

National Aeronautics and  
Space Administration



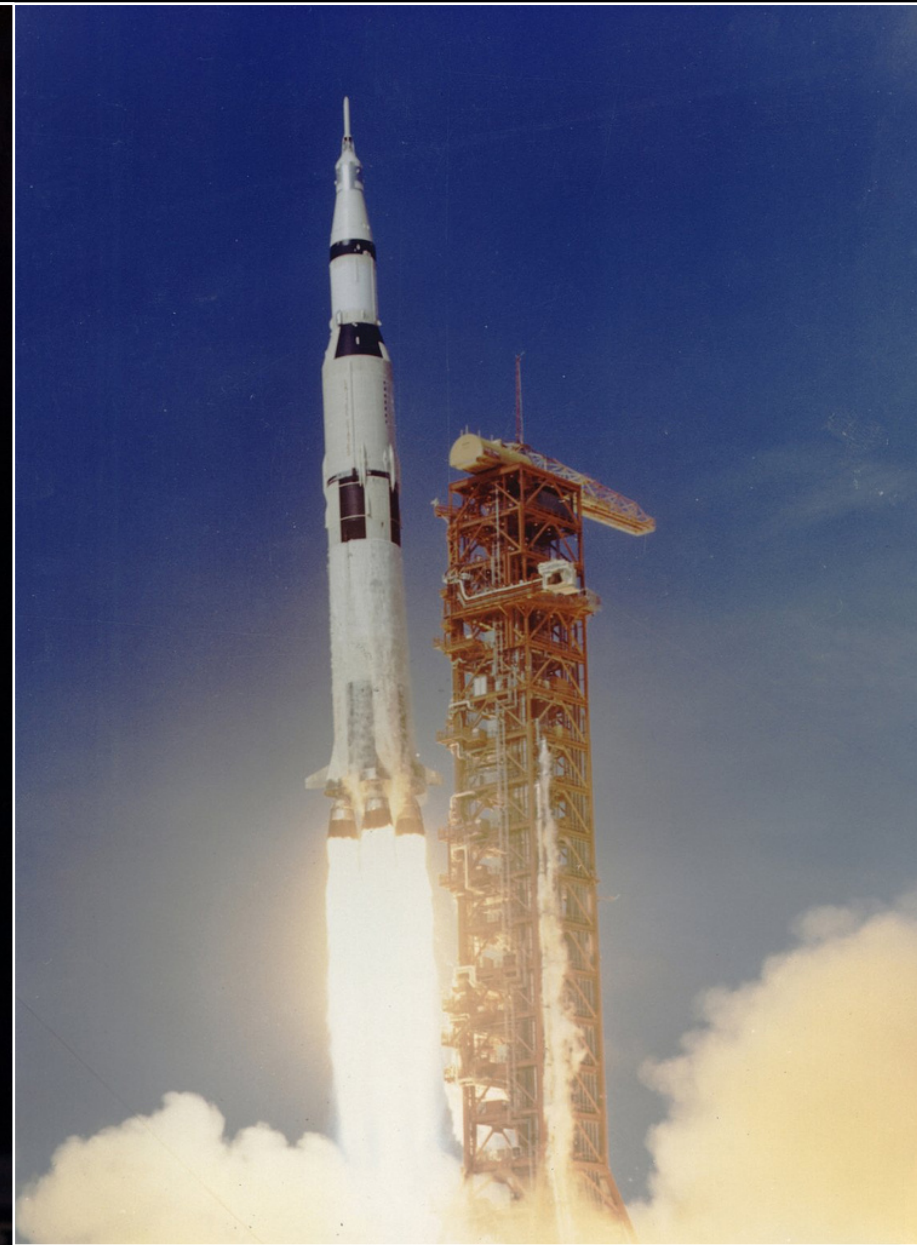
# Forward to the Moon: NASA's Strategic Plan for Lunar Exploration

EXPLORESCIENCE

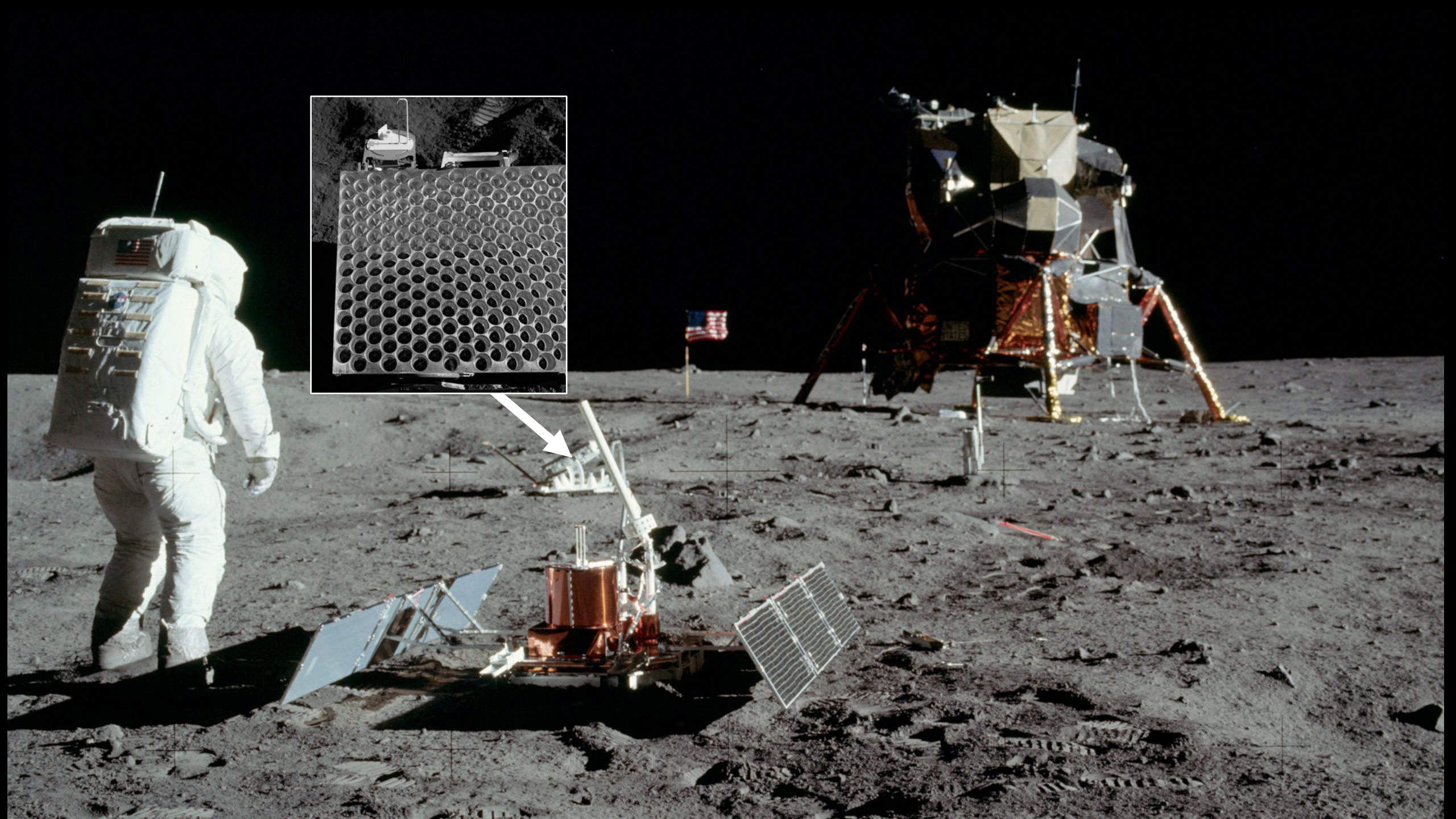
James L. Green  
NASA Chief Scientist

September 23, 2019



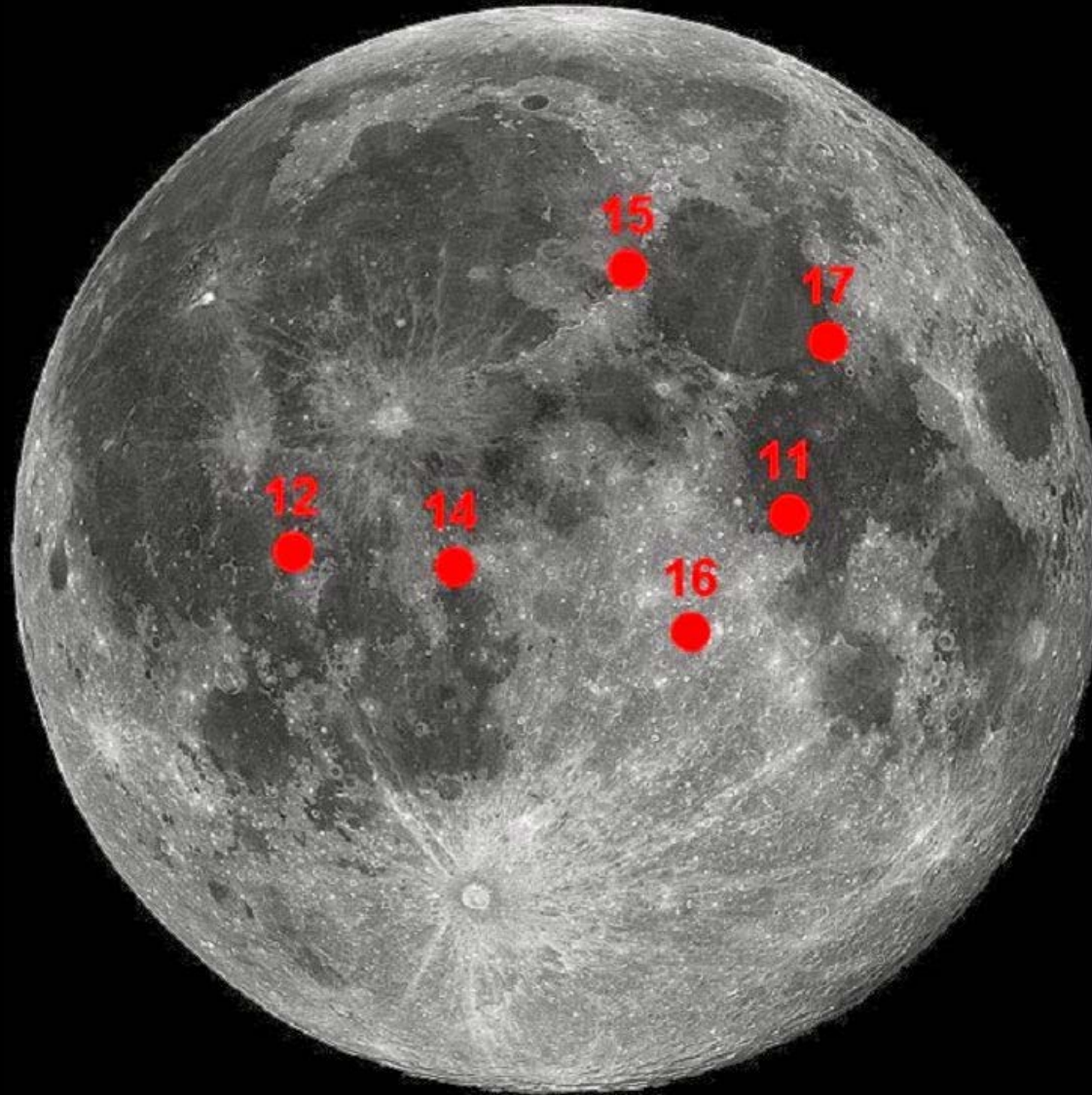








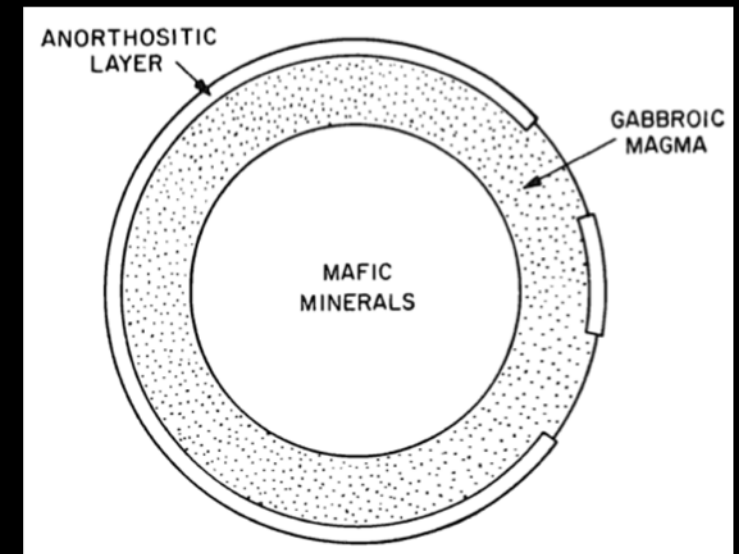
# Apollo Lunar Exploration Program





# 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

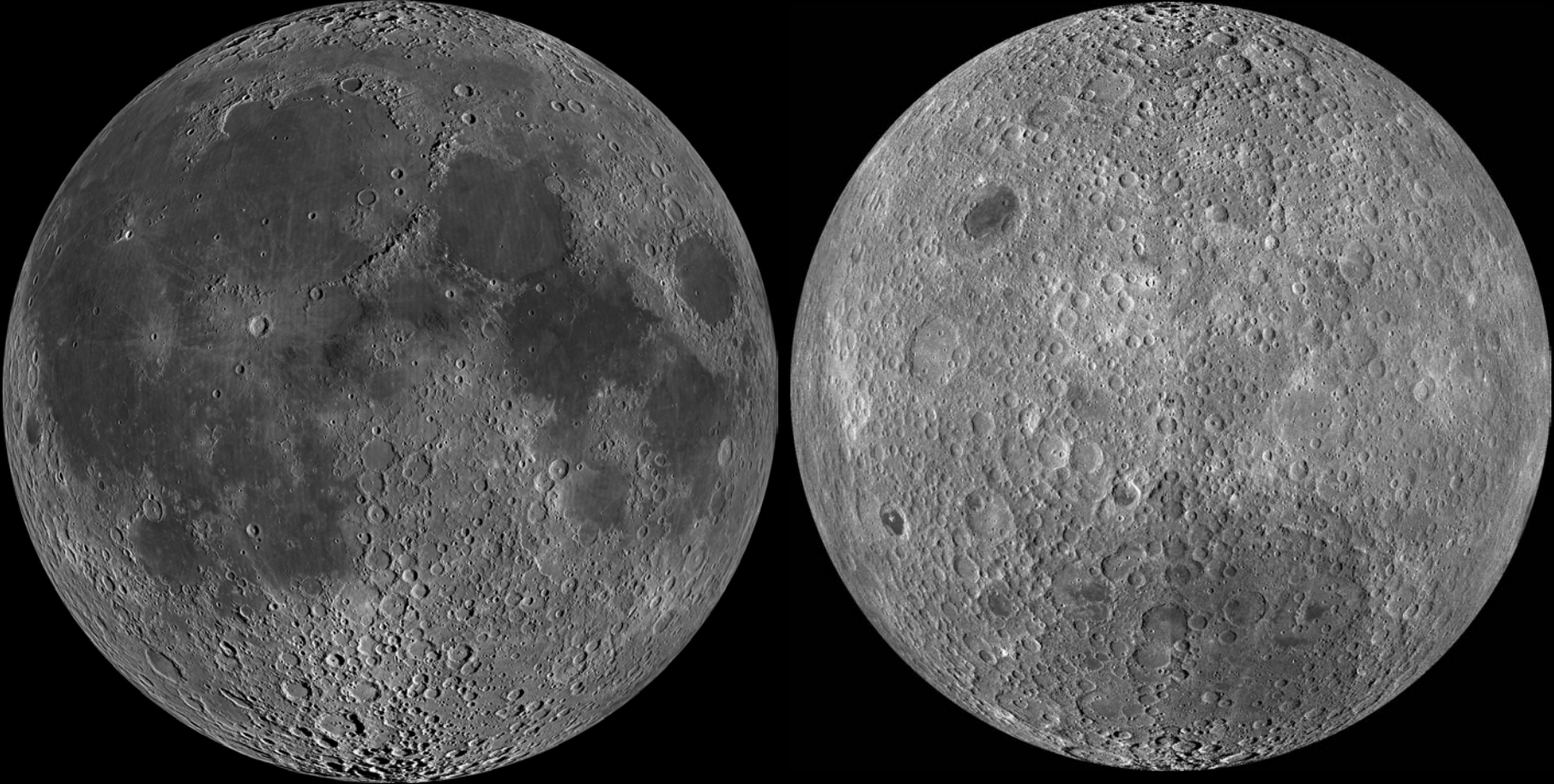




Earth's Moon

Nearside

Farside

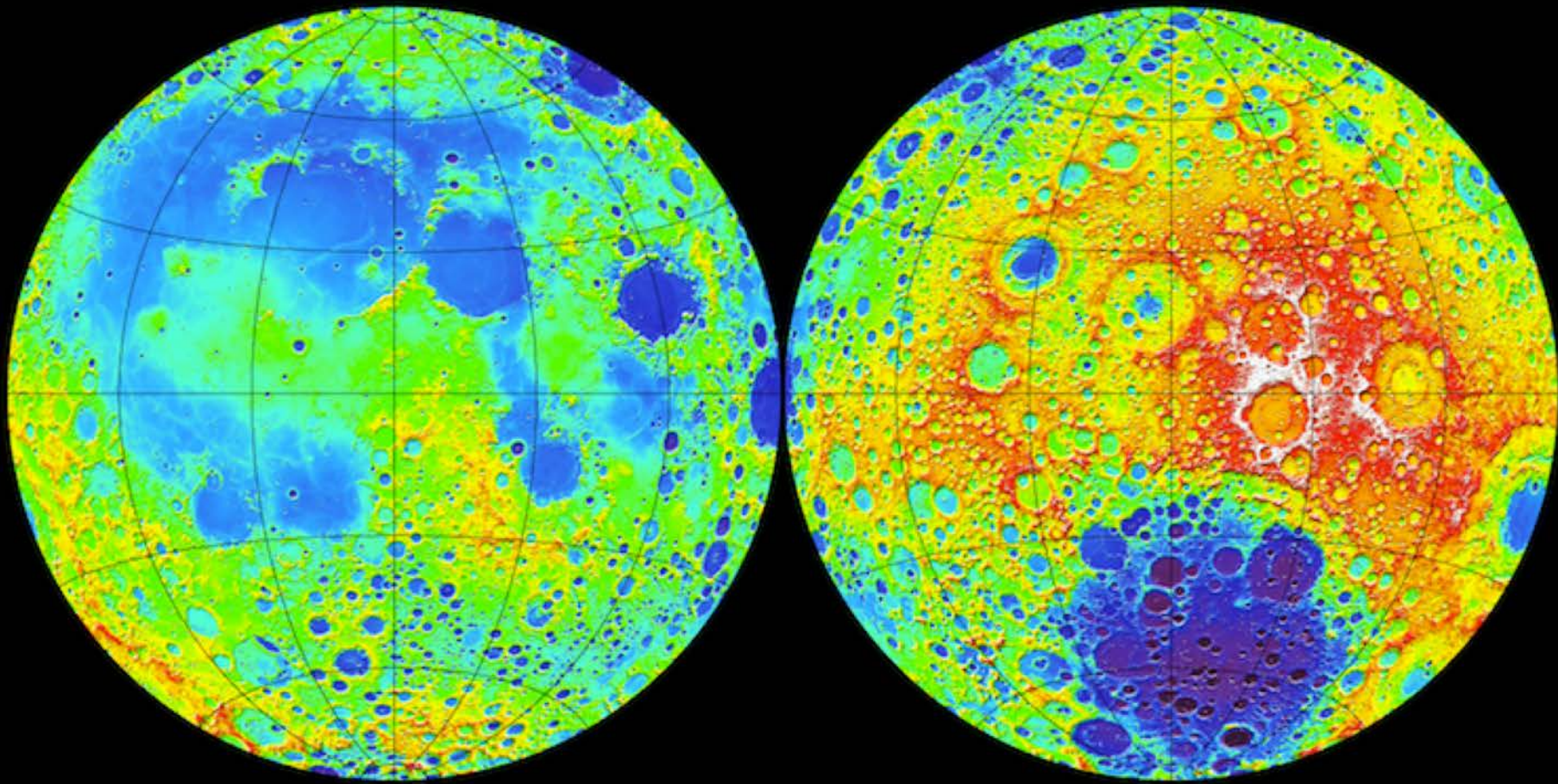




Earth's Moon  
Altitude

Nearside

Farside



Topography (km)

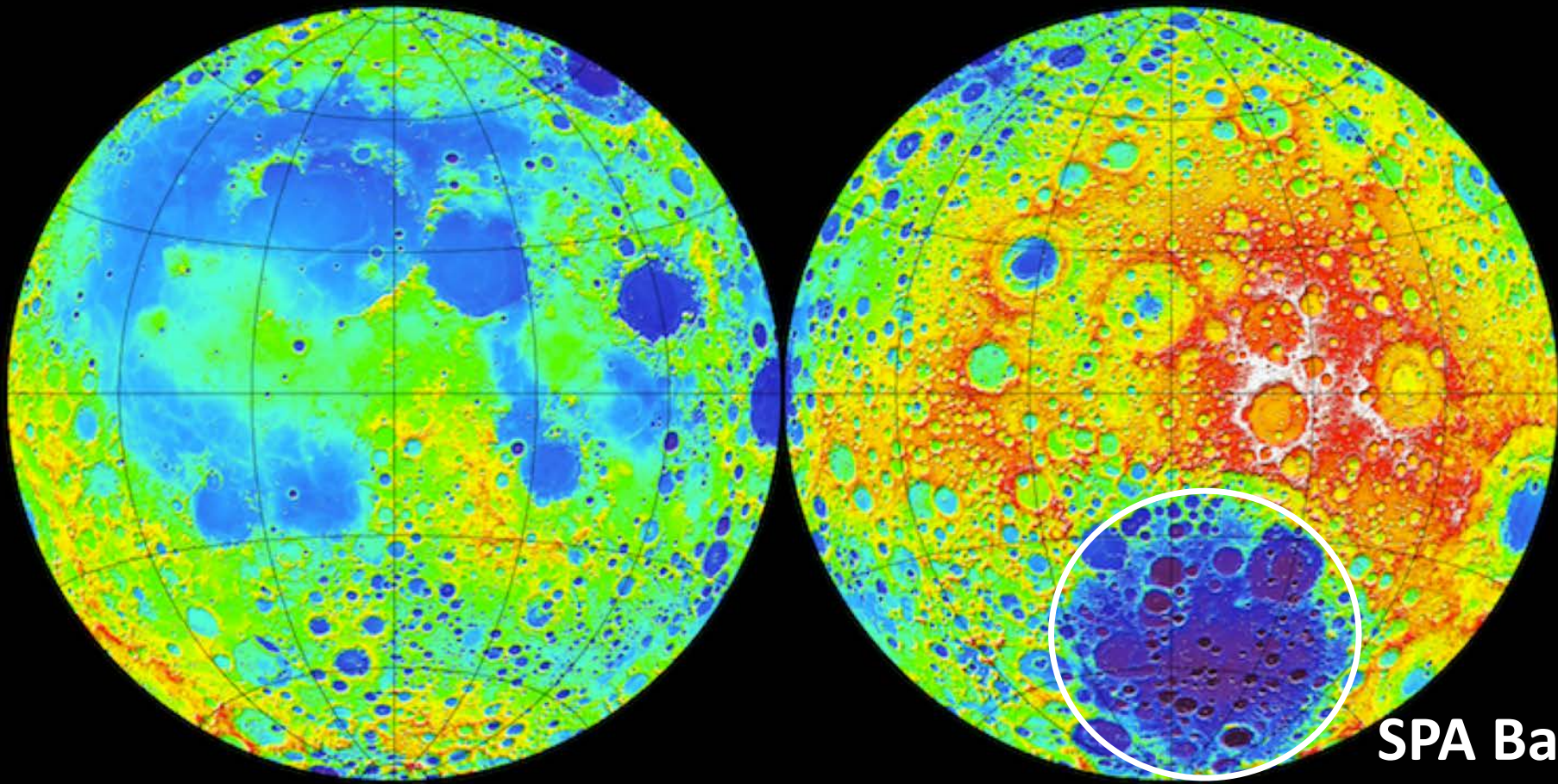




Earth's Moon  
Altitude

Nearside

Farside



SPA Basin

Topography (km)

