

National Aeronautics and  
Space Administration



# The Future of Lunar Exploration

EXPLORESCIENCE

David S. Draper, Ph.D.  
NASA Deputy Chief Scientist

UNOOSA World Space Forum  
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# Outline

National Aeronautics and  
Space Administration



## Two previous eras of lunar exploration

"Space Race" era: Apollo, Luna

Robotic era: 1990s – 2010s

## Return to the Moon

Polar volatiles and permanently shadowed regions

Resources to "live off the land"

## NASA's Artemis Program

Mandate for crewed landing in 2024

Sustainable presence with international and commercial partners

Learn to live & work off-world in preparation for missions to Mars



Flight Test and Flyby Missions



Luna 1



Ranger 1  
Ranger 2

Luna 4



Zond 3



Pioneer 4

Orbiters



Luna 3



Lunar  
Lunar

Landers and Impacts



Luna 2

Ranger 3

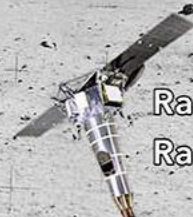
Ranger 4

Ranger 5



Ranger 6

Ranger 7



Luna 5

Luna 6

Luna 7

Luna 8



Ranger 8

Ranger 9



1959

...

1961

1962

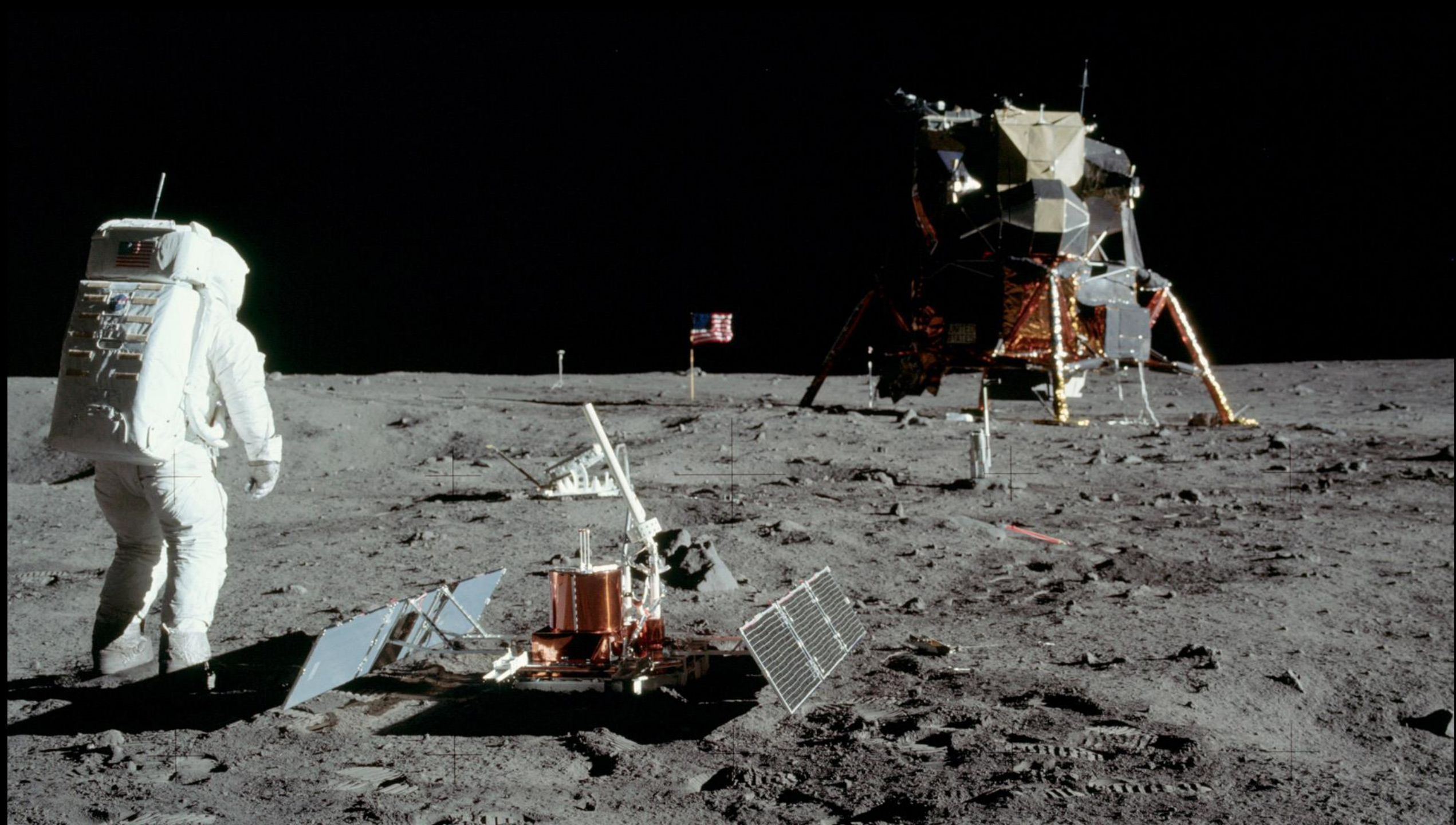
1963

1964

1965

