Astro-1 Honors 2020
Class 2: History of lunar exploration

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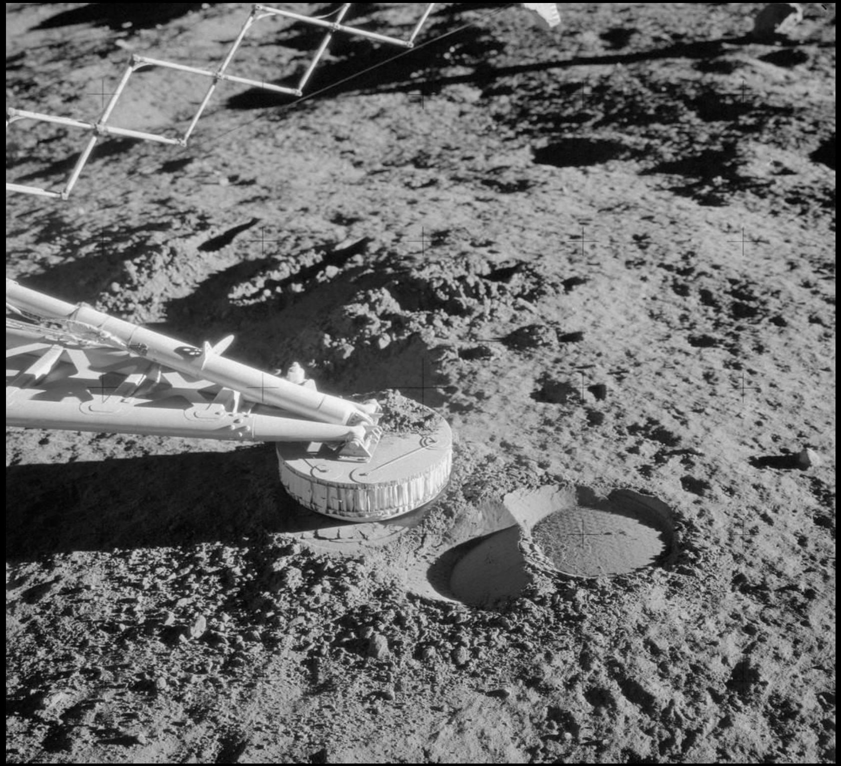
Announcement: News from SpaceRef, Jan. 20th
ESA finds a way to extract oxygen from lunar regolith!

http://spaceref.com/moon/esa-opens-an-oxygen-plant-that-makes-air-out-of-moondust.html

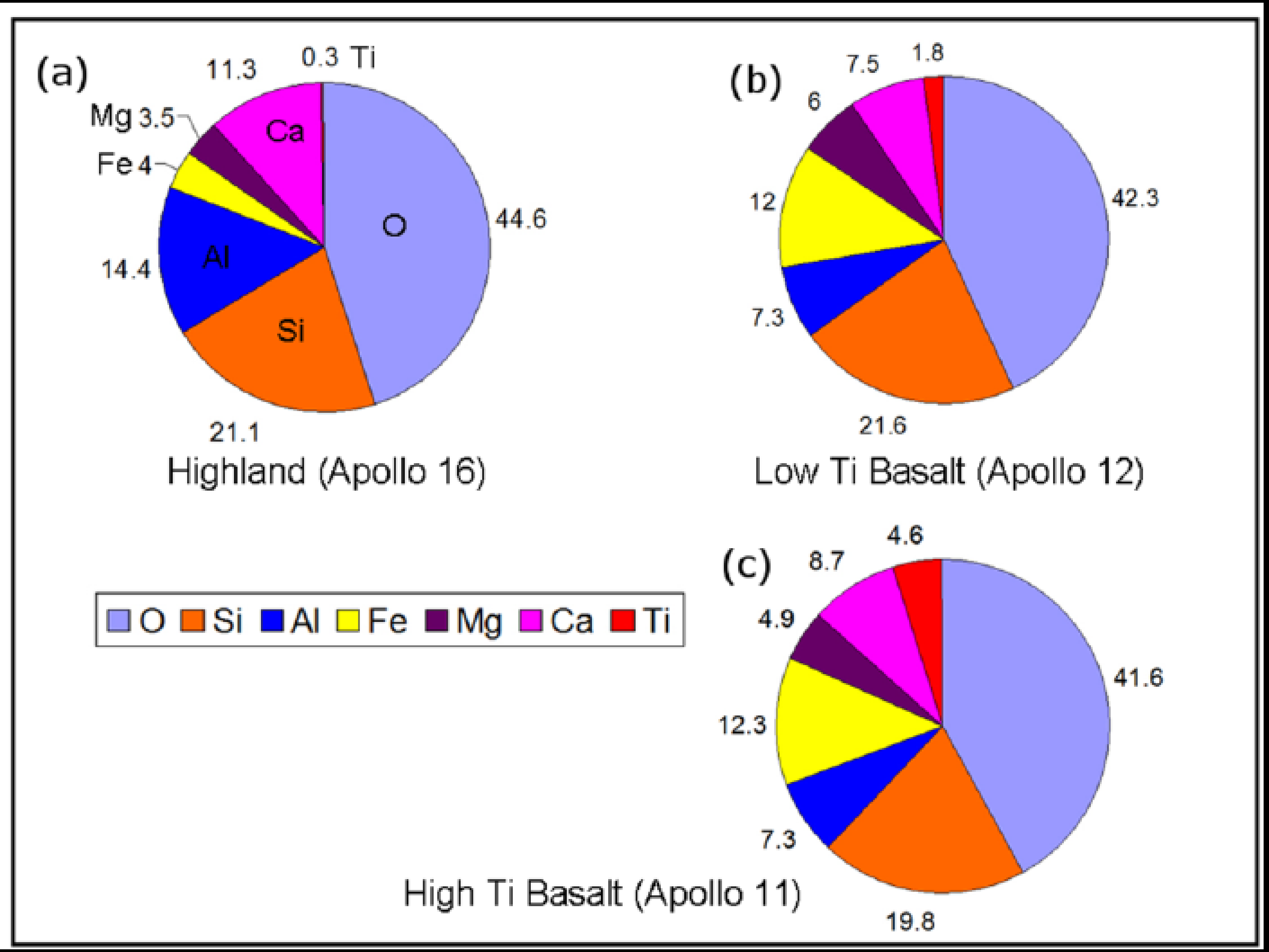


Apollo 12 Mission Report: *The cohesive properties of lunar dust in a vacuum, augmented by electrostatic properties, tend to make it adhere to anything it contacts.*

What is the lunar regolith?

The layer of loose deposits of dust, soil, and broken rock fragments covering the lunar bedrock. Formed by bombardment over 4.6 by, of small and large impacts breaking up the surface. Evidence of melting is shown by the glassy particles found.

Streams of meteoroids striking the Moon's surface.
Credits: NASA's Goddard Space Flight Center



https://www.researchgate.net/publication/267454477_Lunar_Resources_A_Review

Example chemical compositions of lunar soils: (a) lunar highland minerals (Apollo 16); (b) low-Ti basalts (Apollo 12); and (c) high-Ti basalts (Apollo 11). Based on data collated by Stoeser et al. (2010), and reprinted from Planetary and Space Science, Vol. 74, Schwandt C, Hamilton JA, Fray DJ and Crawford IA, ' The production of oxygen and metal from lunar regolith ' 49-56, Copyright (2012), with permission from Elsevier.

HW that was due 1/21:

1. What are the main theories of the origin of the Moon, and which one is most in favor now?

2. What did we learn from the rock samples brought back by the Apollo astronauts?

3. What have we concluded about the history of the Moon since its formation from observing the features on its surface?

4. What are the gravitational influences of the Earth and Moon on each other?

5. What is the significance of water ice on the Moon? What evidence is there for water ice on the Moon, and where?

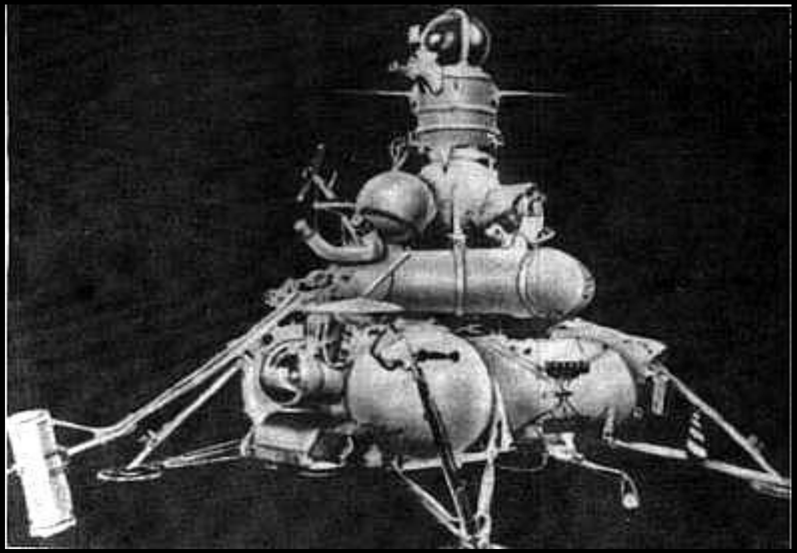
6. What further questions do you have? (You must have a bunch!) Write them all down to discuss in class next time.

