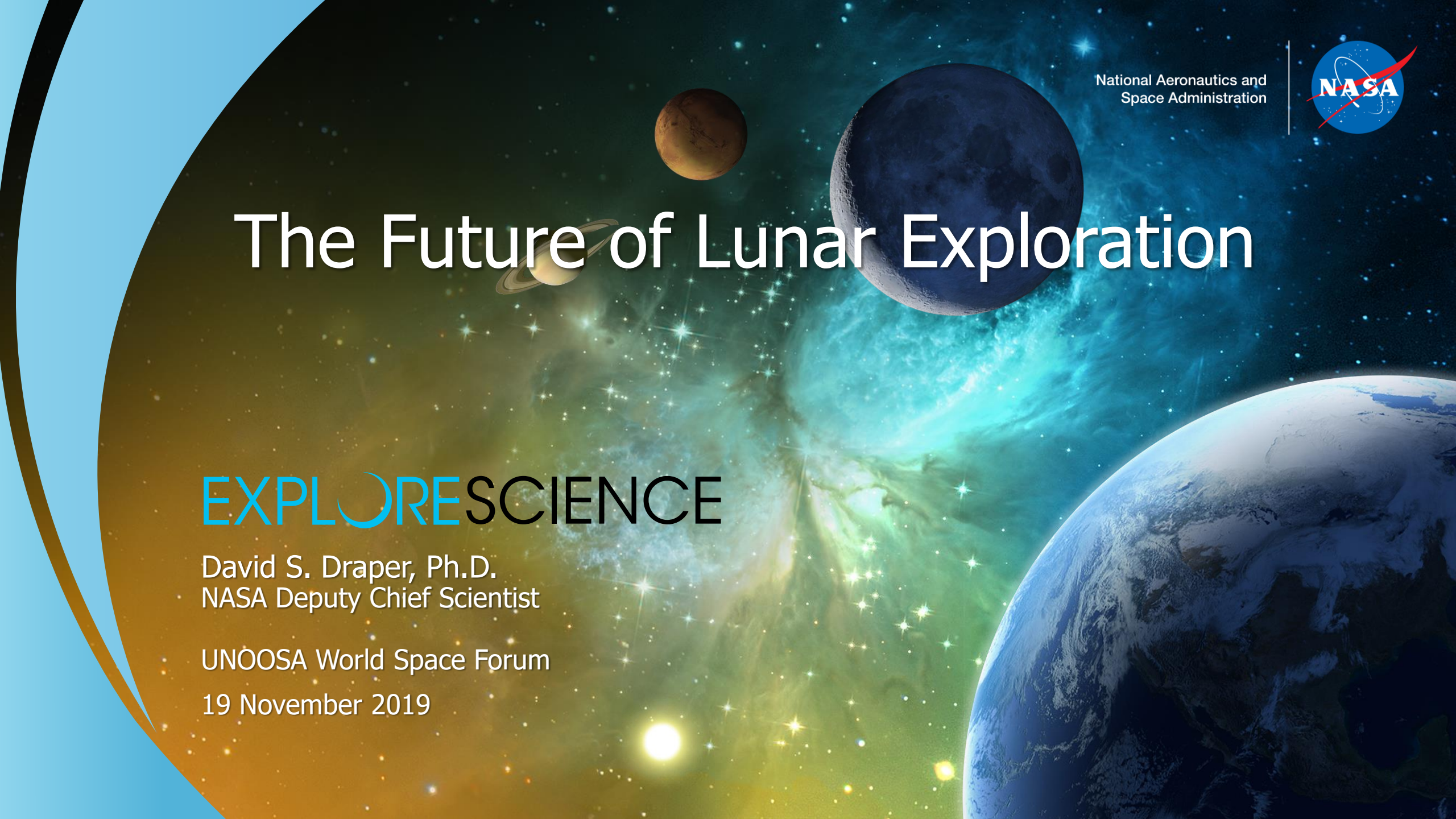
National Aeronautics and Space Administration



The Future of Lunar Exploration

EXPLORESCIENCE

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

UNOOSA World Space Forum

19 November 2019

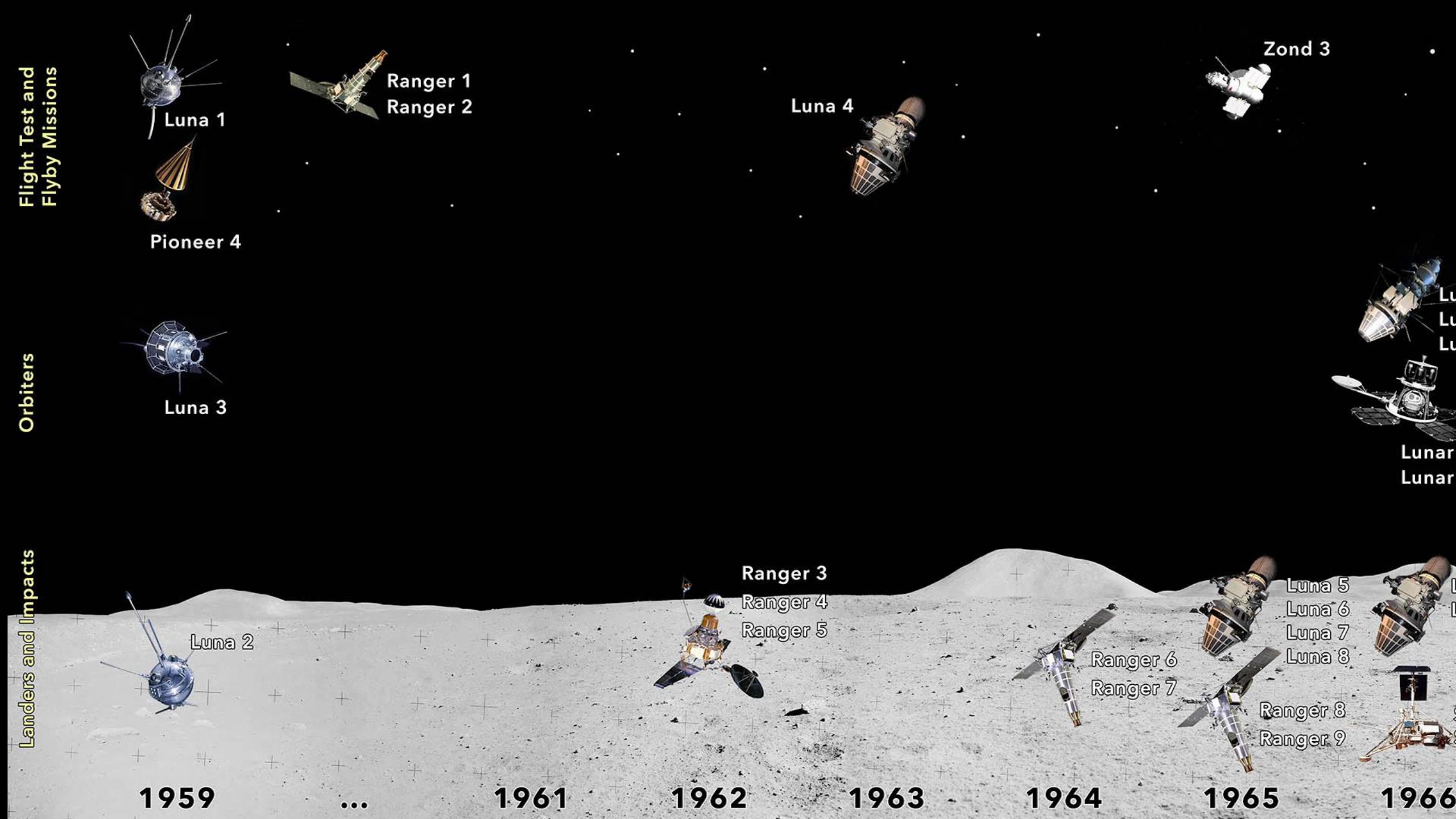
National Aeronautics and Space Administration

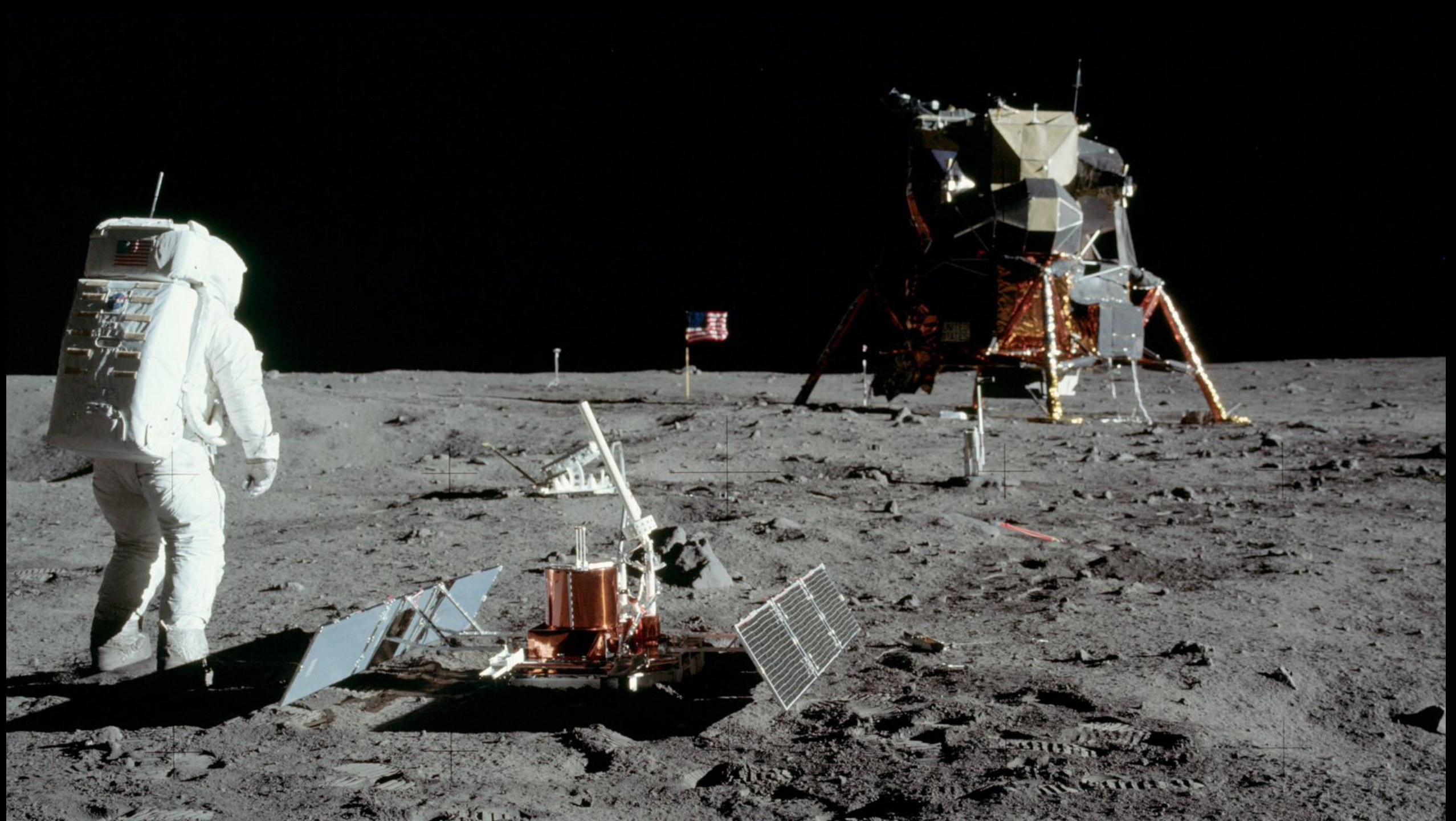
Outline

Two previous eras of lunar exploration
- "Space Race" era: Apollo, Luna
- Robotic era: 1990s – 2010s