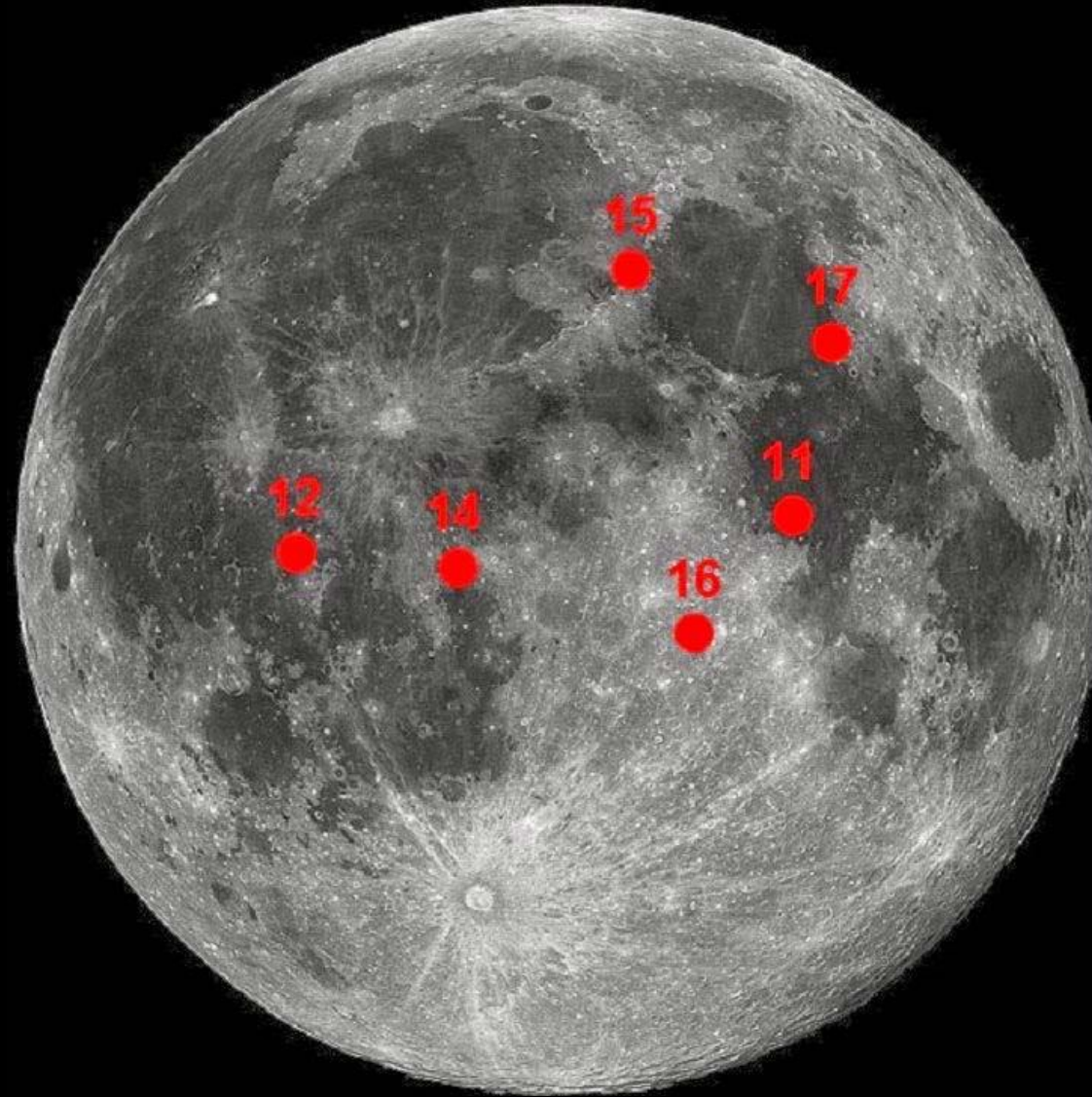
1966







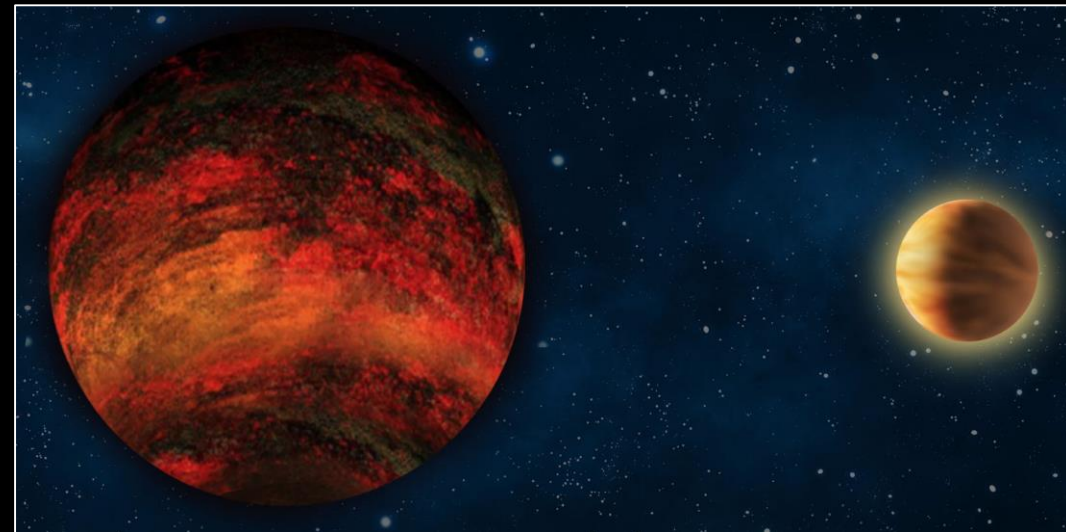
# Apollo Lunar Exploration Program





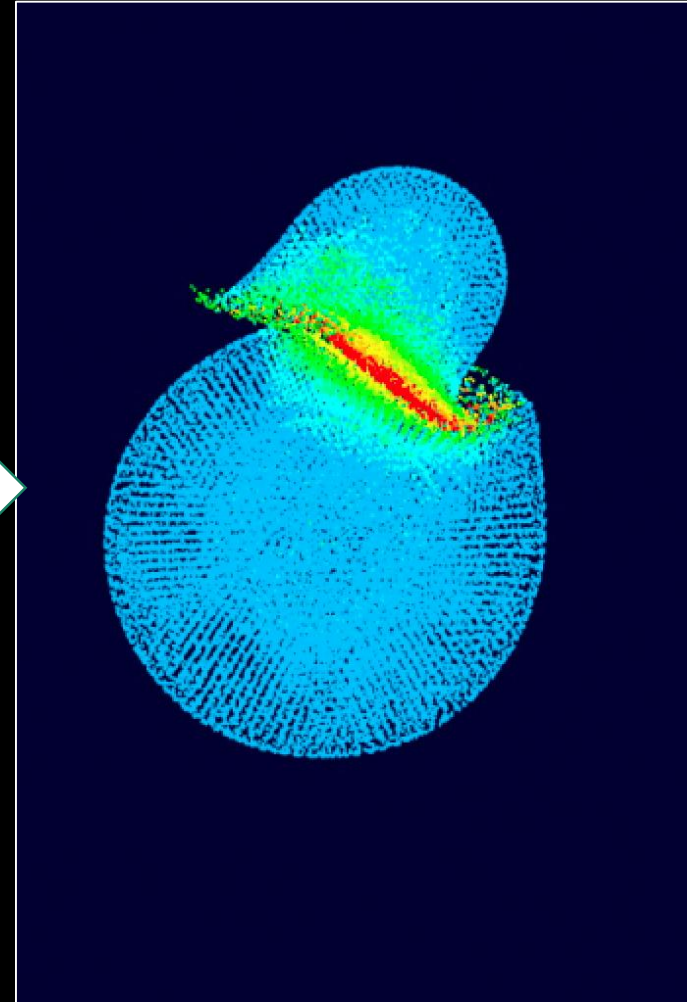
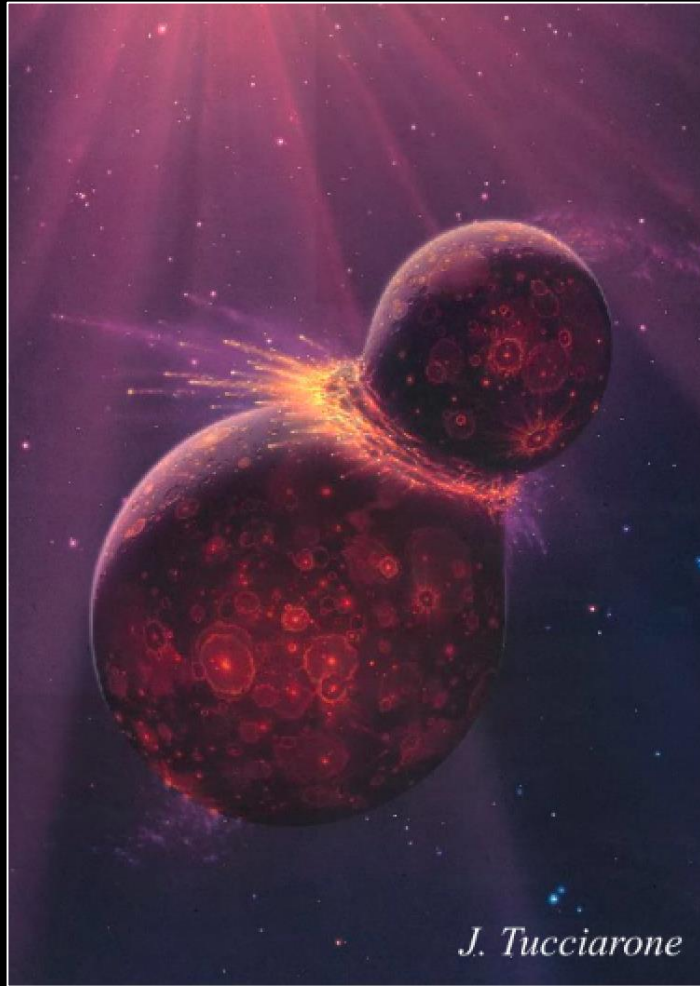
# What did the Apollo Missions Tell us?

- The Moon is old ( $\sim 4.6$  Ga)
- Moon moves away from Earth  $\sim 3$  cm/yr
- Isotopic analysis shows Moon and Earth have crucial compositional similarities
- Early Moon was molten: magma ocean cooled to form the crust
  - Giant Impact Hypothesis
  - Earth was molten too!
- Impact cratering is an important geologic process – history preserved on the Moon
- Volcanic activity occurred  $\sim 4.2$ - $3.16$  Ga





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



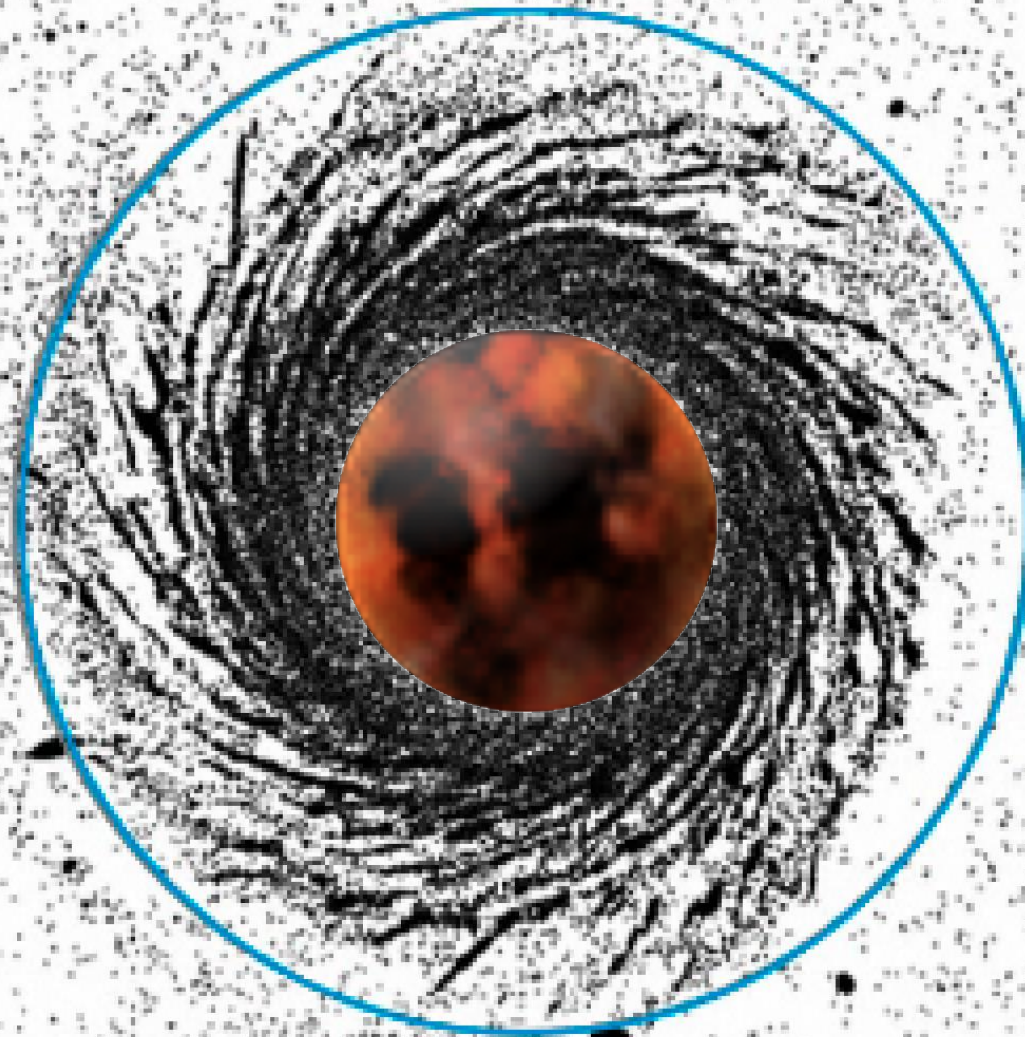
Giant impact hypothesis for origin of Moon







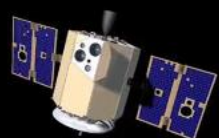
# Roche limit



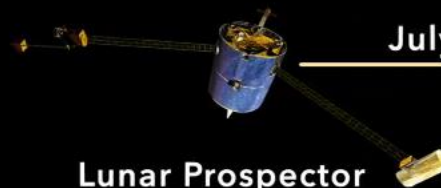




Hitan



Clementine



July 1999

Lunar Prospector



SM



...

1990

...

1994

...

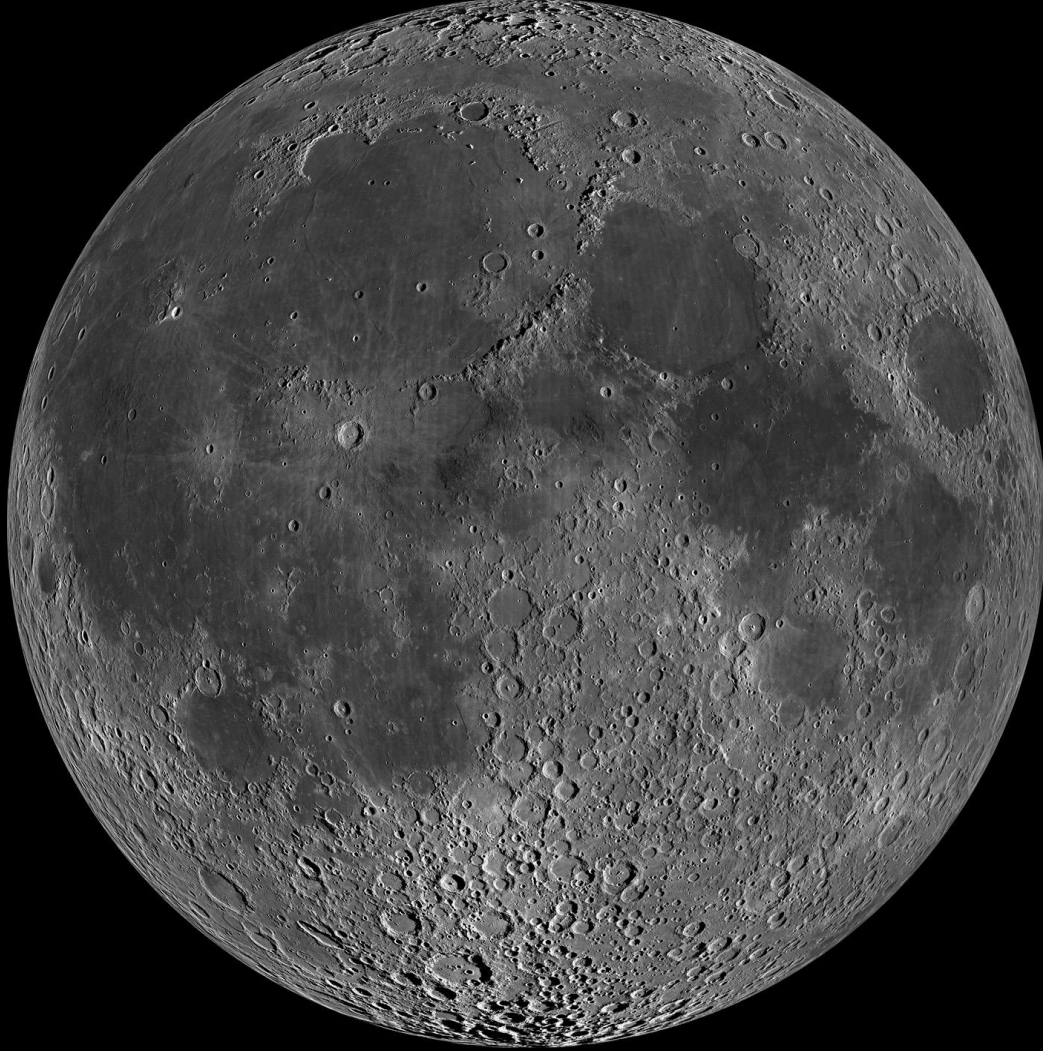
1997

1998

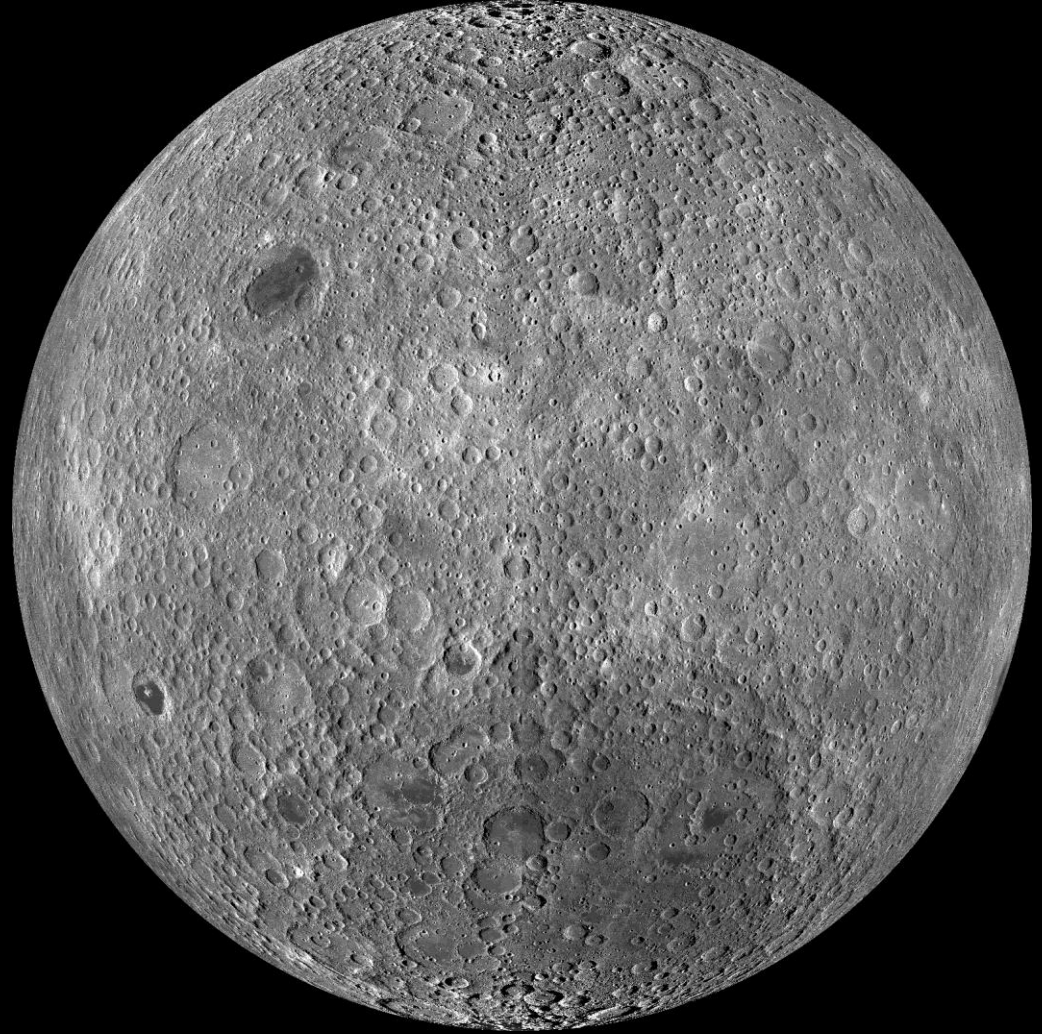
...



