



# Moon

*A very 'happening' place*

*Shyama Narendranath  
Space Astronomy Group, URSC, ISRO*

# Inner Solar System

Mercury



Venus



Earth



Mars



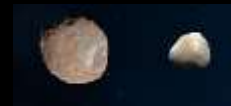
Our Moon is special !

Moon

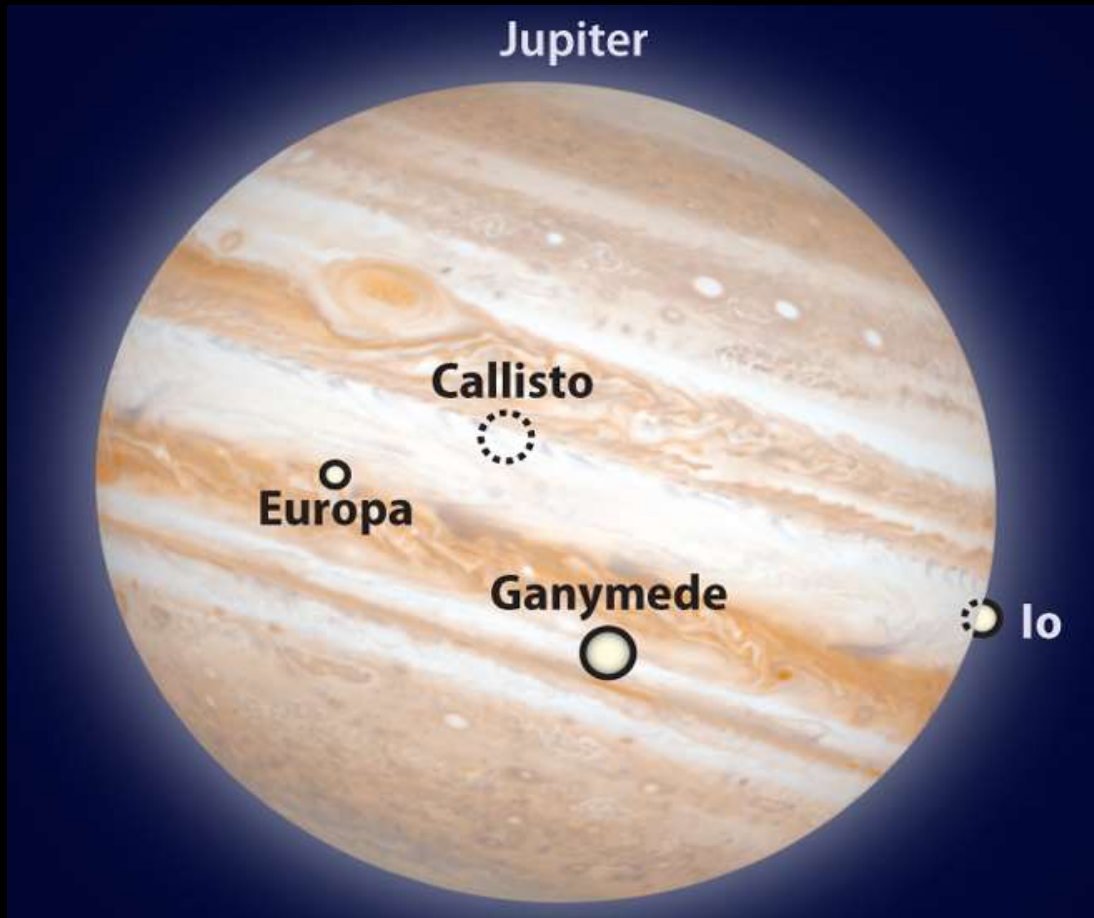


Phobos & Deimos

Zoomed



# Our Moon is special !



Earth  
diameter = 12,760 km



Moon  
diameter = 3,480 km



Near side

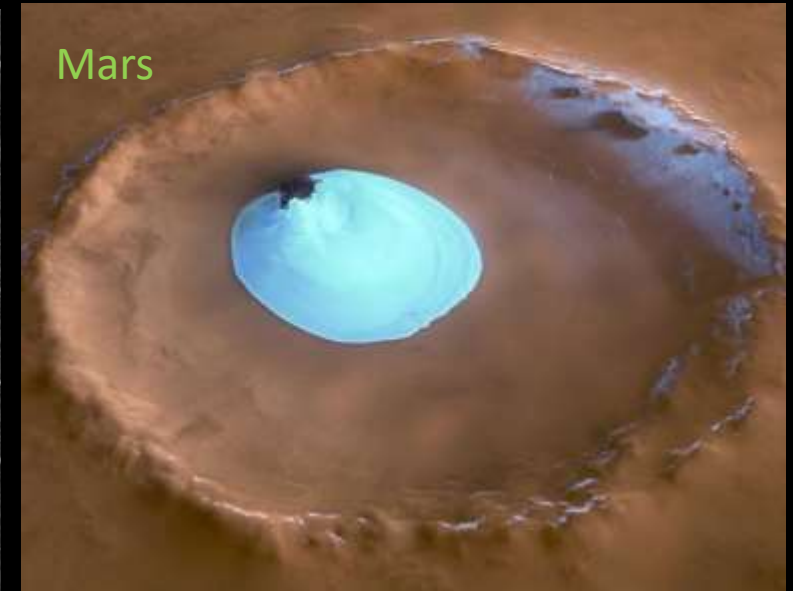
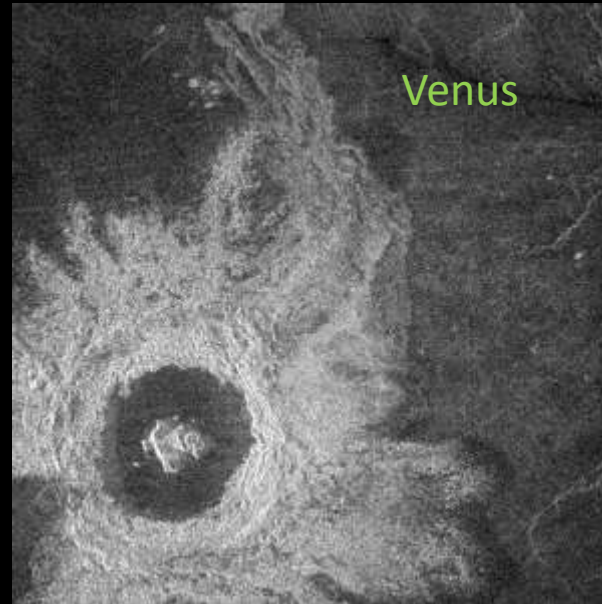


Far side



# Our Moon is special!

- 4.5 billion years of history preserved



Craters on planets : history of bombardment

What made the Moon?



# Myths and folktales across the world



# Rational thinking

George Darwin proposes Moon  
torn off from Earth



Harold Urey : Captured Moon?





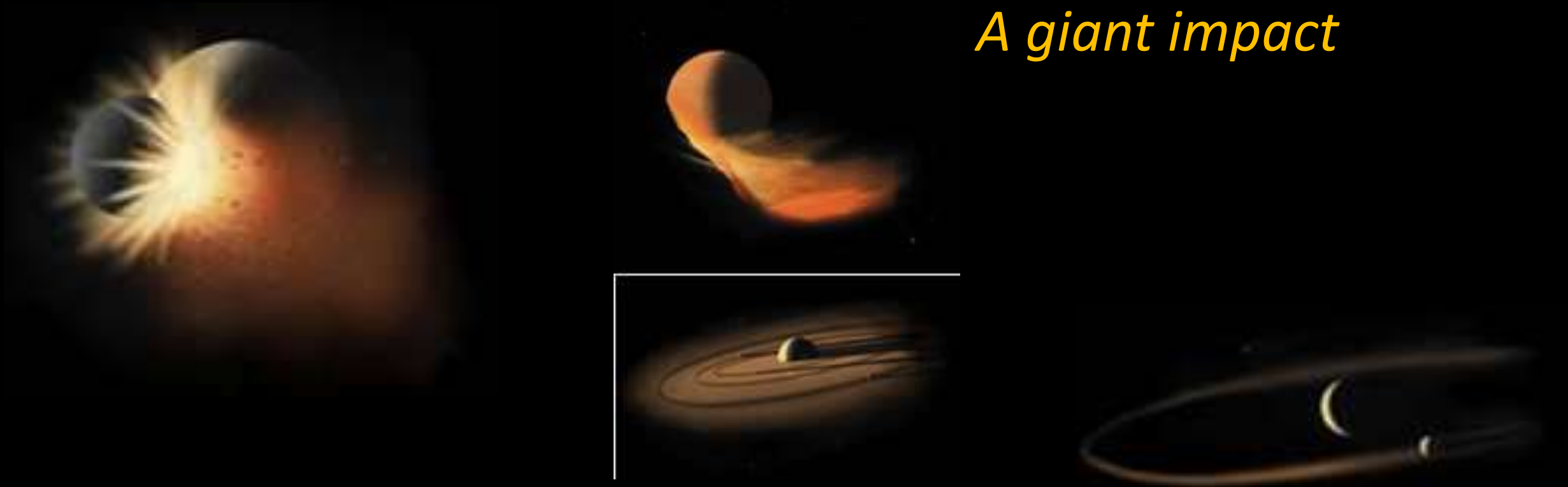
## Putting the pieces of evidence together

- Moon is moving away at the rate of 3.8 cm/year
- Moon has a lower density than Earth
- Moon rocks does not have water
- Moon is as old as Earth

