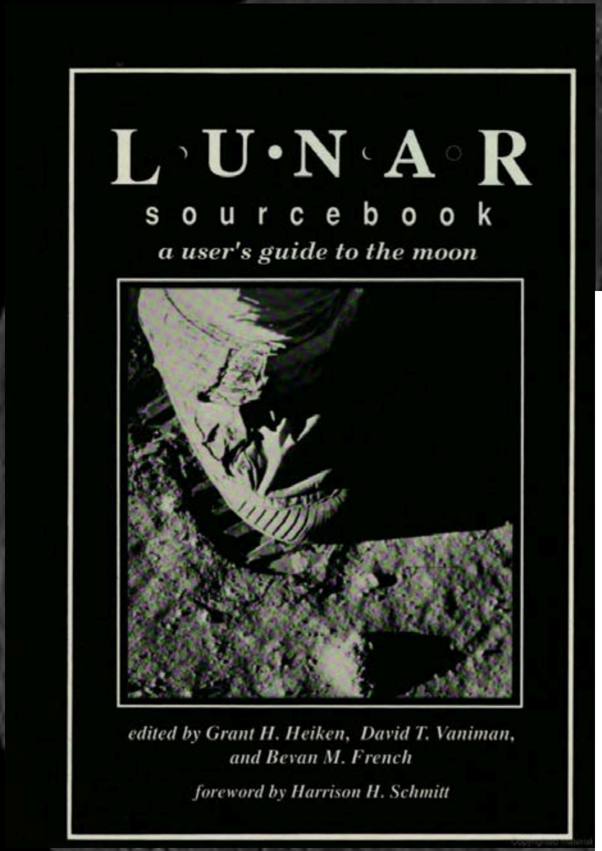
The Lunar Environment

Clive R. Neal

University of Notre Dame
http://www.nd.edu/~cneal
neal.1@nd.edu
@Neal148409276

Lunar Sourcebook, Chapter 3



https://www.lpi.usra.edu/publications/books/lunar_sourcebook/pdf/Chapter03.pdf

Chapter 3: THE LUNAR ENVIRONMENT

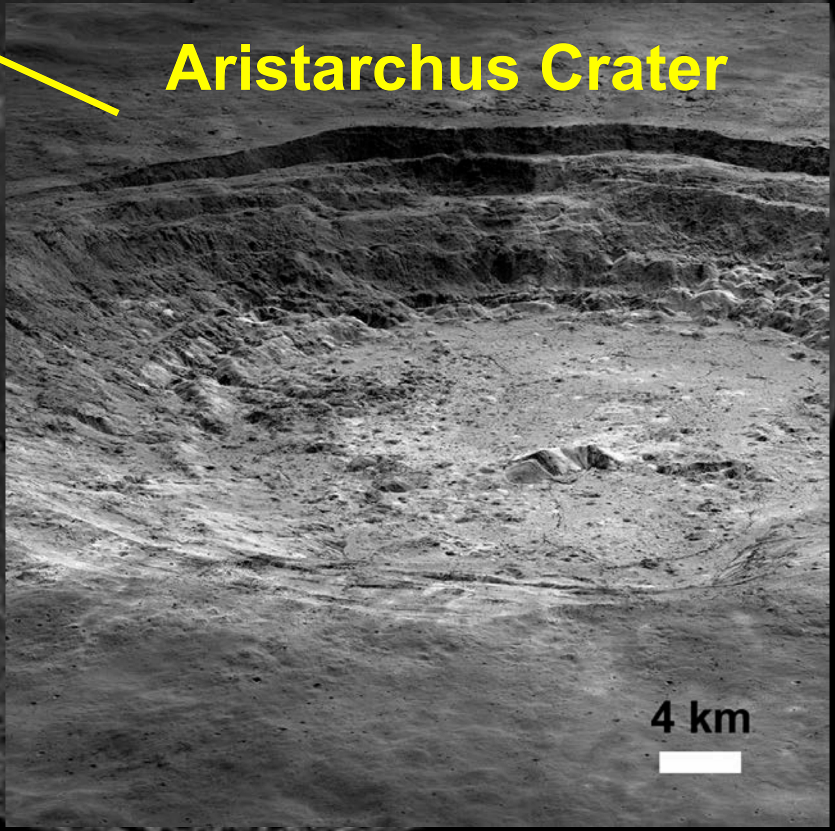
Near (left) and far (right) sides of the Moon

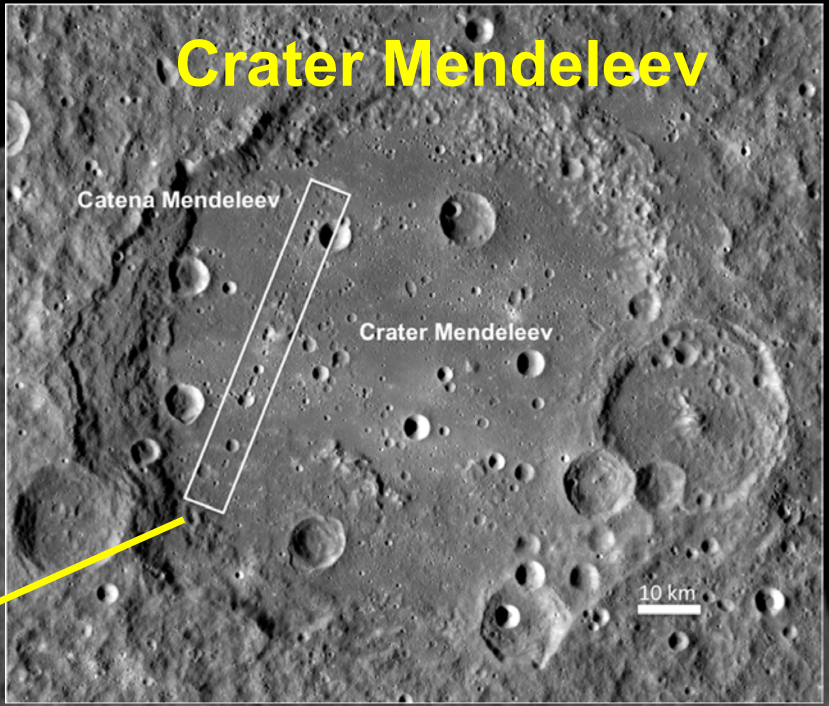
Terrain

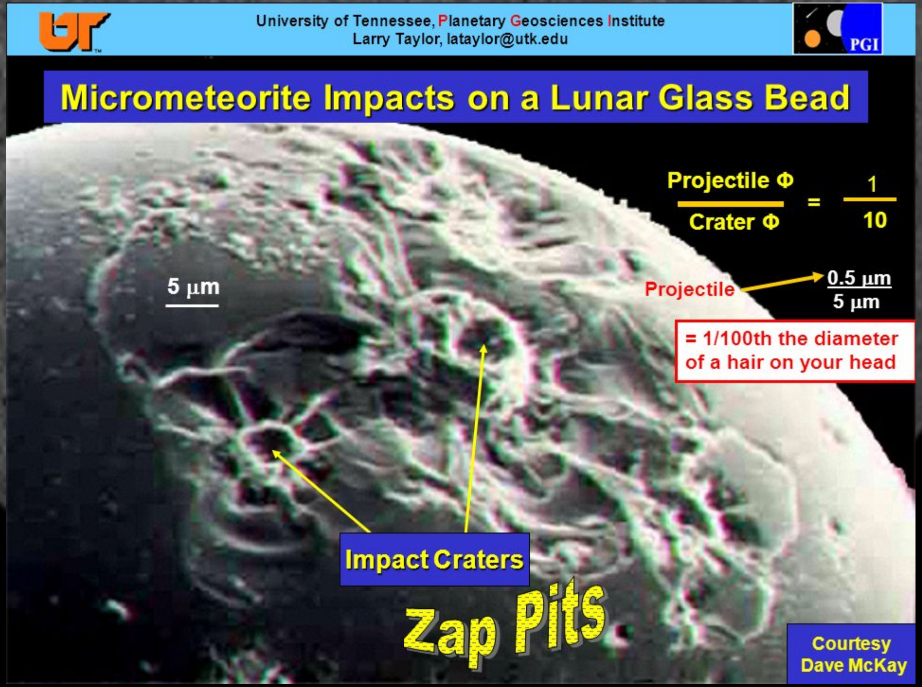
Taken by the Lunar Reconnaissance Orbiter