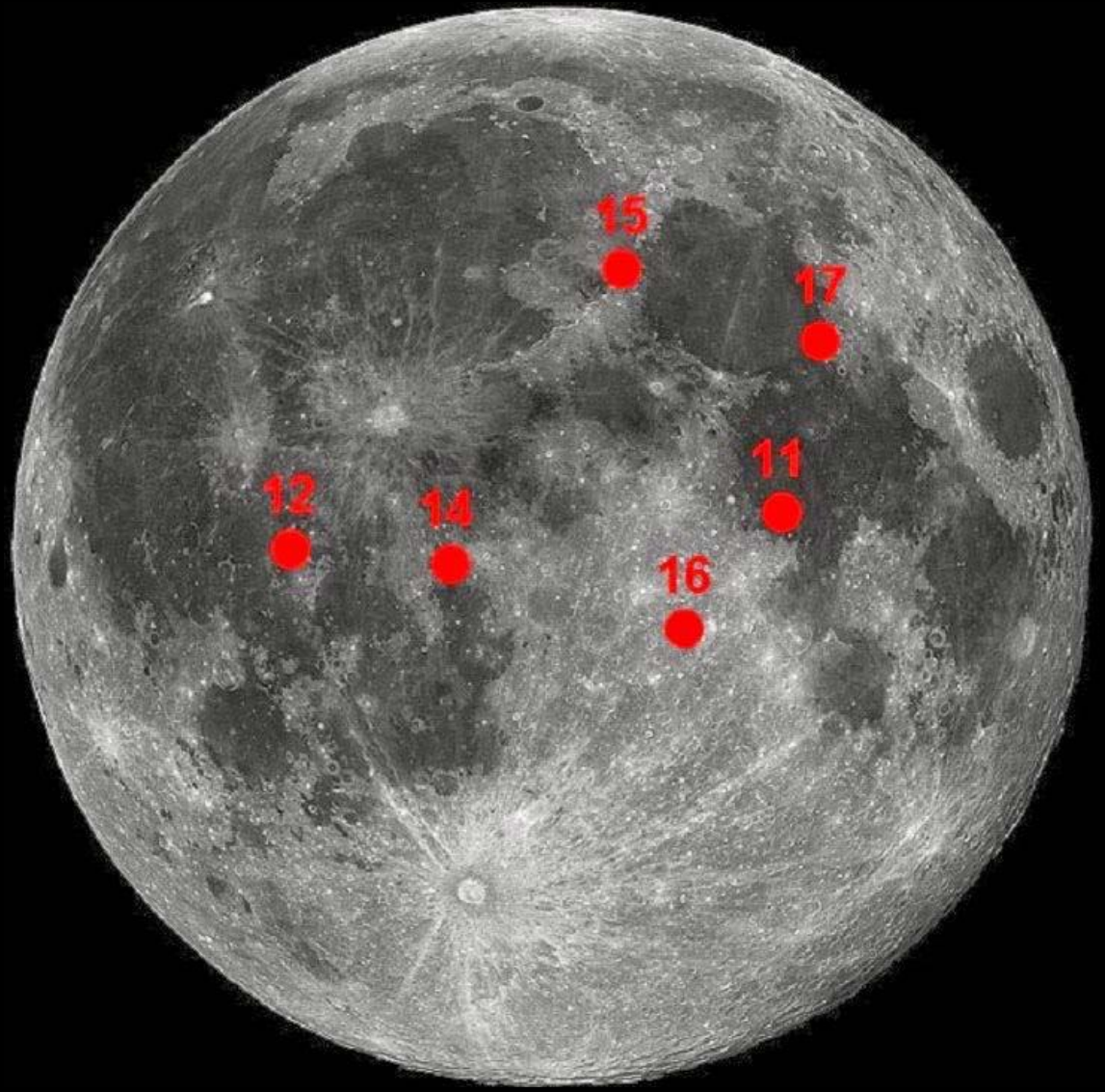
Return to the Moon
- Polar volatiles and permanently shadowed regions
- Resources to "live off the land"

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
Orbiters
Landers and Impacts
Luna 1
Ranger 1
Ranger 2
Luna 4
Zond 3
Pioneer 4
Luna 3
Ranger 3
Ranger 4
Ranger 5
Luna 2
Ranger 6
Ranger 7
Luna 5
Luna 6
Luna 7
Luna 8
Ranger 8
Ranger 9
1959
...
1961
1962
1963
1964
1965
1966

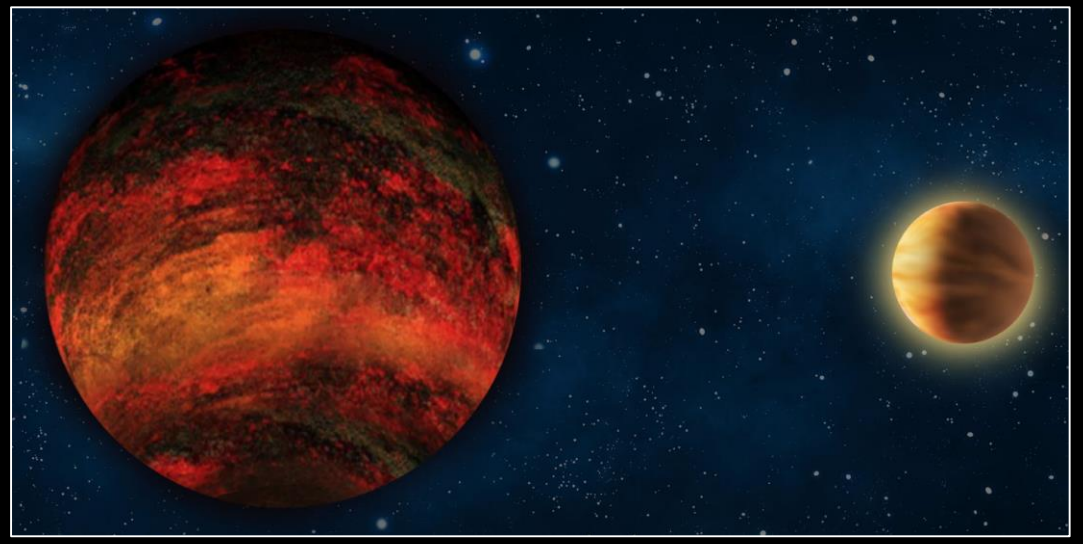


Apollo Lunar Exploration Program

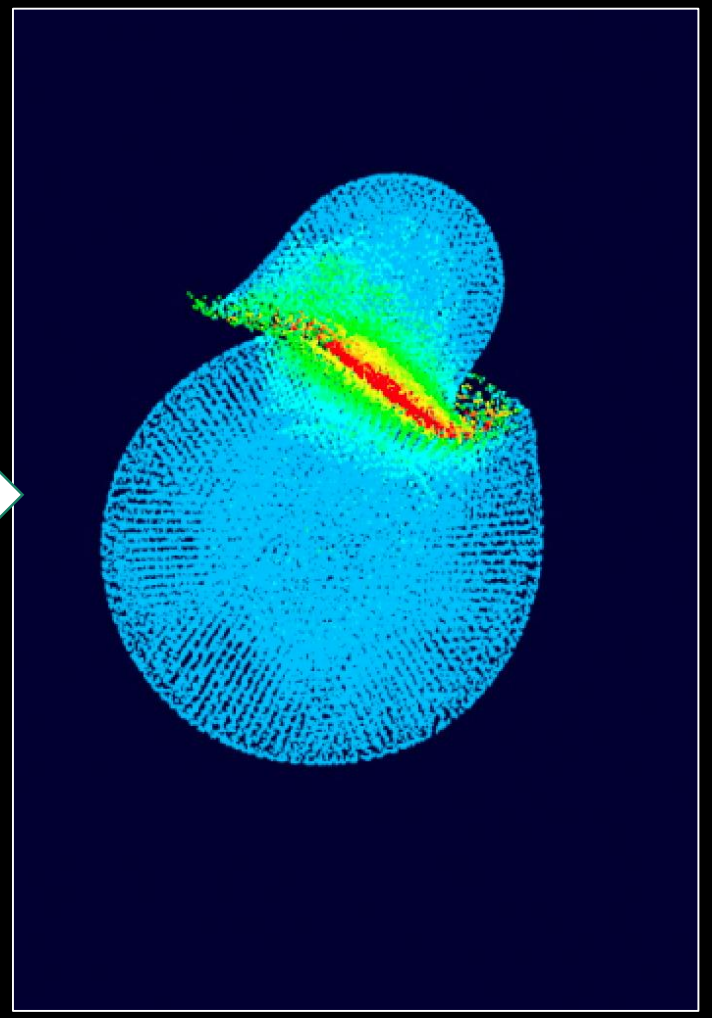


What did the Apollo Missions Tell us?

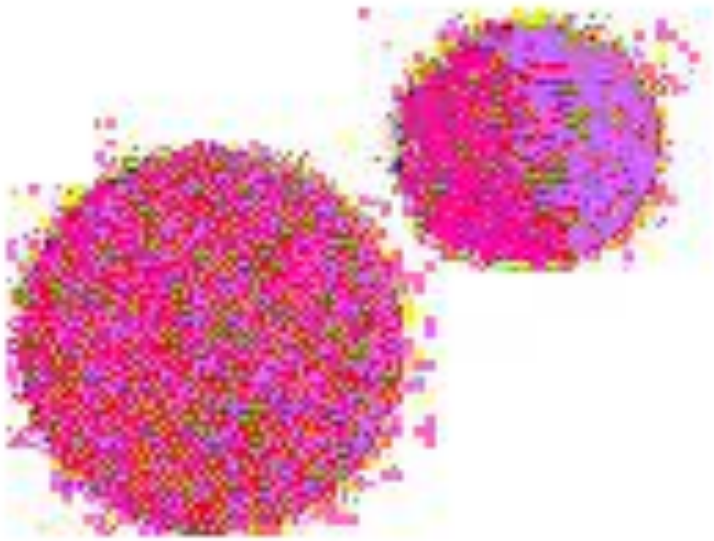
- The Moon is old (~4.6 Ga)
- Moon moves away from Earth ~3 cm/yr
- Isotopic analysis shows Moon and Earth have crucial compositional similarities
- Early Moon was molten: magma ocean cooled to form the crust
  - Giant Impact Hypothesis
  - Earth was molten too!
- Impact cratering is an important geologic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

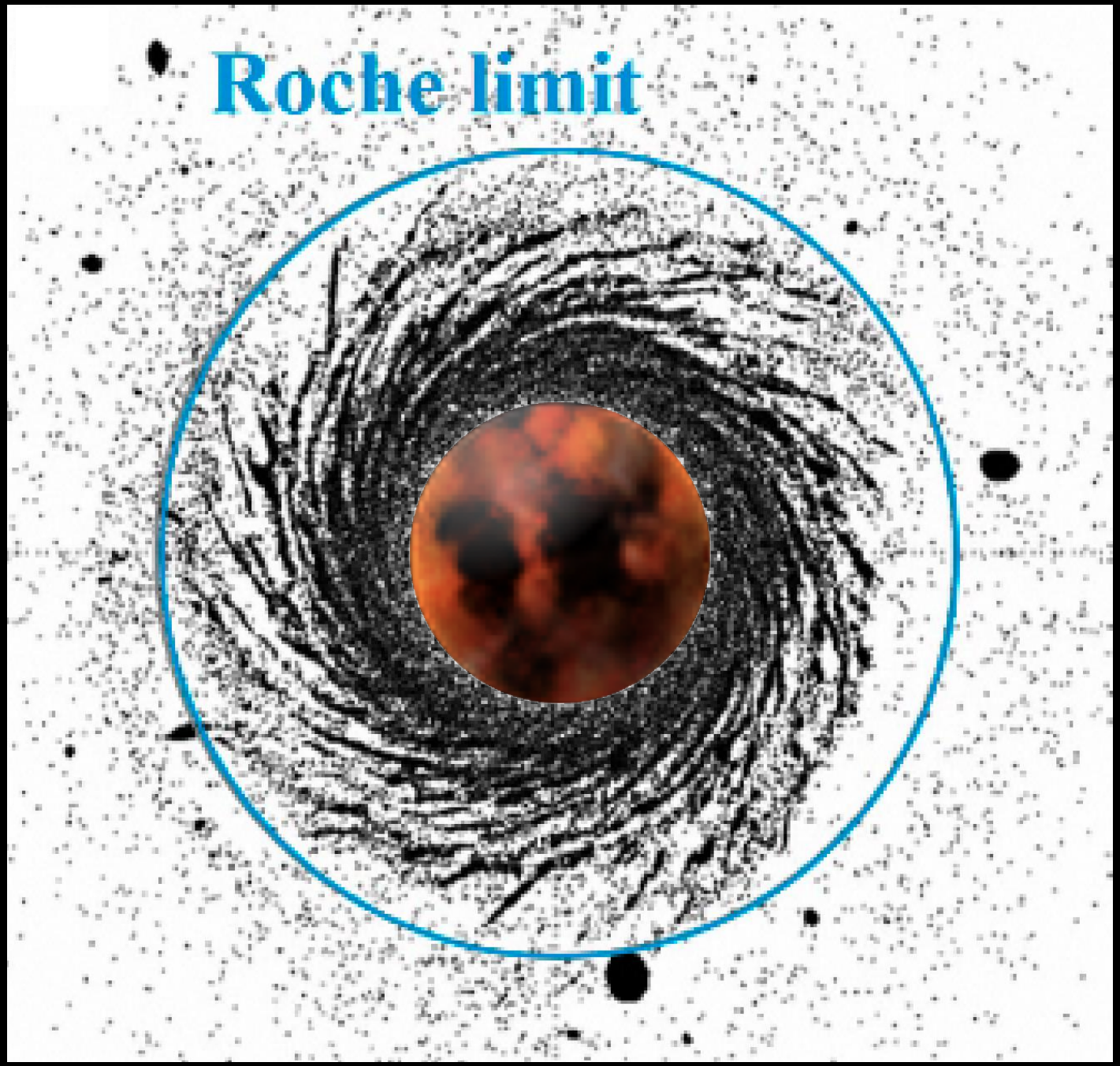


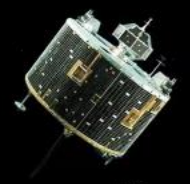
Lunar exploration can reveal how the Earth-Moon system formed



