How we explore space: a (short!) overview

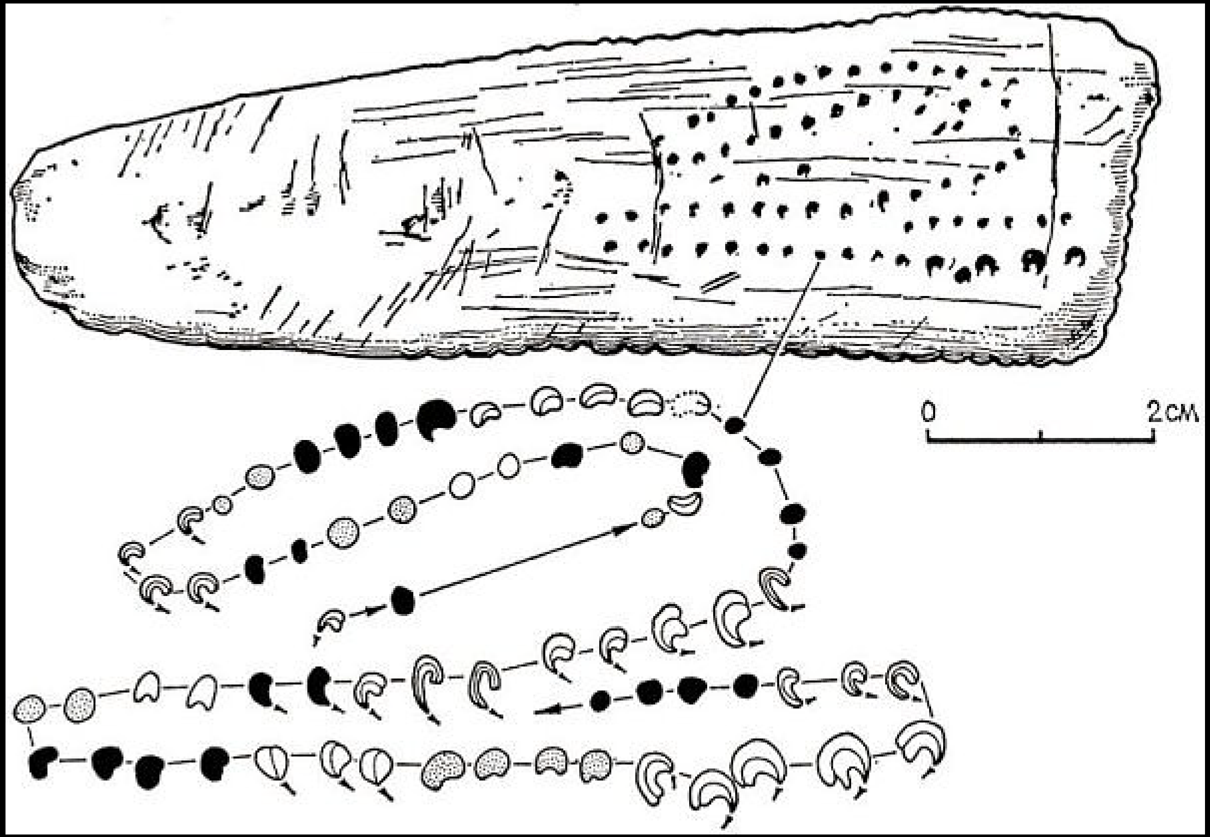
Caleb Fassett
Planetary Scientist

NASA Marshall Space Flight Center

Seeing space: JWST, one of the deepest views

NASA/STSCI

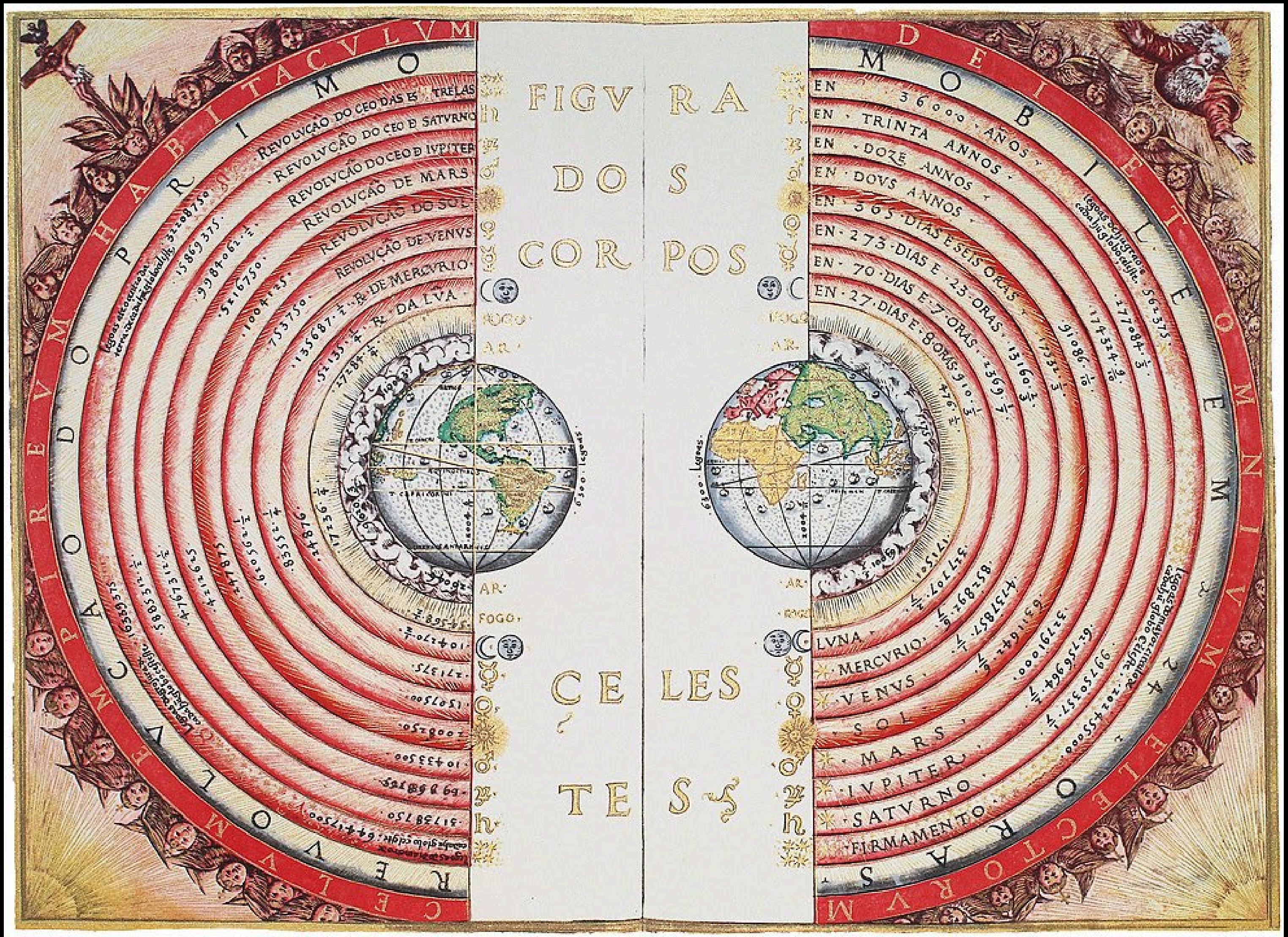
Naked-eye astronomy: the first astronomers



https://sservi.nasa.gov/articles/oldest-lunar-calendars/

- Oldest known lunar calendars are >34000 years old (Aurignacian Culture of Europe)
- Many pre-modern people tracked motions of the stars and planets and observed outer space

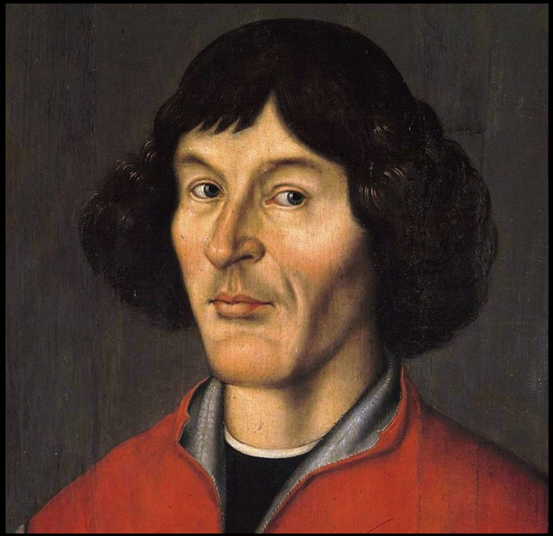
Naked-eye astronomy



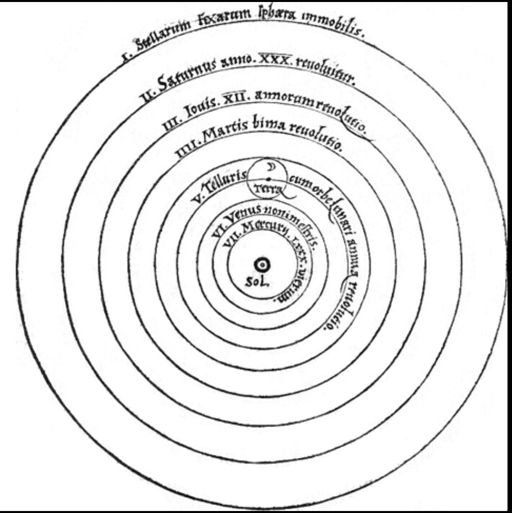
Geocentric model of the Solar System (Velho, 1568; public domain image)

- Aristotle, Ptolemy proposed a *geocentric* model for the Solar System and motions of Earth, the Sun, and stars that was favored until ~1500-1600.
- Some Greek and Islamic astronomers had their doubts prior to the Renaissance…

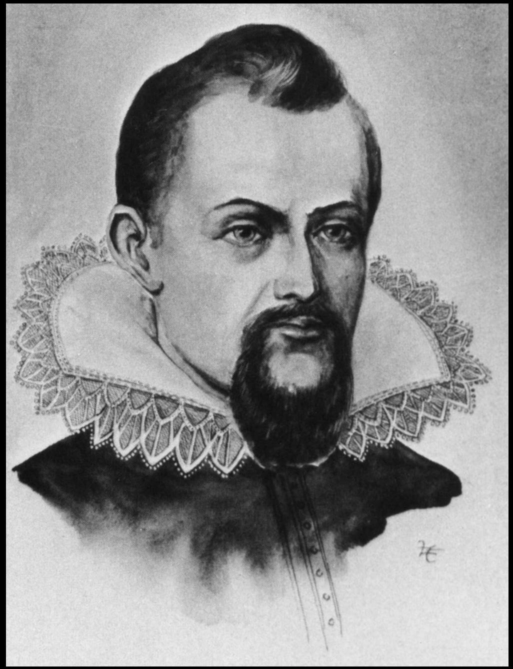
The last great era of naked-eye astronomy



Nicolaus Copernicus, 1473-1543
(public domain image)



Tycho Brahe, 1546-1601
(nasa.gov)

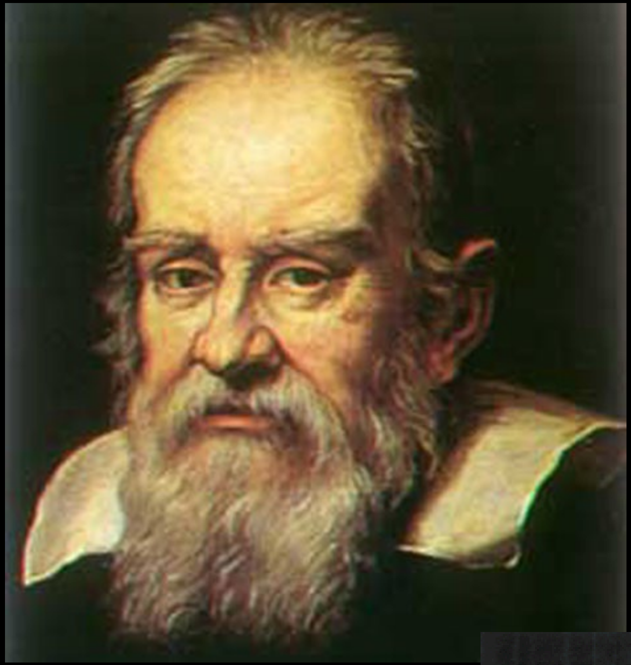


Johannes Kepler, 1571-1630
(https://www.jpl.nasa.gov/news/the-history-of-johannes-kepler)

- Copernicus: mathematically showed that a heliocentric model was preferred (but kept circular orbits).
- Brahe: precision measurements of planetary motion. Didn’t really support Copernican view.
- Kepler: Used Brahe’s data to derive heliocentric model and elliptical orbits of planets.

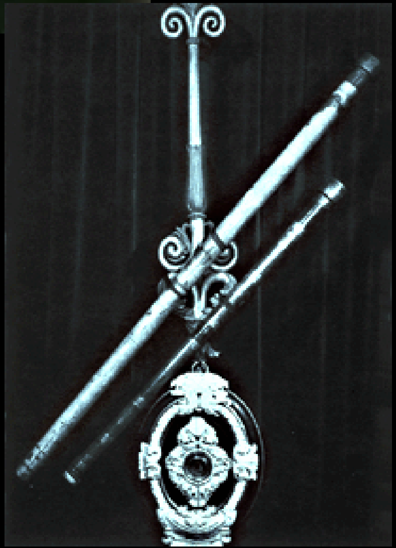
https://earthobservatory.nasa.gov/features/OrbitsHistory

The telescope revolutionizes astronomy, 1600-1950+



(NASA)

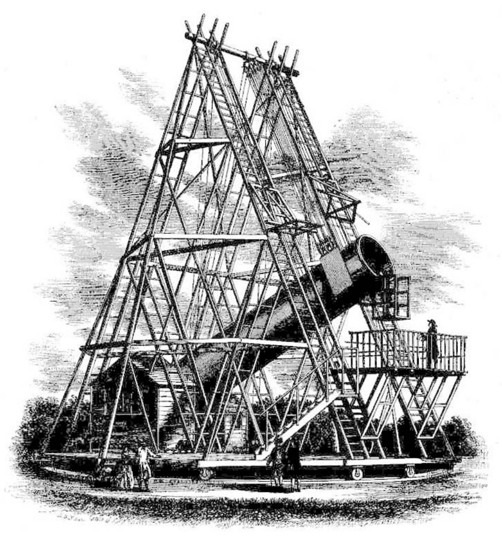
Galileo Galilei (1564-1642): First to use telescope for astronomy. Discovered lunar craters, moons of Jupiter, sunspots, phases of Venus. Championed the heliocentric model.