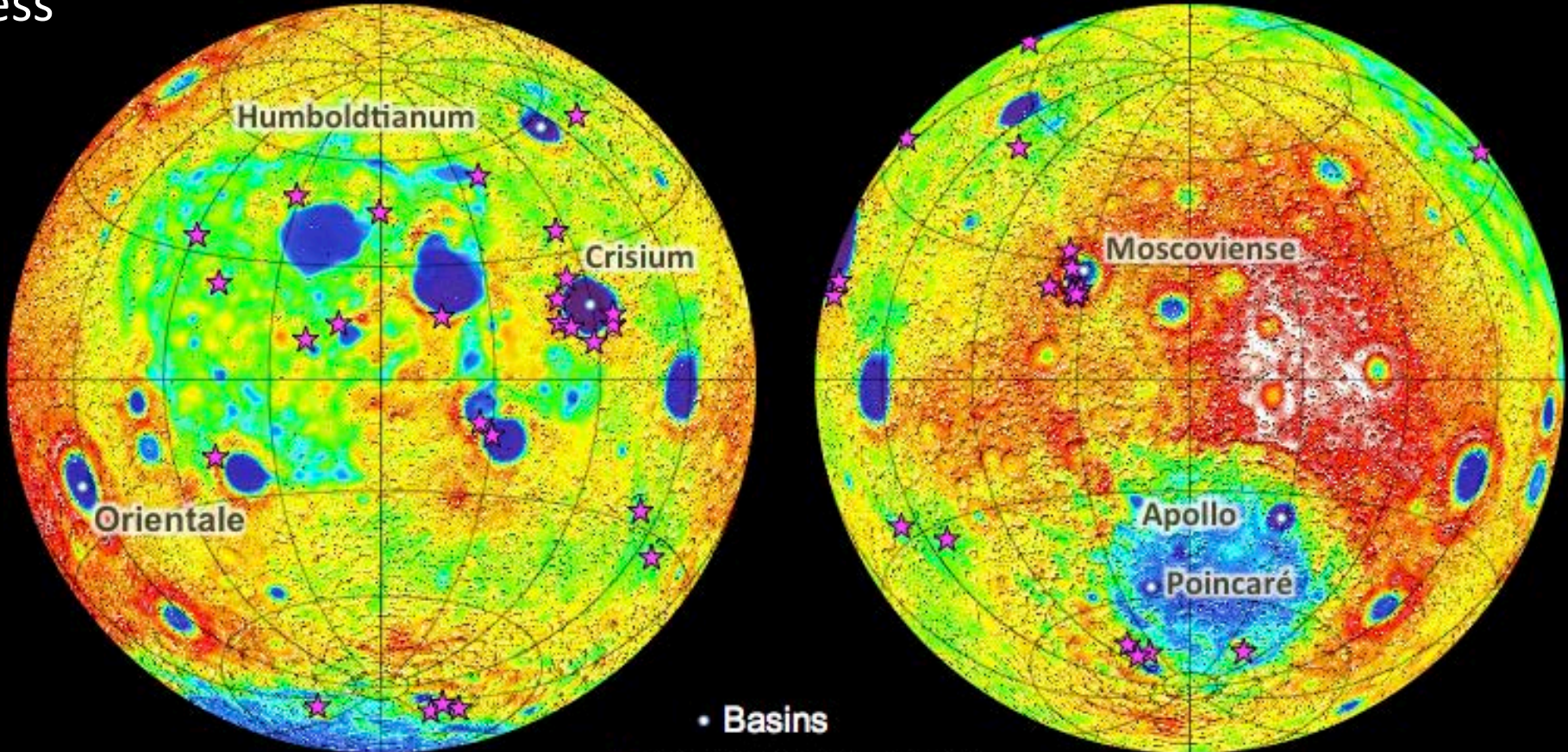




# Earth's Moon Crust Thickness

## Nearside

## Farside



• Basins

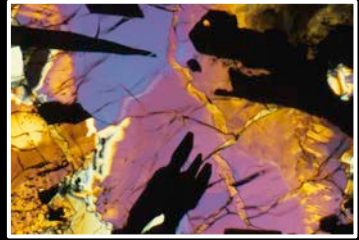
★ Olivine-rich exposures



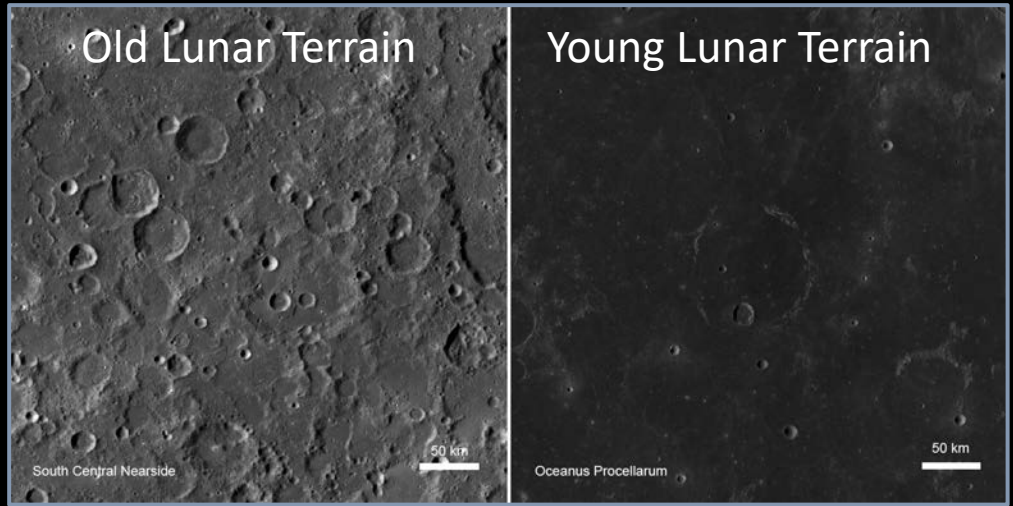
Crustal thickness (km)



# Setting the Solar System's Clock

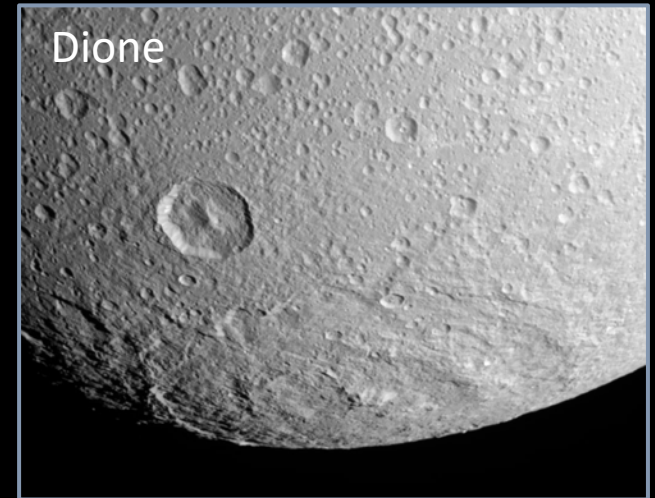


70017



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

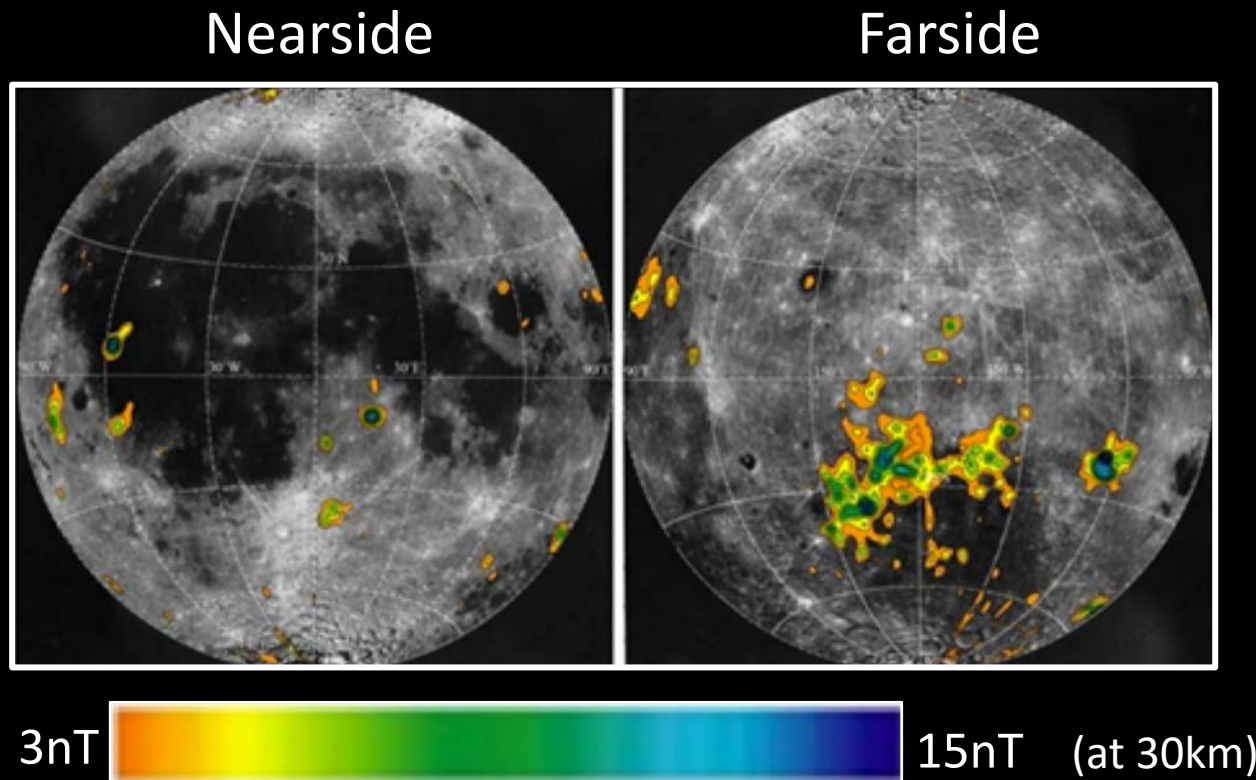
And is used to estimate the ages of all other planetary surfaces in the Solar System





# Magnetic Anomalies: Fe, Ni and PGM

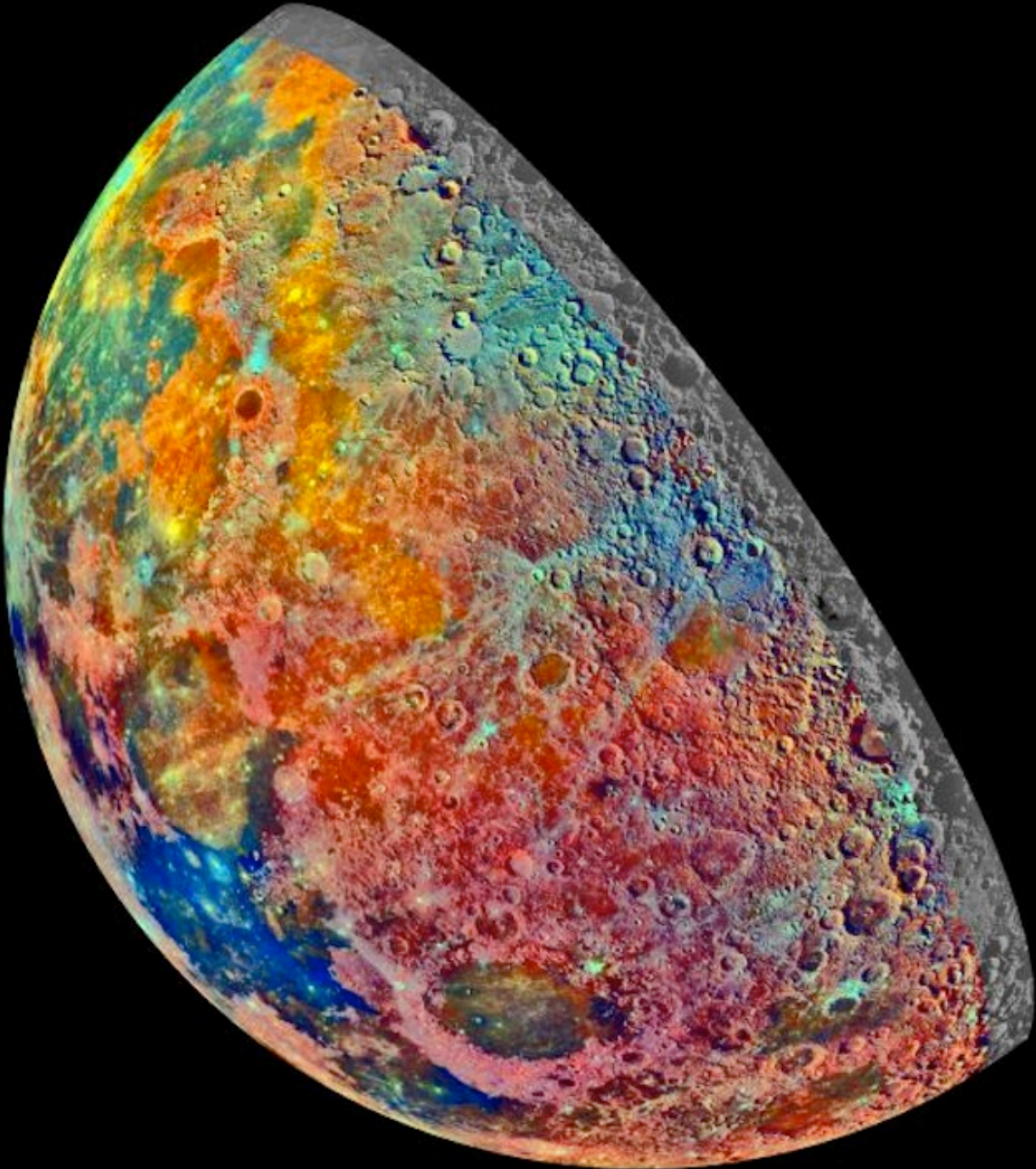
- Platinum group metals (PGM) are primarily located in SPA Basin
- PGM concentration in iron meteorites can reach 200 ppm



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



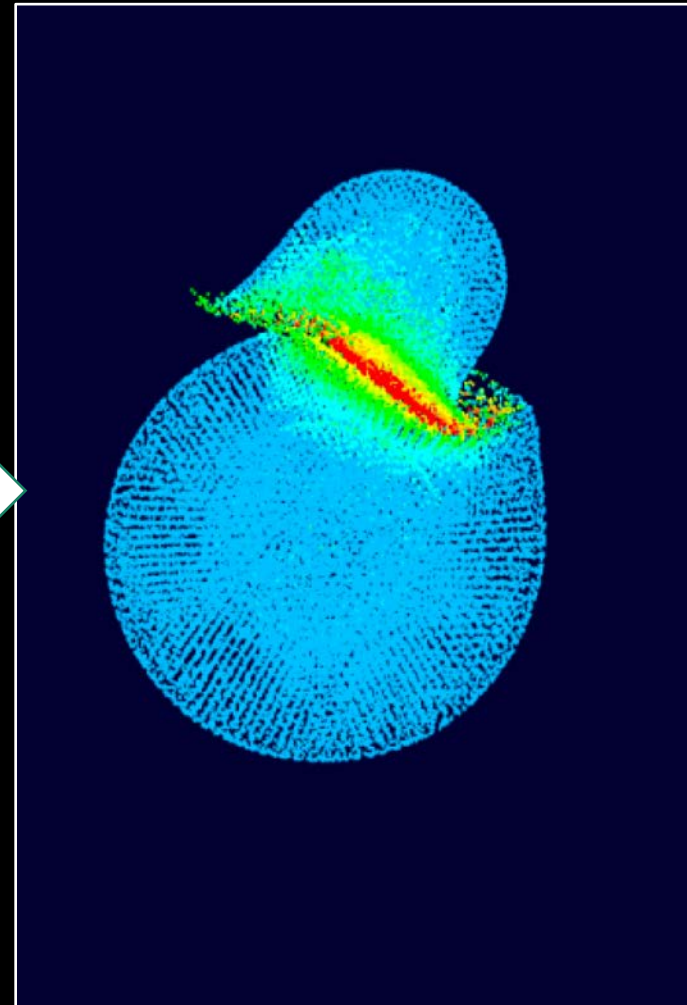


# Earth-Moon Formation



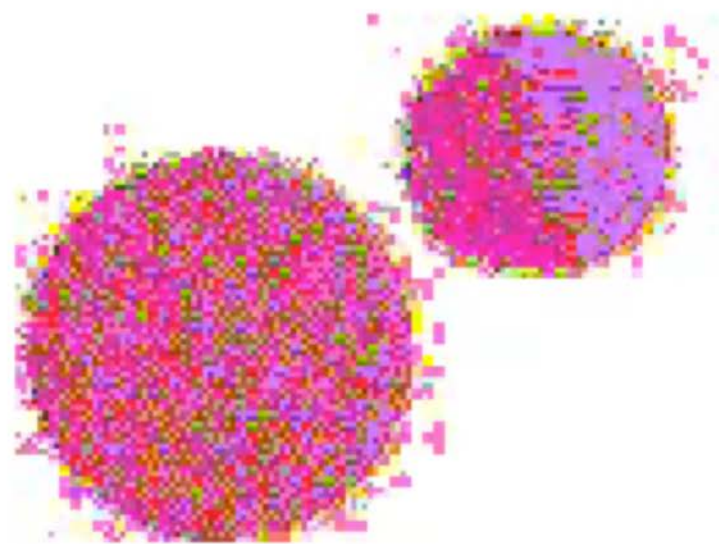


# Lunar exploration can reveal how the Earth-Moon system formed



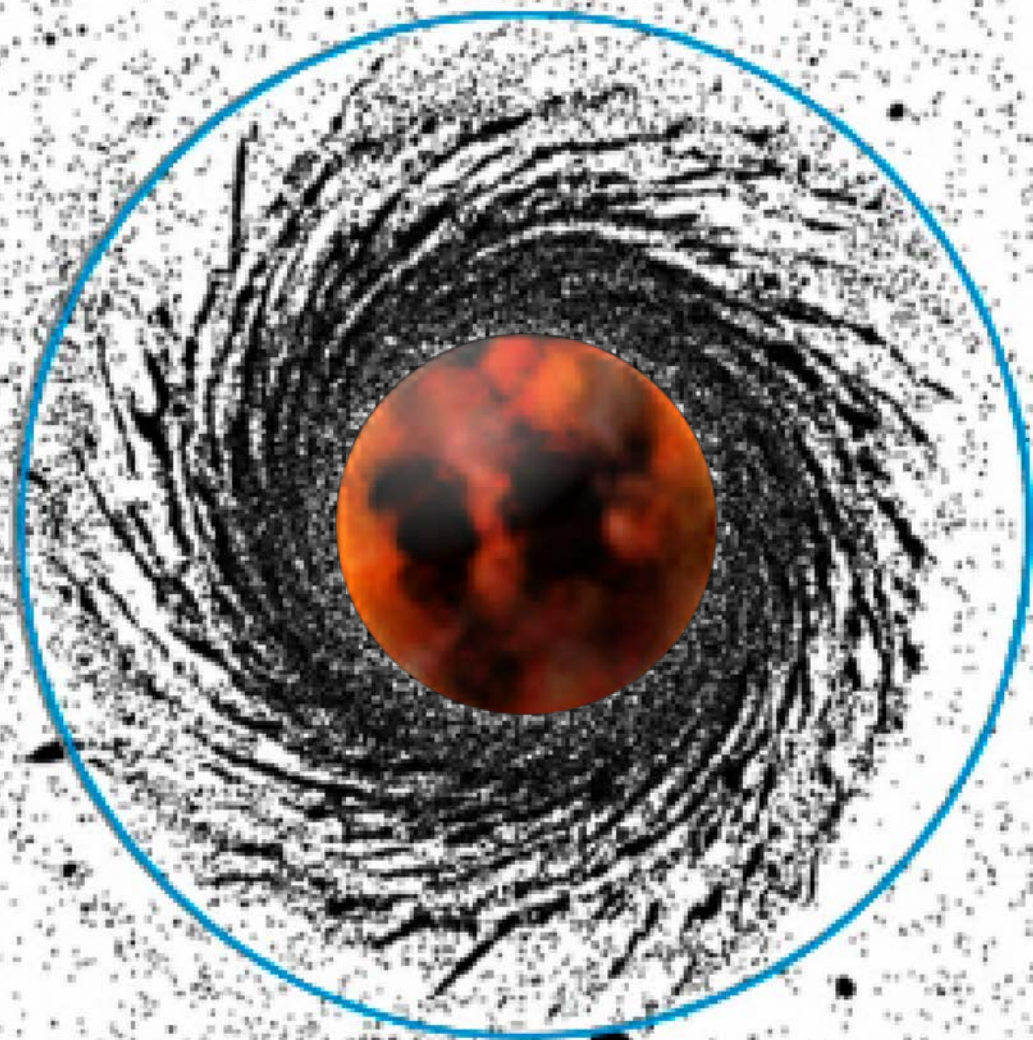
Giant impact hypothesis for origin of Moon