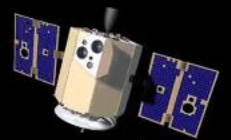
Giant impact hypothesis for origin of Moon



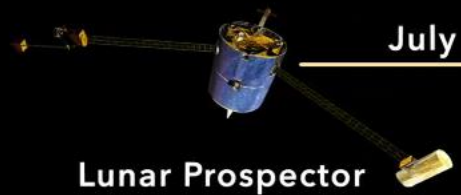

Roche limit



Hitan



Clementine



July 1999

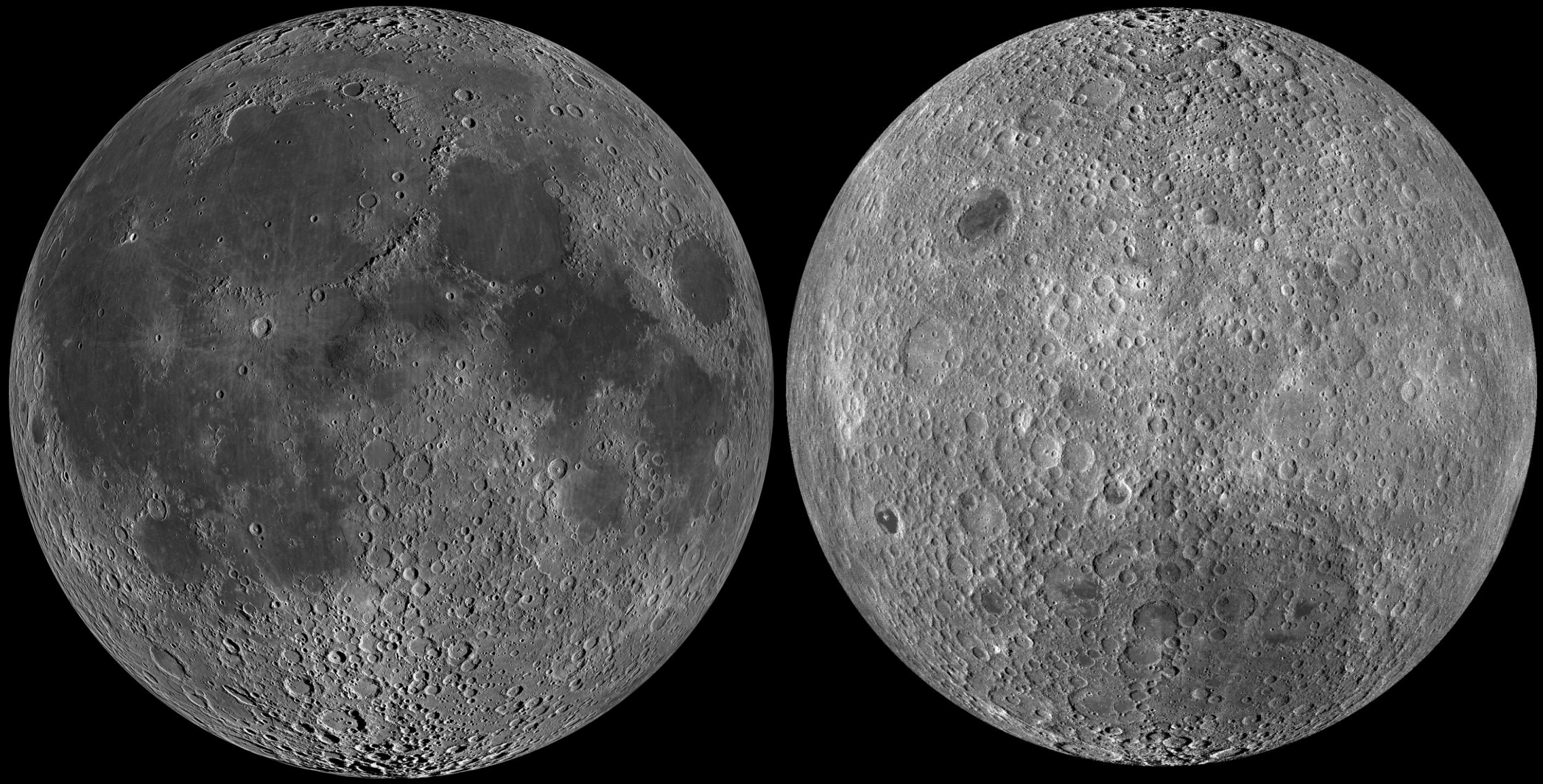
Lunar Prospector

SN

... 1990 ... 1994 ... 1997 1998 ...