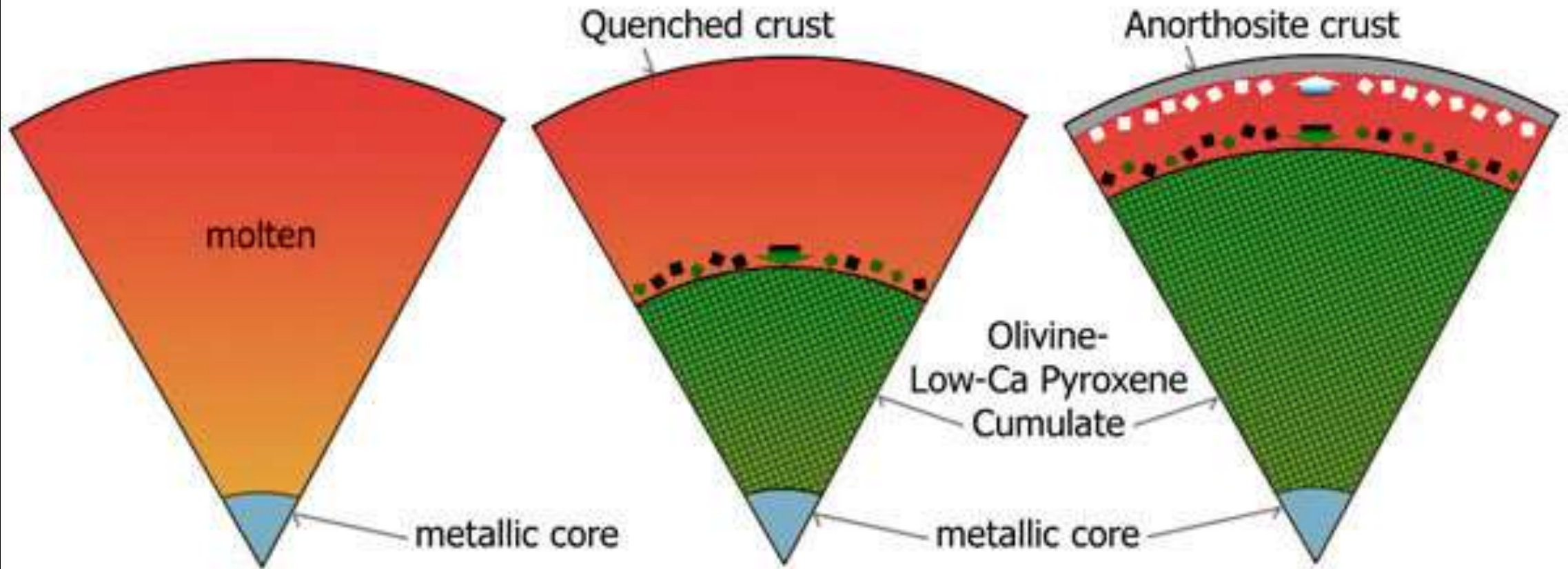


# Origin of the Moon

*A giant impact*



# Lunar Magma Ocean



- Olivine
- Pyroxene
- Plagioclase



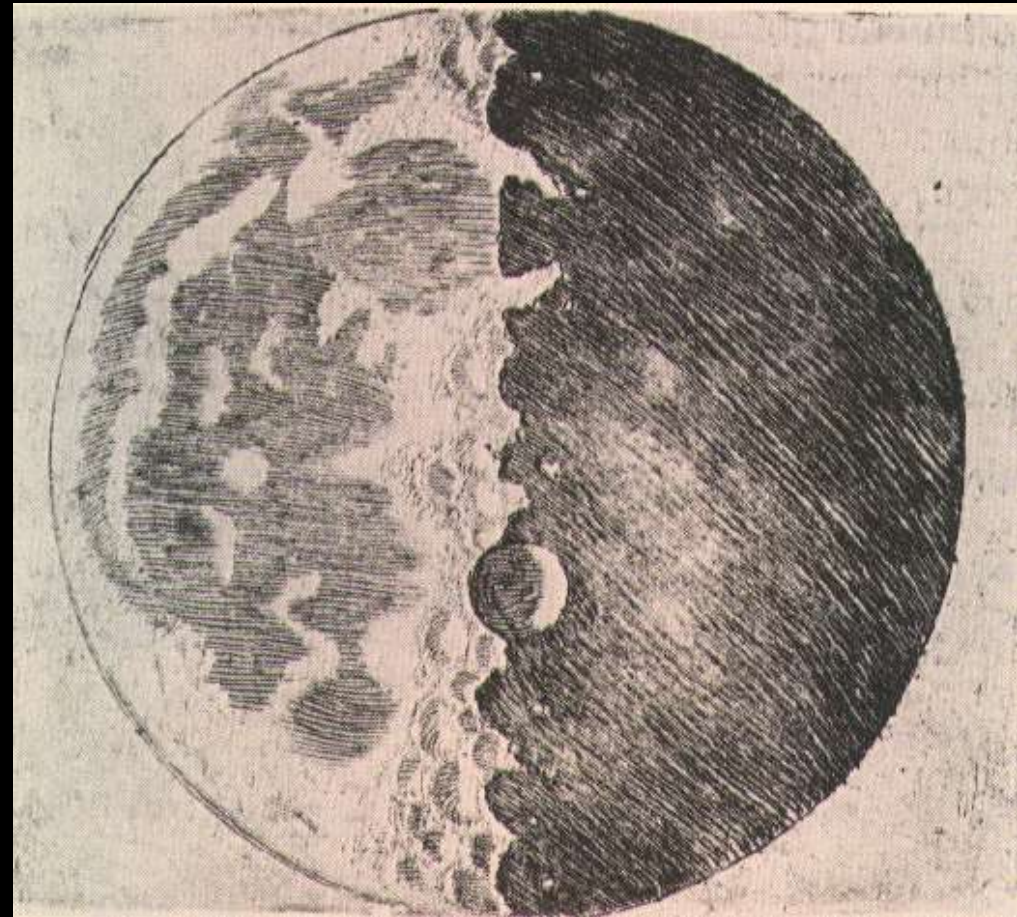
How do we find out?

26 July 1609, the English scholar Thomas Harriot pointed his newly acquired 'dutch trunke' at the Moon and drew what he saw



Whitfield, Nature 2009

30 Nov 1609, Galileo Galili



# Sources of information

- 584 confirmed lunar meteorites
  - <https://www.lpi.usra.edu/meteor/metbull.php>
- Returned samples
  - Apollo: ~382 Kg, Luna: 320g, Chang'e 5: 1.7 Kg  
<https://curator.jsc.nasa.gov/lunar/lsc/>
- In situ measurements
  - Rover, Lander
- Remote sensing from an orbit
- Ground telescopes



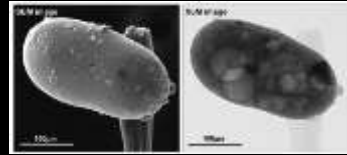


# Moon soil is special!

- Lunar soil



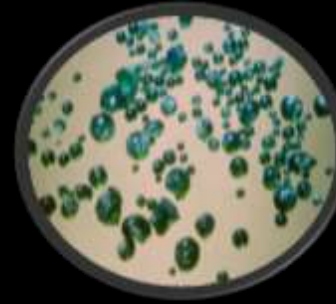
Luna -16 core



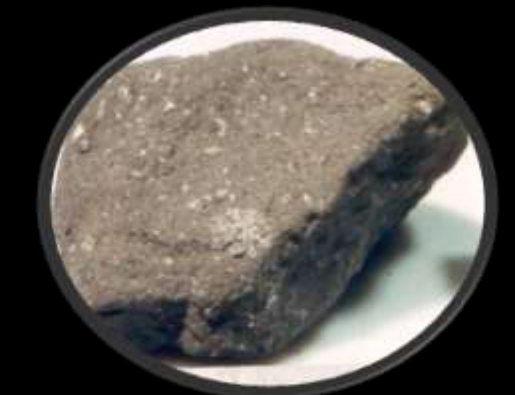
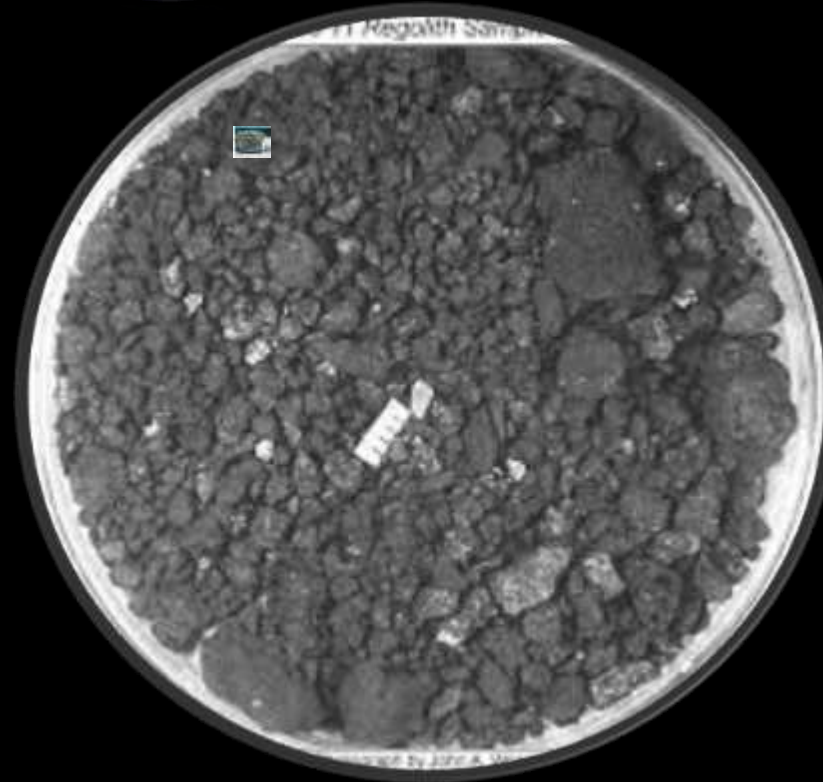
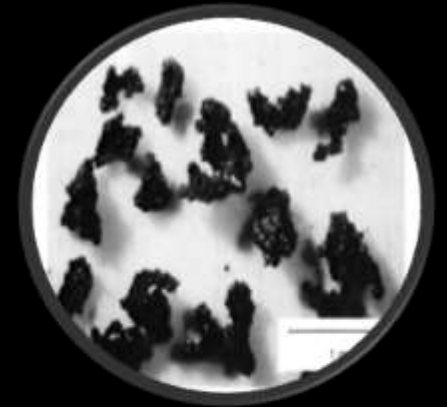
*Glass sphere*



Green glasses



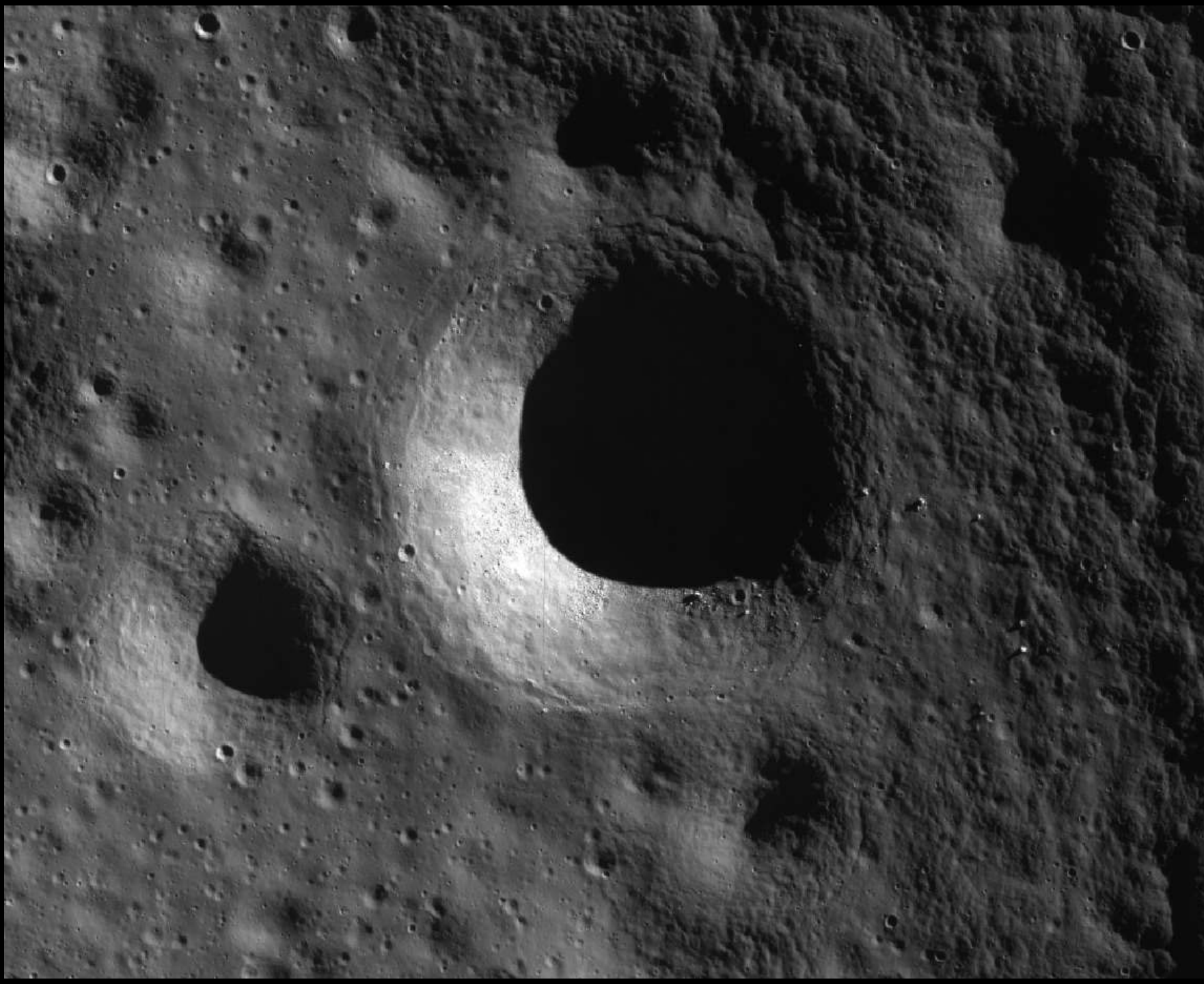
Agglutinates



Regolith breccia

# Some early revelations

- Moon is an evolved differentiated body
- Moon formed magmatically hot
- Moon rocks are older than Earth's
- Moon formed in anhydrous (without water) environment
- Moon's surface is covered by a thick regolith
- Moon does not have life