Galileo's telescope (https://starchild.gsfc.nasa.gov/docs/StarChild/questions/question37.html)

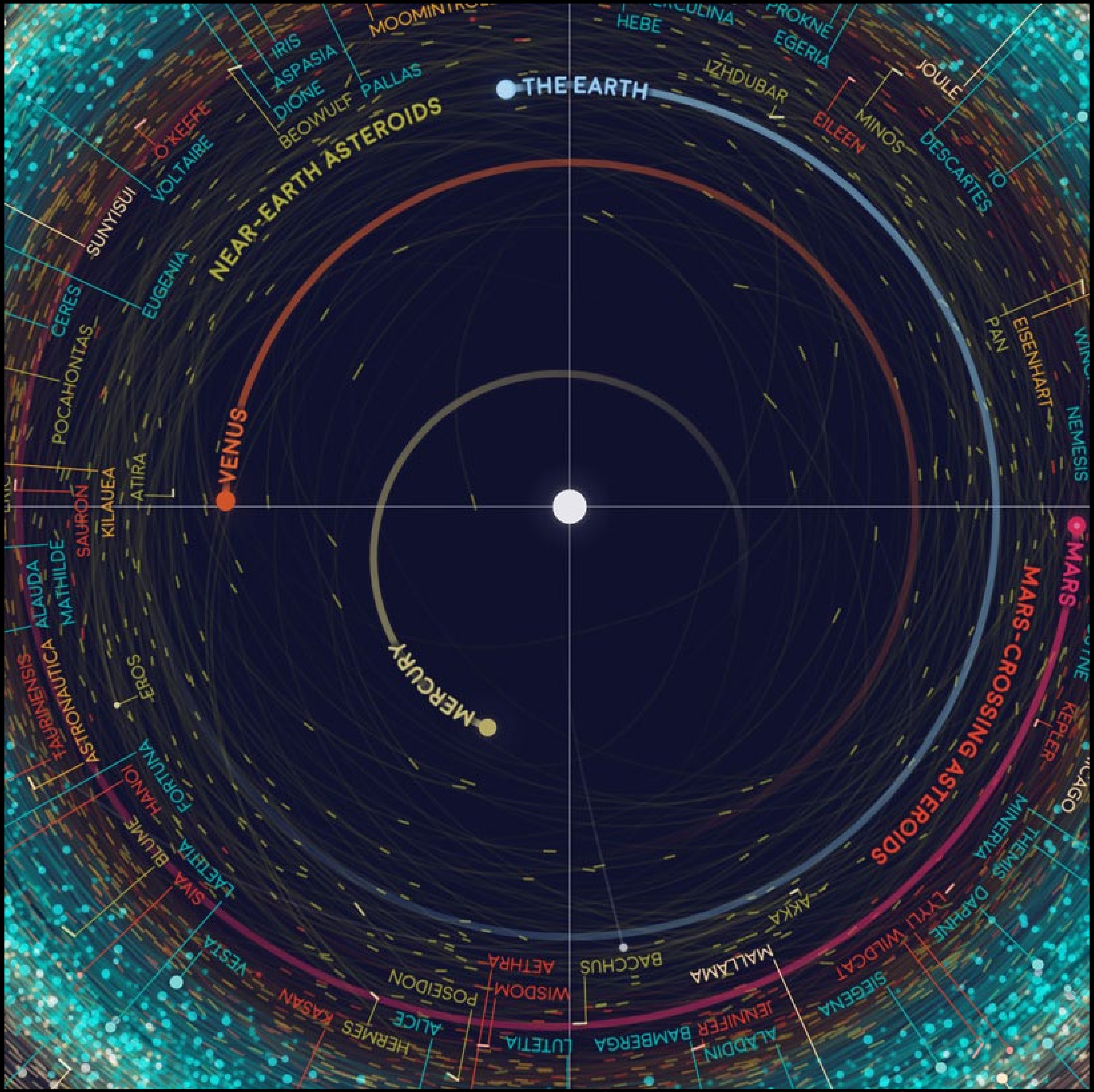
(Wellcome collection/Creative Commons)

William (1738-1822) + Caroline Herschel (1750-1848): Brother and sister. William discovered Uranus, Caroline, 8 (!) comets.



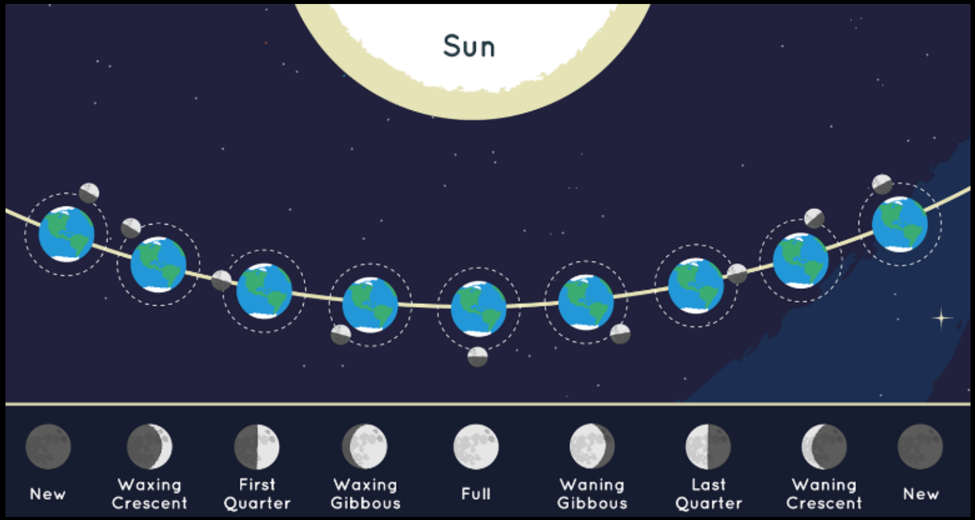
Herschel's 40-ft telescope (public domain)

The Inner Solar System



https://www.jpl.nasa.gov/infographics/an-orbit-map-of-the-solar-system

The Earth and Moon



https://moon.nasa.gov/moon-in-motion/moon-phases/

A lesson from this history: as our ability to observe improves technologically, so does our understanding

https://www.nasa.gov/image-feature/goddard/views-of-pluto-through-the-years

Interlude for Questions / Discussion

Some possible thought/discussion questions:

1. Let's say you are standing at the top of a mountain at night with a great telescope and have perfectly clear seeing.

    What is the maximum fraction of the universe you can see?

2. Now, let's say there is a <u>Full Moon</u> in the sky:

    -What is the maximum fraction of the Moon's surface you can see?

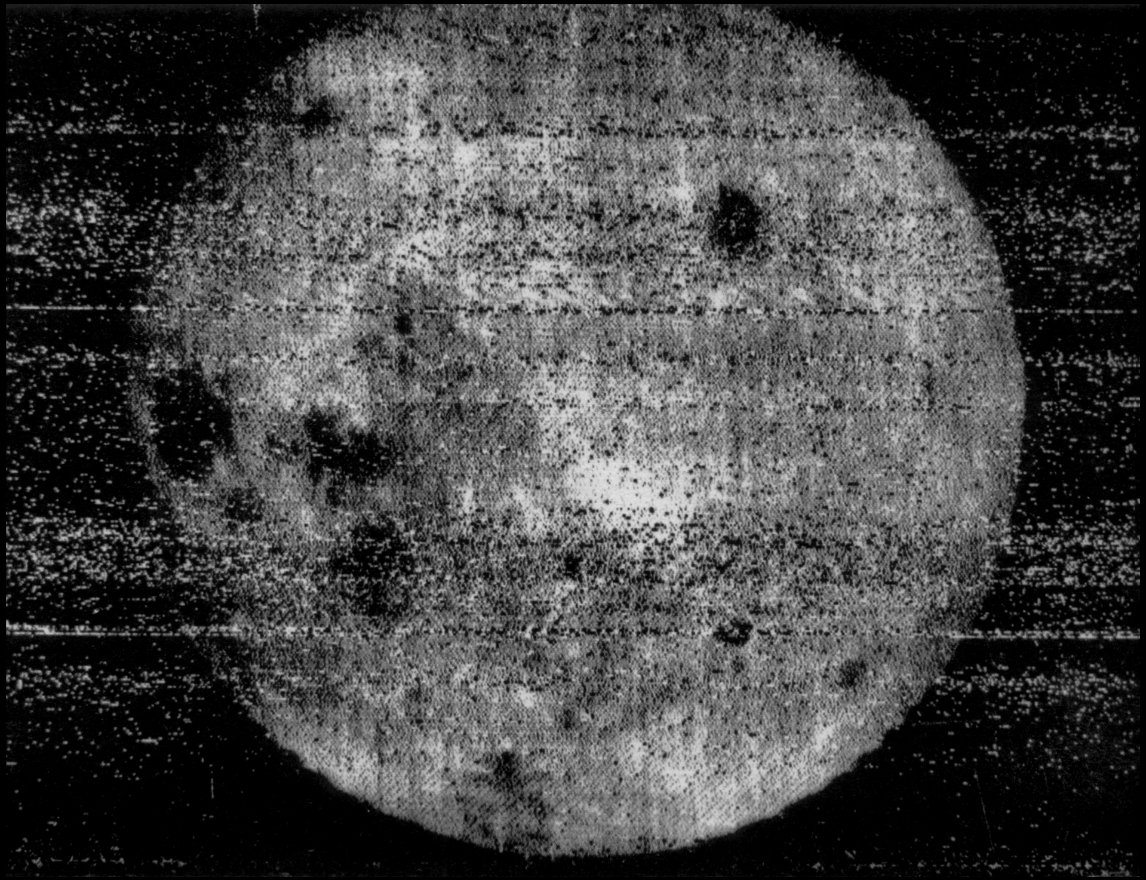
    -Is the Moon the exactly the same distance as the Earth from the Sun, a bit farther than the Earth from the Sun, or a bit closer than the Earth to the Sun?

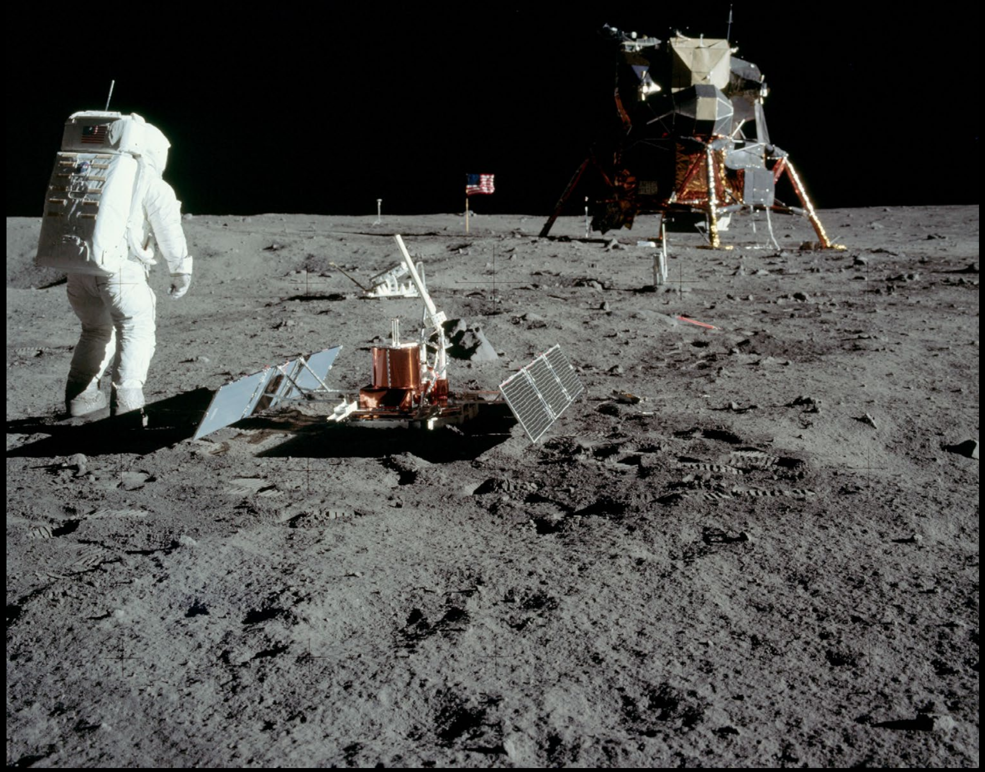
Space exploration (in Space) begins

Sputnik: 1957

Luna-3 (below) 1959

Apollo 11 (right): 1969

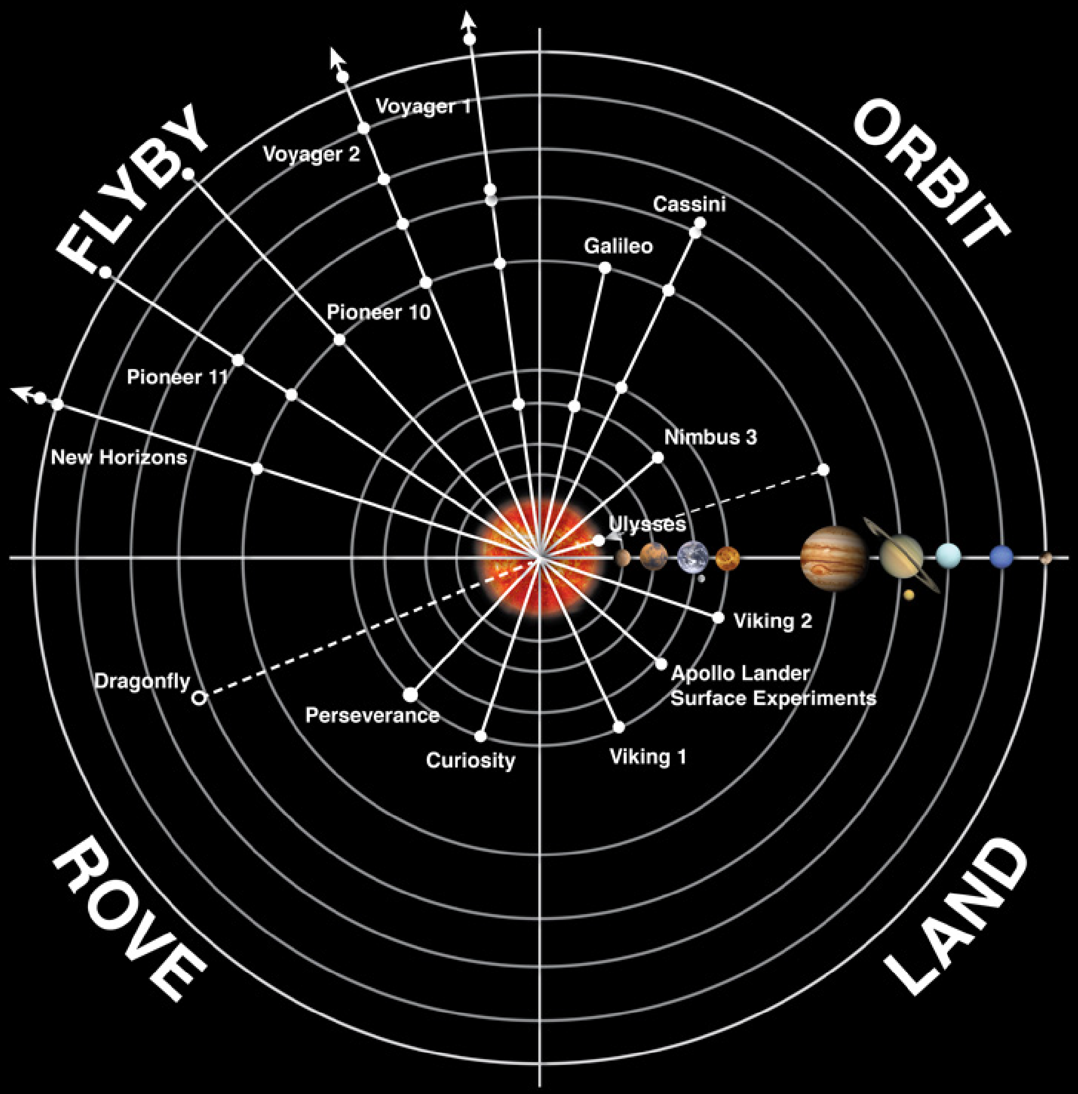




Landed 53 years ago, tomorrow!

https://nssdc.gsfc.nasa.gov/imgcat/html/mission_page/EM_Luna_3_page1.html

Flyby, Orbit, Land, Rove, Return Samples



https://rps.nasa.gov/resources/69/flyby-orbit-rove-and-land/?category=reports

https://mars.nasa.gov/resources/26685/mars-sample-retrieval-lander-mars-ascent-vehicle-launch-illustration/