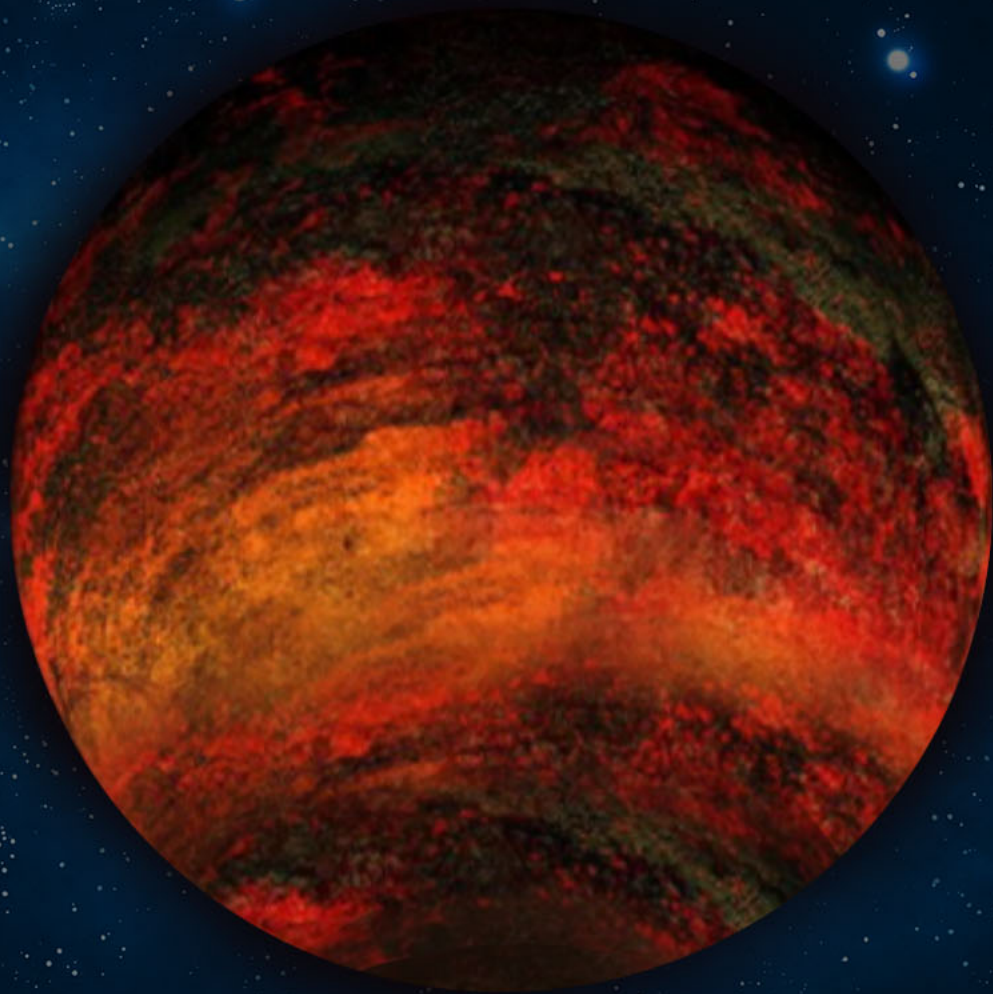


# Roche limit

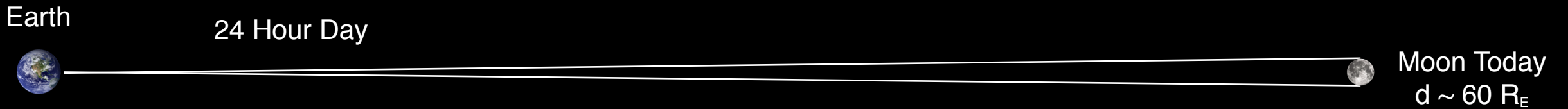
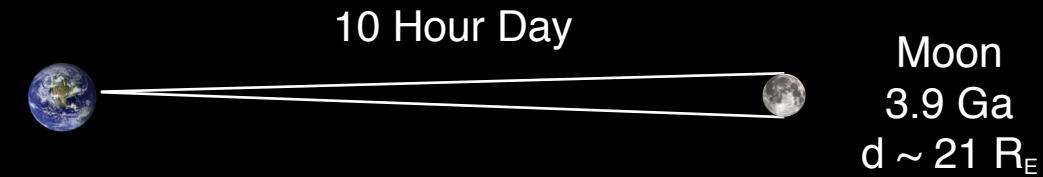
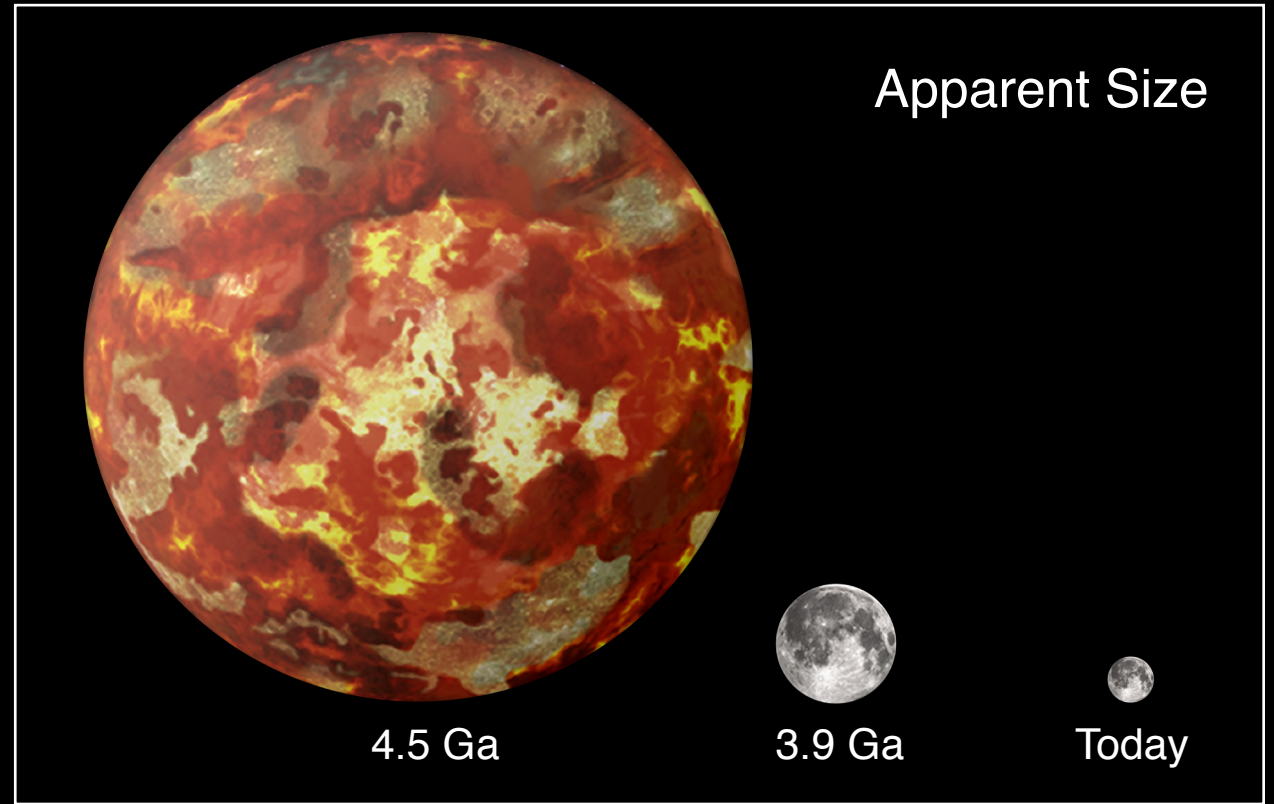




5-Hour Day



# The Moon Stabilizes Our Spin Axis

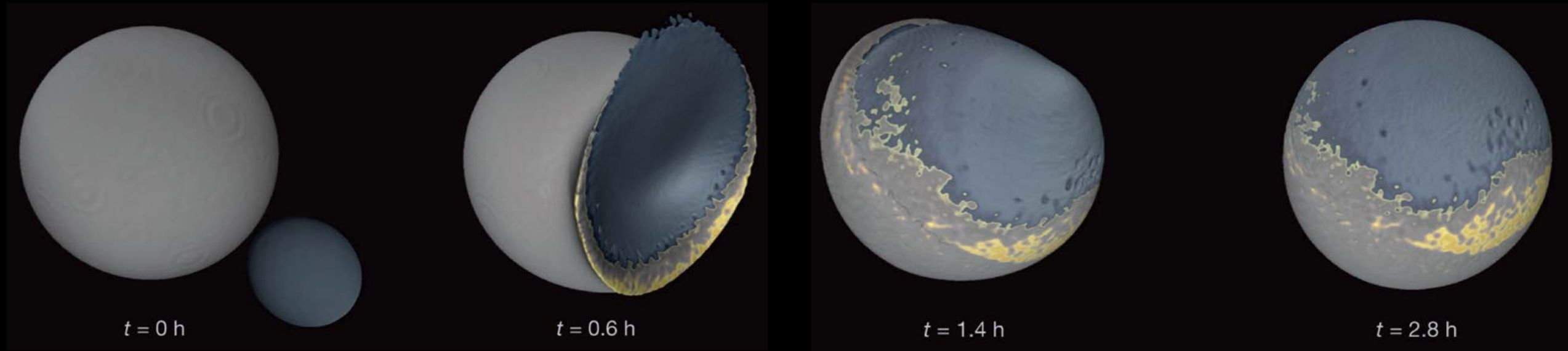




# Theory 1: Formation of Farside Highlands



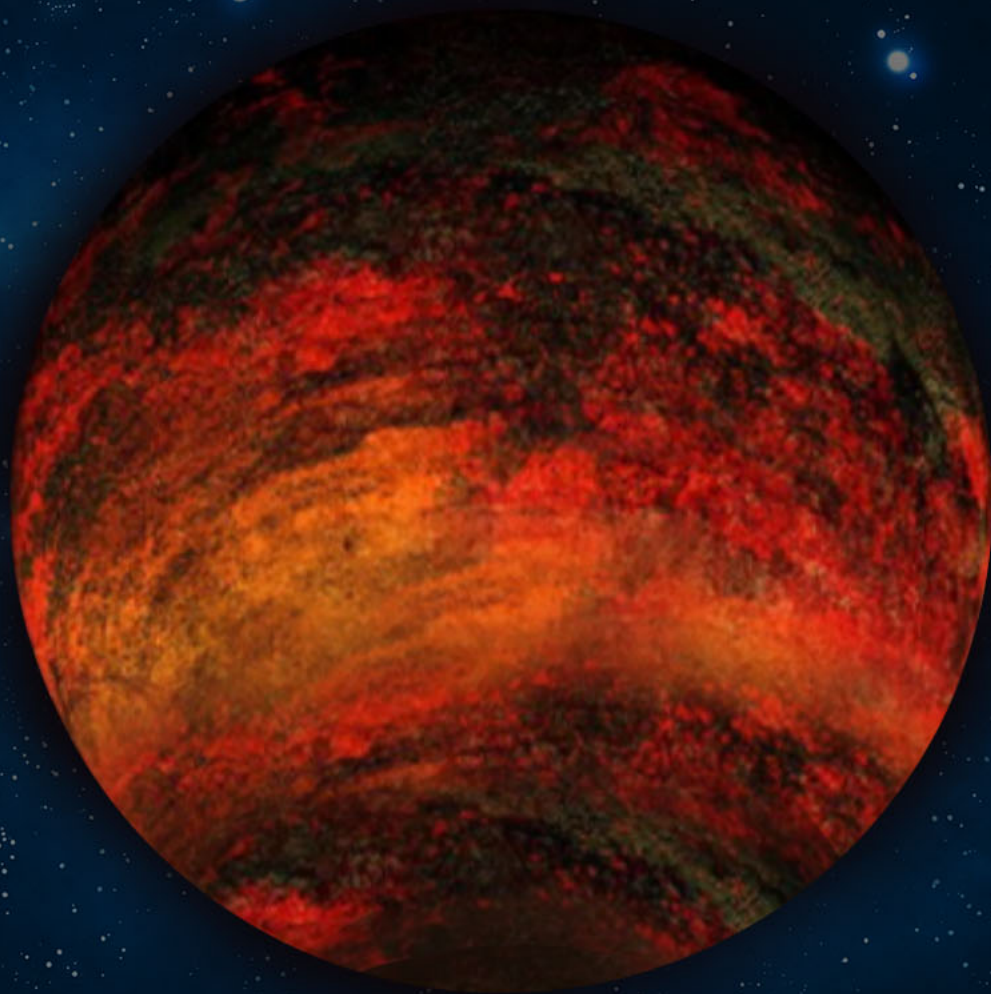
# Theory 1: Formation of Farside Highlands



Thicker Crust on the  
Far side of the Moon

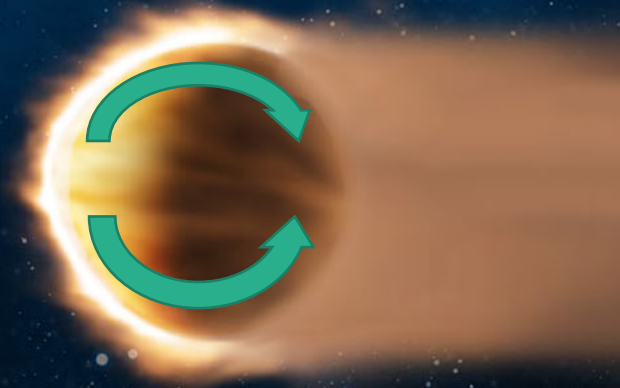
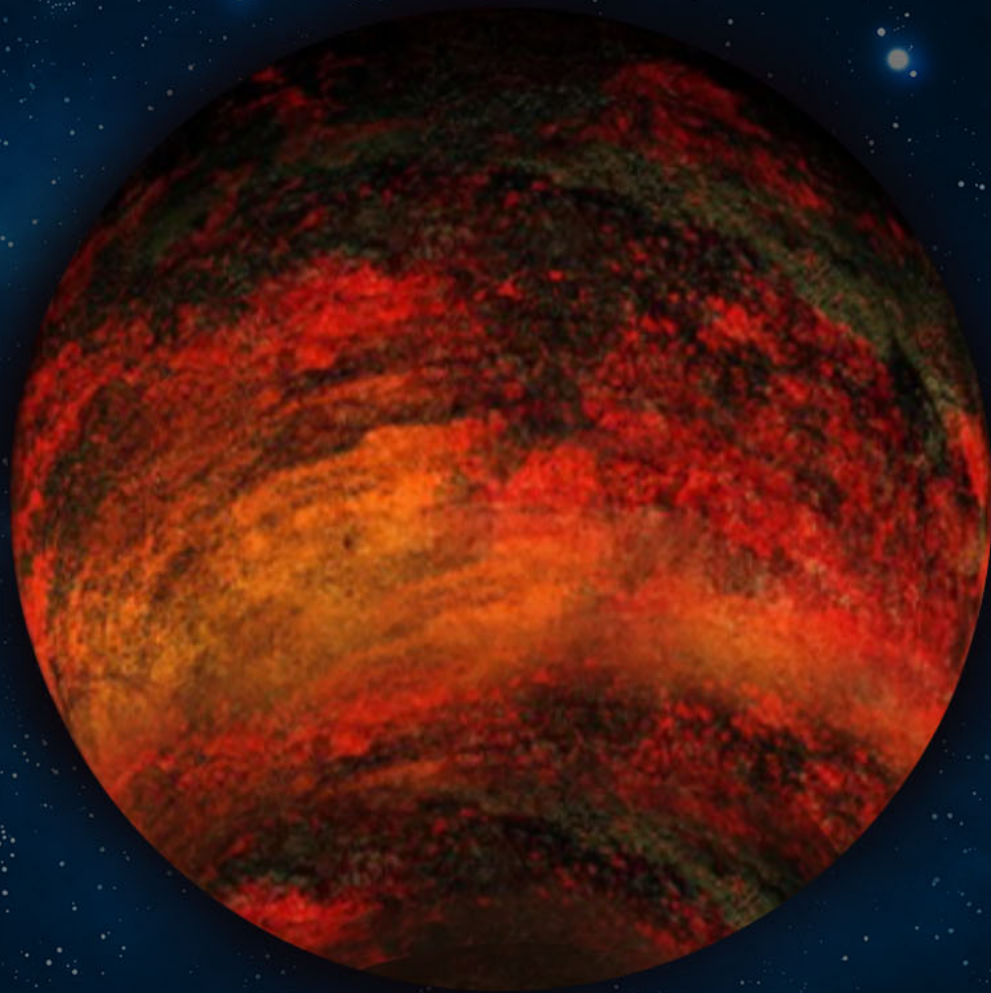


# Theory 2: Formation of Farside Highlands





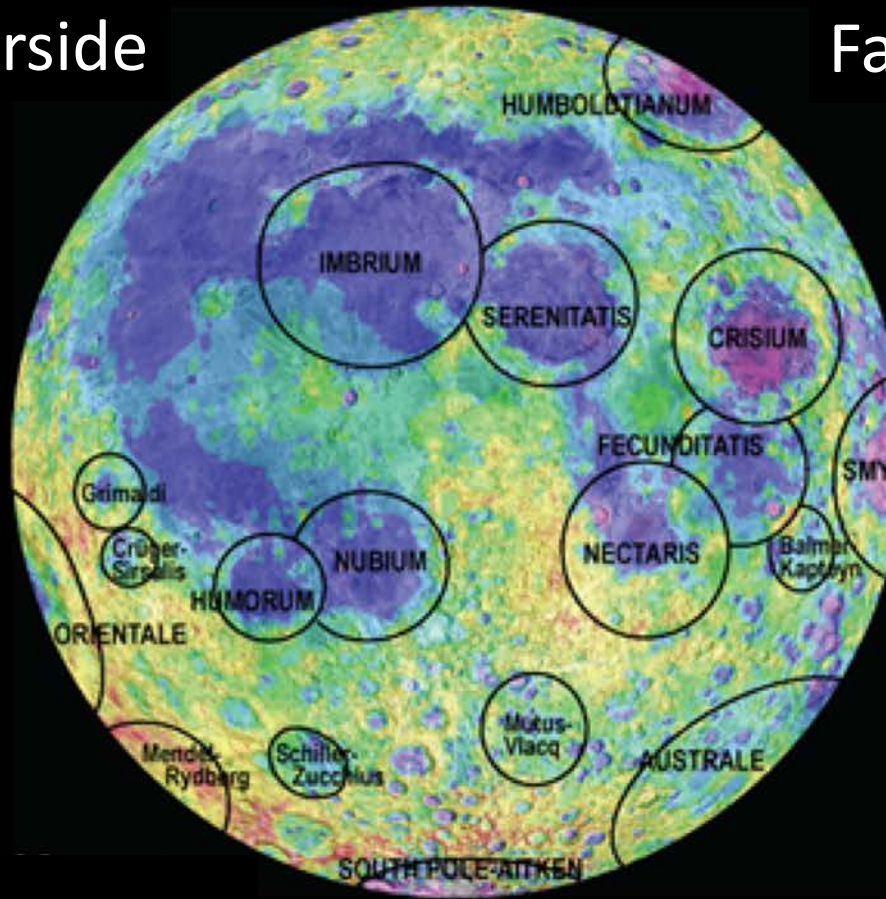
# Theory 2: Formation of Farside Highlands



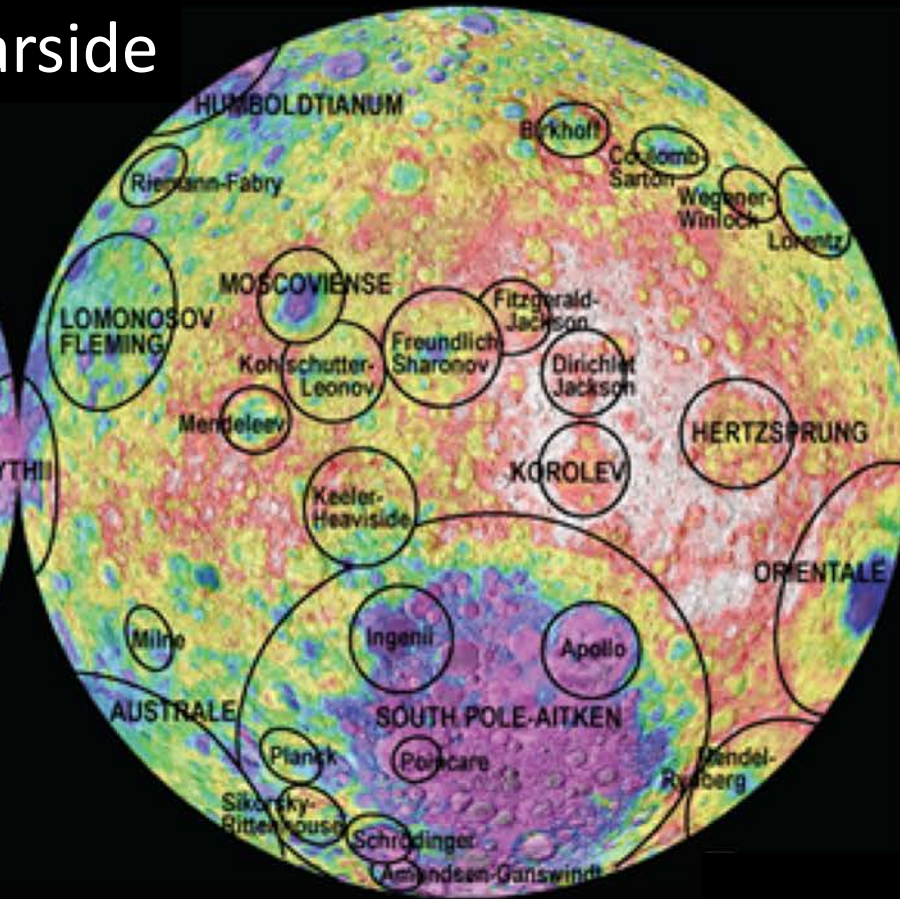


# Bombardment History

Nearside



Farside

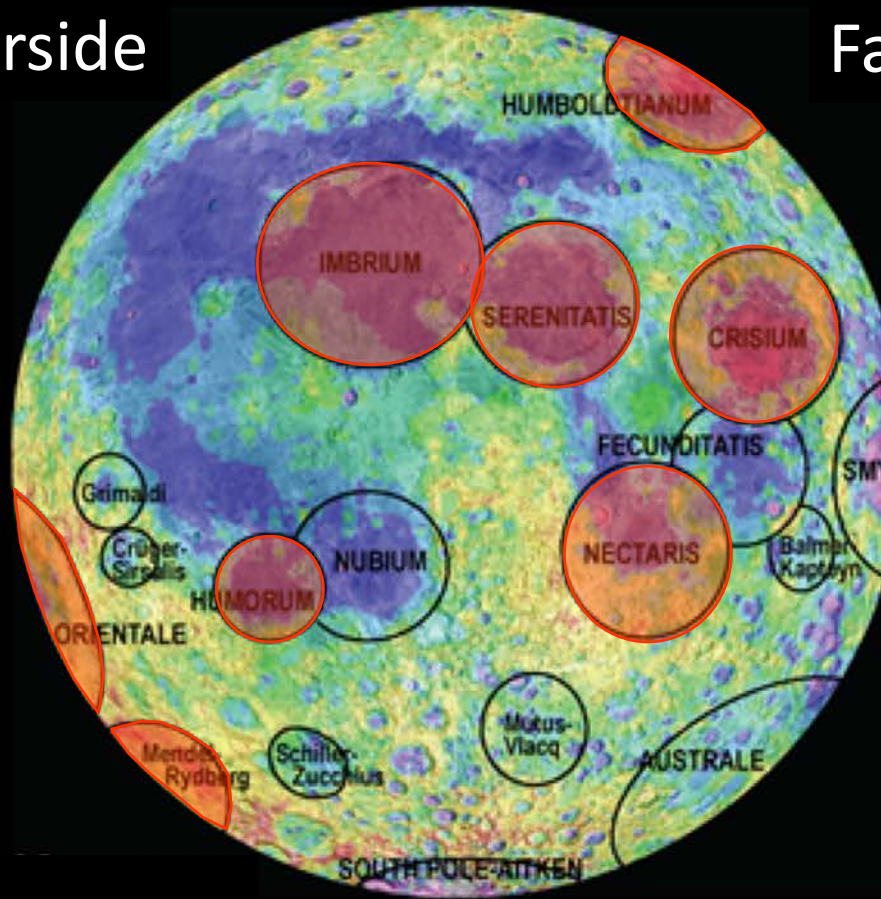


For every 1 impact on the Moon the Earth should have 20 impacts!