Terrain

Average impact velocity ~14 km sec^{-1}







Gravity

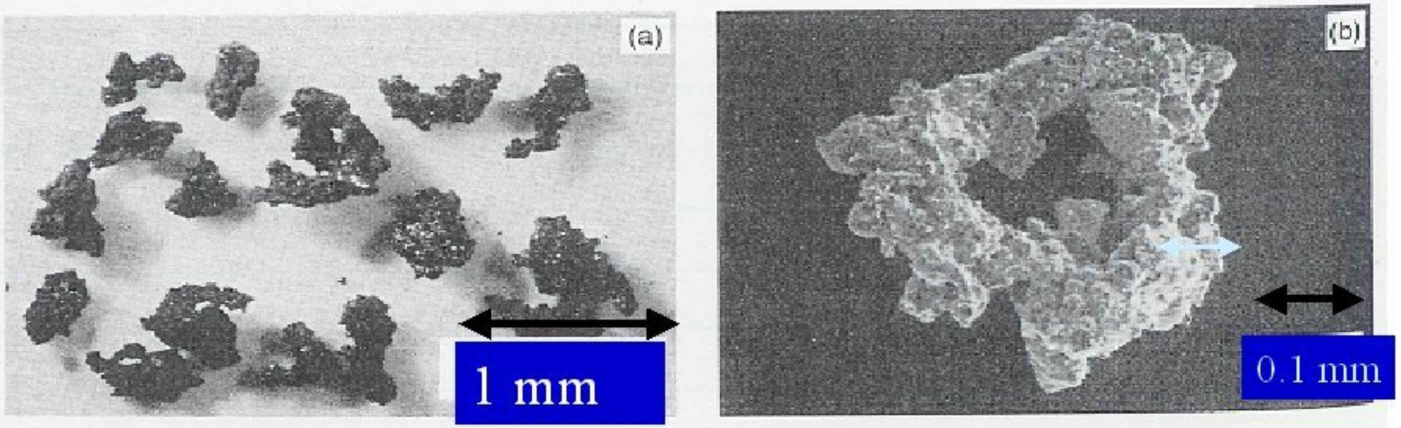
1/6 that of Earth

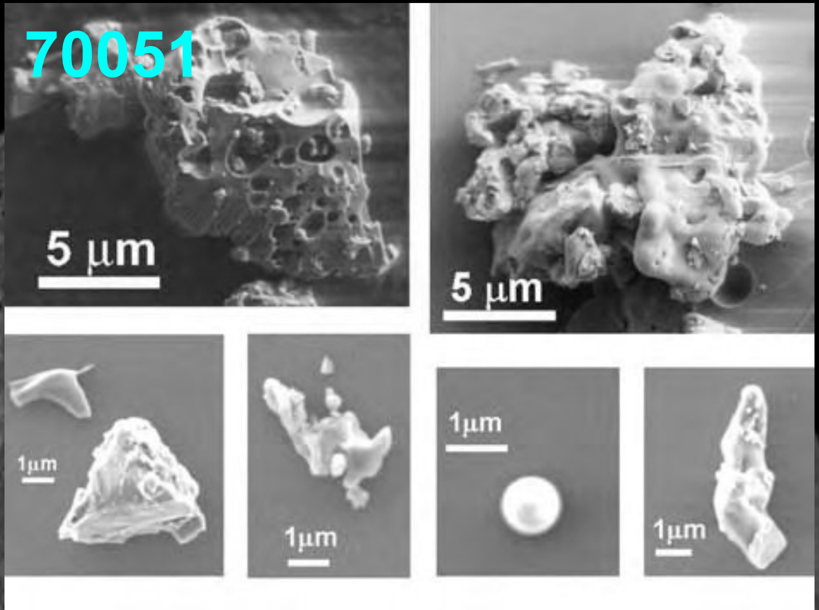
Harrison Schmitt on Walking on the Moon:
https://www.youtube.com/watch?v=w7IfxF20rz8

Dust

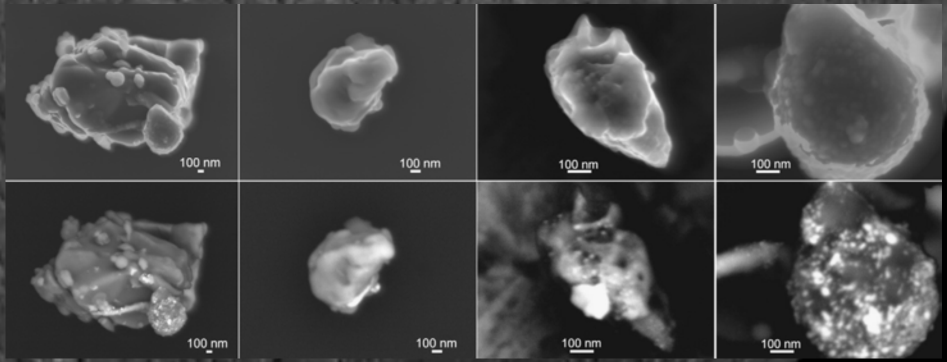
What is Lunar Dust Like?

- Similar to Ash
  - Diverse Size Distribution
    - Mean size = 19 microns
  - SiO_2 (44.72%) and Al_2O_3 (14.86%)
  - Properties
    - Magnetic (Fe^0 Patina)
    - Jagged
    - High Porosity



