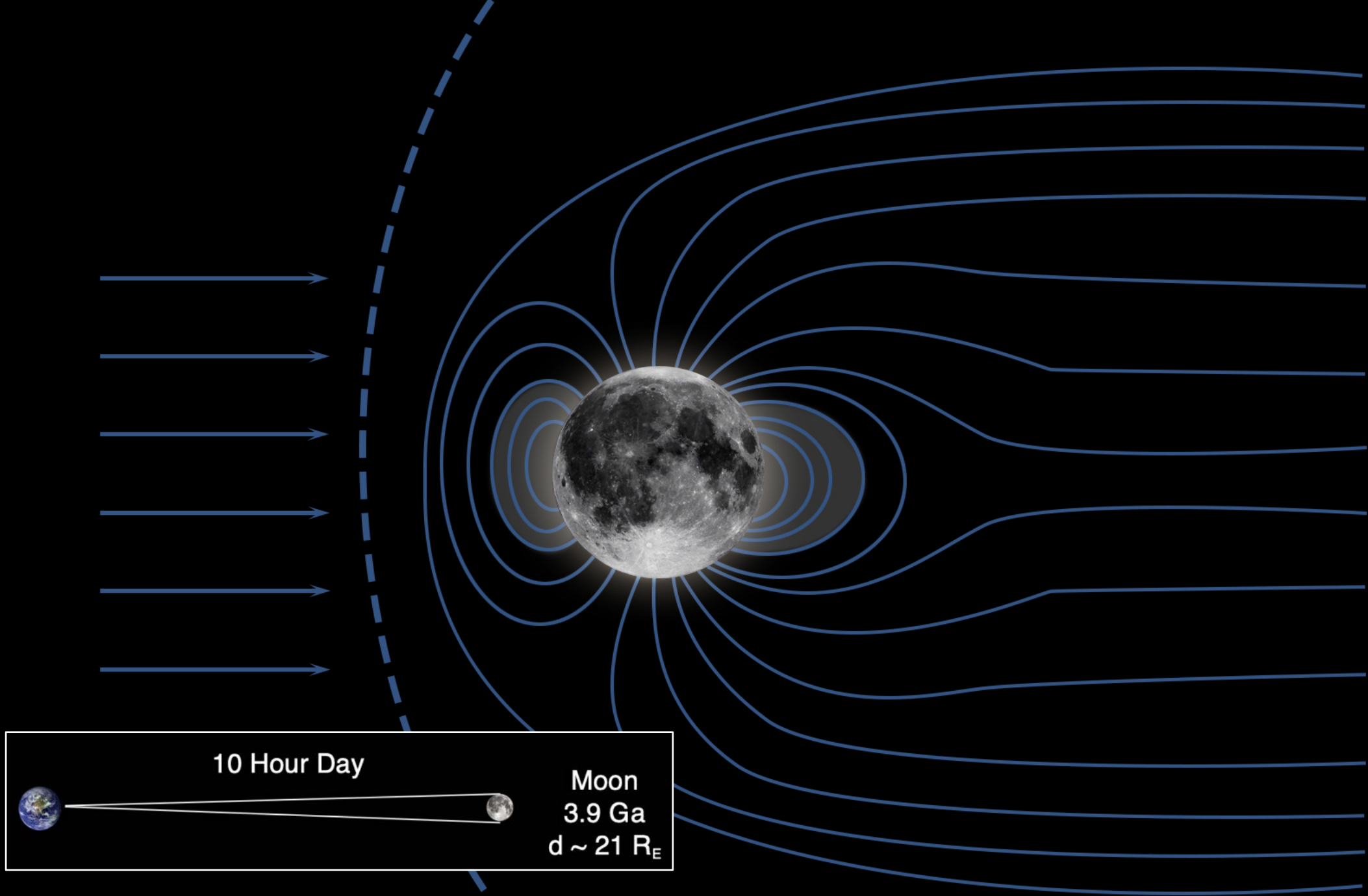


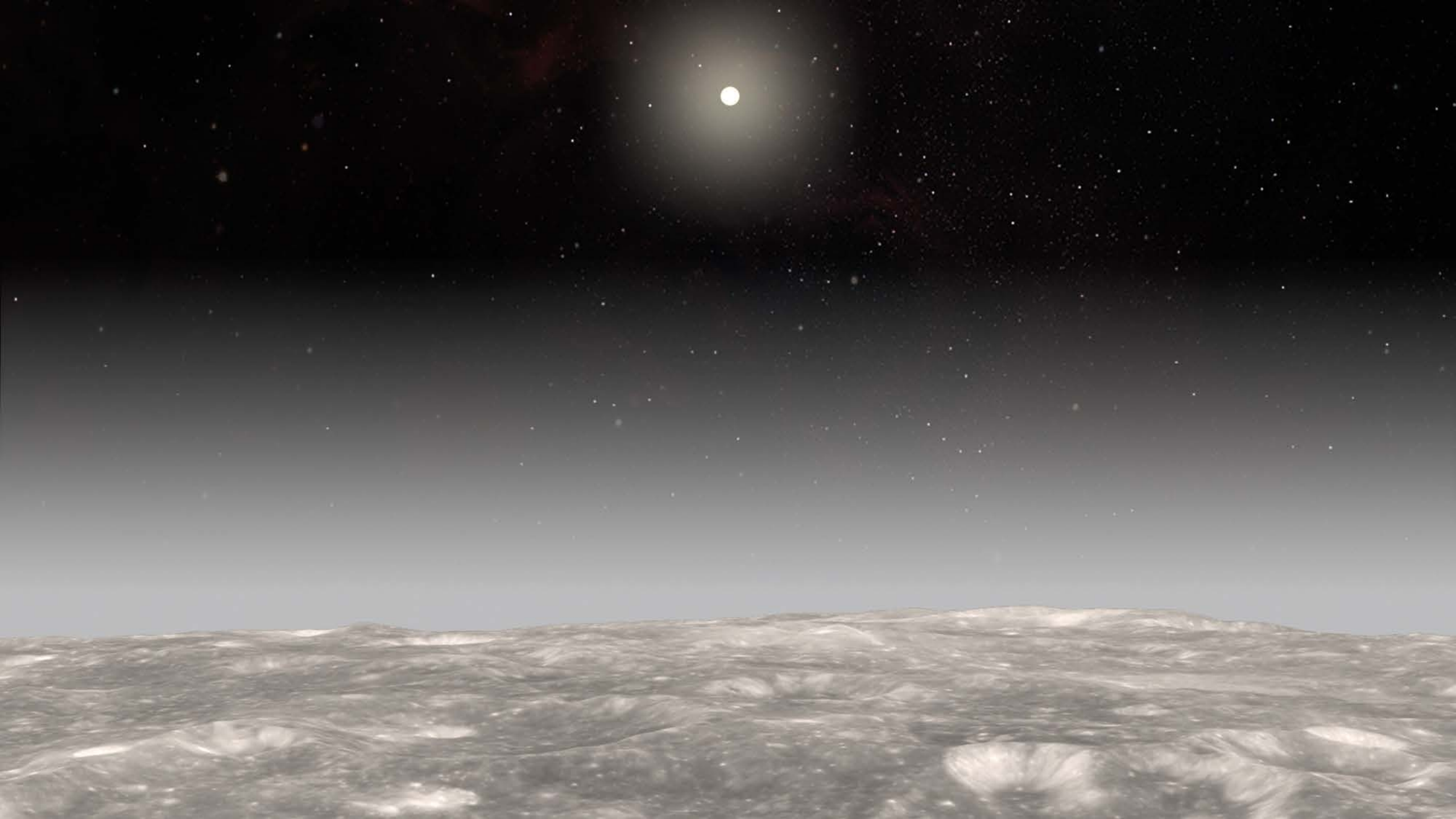


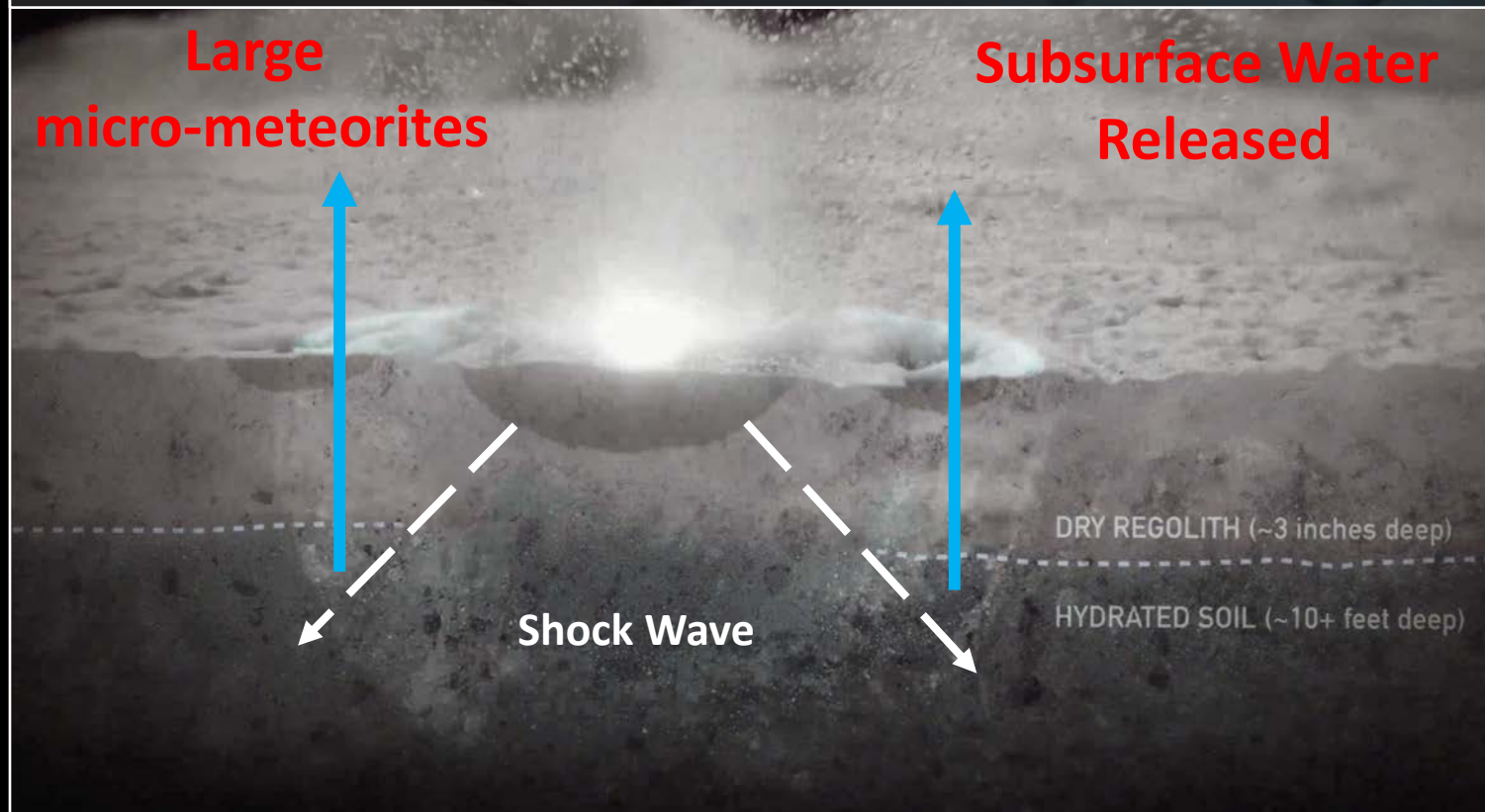
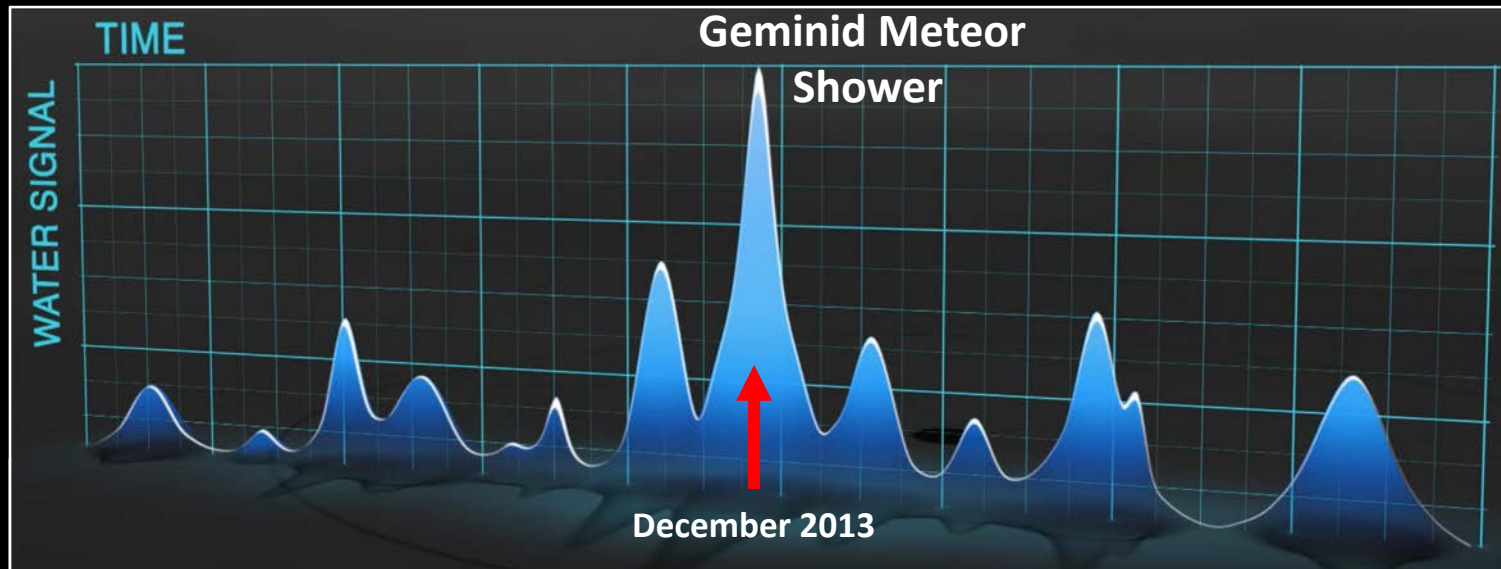