# A crater on the Moon

Photo credit: Chandryayaan-2

Location: Hagecius Crater area



400m



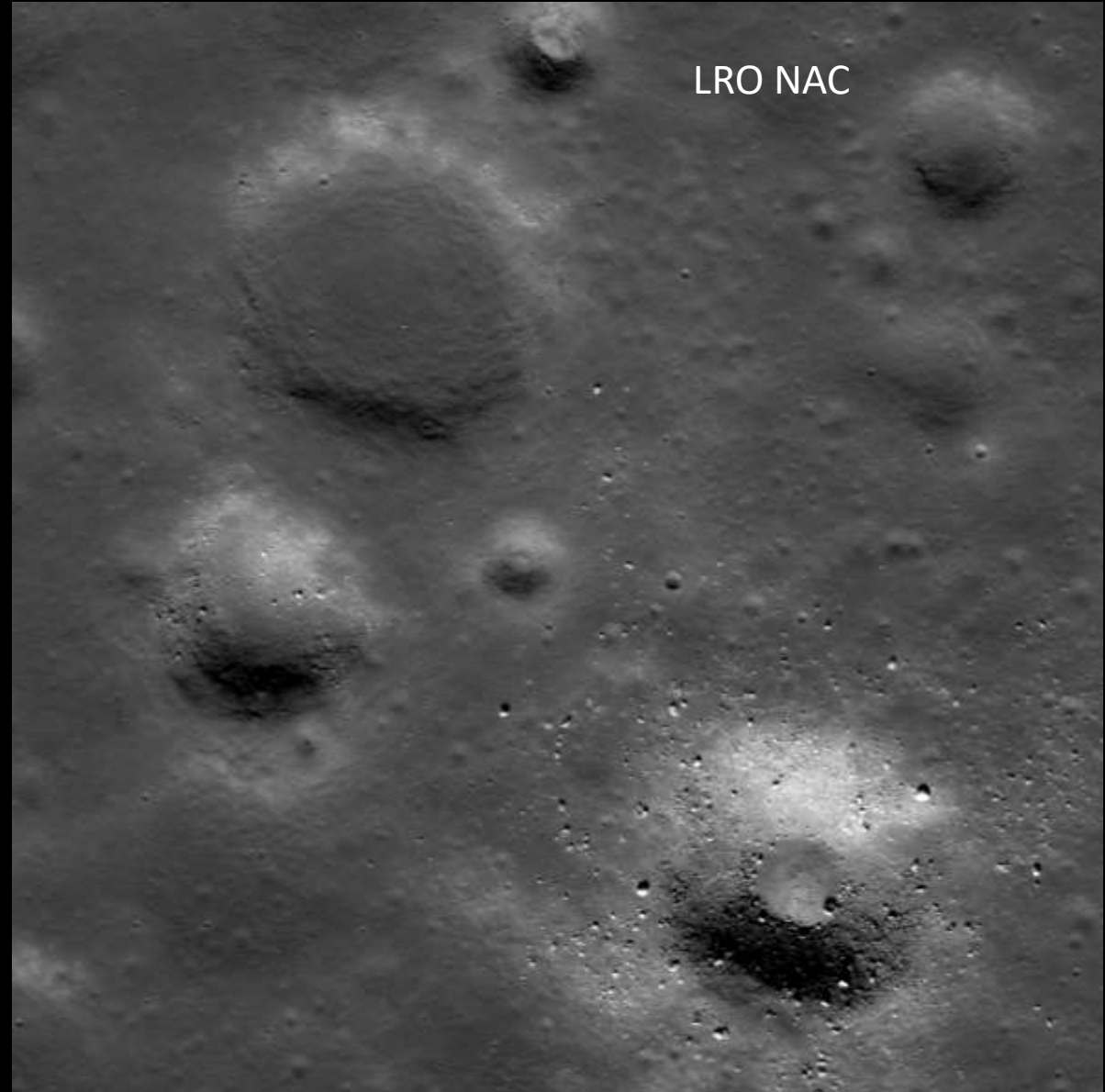
Boulders  
Unsafe to land!



Photo credit: Chandryayaan-2



TMC-2 on Chandrayaan-2



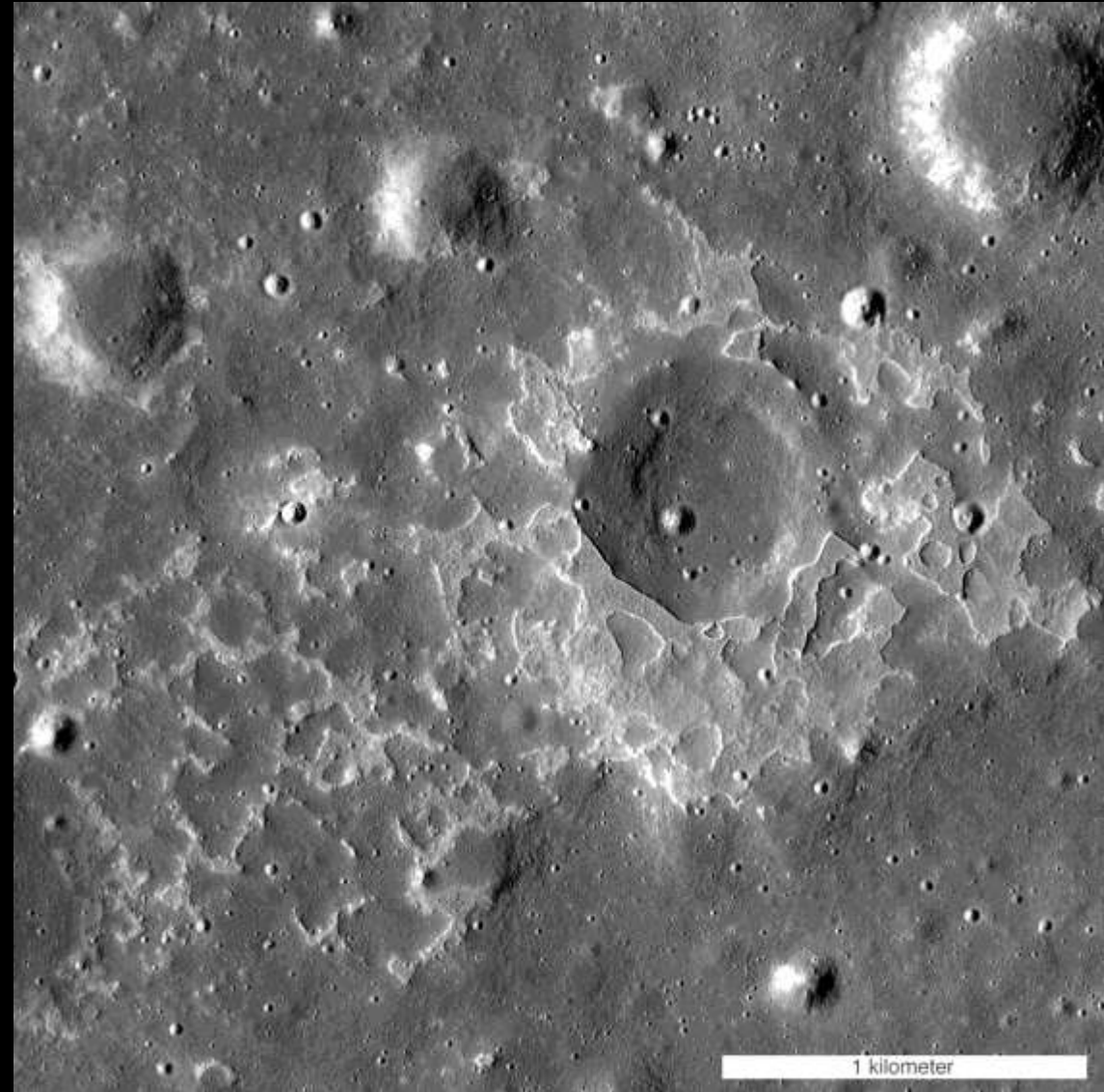
LRO NAC

# CRATERS : AGE INDICATORS

# Young mare volcanism

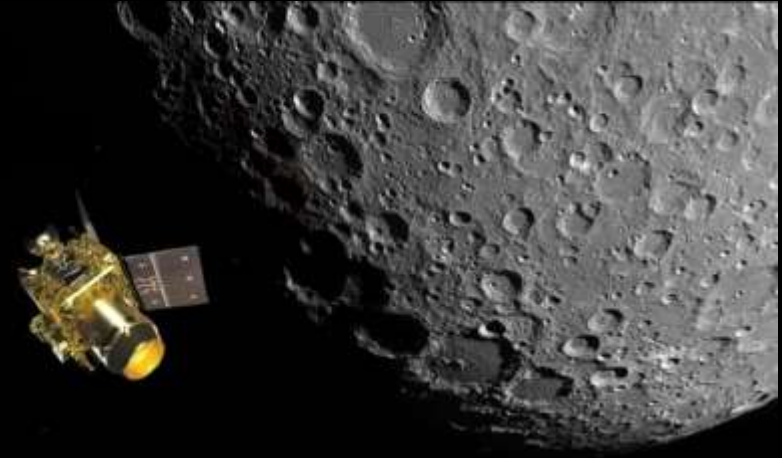
- $2,030 \pm 4$  million years for the Chang'e-5 basalts

*How did the cooling Moon have enough heat?*



Young volcanic deposits (100-50 million year old)

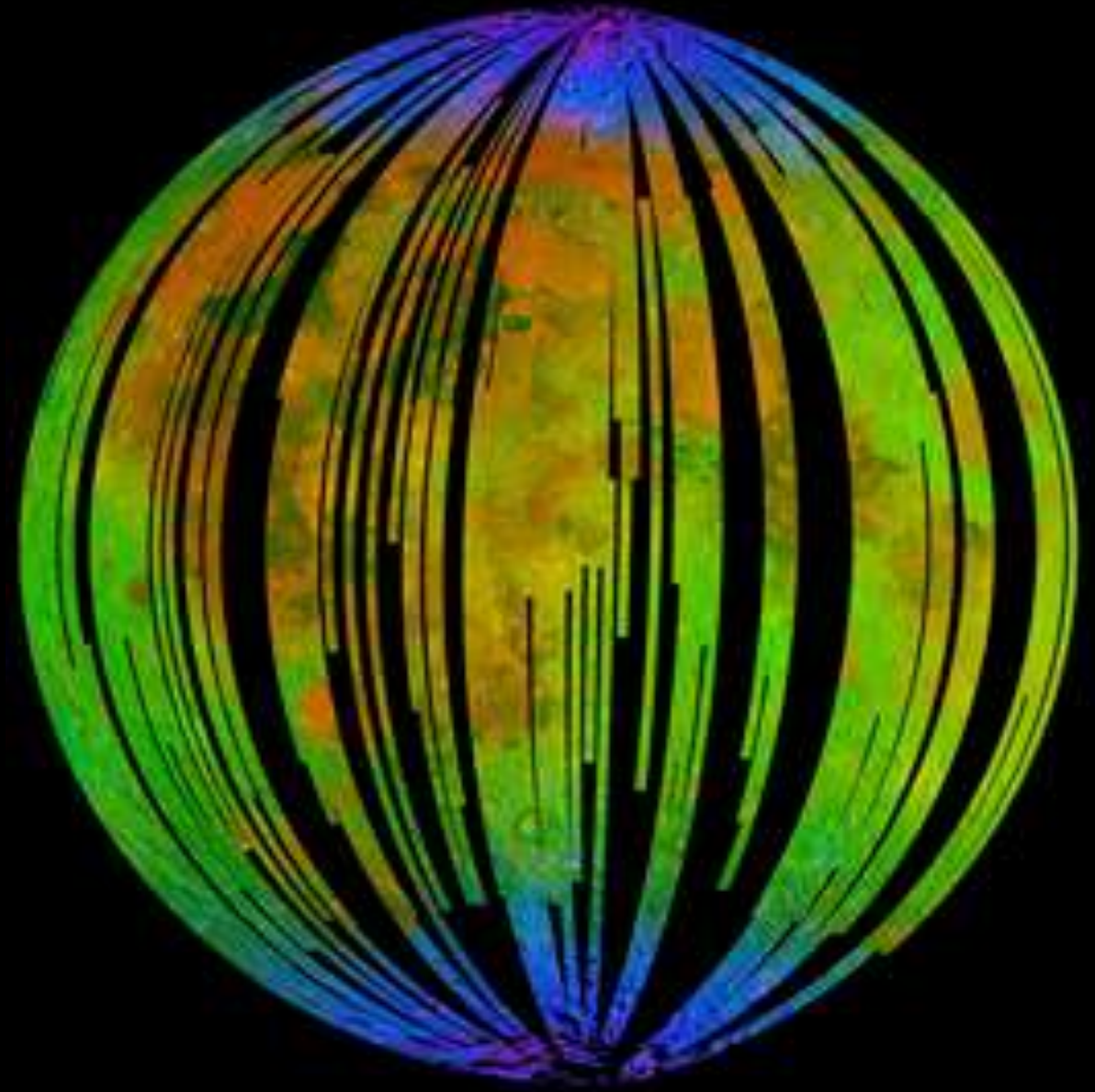
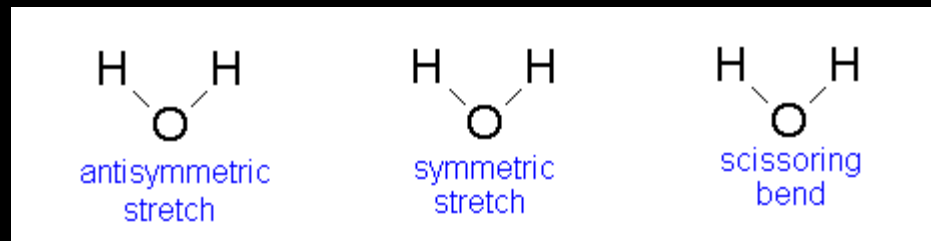
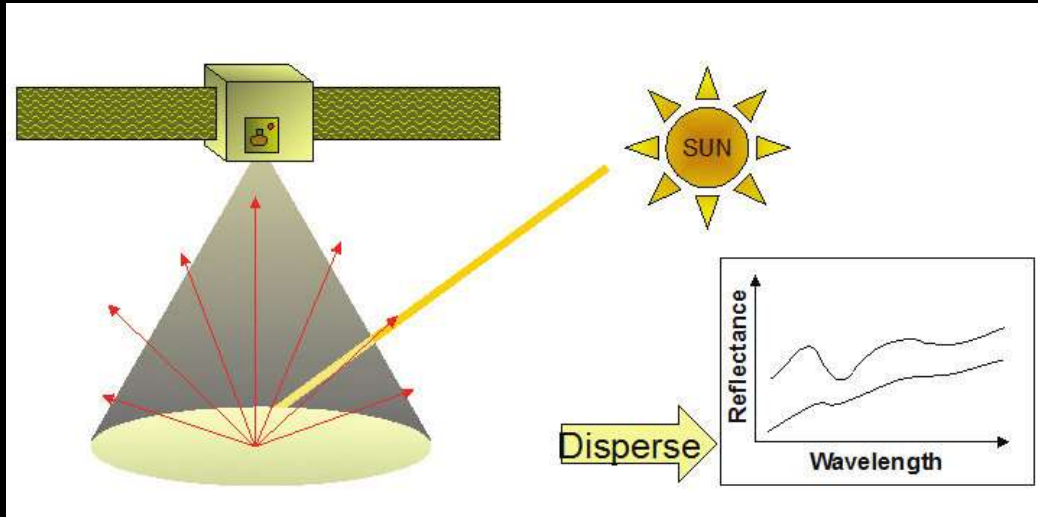