Nearside

Farside

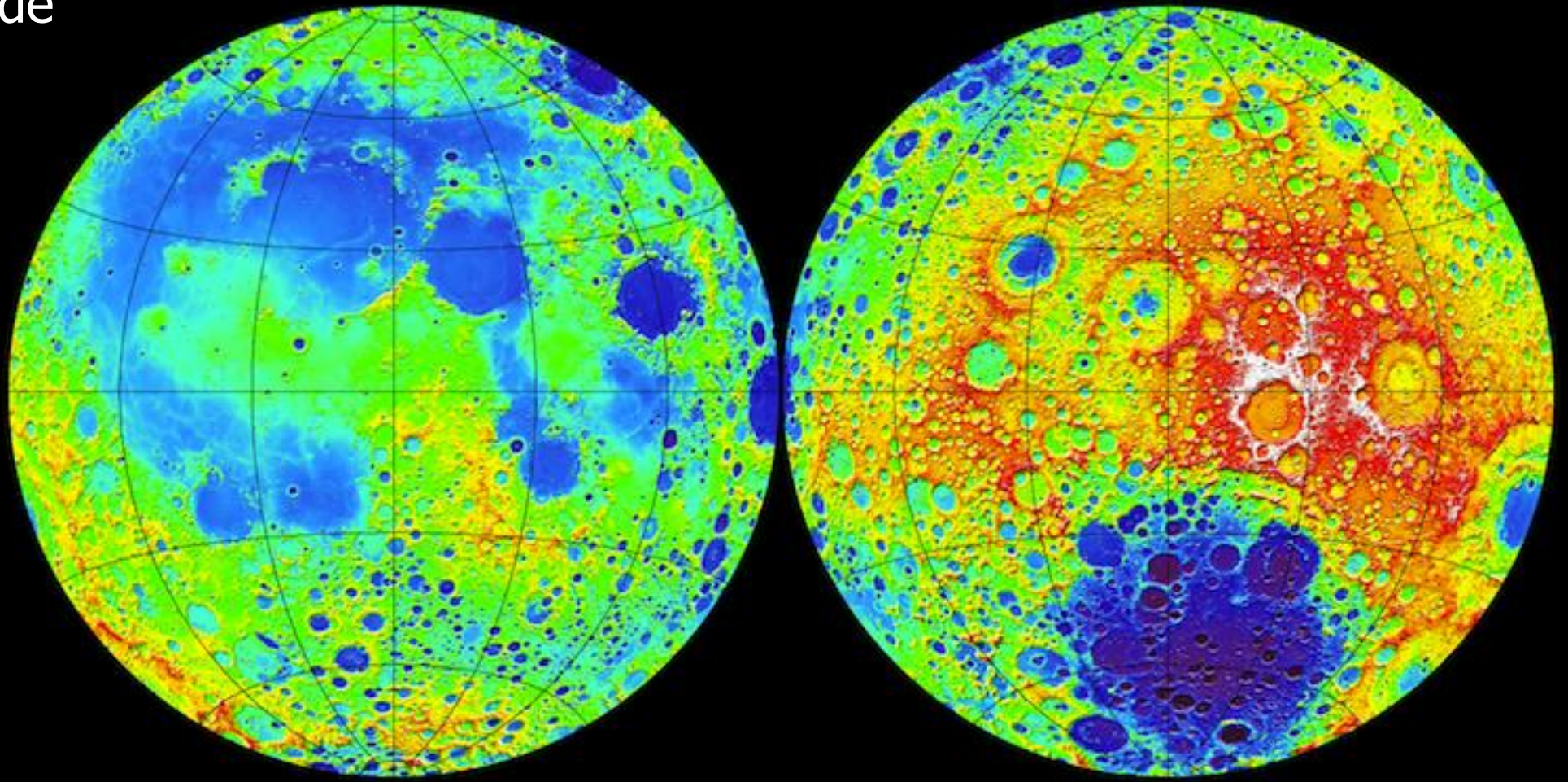


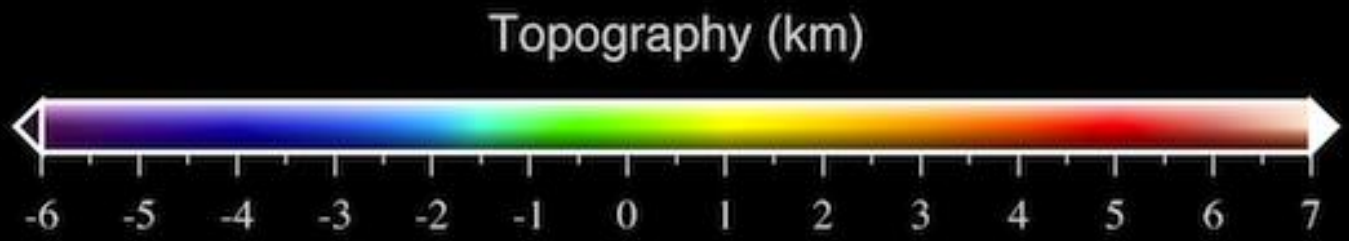
Earth’s Moon

Earth's Moon
Altitude

Nearside

Farside

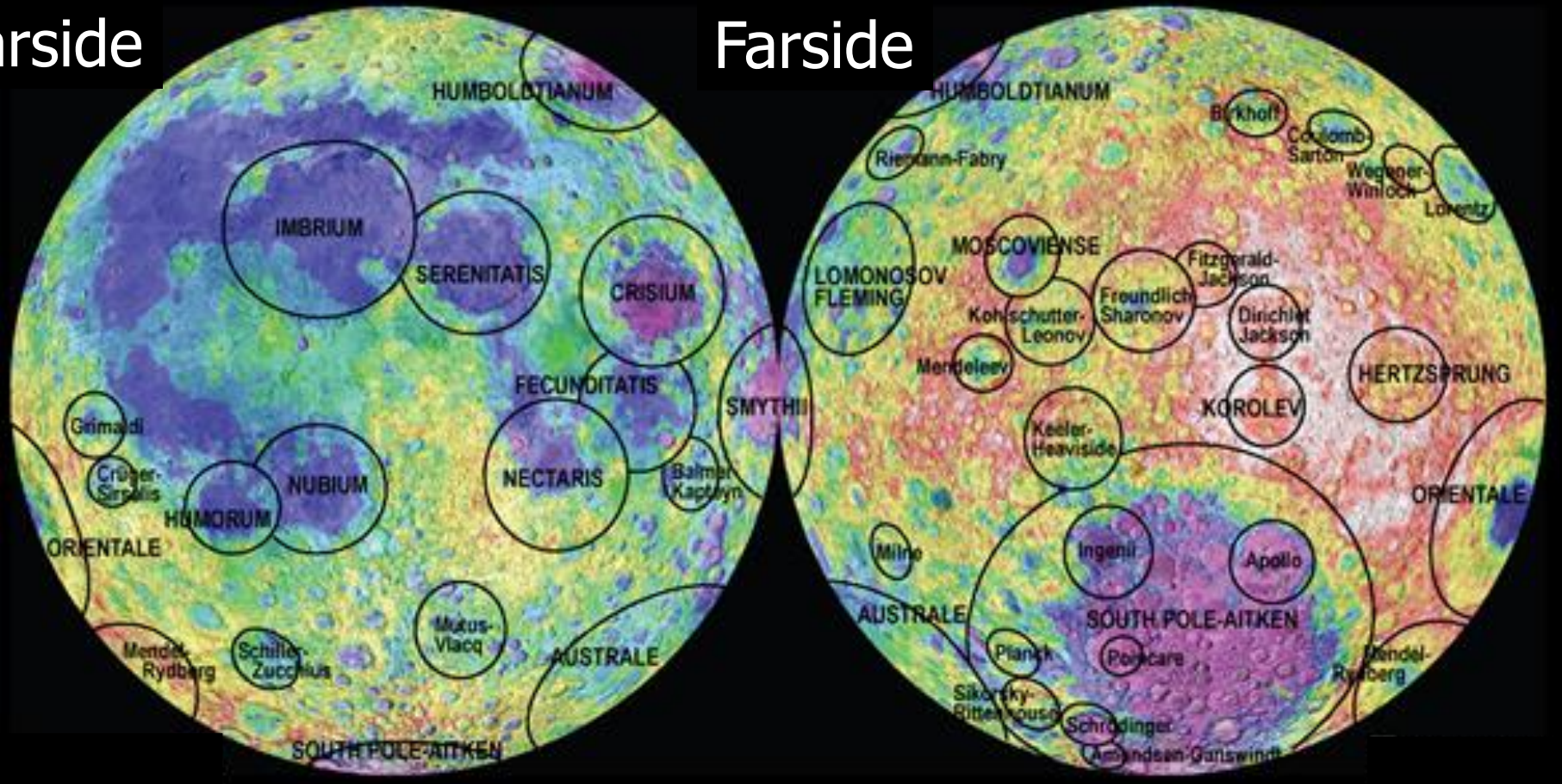




The Late Heavy Bombardment (4.0 - 3.8 Ga)

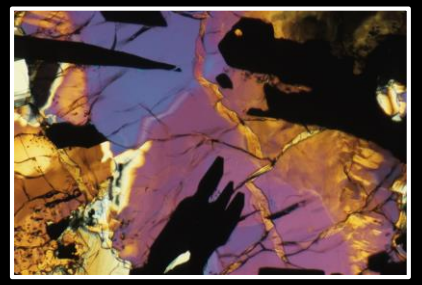
Nearside

Farside

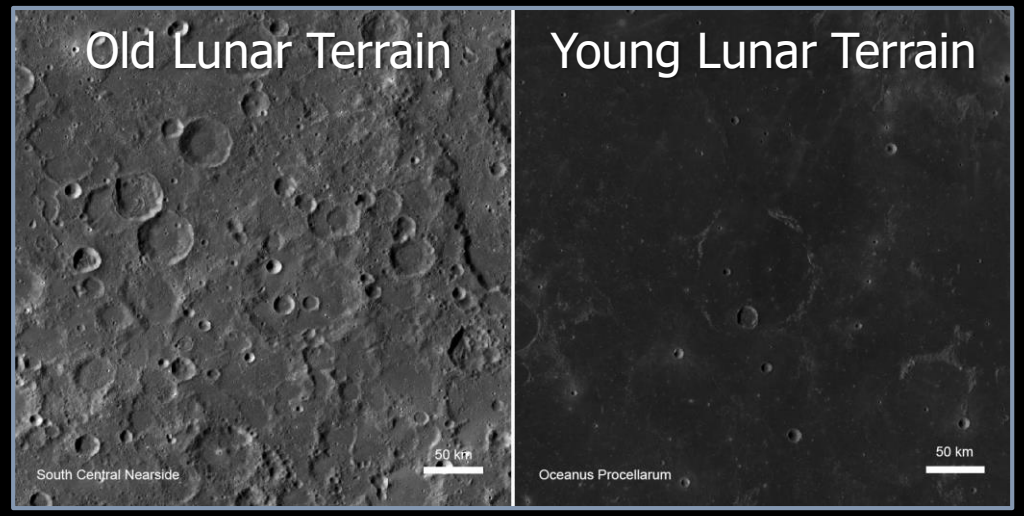


We have reliable radiometric dates only for Imbrium and Orientale Basins

Setting the Solar System's Clock

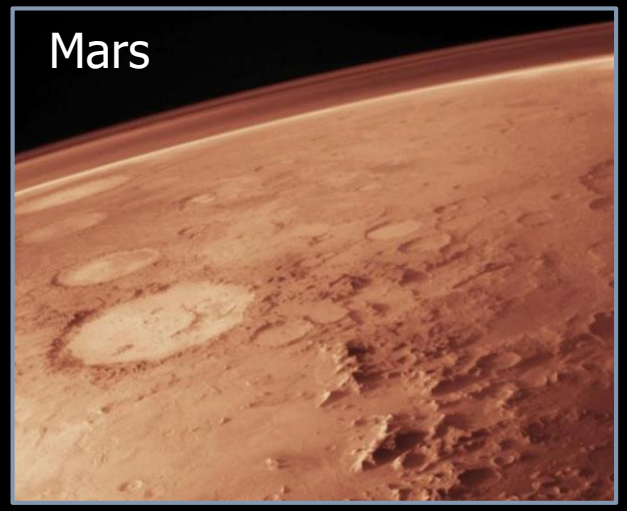


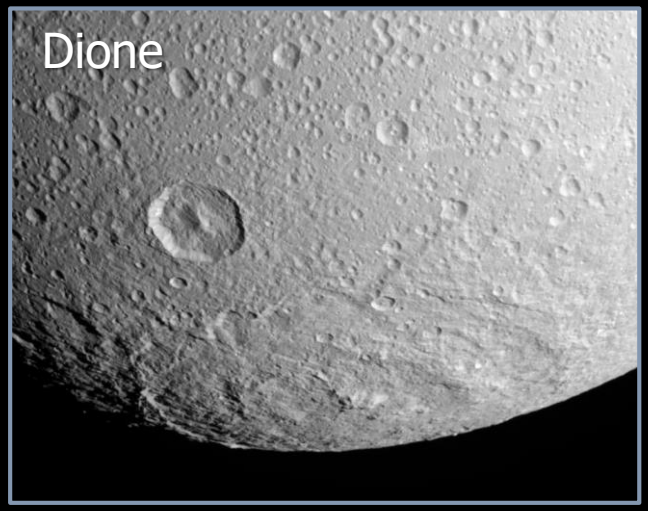
70017



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





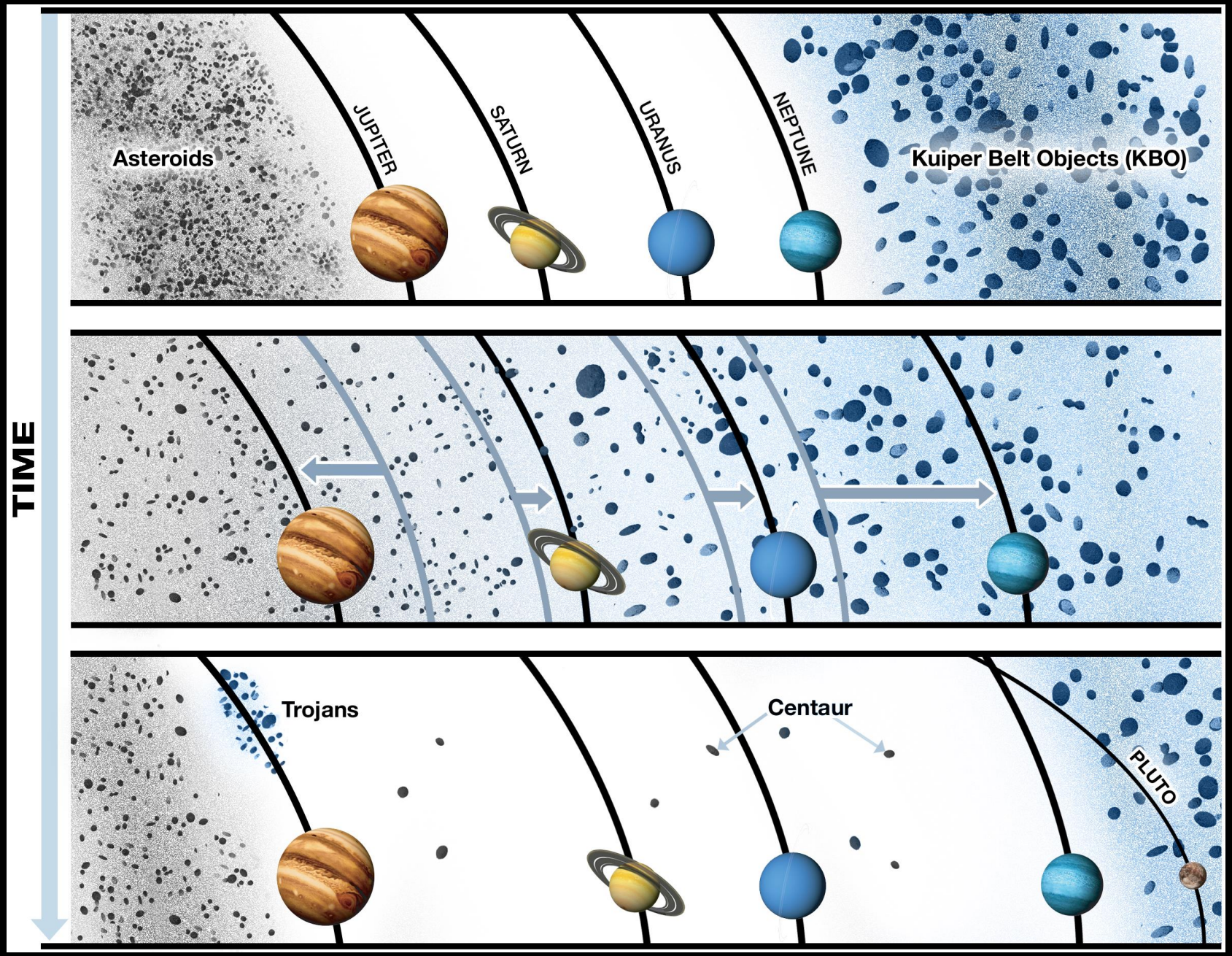
Nice Model: Evolution of the Solar System