Nearside



Farside



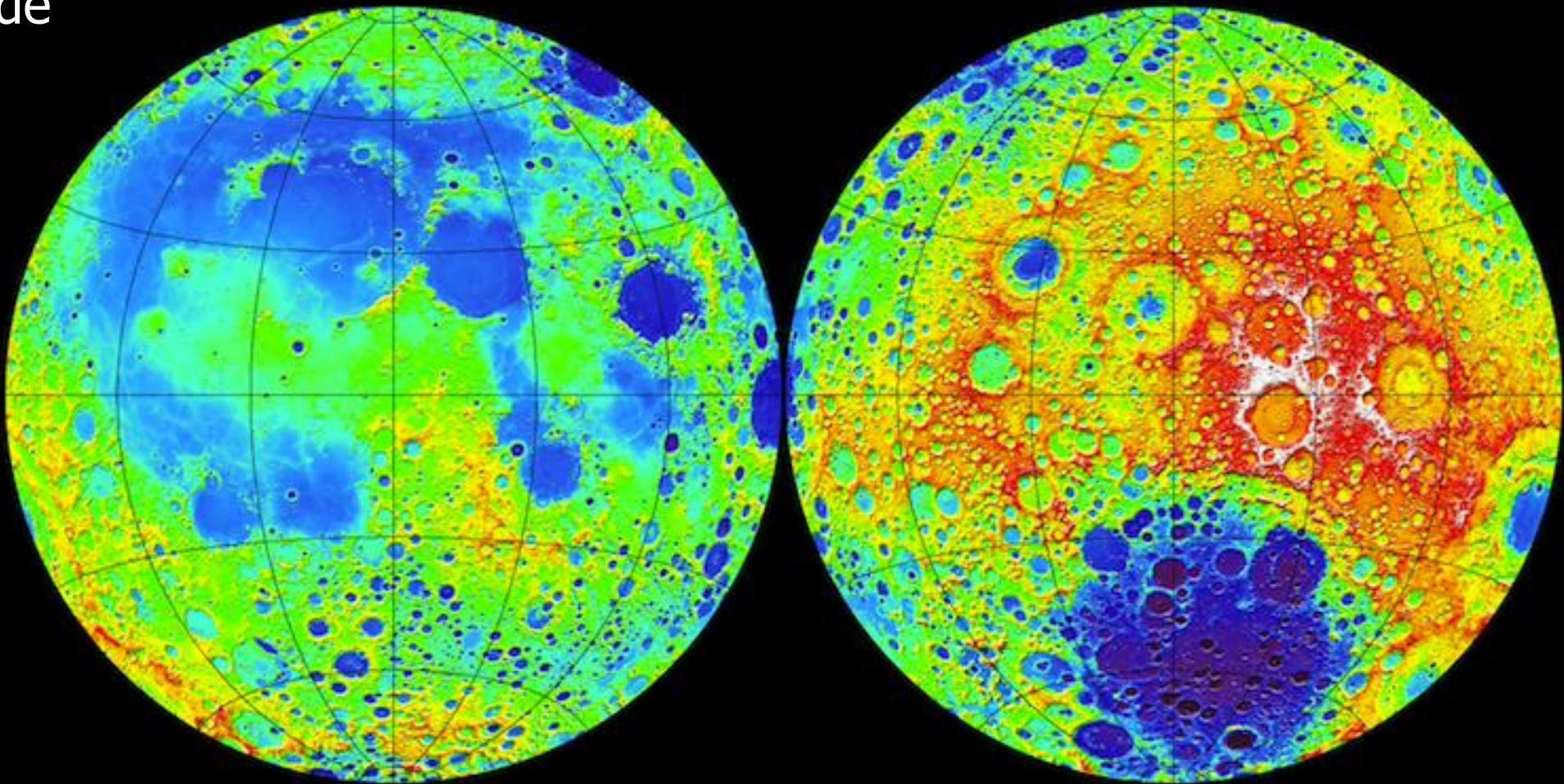
Earth's Moon



Earth's Moon  
Altitude

Nearside

Farside



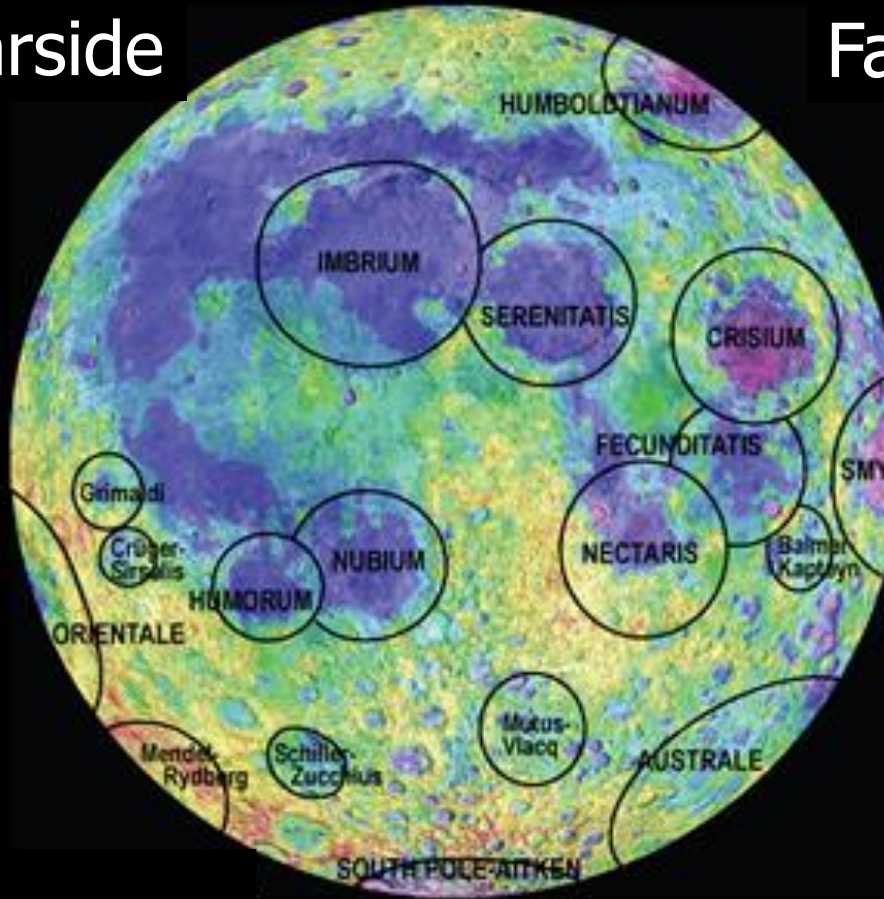
Topography (km)



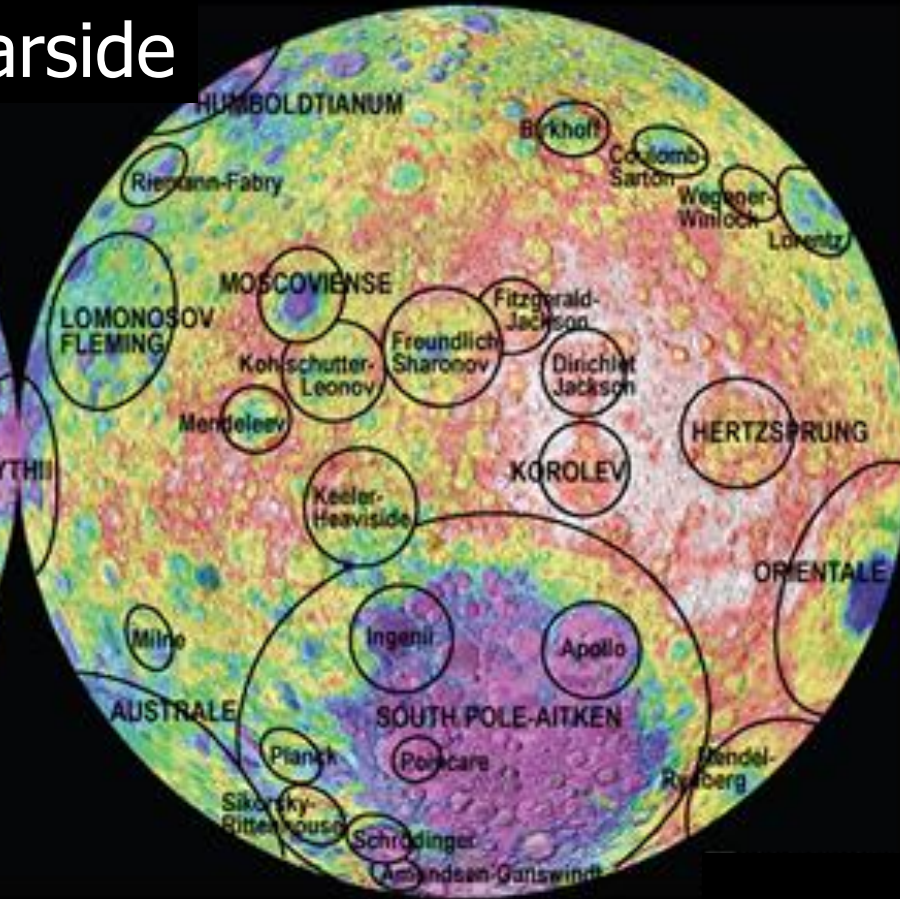


# The Late Heavy Bombardment (4.0 - 3.8 Ga)

Nearside



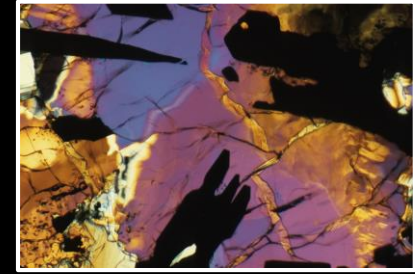
Farside



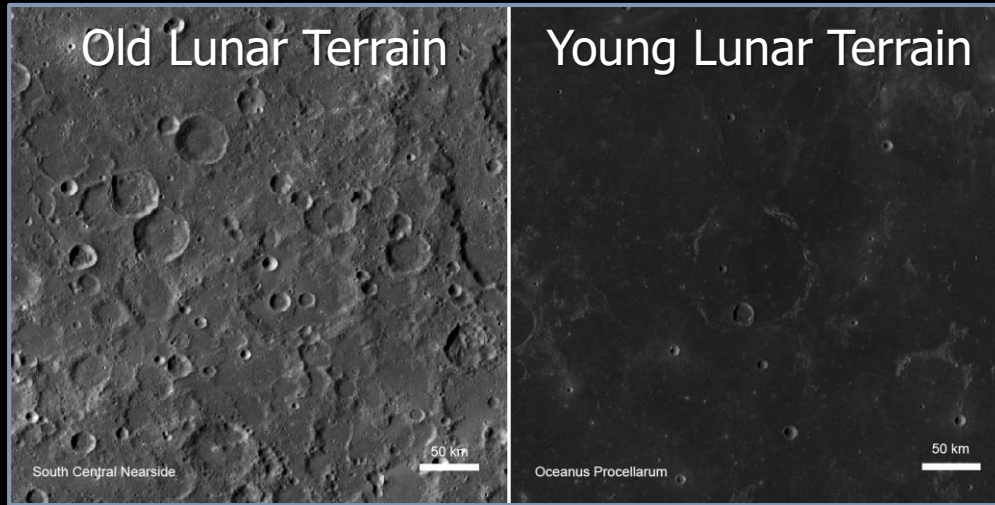
We have reliable radiometric dates only for Imbrium and Orientale Basins