Magnetic History of the Moon

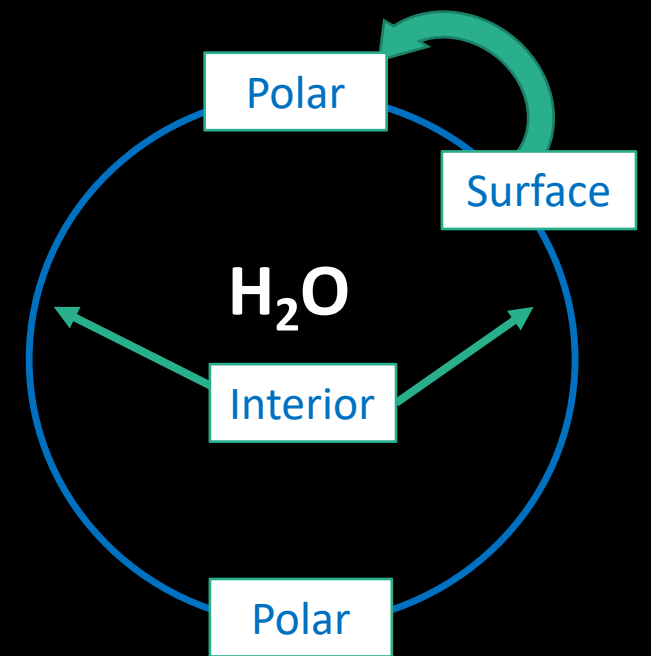


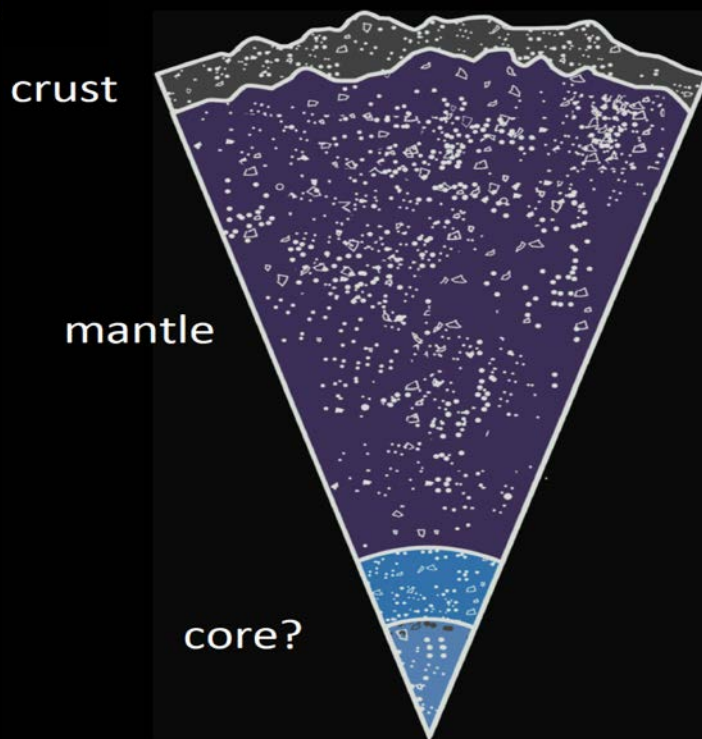
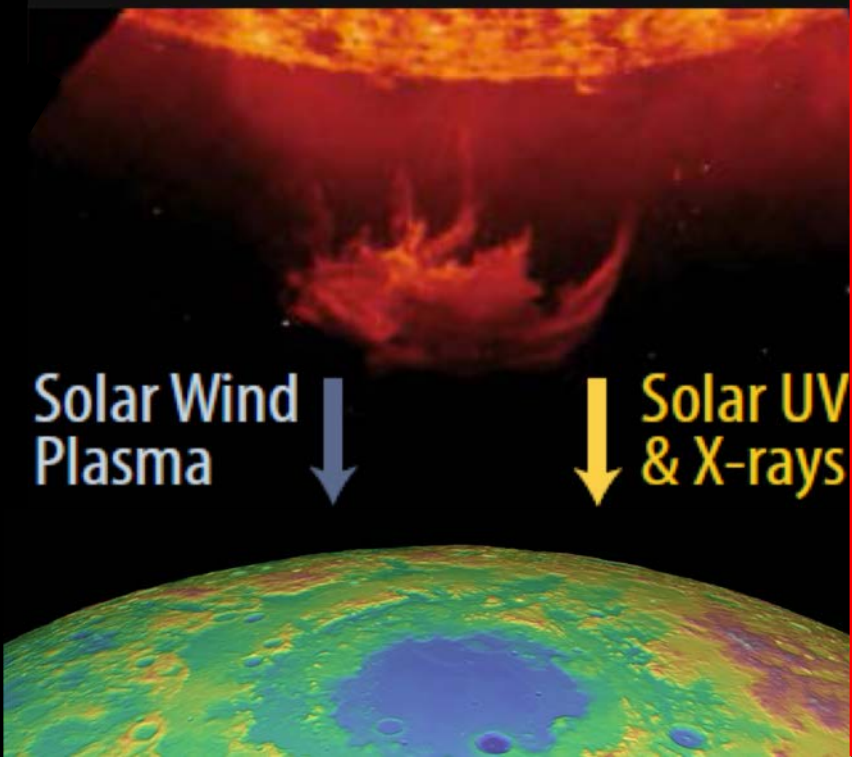
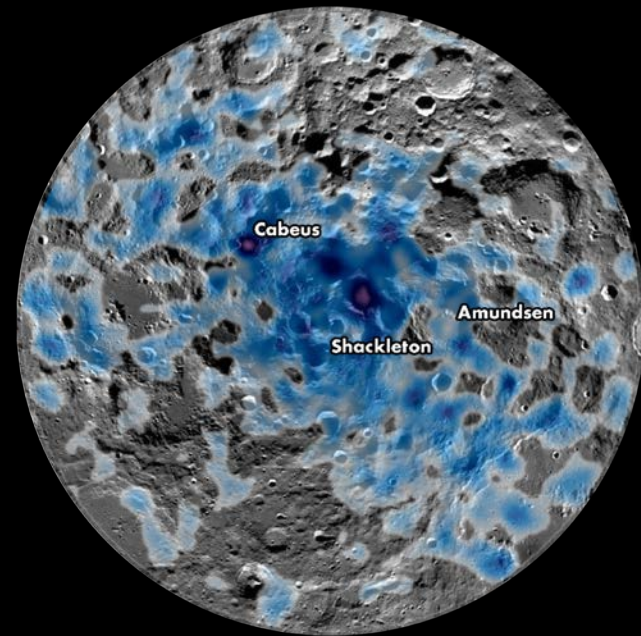
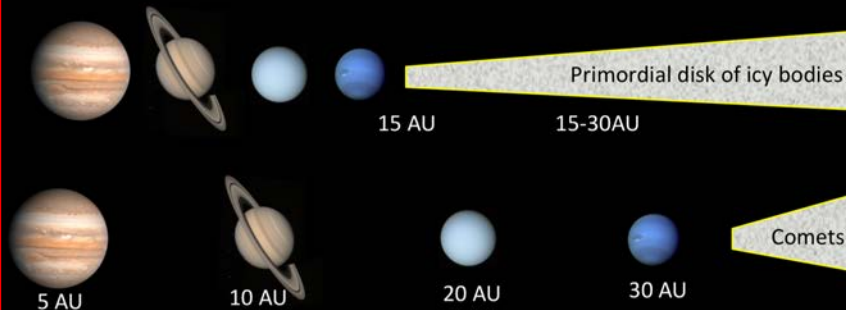
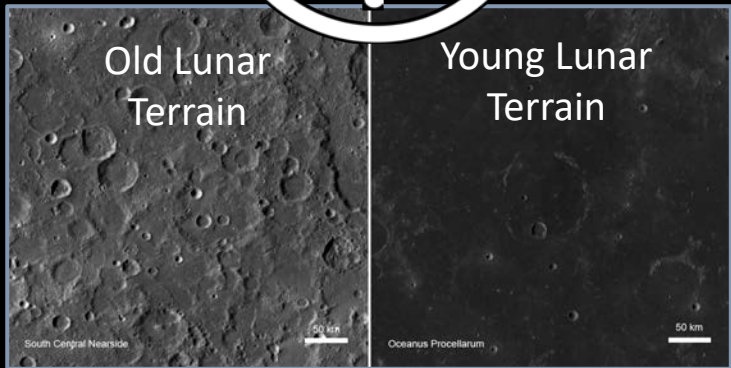






Water Released During Meteor Showers





Space Policy Directive – 1

Reinvigorating America's Human Space Exploration Program



“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.”

NASA is also charged with landing the first woman and next man at the South Pole of the Moon by 2024.



Astrobotic Technology

July 2021

DEEP SPACE SYSTEMS

ARTEMIS-7

DRAPER

GENERAL ATOMICS

SPACEFLIGHT

Intuitive Machines

July 2021

INTUITIVE MACHINES
NOVA-C LUNAR LANDER

Commercial Lunar Payload Services

- US commercial providers of space transportation services,
- 10-year multi-vendor catalog for payload missions

Lockheed Martin Space

ORBIT Beyond
#Thinking Tomorrow