~4.2 Billion Years

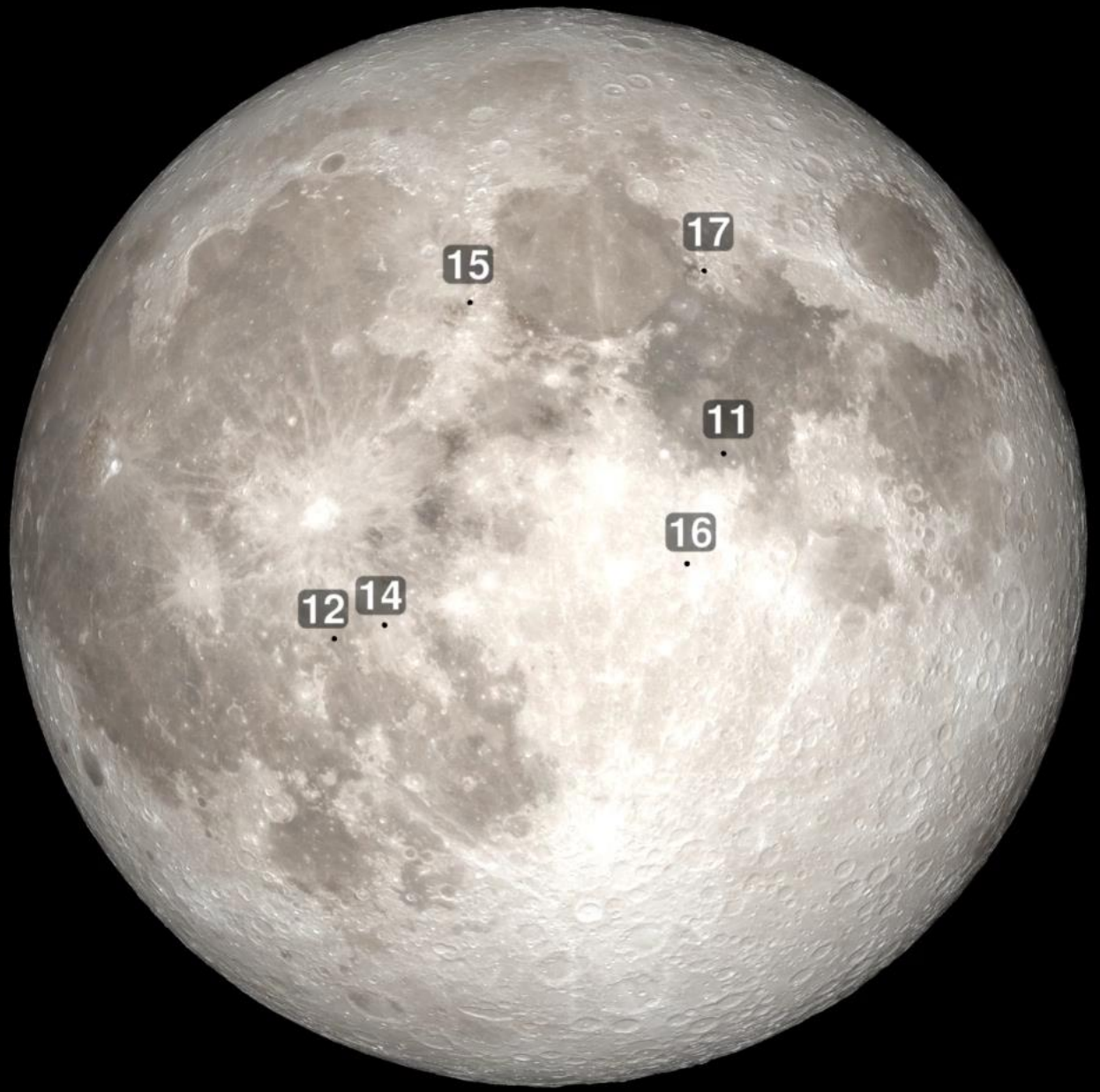
~3.8 Billion Years

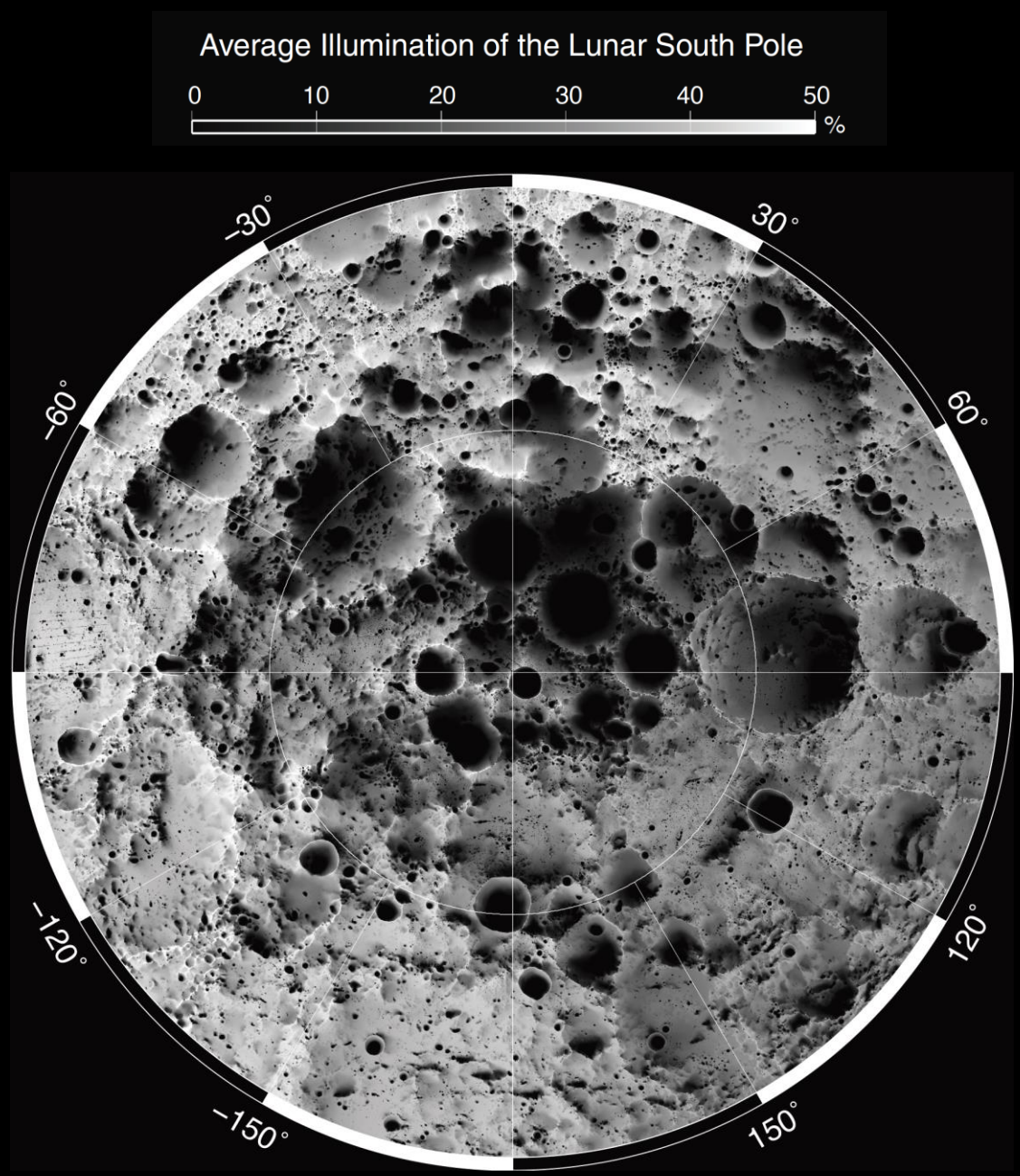
"Late Heavy Bombardment"

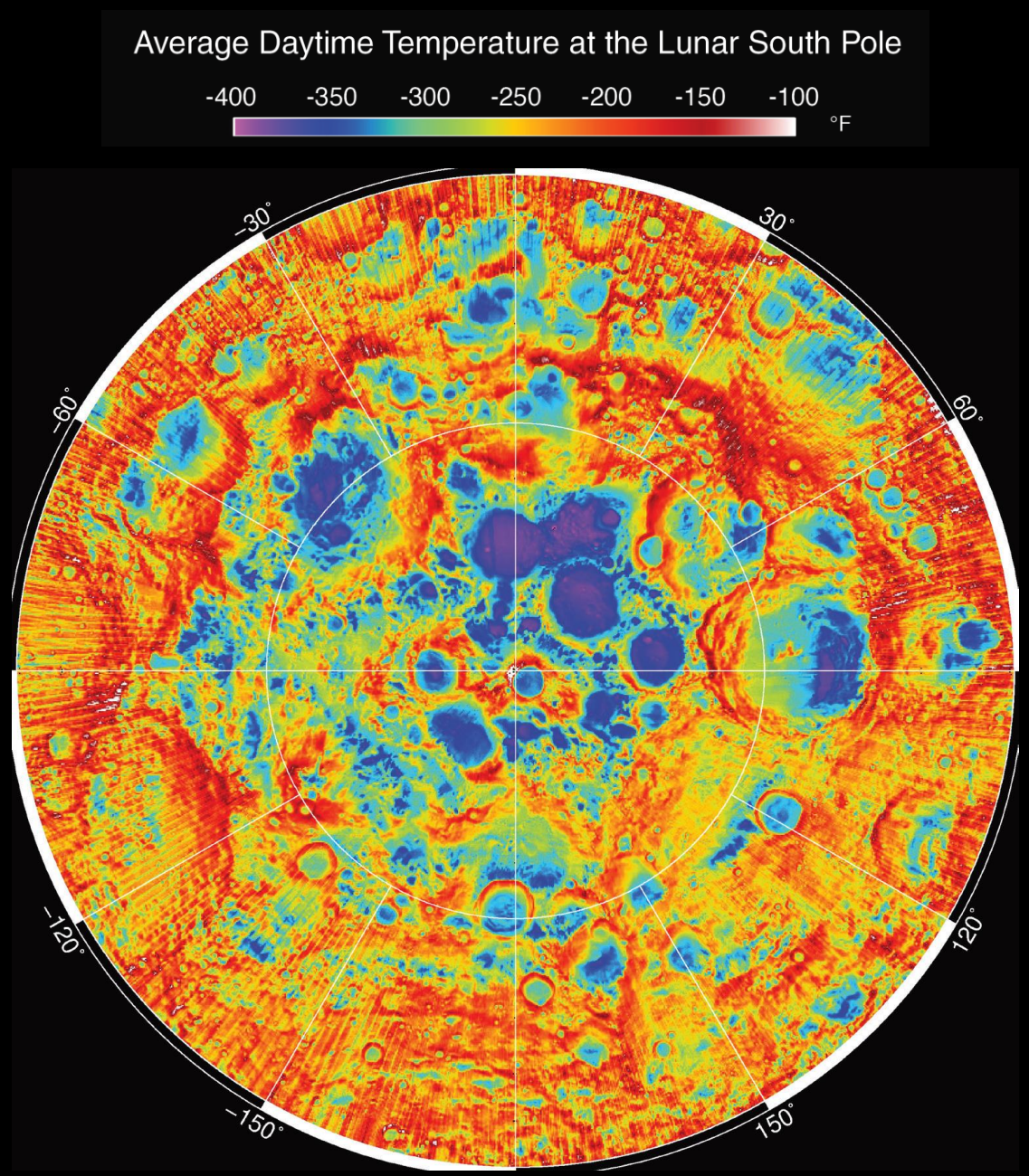
Today



Developing this model possible *only* by having lunar samples

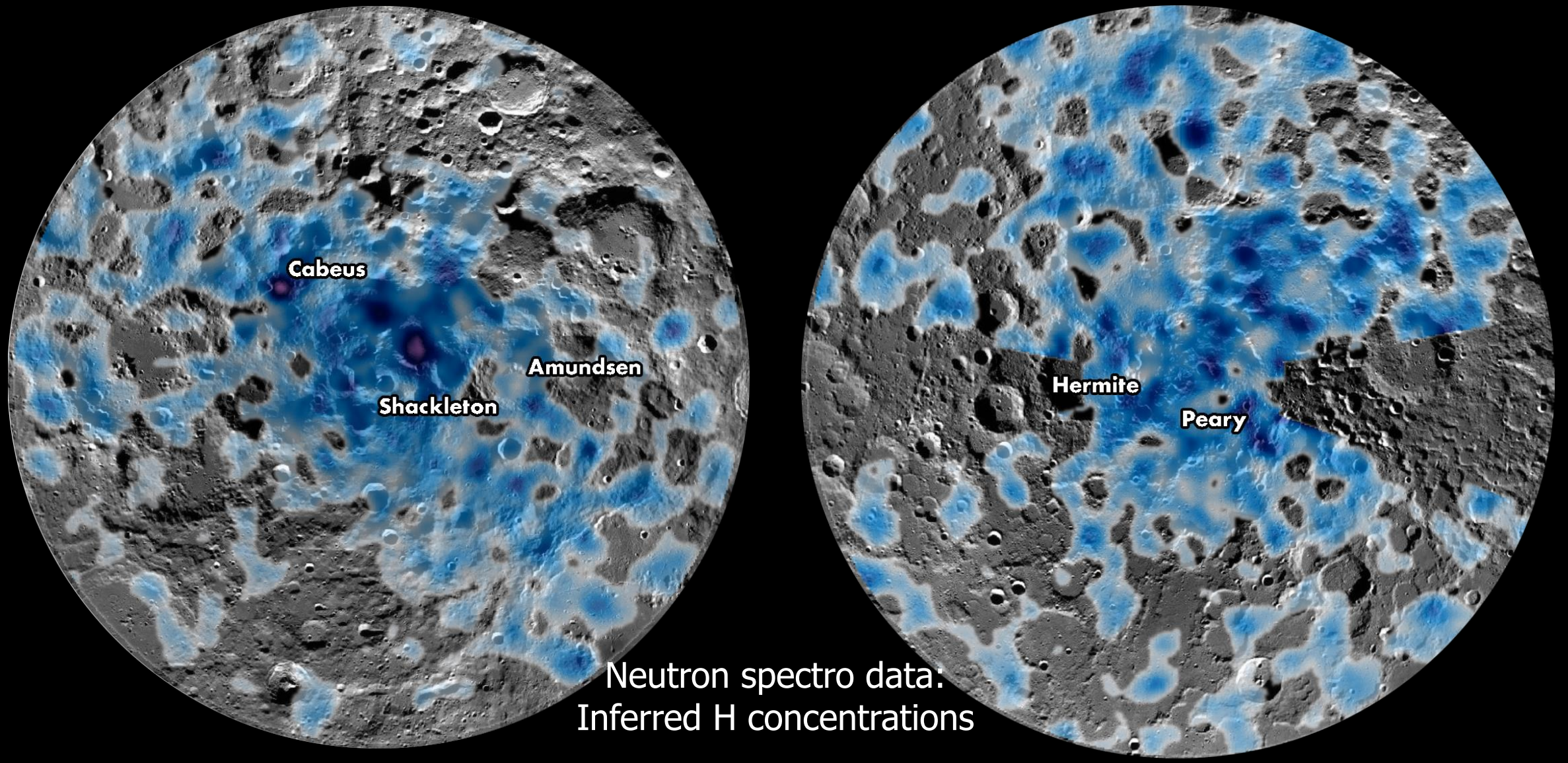

17
15
11
16
12
14


Average Illumination of the Lunar South Pole
0
10
20
30
40
50
%
-30°
30°
-60°
60°
-120°
120°
-150°
150°