# Setting the Solar System's Clock

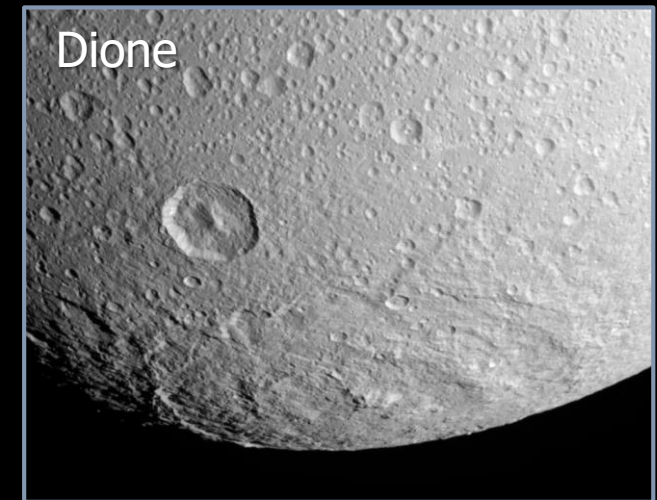


70017



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

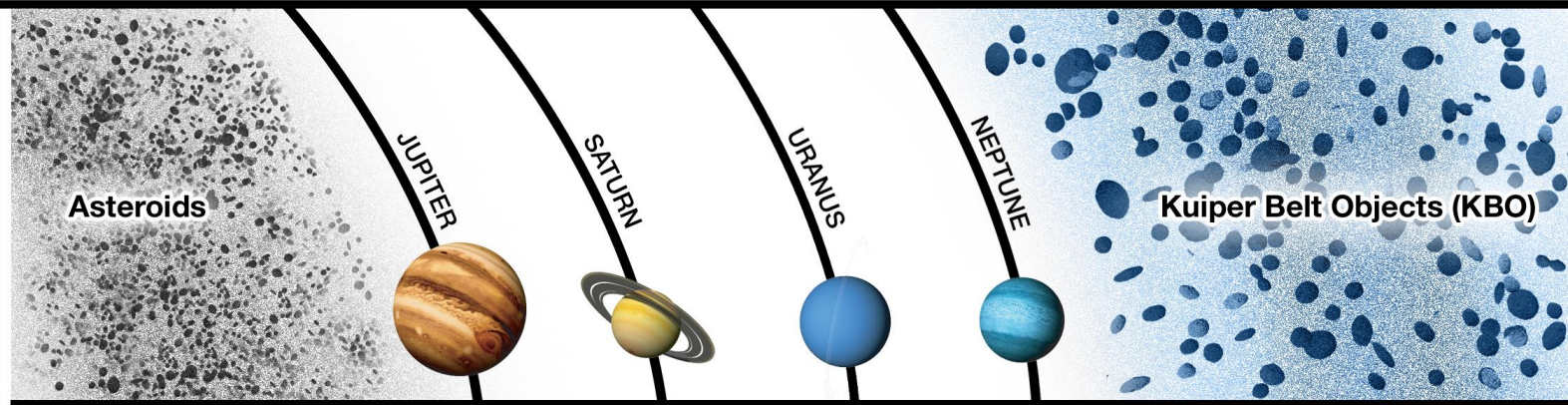
Also used to estimate ages of all other rocky-planetary surfaces in the Solar System despite major uncertainties





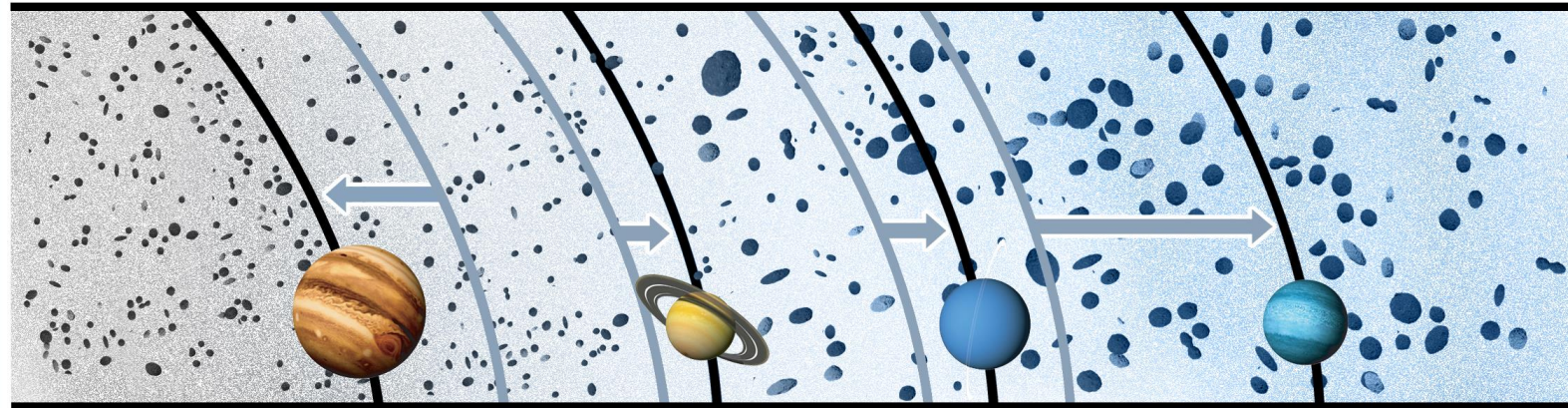
# Nice Model: Evolution of the Solar System

~4.2 Billion  
Years



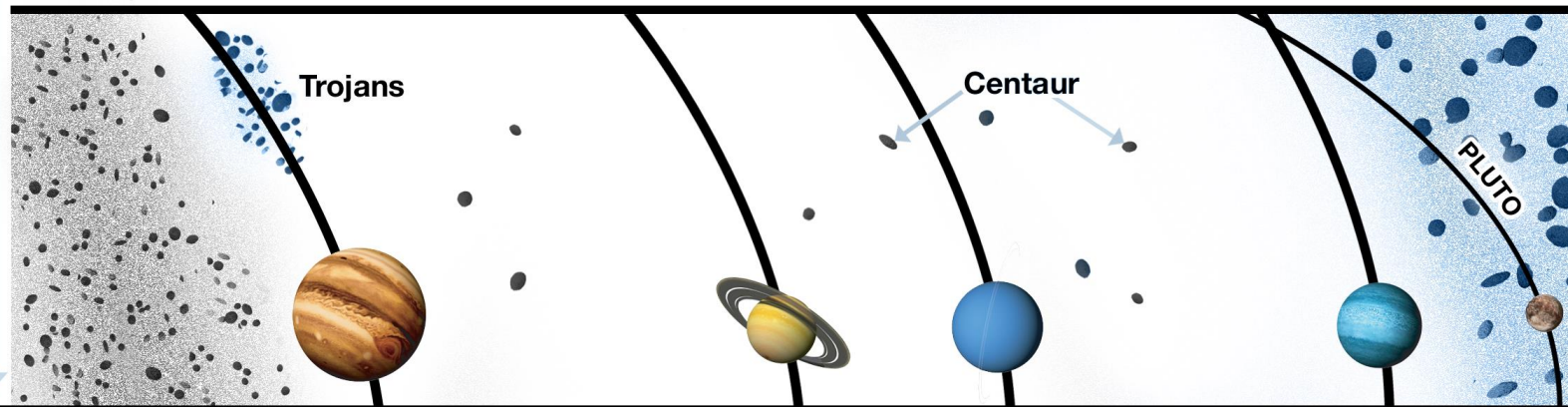
~3.8 Billion  
Years  
"Late Heavy  
Bombardment"