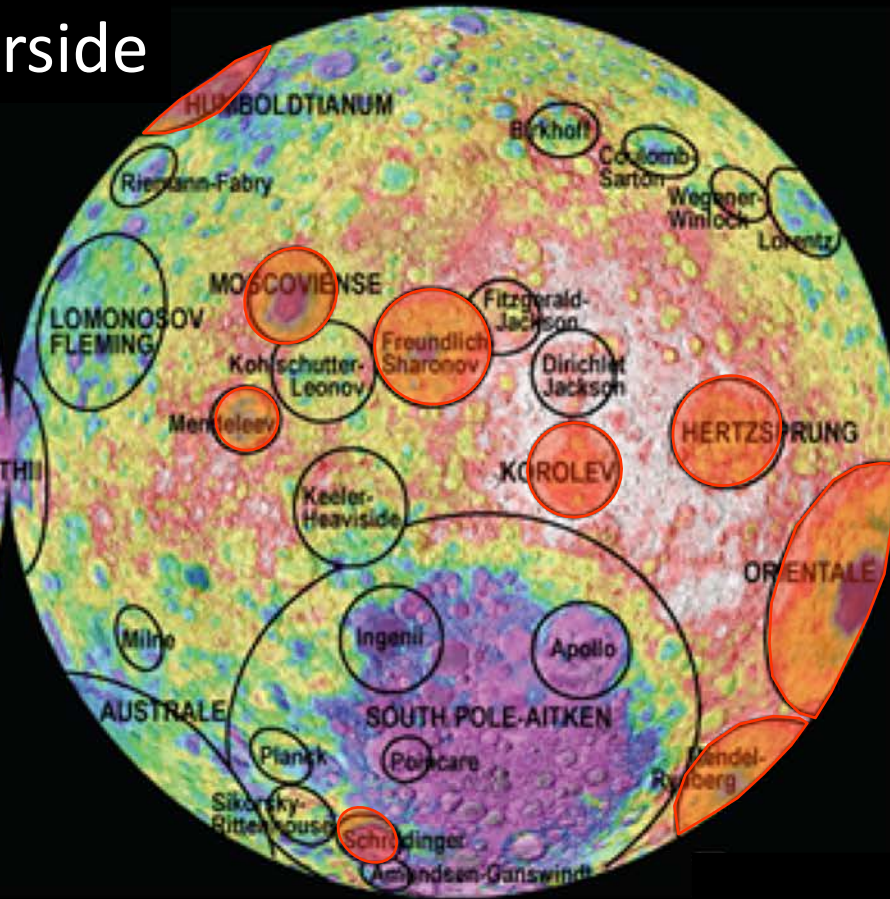


# The Late Heavy Bombardment (4.0 - 3.8 Ga)

Nearside



Farside



We only have reliable dates for Imbrium and Orientale Basins

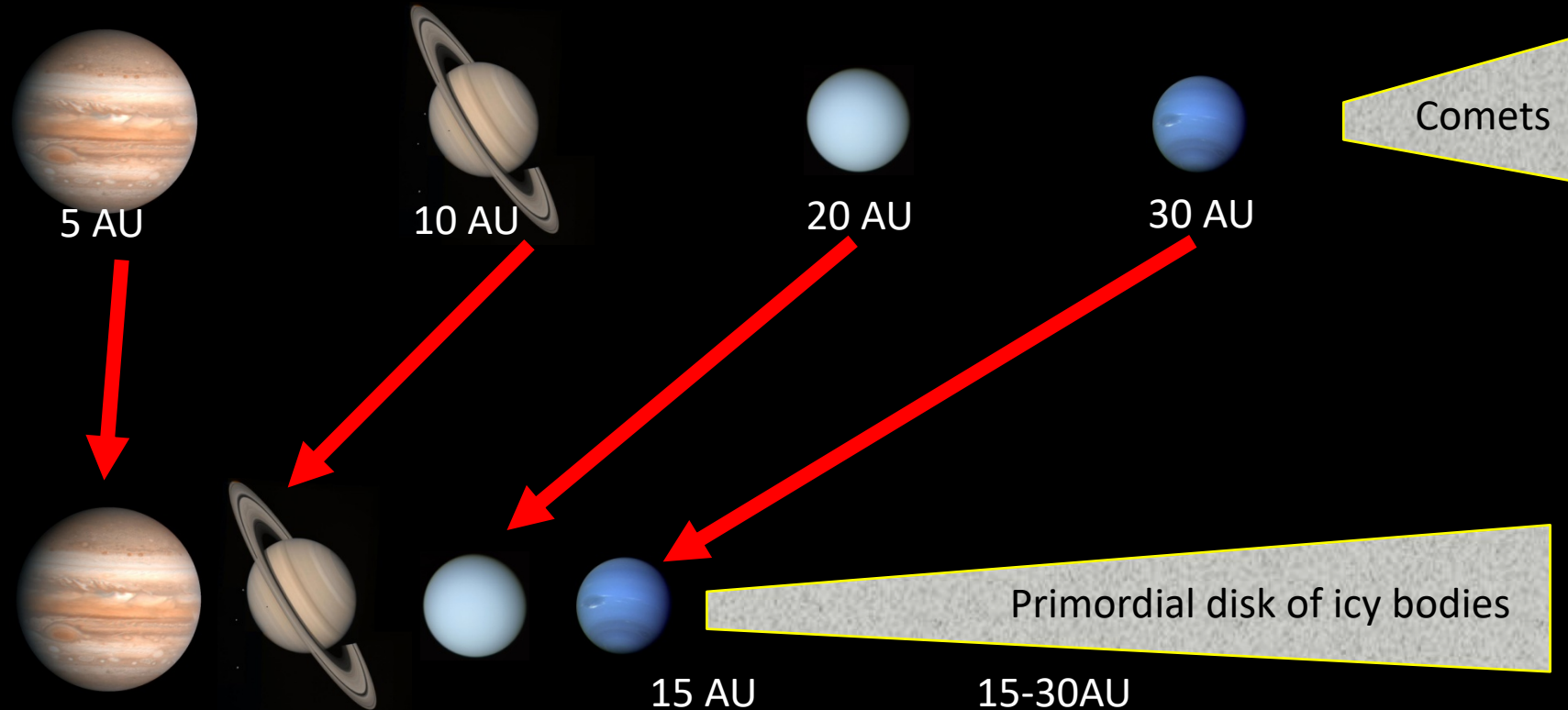


# Solar System Formation Models



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

# Solar System Formation Models

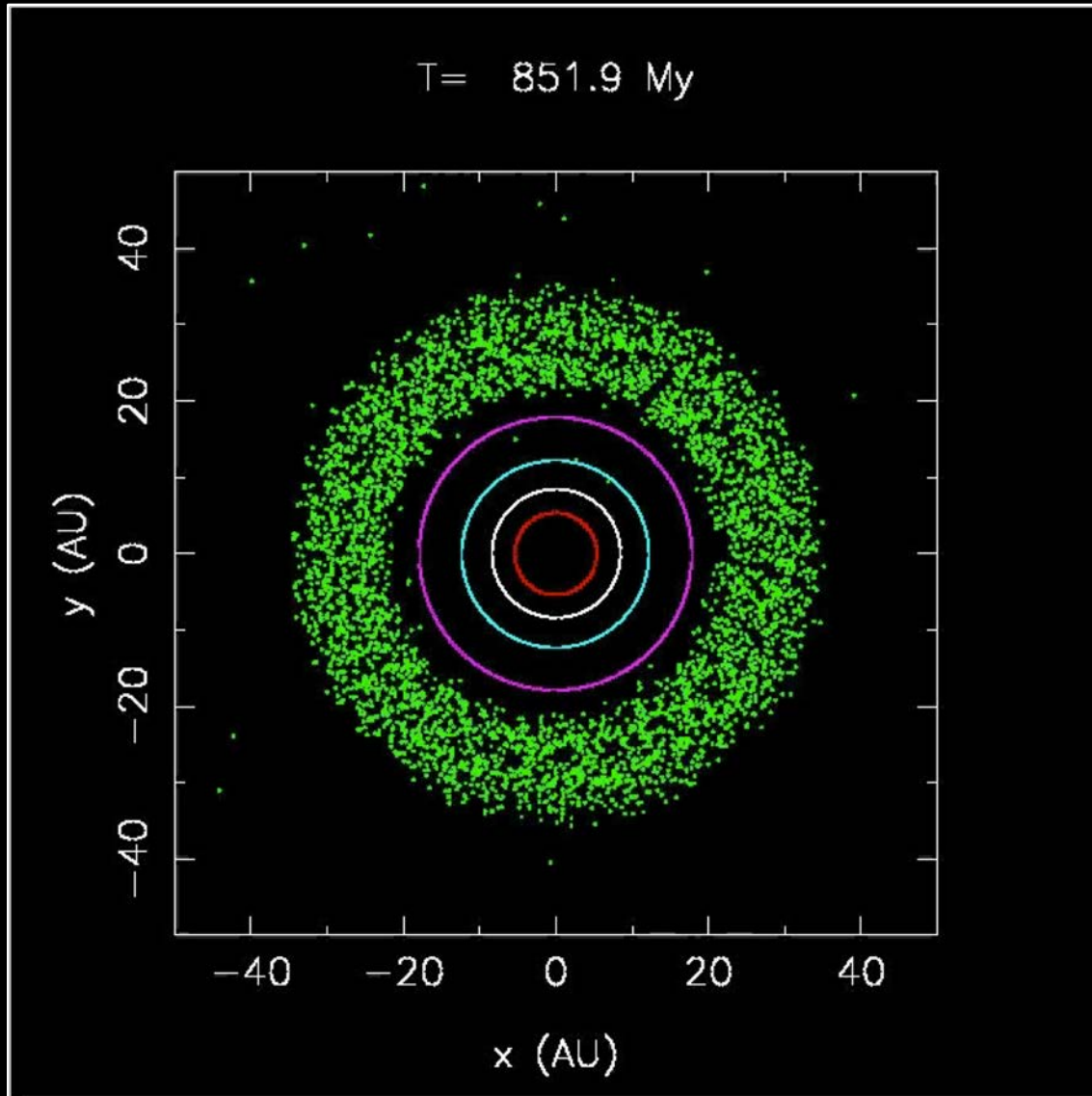


Basic Principle: Objects closer to the Sun can grow *faster*

- 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



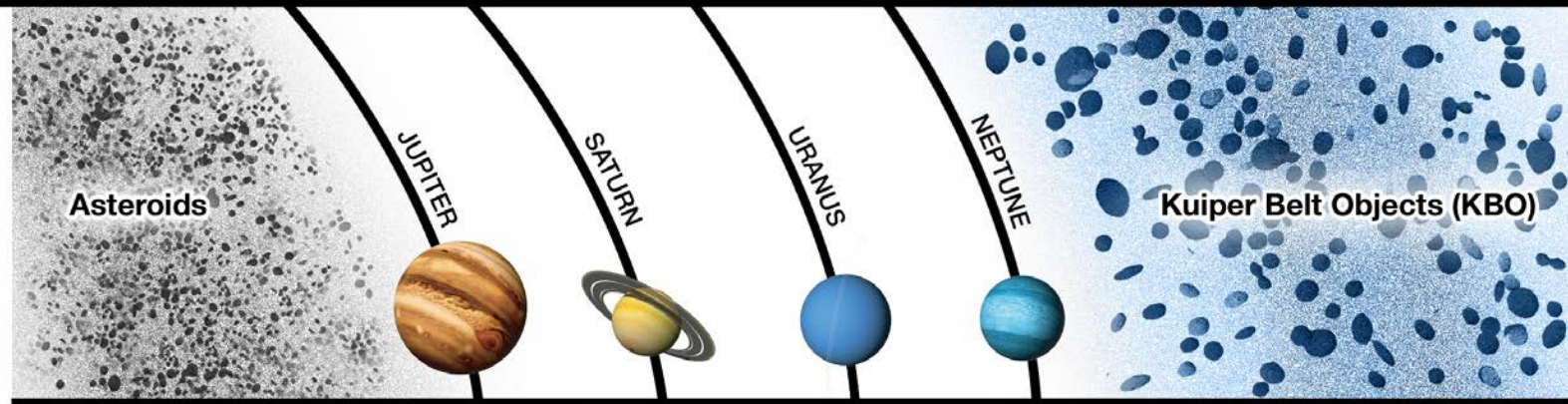
Watch what happens after 890 My



The Late Heavy Bombardment

# Theory: Evolution of the Solar System

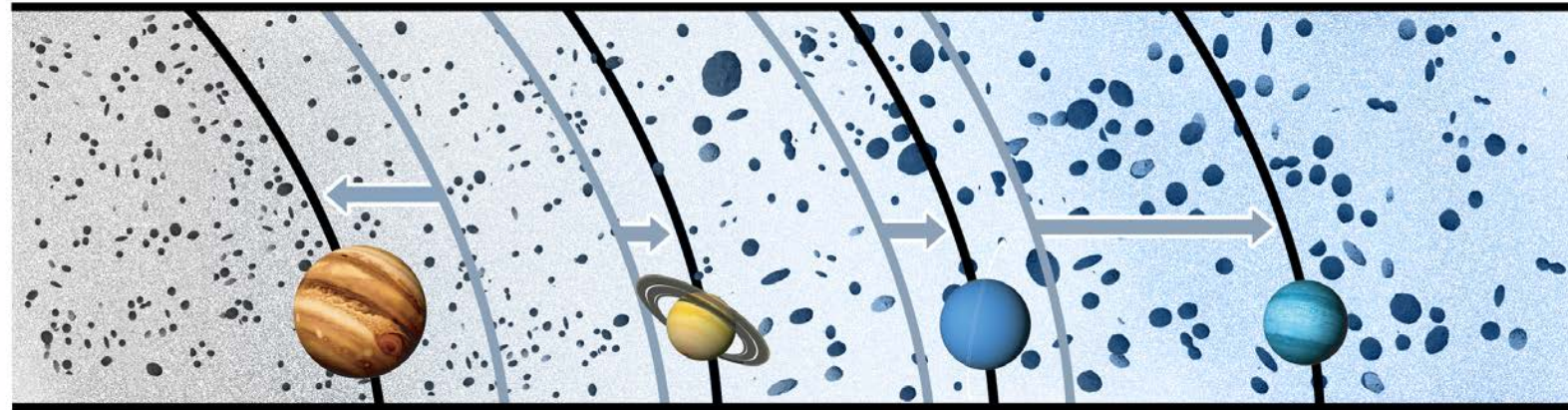
~4.2 Billion  
Years



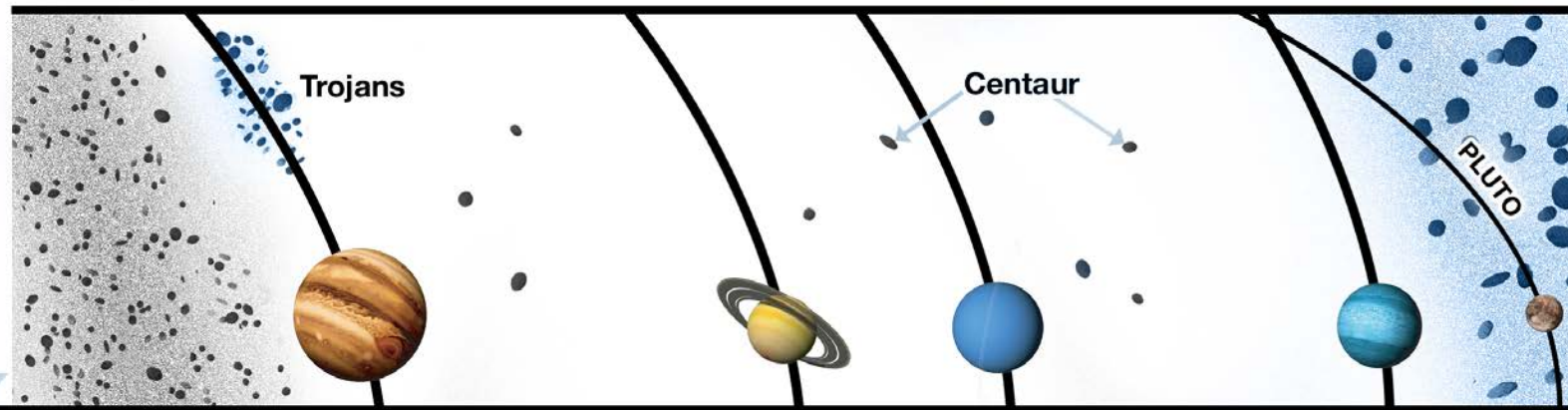
~3.8 Billion  
Years

"Late Heavy  
Bombardment"