A Brief History of lunar exploration

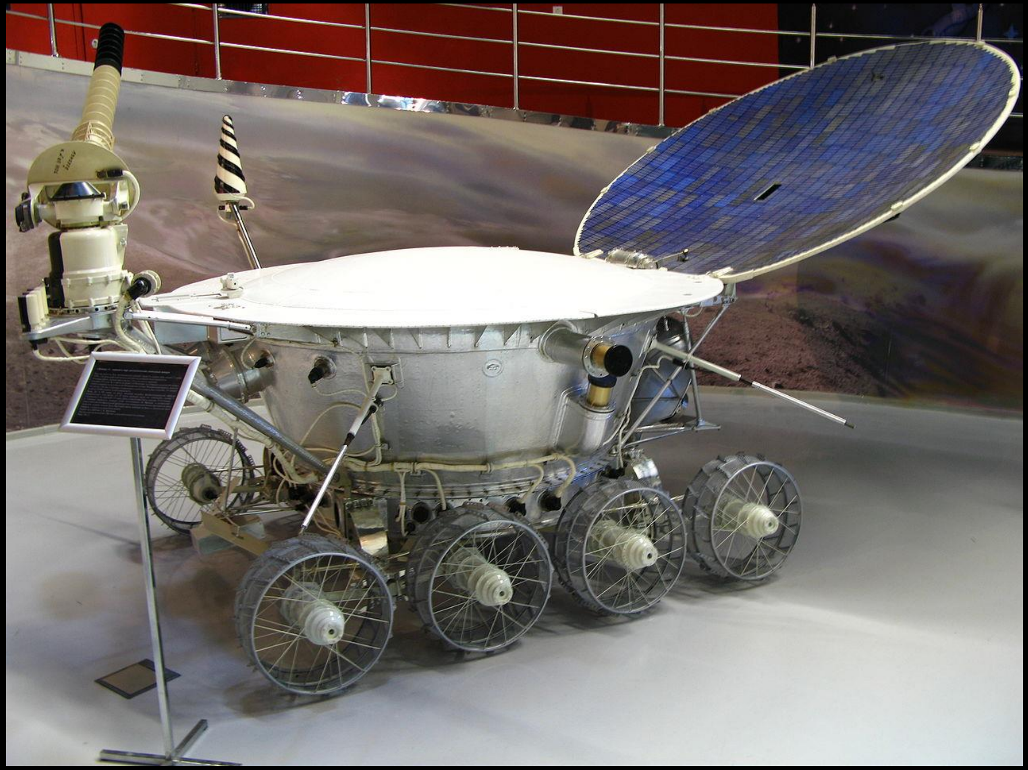
Луна

Луноход

Luna (Moon) and Lunokhod (Moonwalker) Soviet program, 1959 – 1976, 24 missions including fly-by missions, orbiters, soft landers, and impact probes – FIRST lunar missions



Luna 16 sample return probe



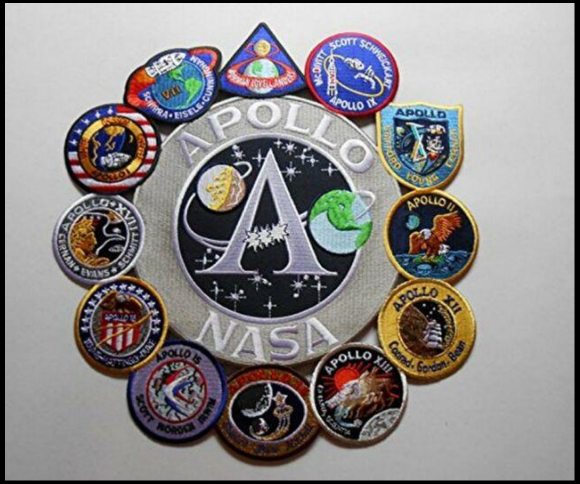
Lunokhod soft landed rover explorer

US Apollo Program, 1963 – 1972 – First humans to explore the Moon

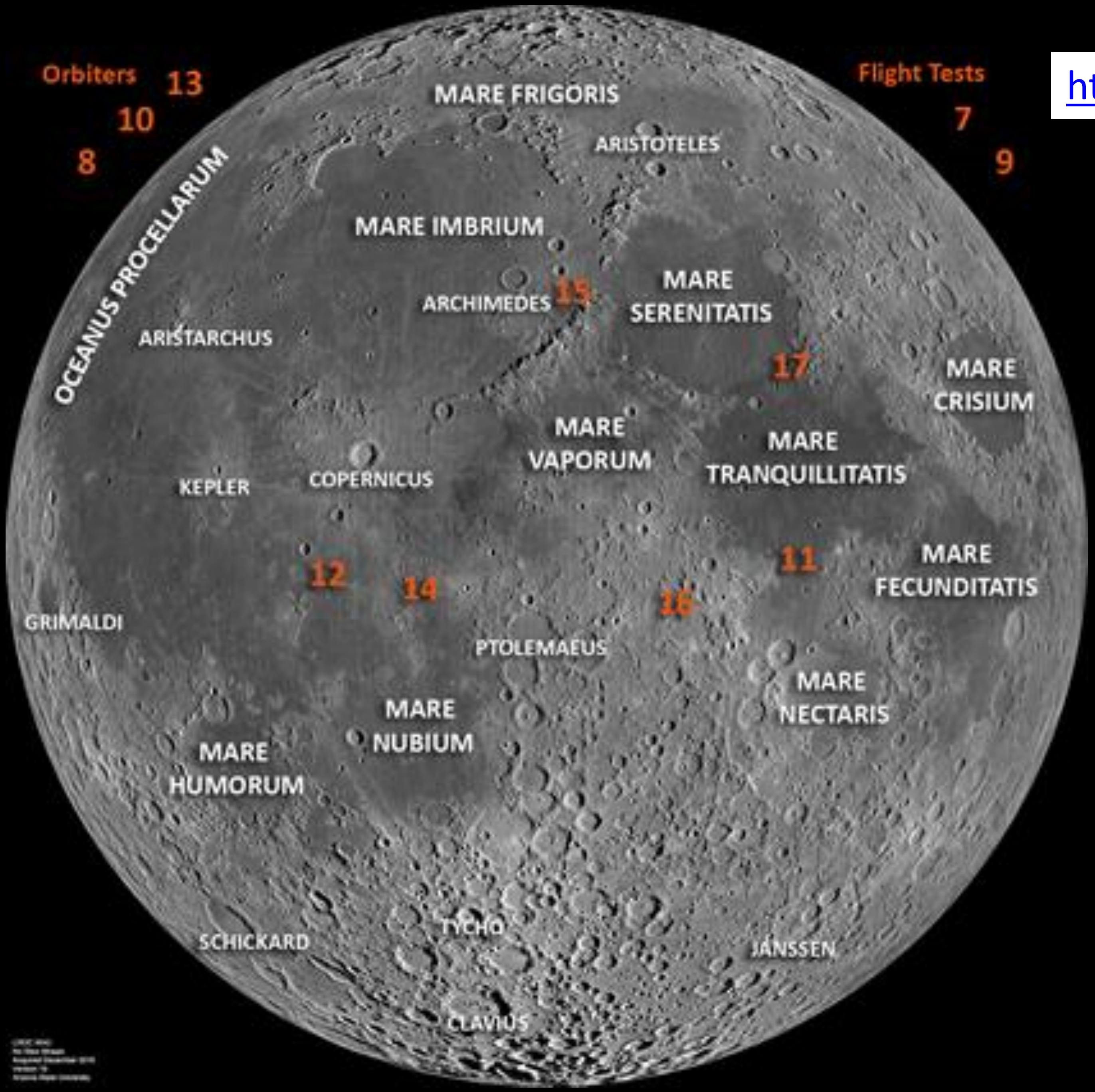
Apollo lunar missions:

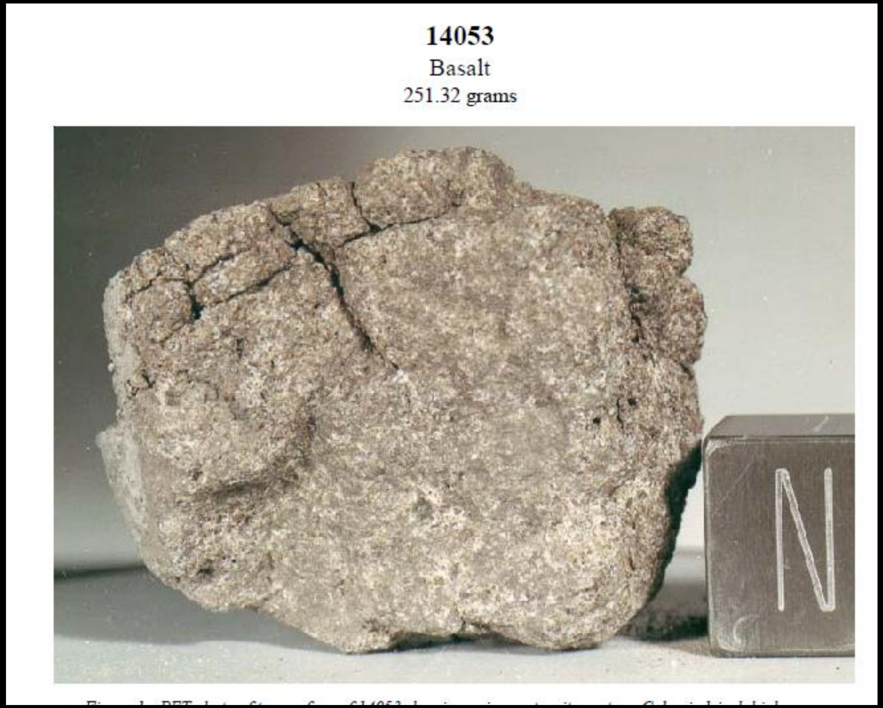
Apollo 8 – lunar orbit & return, Dec. 21 – 27, 1968 – first humans to see the far side
Apollo 10 – lunar orbit & return, May 18-26, 1969
Apollo 11 – First landing, July 20th 1969, Mare Tranquilitatis Landing site
Apollo 12 – Second landing, Nov. 19th, 1969, Oceanus Procellarum landing site
Apollo 13 – Flyby and return; did not land due to malfunction, safe return April 17th 1970
Apollo 14 – Third landing, Fra Mauro Basin, Feb. 5th, 1971
Apollo 15 – Fourth landing, Hadley Rille, July 30th, 1971
Apollo 16 – Fifth landing, Descartes Crater, April 20th, 1972
Apollo 17 – Final landing, Taurus-Littrow Basin, Dec. 11th, 1972