TIME

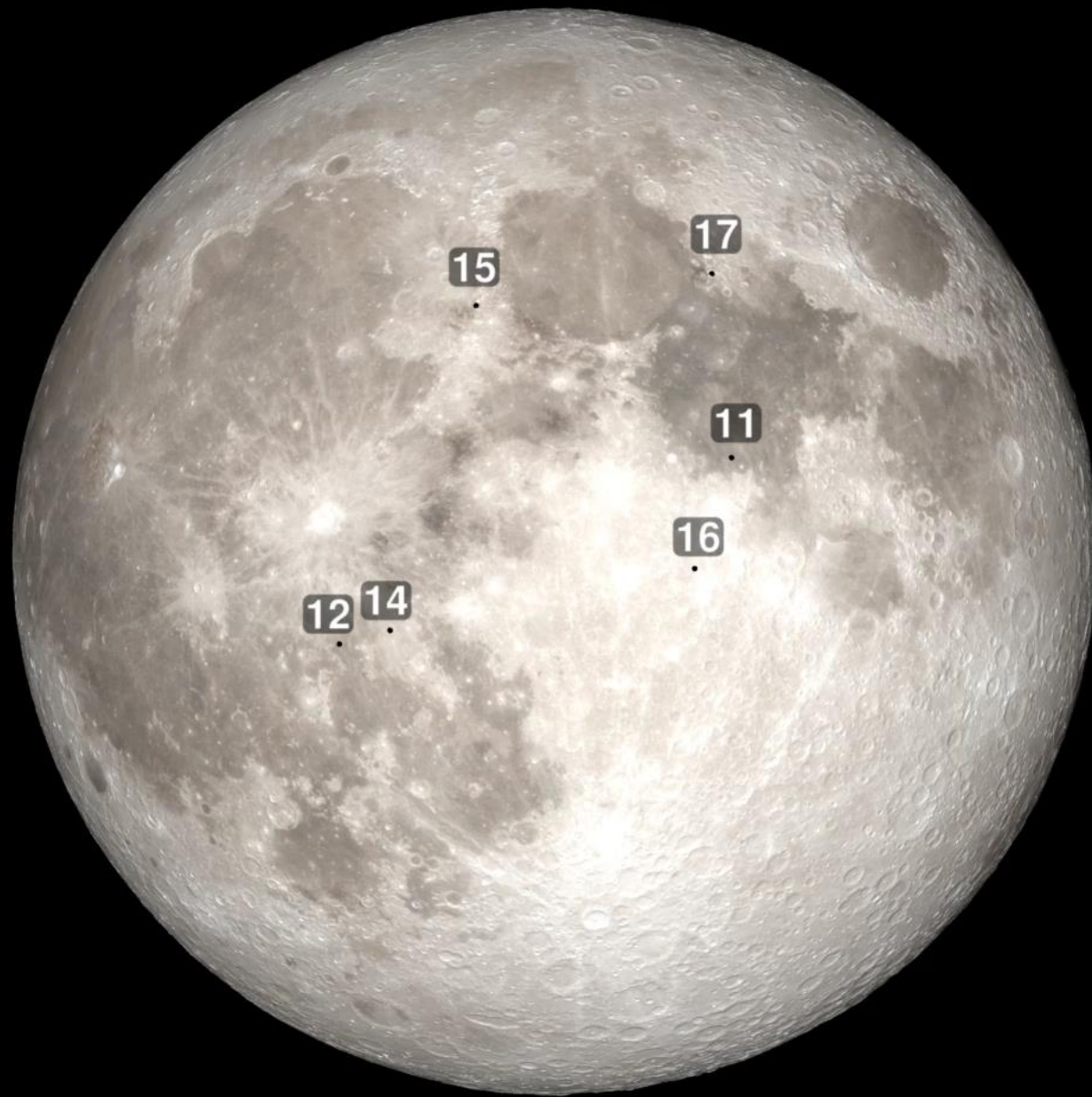


Developing  
this model  
possible *only*  
by having  
lunar  
samples

Today







15

17

11

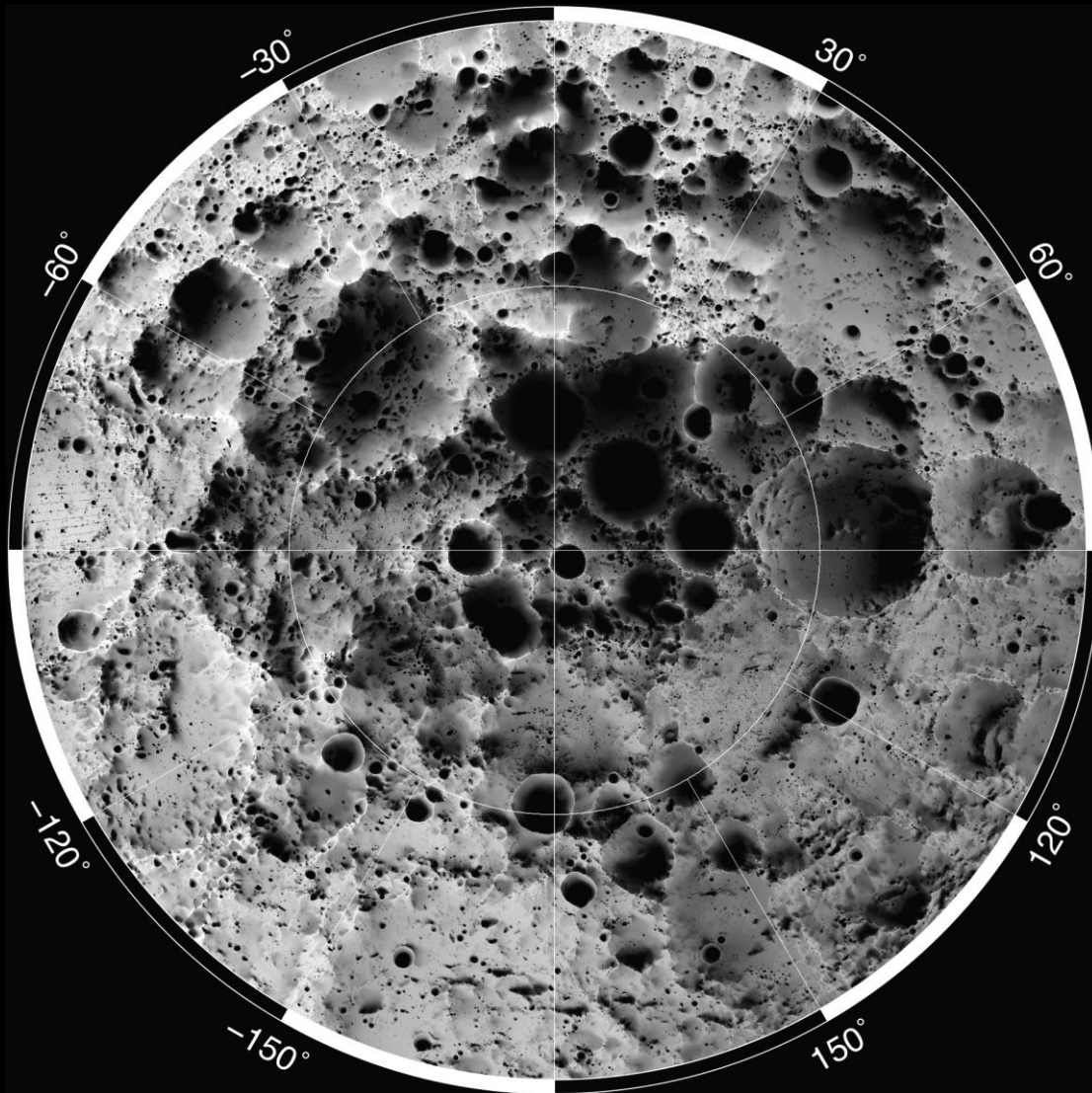
16

12

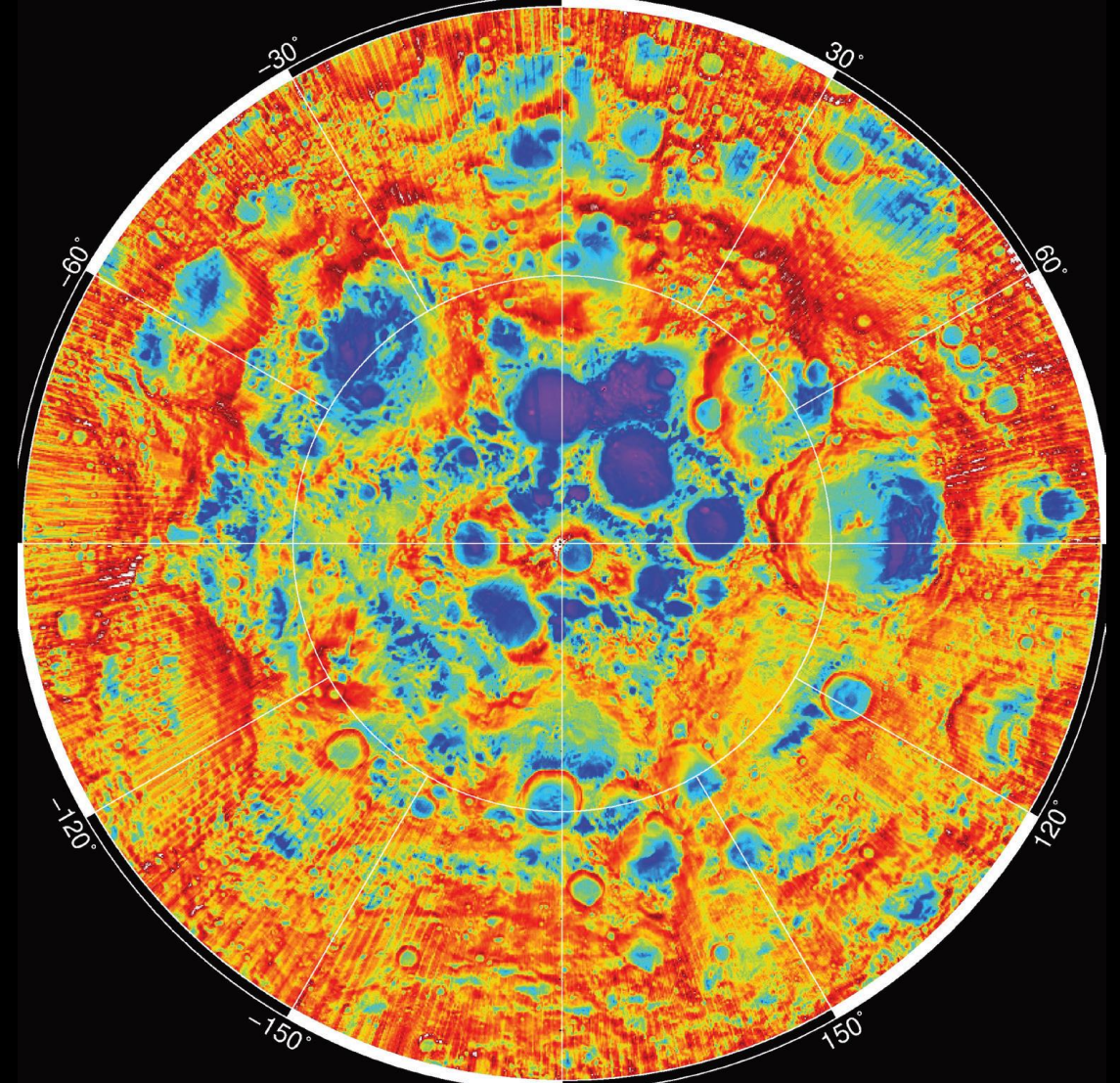
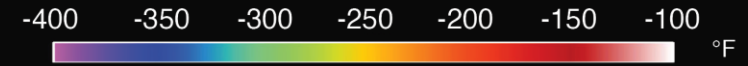
14