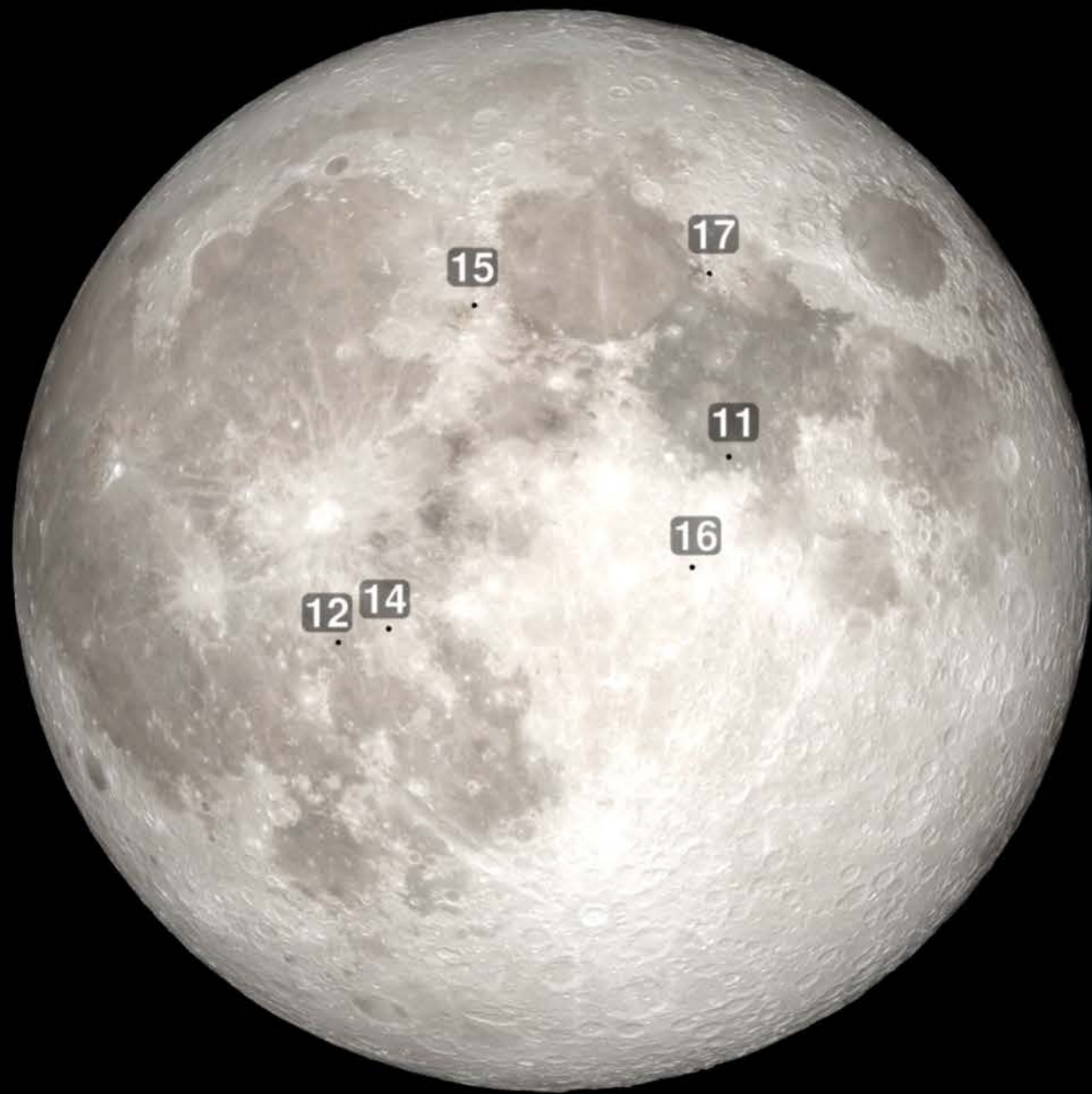
TIME



Today







15

17

11

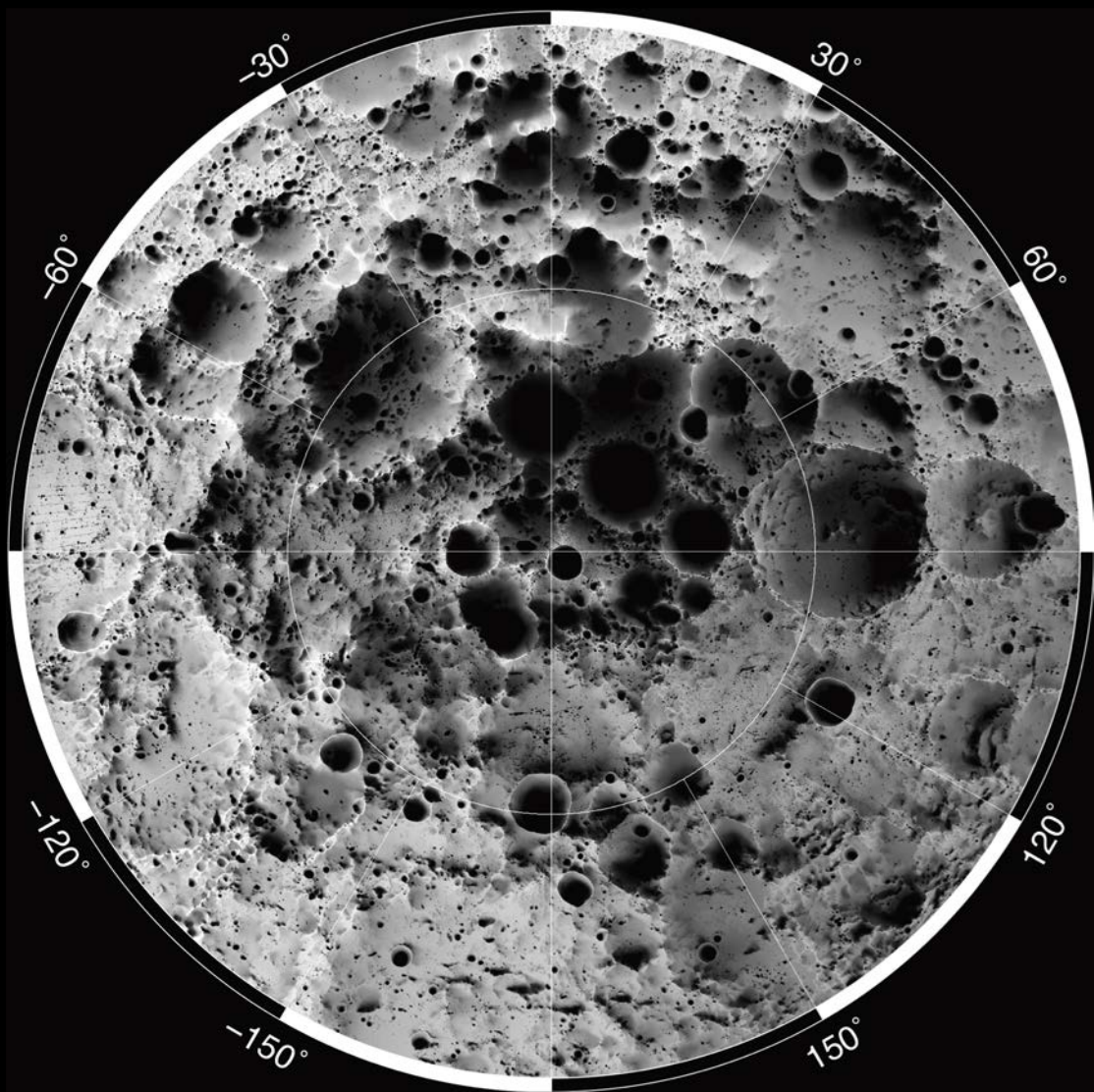
16

12

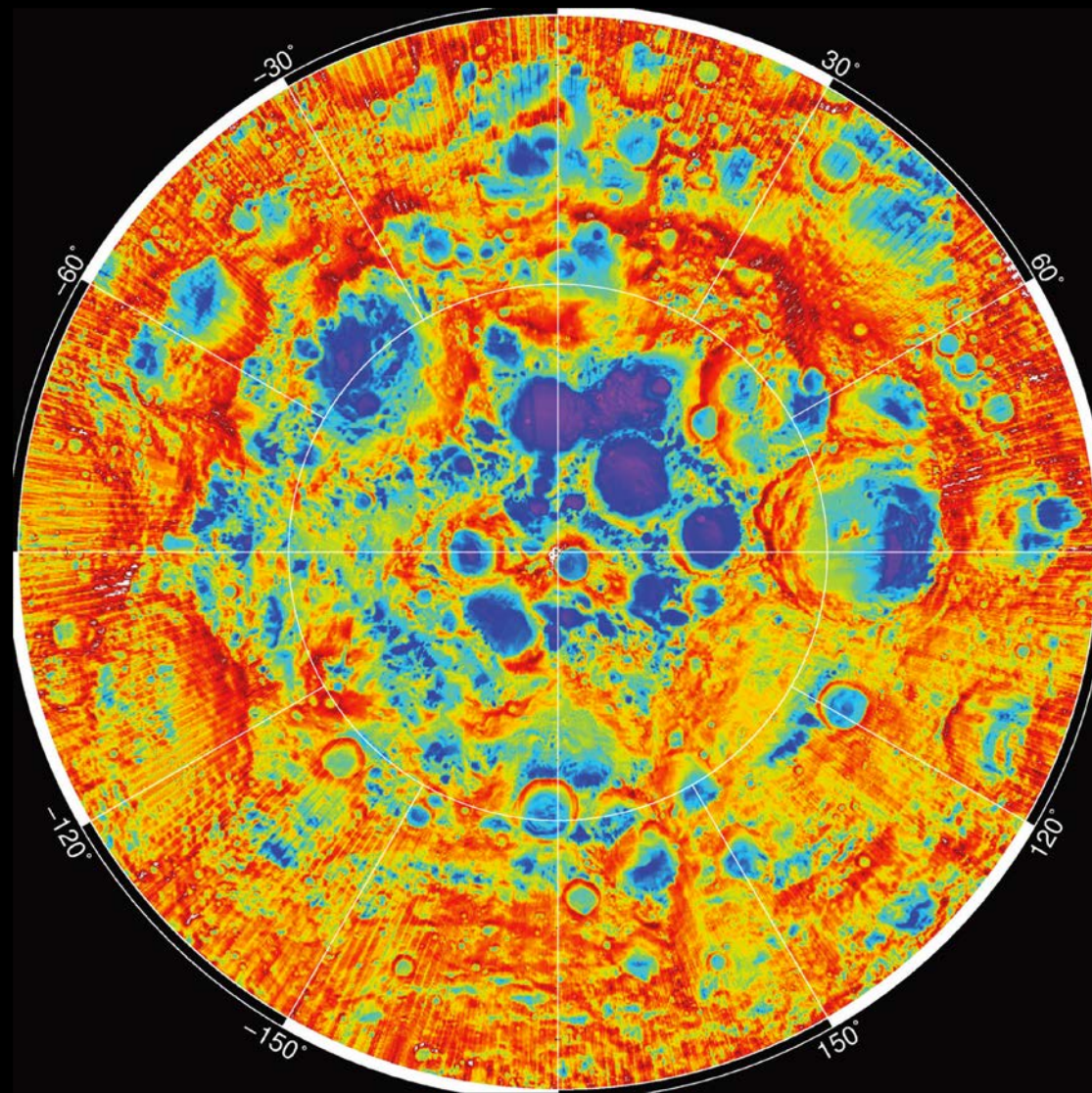
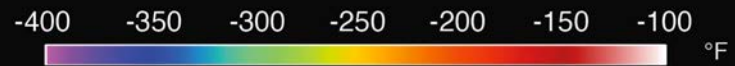
14



Average Illumination of the Lunar South Pole

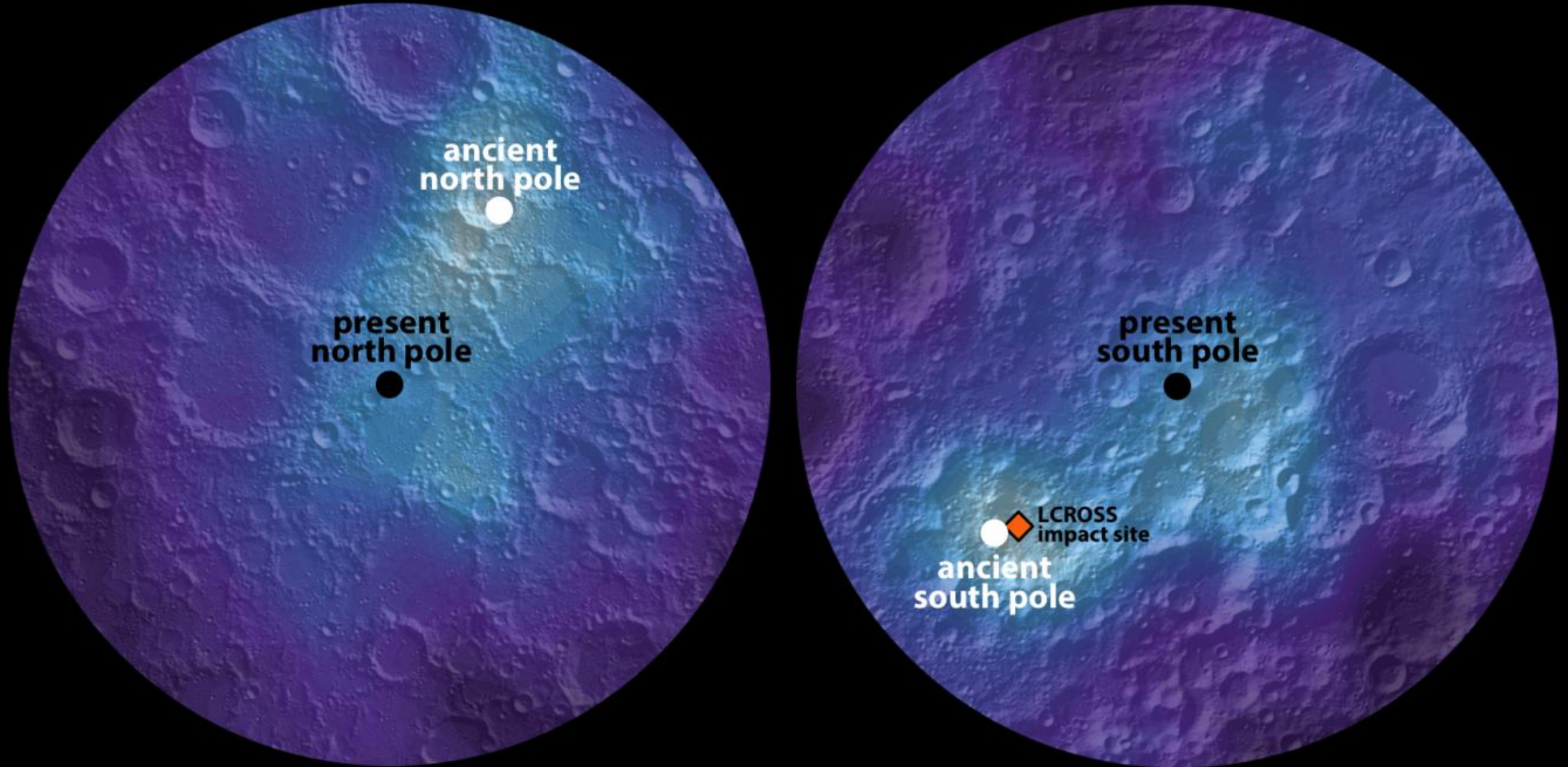


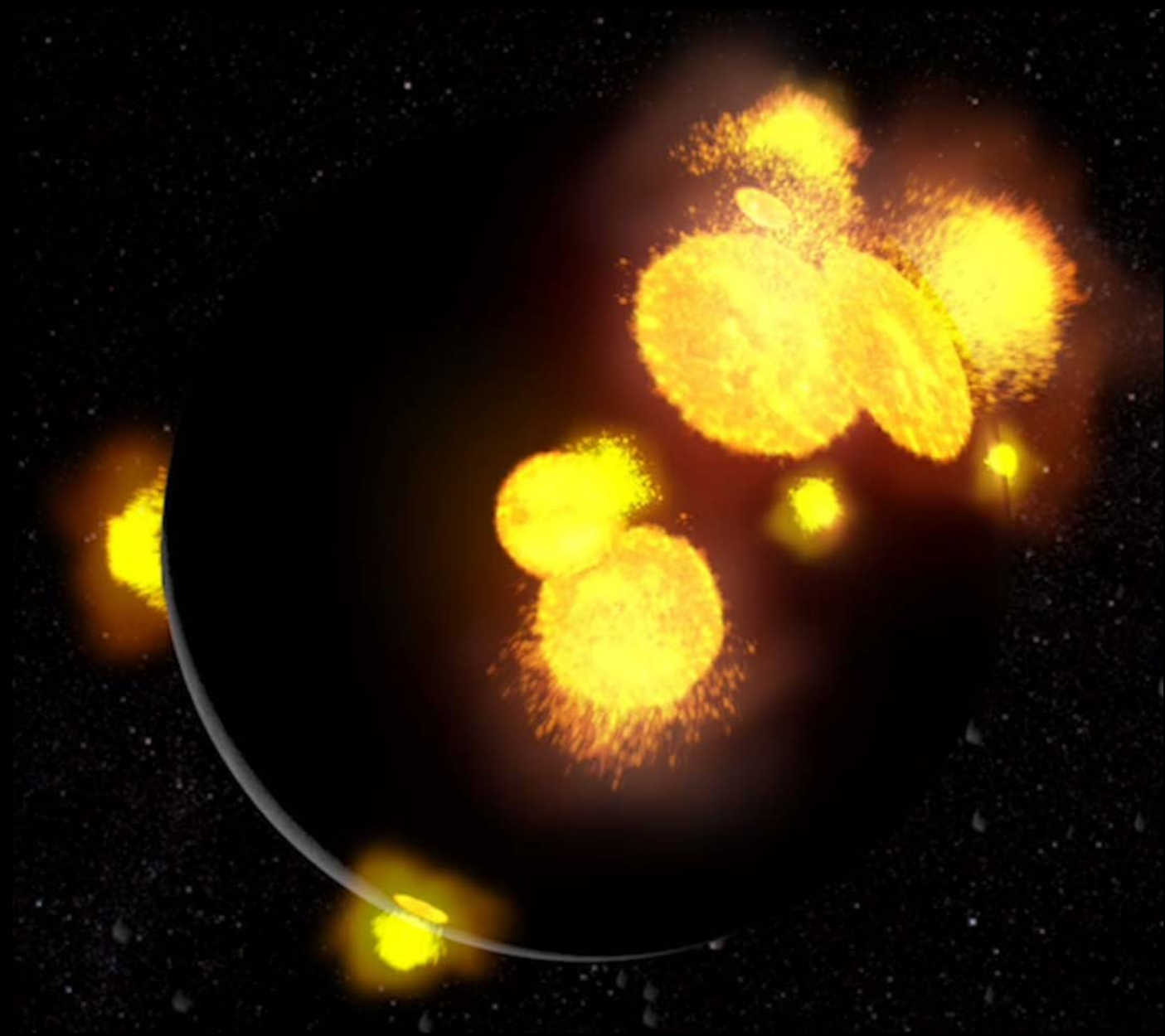
Average Daytime Temperature at the Lunar South Pole



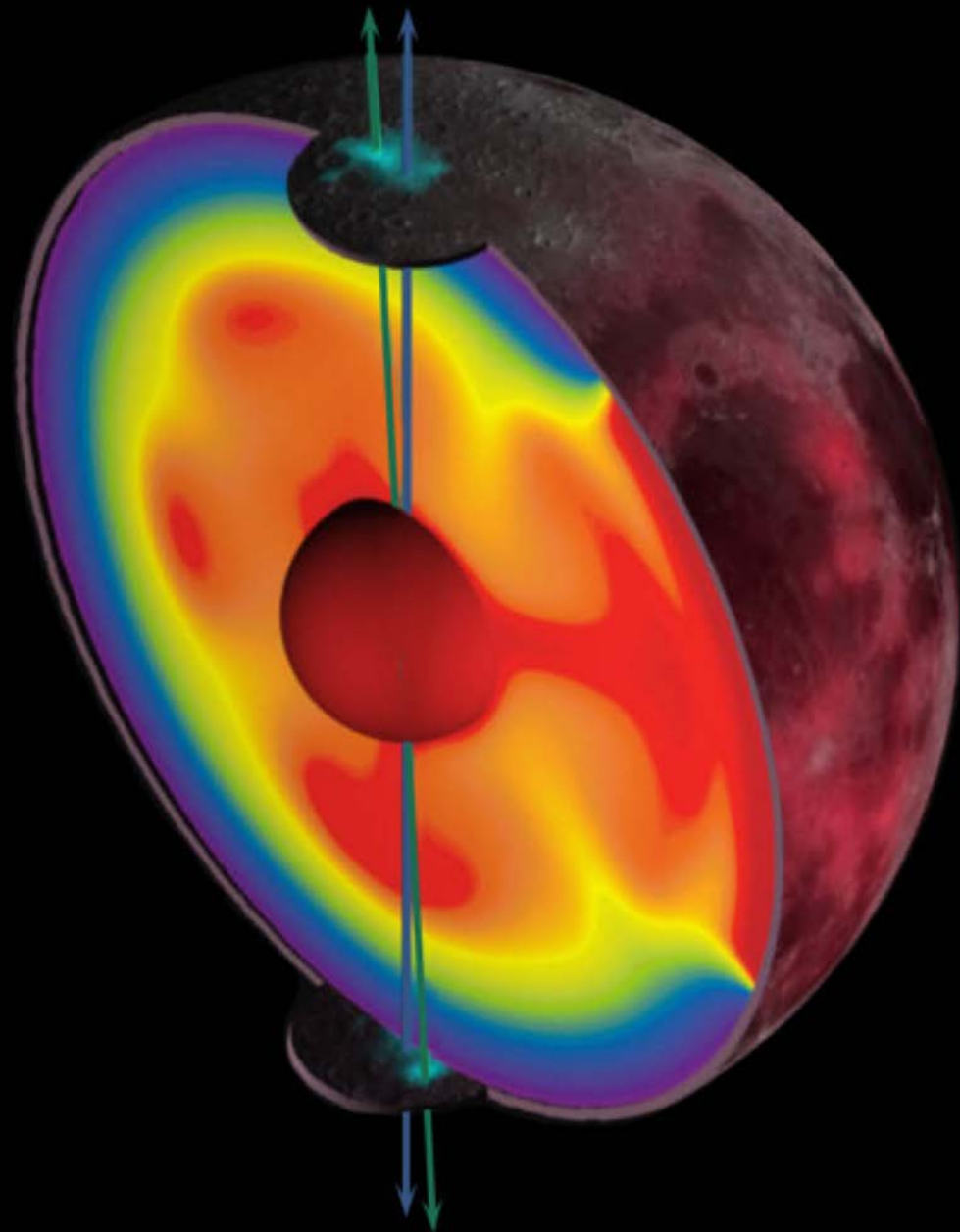


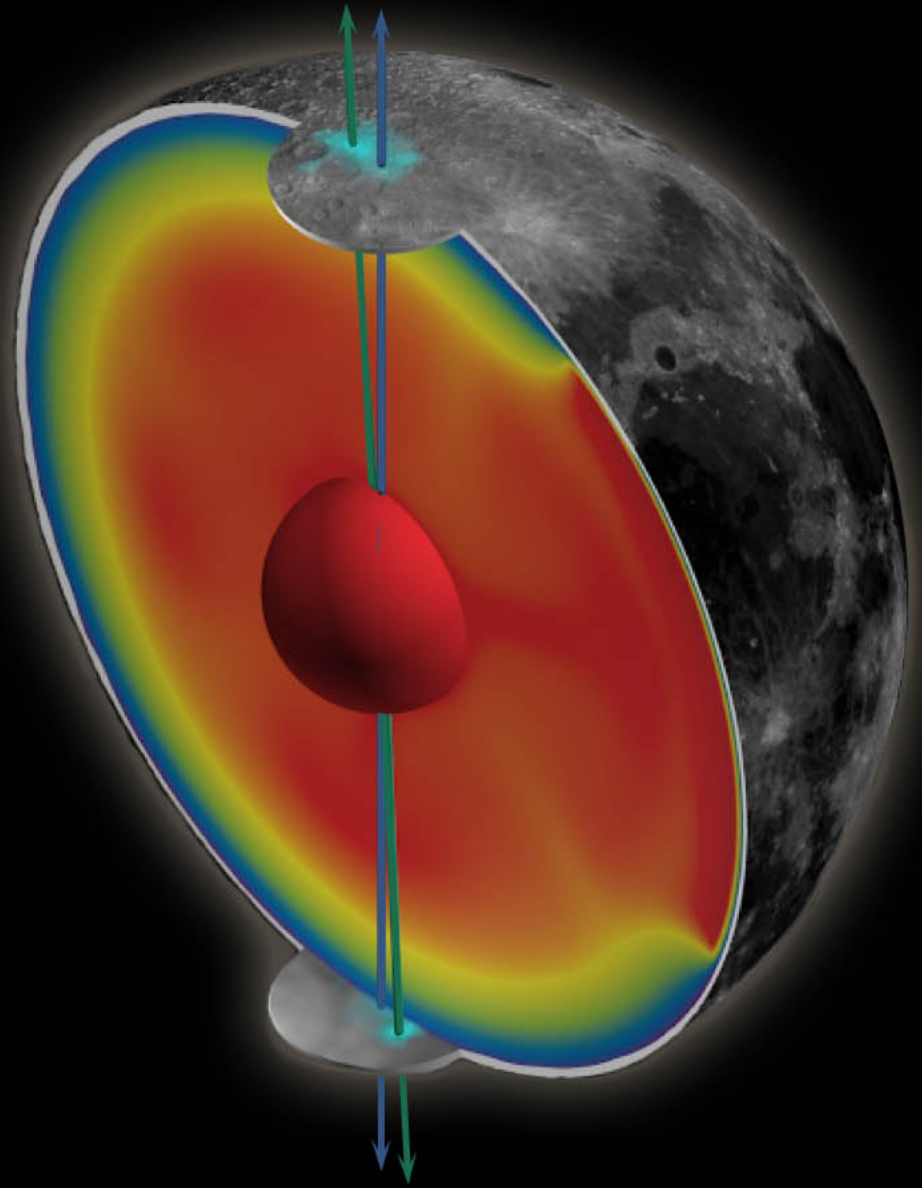
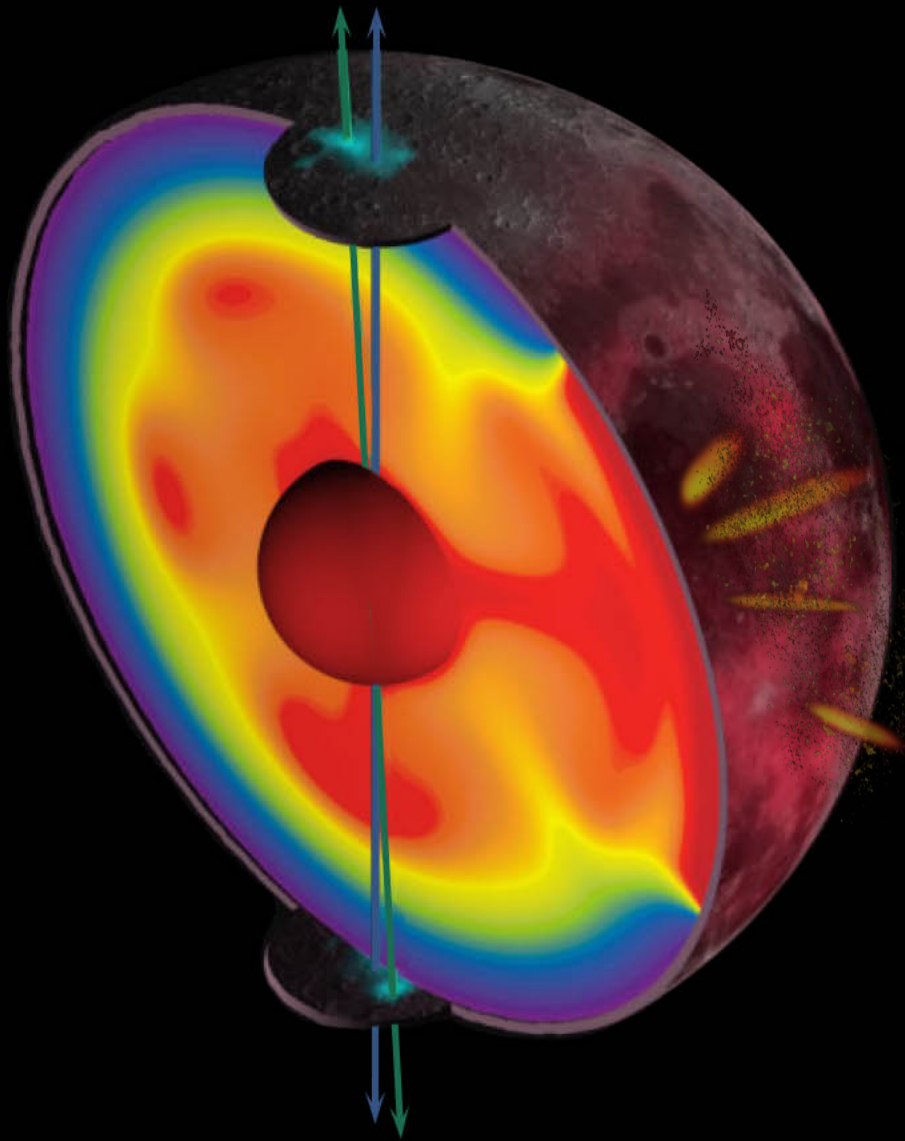
# Lunar Polar Water