See https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo.html



https://www.lpi.usra.edu/lunar/missions/apollo/

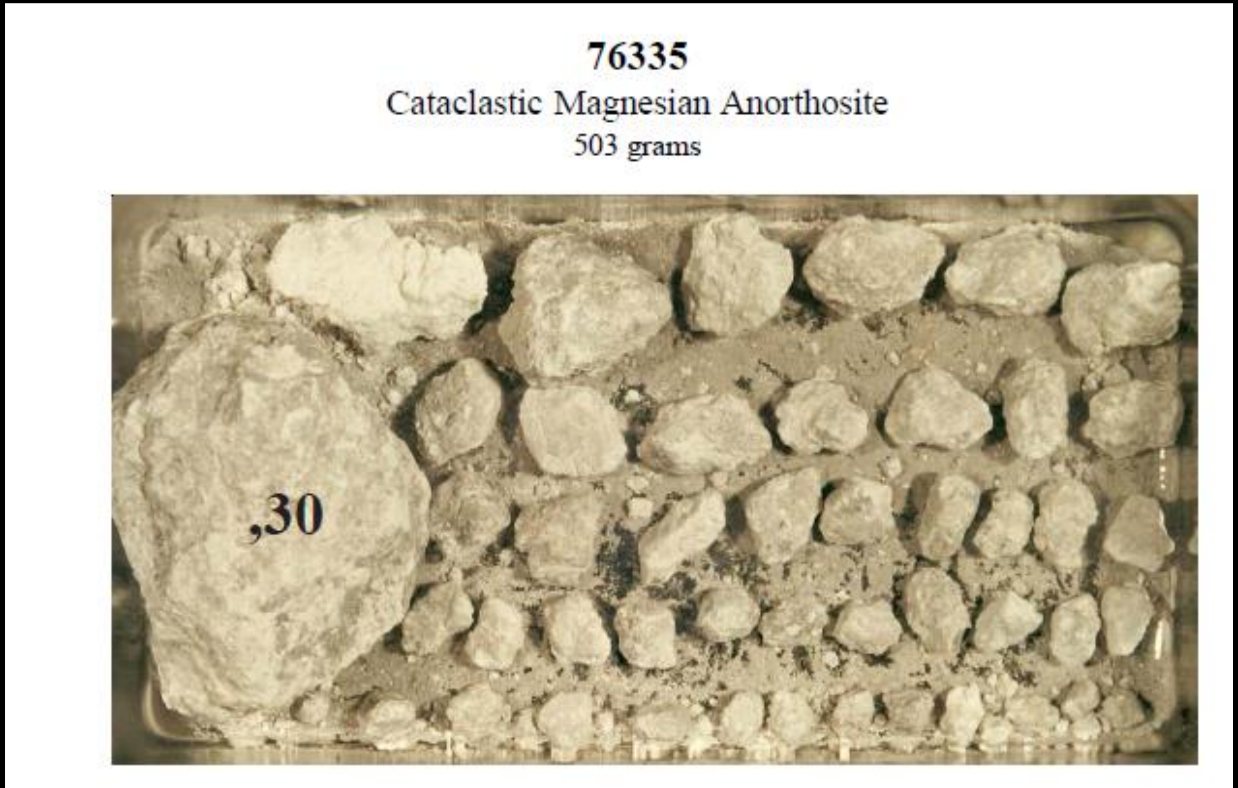




Apollo 14 Basalt (lava)

The Apollo and Lunakhod Missions returned tons (literally) of rock and soil samples. You can find them catalogued here:

https://www.lpi.usra.edu/lunar/samples/#lunas



Apollo 17 Anorthosite

Apollo 17 TiO_2 – rich basalt

After the Apollo and Lunakhod Missions, the focus turned from landing to orbiting and mapping the geology, gravity, magnetism, and searching for water and other volatiles

Huge, extensive collection of lunar orbiters and landers, through 2019:

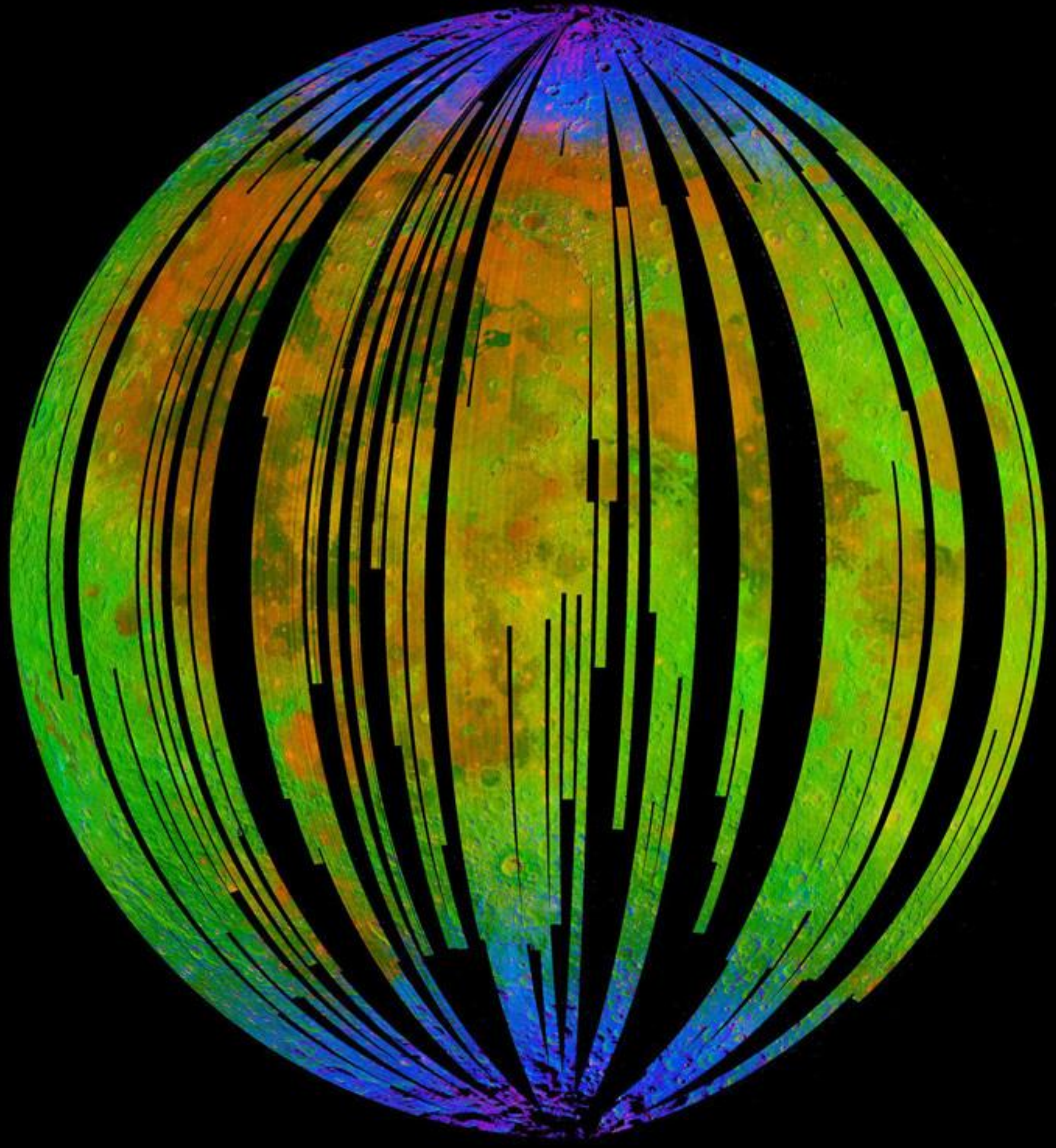
https://en.wikipedia.org/wiki/List_of_lunar_probes

https://moon.nasa.gov/exploration/moon-missions/

for history of all Moon efforts

Lunar robotic missions in the 2000's:

SMART-1	Europe	9/27/2003	11/15/2004	Orbiter/Impact	Successful; **first European Moon mission**
SELENE (Kaguya)	Japan	9/14/2007	10/3/2007	Orbiter/Impact	Successful
Chang'e 1	China	10/24/2007	11/5/2007	Orbiter/impactor	Successful; **first Chinese Moon mission**
Chandrayaan-1	India	10/22/2008	11/12/2008	Orbiter	Successful
Lunar Reconnaissance Orbter (LRO)	USA	6/18/2009	6/23/2009	Orbiter	**(Active Mission)** Successful; **extended mission in progress**
LCROSS	USA	6/18/2009	10/9/2009	Impact	Successful; **impact of LRO upper stages**