Average Illumination of the Lunar South Pole

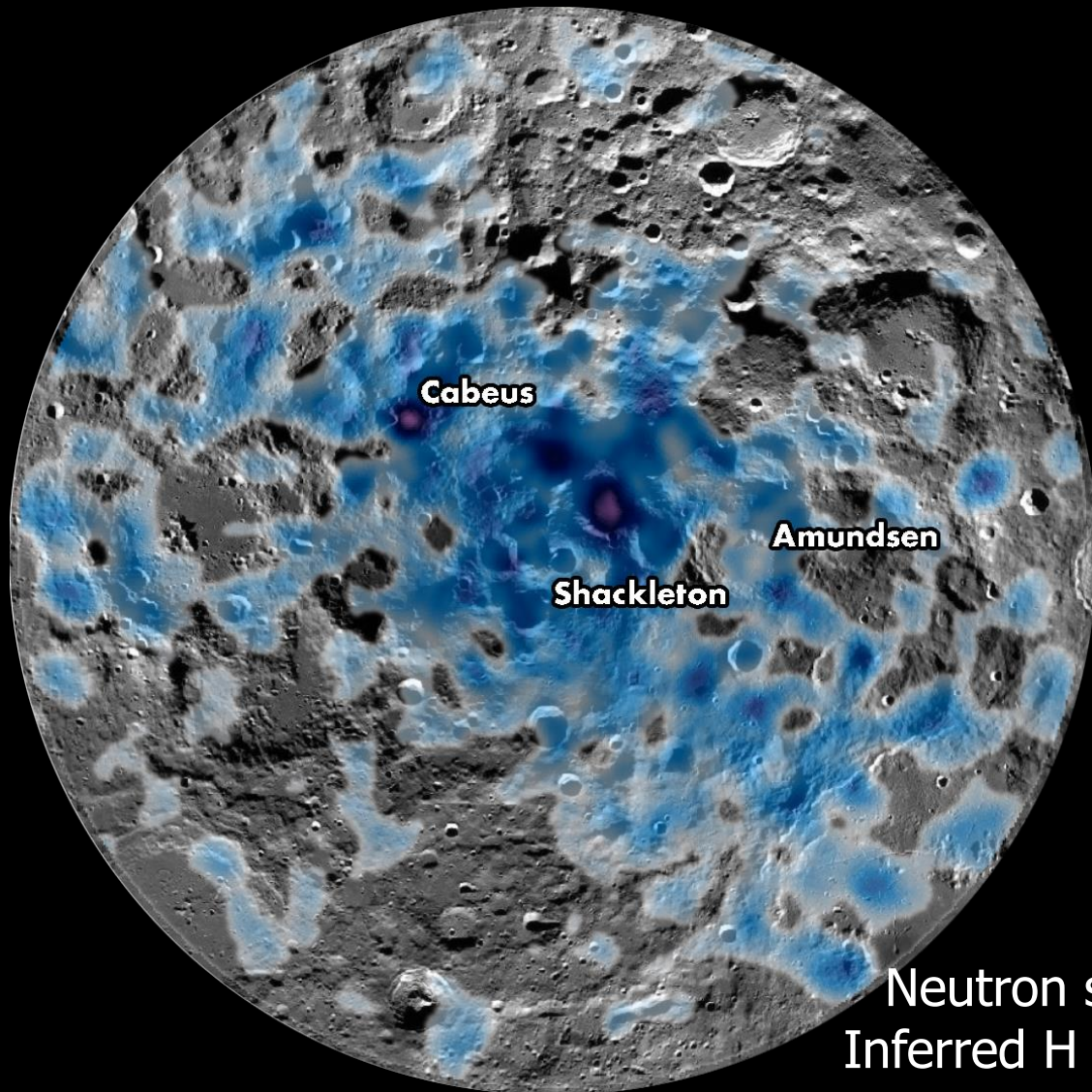


Average Daytime Temperature at the Lunar South Pole

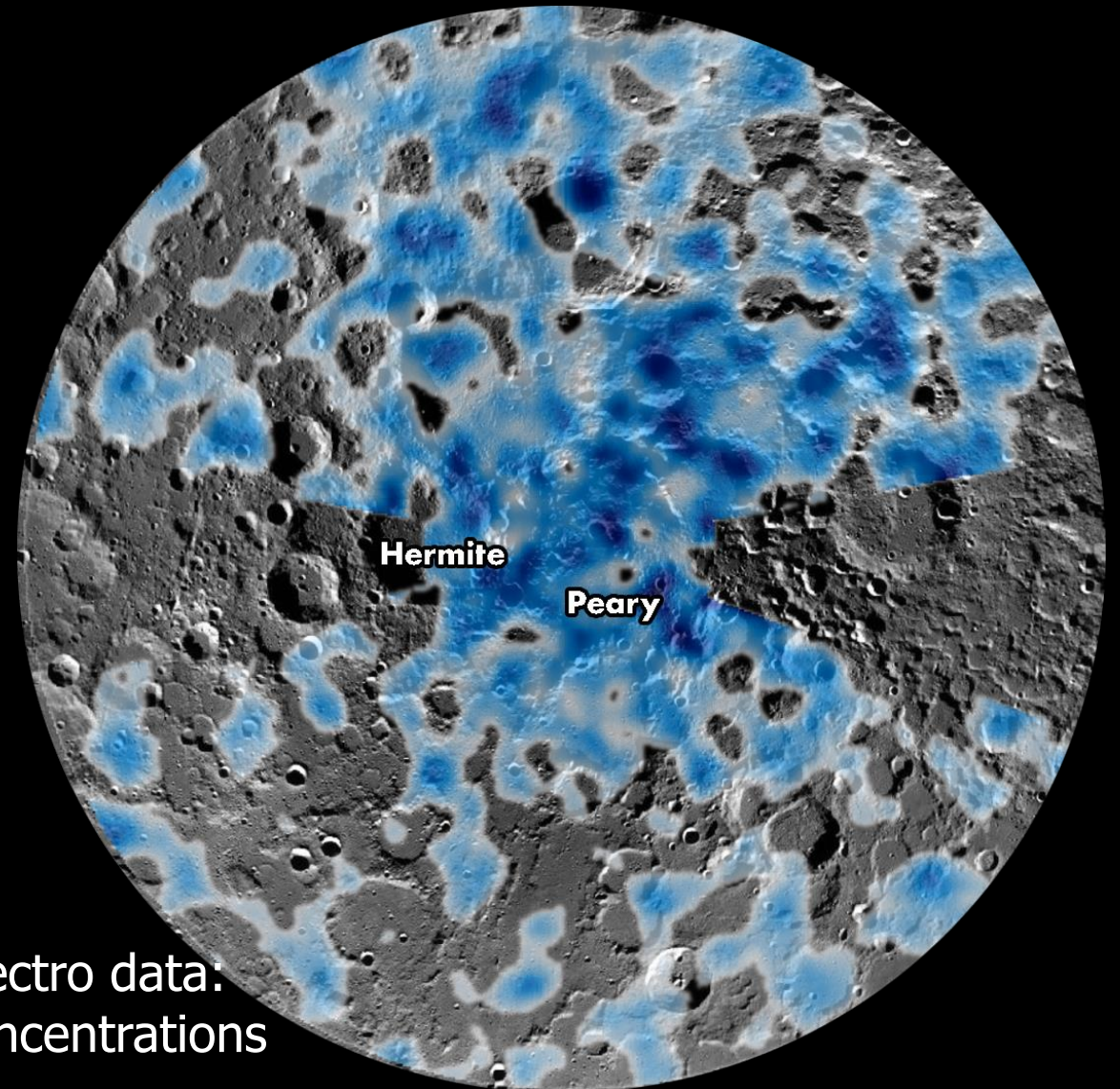




# South Pole



# North Pole



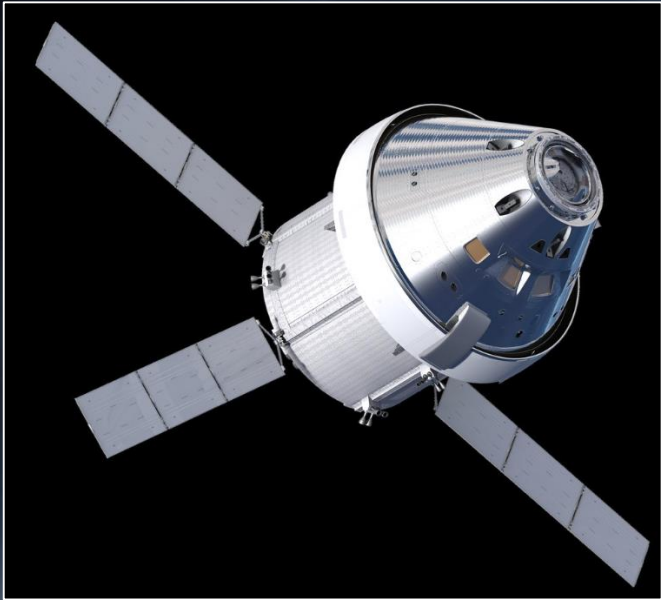
Neutron spectro data:  
Inferred H concentrations



# NASA's SLS and Orion

- with our international partners

## ORION





# 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

**Artemis Support Mission:** First pressurized module delivered

**Artemis Support Mission:** Human Landing System delivered

**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

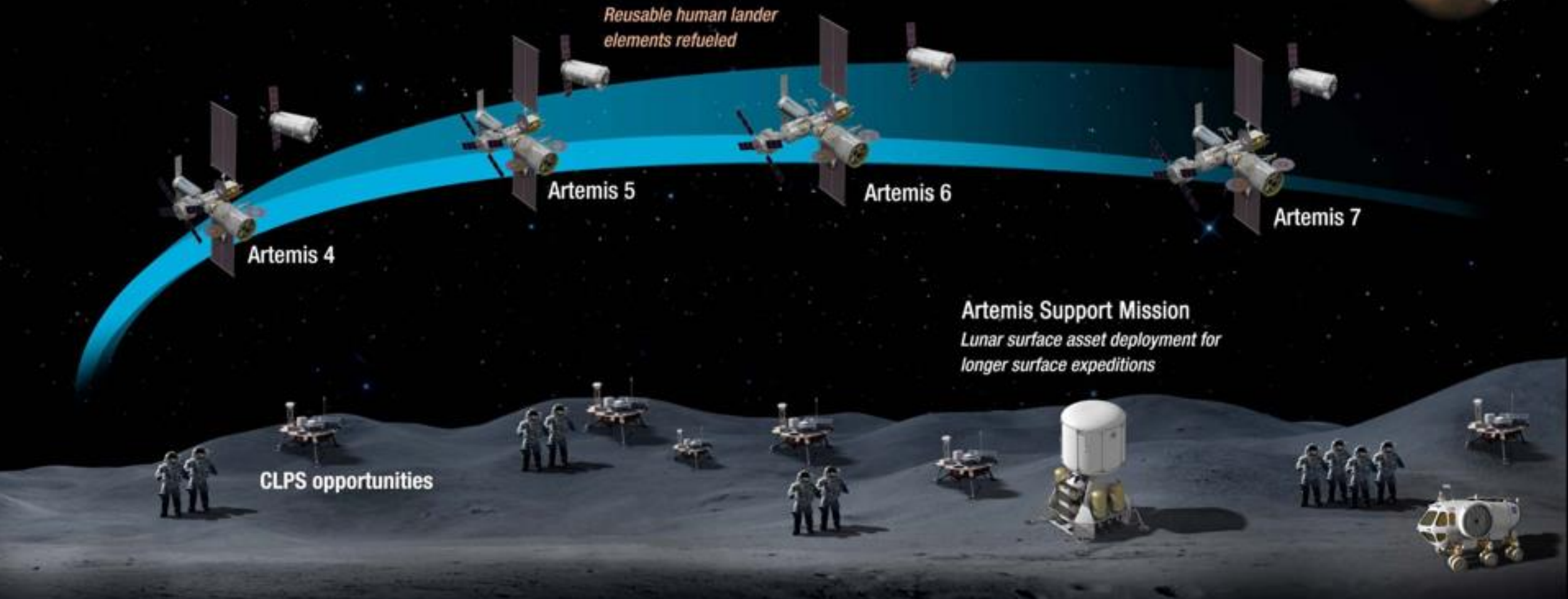
- Increased capabilities for science and technology payloads

**LUNAR SOUTH POLE TARGET SITE**

2020

2024

# Artemis Phase 2: Building Capabilities for Mars Missions



## **SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION**

MULTIPLE SCIENCE AND CARGO PAYLOADS

INTERNATIONAL PARTNERSHIP OPPORTUNITIES

TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

2025

2029



# Space For All

National Aeronautics and  
Space Administration



## Unique moment for partnerships

Unlike "Space Race" era, robust international and commercial sectors  
First steps in permanent human offworld presence

## Everybody is needed

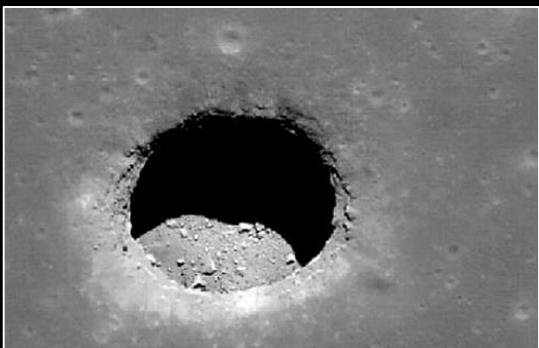
For every astronaut, maybe 20K people on the ground  
All walks of life required!

## A Generational Change

The "Artemis Generation" to succeed the "Apollo Generation"  
Setting the stage for eventual human landings on Mars



## Science & Exploration



## Living off the Land



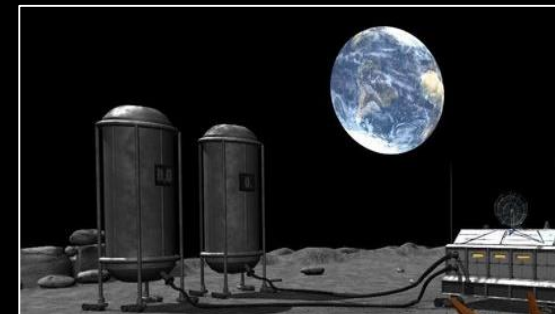
## Multi-planet Species



# Future Moon



## Fuel Depot



## Mining



## Manufacturing



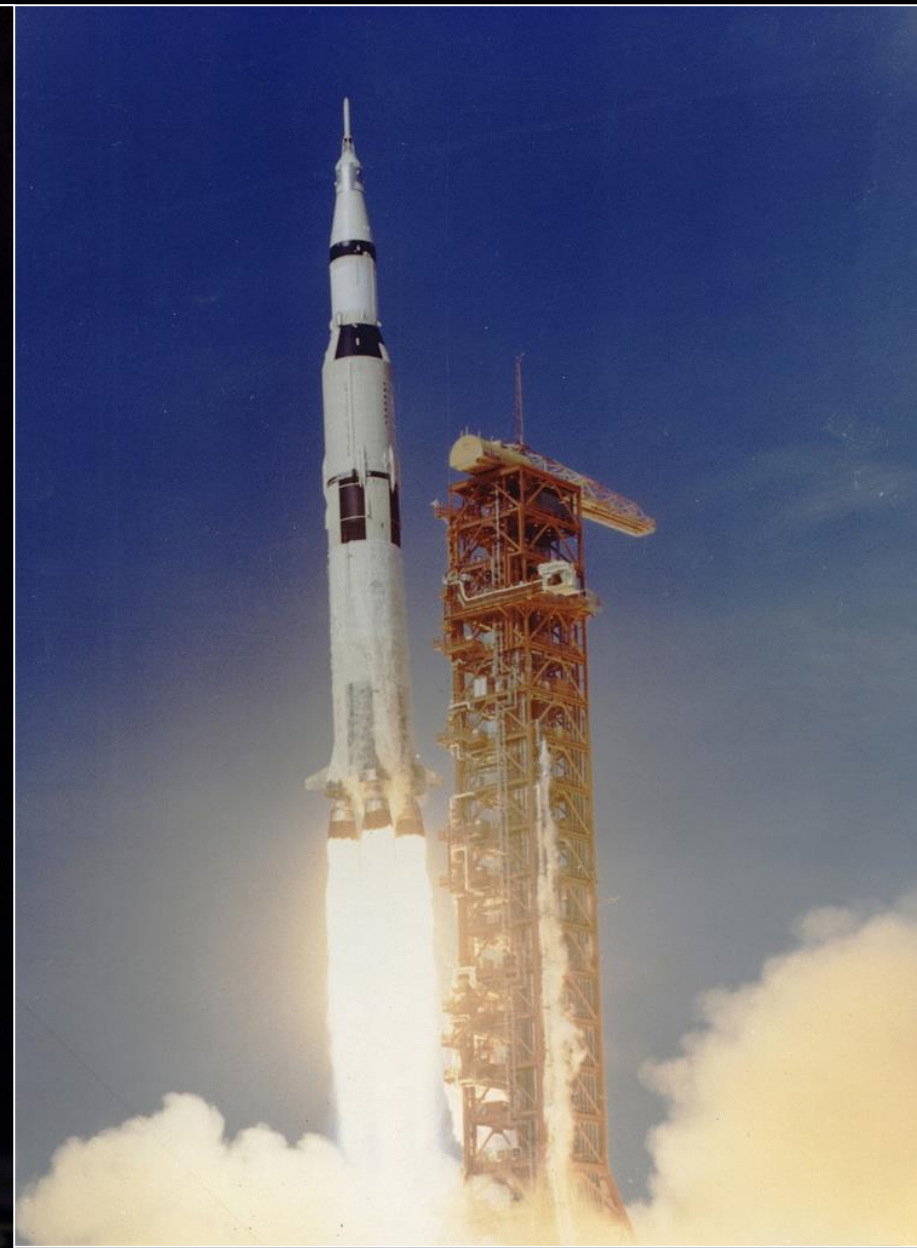


A full-page background image showing an astronaut in a white spacesuit standing on the lunar surface. The astronaut is positioned in the lower-left foreground, facing slightly towards the right. The lunar surface is grey, dusty, and covered in numerous small craters and larger depressions. In the background, a large, dark, and heavily cratered lunar hill rises. The sky is a deep black, filled with many small, bright stars. In the upper right corner, the Earth is visible as a blue and white sphere, partially illuminated. The word "Backup" is written in a large, white, sans-serif font, centered horizontally and slightly above the middle vertically.