Average Daytime Temperature at the Lunar South Pole
-400
-350
-300
-250
-200
-150
-100
°F
-30°
30°
-60°
60°
-120°
120°
-150°
150°

South Pole

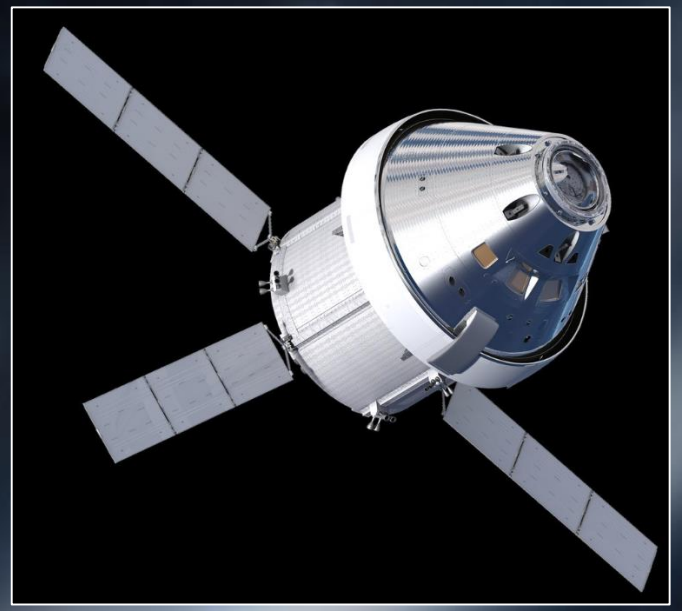
North Pole



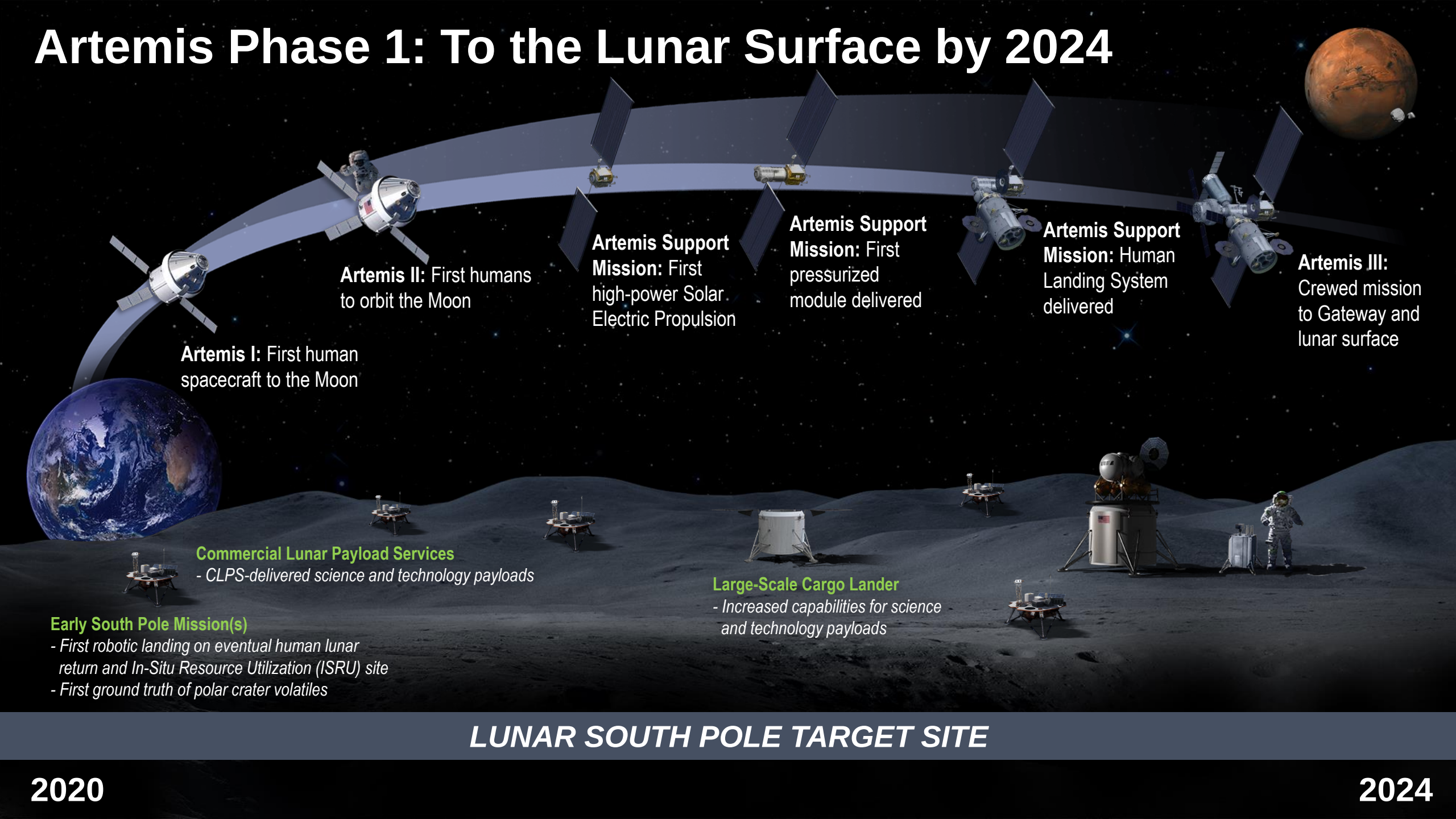
Neutron spectro data:
Inferred H concentrations

NASA's SLS and Orion
- with our international partners

ORION



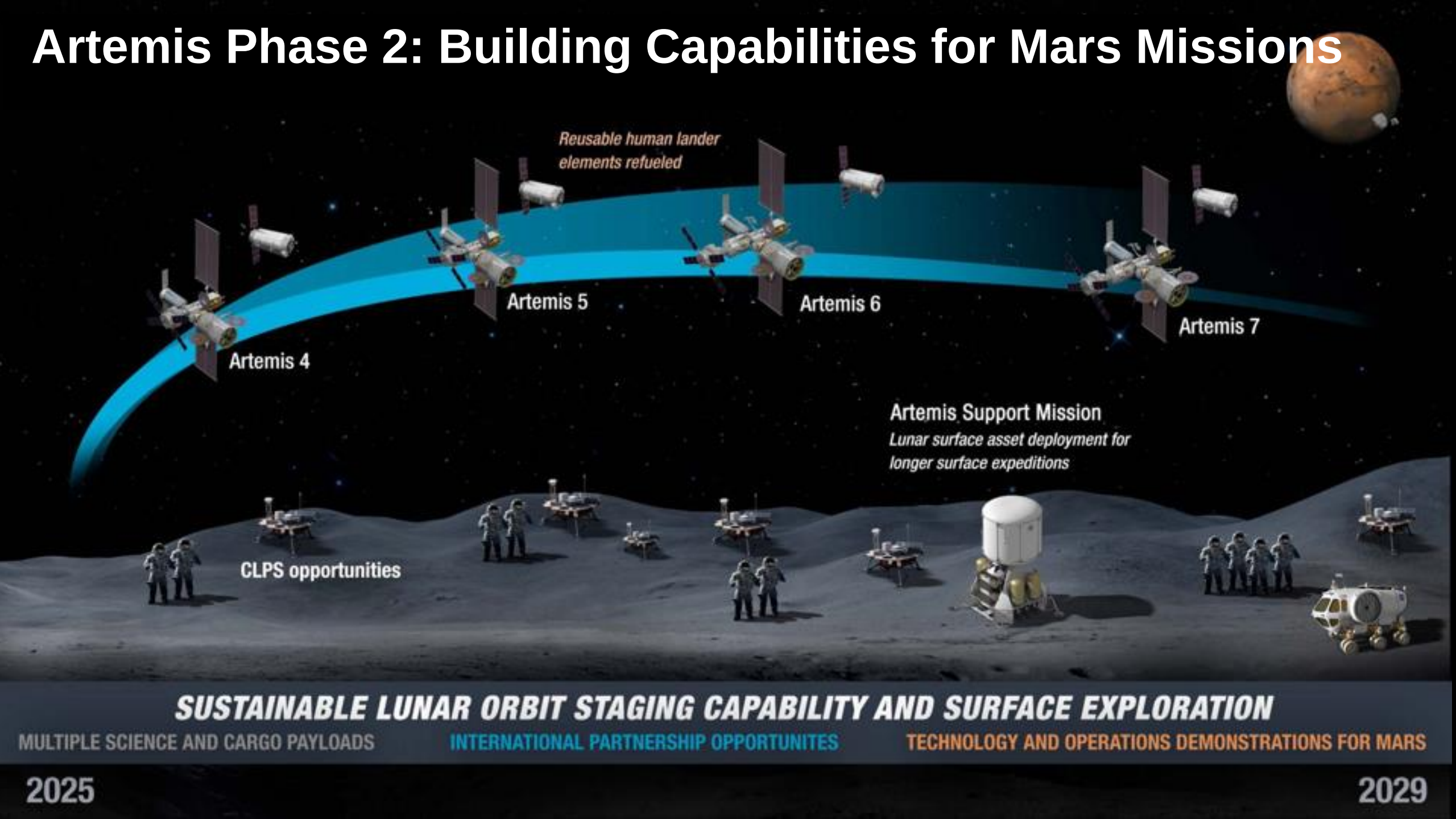
Artemis Phase 1: To the Lunar Surface by 2024



LUNAR SOUTH POLE TARGET SITE

2020 **2024**

Artemis Phase 2: Building Capabilities for Mars Missions



National Aeronautics and Space Administration

Space For All

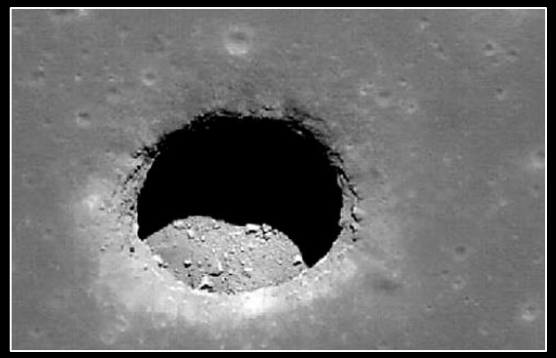
Unique moment for partnerships
- Unlike "Space Race" era, robust international and commercial sectors
- First steps in permanent human offworld presence