Flyby, Orbit, Land, Rove, <u>Return Samples</u>

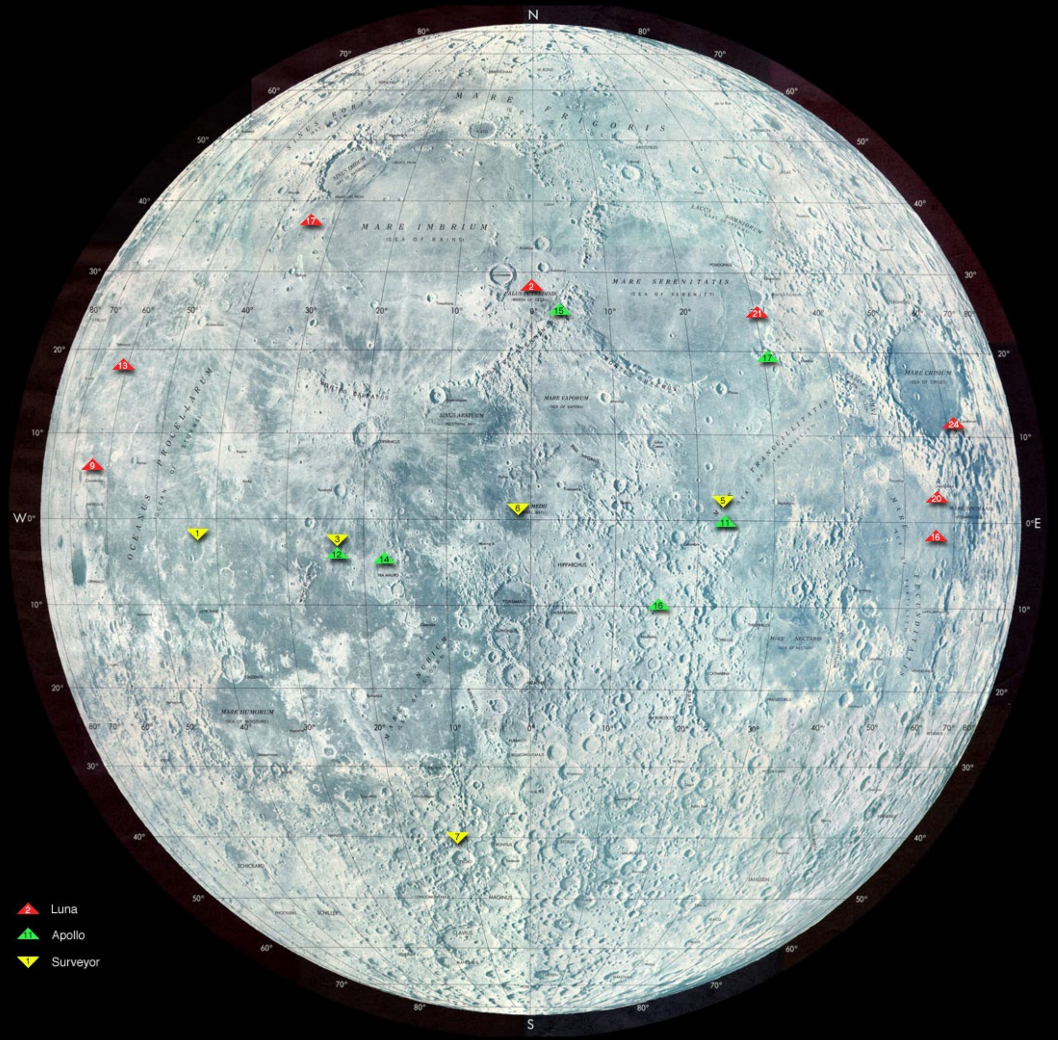
A couple of quick (hard) questions:

1. Roughly how many (or which, if you prefer) Solar System objects have we gotten samples of with astronauts or spacecraft?

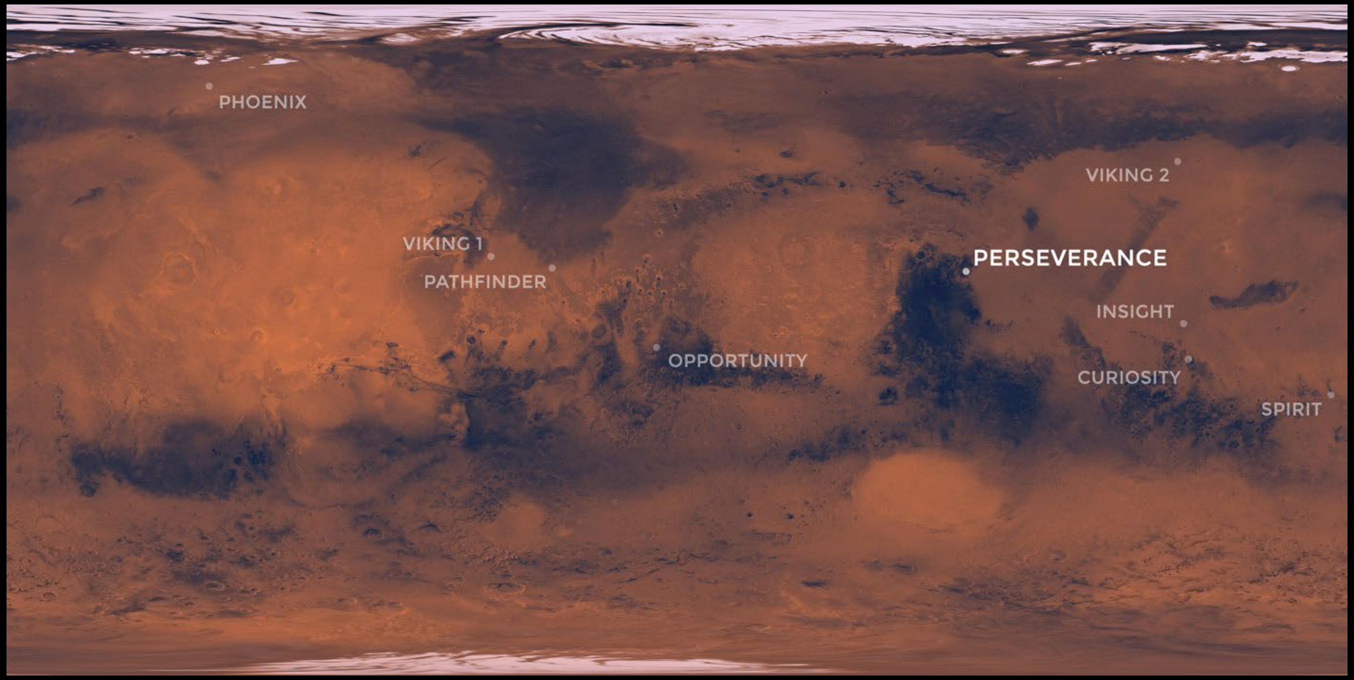
2. Roughly how many Solar System objects do we have samples from? [answer 1≠answer 2]

Flyby, Orbit, Land, Rove, Return Samples

- It's pretty impossible to land, rove, or send astronauts everywhere…



NASA + USSR landing sites on the Moon



NASA's landing sites on Mars

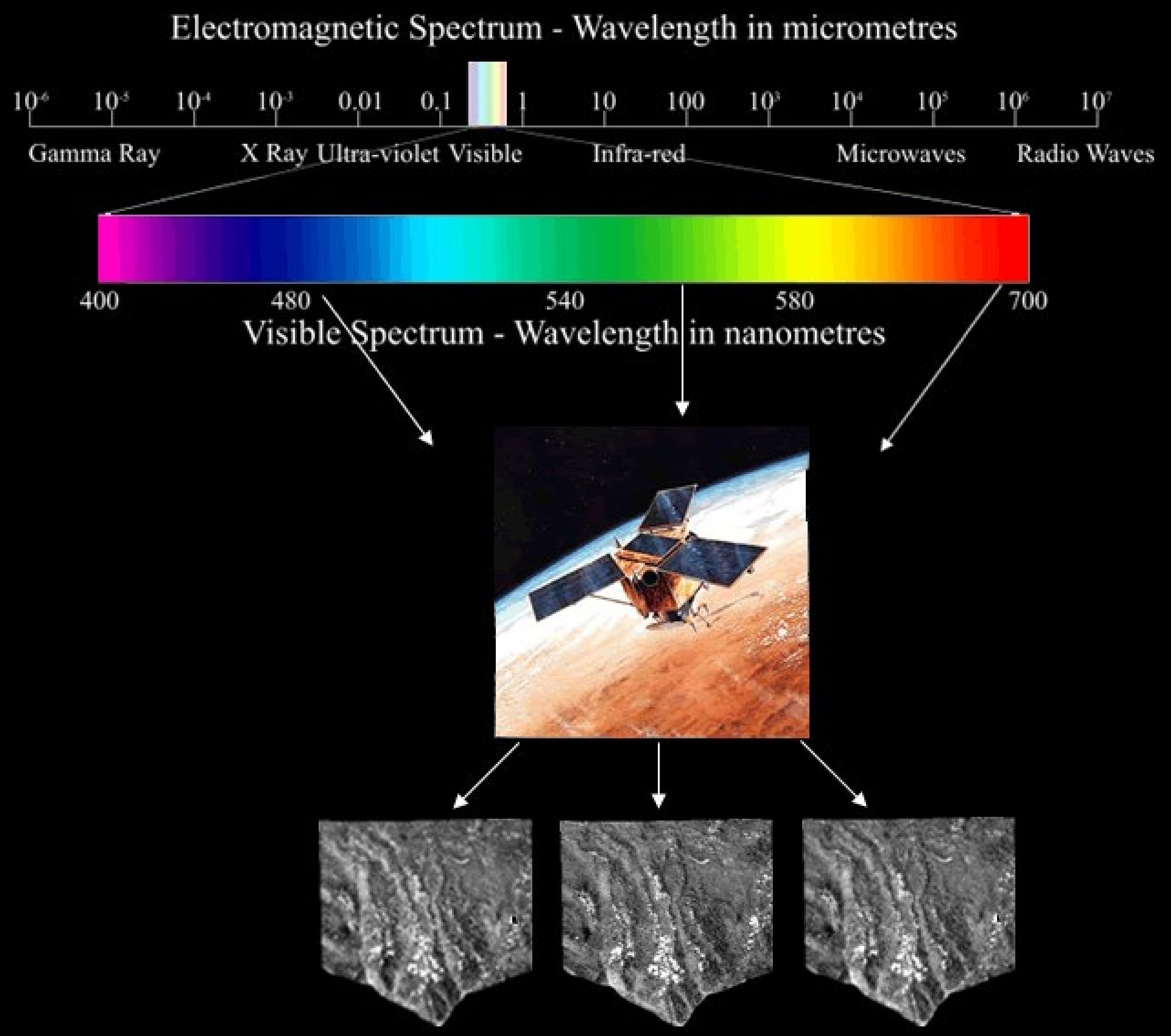
Sources: https://mars.nasa.gov/resources/24729/map-of-nasas-mars-landing-sites/
https://moon.nasa.gov/resources/65/moon-landing-sites/

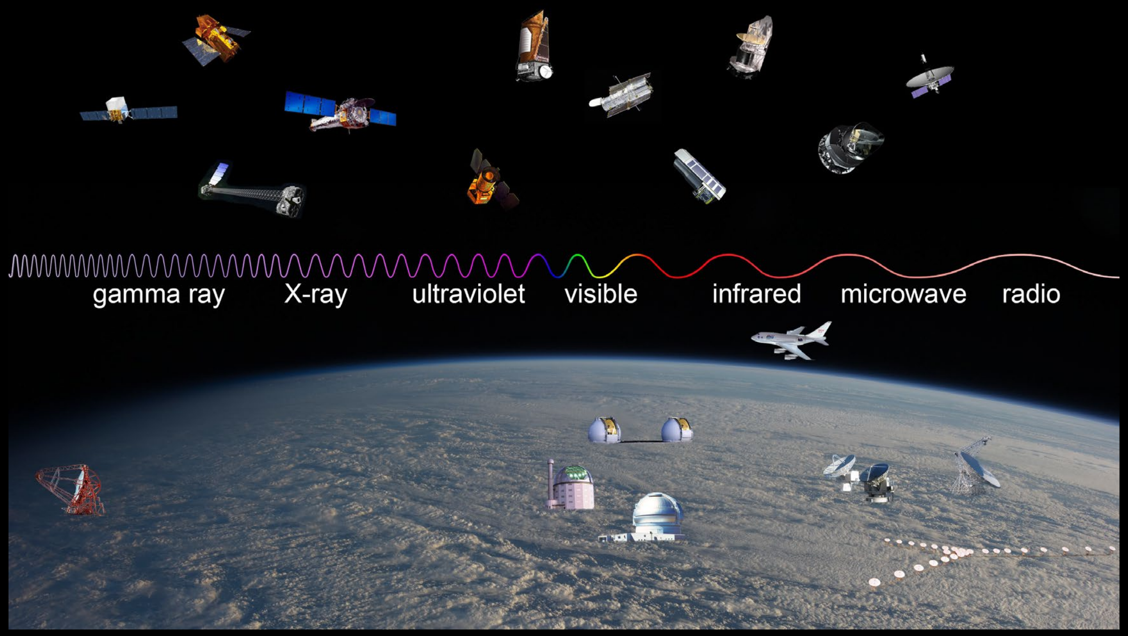
Flyby, Orbit, Land, Rove, Return Samples

https://svs.gsfc.nasa.gov/3835

https://lunar.gsfc.nasa.gov/

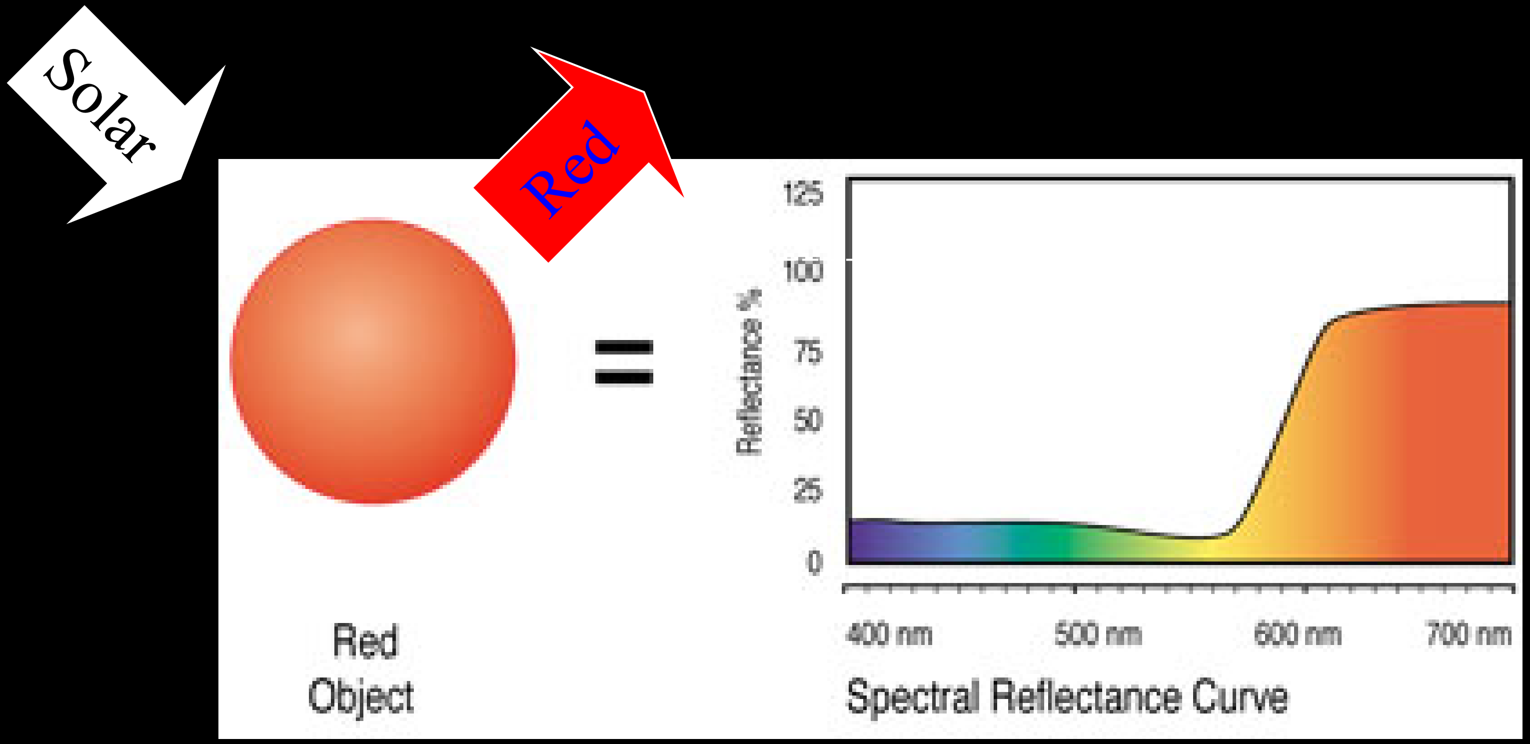
Remote Sensing Across the Electromagnetic Spectrum





Nasa.gov

Remote Sensing Across the Electromagnetic Spectrum



Powerpoint art / GSFC

For planetary remote sensing, rough rule of thumb is that interactions occur within a few wavelengths (actual behavior complicated!)