# The Chandrayaan missions

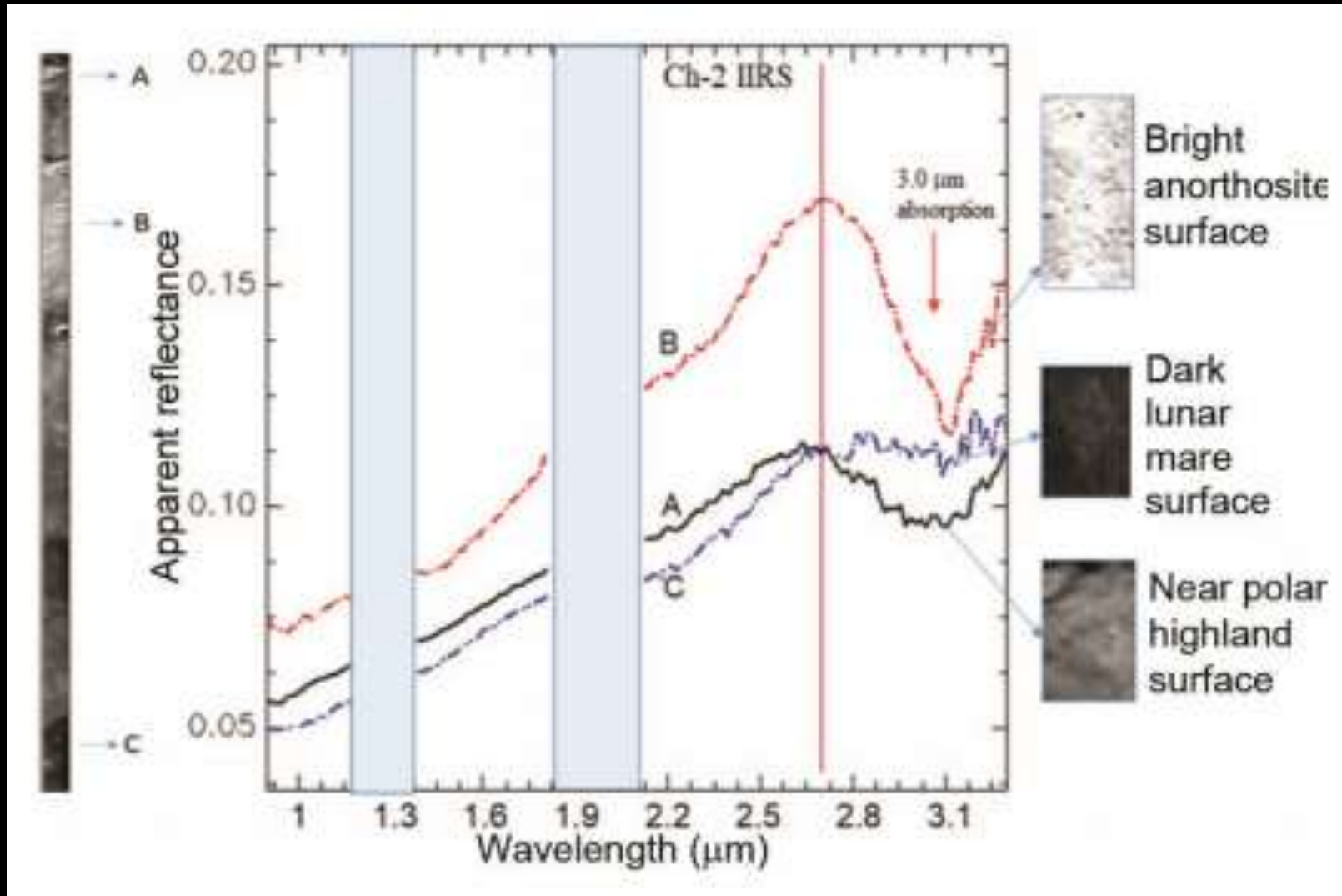
New views of the Moon

# Hydration on the Moon



Pieters et al, 2009

# Water indeed ! (Chauhan et al, 2021)

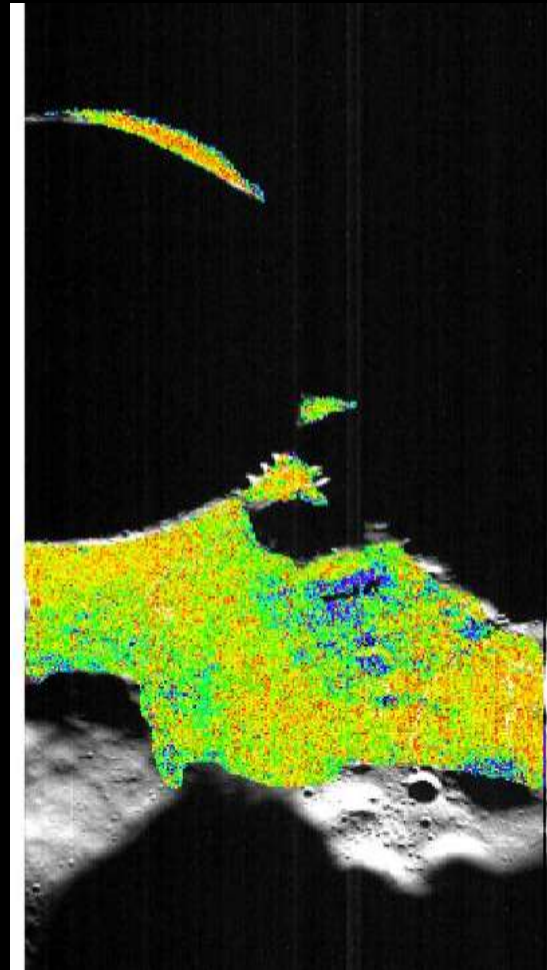




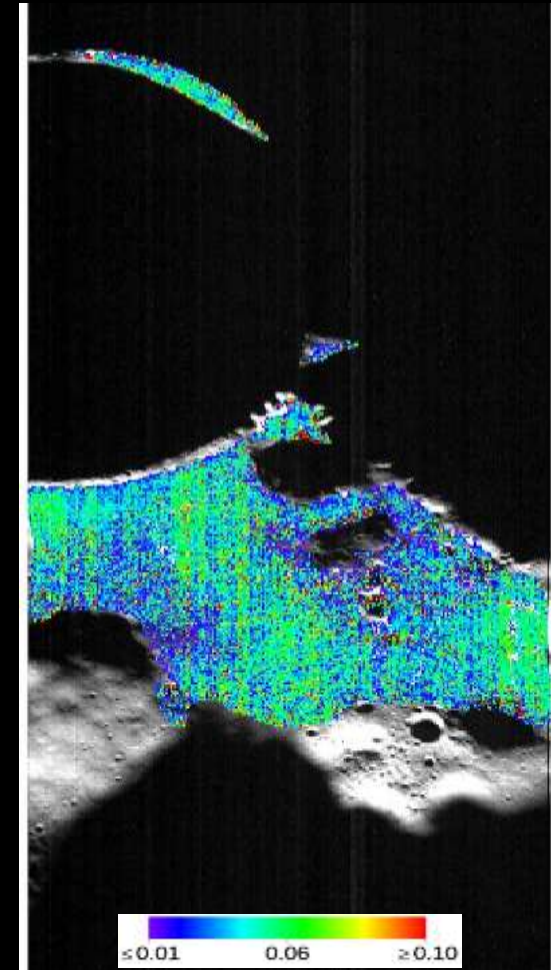
# Identifying hydration-association around Shackleton Crater in the Lunar South Pole using Chandrayaan-2 IIRS Datasets



Band: 1588 nm

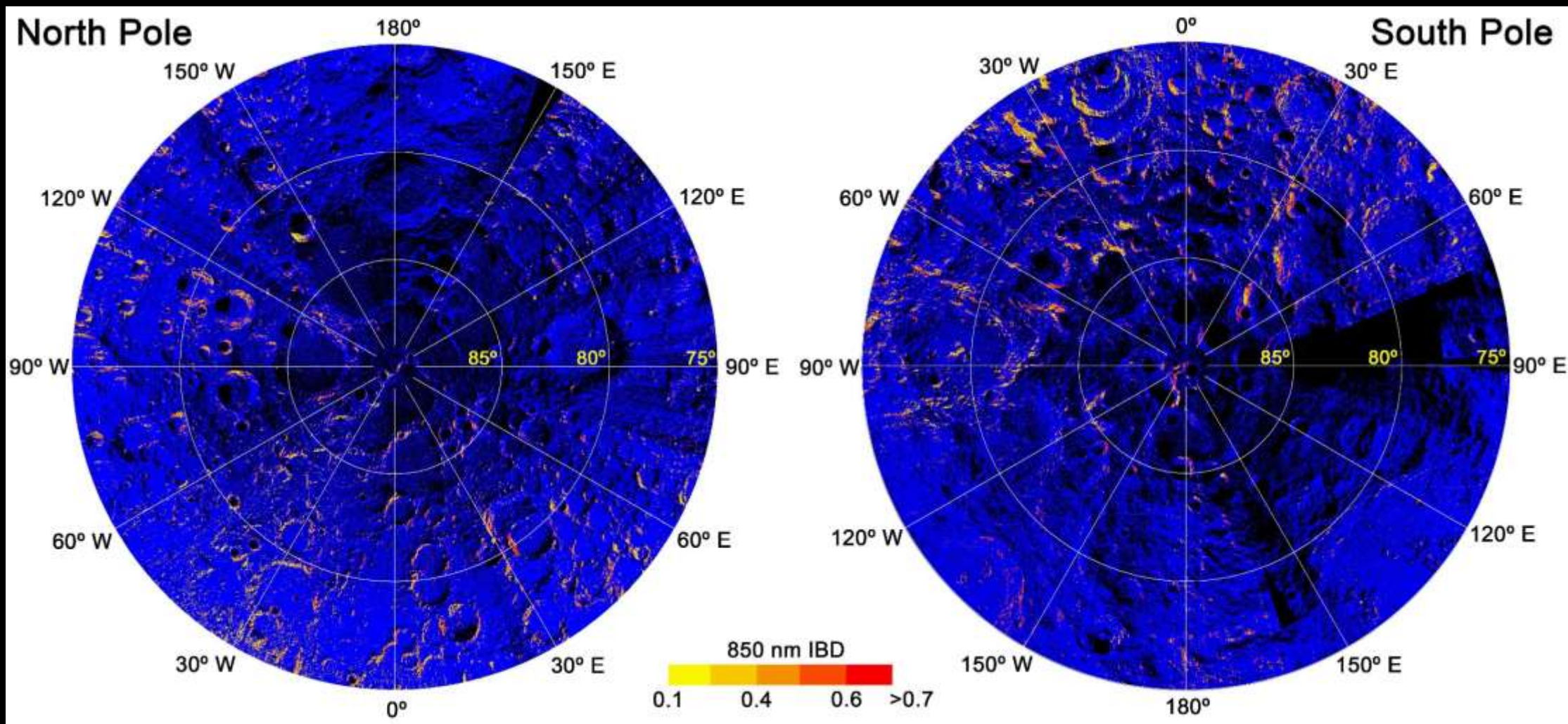


3000-nm Band Depth Map



Ch-2 IIRS Data  
Water Content Map (wt.%)