MOON EXPRESS

COMMERCIAL LUNAR PAYLOAD SERVICES

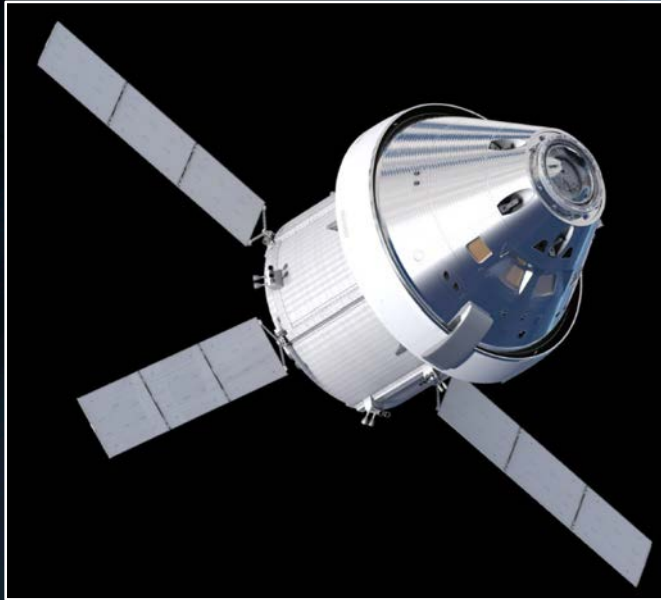
Science. Commerce. Exploration.

snc (SNC ORBITAL SERVICES CORPORATION) **PARAGON** **NANORACKS** **ODYSSEY** (SPACE SYSTEMS)

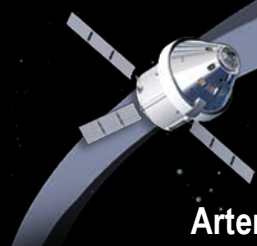
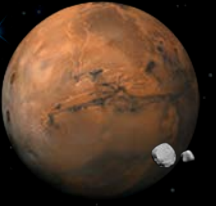
Masten Space Systems

The Power of SLS and Orion

ORION



Artemis Phase 1: To the Lunar Surface by 2024



Artemis I: First human spacecraft to the Moon

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

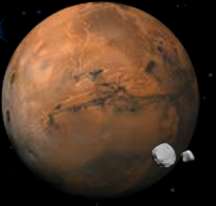
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

LUNAR SOUTH POLE TARGET SITE

2020

2024

Artemis Phase 1: To the Lunar Surface by 2024



Artemis II: First humans to orbit the Moon

Artemis I: First human spacecraft to the Moon

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

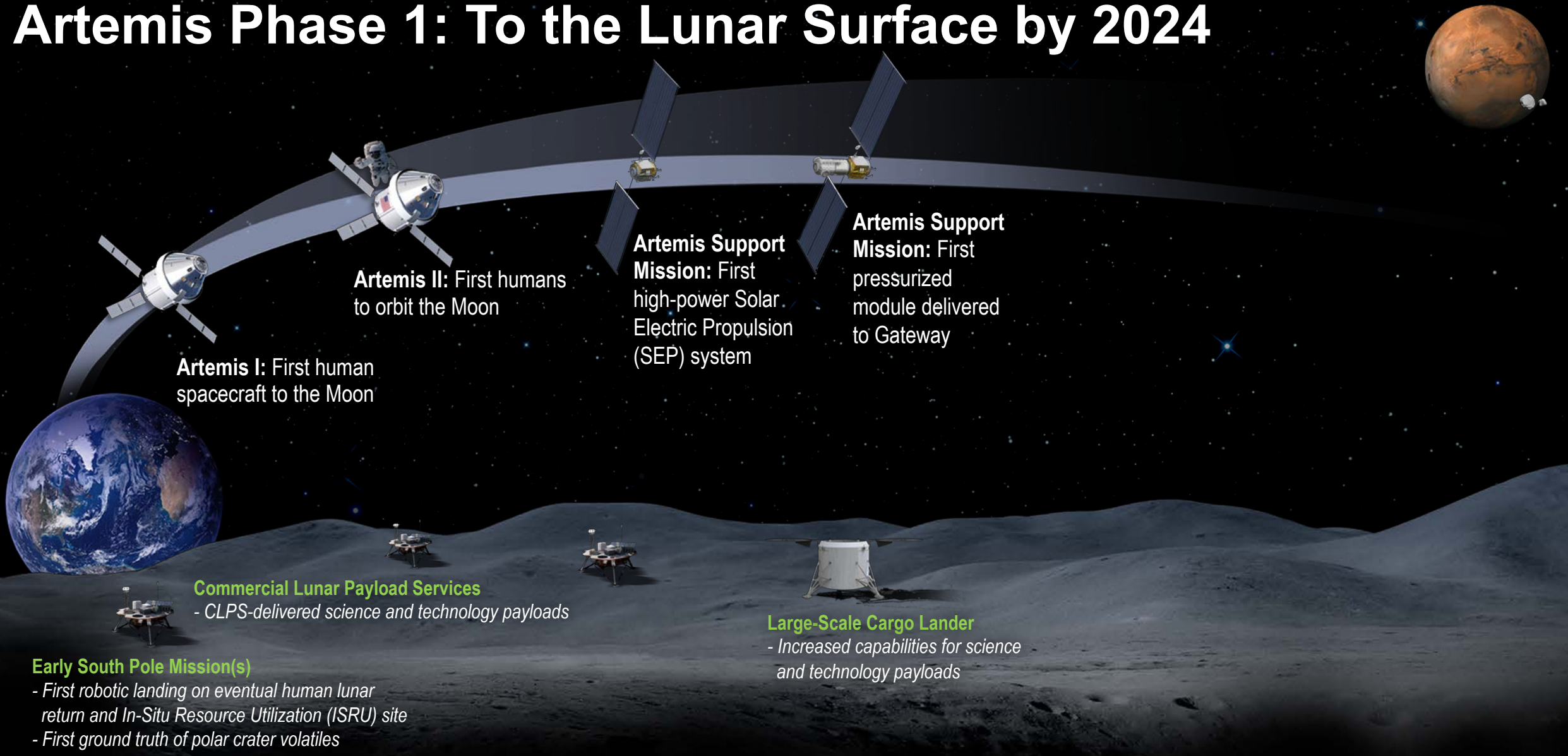
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LUNAR SOUTH POLE TARGET SITE