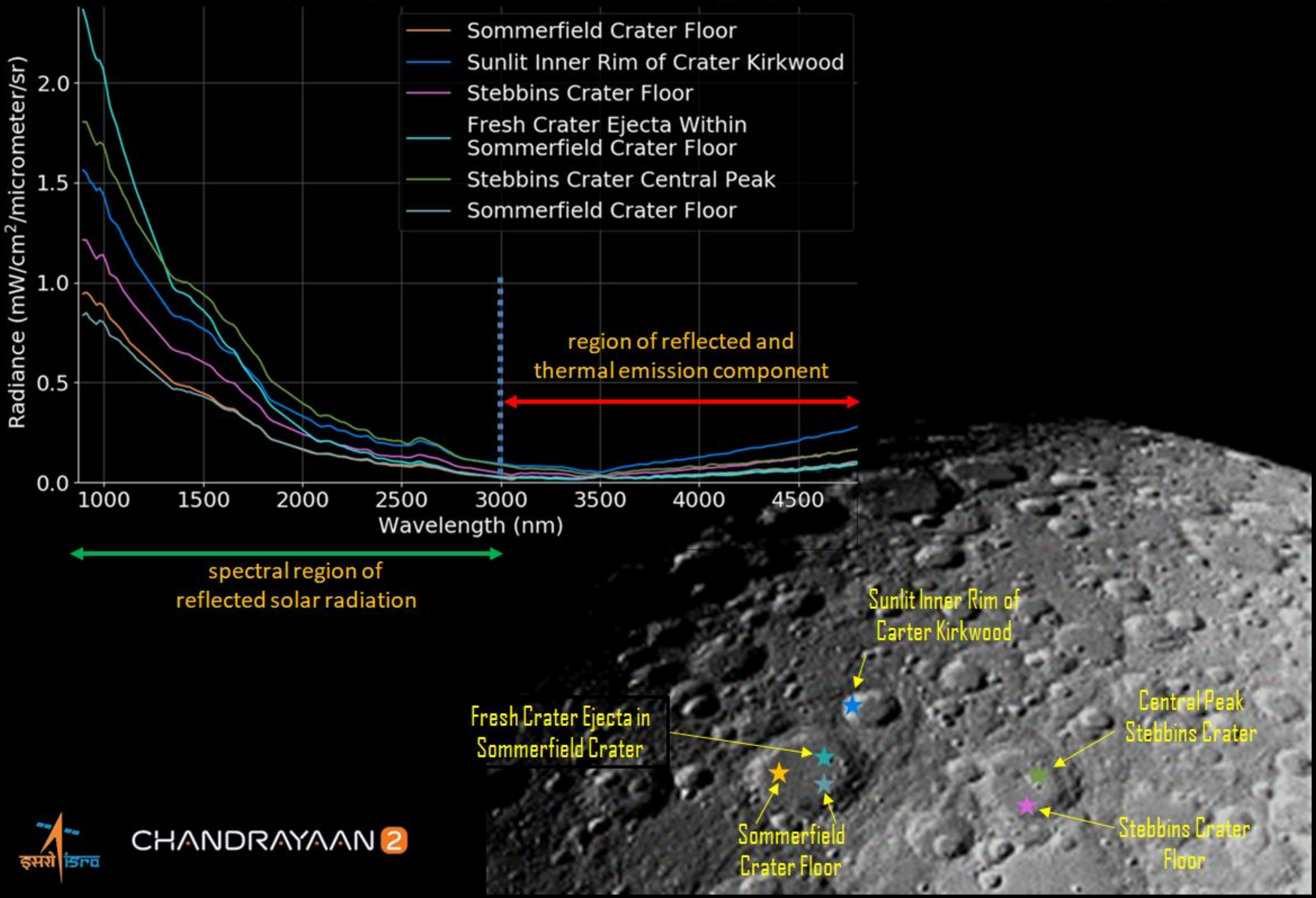


India's Chandrayaan-1 played a crucial role in the discovery of water molecules on the Moon.
Chandrayaan-1 was India's first deep space mission.

Among its suite of instruments, it carried NASA's Moon Minerology Mapper (M^3), an imaging spectrometer helped confirm the discovery of water locked in minerals on the Moon.

The orbiter also released an impactor that was deliberately crashed into the Moon, releasing debris that was anyalyzed by the orbiting spacecraft's science instruments.

Preliminary analysis of Chandrayaan-2 Imaging Infrared Spectrometer (IIRS) data



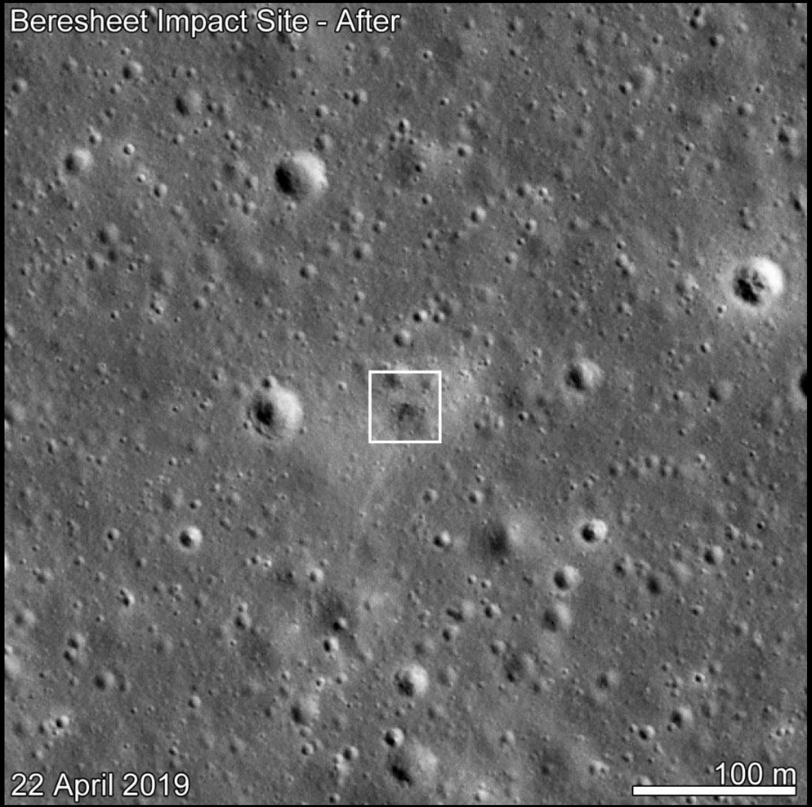
CHANDRAYAAN 2

https://www.isro.gov.in/chandrayaan2-payloads

Lunar Reconnaissance Orbiter

NASA's Lunar Reconnaissance Orbiter (LRO) was the first U.S. mission to the Moon in over 10 years. LRO's primary goal was to make a 3D map of the Moon's surface from lunar polar orbit. LRO continues to orbit the Moon.

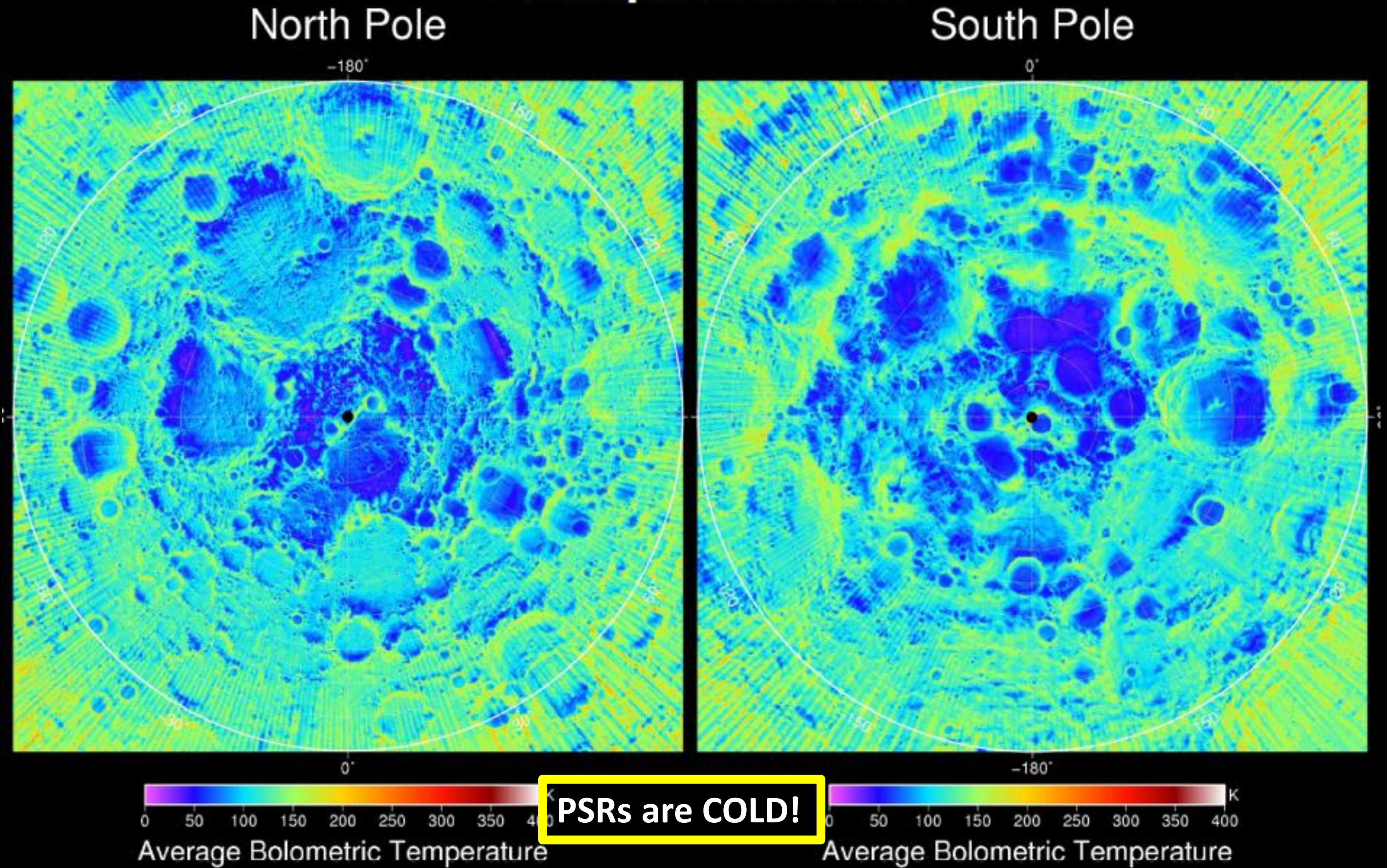
http://lroc.sese.asu.edu/about/whereislro