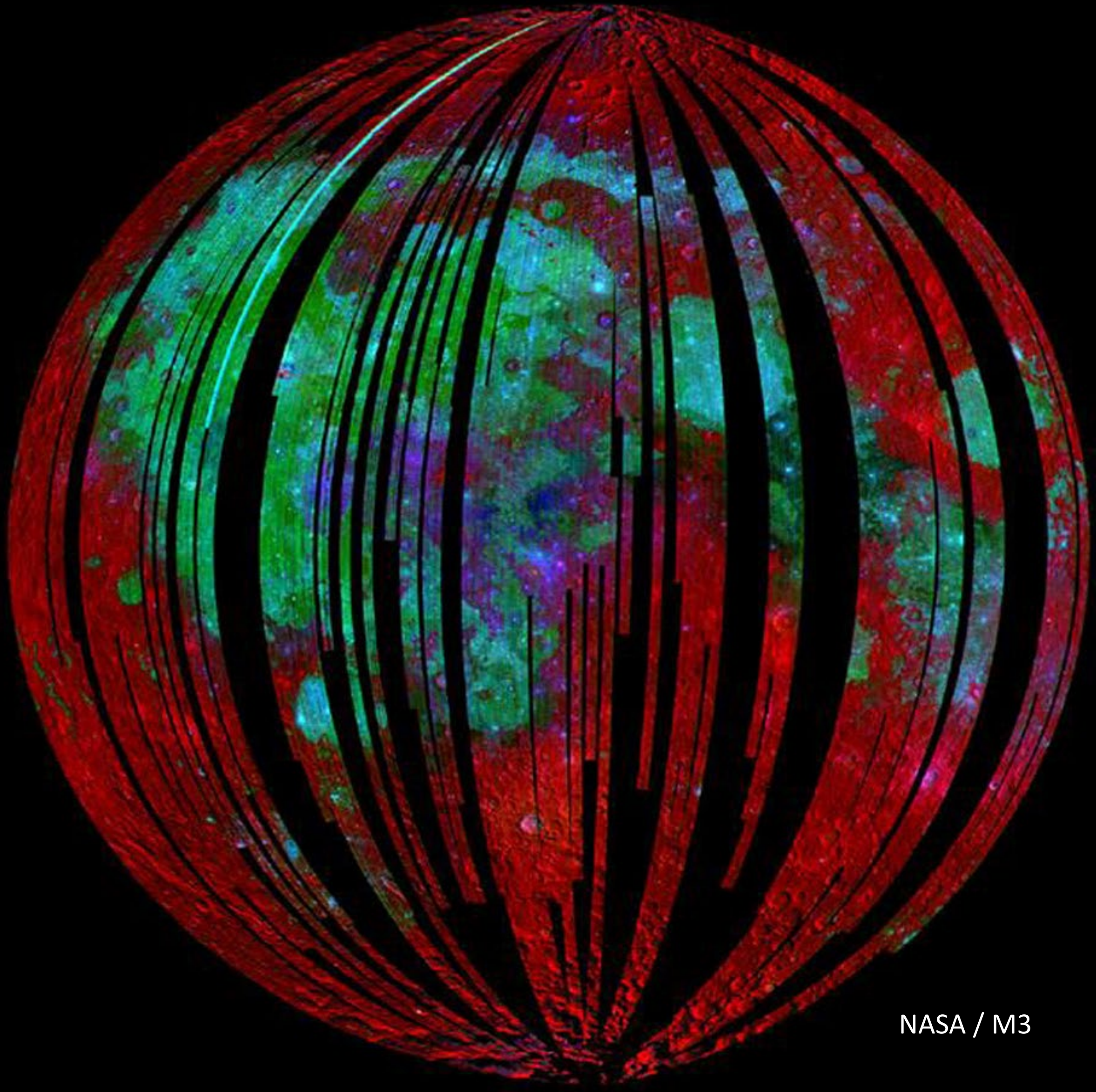
{Radar/microwave sense to >meter depths}

A whole new Moon

Red: 1.58 μ
Green: 1.00 μ
Blue: 2.00 μ

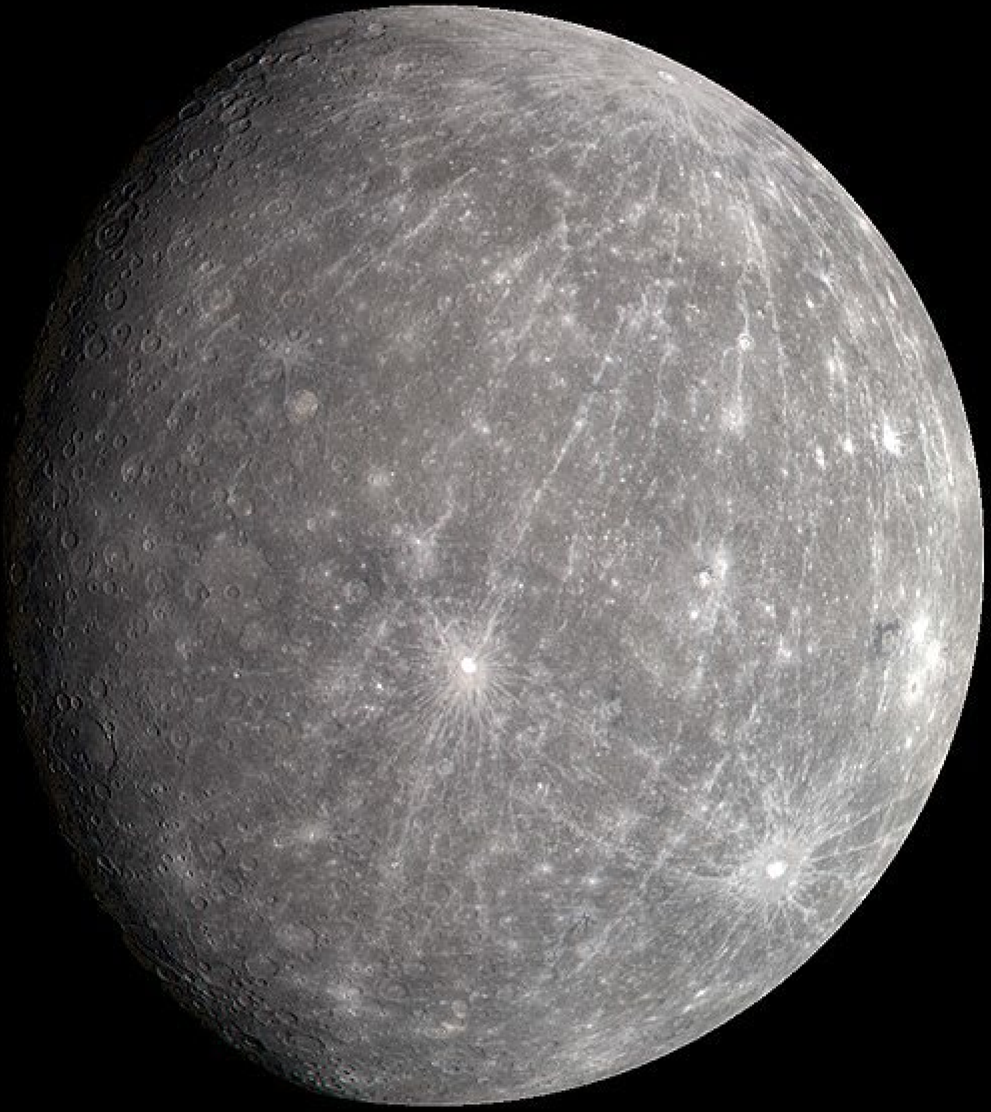
Redder area => more plagioclase feldspar and less mafic minerals, indicating the lunar highlands material.

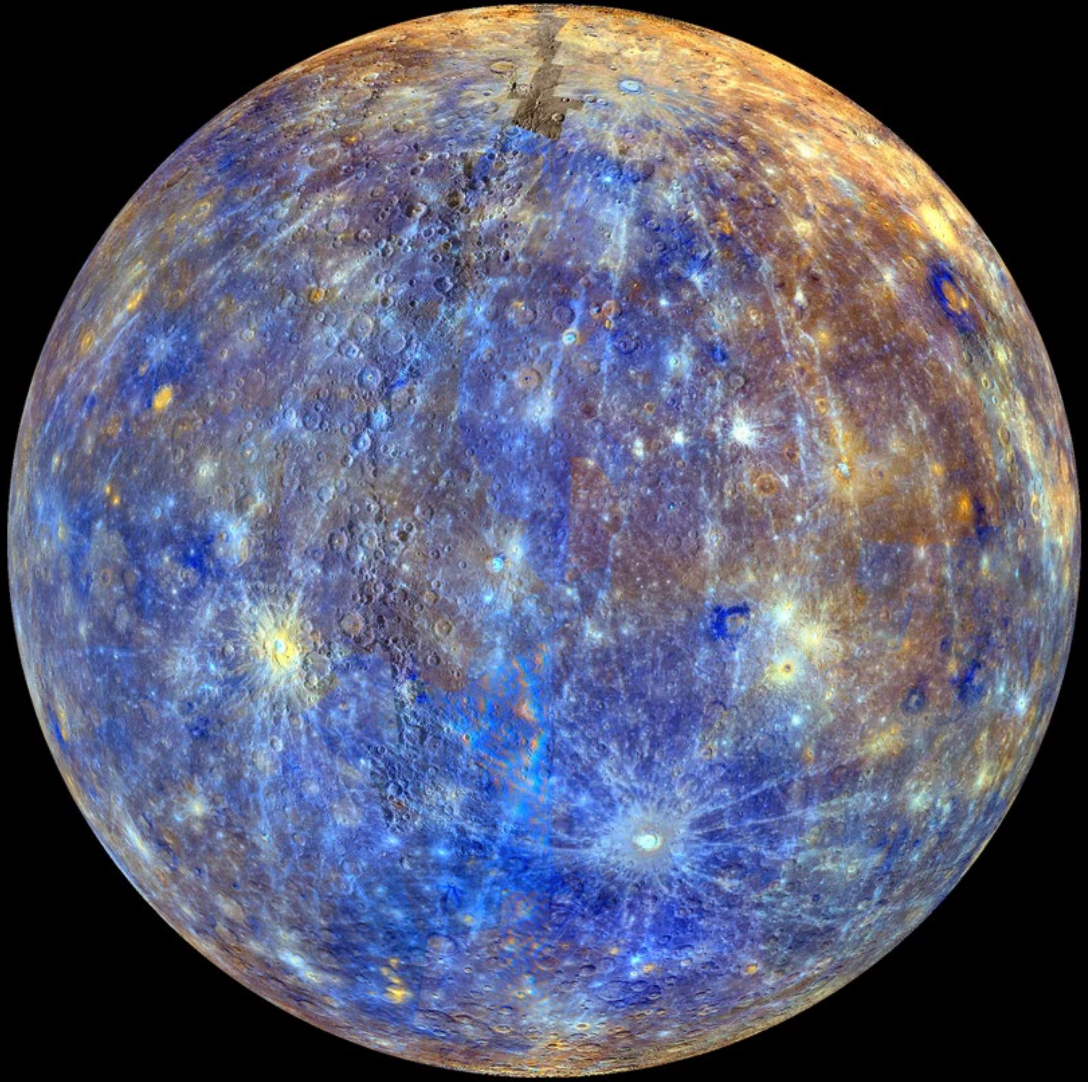
Bluer/Greener areas show presence of iron-bearing "mafic" minerals common in basalt. Different lava flows contain different abundances of these mafic minerals, resulting in different colors in this portrayal.



NASA / M3

Mercury, “True” and “False” Color

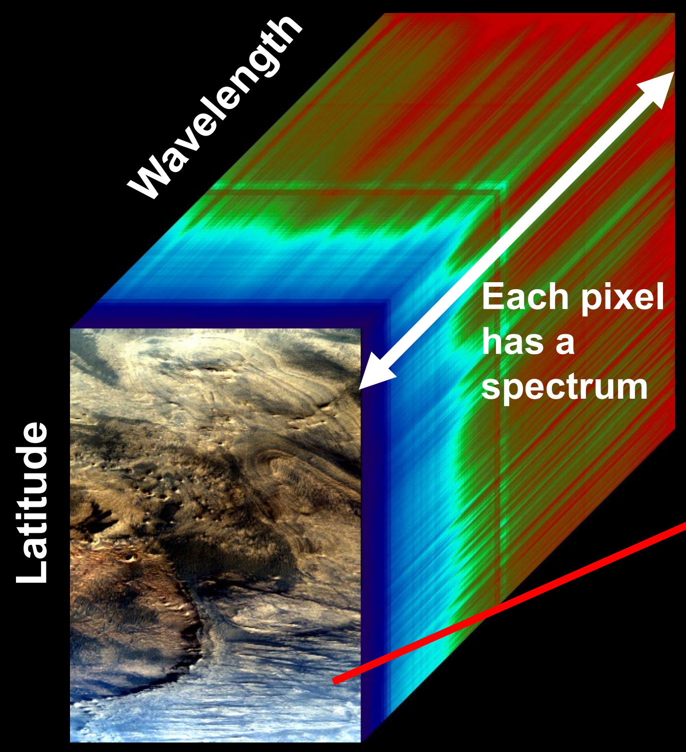


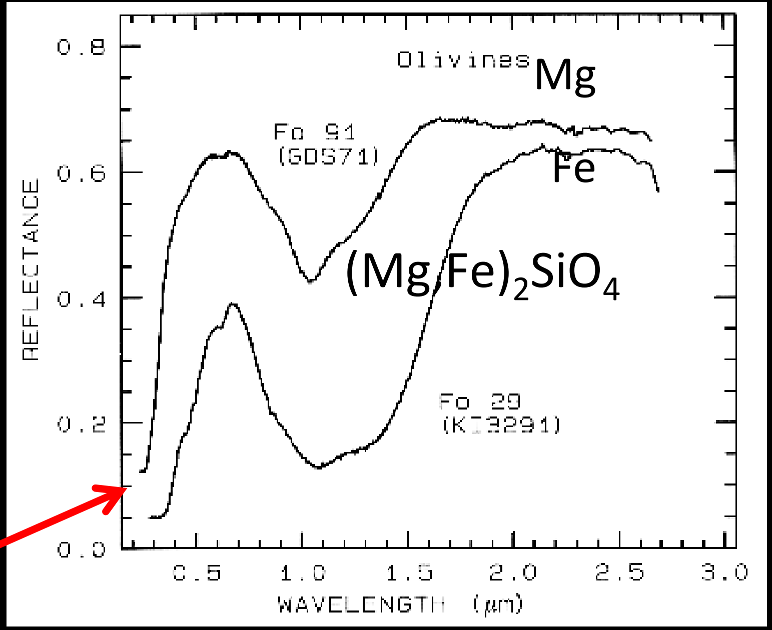


NASA / MESSENGER

Visible/NIR Reflectance and Mineral Fingerprints

Reflectance and Minerals





A single image is taken in many wavelengths (544 channels)

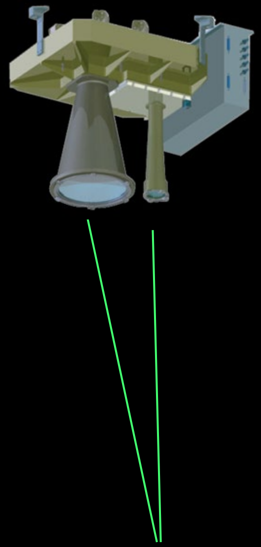
Each pixel has a spectrum. Spectra can "fingerprint" minerals formed by volcanism or past water.