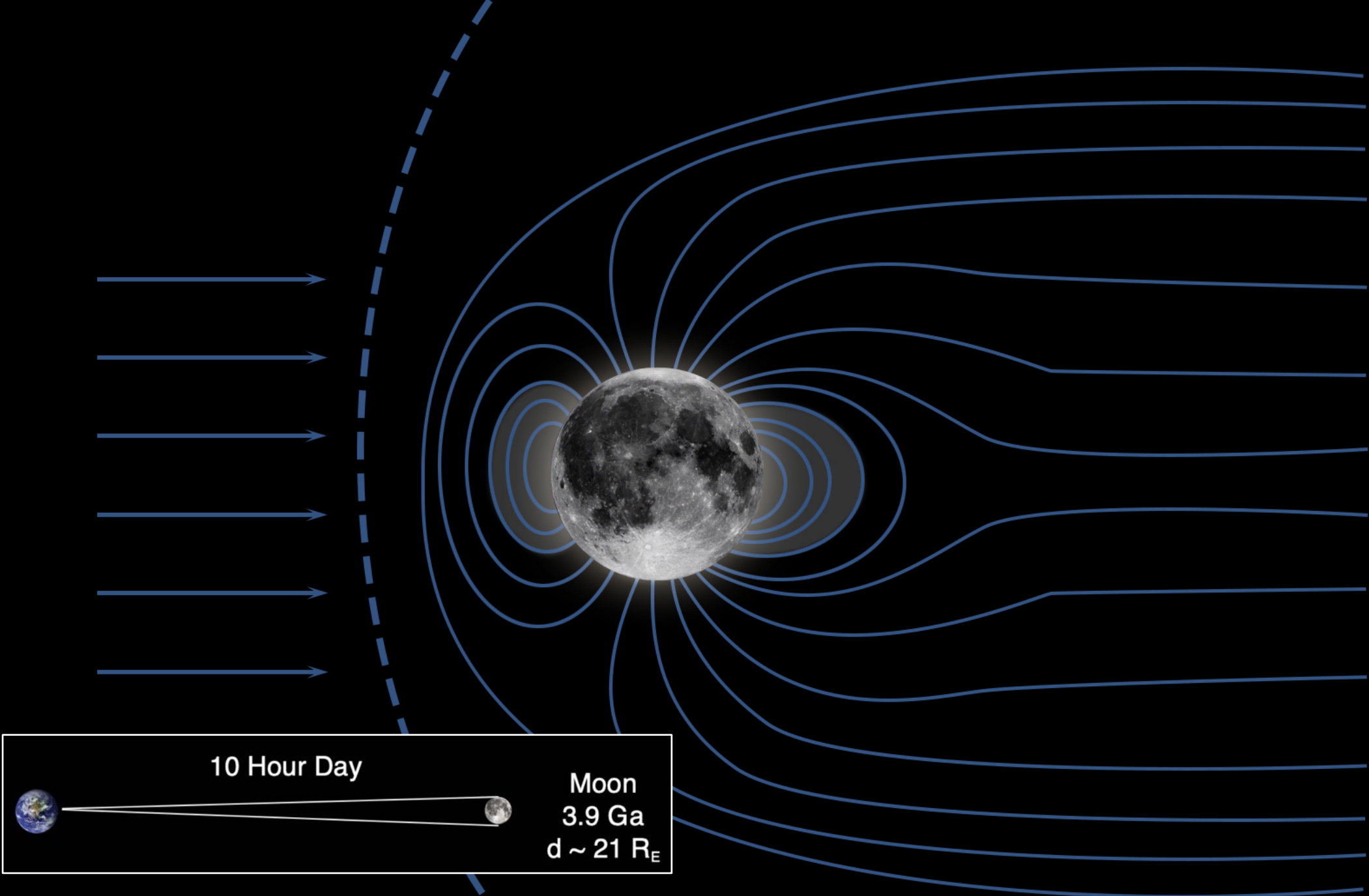




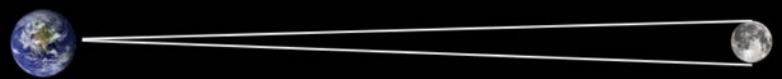








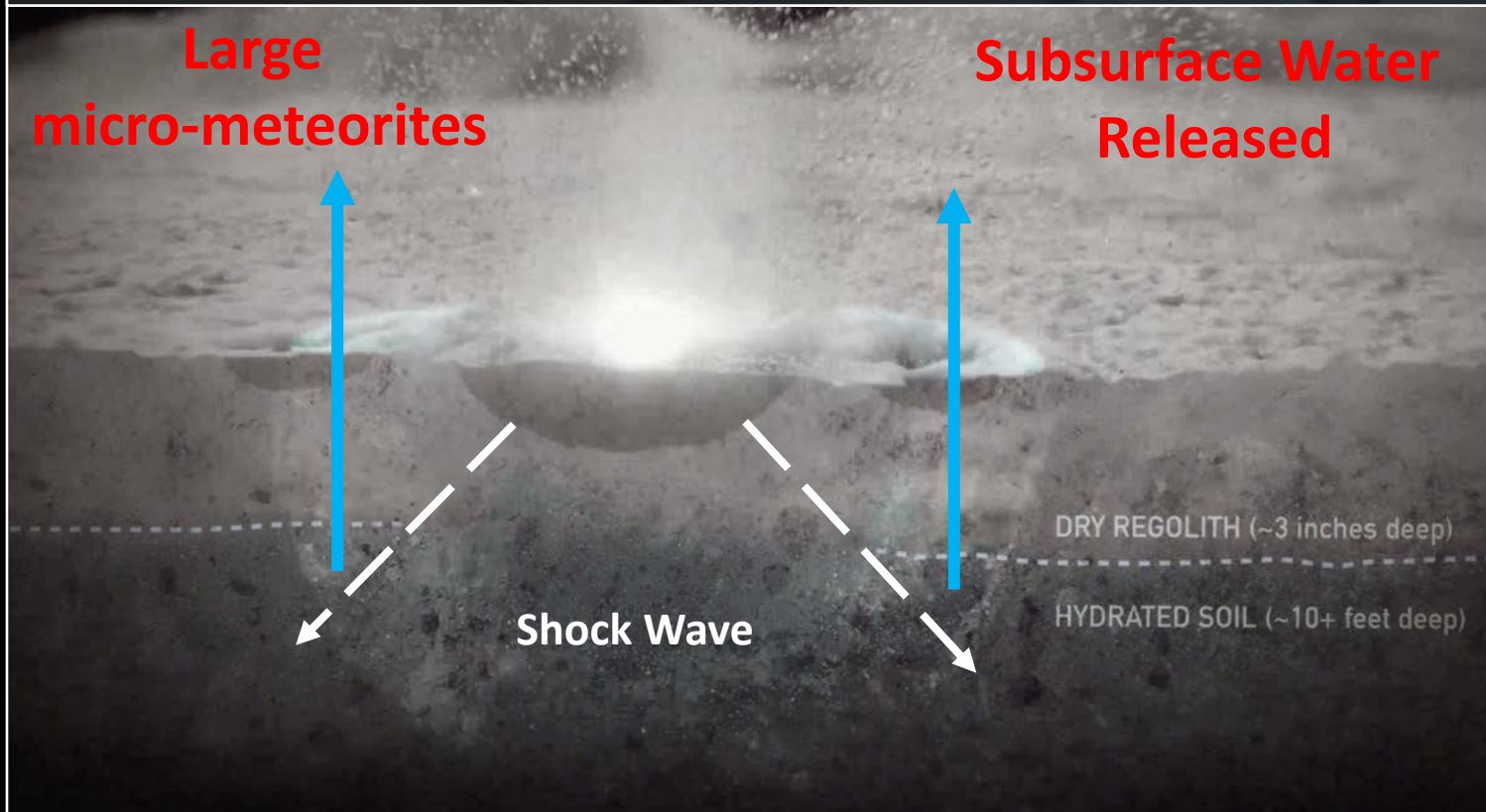
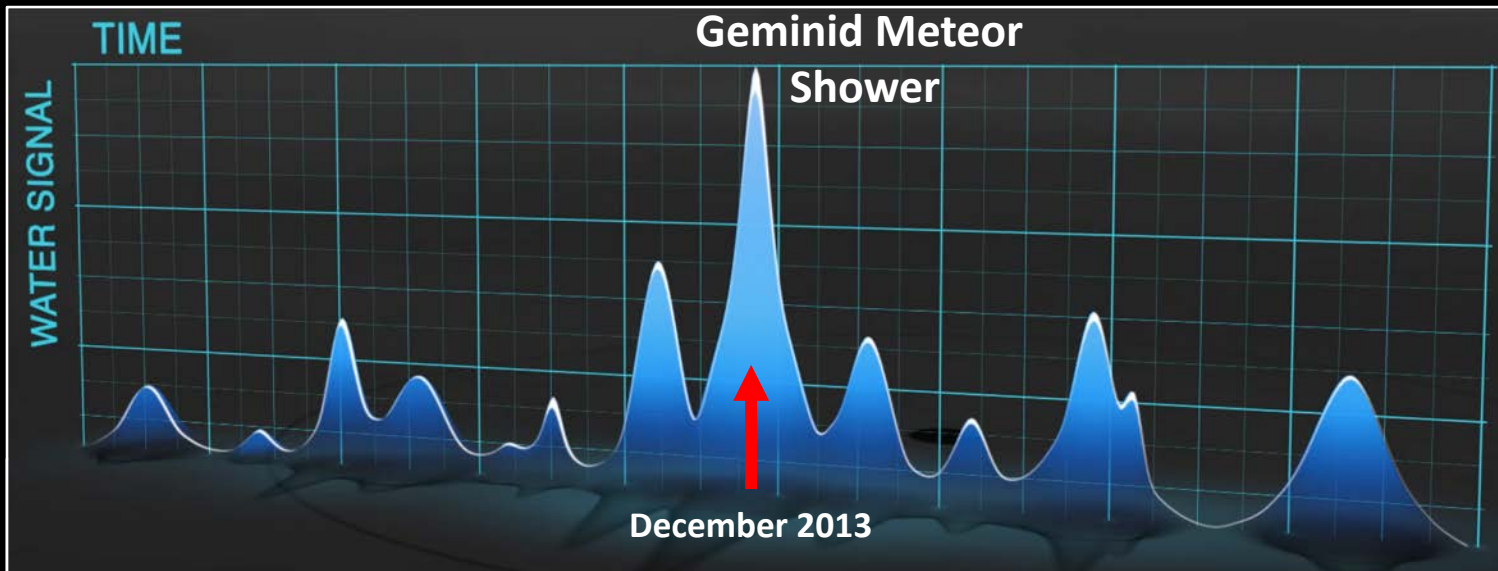
10 Hour Day



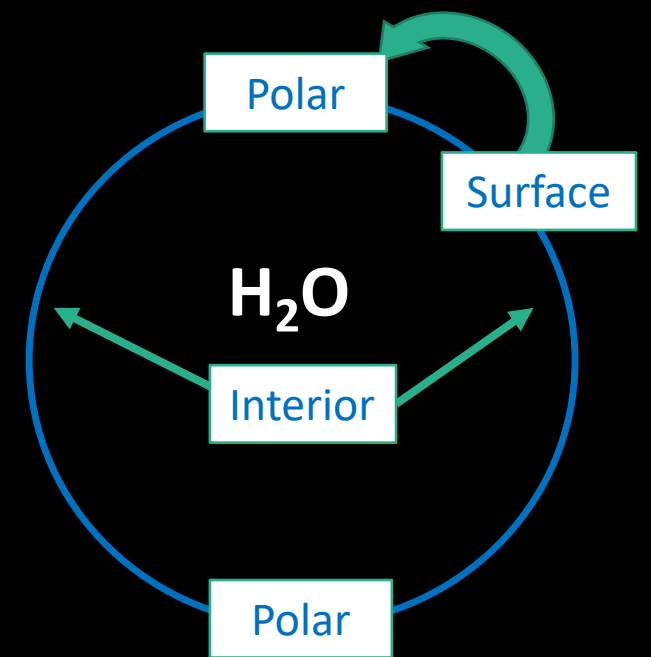
Moon  
3.9 Ga  
d ~ 21 R<sub>E</sub>



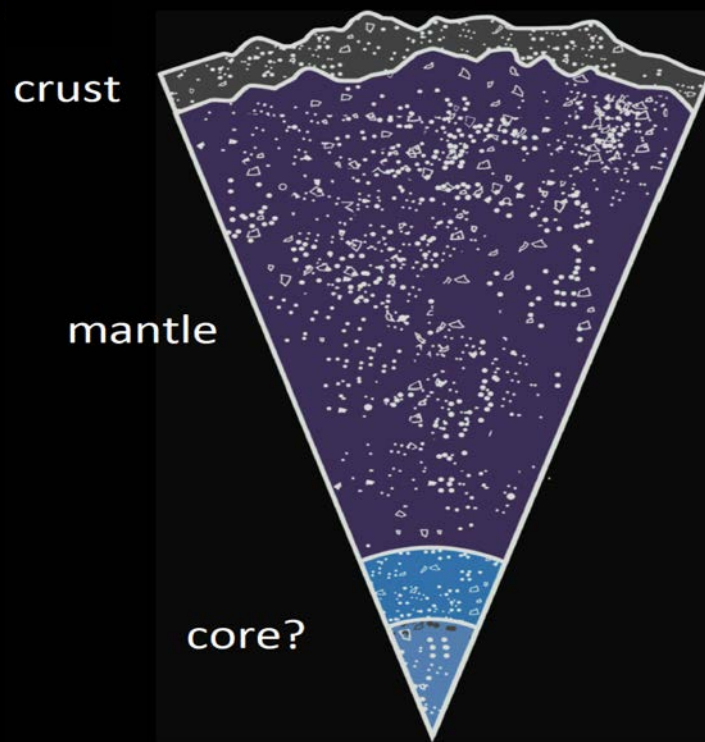
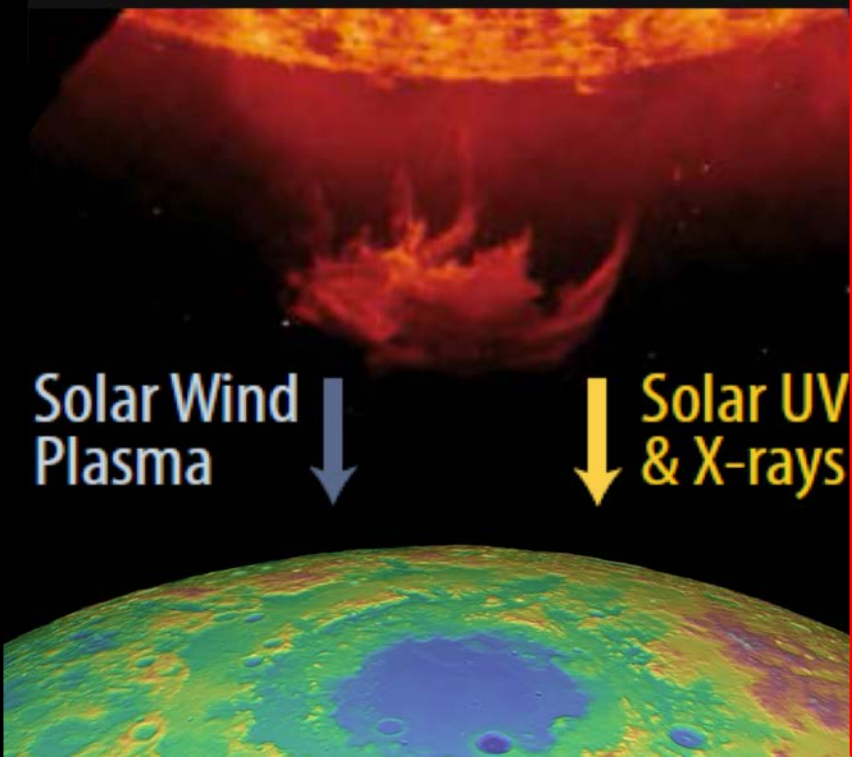
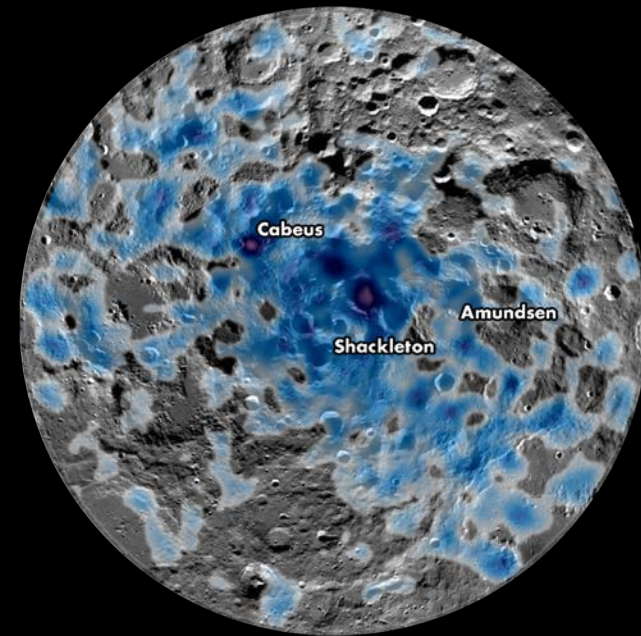
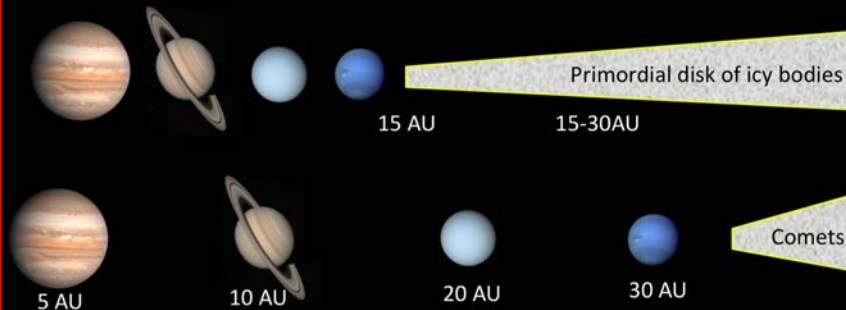
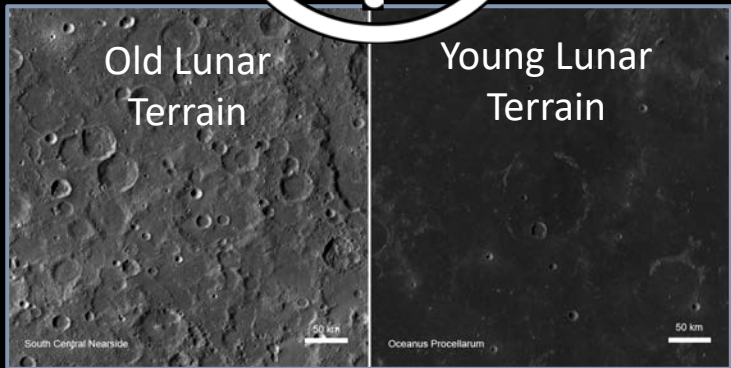




# Water Released During Meteor Showers







# 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.

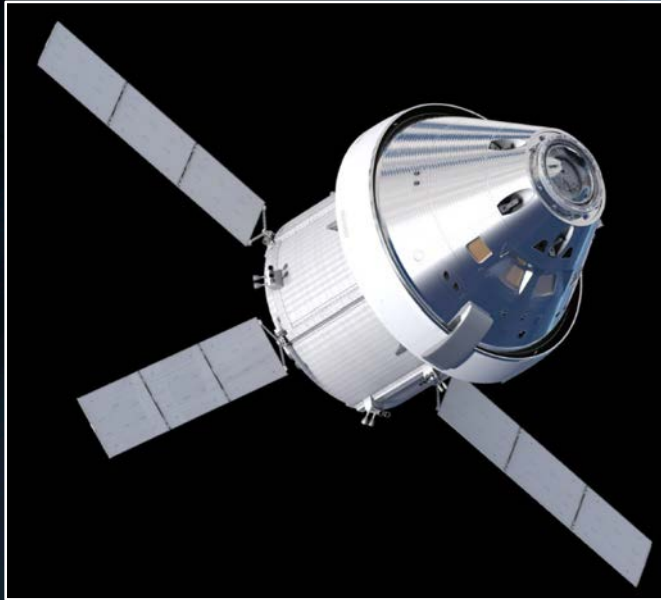
**snc** (SNC ORBITAL SERVICES CORPORATION) | **PARAGON** | **NANORACKS** | **ODYSSEY** (SPACE SYSTEMS)