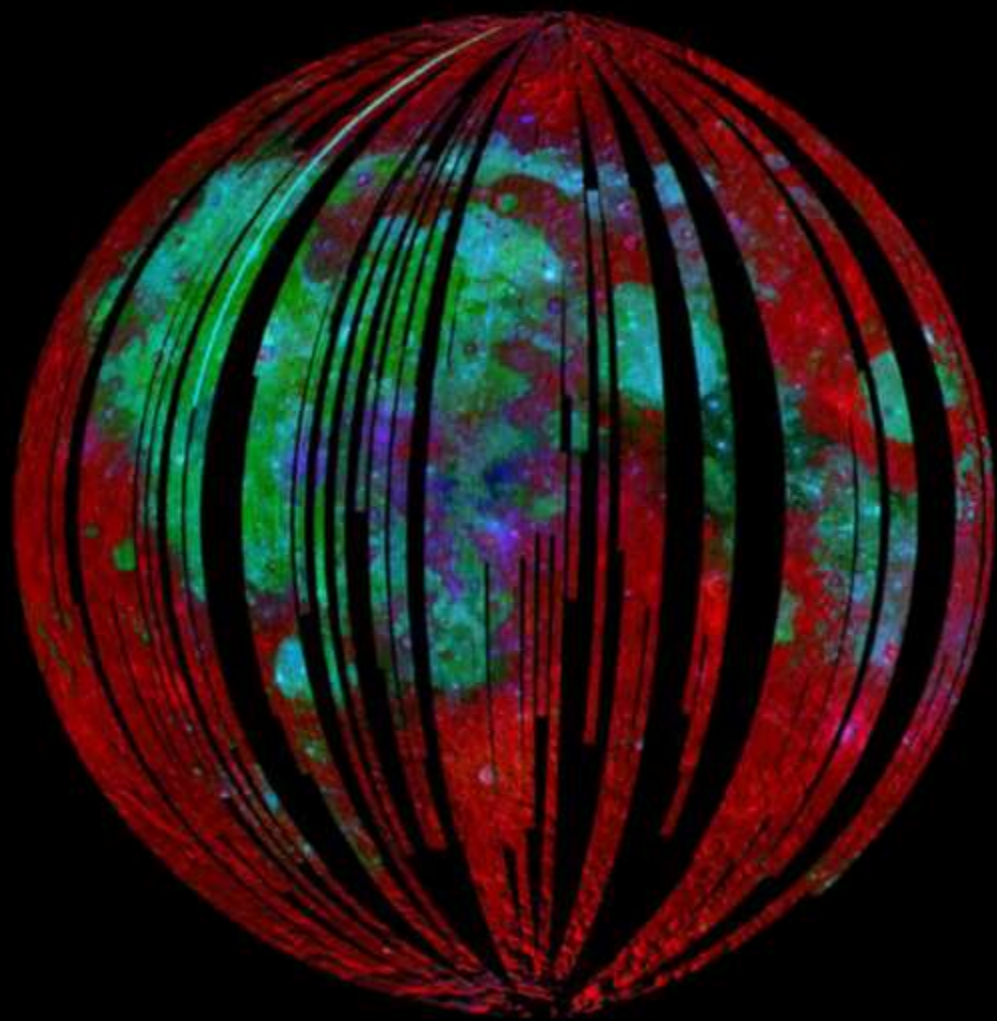
# Hematite on the Moon



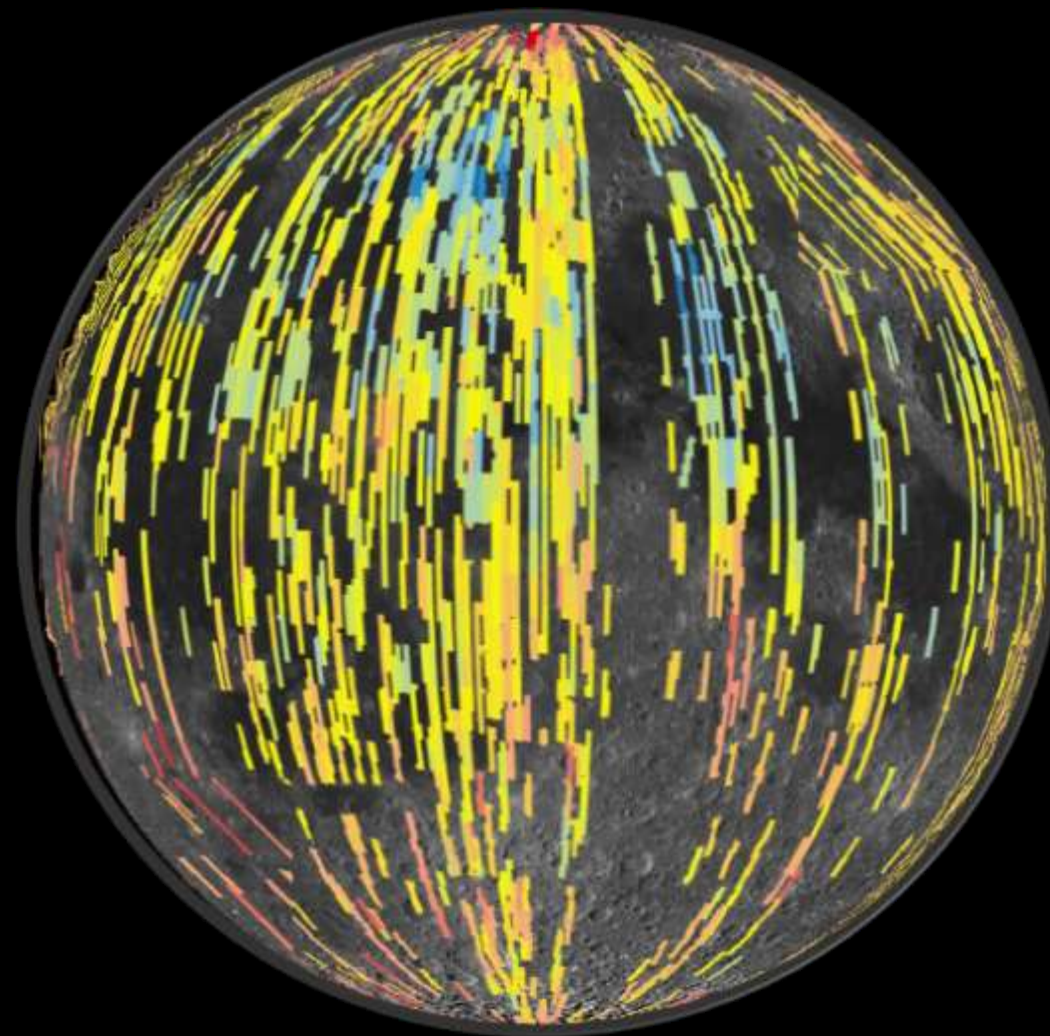
Li et al, 2020



Chandrayaan-1 mineral mapping



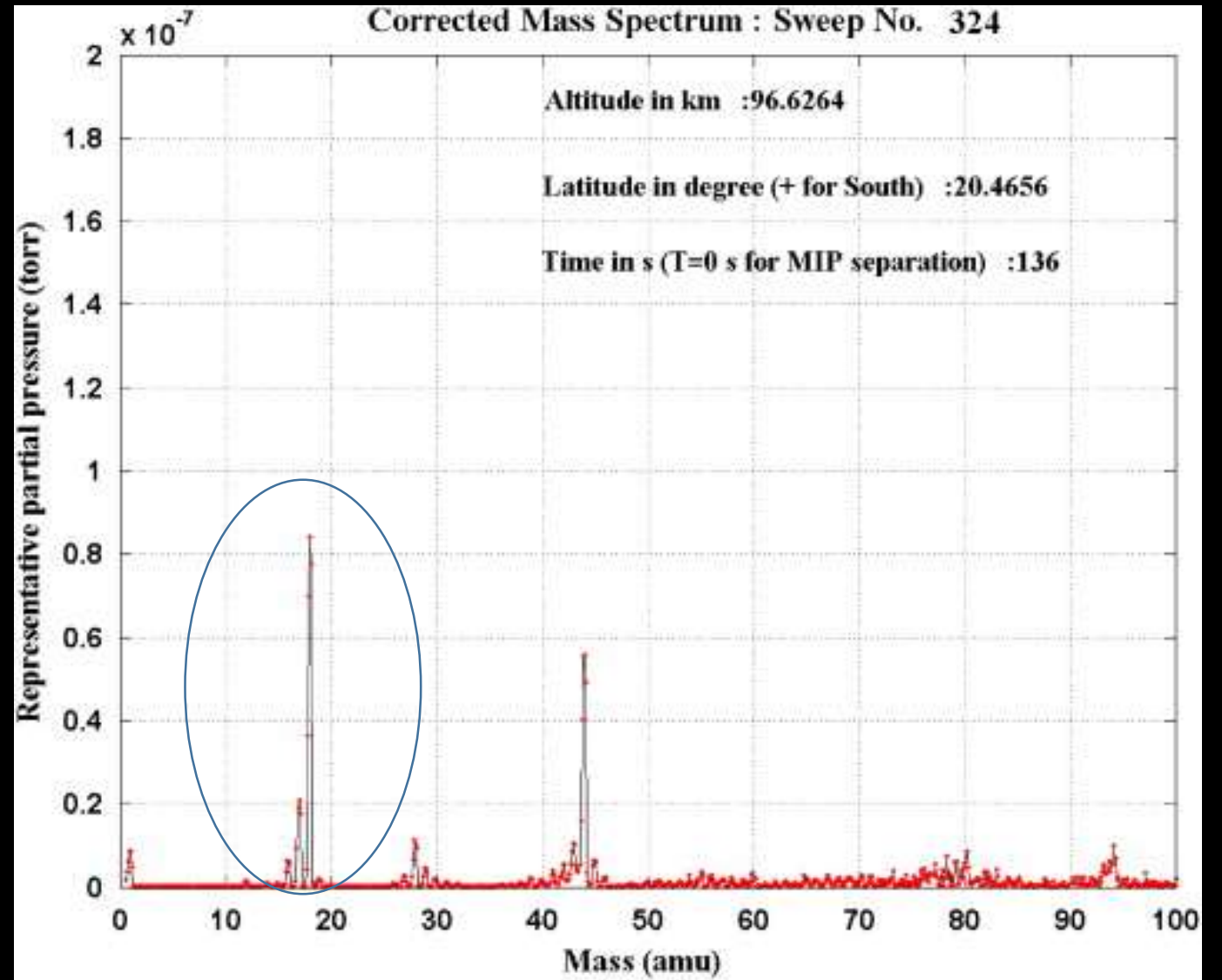
Chandrayaan-2 elemental mapping





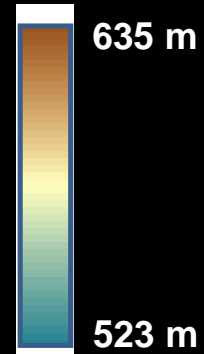
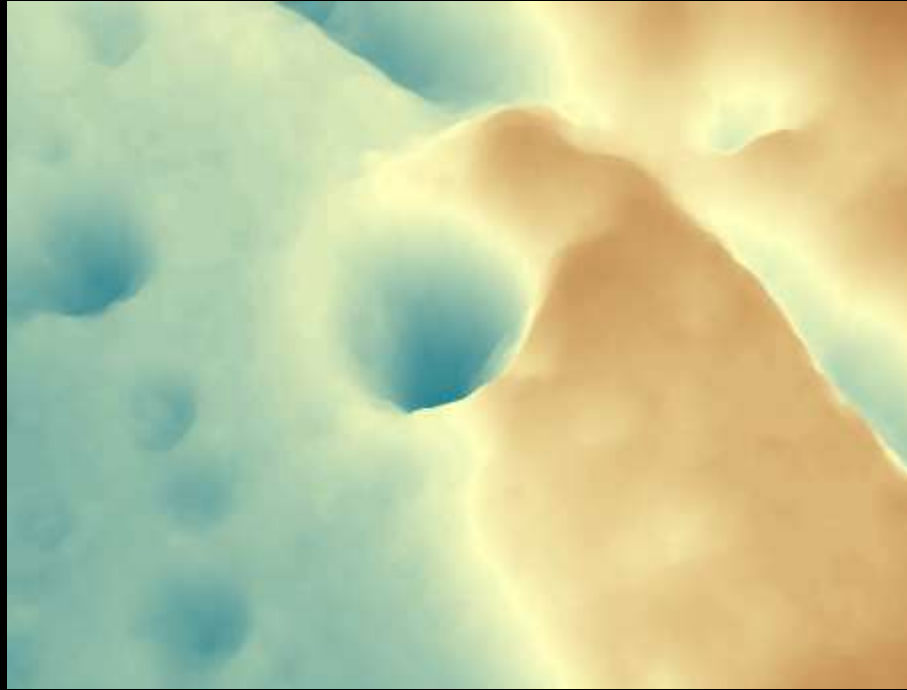
Water in the exosphere

Mass spectrometer on  
the Moon Impact Probe  
on Chandrayaan-1



Sridharan et al, 2010

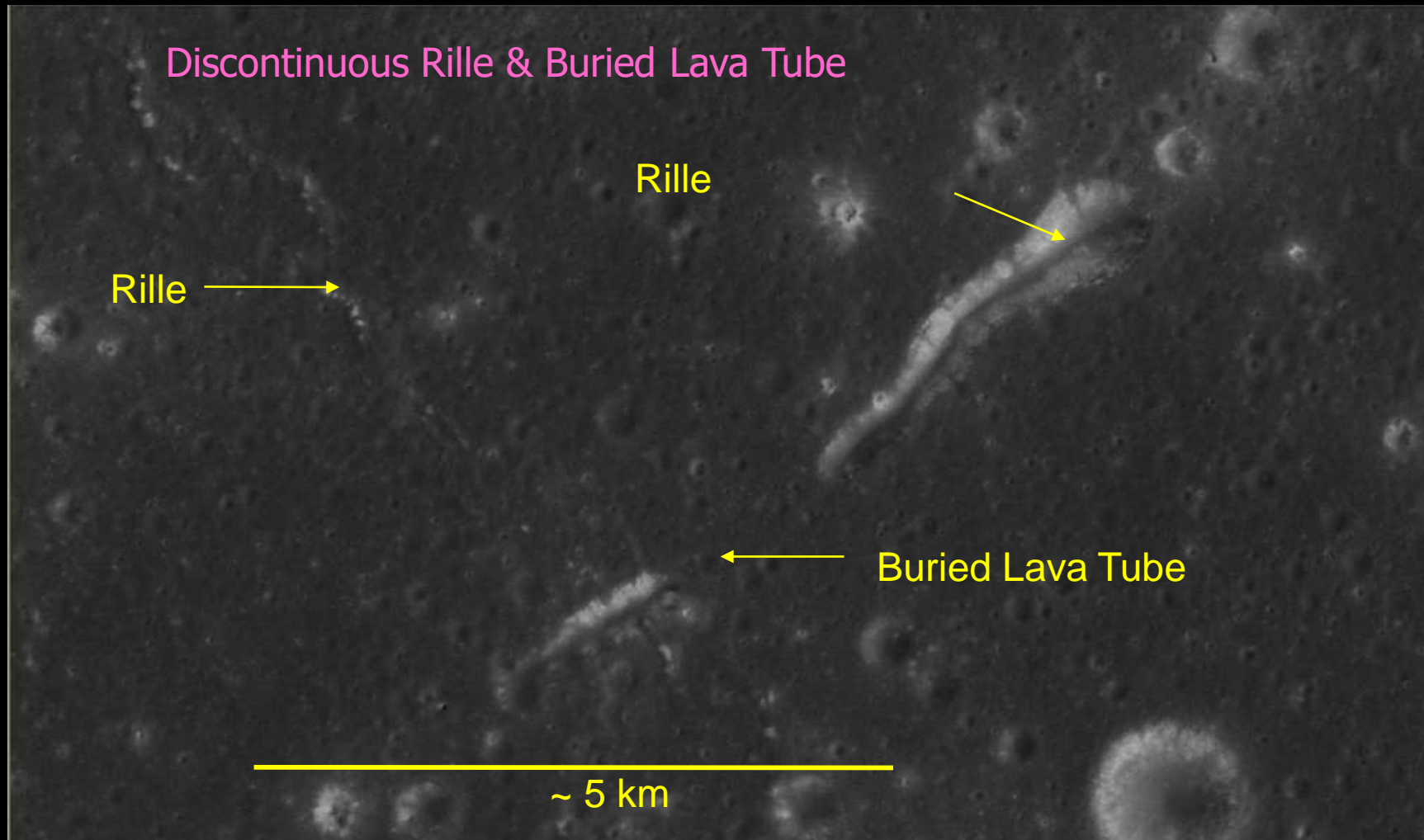
# CHANDRAYAAN1: 3D map of a lunar crater



Terrain Mapping Camera  
5M resolution  
Area – 5 X 4.5 Km