Important: Not every mineral has diagnostic spectral features (particularly in a given λ region)

From NASA-Brown ReLAB/Ralph Milliken

Remote Sensing: Active vs. Passive

- Active versus passive
  - Passive: Detect naturally reflected or emitted light
  - Active: Instrument sends source to planet, looks at results.



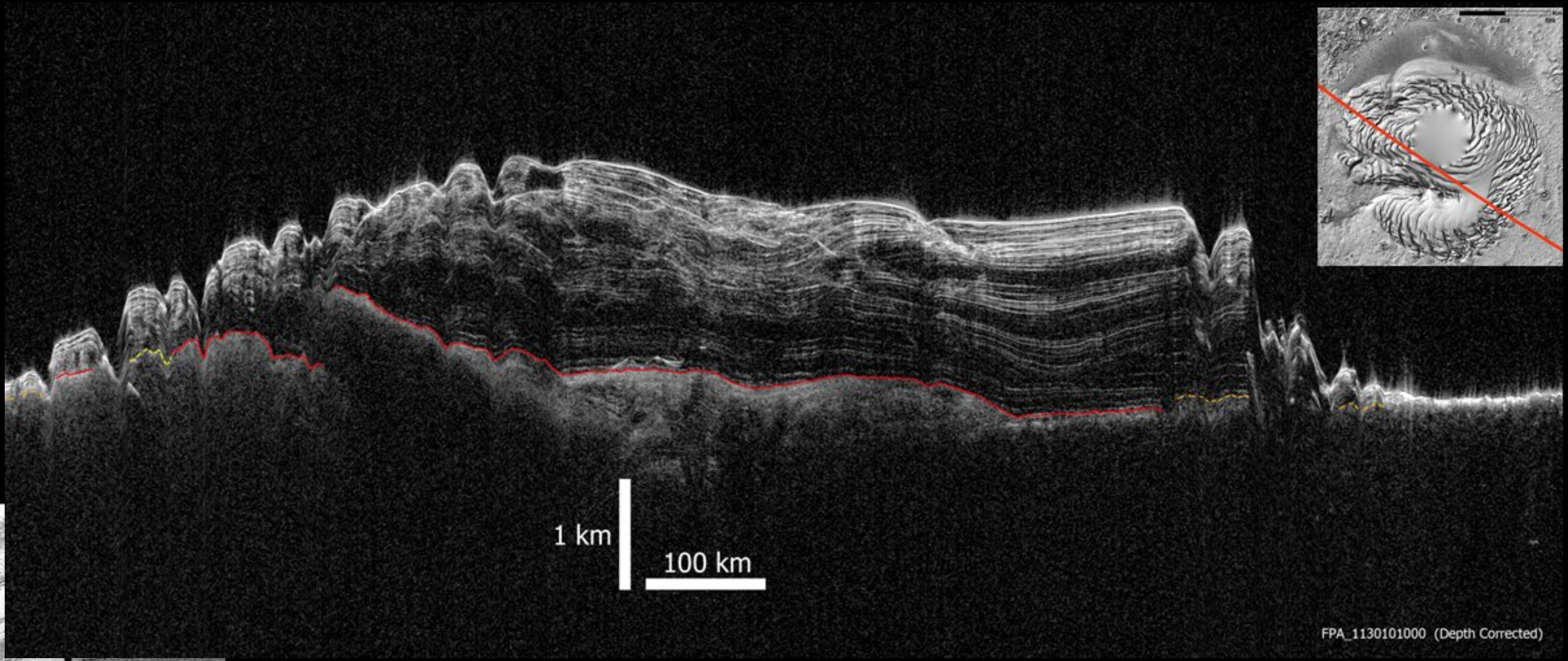
LIDAR: Uses laser to transmit, bounces off planet

Radio telescope (active-mode: radar) send a signal, bounce off planets

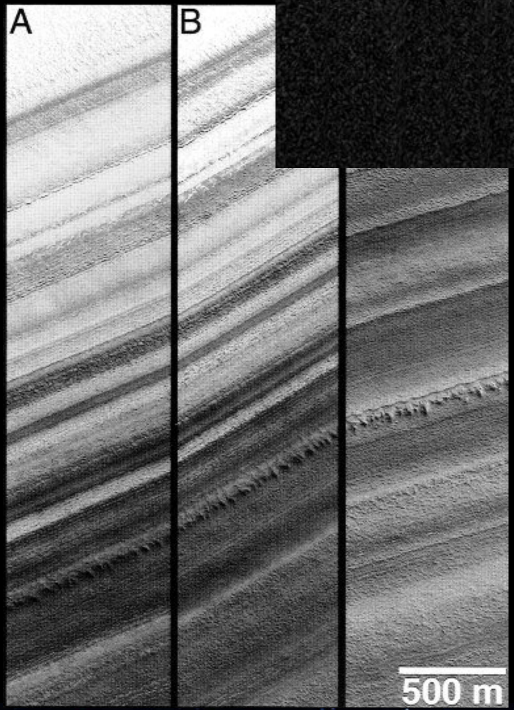
DIVINER: Thermal Emission Camera

NASA

Orbital Radar Example: SHARAD views Mars polar caps

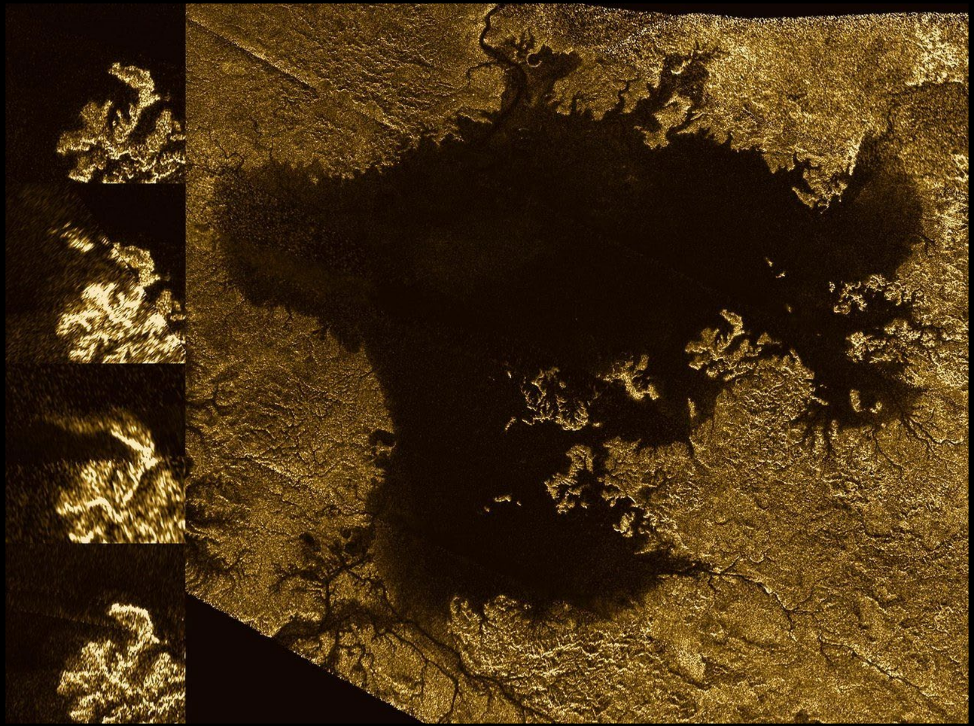


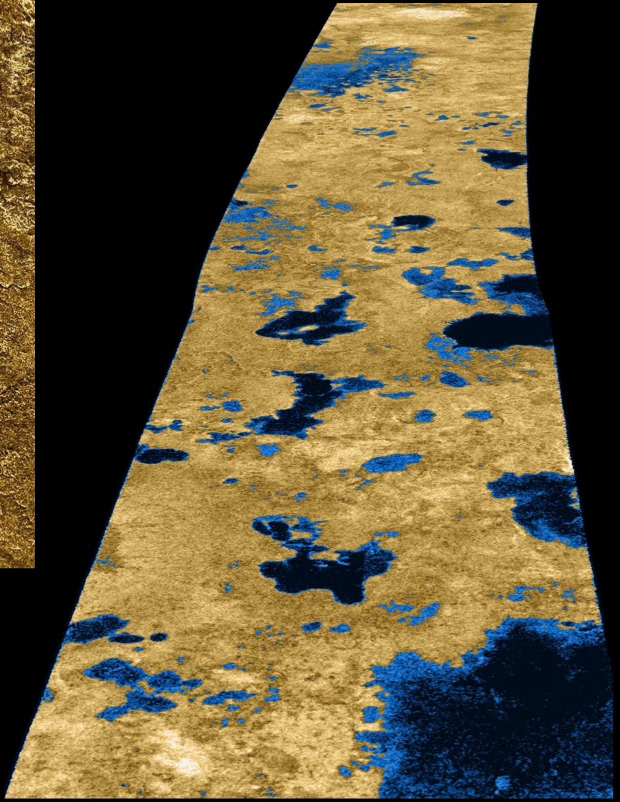
Mars north polar cap in penetrating radar (SHARAD instrument, λ=15 m).

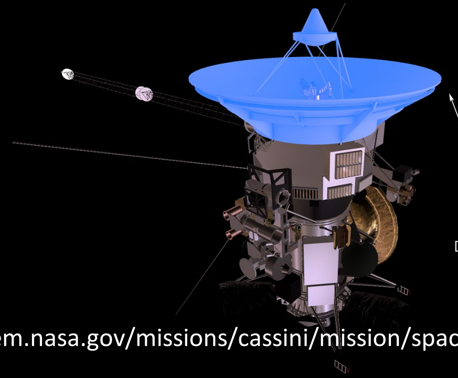


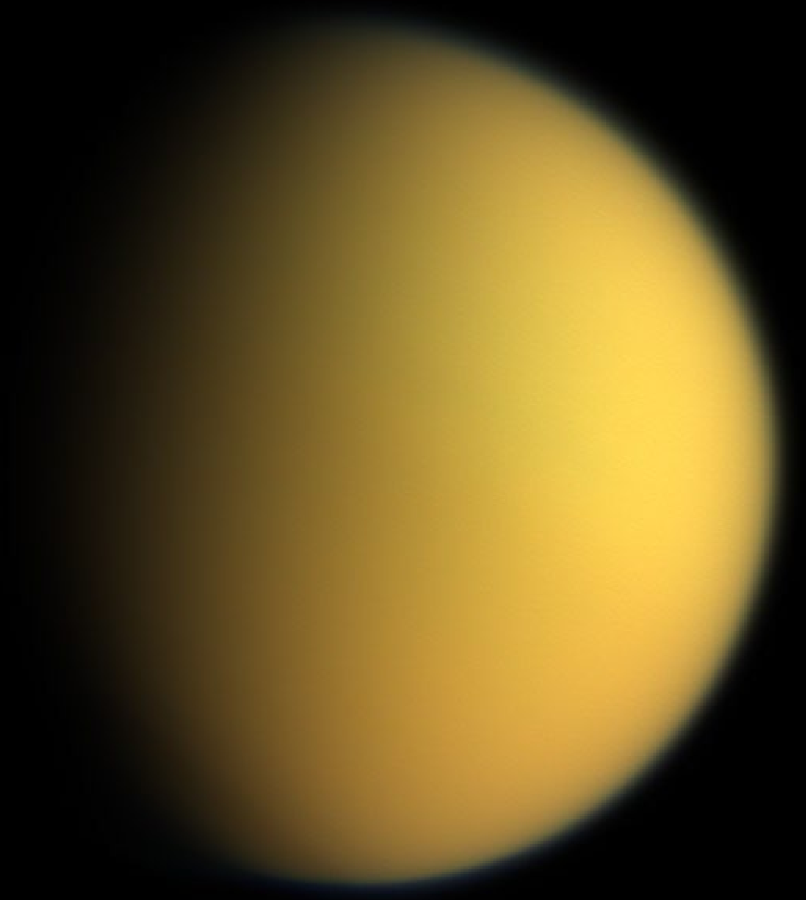
Visible image
(surface)

Orbital Radar Example: Titan









Titan

https://solarsystem.nasa.gov/missions/cassini/mission/spacecraft/cassini-orbiter/radio-detection-and-ranging/