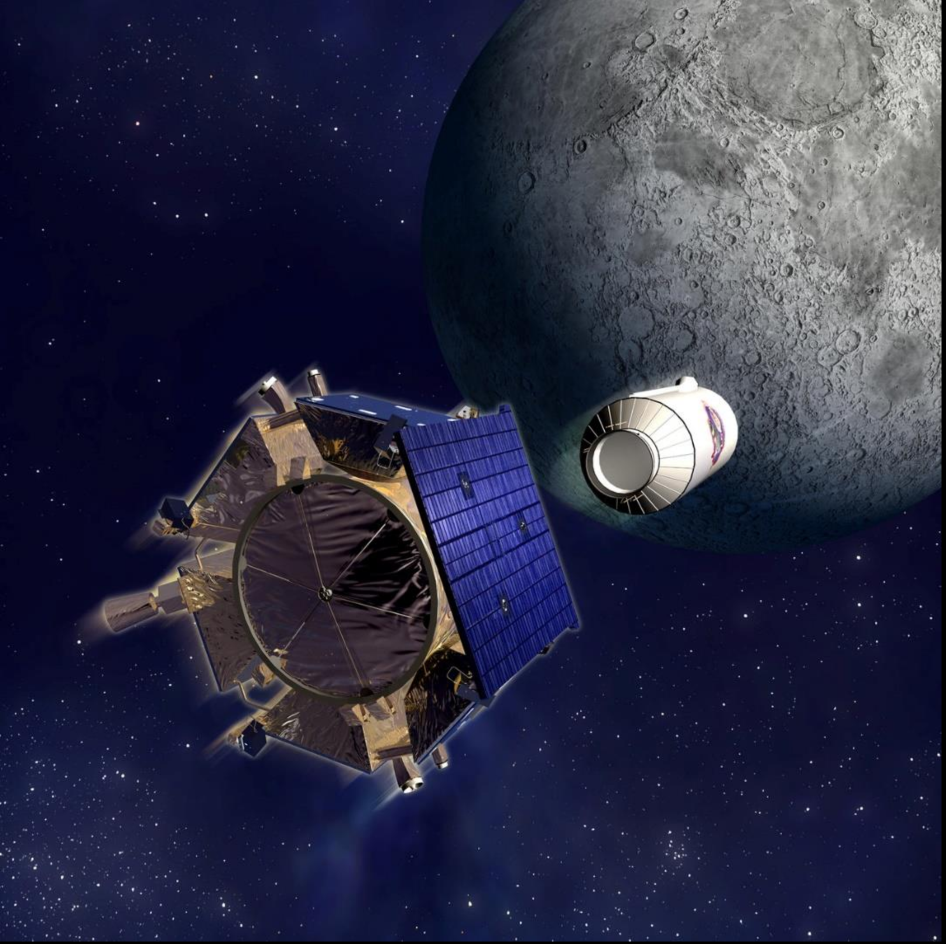
LRO is in extended mission phase, continuing to orbit to address key lunar science questions, including chronology of bombardment, crustal evolution, regolith evolution, and polar volatiles

Scientific Instruments	1.Cosmic Ray Telescope for the Effects of Radiation (CRaTER) 2.Diviner Lunar Radiometer Experiment (DLRE) 3.Lyman-Alpha Mapping Project (LAMP) 4.Lunar Exploration Neutron Detector (LEND) 5.Lunar Orbiter Laser Altimeter (LOLA) 6.Lunar Reconnaissance Orbiter Camera (LROC) 7.Mini-RF Miniature Radio Frequency Radar

Diviner Observed Average Temperature



PSRs are COLD!

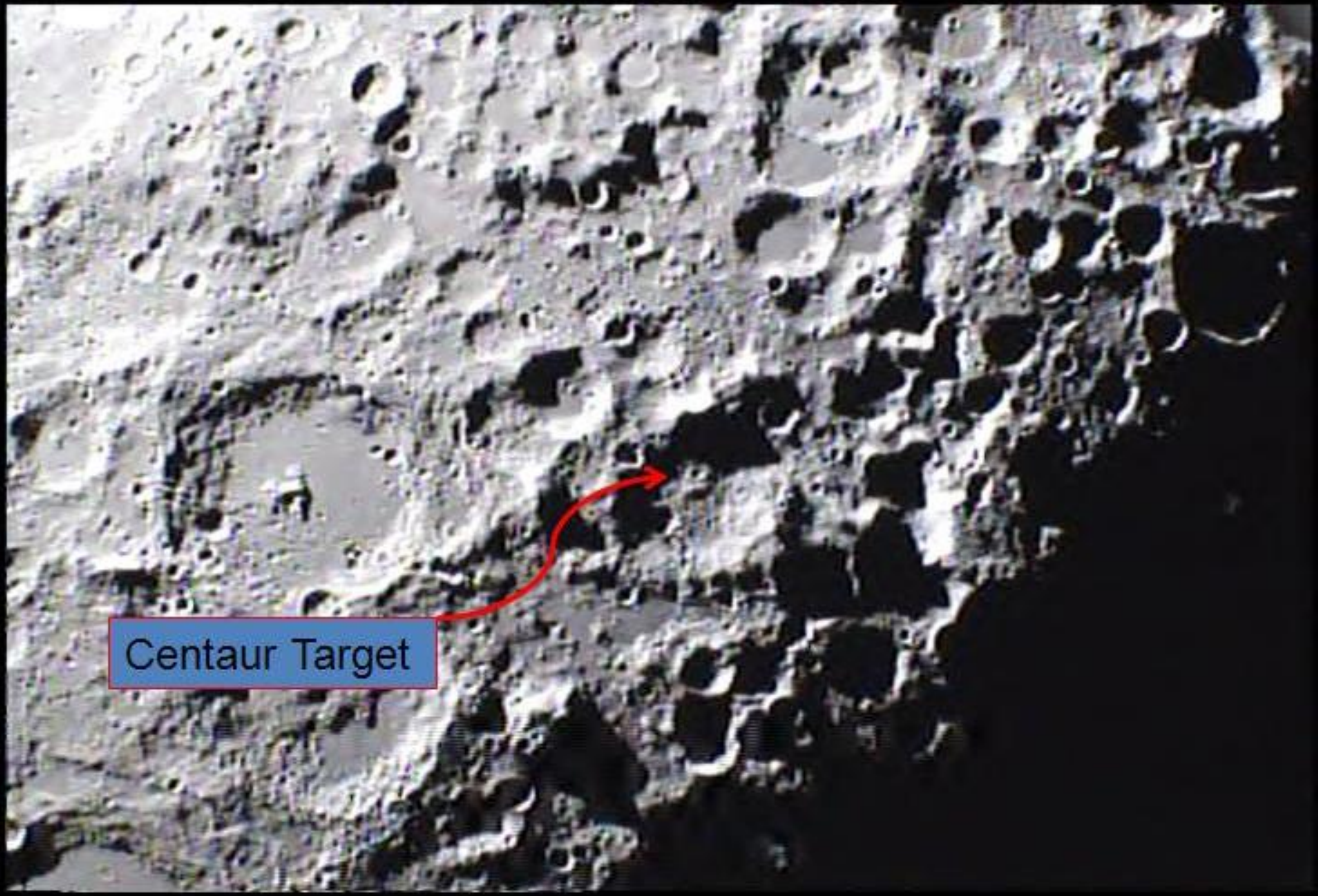


https://solarsystem.nasa.gov/missions/lcross/in-depth/

NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) was launched with the Lunar Reconnaissance Orbiter to determine if water-ice exists in a permanently shadowed crater at the Moon's south pole. As planned, LCROSS and its Centaur stage impacted the Moon on Oct. 9, 2009. The twin impacts exposed a plume of material that might not have seen direct sunlight for billions of years.

LCROSS and LRO found evidence that the lunar soil in shadowy craters is rich in useful materials, and that the Moon is chemically active and has a water cycle. Scientists also confirmed the water was in the form of mostly pure ice crystals in some places.

Cabeus Crater, near South Pole, was the site of the LCROSS impact site, intended to observe water and volatiles in the ejecta plume.



Model for ice in Cabeus Crater derived from LCROSS observations copied from the KISS 2013 presentation:

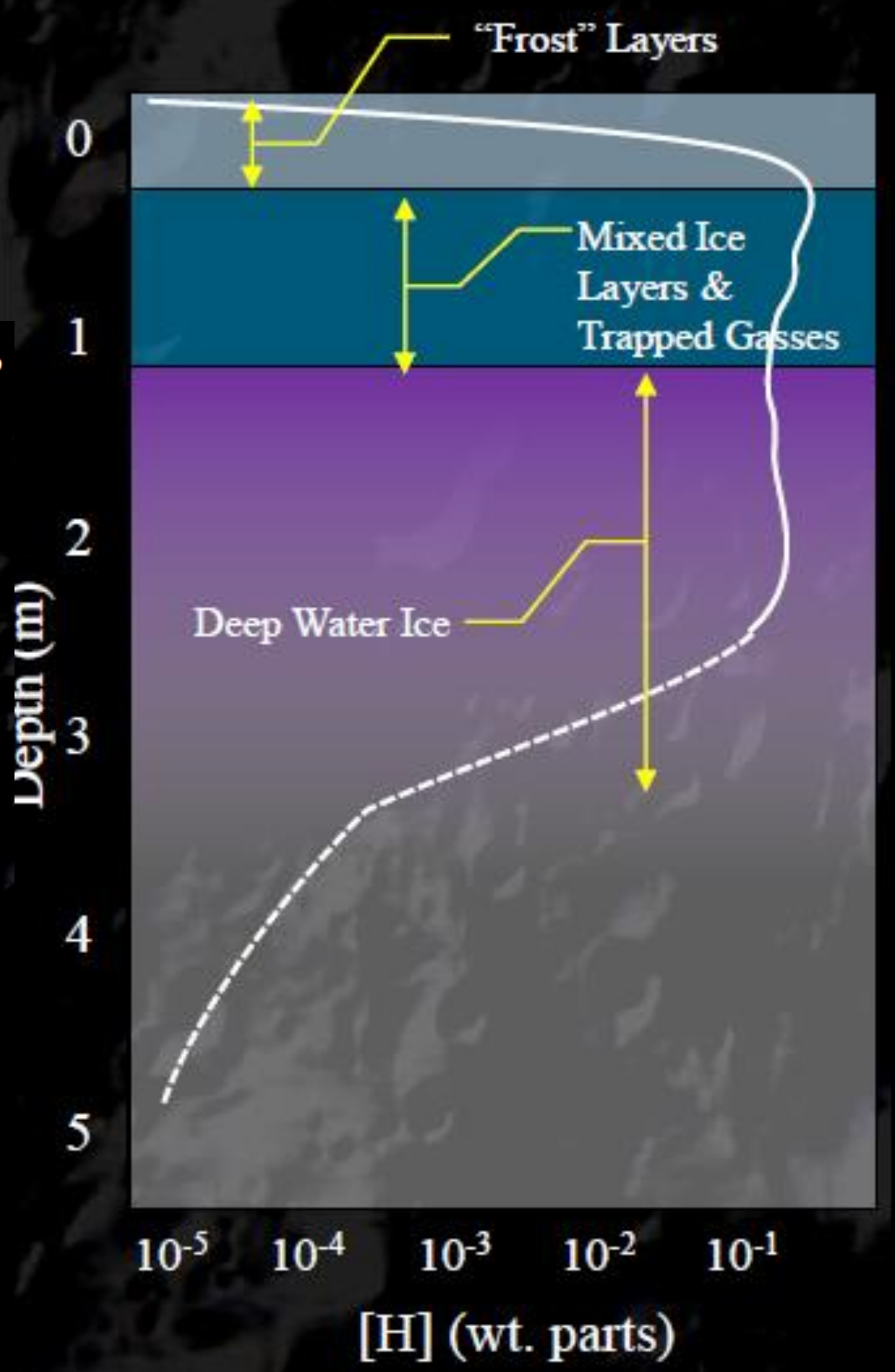
The Final Minute: Results from the LCROSS Solar Viewing NIR Spectrometer