Terrain mapping camera visible band

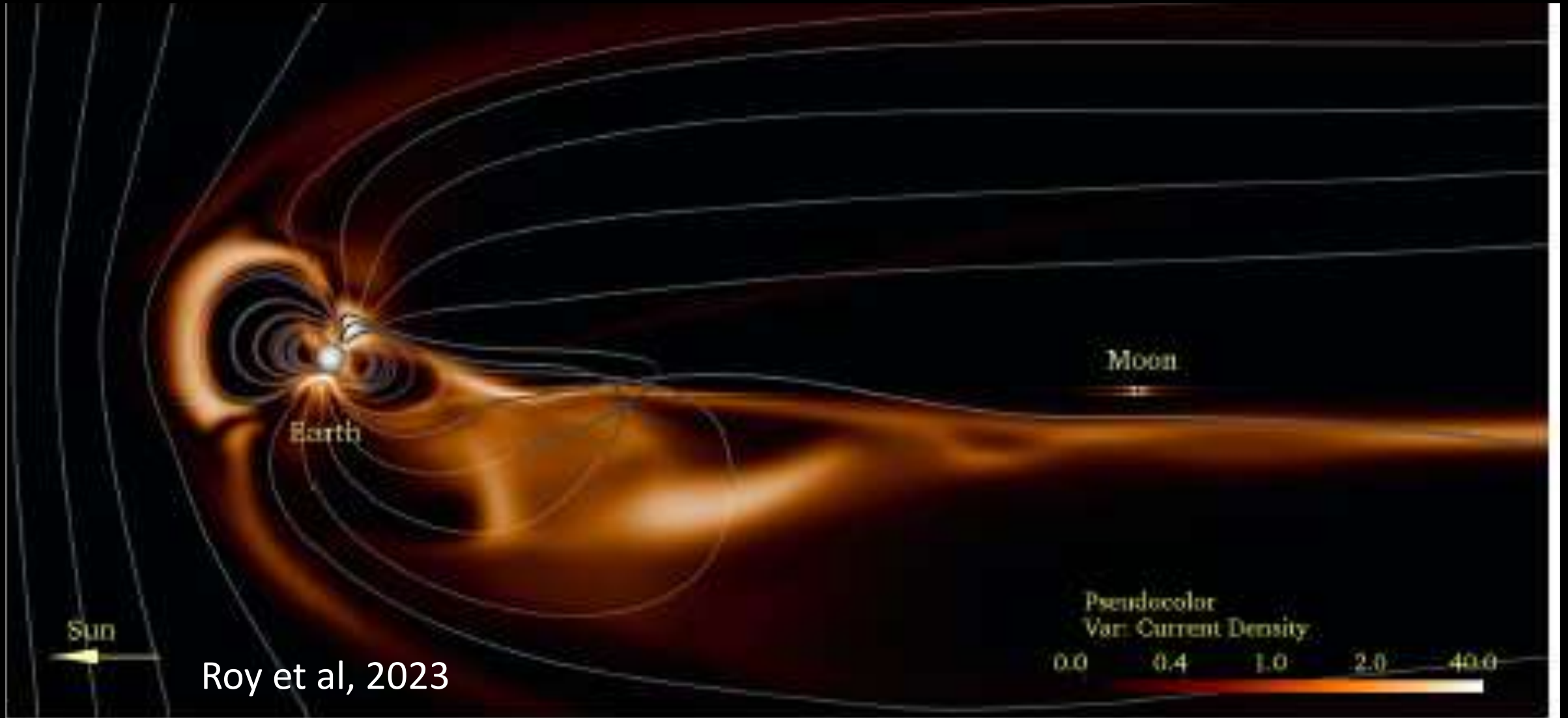


Chandrayaan-1, TMC Orbit 798 13 January, 2009  
Location: **Oceanus Procellarum**  
Longitude: 58.317 W / Latitude: 14.111 N

Arya et al, 2010



# Moon glides through the Earth's magnetotail



# Lunar Exploration

*We came in peace for all mankind*

*I said to him, "Neil, are you scared that you will die in space?"*

*And Neil Armstrong said to me, "Mr. President, I am worried about dying in space, but my irrational lust for bizarre faraway rocks is stronger than my fear of exploding"*