Orbital Radar Example: Venus

λ=12.6 cm

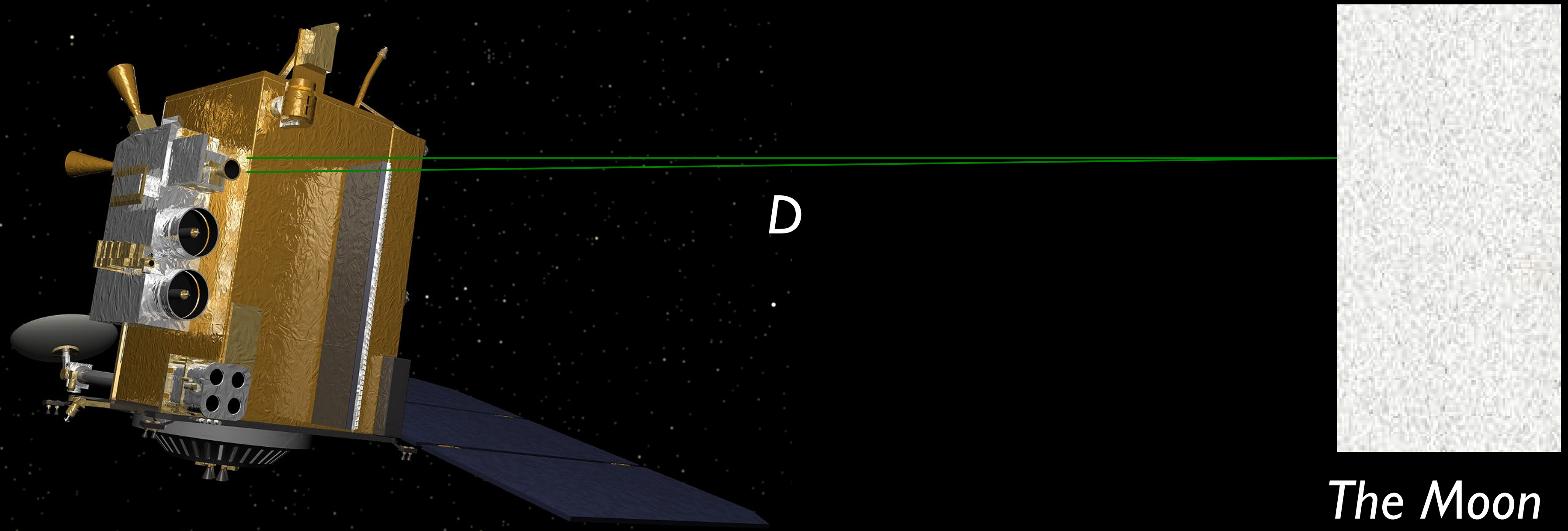
Venus

LIDAR

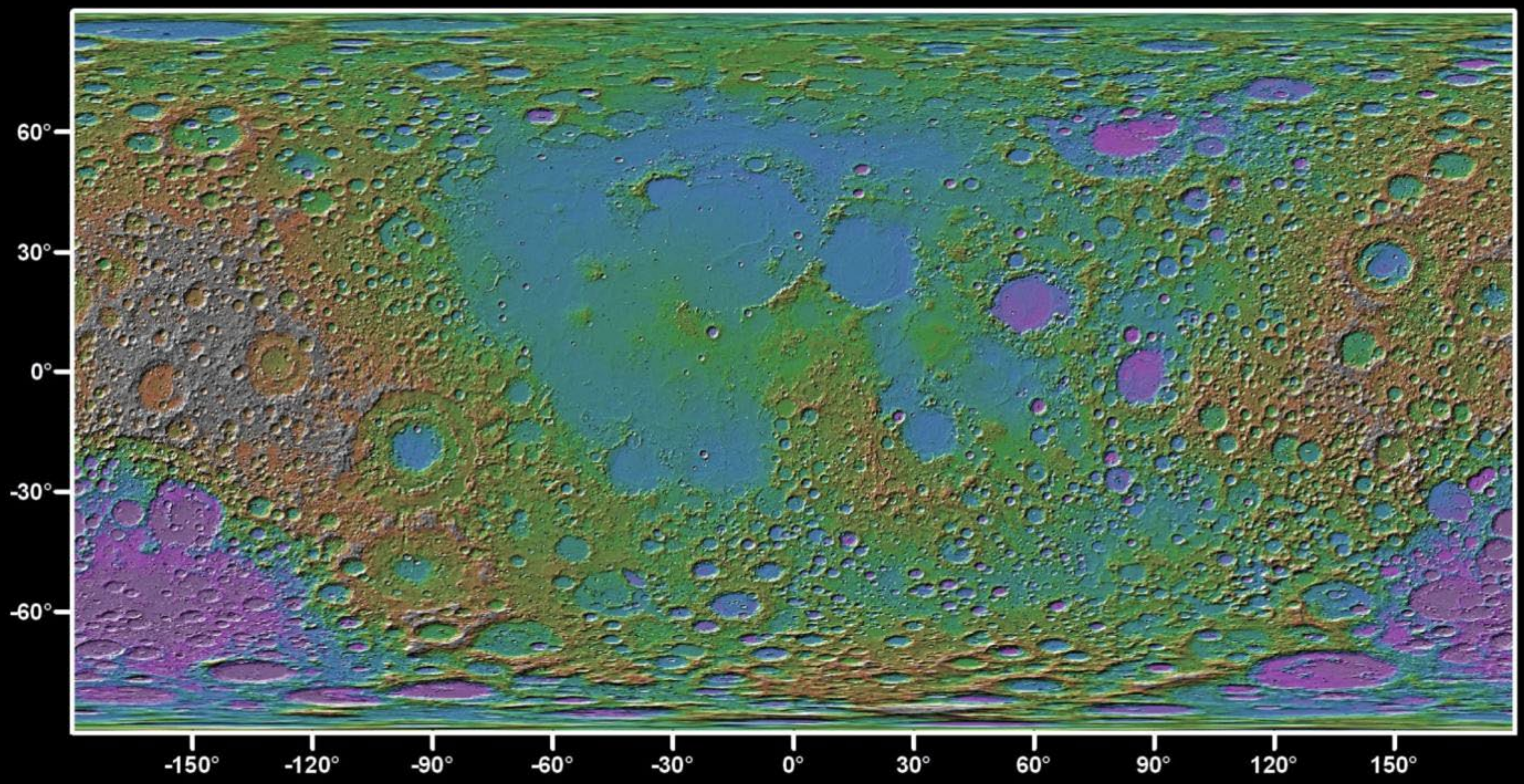
Speed of light *c* is known very precisely *(*299792458 m/s)

Time for light to travel from spacecraft to range and back….
Distance (to surface, D) is: $2D=cT$

Precision of LOLA is ~±10 cm. Timing needs to be known to $\Delta T < 1$ ns (!)



The Moon: Topography

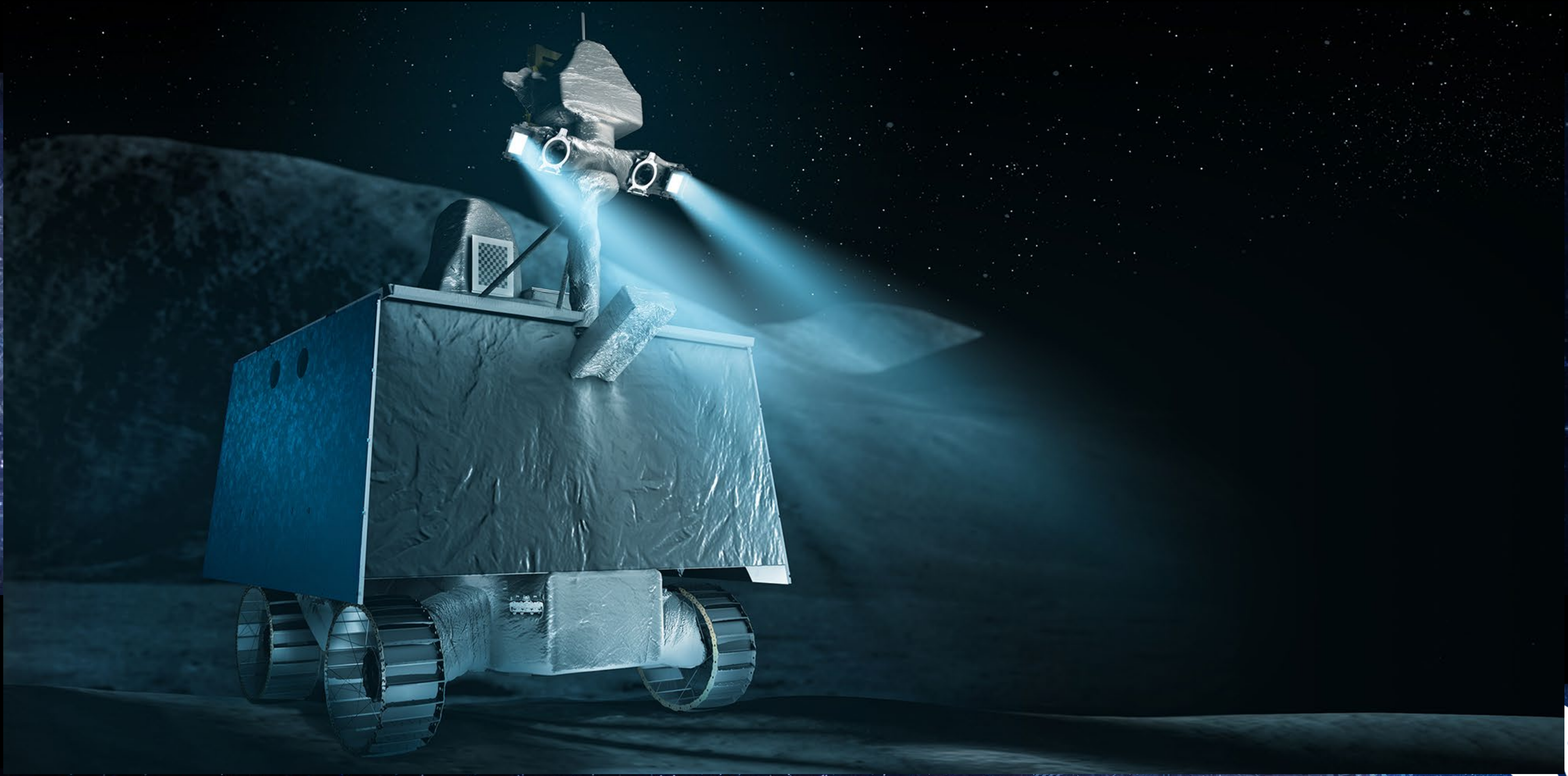


LOLA Data: >6.5 billion surface observations (as of 2014)

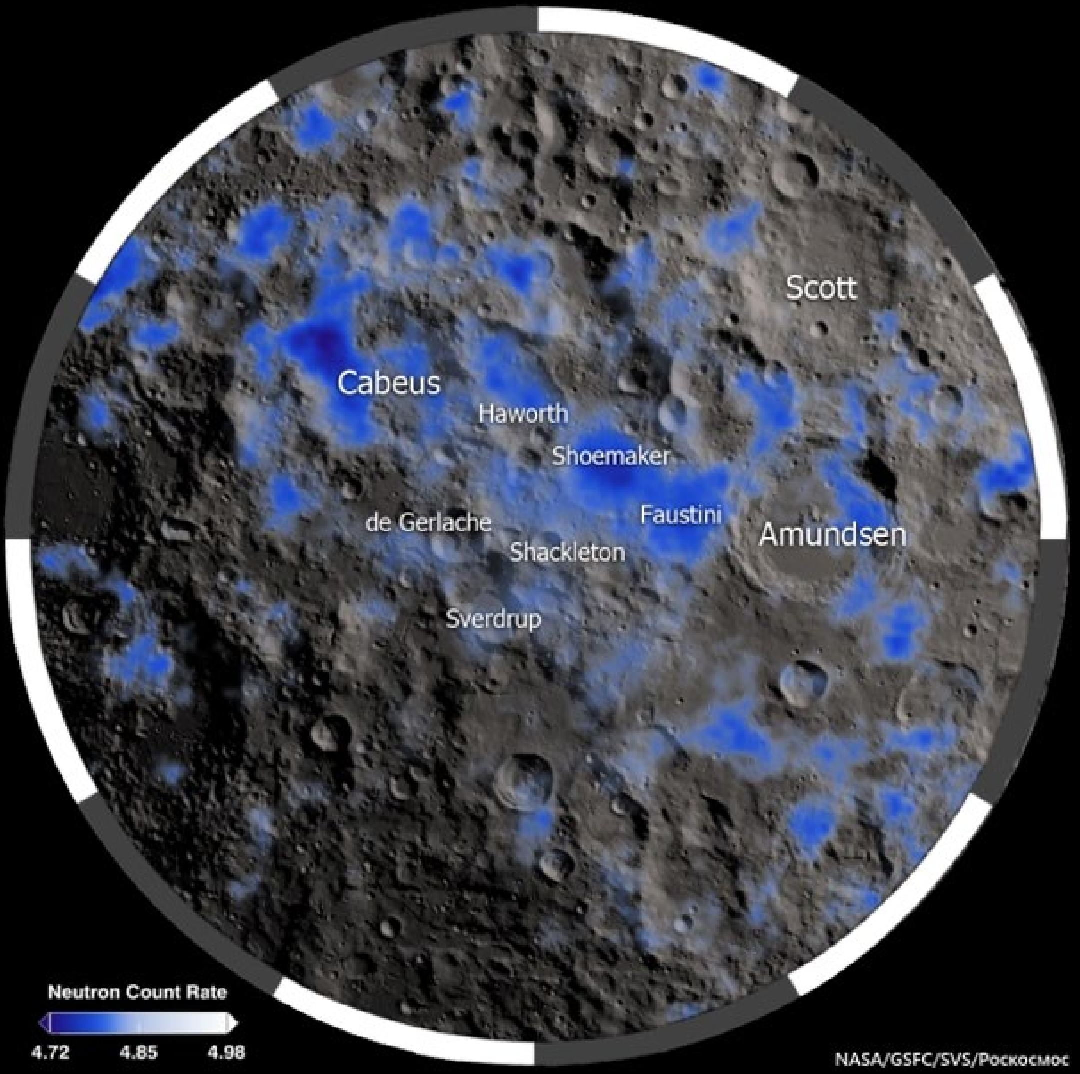
Discussion Questions

1. Think about some *everyday* applications where you see electromagnetic sensors in use (radar, infrared, visible, X-Ray, lidar, etc). What are some examples?
2. What are some areas where landers and rovers have advantages, and what are advantages of orbiters?

One of my missions: the VIPER rover



Water at the Lunar South Pole



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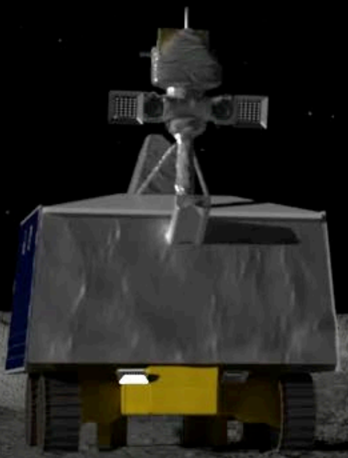
Future Vision: Living off Lunar Water

NASA

VIPER

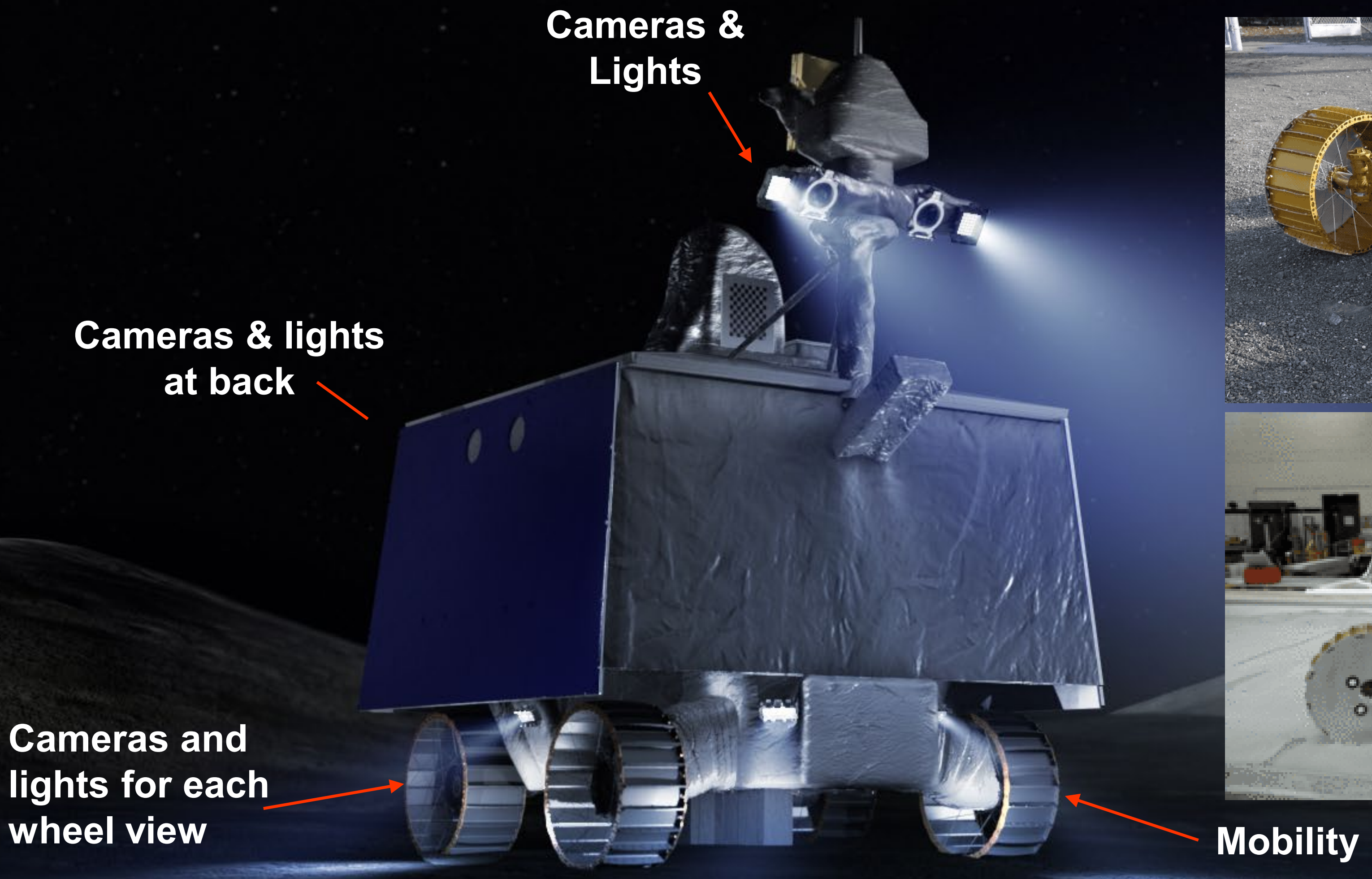
Characterize the distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith.