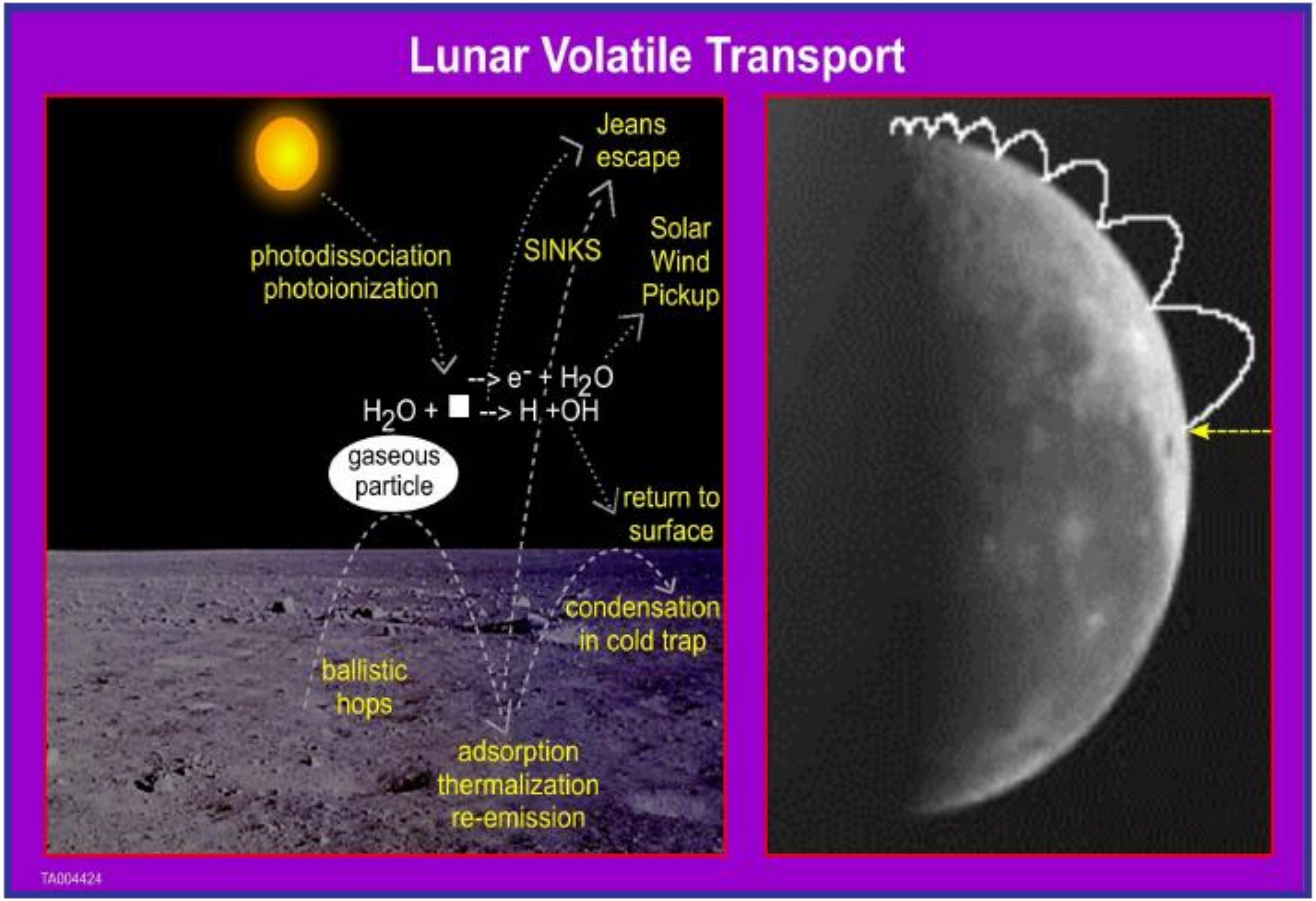
Anthony Colaprete

NASA Ames Research Center, Moffett Field, CA, Anthony.Colaprete-1@nasa.gov

KISS: New Approaches to Lunar Ice Detection and Mapping

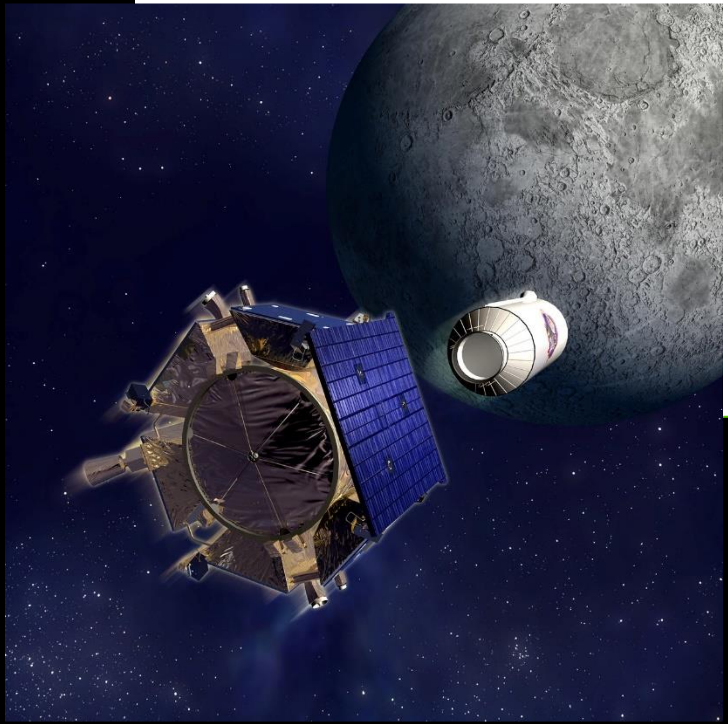
7/22/2013





Water is expected at polar cold traps from solar wind protons [e.g., *Crider & Vondrak* 2000]

Scientific Instruments on LRO:



1. **Cosmic Ray Telescope for the Effects of Radiation (CRaTER)**
2. **Diviner Lunar Radiometer Experiment (DLRE)**
3. **Lyman-Alpha Mapping Project (LAMP)**
4. **Lunar Exploration Neutron Detector (LEND)**
5. **Lunar Orbiter Laser Altimeter (LOLA)**
6. **Lunar Reconnaissance Orbiter Camera (LROC)**
7. **Mini-RF Miniature Radio Frequency Radar**

EM spectrum explained:

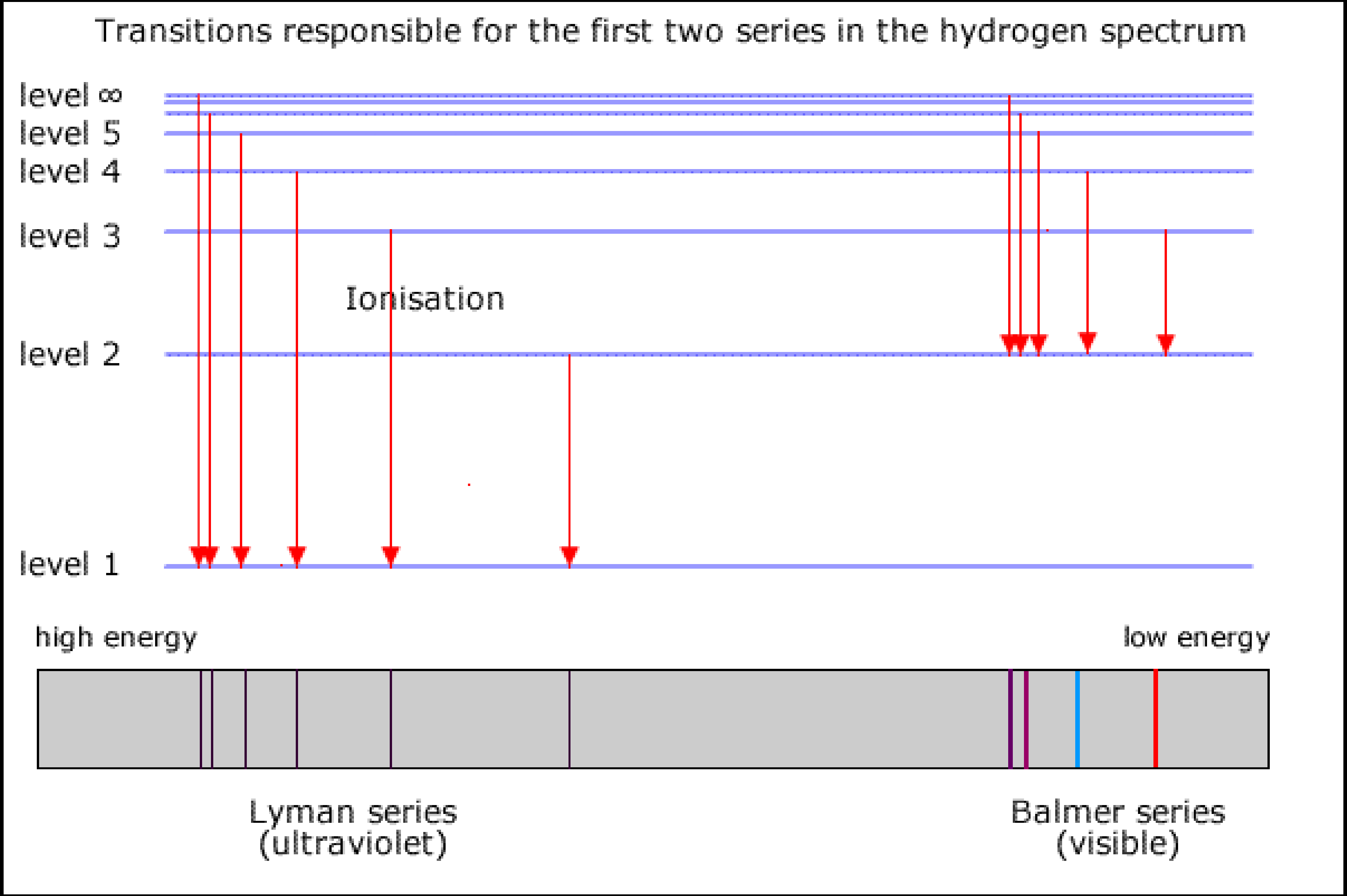
https://www.youtube.com/watch?v=lwfJPc-rSXw