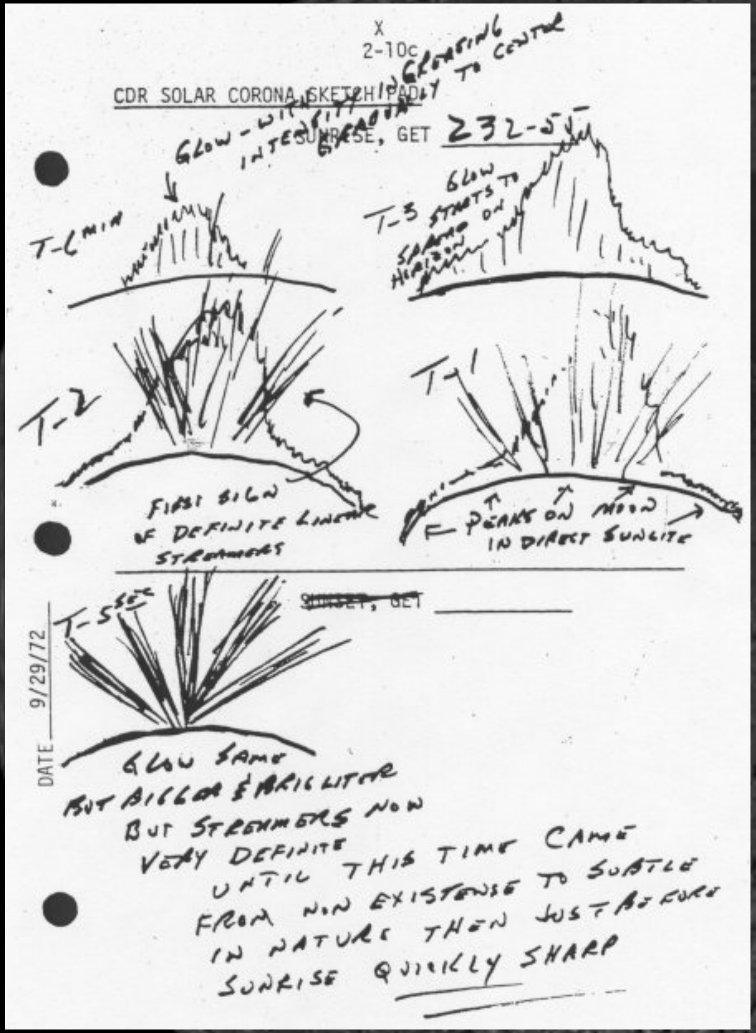


Park et al. (2006) *LPSC* **XXXVII**, #2193



McKay et al. (2015) *Acta Astron.* **107**, 163-176

Dust



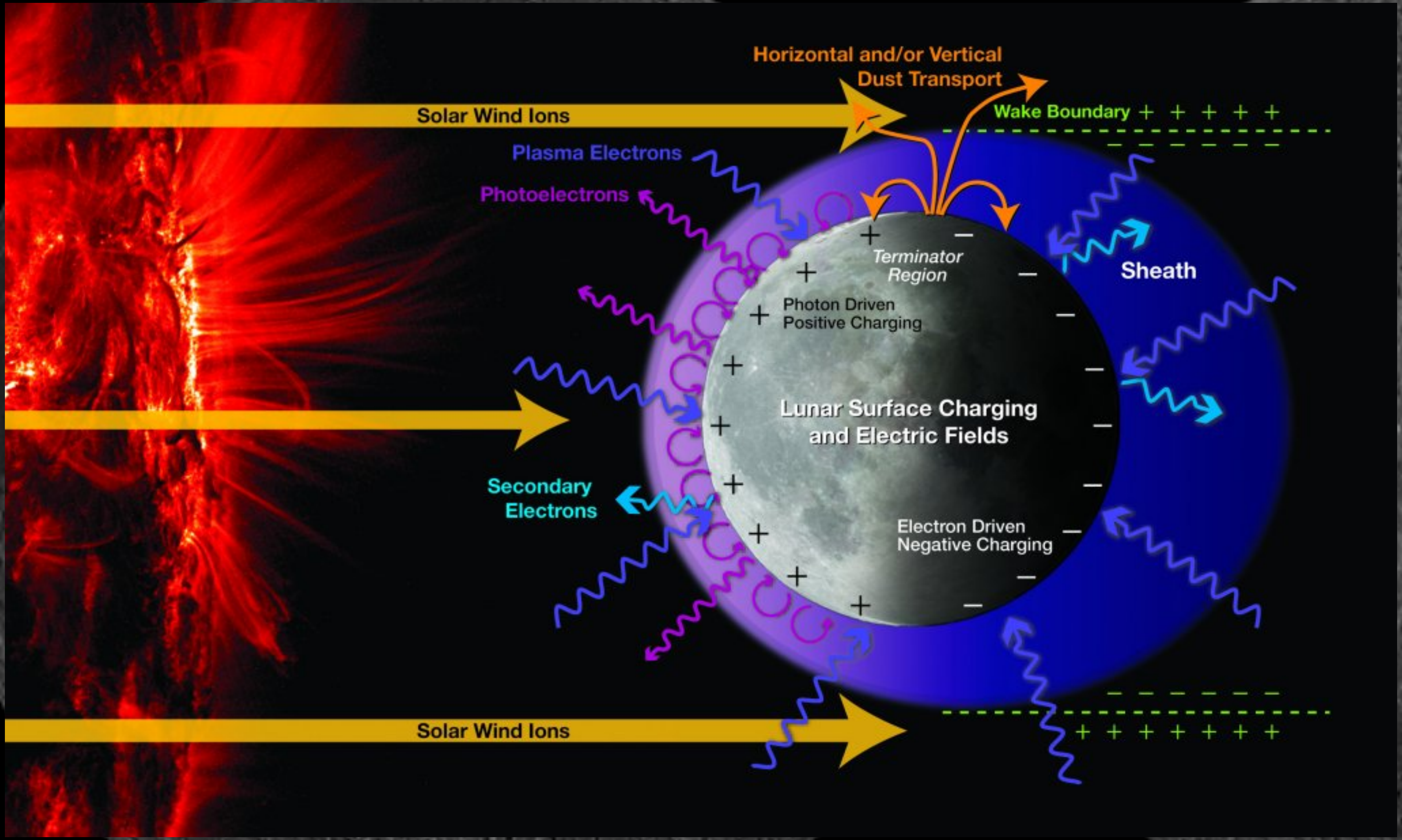
Surface dust detector results suggest there are sunrise-driven movements of dust.

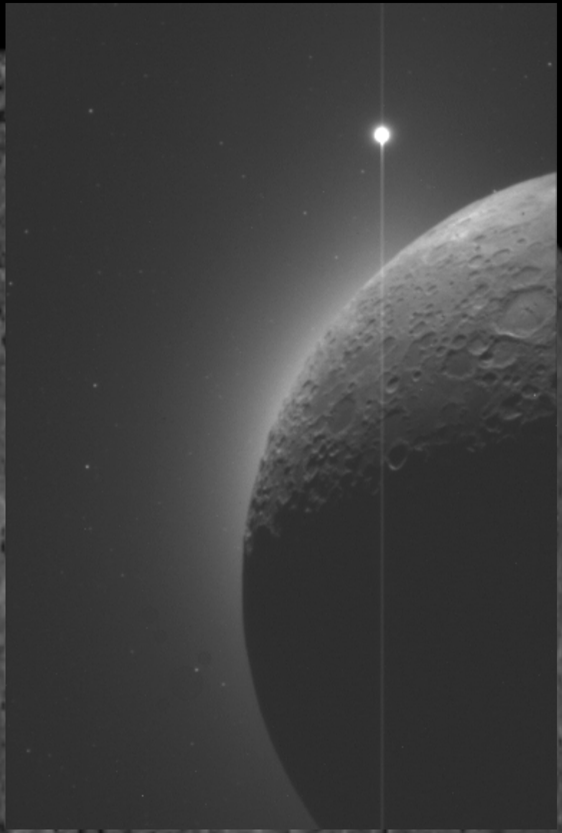
O’Brien & Hollick (2015) *Planet. Space Sci.* **119**, 194-199

The Lunar Dust Experiment on LADEE found LDEX found no evidence of the expected density enhancements over the terminators where electrostatic processes were predicted to efficiently loft small grains.

Horanyi (2016) COSPAR 41

Dust



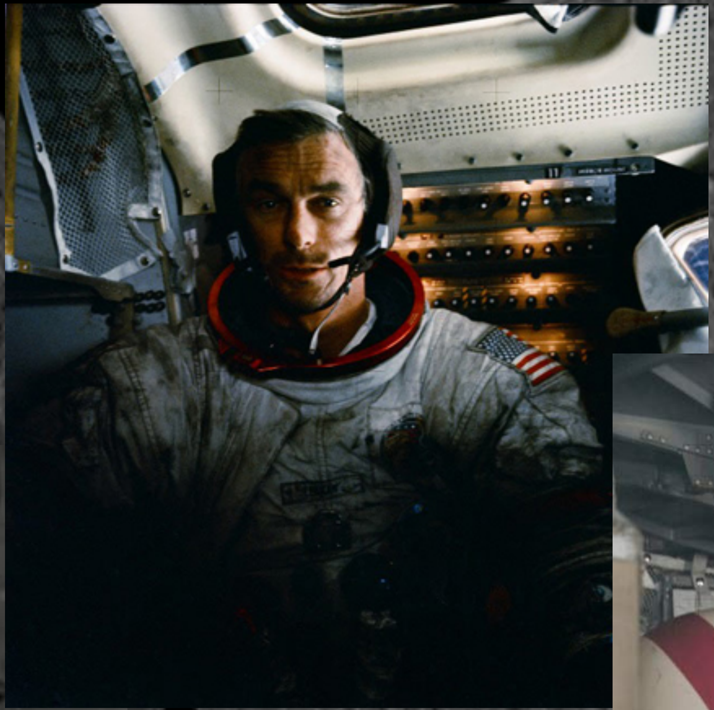


No clear evidence for dust scattering horizon glow from LRO-LAMP.

Feldman et al. (2014) *Icarus* **233**, 106-113.