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2024

Artemis Phase 1: To the Lunar Surface by 2024

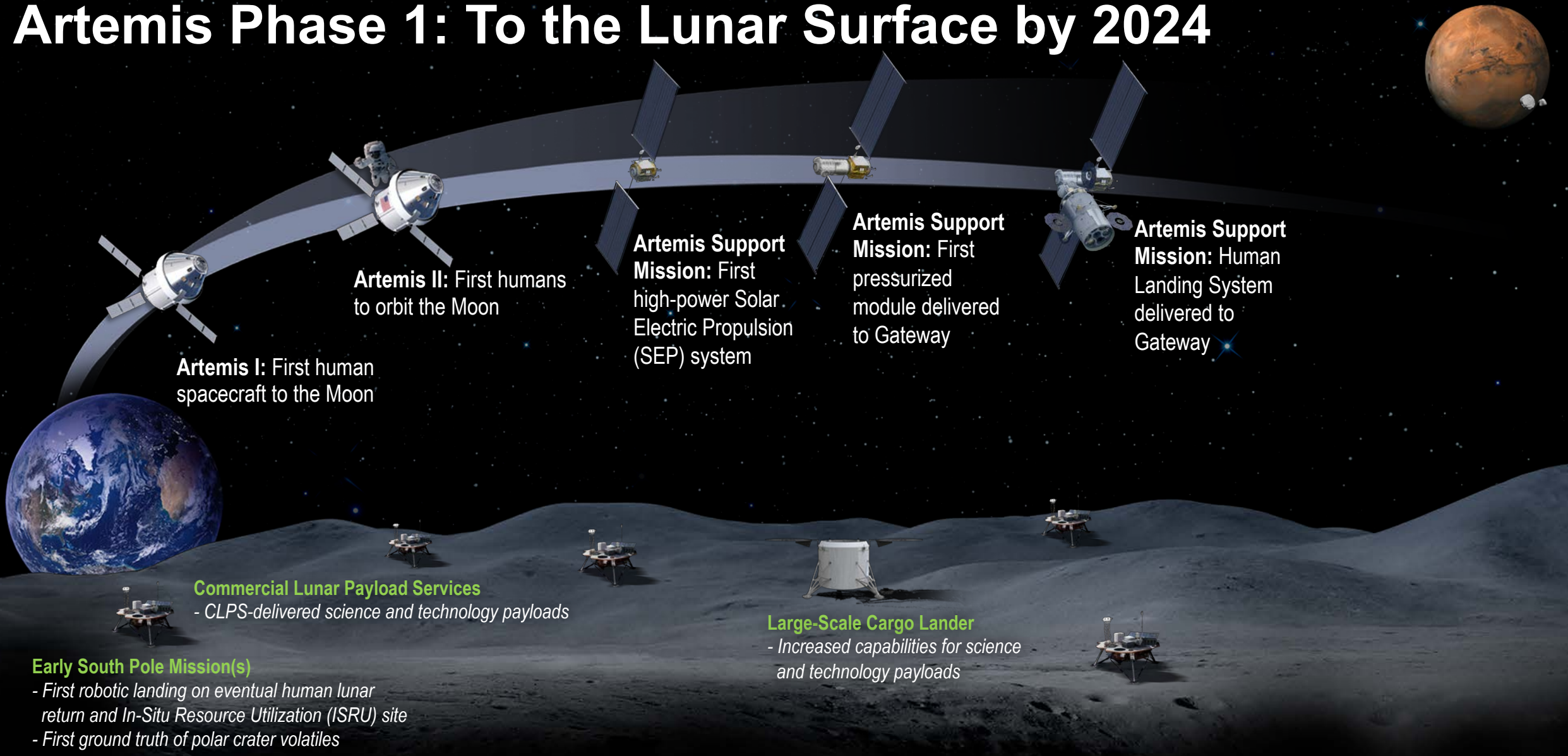


LUNAR SOUTH POLE TARGET SITE

2020

2024

Artemis Phase 1: To the Lunar Surface by 2024



Artemis I: First human spacecraft to the Moon

Artemis II: First humans to orbit the Moon

Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system

Artemis Support Mission: First pressurized module delivered to Gateway

Artemis Support Mission: Human Landing System delivered to Gateway

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

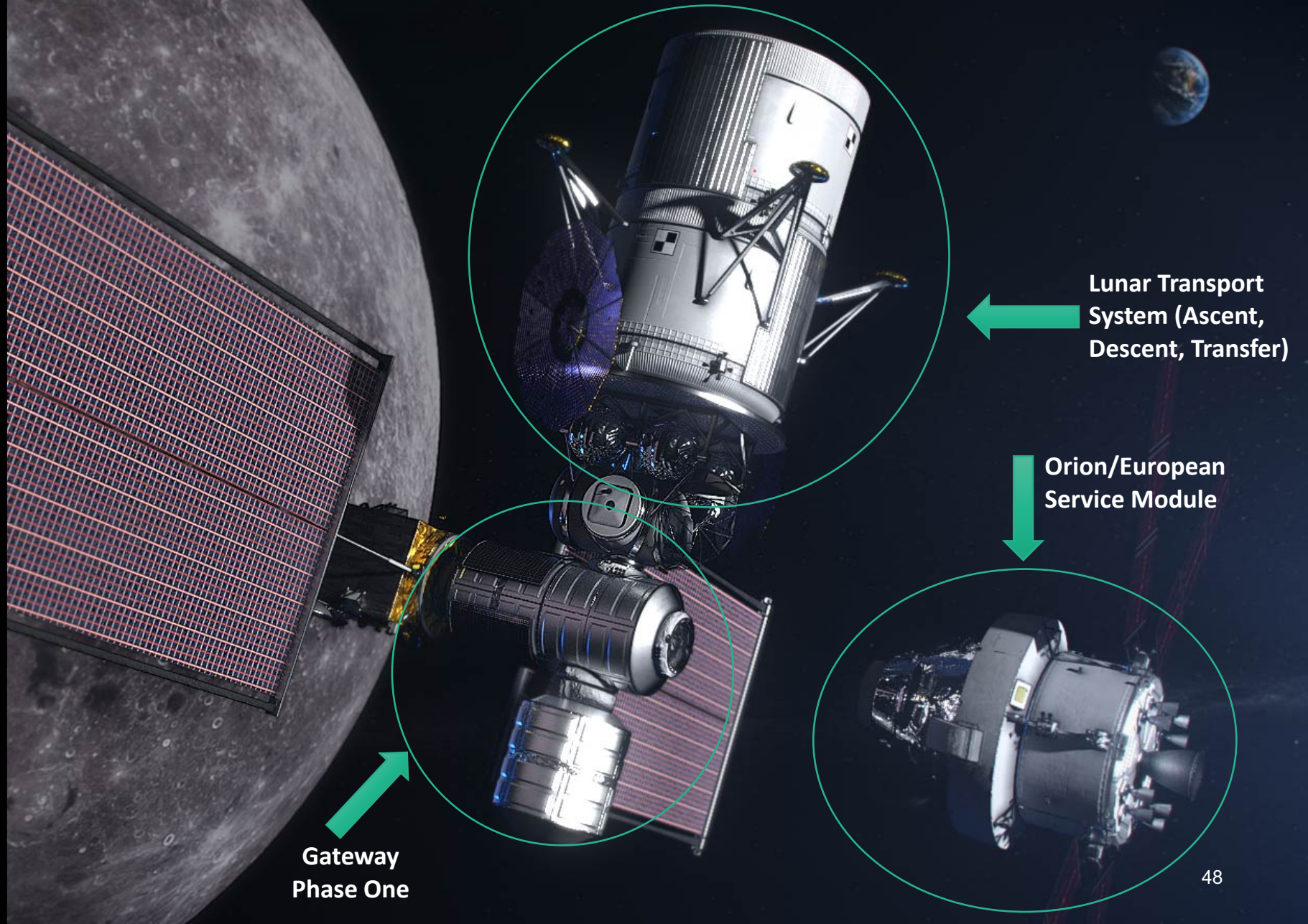
Large-Scale Cargo Lander

- Increased capabilities for science and technology payloads

LUNAR SOUTH POLE TARGET SITE

Gateway is Essential for 2024 Landing

Six Days to Orbit the Moon

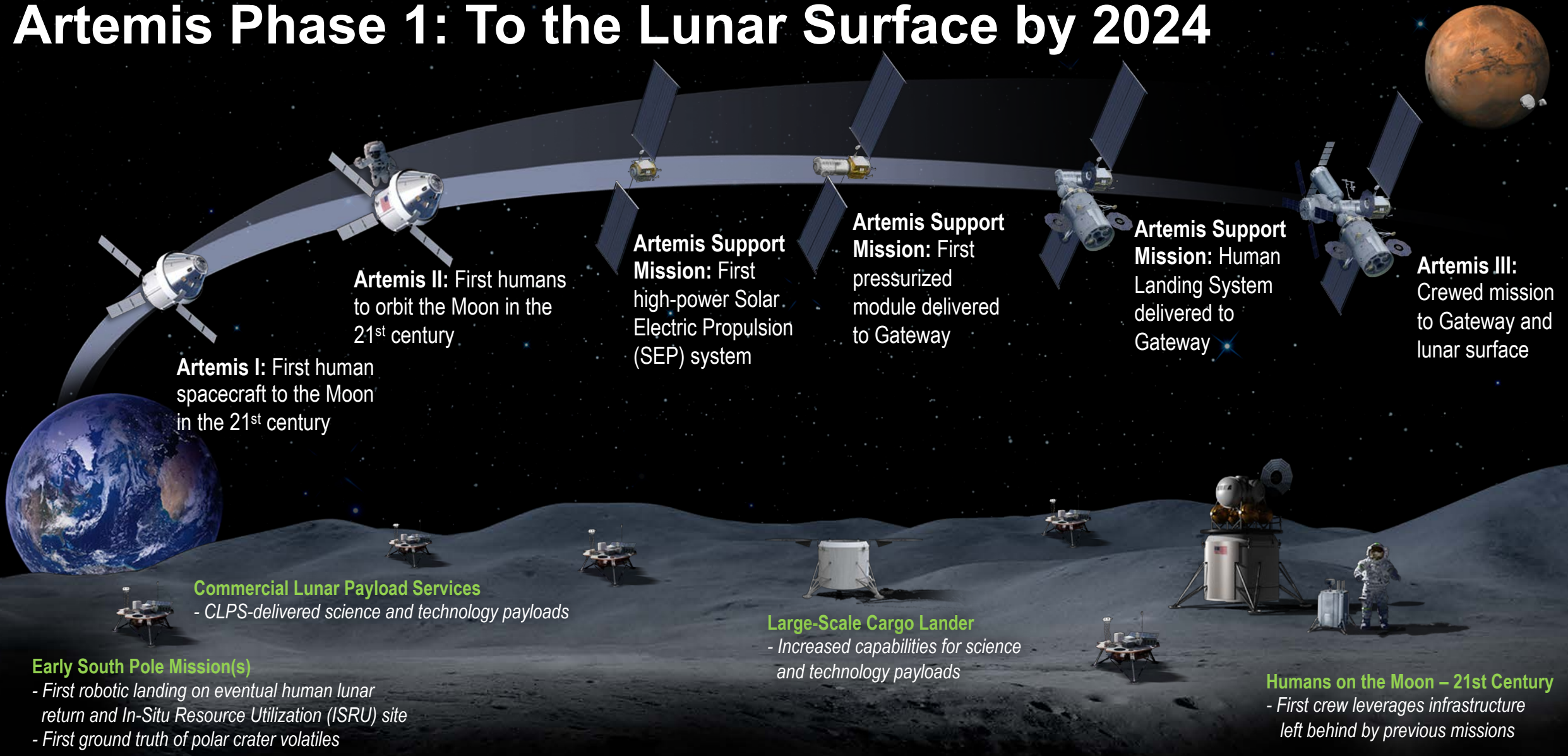


Lunar Transport System (Ascent, Descent, Transfer)

Orion/European Service Module

Gateway Phase One

Artemis Phase 1: To the Lunar Surface by 2024



Artemis I: First human spacecraft to the Moon in the 21st century

Artemis II: First humans to orbit the Moon in the 21st century

Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system

Artemis Support Mission: First pressurized module delivered to Gateway

Artemis Support Mission: Human Landing System delivered to Gateway

Artemis III: Crewed mission to Gateway and lunar surface

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

Large-Scale Cargo Lander

- Increased capabilities for science and technology payloads

Humans on the Moon – 21st Century

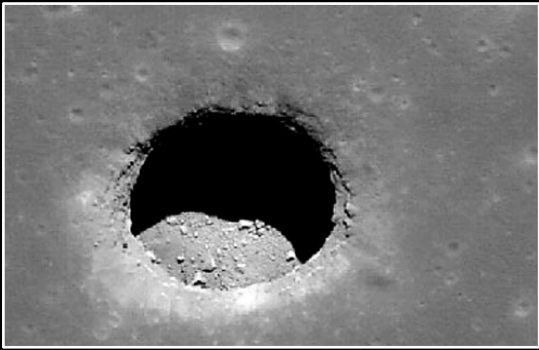
- First crew leverages infrastructure left behind by previous missions

LUNAR SOUTH POLE TARGET SITE

2020

2024

Science & Exploration



Living off the Land



Multi-planet Species



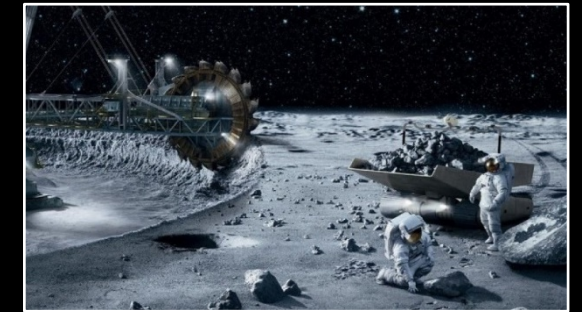
Future Moon



Fuel Depot



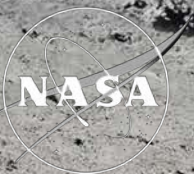
Mining



Manufacturing



QUESTIONS?





GRAVITY ASSIST



Podcast



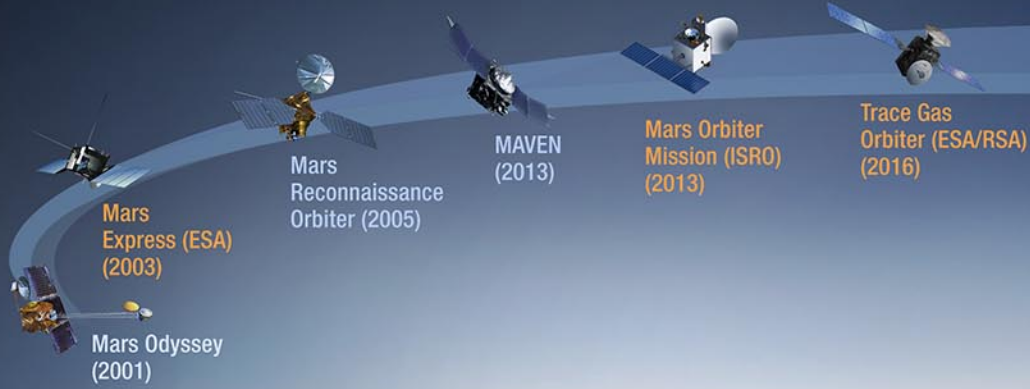
www.nasa.gov/podcasts



MARS MISSIONS

OPERATIONAL 2001–2019

2020 AND BEYOND



Curiosity Rover (2011)



InSight



Mars Lander & Rover (China)



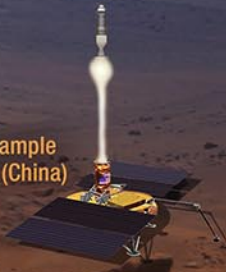
Mars 2020 Rover (NASA)



ExoMars Rover (ESA/RSA)



Mars Sample Return Lander



Mars Sample Return (China)