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

Future Moon

Science & Exploration



Living off the Land

Multi-planet Species

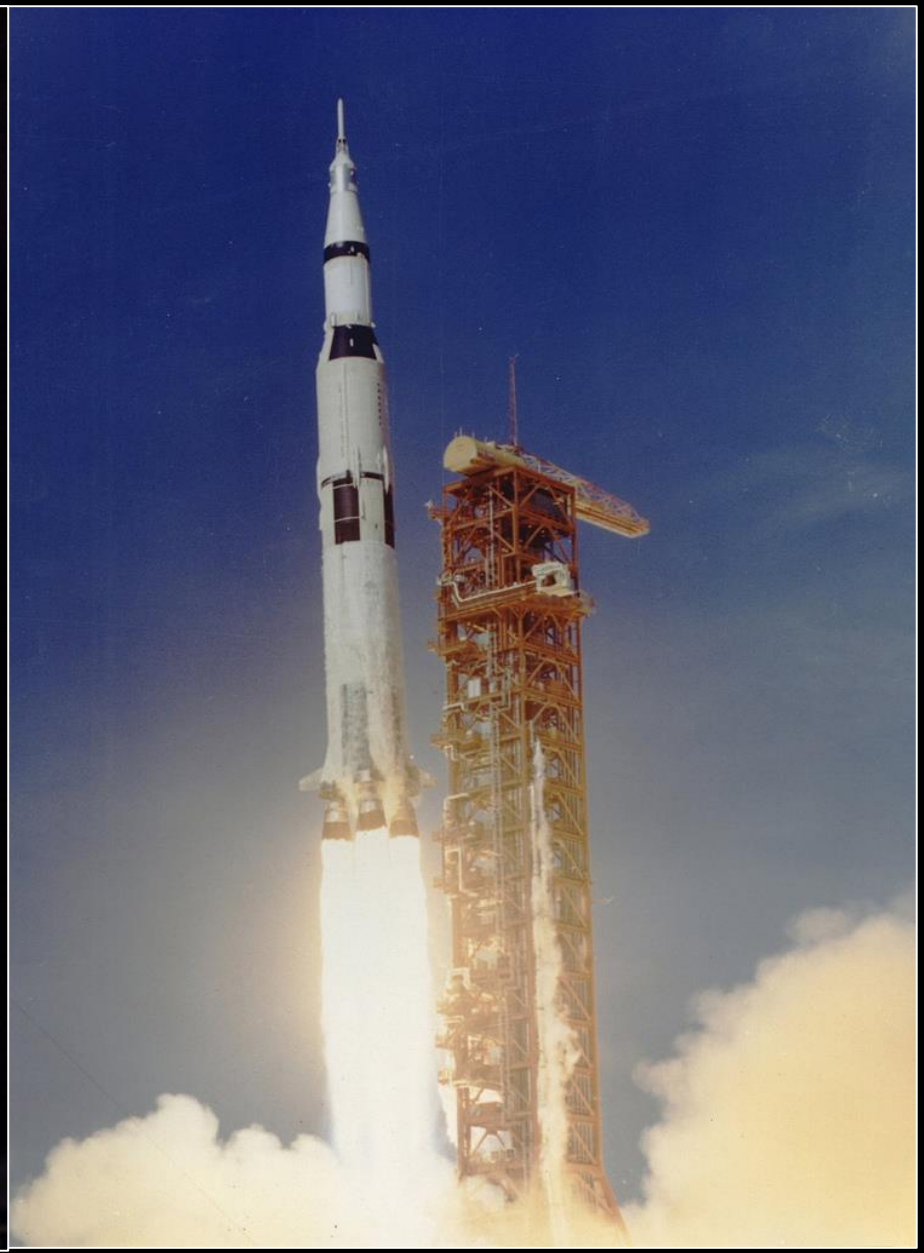
Fuel Depot

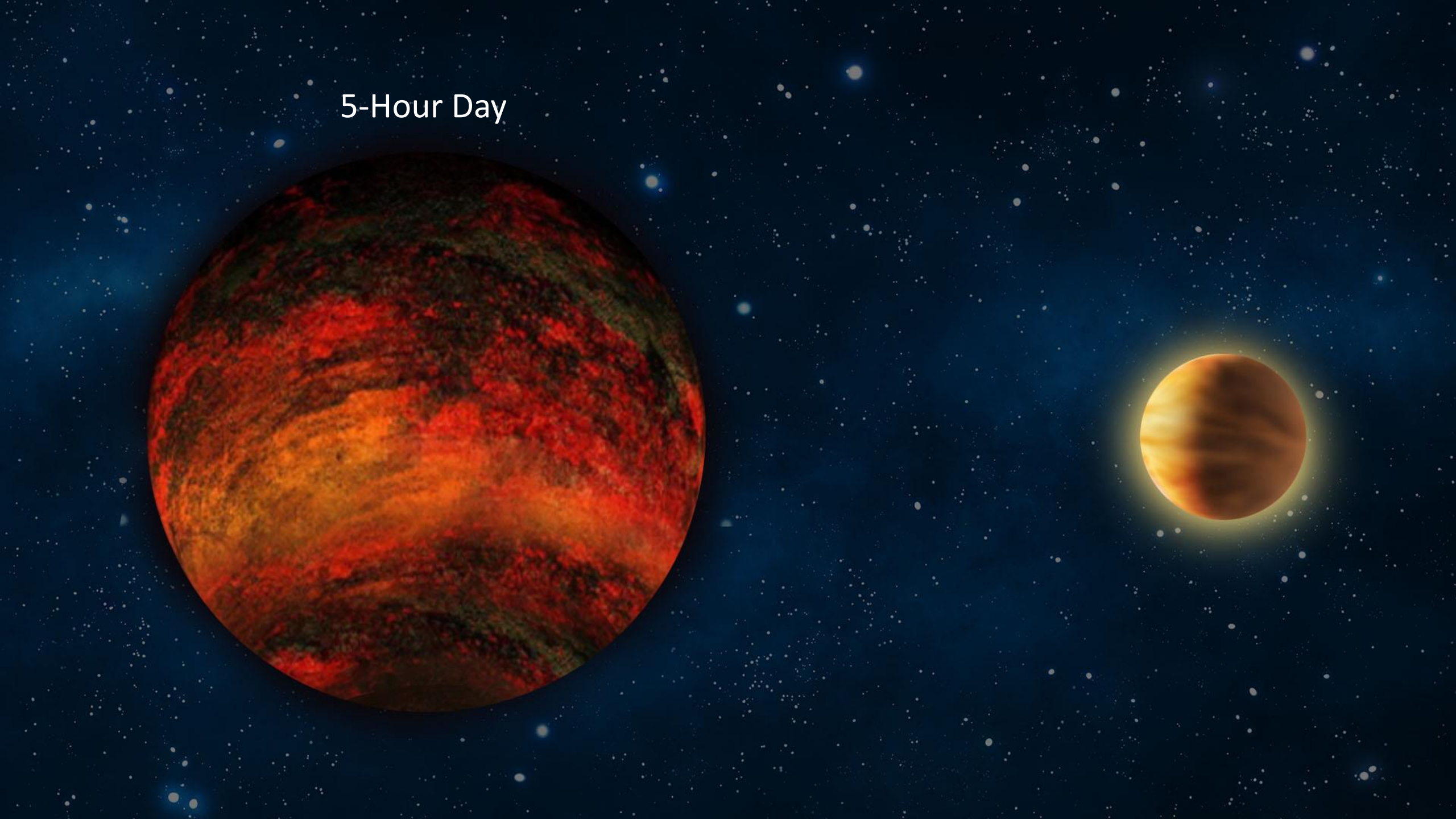
Mining

Manufacturing


Backup


NASA
ARMSTRONG
COLLINS
NASA
ALDRIN
NASA




5-Hour Day

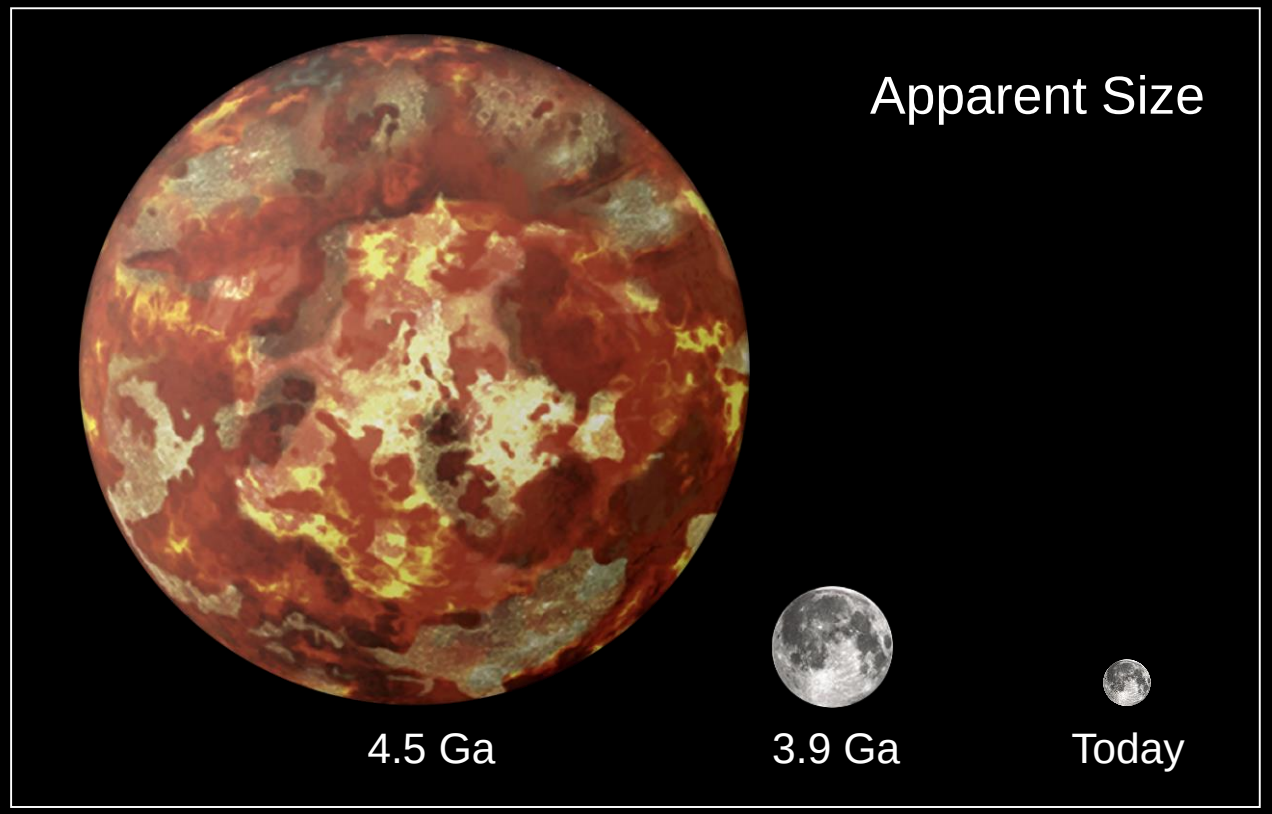
The Moon Stabilizes Our Spin Axis

Roche Limit

5 Hour Day

Moon
4.5 Ga

Slipping away
1 ½ inches per year



10 Hour Day

Moon
3.9 Ga
d ~ 21 R_E

Earth

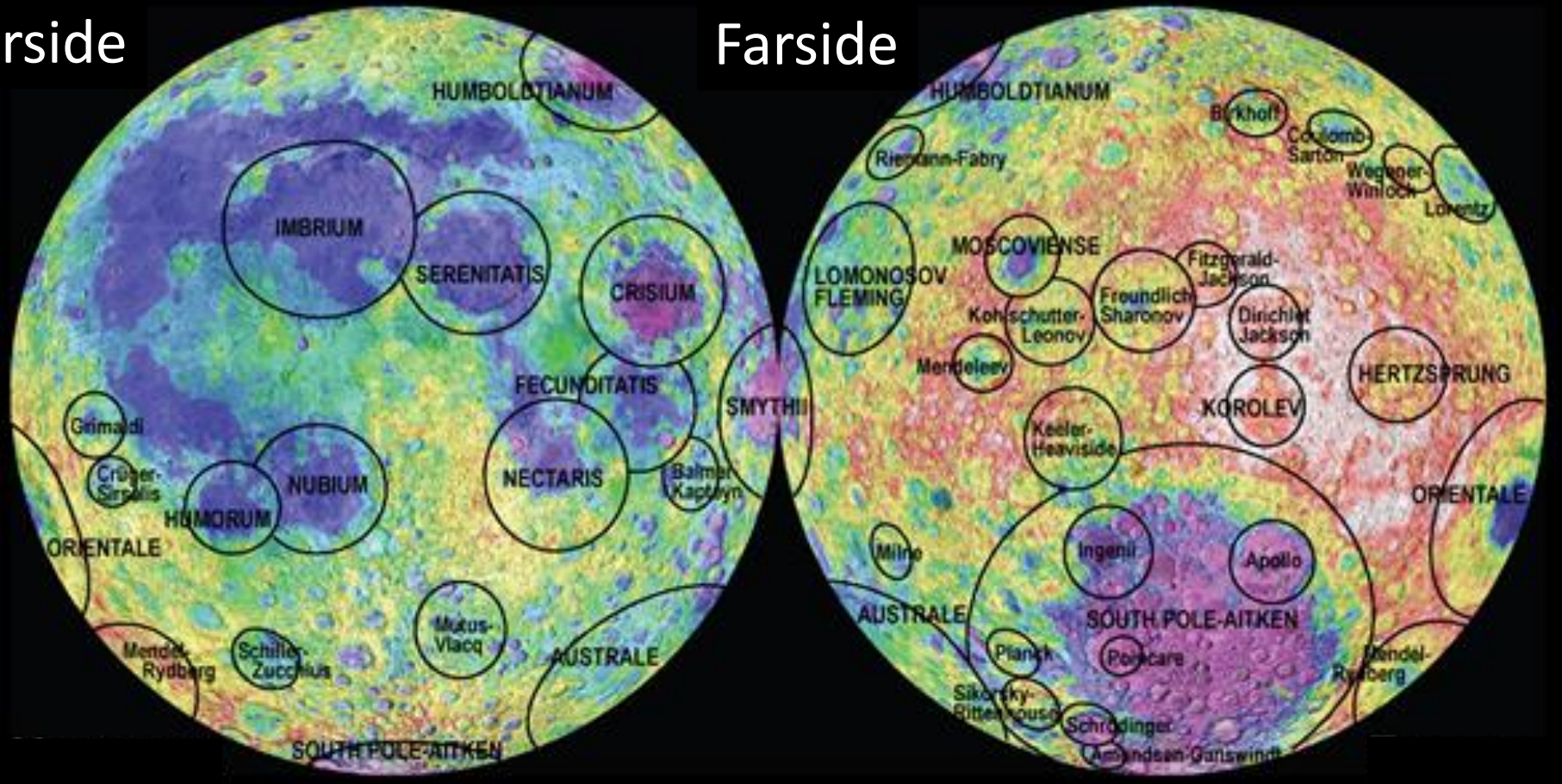
24 Hour Day

Moon Today
d ~ 60 R_E

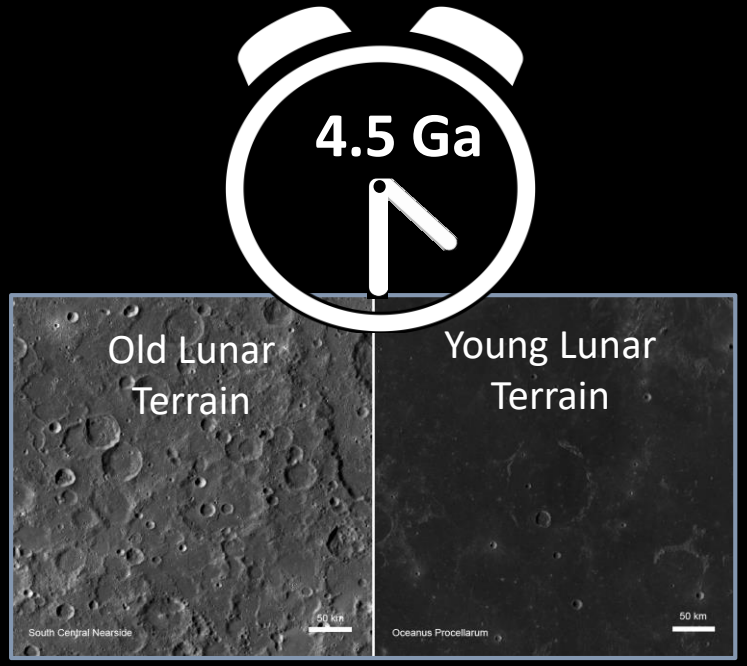
Bombardment History

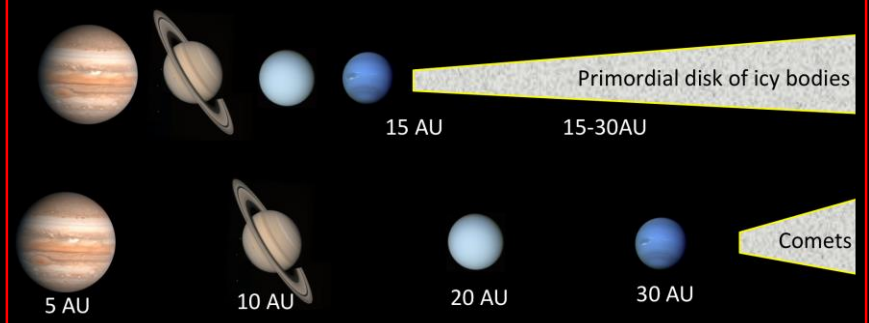