Dust

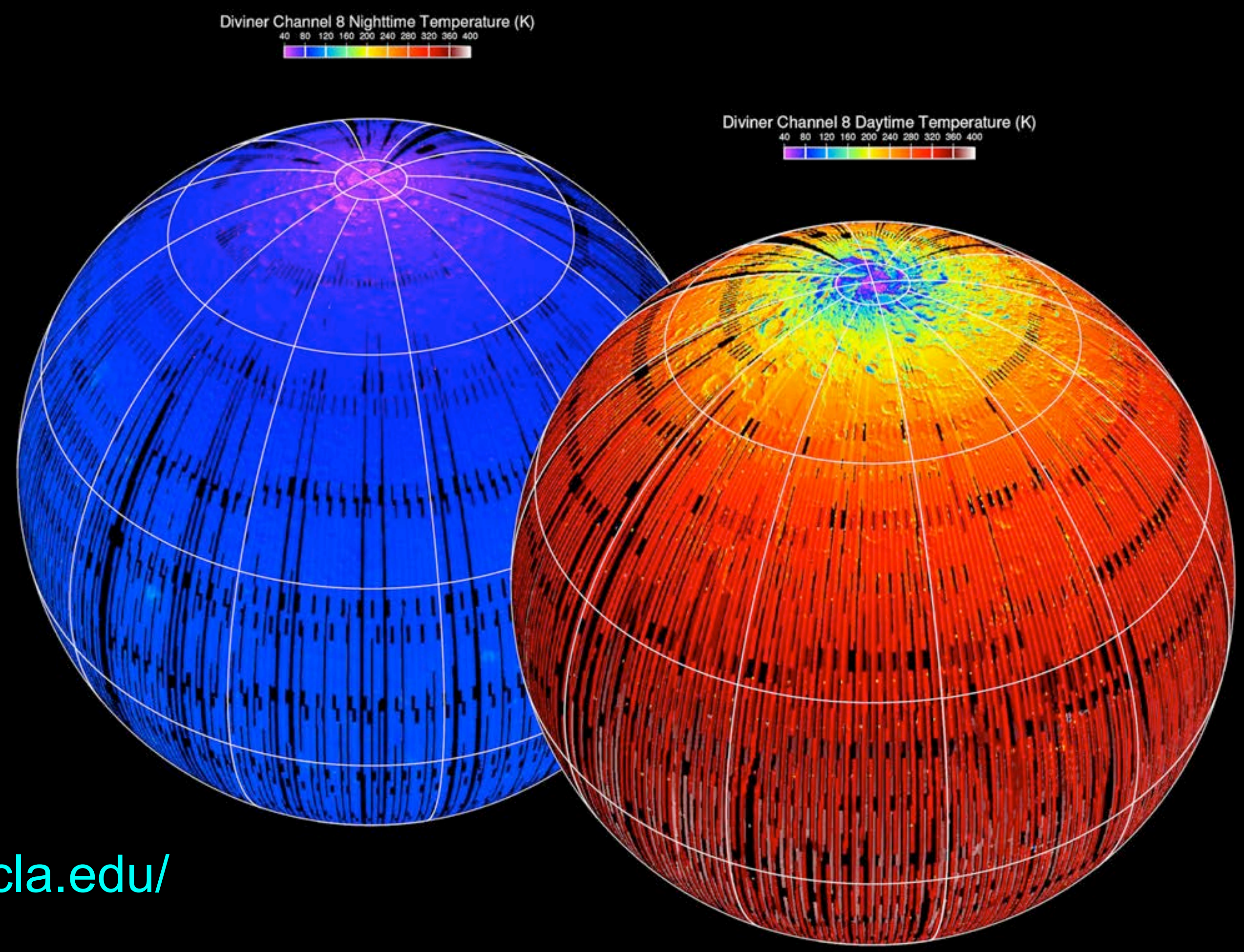



Temperature

Lunar surface temperatures measured during Apollo, vary almost 300 K between lunar night and day.

LRO Diviner



Apollo 15 measurements.
Day = 374 K (101˚C)
Night = 92 K (-181˚C)

Langseth et al. (1976)
Proc. Lunar Sci. Conf.
7th, 3143-3171.

Apollo 17 measurements.
Day = 410 K (137˚C)
Night = 103 K (-170˚C)

https://www.diviner.ucla.edu/

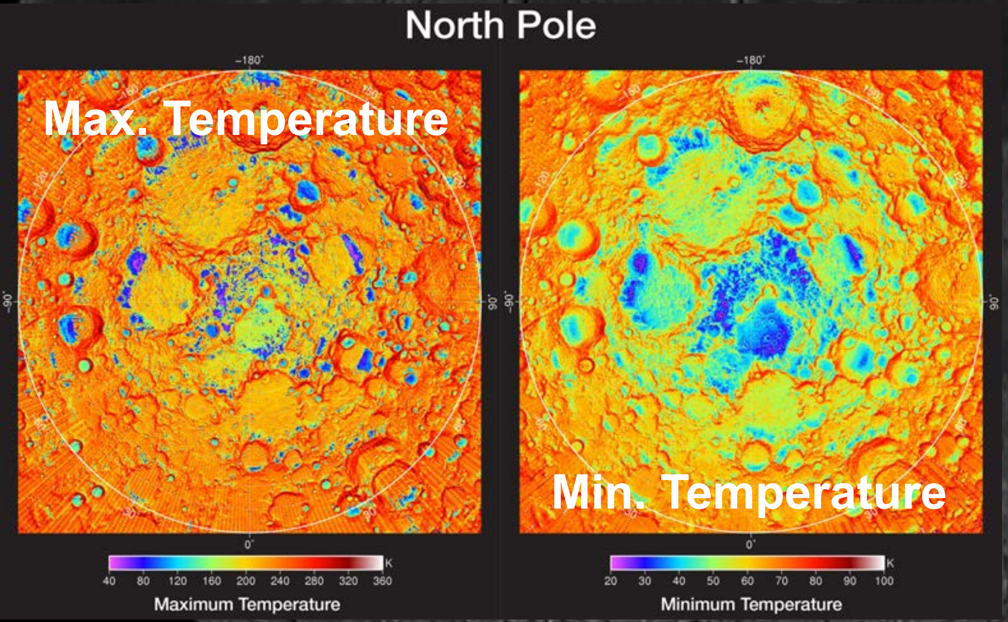
Temperature

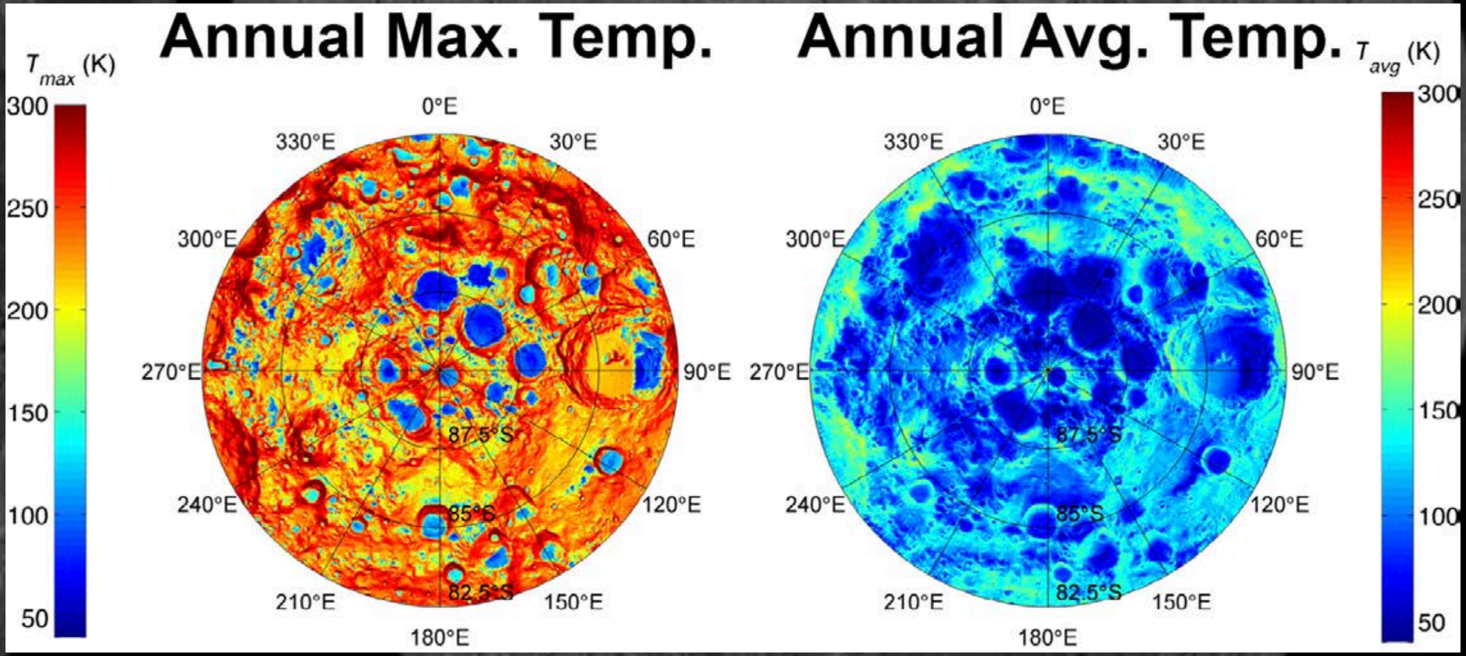
Permanently shadowed craters at the poles are some of the coldest places in our Solar System.