**Masten Space Systems**



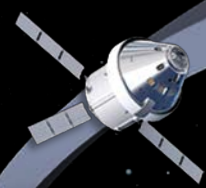
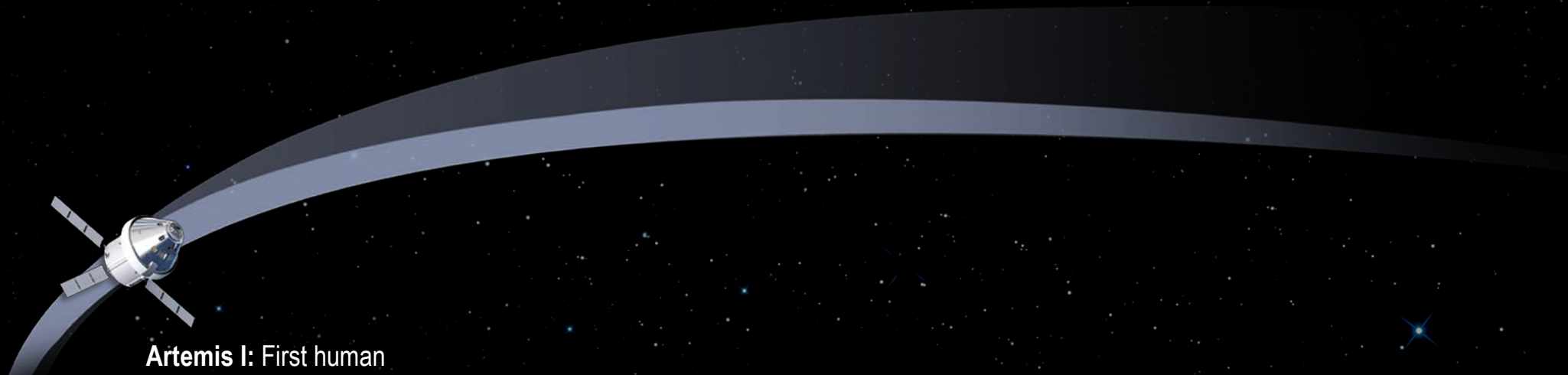
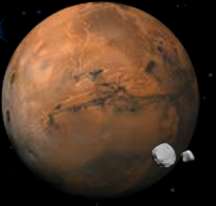
# The Power of SLS and Orion

## 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)

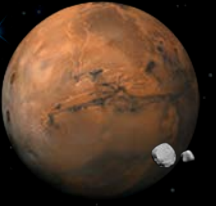
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

**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)

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

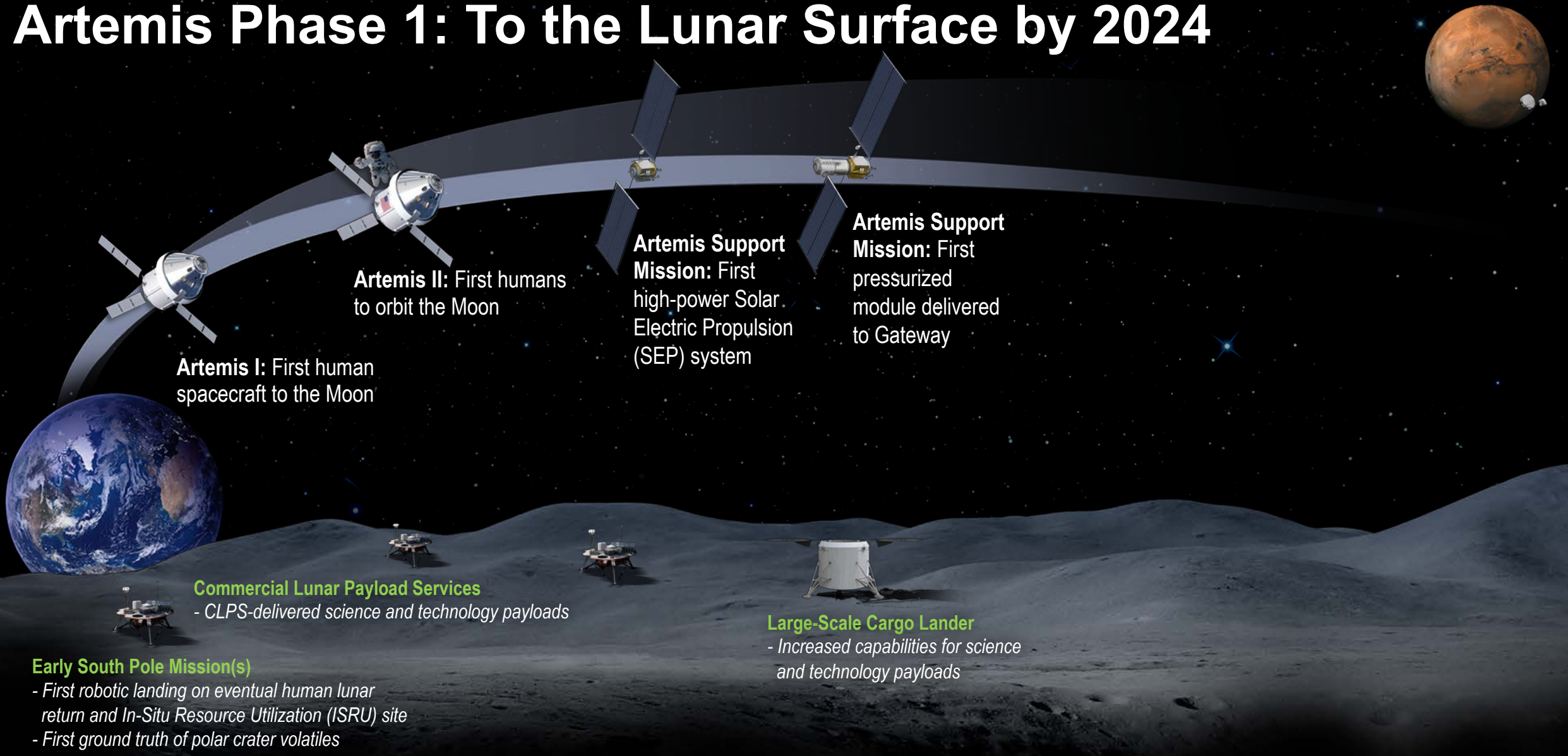
**LUNAR SOUTH POLE TARGET SITE**

**2020**

**2024**



# Artemis Phase 1: To the Lunar Surface by 2024

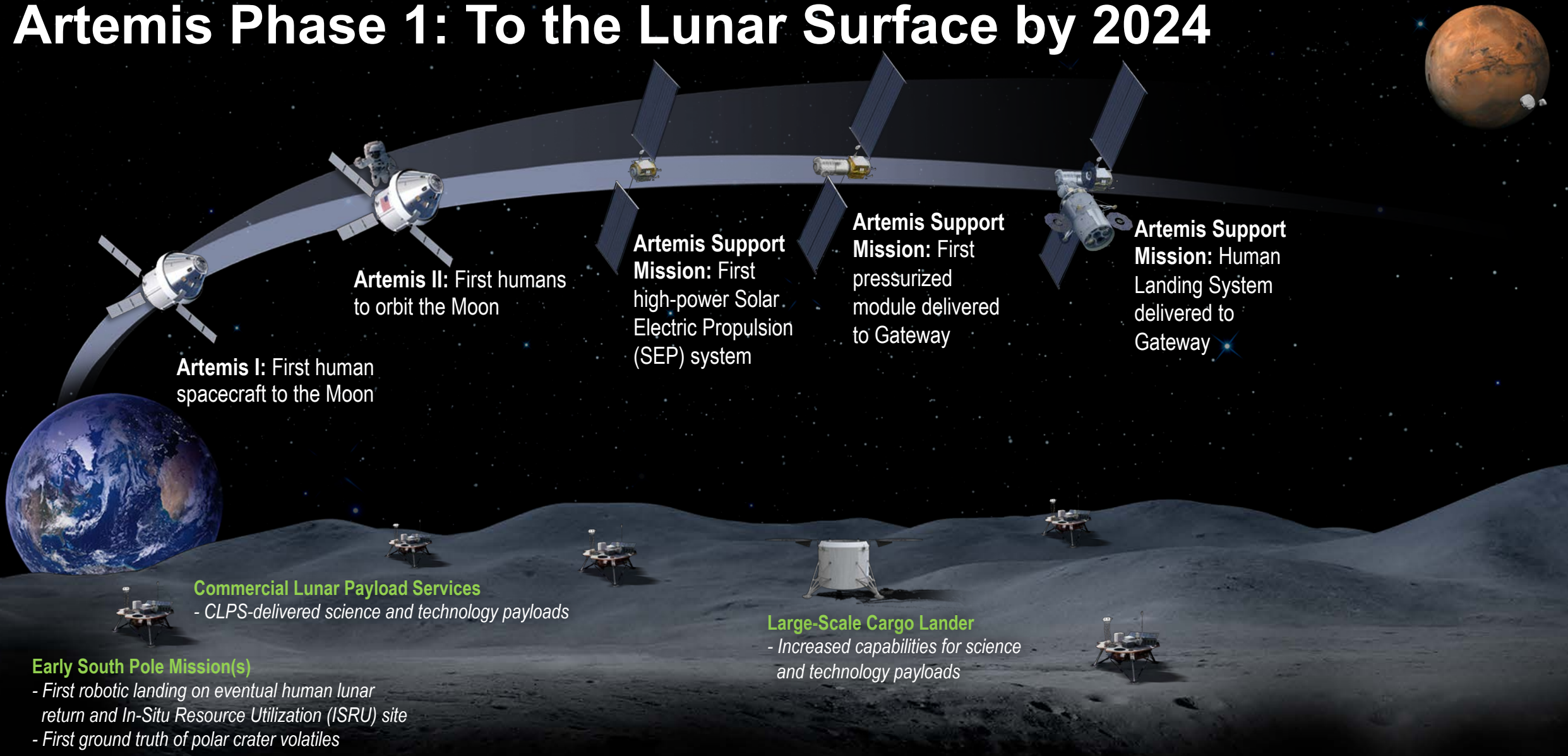


**LUNAR SOUTH POLE TARGET SITE**

**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

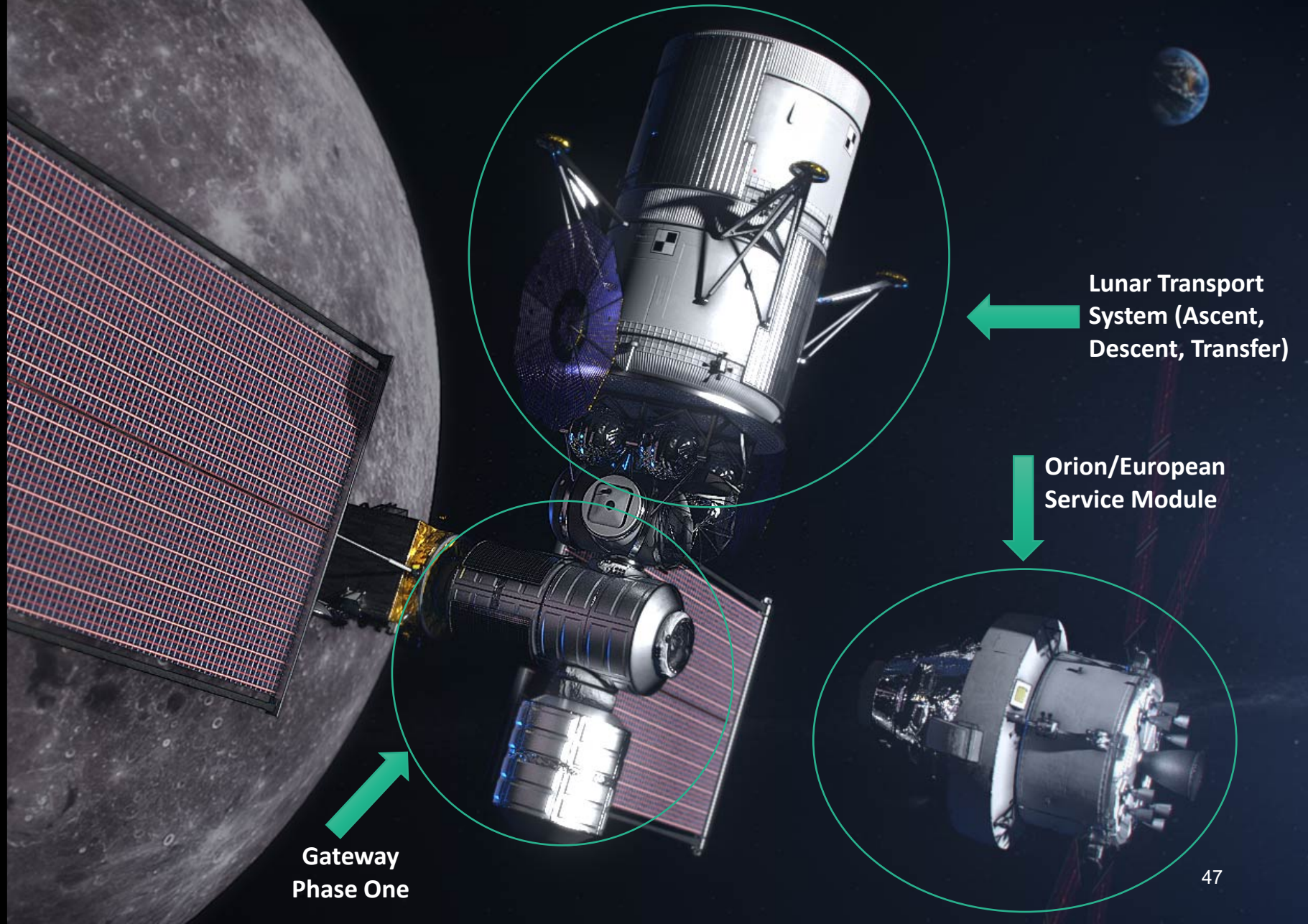
- Increased capabilities for science and technology payloads

## LUNAR SOUTH POLE TARGET SITE



# Gateway is Essential for 2024 Landing

Six Days to Orbit the Moon

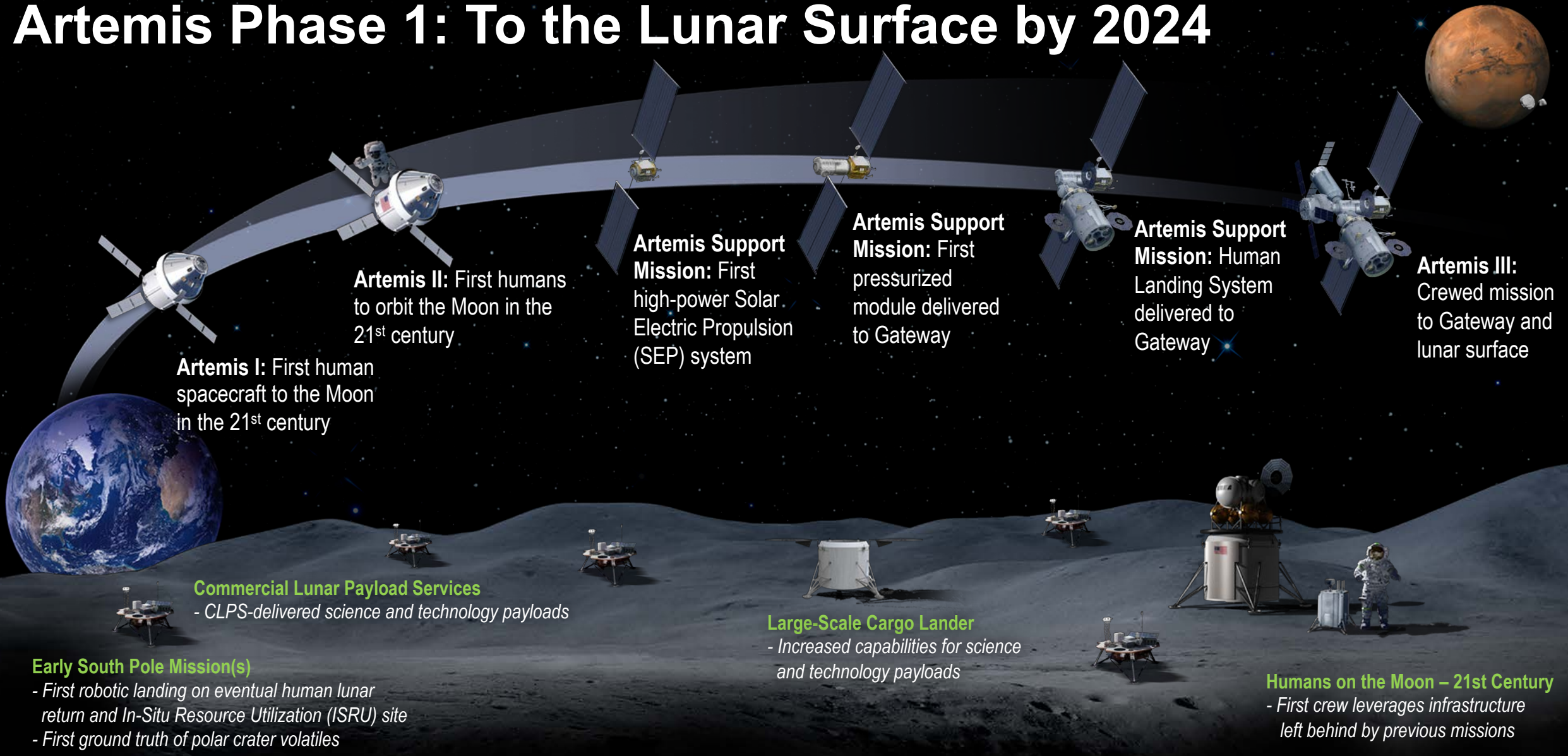


Lunar Transport System (Ascent, Descent, Transfer)

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 21<sup>st</sup> century

**Artemis II:** First humans to orbit the Moon in the 21<sup>st</sup> 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

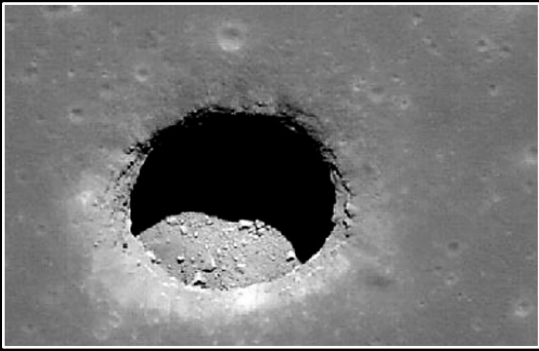
## LUNAR SOUTH POLE TARGET SITE

2020

2024



## Science & Exploration



## Living off the Land



## Multi-planet Species



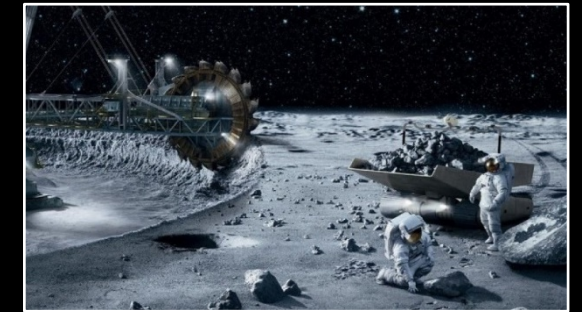
# Future Moon



## Fuel Depot



## Mining

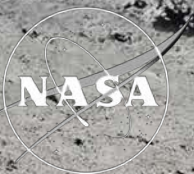


## Manufacturing





QUESTIONS?







# GRAVITY ASSIST



Podcast



[www.nasa.gov/podcasts](http://www.nasa.gov/podcasts)

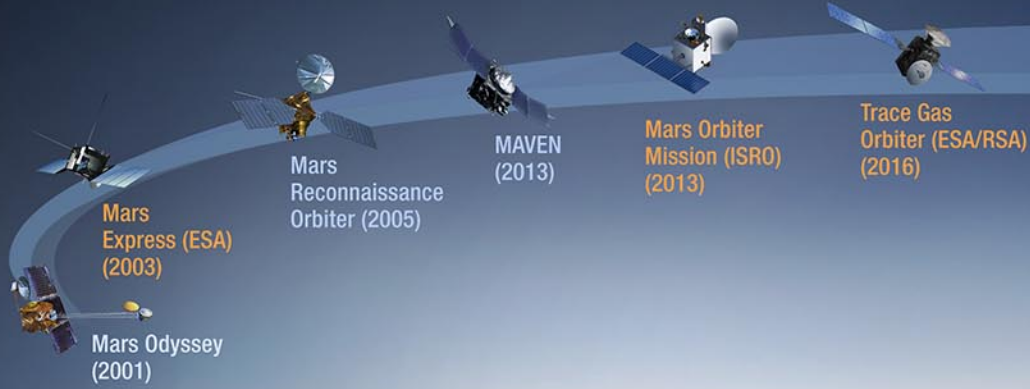




# MARS MISSIONS

OPERATIONAL 2001–2019

2020 AND BEYOND



Curiosity Rover (2011)



InSight



Mars Lander & Rover (China)



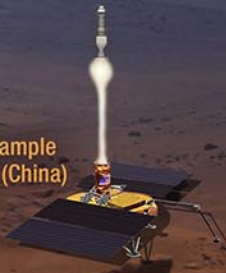
Mars 2020 Rover (NASA)