Nearside

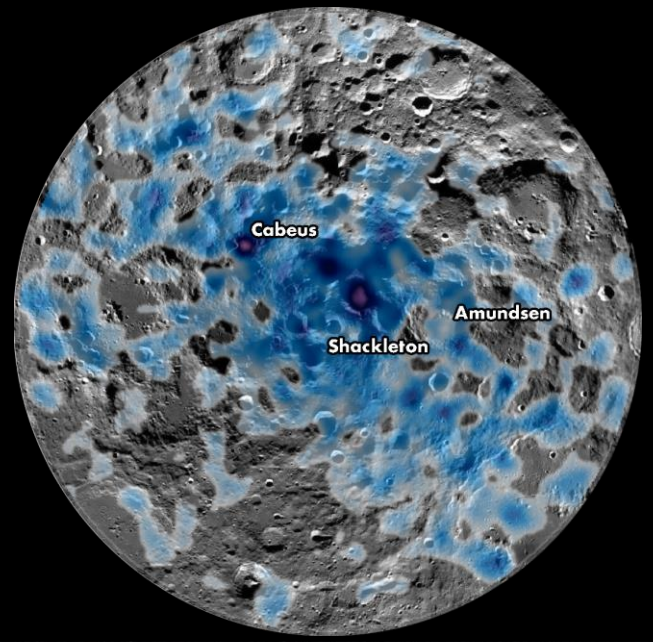
Farside

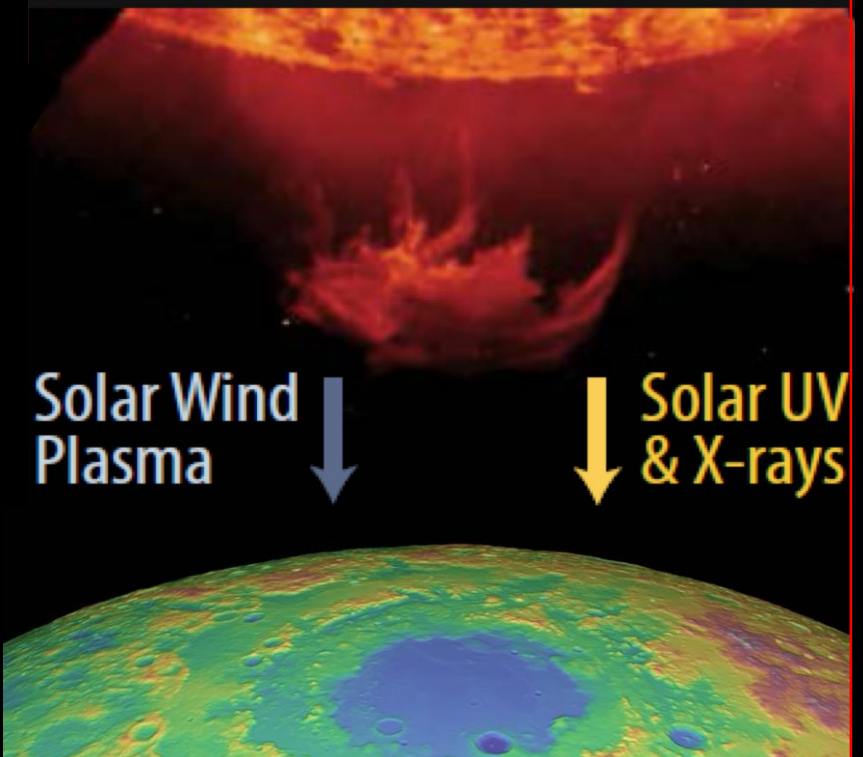


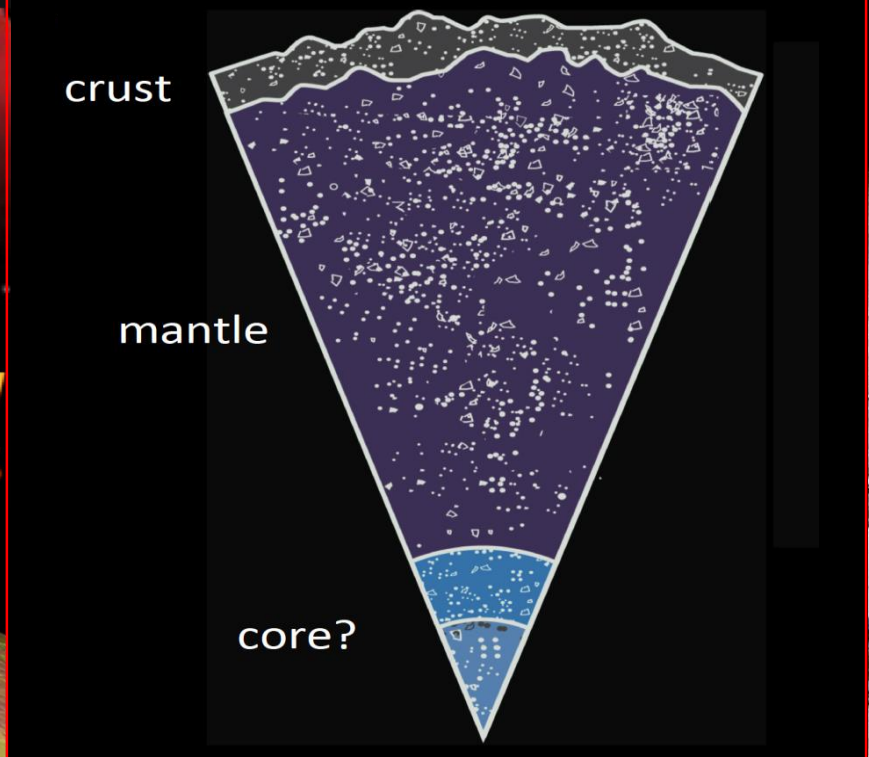
For every 1 impact on the Moon the Earth should have 20 impacts!


4.5 Ga
Old Lunar Terrain
Young Lunar Terrain
South Central Nearside
50 km
Oceanus Procellarum
50 km


Primordial disk of icy bodies
15 AU
15-30AU
5 AU
10 AU
20 AU
30 AU
Comets


Cabeus
Amundsen
Shackleton

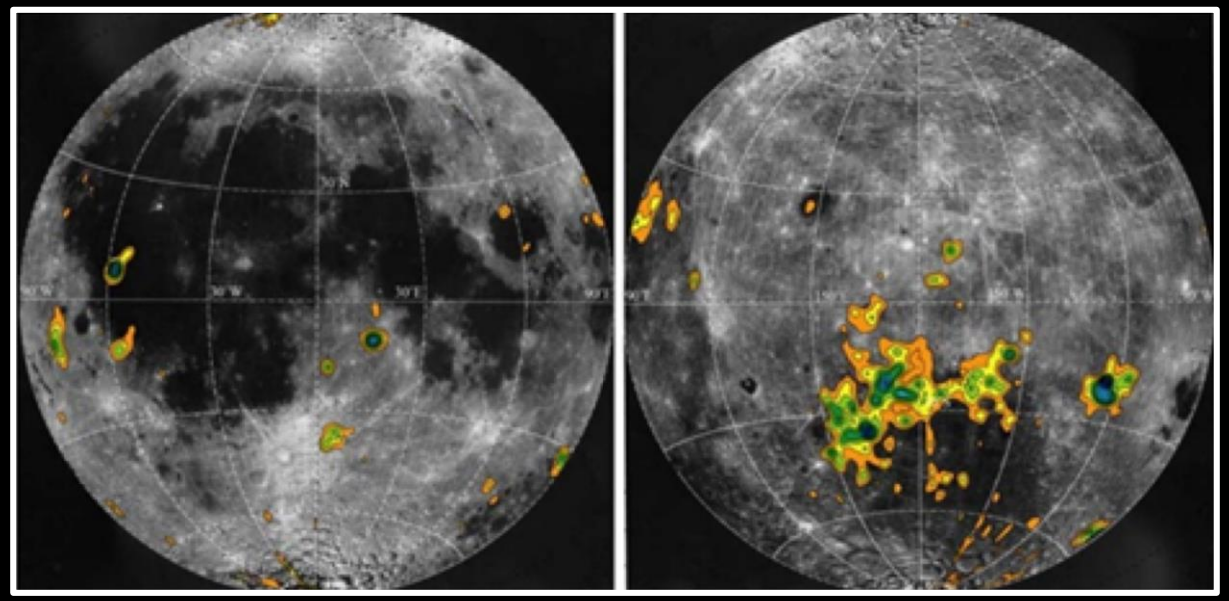

Solar Wind Plasma
Solar UV & X-rays


crust
mantle
core?

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

Nearside Farside



3nT 15nT (at 30km)

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