LRO Diviner

Hayne et al. (2015) *Icarus* **255**, 58-69.

North Pole



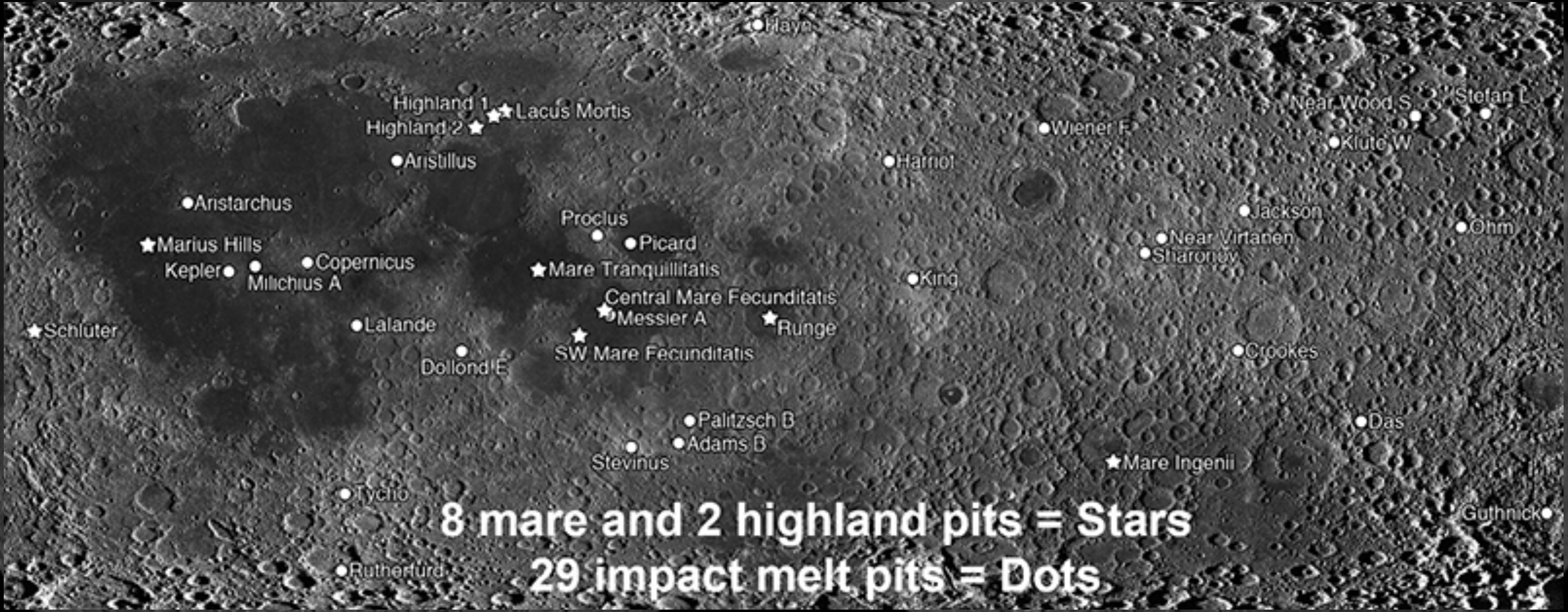


South Pole

Paige et al. (2010) *Science* **330**, 479-482.

Lava Tubes (Skylights or Pits)

Potential Human Habitats

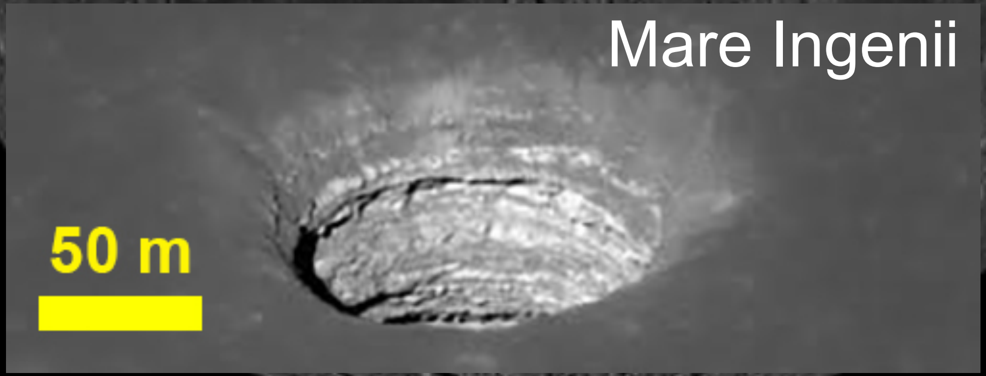


Offers Protection: Meteoroids, Radiation, Diurnal Temperature Swings.

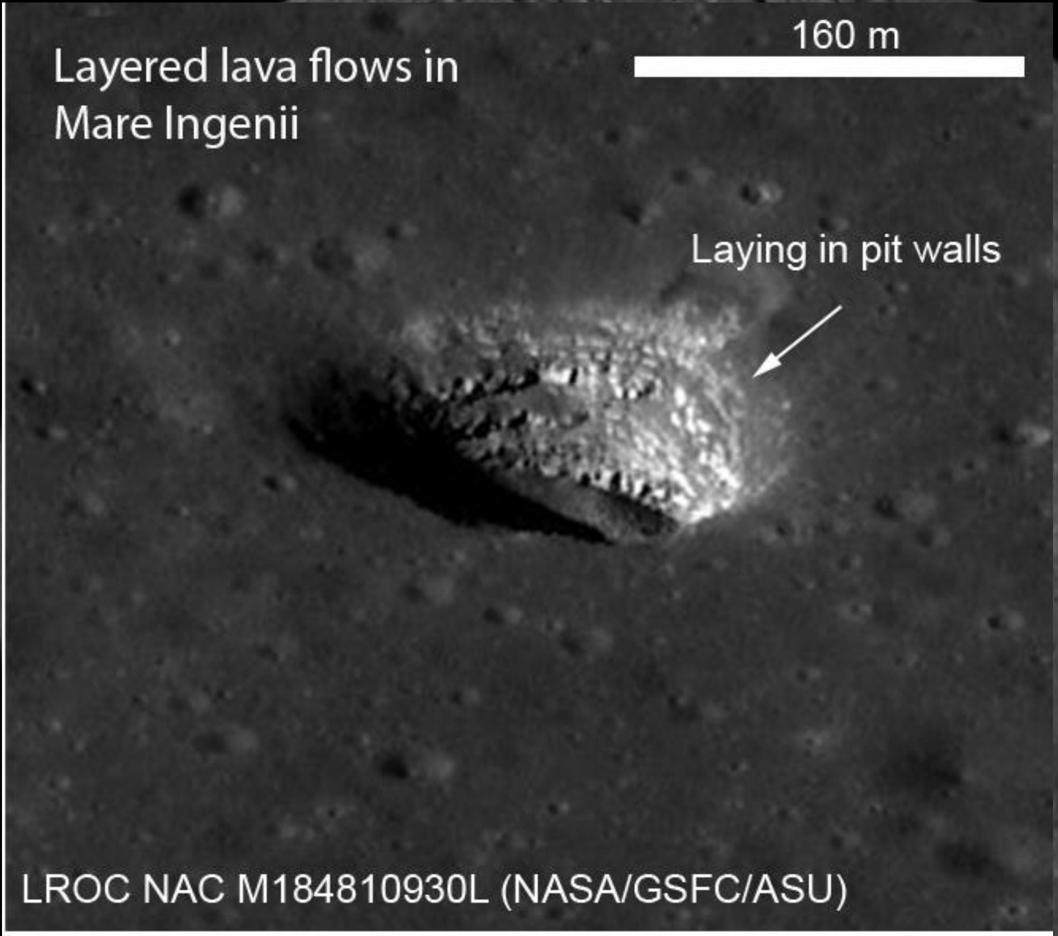
Wagner & Robinson (2014) *Icarus* **237**, 52-60.