Spectroscopy – How atoms and molecules transmit, absorb, reflect, and emit radiation of different wavelengths when energy is input into them.

Atomic spectra – Electrons oscillate between higher and lower energy levels when excited by just the right amount of energy to make them resonate at characteristic frequencies.

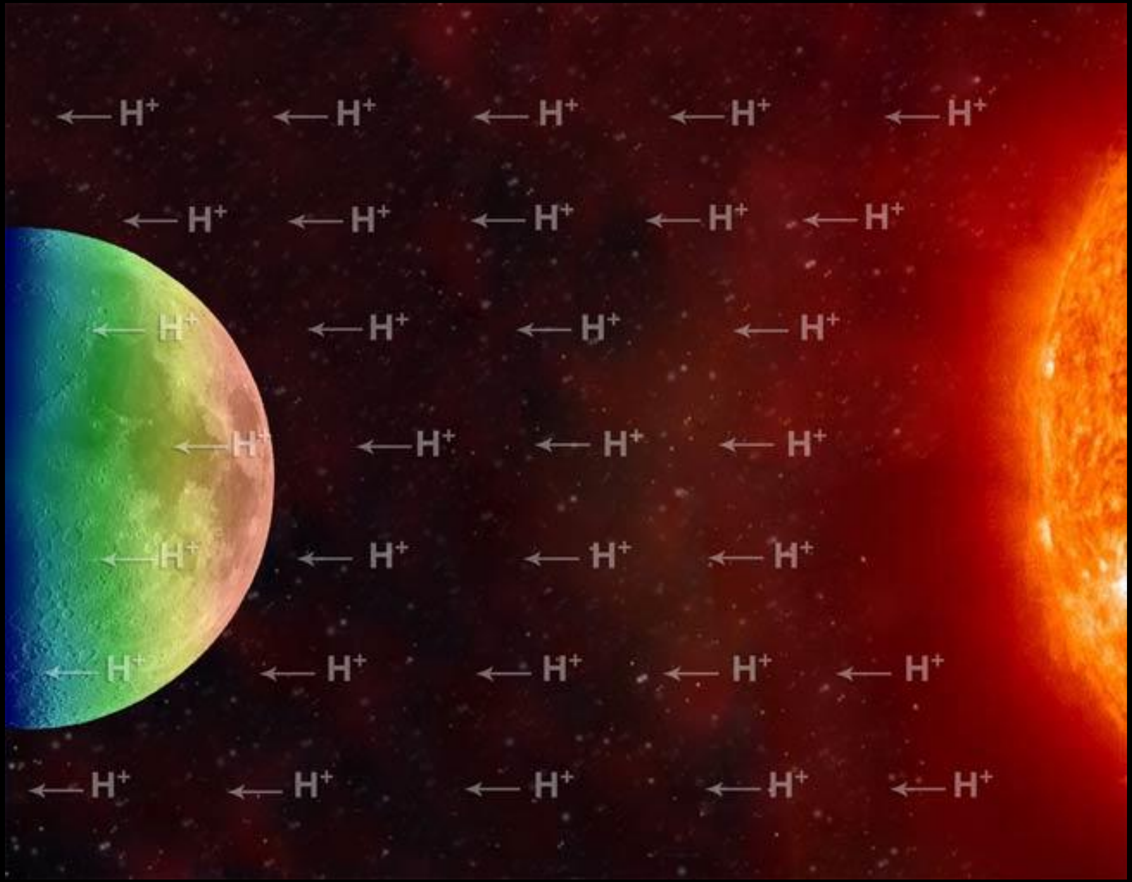
Molecular spectra – Molecules absorb just the right amount of energy to make their atomic bonds oscillate in characteristic modes (vibration, rotation, or a combination).

By observing spectra of objects we can measure what they are made of by how they reflect, transmit, absorb, or emit light of different wavelengths.

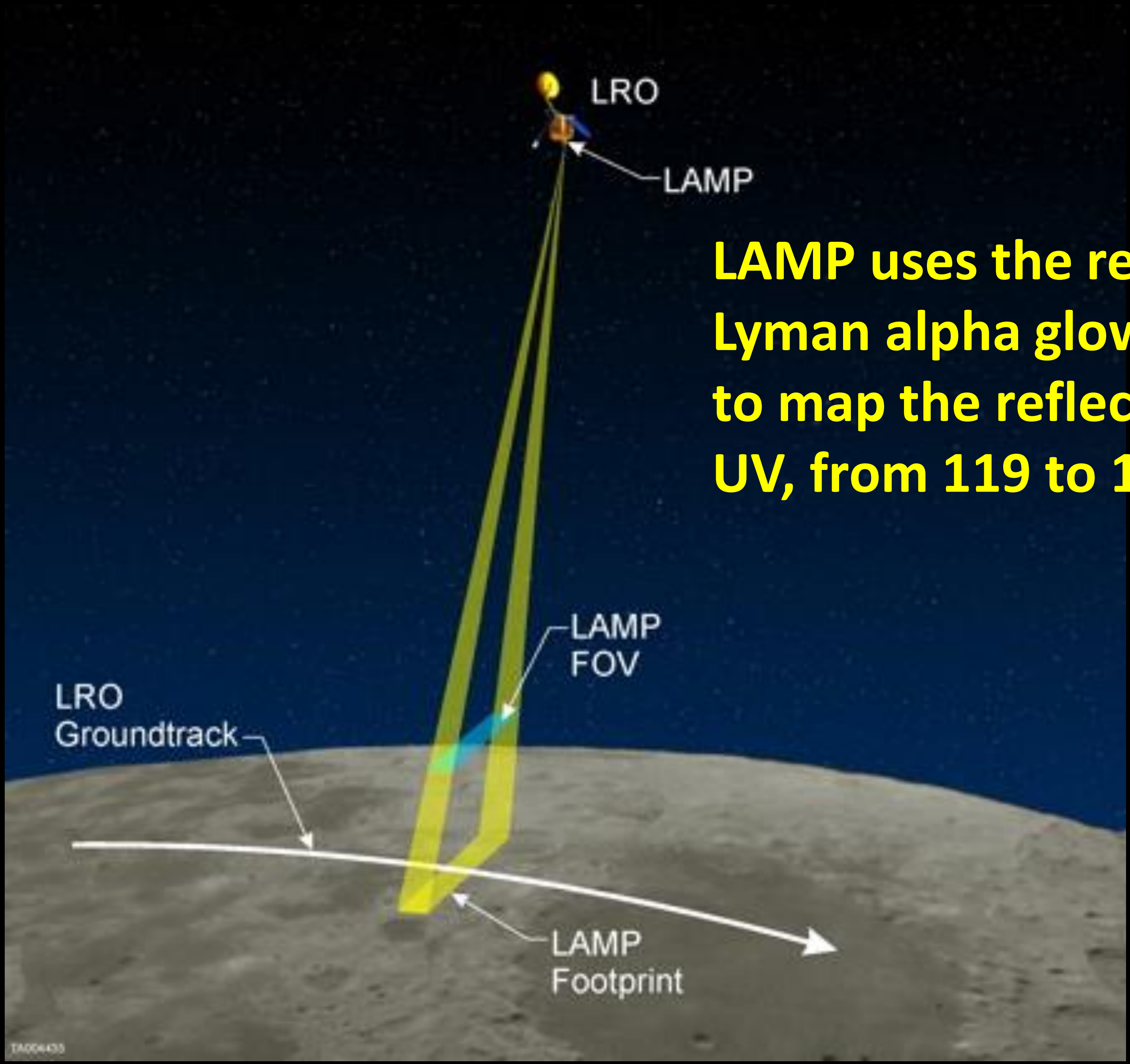


Transitions responsible for the first two series in the hydrogen spectrum
level ∞
level 5
level 4
level 3
Ionisation
level 2
level 1
high energy
low energy
Lyman series
(ultraviolet)
Balmer series
(visible)