# Backup

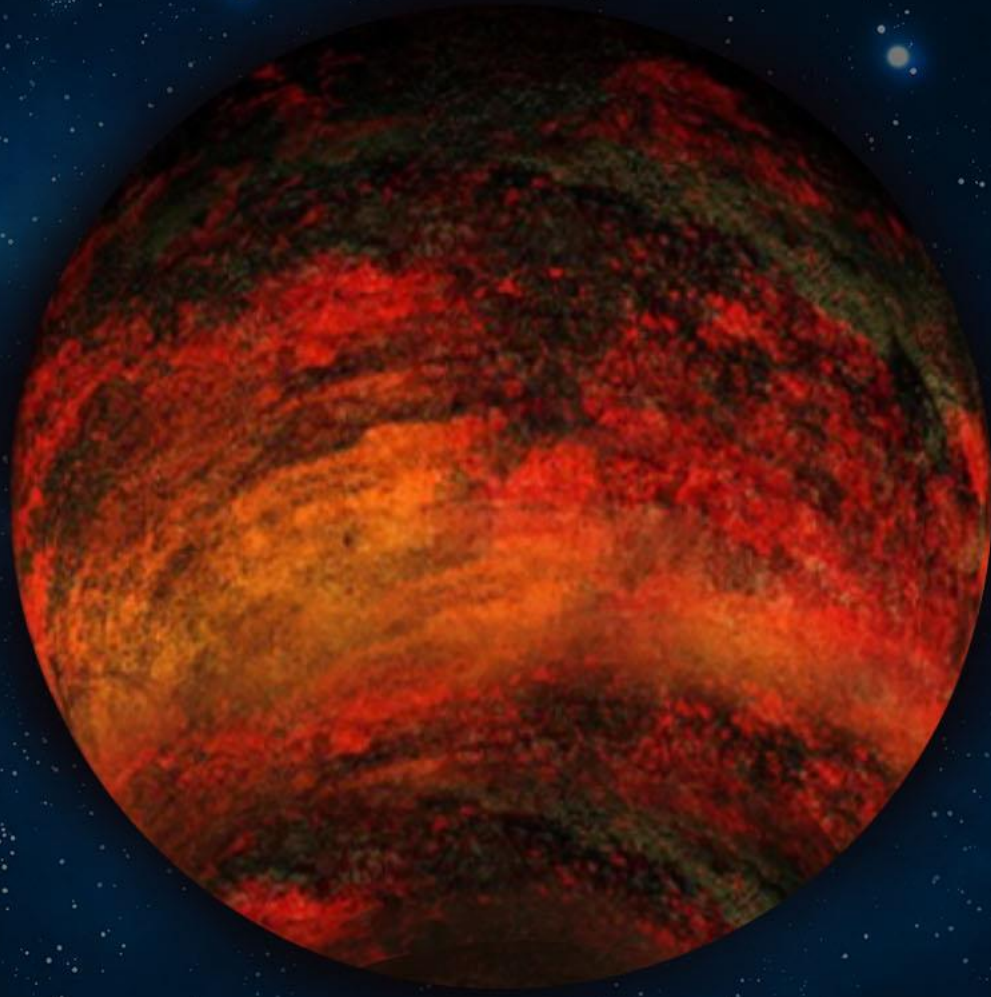








5-Hour Day

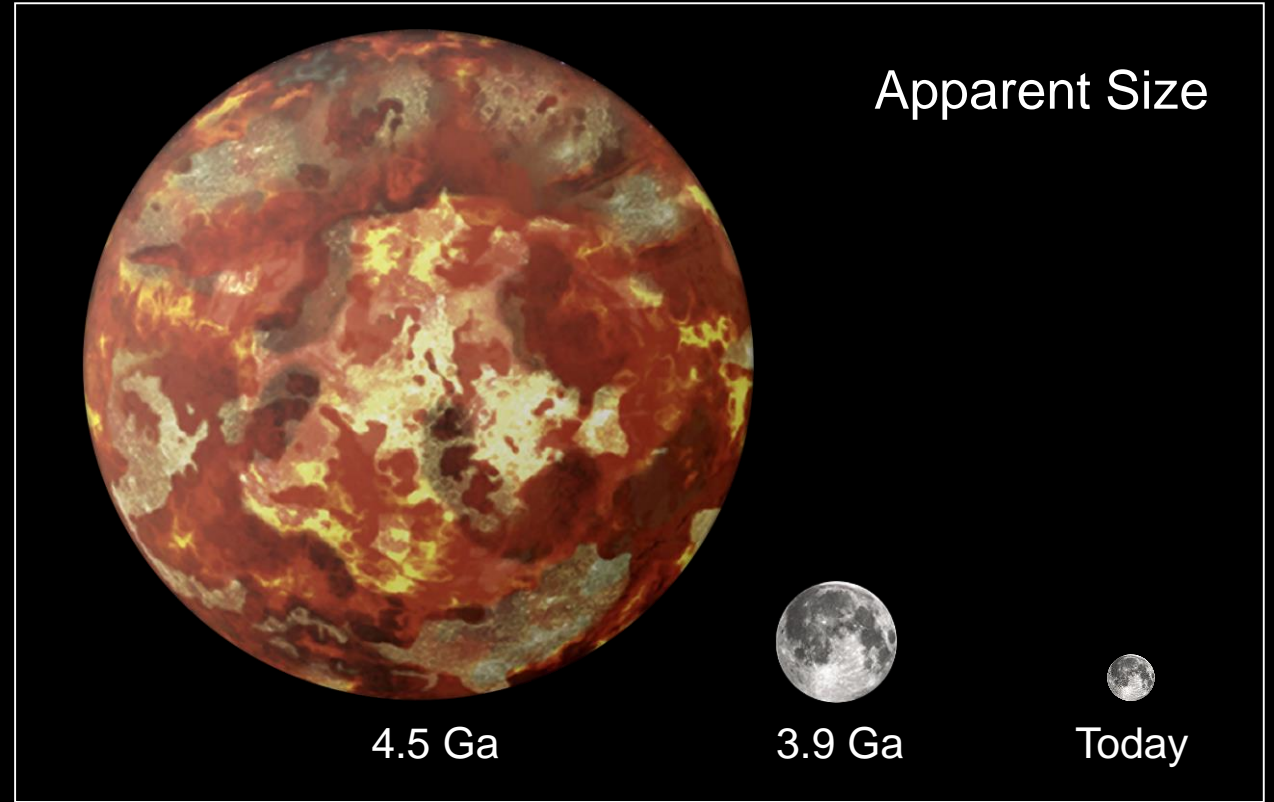
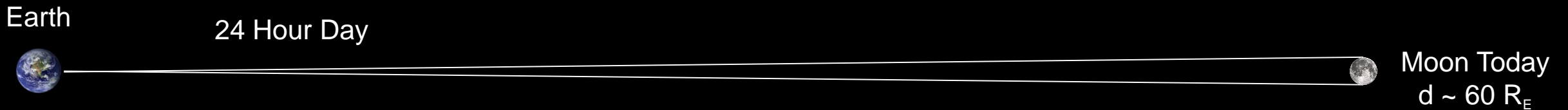
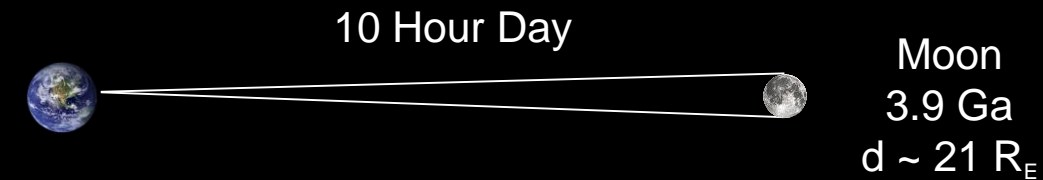