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



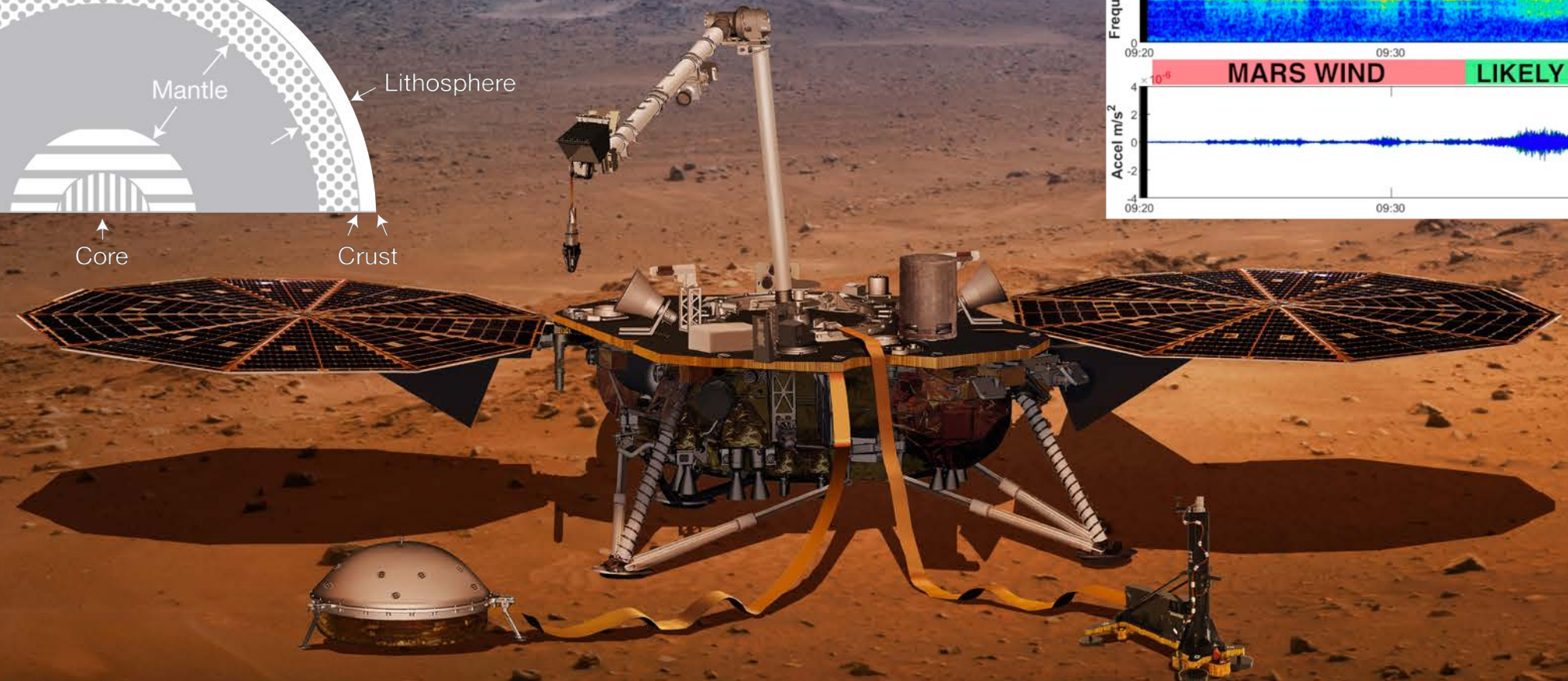
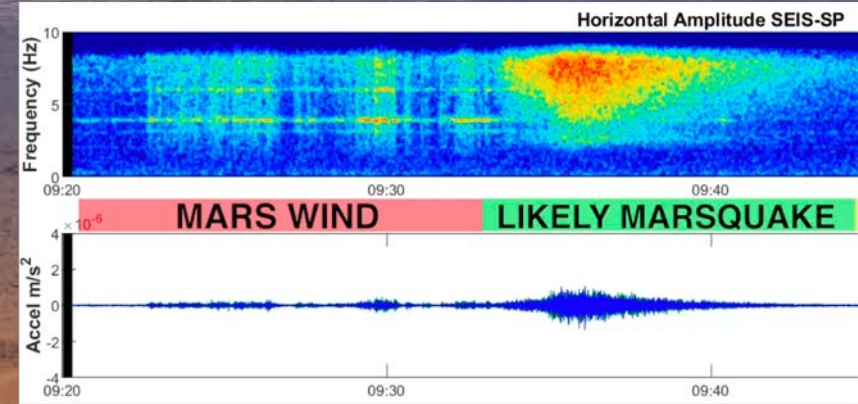
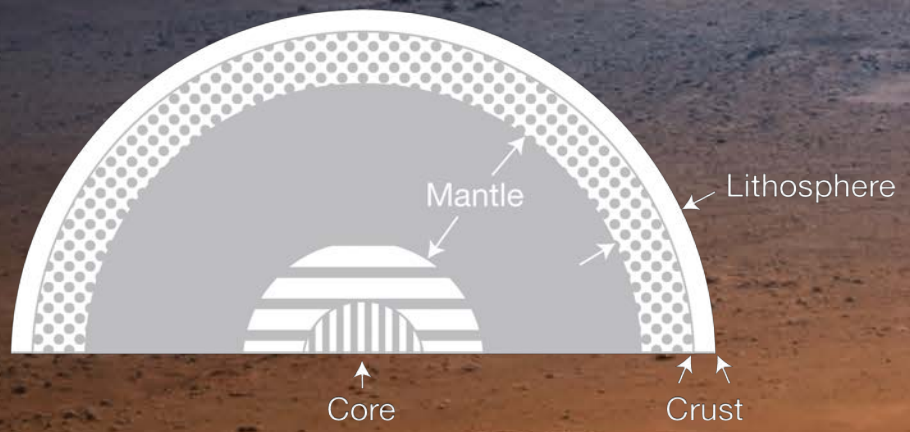
# An Ancient Habitable Environment

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)

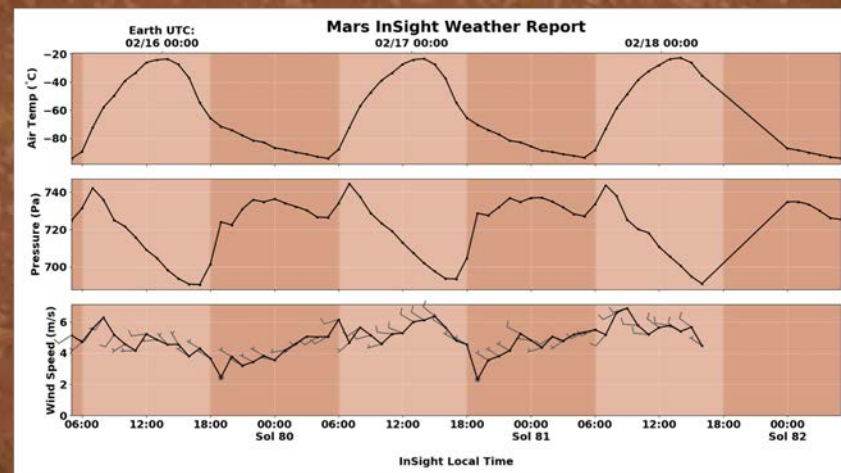


Landed on Nov 26, 2018



# 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

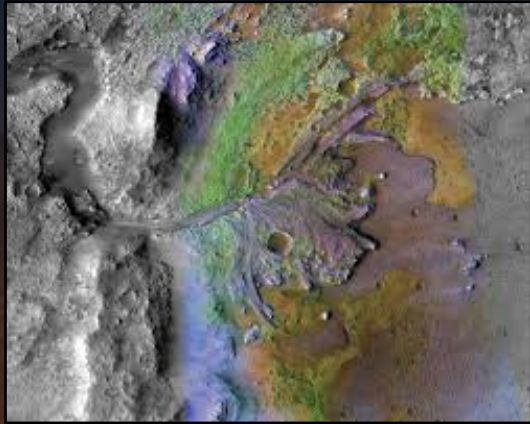
Feb. 17

High: 2° F  
Low: -138° F

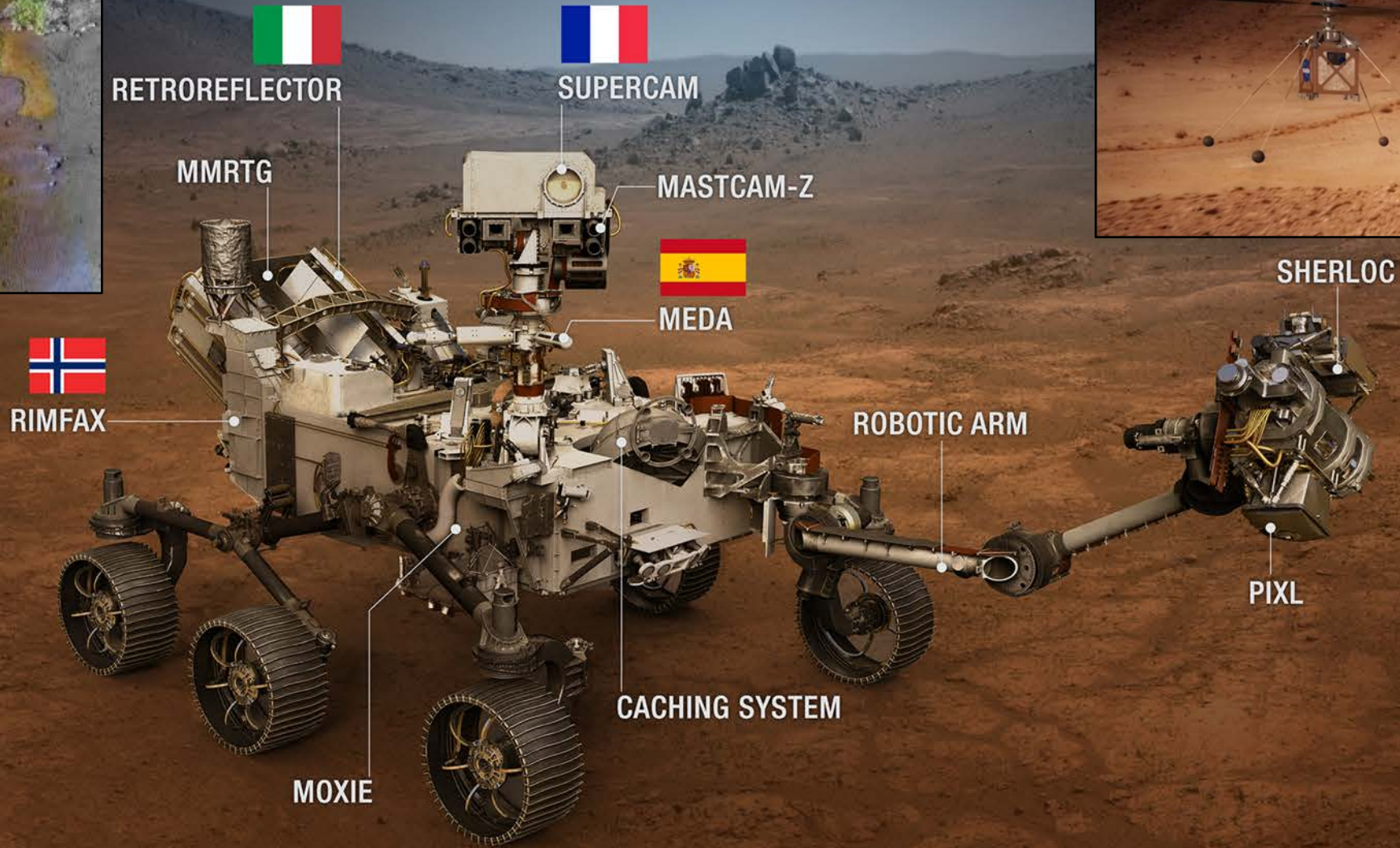
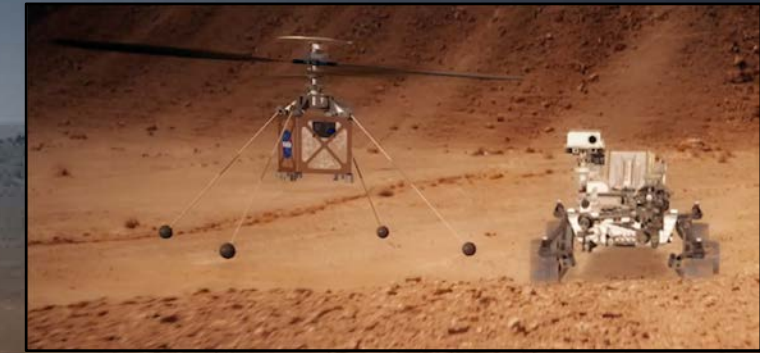


# Seeking Signs of Life: Mars 2020 Rover

Jezero Crater



Mars Helicopter



RETROREFLECTOR

SUPERCAM

MMRTG

MASTCAM-Z

MEDA

RIMFAX

ROBOTIC ARM

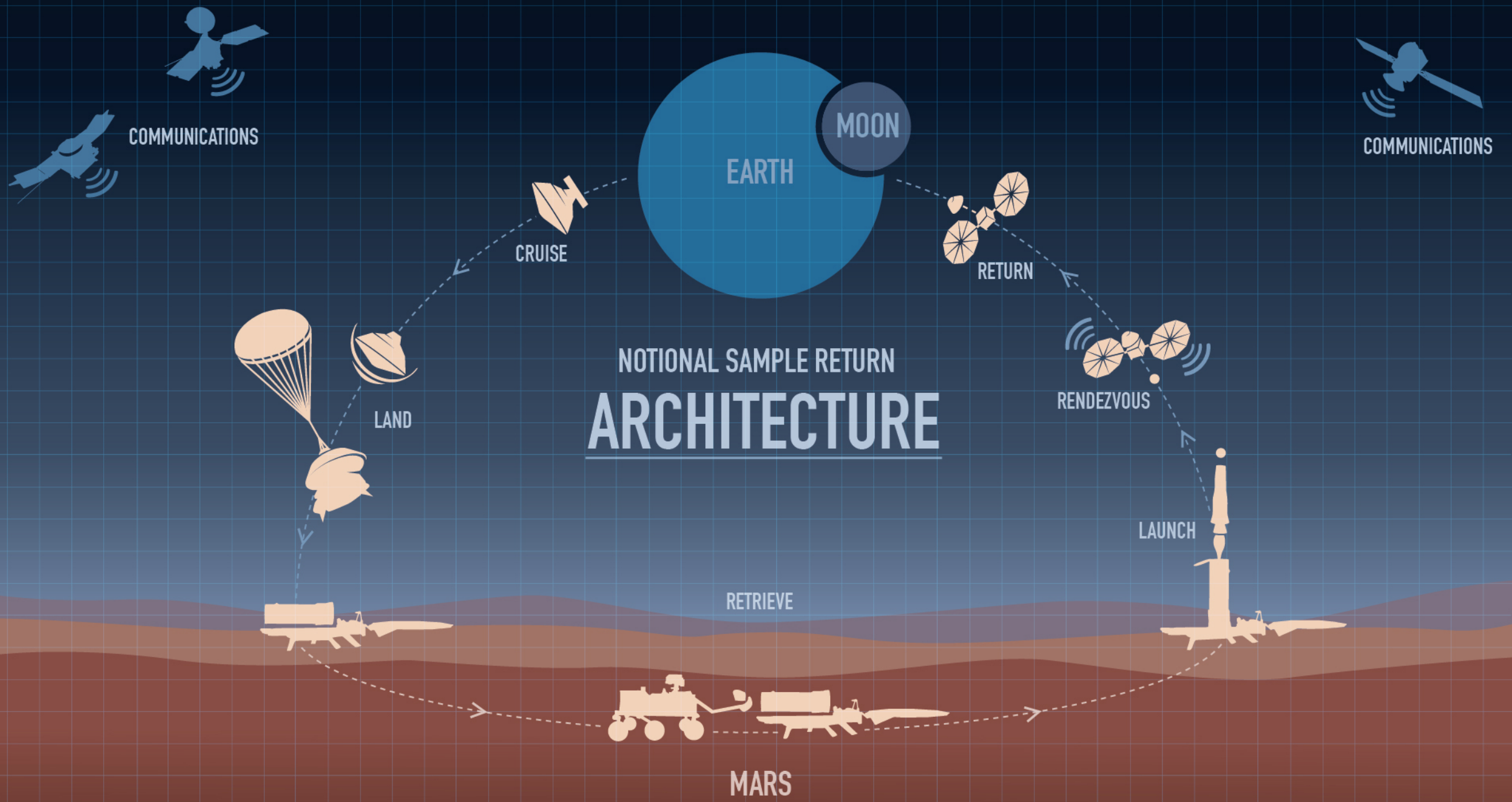
SHERLOC

PIXL

MOXIE

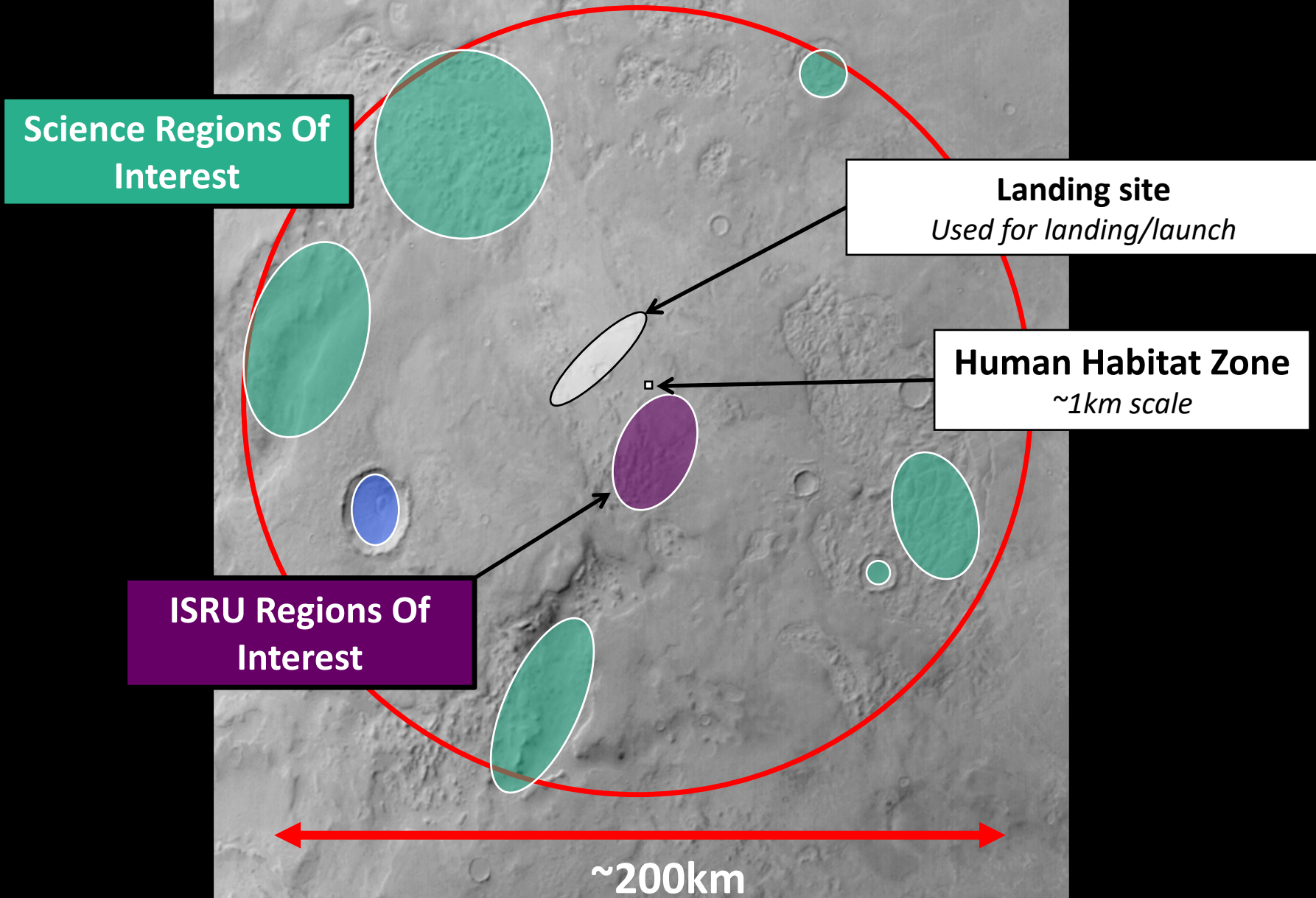
CACHING SYSTEM





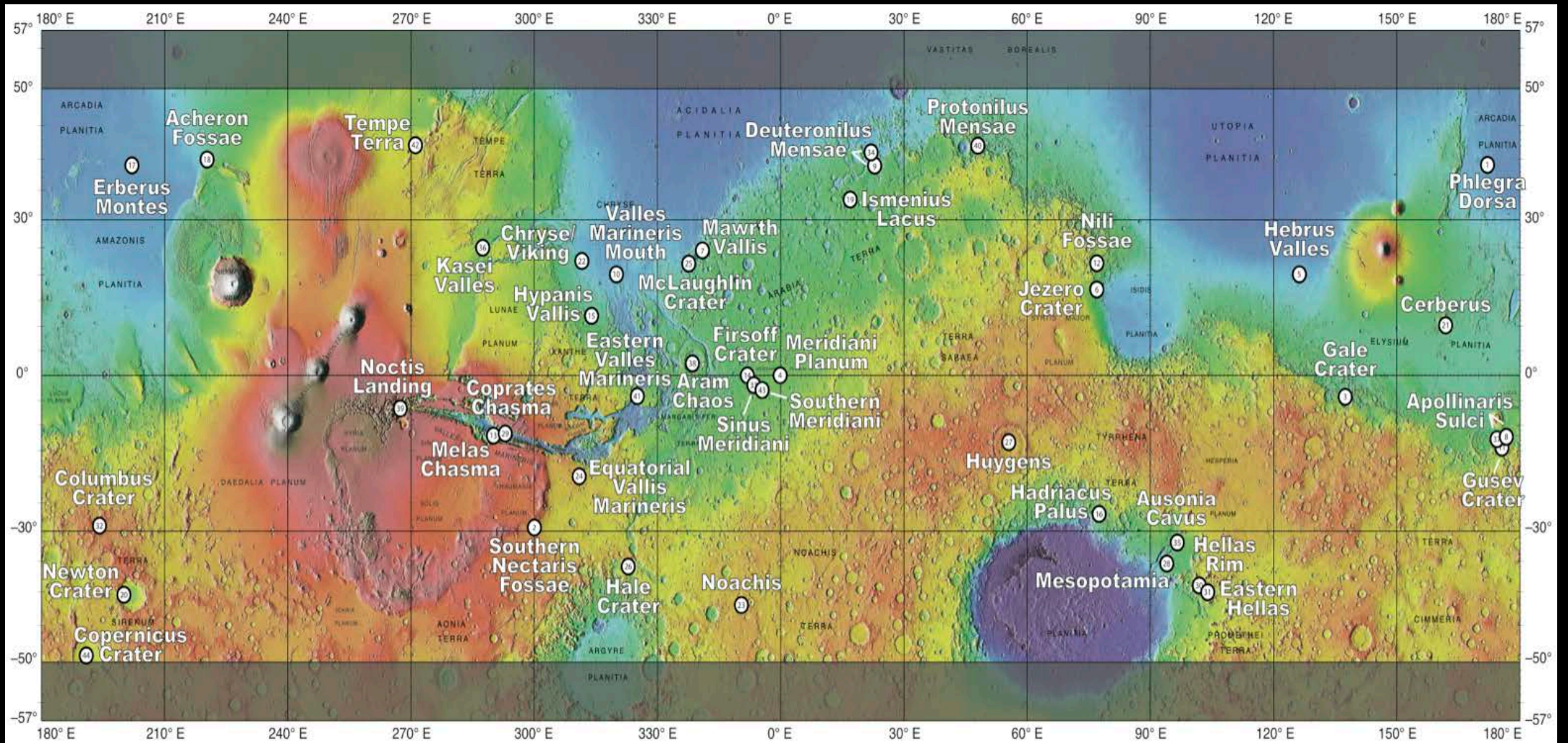
# NOTIONAL SAMPLE RETURN ARCHITECTURE

# Human Exploration Zone





# Potential Exploration Zones



1<sup>st</sup> 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



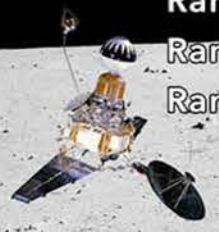
Lunar  
Lunar

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

...

1961

1962

1963

1964

1965

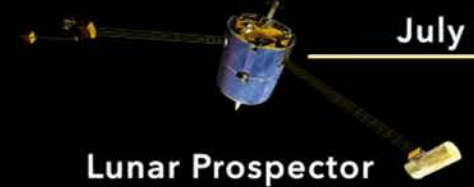
1966



Hitan



Clementine



Lunar Prospector

July 1999



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1990

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1994

...

1997

1998

...

SM