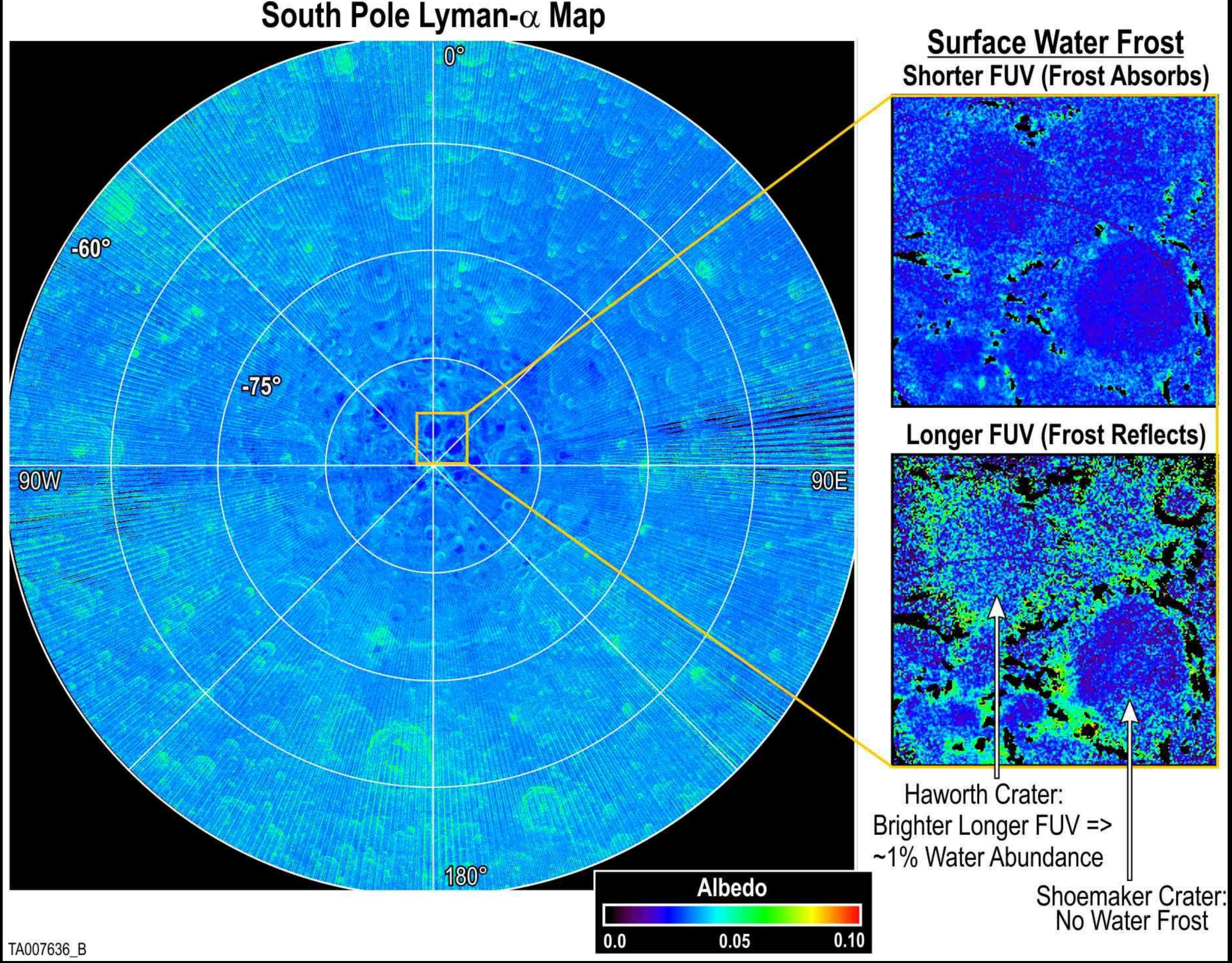
Lyman alpha light from the Sun



Lyman-alpha emitters are typically low mass galaxies of 10^8 or 10^{10} solar masses. They are typically young galaxies that are 200 to 600 million years old, and they have the highest specific star formation rate of any galaxies known.



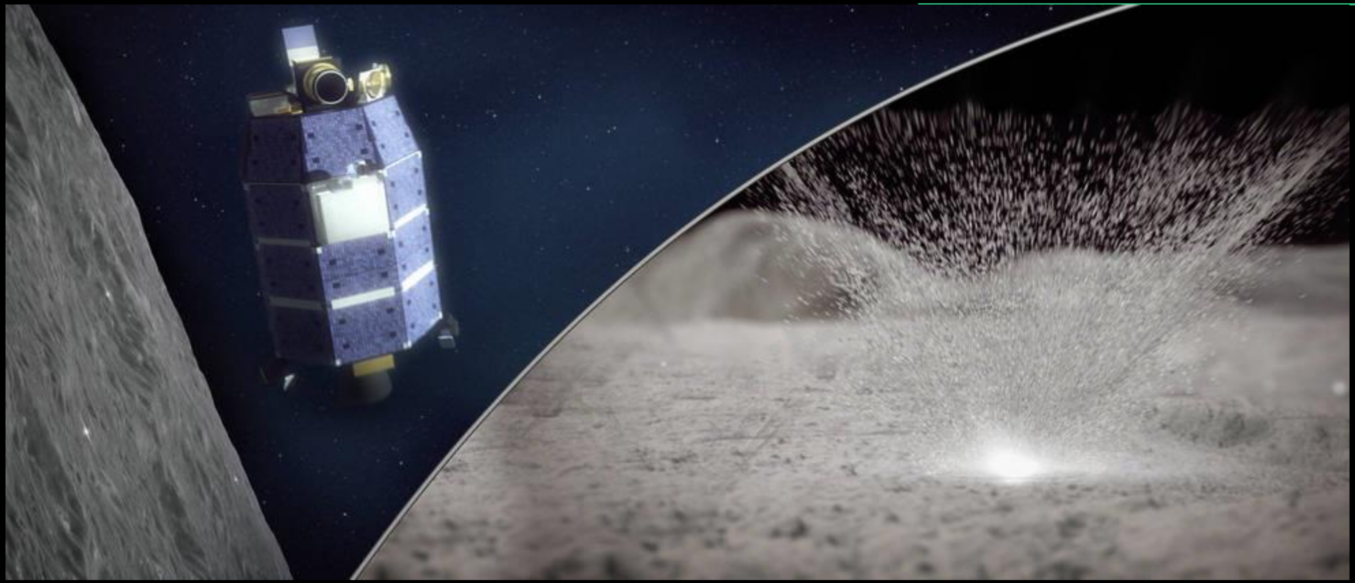
LAMP uses the reflected UV light from the diffuse Lyman alpha glow from the Sun and distant galaxies to map the reflectivity of the surface of the Moon in UV, from 119 to 190 nm.


South Pole Lyman-α Map
0°
-60°
-75°
90W
90E
180°
Surface Water Frost
Shorter FUV (Frost Absorbs)
Longer FUV (Frost Reflects)
Haworth Crater:
Brighter Longer FUV =>
~1% Water Abundance
Shoemaker Crater:
No Water Frost
Albedo
0.0
0.05
0.10
TA007636_B

Name	Nation	Launch	Arrival	Type	Results
Chang'e 2	China	10/1/2010	10/5/2010	Orbiter	Successful
ARTEMIS	**USA**	**2010**	**2011**	**Orbiters**	**(Active Mission) Successful; twin spacecraft on an extended lunar mission after successful Earth observartions**
Gravity Recovery and Interior Laboratory (GRAIL)	USA	9/10/2011	1/1/2012	Orbiters	Successful; **twin spacecraft**
Lunar Atmosphere and Dust Environment Explorer (LADEE)	USA	9/7/2013	10/6/2013	Orbiter	Successful
Chang'e 3	**China**	**12/6/2013**	**12/14/2013**	**Lander**	**(Active Mission) Successful; delivered Yutu rover to lunar surface**
Yutu	China	12/6/2013	12/14/2013	Rover	Successful; **first non-Soviet rover on the Moon**
Chang'e 5-Test Vehicle	China	10/23/2014	10/27/2014	Flyby	Successful
Queqiao	China	5/20/2018		Orbiter	Successful; **lunar relay satellite**
Chang'e 4 and Yutu 2	China	12/7/2018		Lander, Rover	Successful; **first lunar farside landing**
Beresheet	Israel	2/22/2019	4/11/209	Lander	Unsuccessful; first lunar landing attempt by a private company

NASA's LADEE was a robotic mission that orbited the Moon to gather detailed information about the lunar atmosphere, conditions near the surface and the environmental influences on lunar dust.

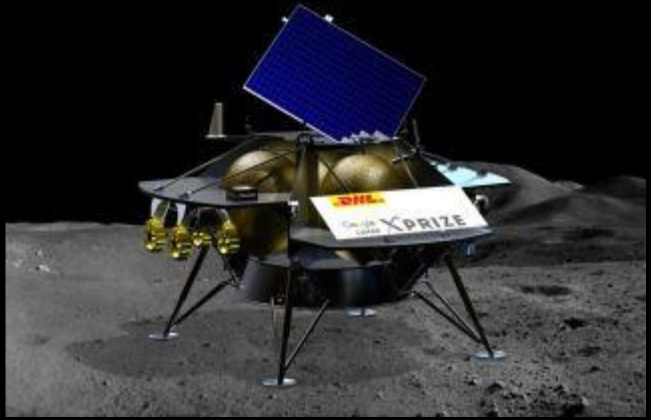
Scientific nstruments	1. Ultraviolet and Visible Light Spectrometer (UVS) 2. Neutral Mass Spectrometer (NMS) 3. Lunar Dust Experiment (LDEX) 4. Lunar Laser Communications Demonstration Experiment (LLCD)



H_2O and OH vapor detected by LADEE's NMS instrument from meteorite impacts

https://www.nasa.gov/press-release/goddard/2019/ladee-lunar-water

Future missions are being planned to land at the lunar poles and explore the PSRs for water using a variety of mapping techniques, and eventually to colonize the Moon by the US, China, Japan, Russia, and the European Space Agency.



European Space Agency is exploring in its formulation of a moon village that incorporates 3D printing.