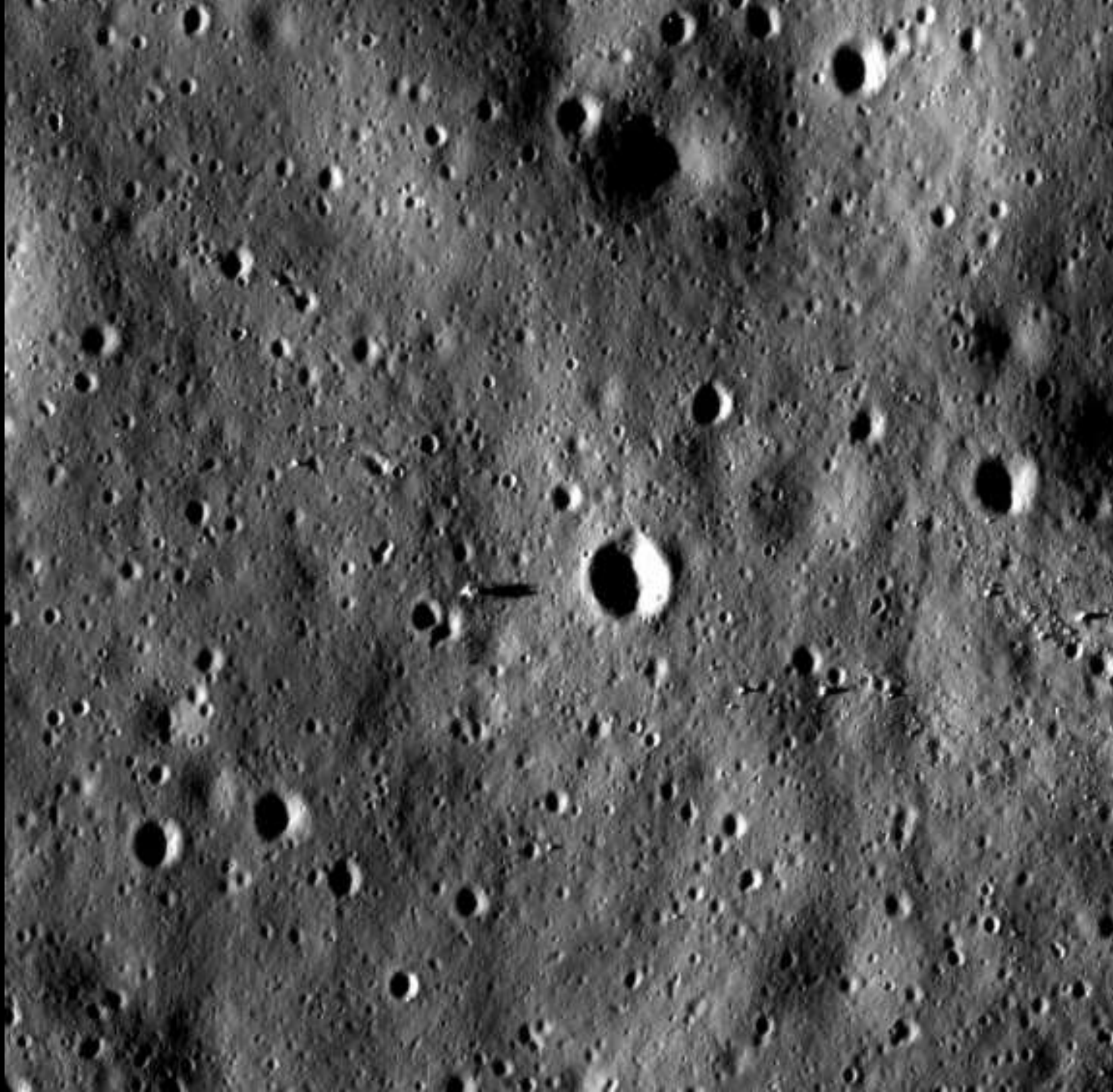




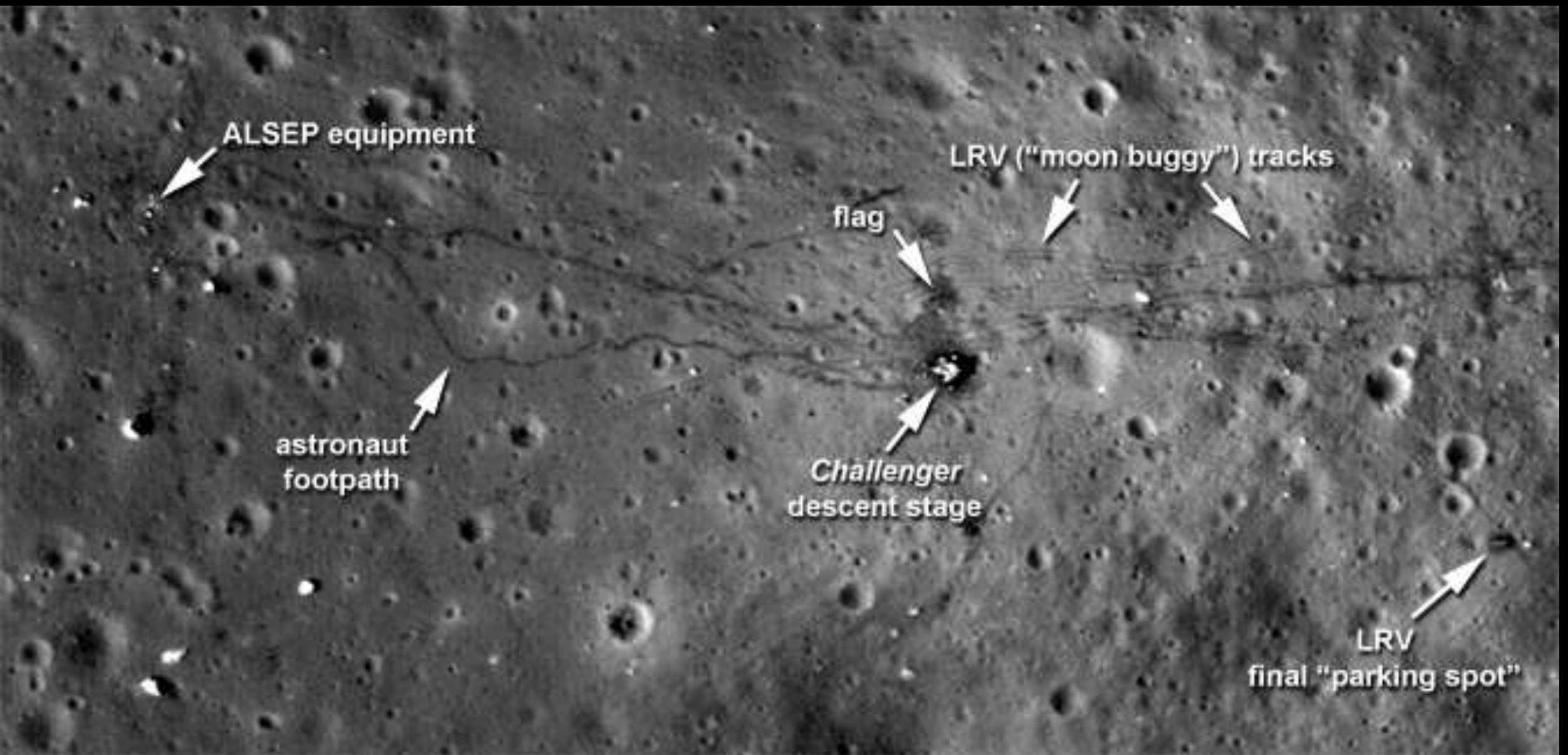


Edwin "Buzz" Aldrin

Near the lunar module  
"Eagle"



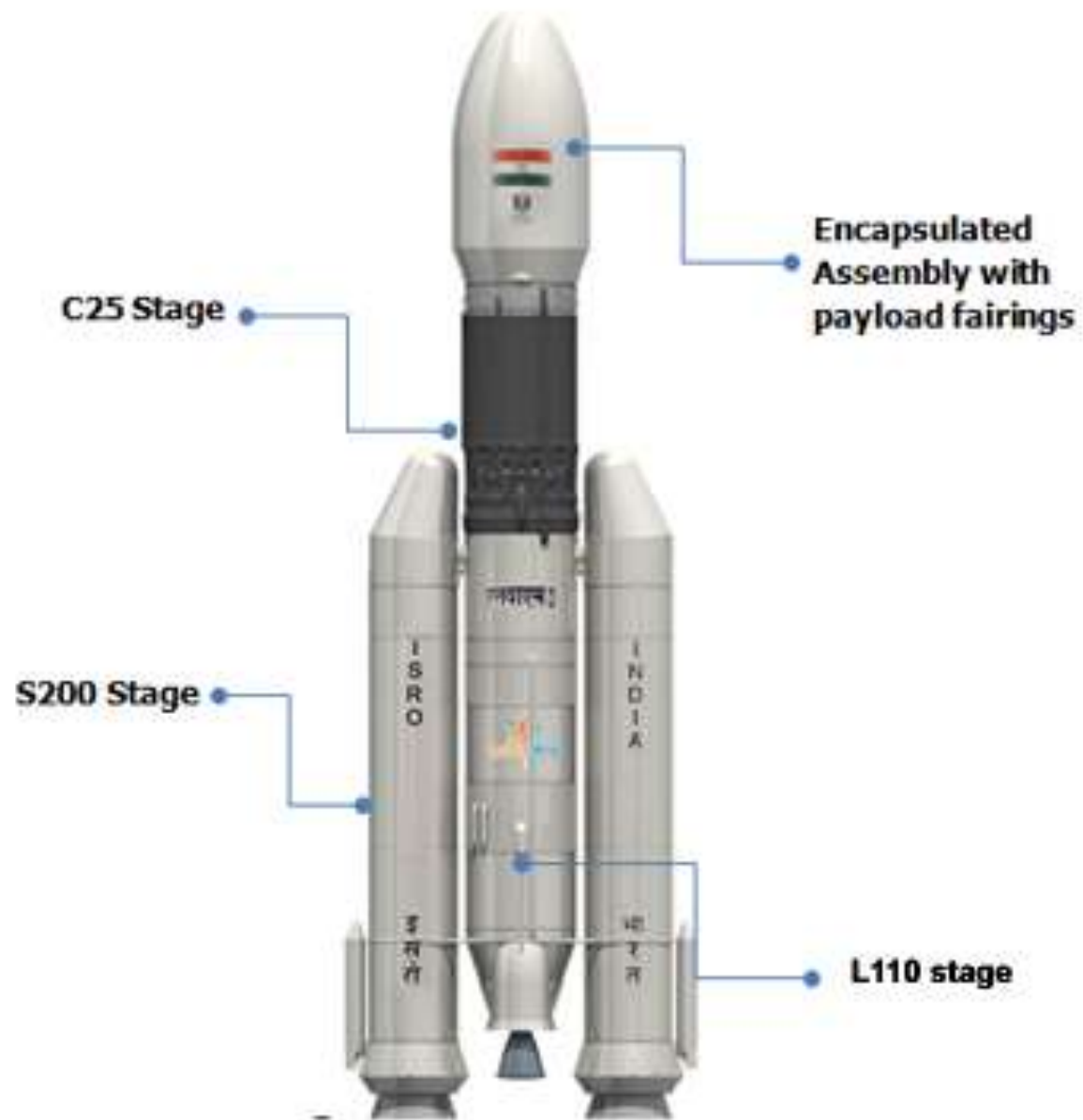
Apollo 11 descent stage  
photographed by  
Chandrayan-2 100 km  
away !