Lava Tubes (Skylights or Pits)

Potential Human Habitats



Robinson et al. (2012) *Planet. Space Sci.* **69**, 18-27

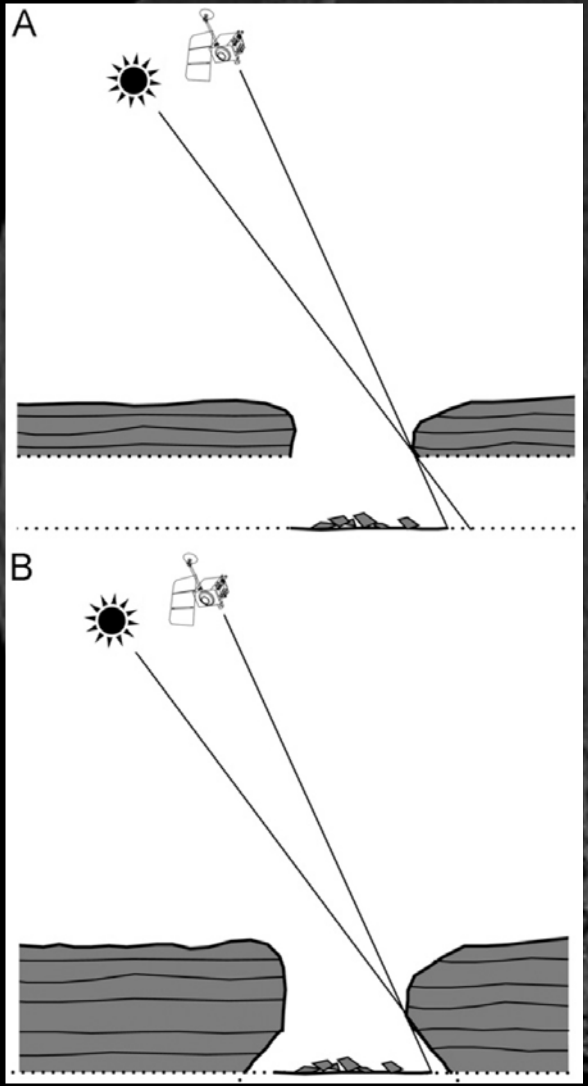


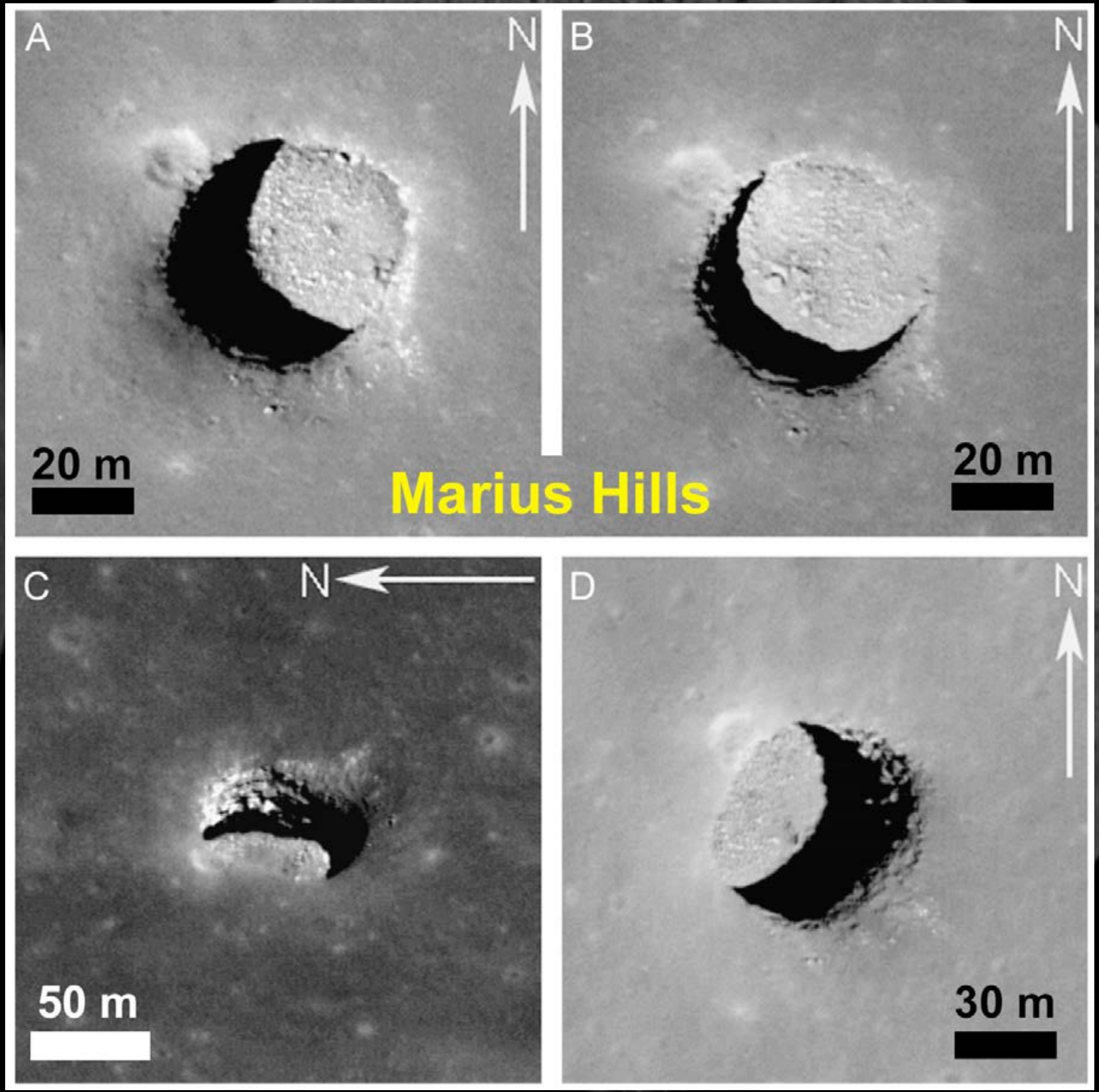
Annual temperature of about -20˚C year round.

Hörz (1986) Lunar Bases & Space Activities, 405-411. Lunar & Planetary Institute: https://www.lpi.usra.edu/publications/books/lunar_bases/Book.pdf

Lava Tubes (Skylights or Pits)