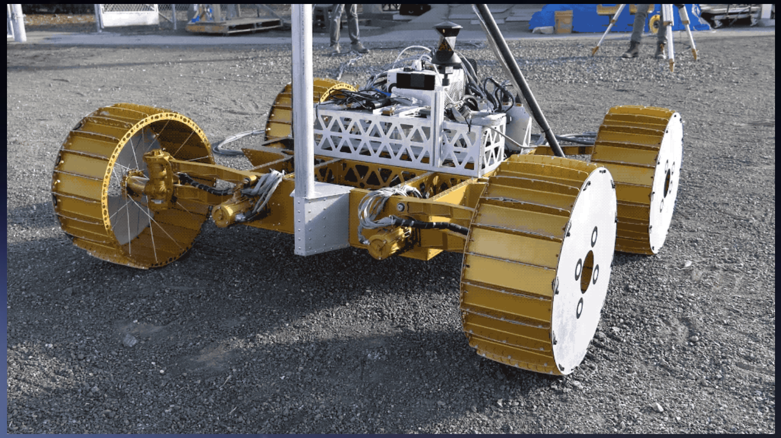
Provide the data necessary for NASA to evaluate the potential return of In-Situ Resource Utilization (ISRU) from the lunar polar regions.

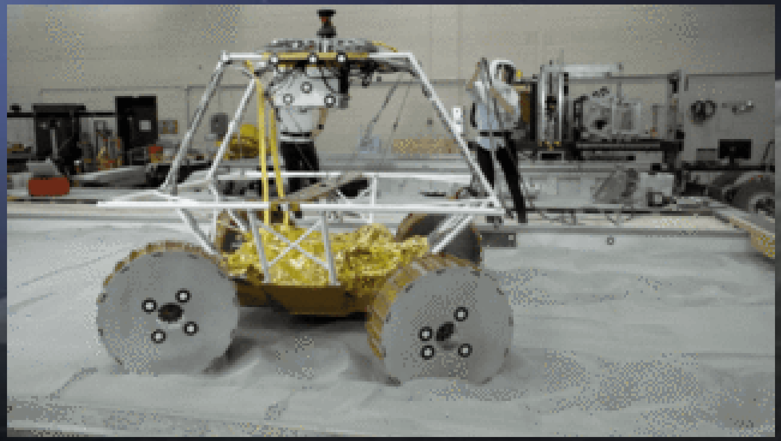


The next great leap in understanding lunar water is mapping these volatiles at the human scale.

VIPER Rover


Cameras &
Lights
Cameras & lights
at back
Cameras and
lights for each
wheel view
Mobility

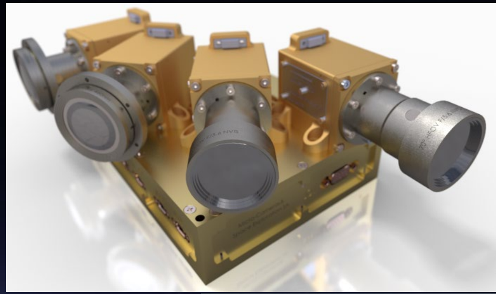


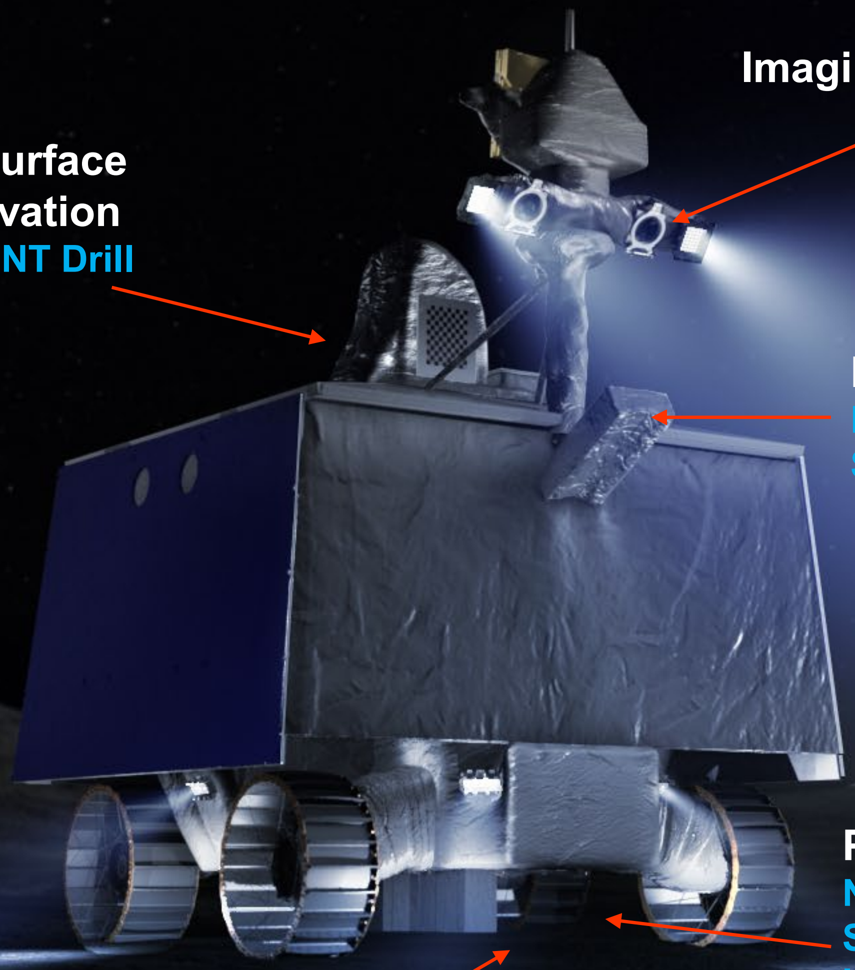


Science Instruments

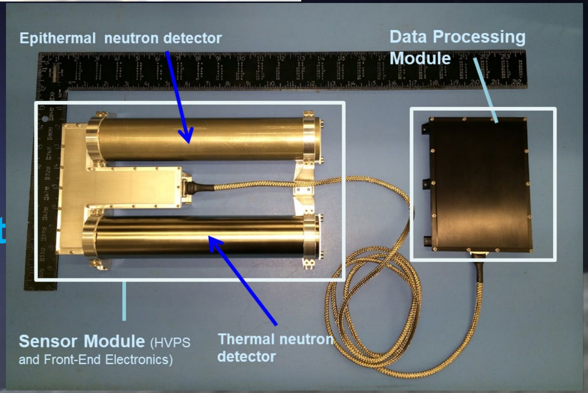
Subsurface excavation
TRIDENT Drill

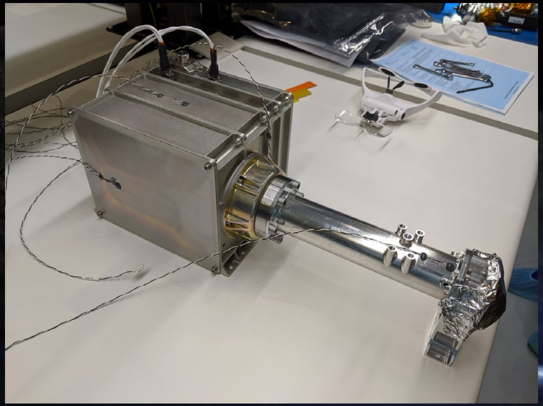
Imaging Science
VIS



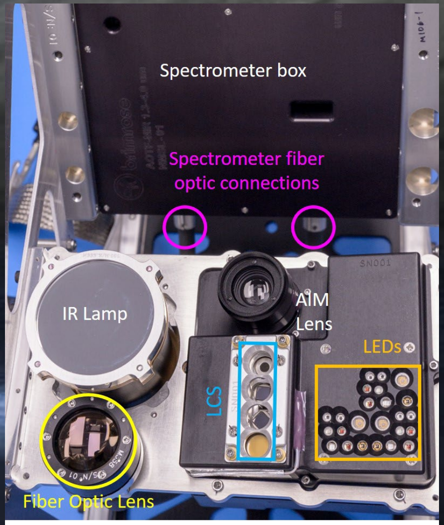


Prospecting
Neutron Spectrometer System (NSS) Instrument





Prospecting & Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS) Instrument



Prospecting & Evaluation
Mass Spectrometer Observing Lunar Operations (MSolo) Instrument

The Lander

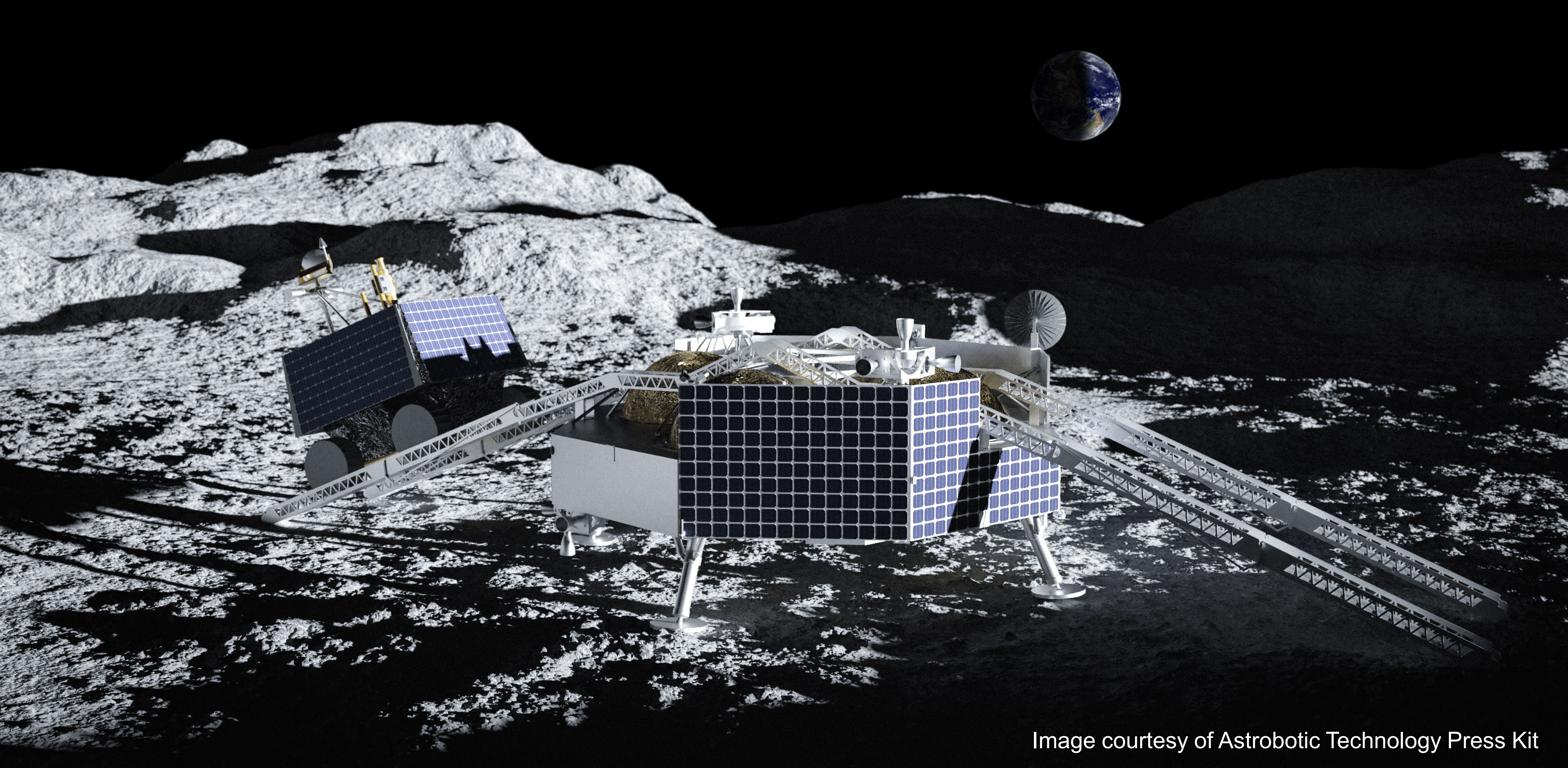
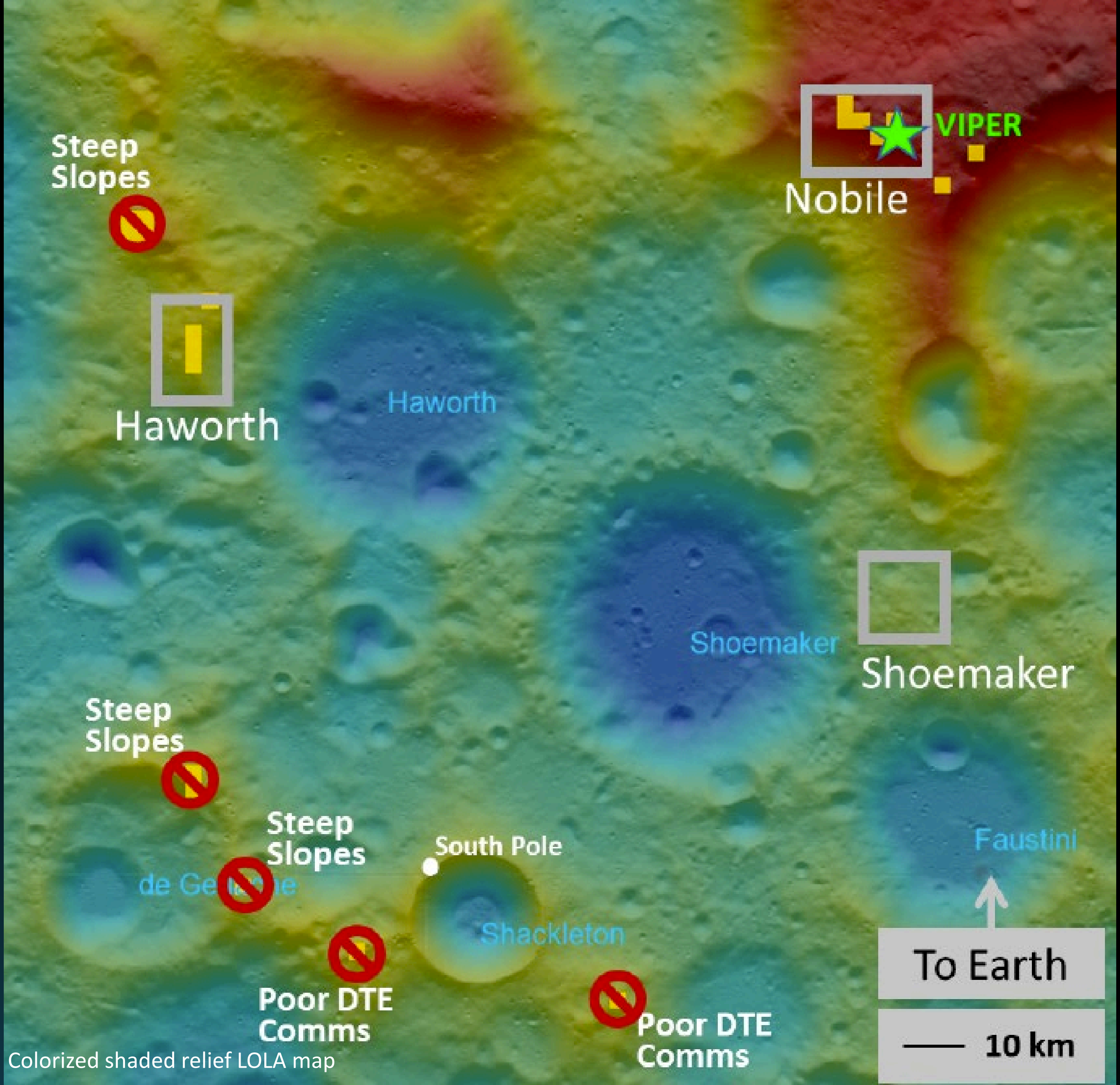