Follow the Water

Explore Habitability

Seek Signs of Life

Prepare for Future Human Explorers

U.S. Missions

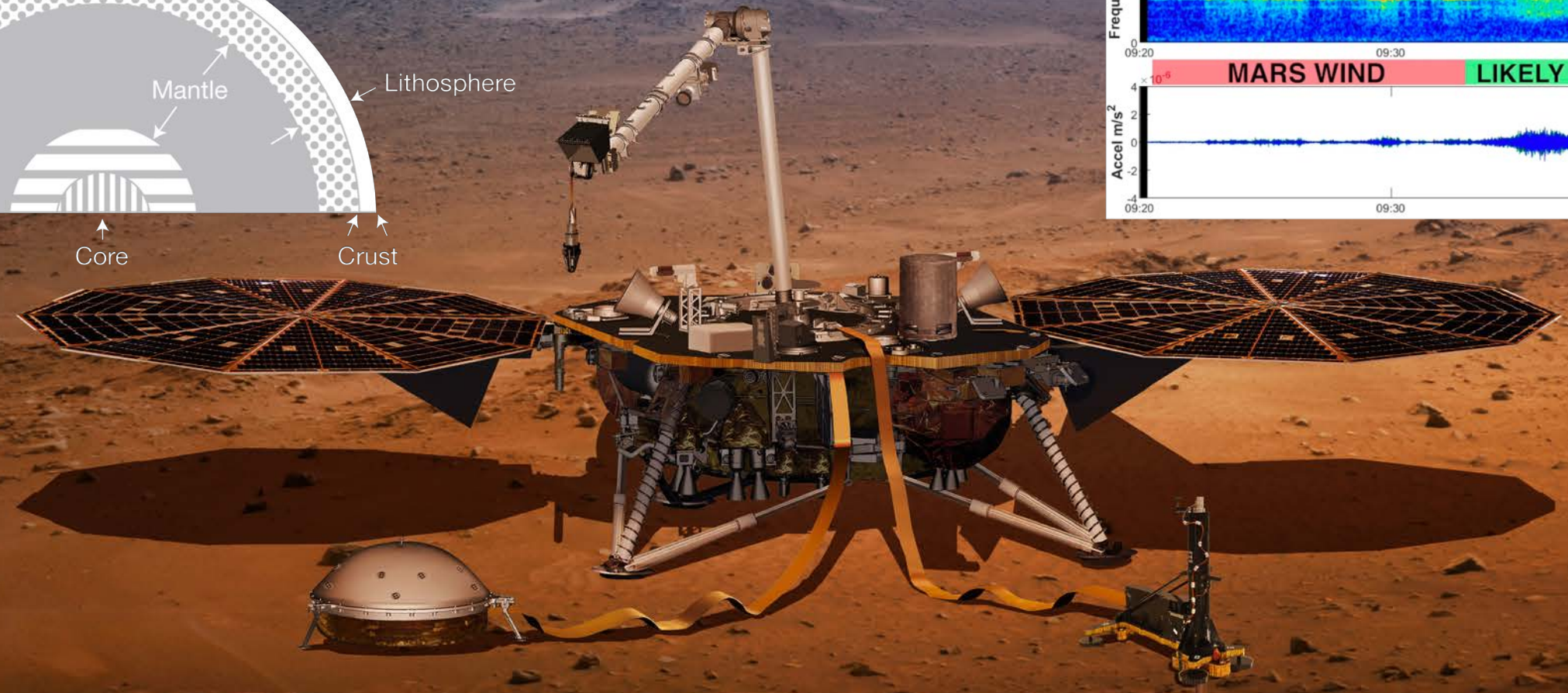
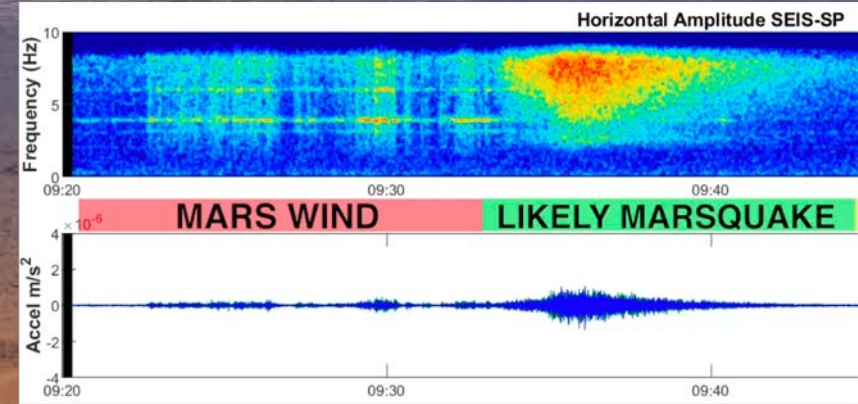
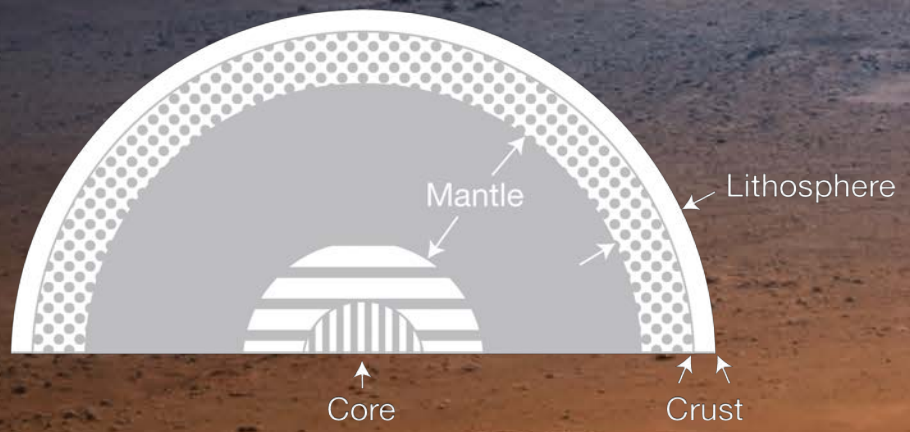
non-U.S. Missions

An Ancient Habitable Environment

Mineralogy indicates sustained interaction with liquid water also providing a source of energy for primitive biology. Key chemical ingredients for life are present: carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. Also the soil is moist and there are nitrates!



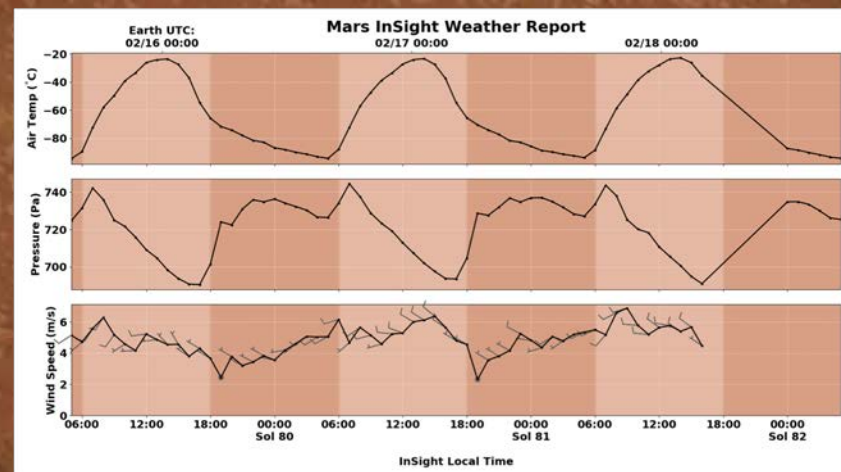
Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight)



Landed on Nov 26, 2018

Latest Weather at Elysium Planitia

InSight is taking daily weather measurements (temperature, wind, pressure) on the surface of Mars at Elysium Planitia, a flat, smooth plain near Mars' equator.



<https://mars.nasa.gov/insight/weather/>

Sol 81

February 17

High: 2° F | C

Low: -138° F | C

Sol 75

Feb. 11

High: 15° F
Low: -138° F

Sol 76

Feb. 12

High: 10° F
Low: -137° F

Sol 77

Feb. 13

High: 9° F
Low: -136° F

Sol 78

Feb. 14

High: 4° F
Low: -138° F

Sol 79

Feb. 15

High: 8° F
Low: -140° F

Sol 80

Feb. 16

High: 3° F
Low: -139° F

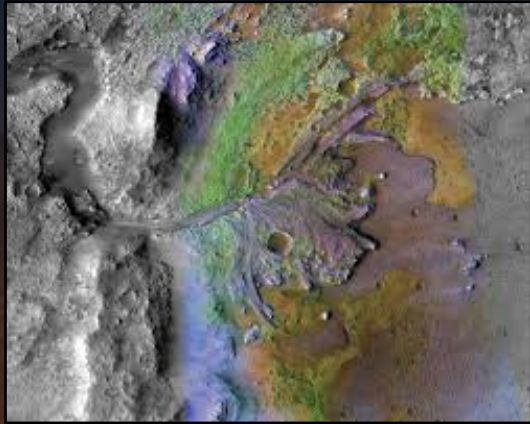
Sol 81

Feb. 17

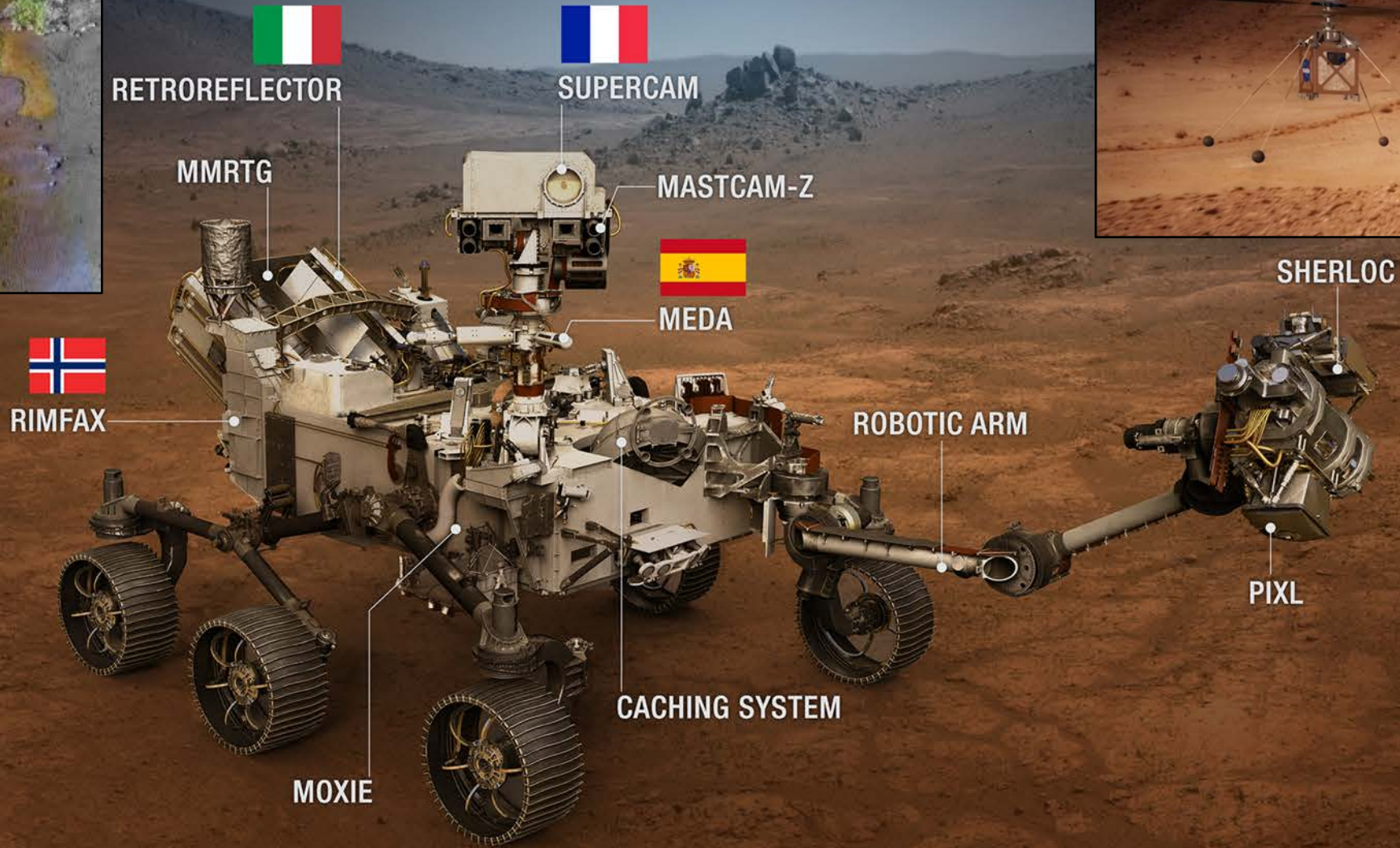
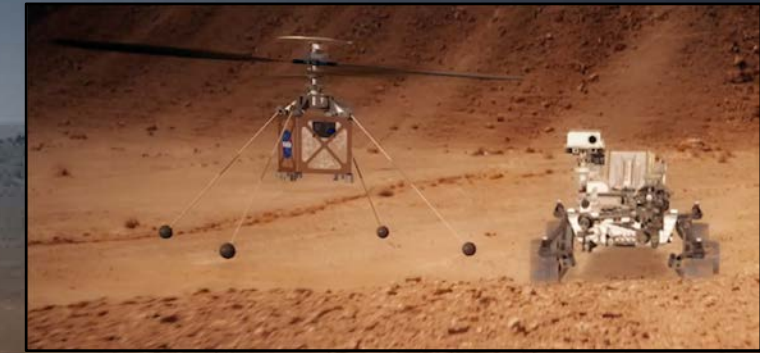
High: 2° F
Low: -138° F