Marius Hills



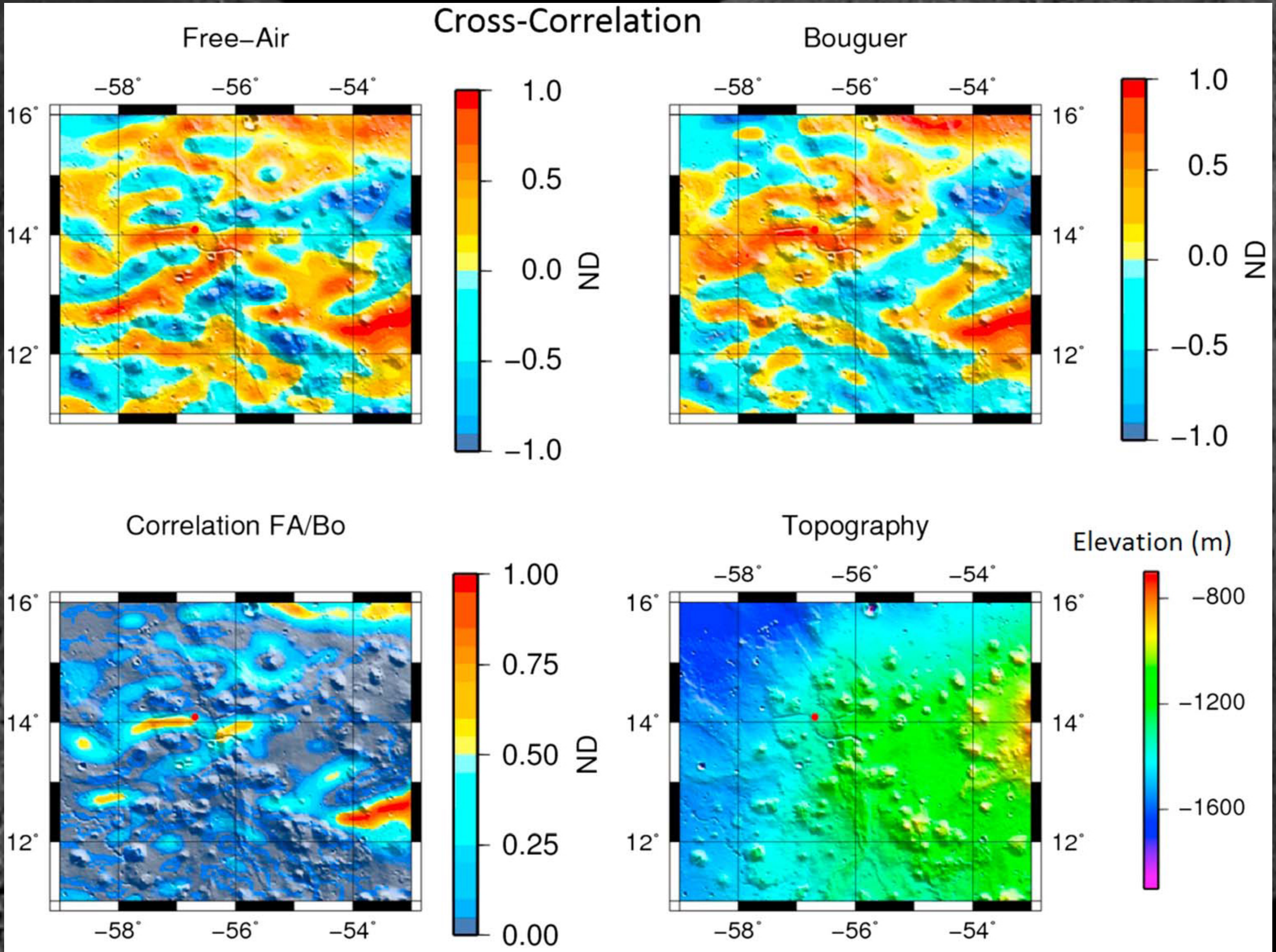


Robinson et al. (2012)
Planet. Space Sci. **69**, 1-27

Lava Tubes (Skylights or Pits)

Marius Hills

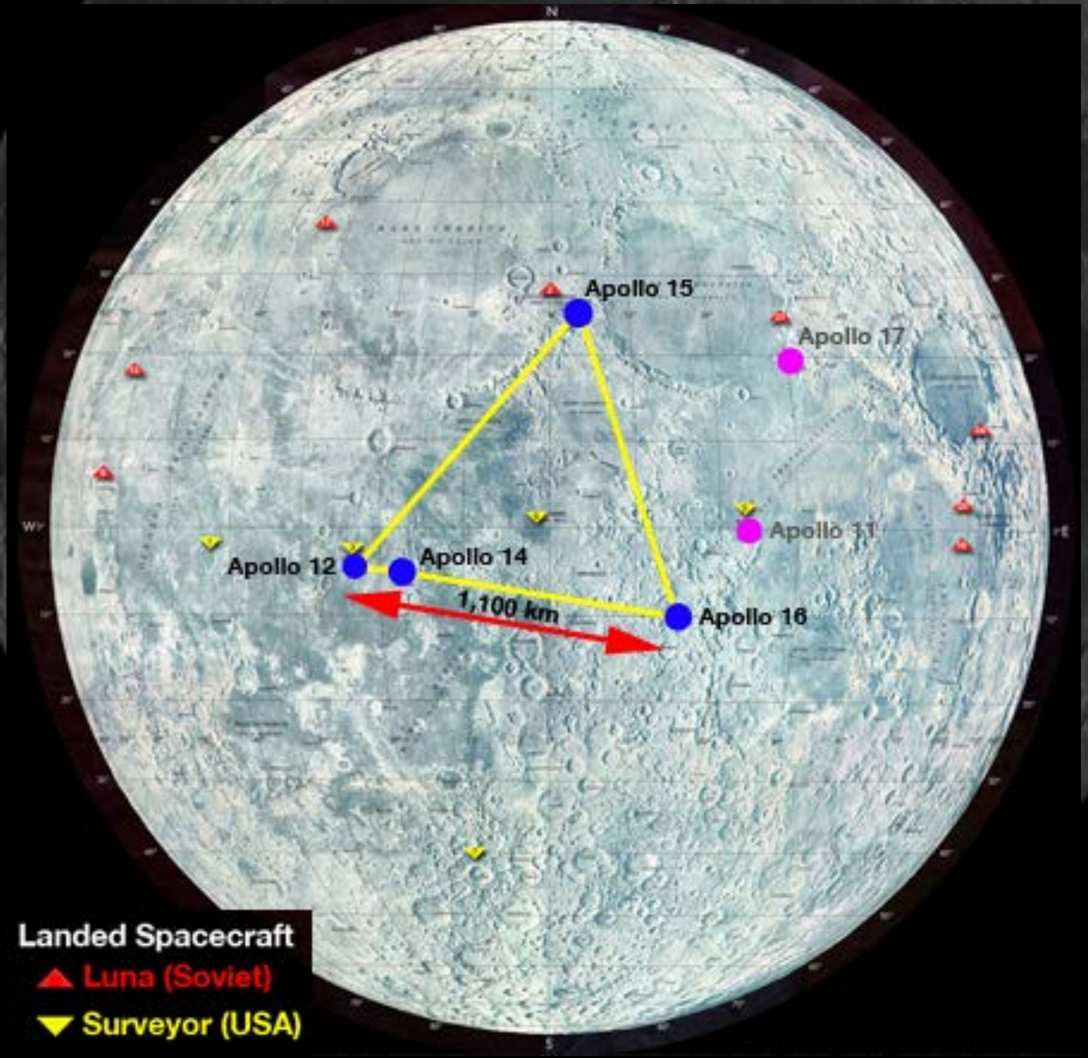
Gravity data show lava tubes are extensive

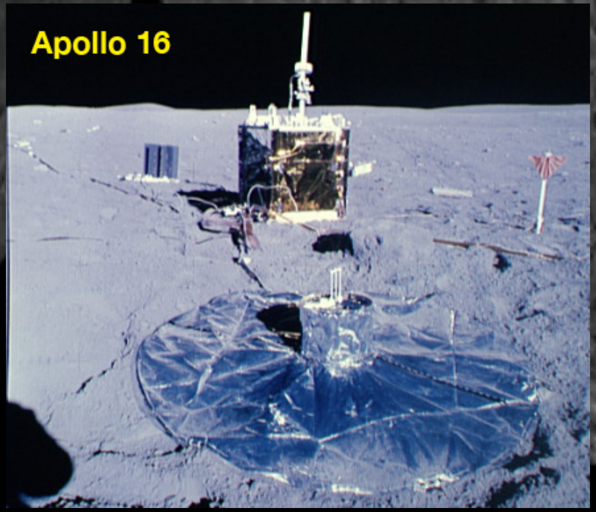


Chappaz et al. (2017) *Geophys. Res. Lett.* **44**, 105-112

Seismicity

The *complete* Apollo passive seismic network operated from 20 April, 1972, until 30 September, 1977.