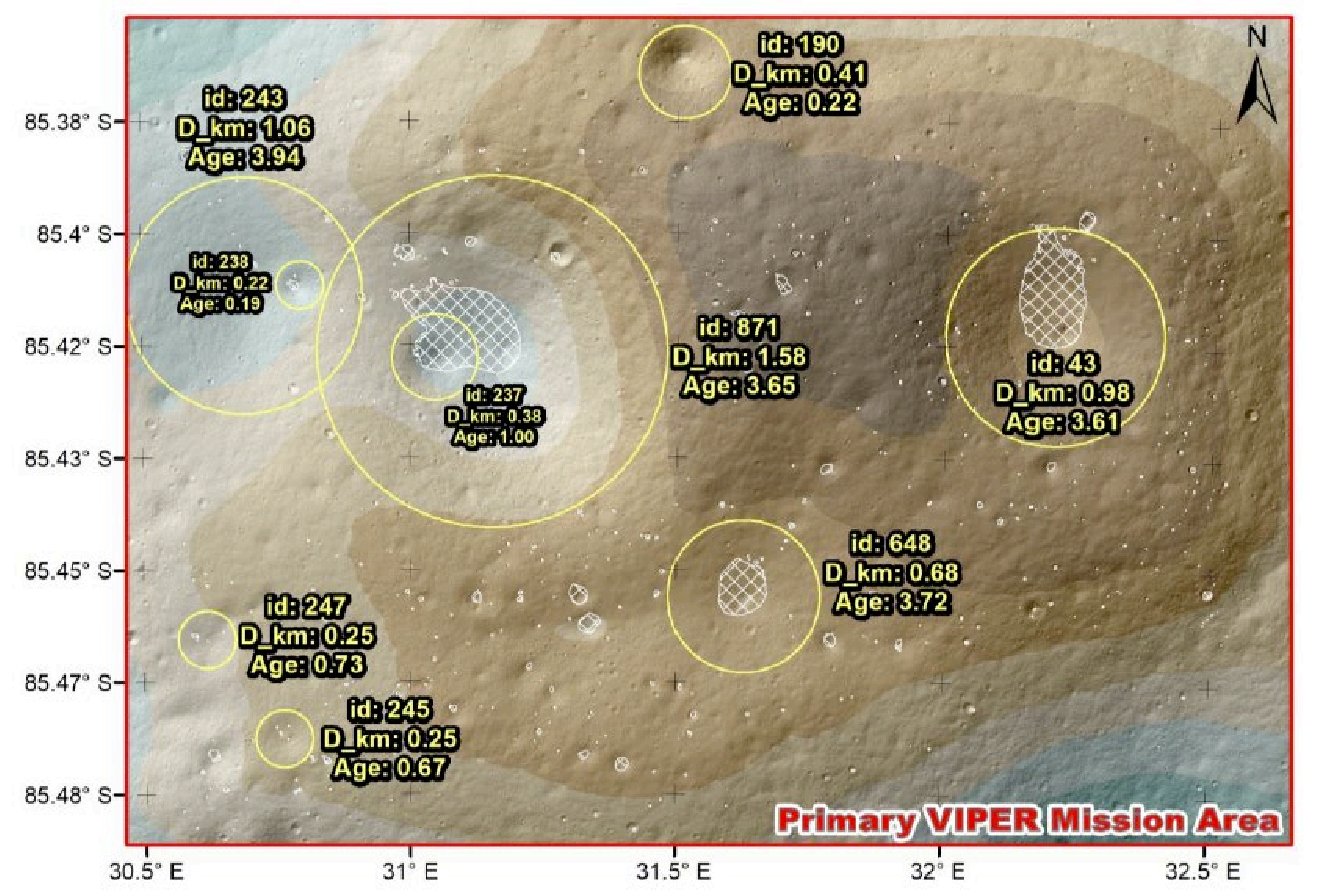
Image courtesy of Astrobotic Technology Press Kit

Landing where?



Beyer et al. 2022

VIPER Mission Area



Fassett et al. 2022

VIPER Mission Area hosts craters ranging from 100 Mya to >3 Gya

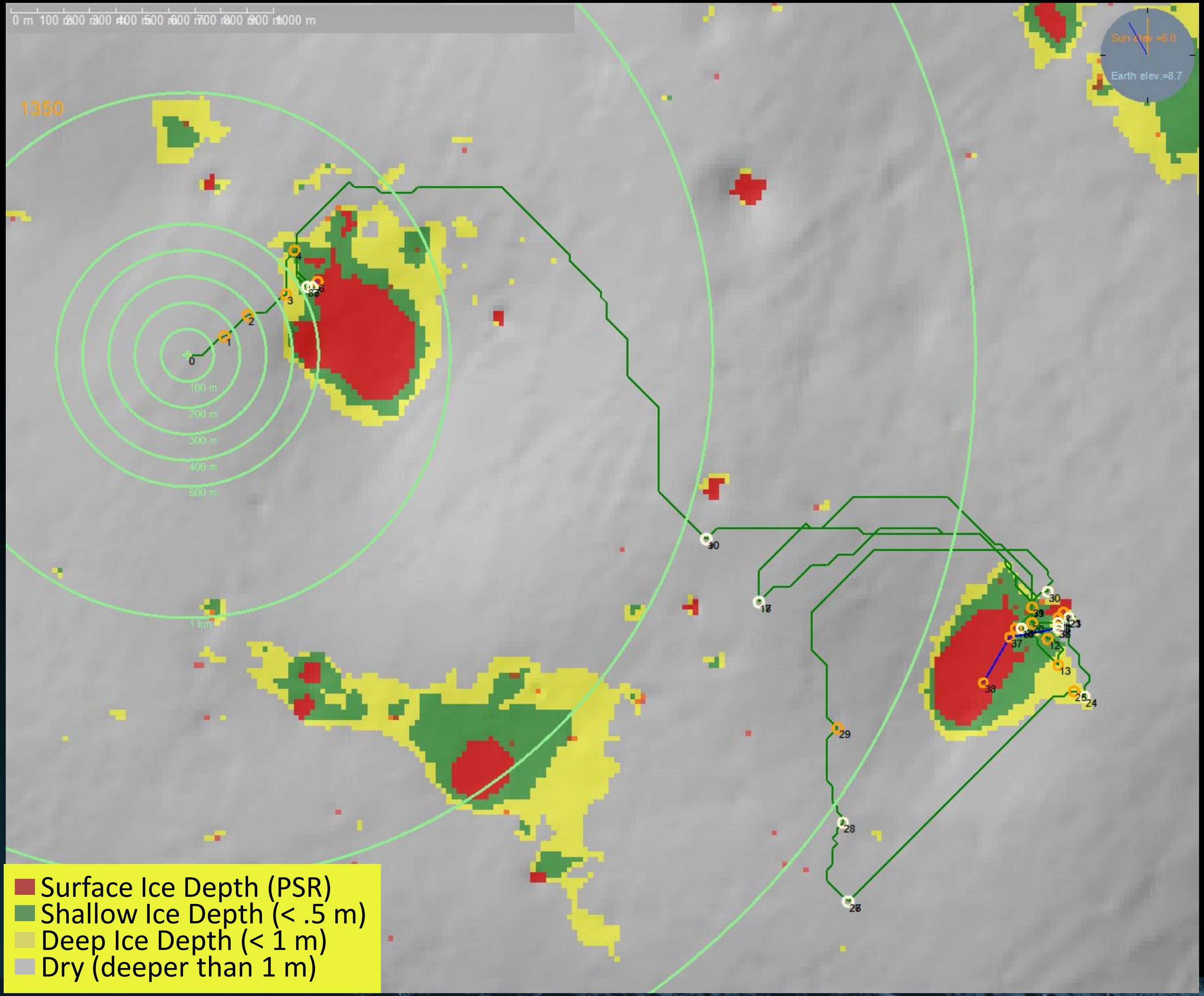
Role that the age of PSRs plays in controlling the presence or absence of polar volatiles is of substantial interest for discerning volatile history.

Nobile Reference Traverse

Duration	91 days
Length	13.25 km
PSRs	2 (4 entries)
Shallow	6
Deep	3
Dry	2

- 1st lunar day: 1 dry, 1 deep, 1 shallow, 1 PSR
- Full mission success on mission day 36, day 7 of second lunar day

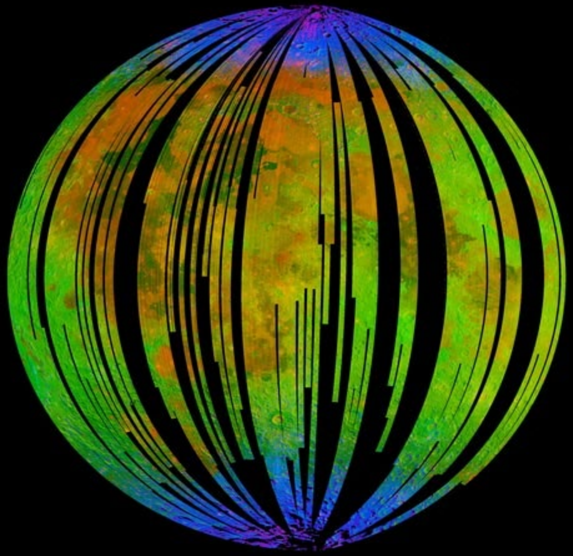
Total number of drill sites = 35
Total mapped ISR area (m^2):
PSR = 765
Shallow = 2295
Deep = 1241
Dry = 765



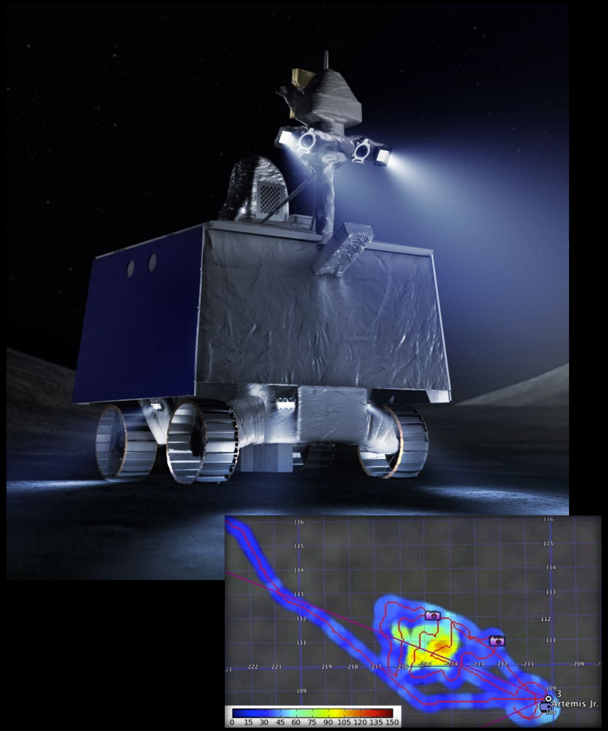
Leaps in our understanding of water on the moon

1969

1998-
2009



2023



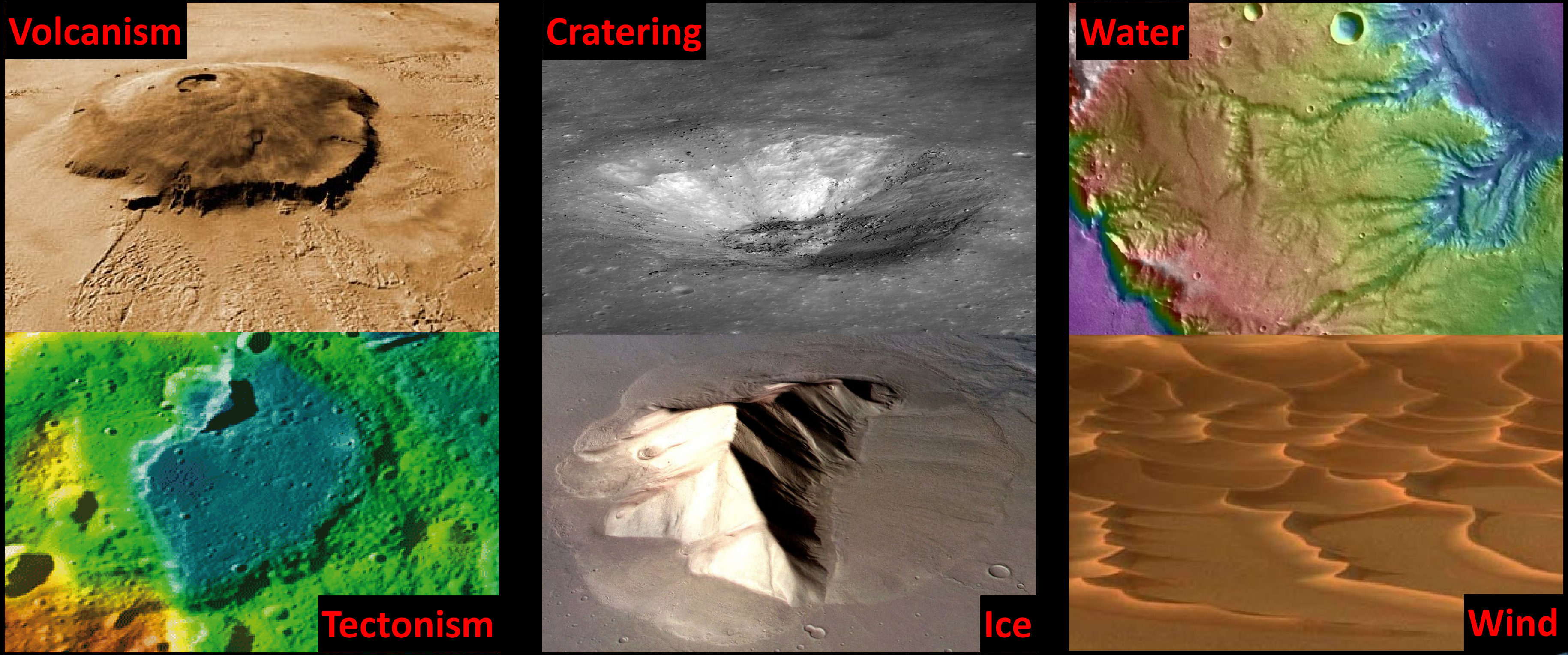
Moon Water

- The past decade of observations have built a fascinating and complicated story about lunar water.
- From “frosts” to buried ice blocks, there appears to be water everywhere, but its nature and distribution is very uncertain.
- The next steps in exploration require surface assets, including surface mobility.
- VIPER is that mission to conduct exploration science, modeled after terrestrial resource exploration processes and techniques.

https://www.nasa.gov/viper

Planetary Science Today

- We use remote and direct observations of planets to:
  - Understand the *physical processes* affecting planets;
  - Infer the *rates* of processes & how these connect to *their geologic history*;
  - Seek out evidence for past or present habitability;
  - Help set boundary conditions for other measurements and *future exploration*.



We are going…

Artemis is to take us back to the Moon and on to Mars…