Seeking Signs of Life: Mars 2020 Rover

Jezero Crater



Mars Helicopter




RETROREFLECTOR


SUPERCAM

MMRTG

MASTCAM-Z


MEDA


RIMFAX

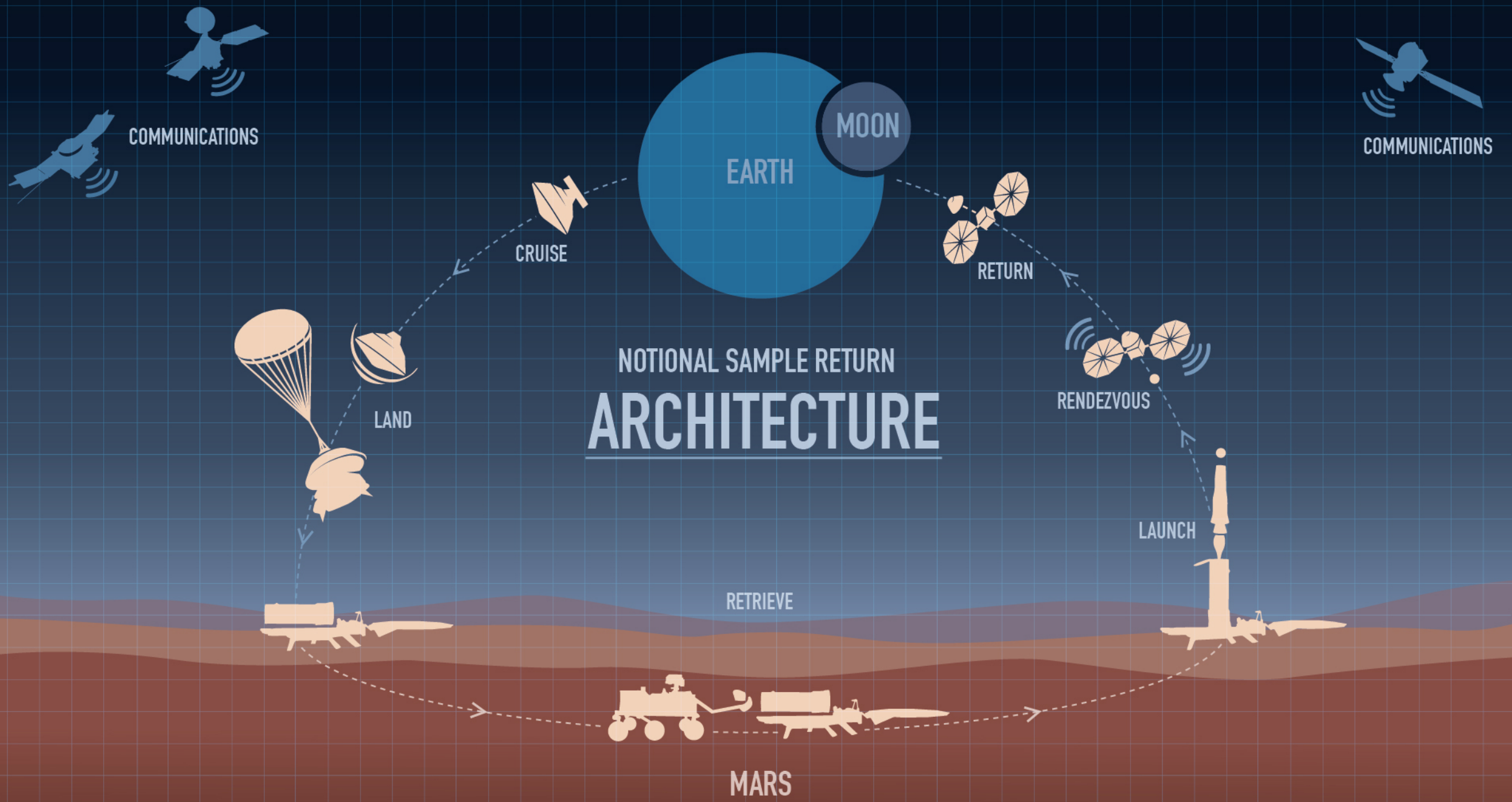
ROBOTIC ARM

SHERLOC

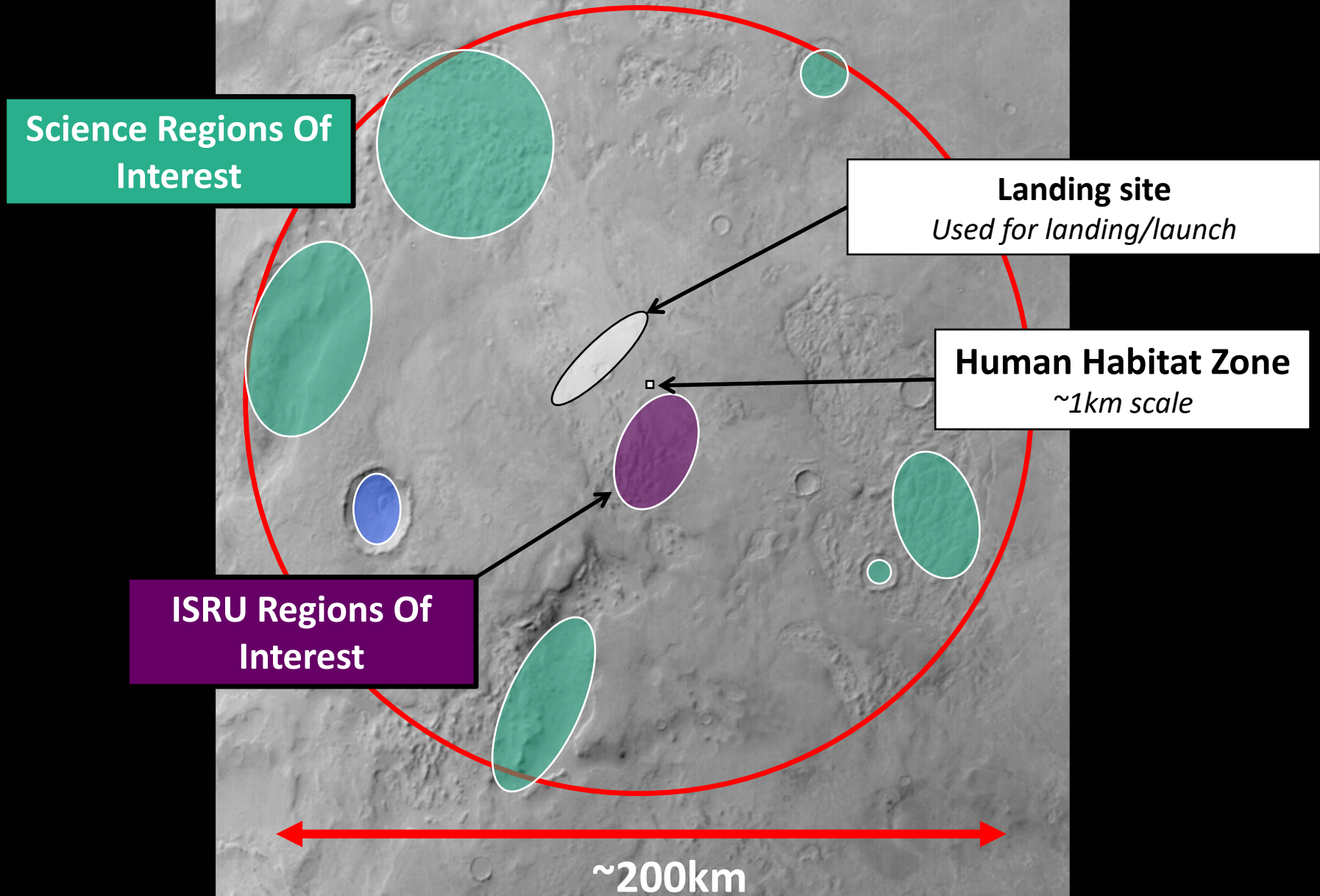
PIXL

MOXIE

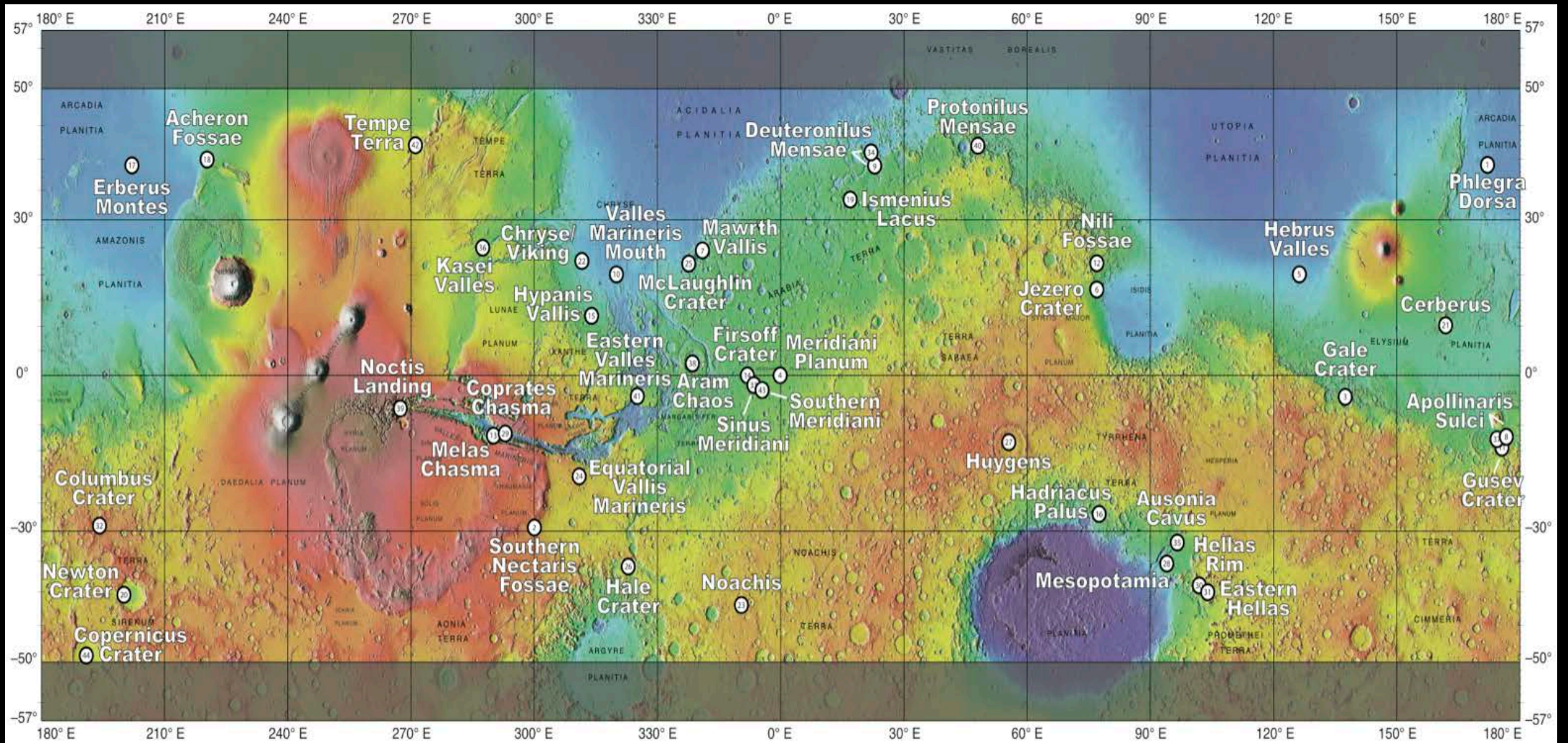
CACHING SYSTEM



Human Exploration Zone



Potential Exploration Zones



1st Human Landing Site Workshop
October 27-30 at LPI

A composite image featuring a mountain valley at night. A large, bright full moon hangs in a dark blue, starry sky. The valley below is illuminated by a soft light, and a calm lake in the foreground reflects the moon and the surrounding green mountains. In the lower center of the image, a reddish-brown planet with a textured surface is visible, also reflected in the water.