# The Moon Stabilizes Our Spin Axis



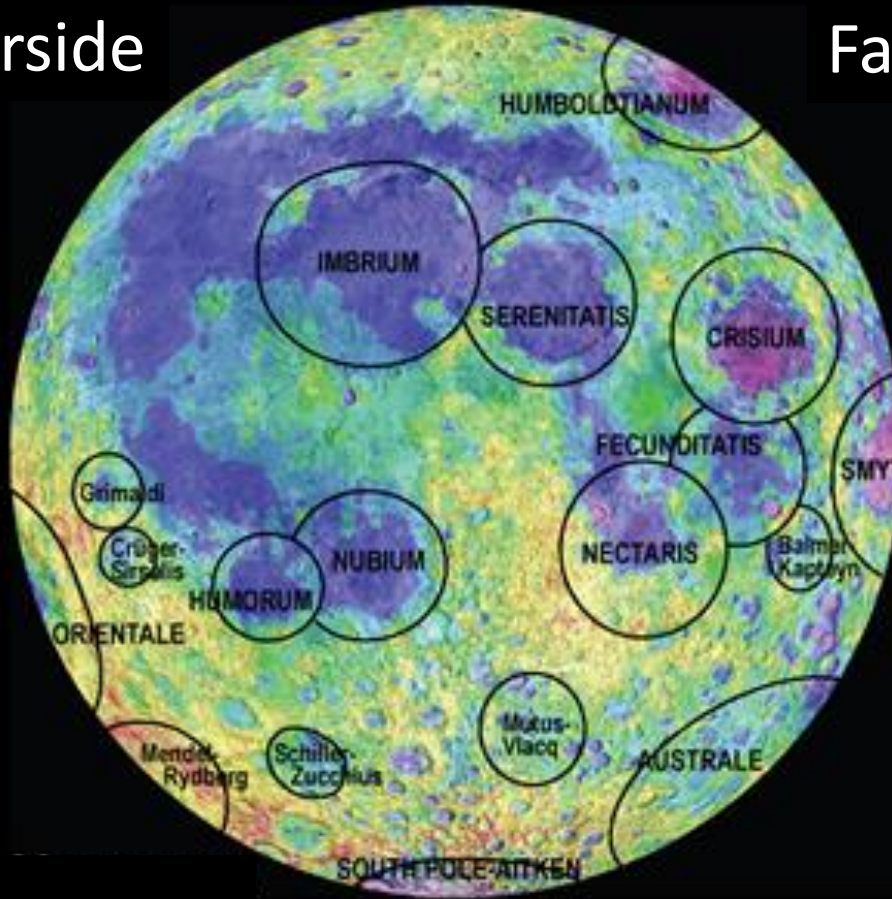
Slipping away  
1 ½ inches per year



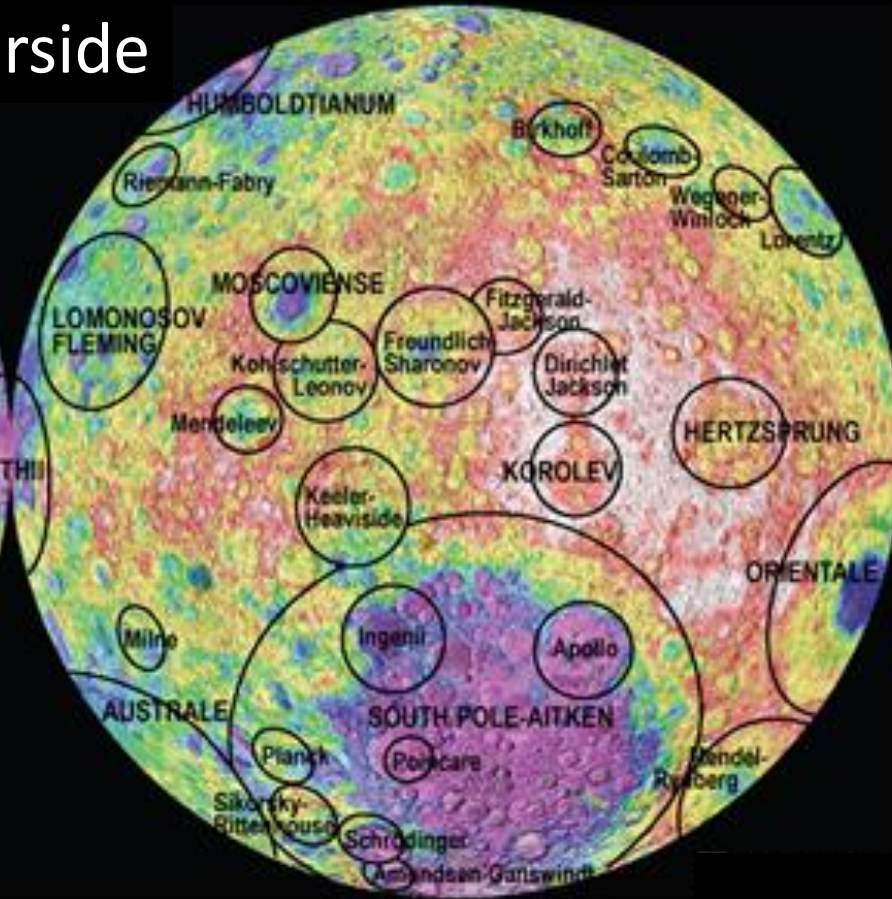


# Bombardment History

Nearside

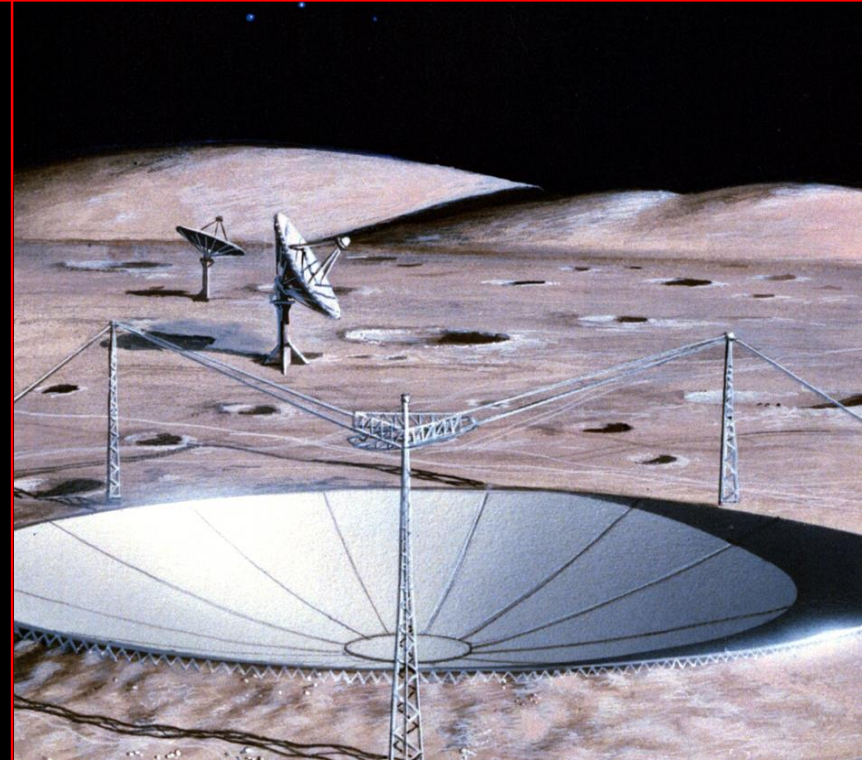
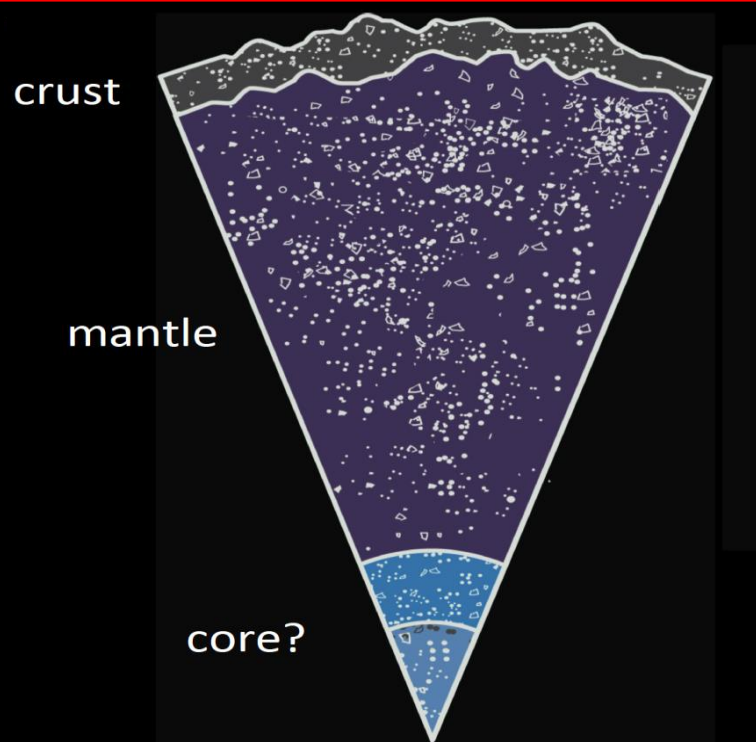
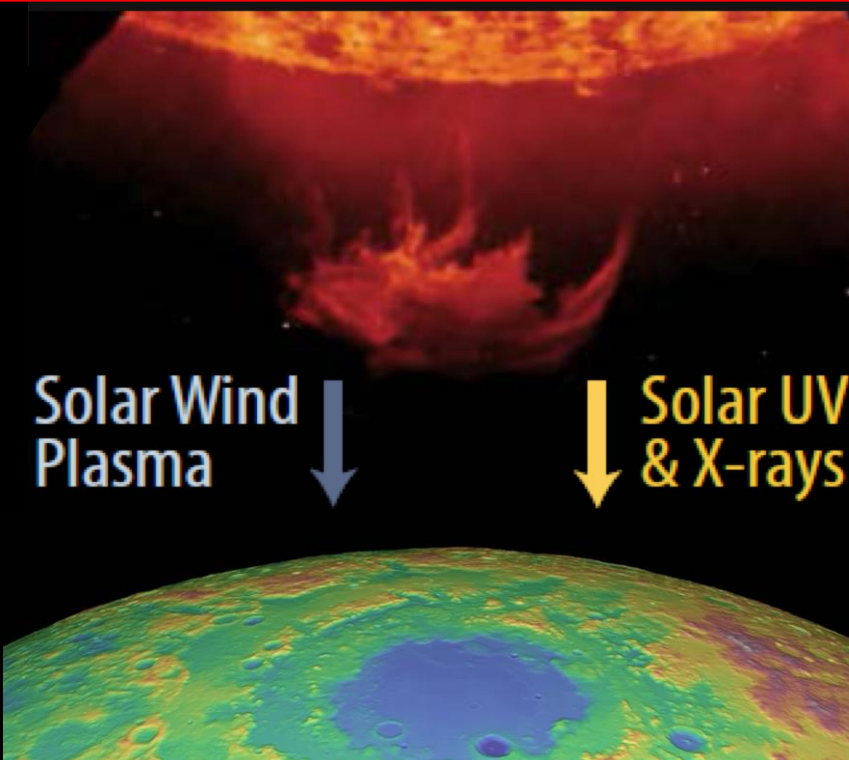
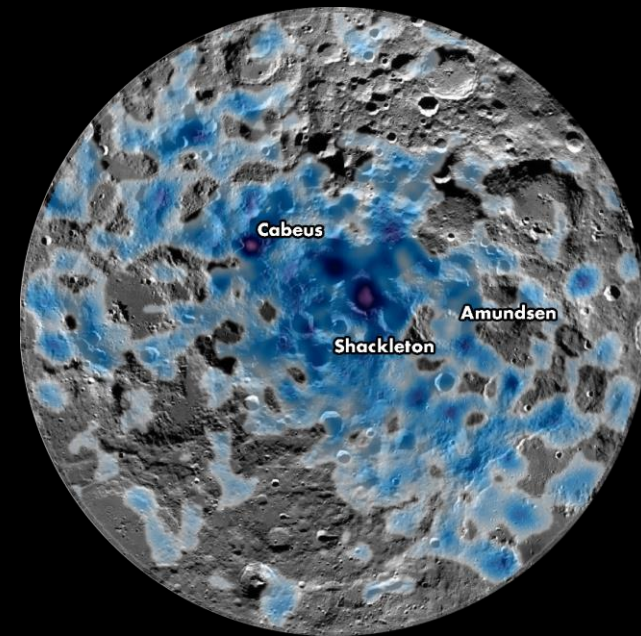
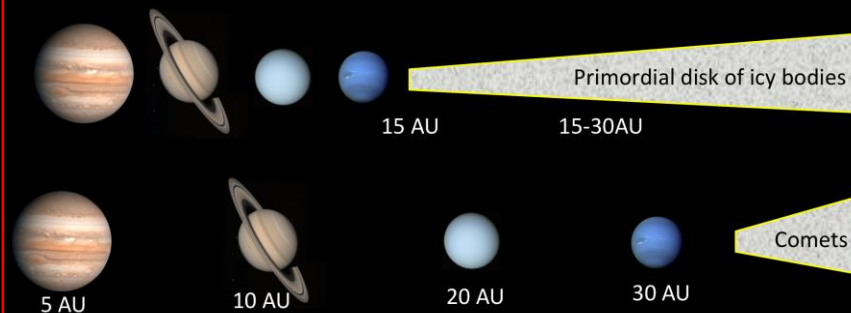
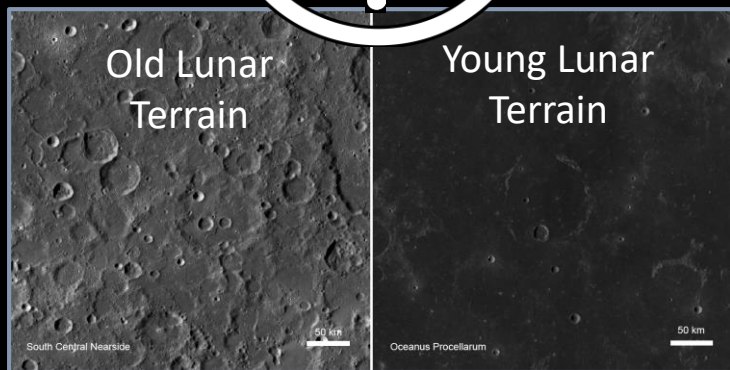


Farside



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

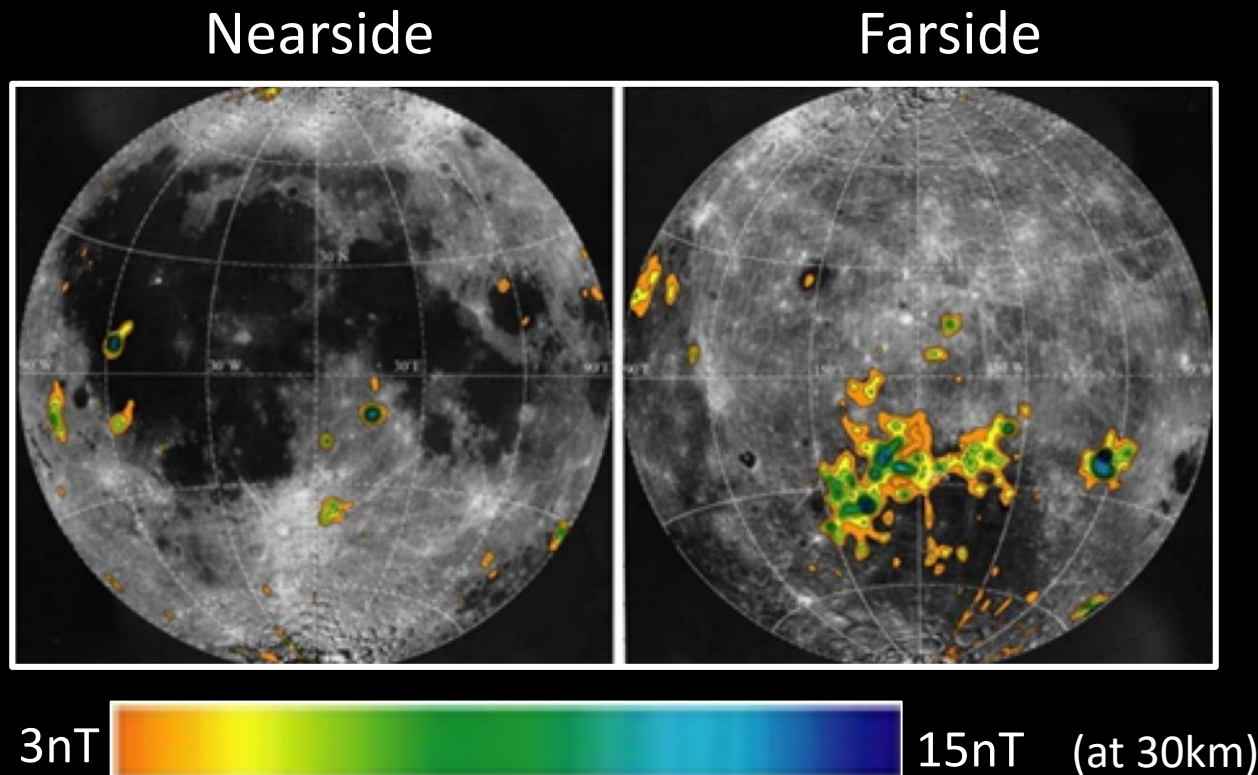






# Magnetic Anomalies: Fe, Ni and PGM

- 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