Tracks on the Moon photographed by the Lunar Reconnaissance Orbiter Camera

India goes to the Moon



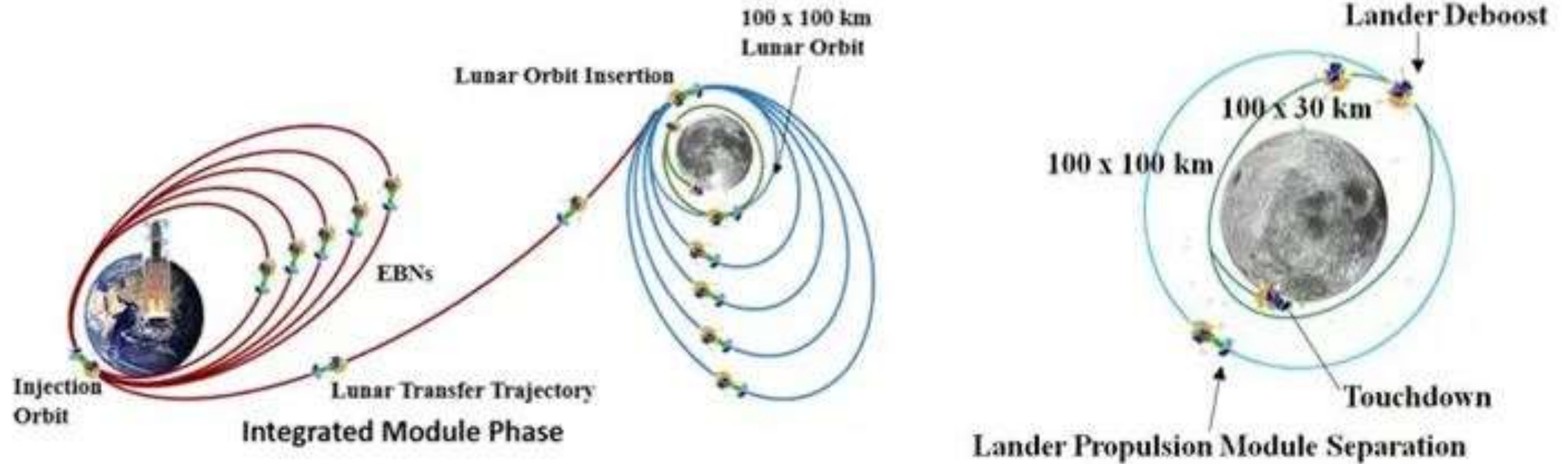


GSLV MKIII Vehicle configuration

14 July 2023



# How are we going?



# Chandrayaan-3



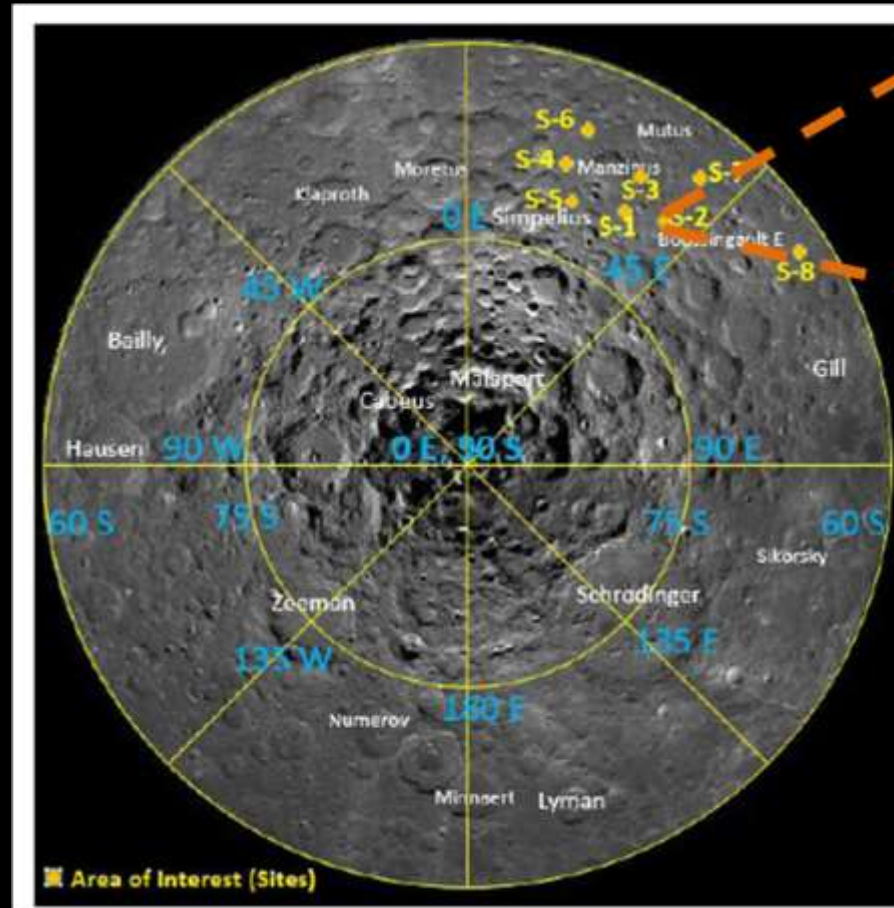


# What will Ch3 do at the Moon?

Instruments on the rover and lander will measure

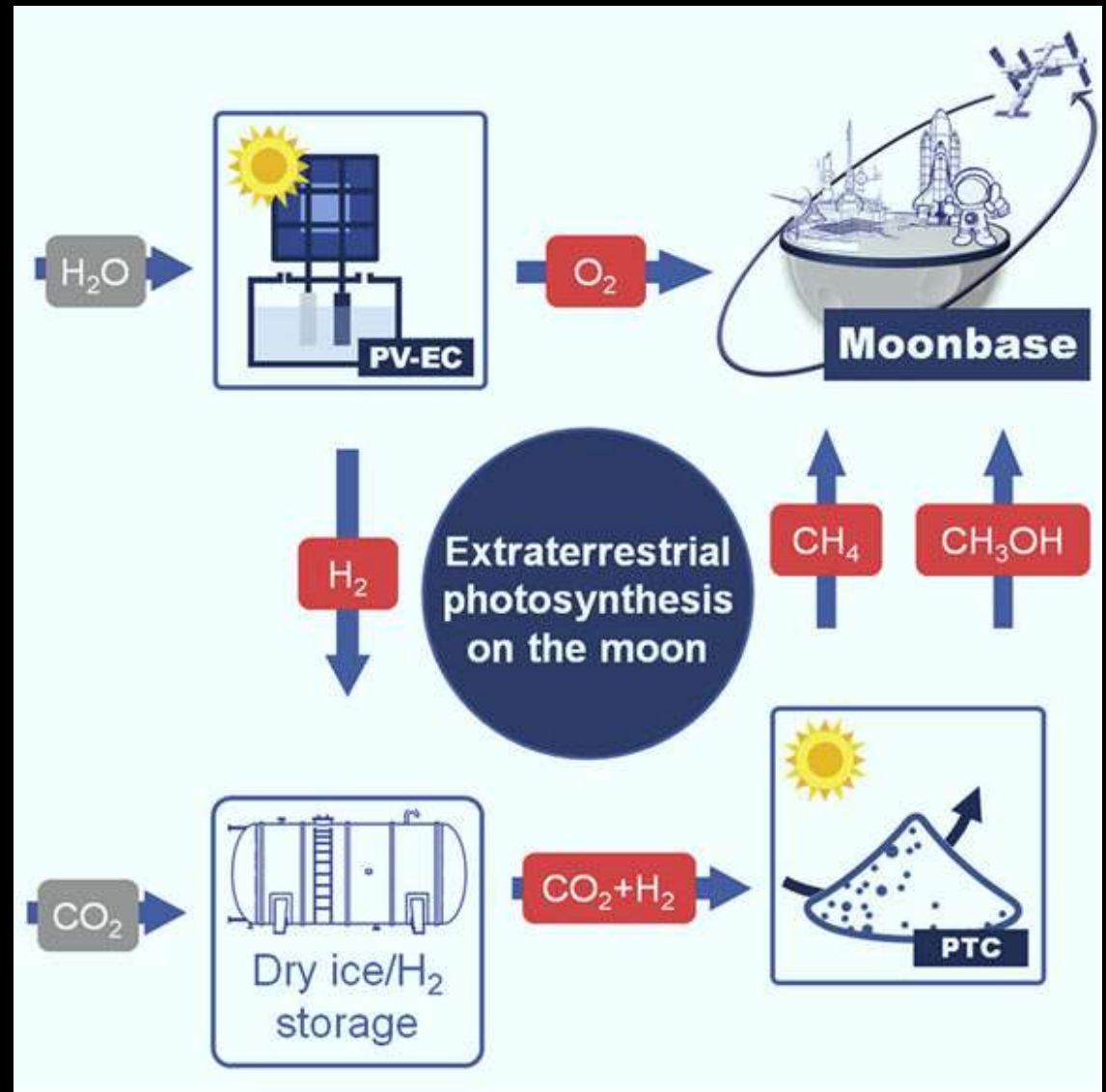
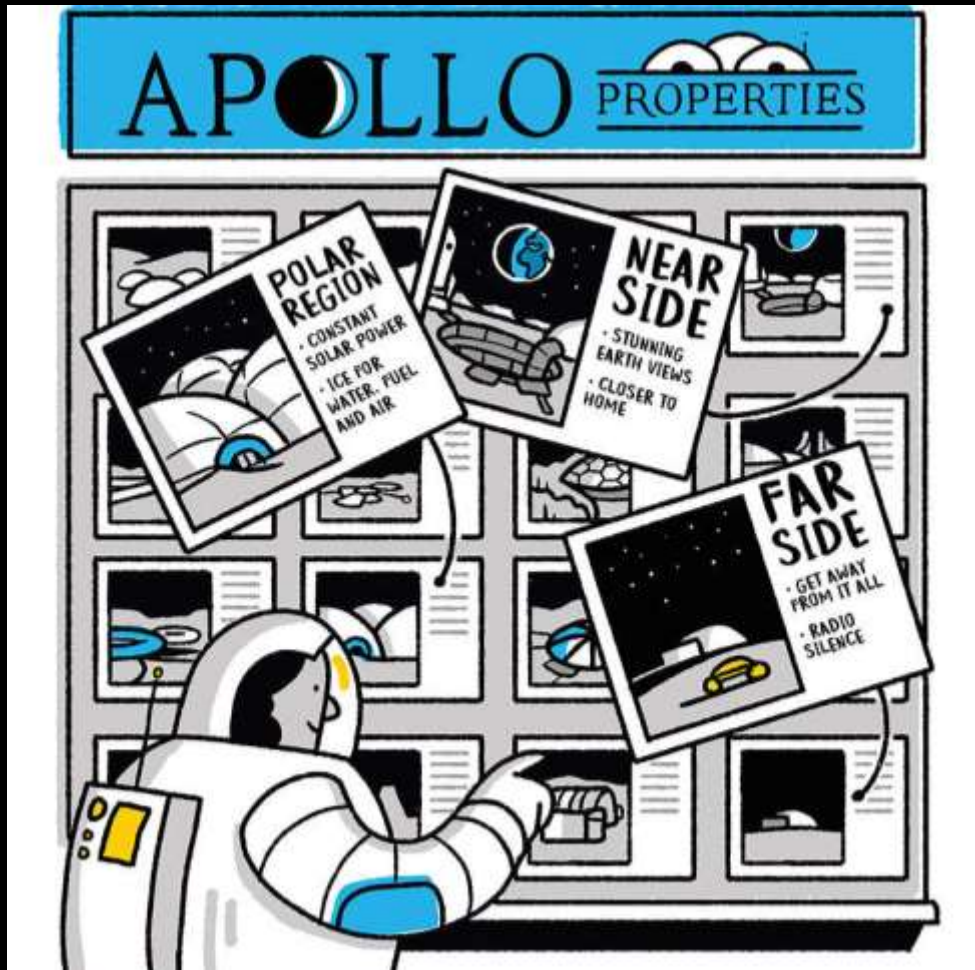
- Soil composition
- Temperature
- Look for any seismic signals (Moon quakes?)
- Measure the plasma properties

Un sampled highlands in the Southern high latitude region



*Amitabh et al, LPSC 2023*

# Future at the Moon



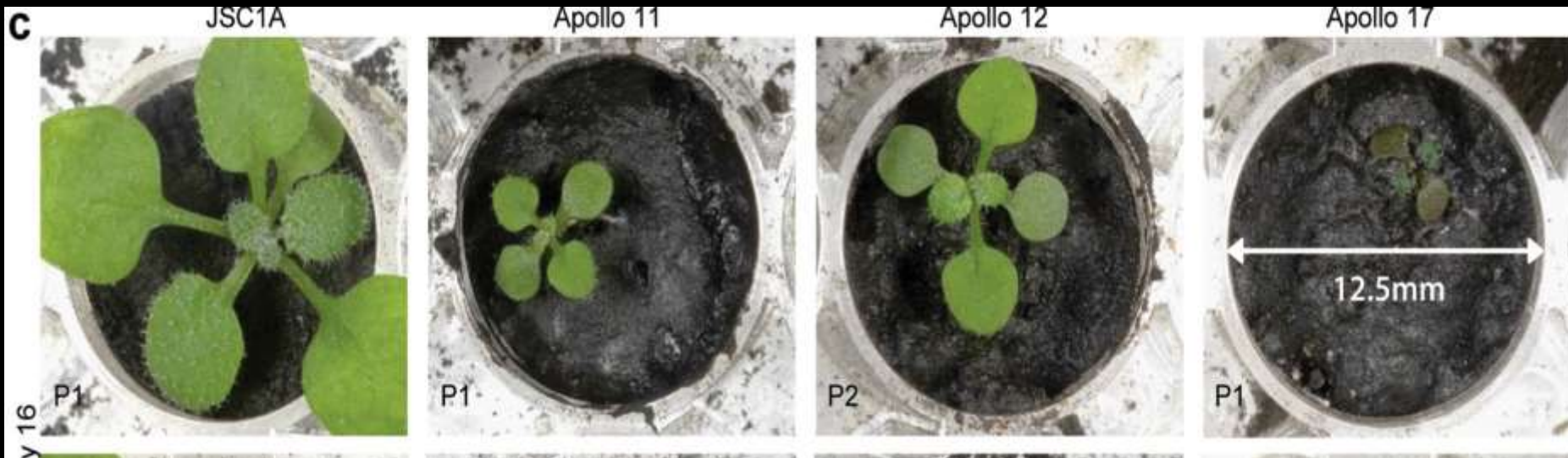
Yao et al, 2022

Can we have permanent settlements on the Moon?



Cotton plant seeds sprouted on the Moon-  
Chang'e-4

*Thale cress (a common weed) grown in returned Apollo soils (Paul et al, 2022)*





BEAUTIFUL! BEAUTIFUL!  
MAGNIFICENT DESOLATION.

- BUZZ ALDRIN -