QUESTIONS?

EXPLORE
with us

Flight Test and Flyby Missions



Luna 1



Ranger 1
Ranger 2



Pioneer 4

Luna 4



Zond 3



Orbiters



Luna 3



Lunar
Lunar
Lunar

Landers and Impacts



Luna 2



Ranger 3
Ranger 4
Ranger 5



Ranger 6
Ranger 7



Luna 5
Luna 6
Luna 7
Luna 8



Ranger 8
Ranger 9

1959

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1961

1962

1963

1964

1965

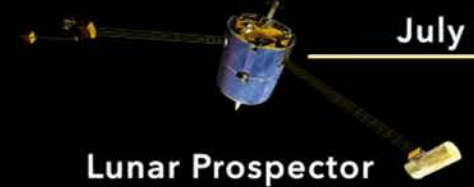
1966



Hitan



Clementine



Lunar Prospector

July 1999



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1990

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1994

...

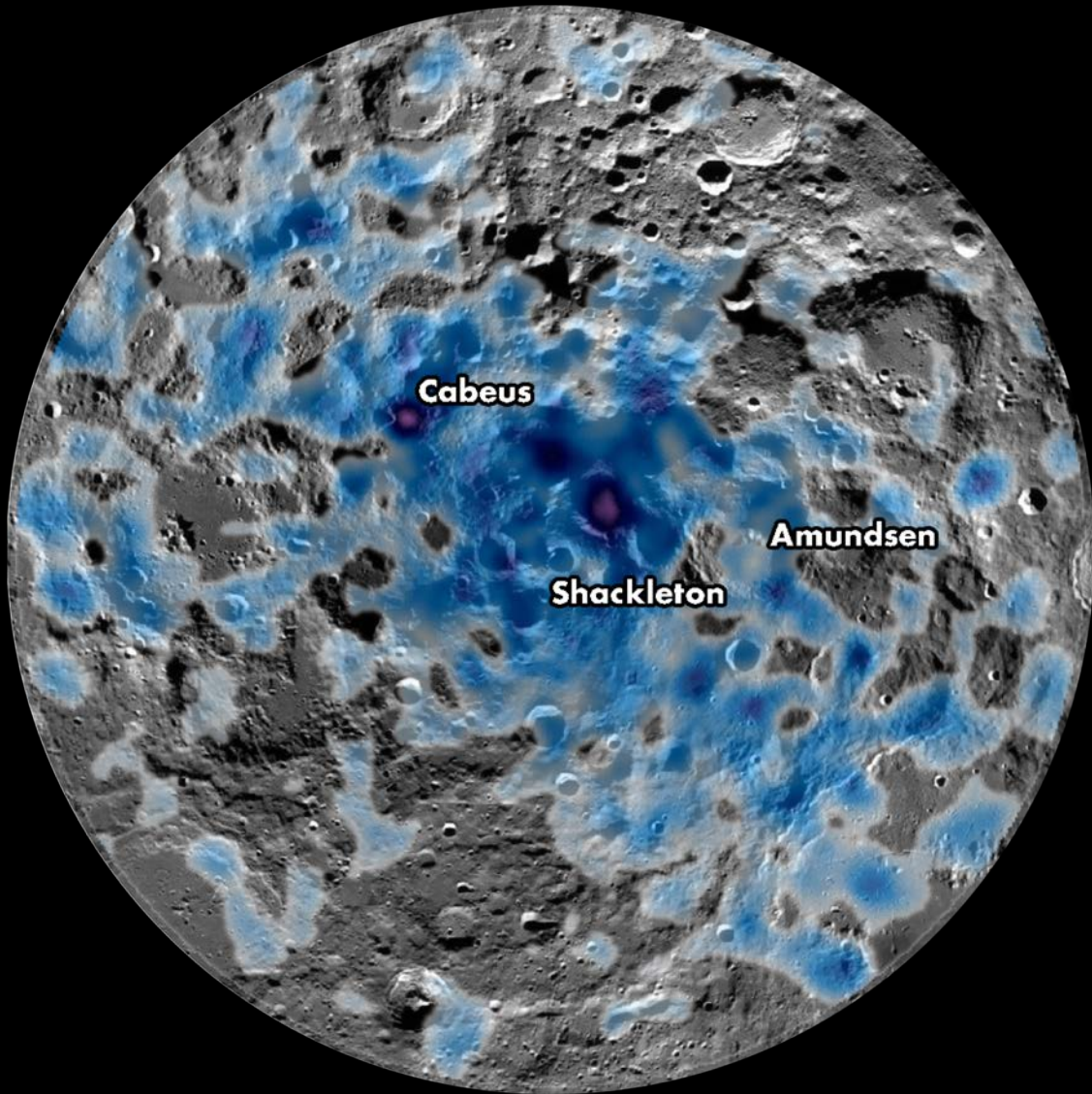
1997

1998

...

SM

South Pole



North Pole