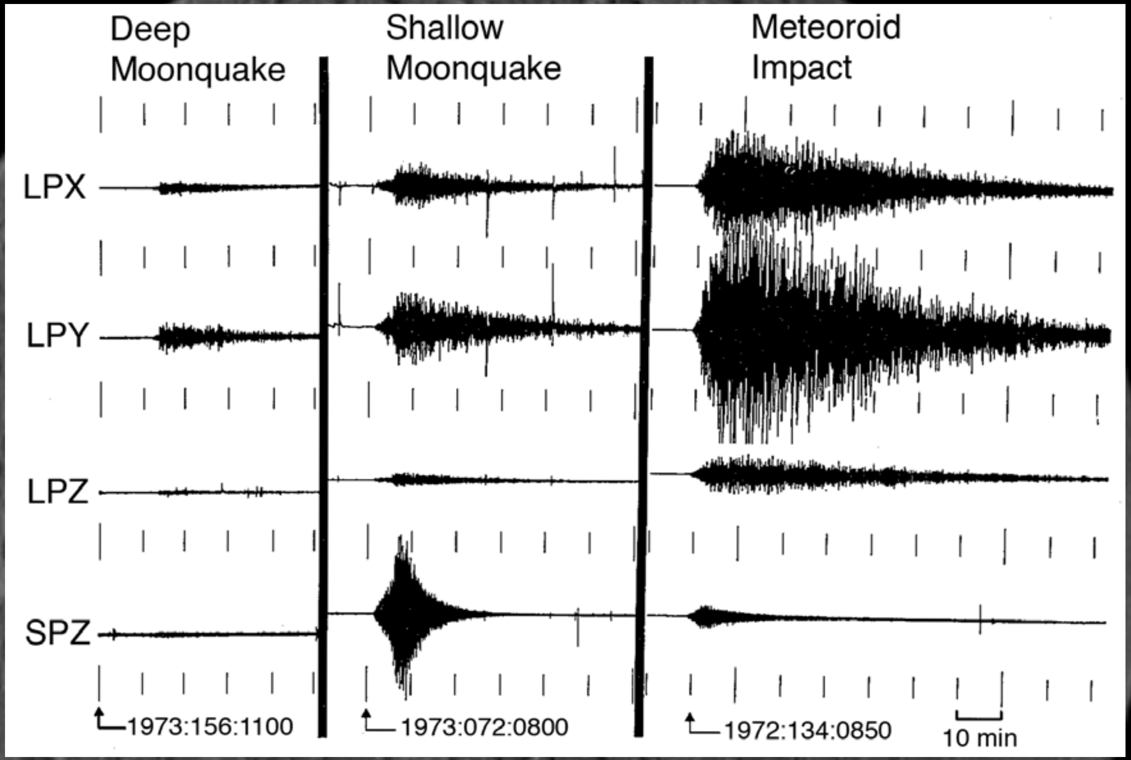




- Network in the central nearside of the Moon.
- Too restricted to define moonquake epicenters precisely.

Seismicity

4 types of seismicity on the Moon.

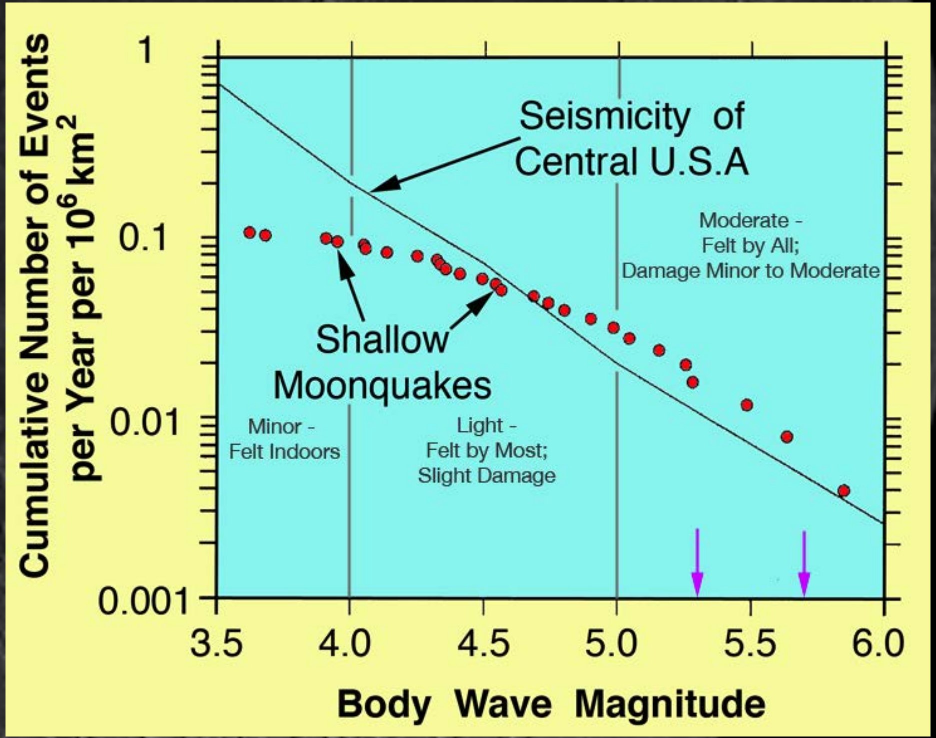


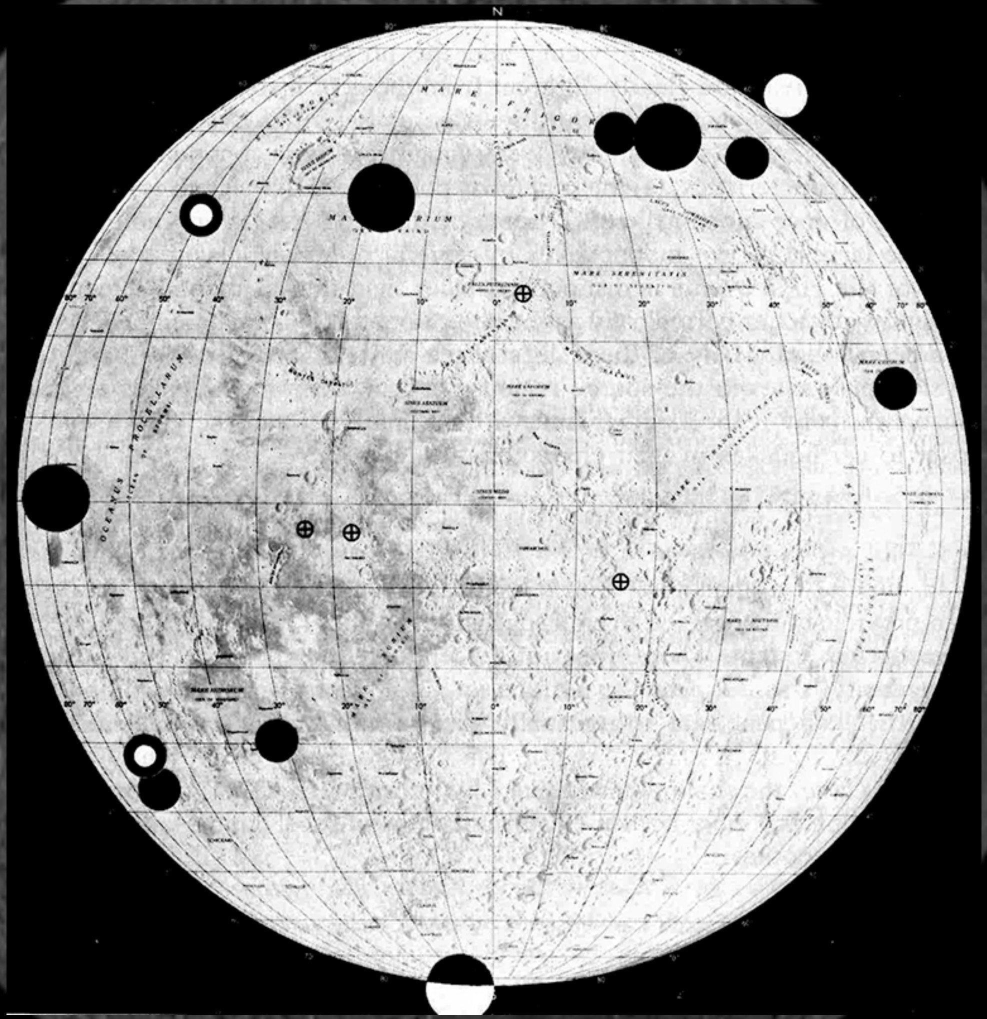
- **Thermal Moonquakes:** Associated with heating and expansion of the crust. Lowest magnitude of all Moonquakes.
- **Deep Moonquakes:** 850-1,000 km. > 7,000 recorded. Originate from "nests" or "clusters" - >300 defined from Apollo seismic data to date. Small magnitude (< 3). Associated with tidal forces. Predominantly near side.
- **Meteoroid Impacts:** > 1,700 events representing meteoroid masses between 0.1 and 100 kg were recorded 1969-1977. Smaller impacts were too numerous to count.
- **Shallow Moonquakes:** Some > 5 magnitude. Exact locations unknown. Indirect evidence suggests focal depths of 50-200 km. May be associated with boundaries between dissimilar surface features. Exact origin and location unknown.

Seismicity

Shallow Moonquakes.

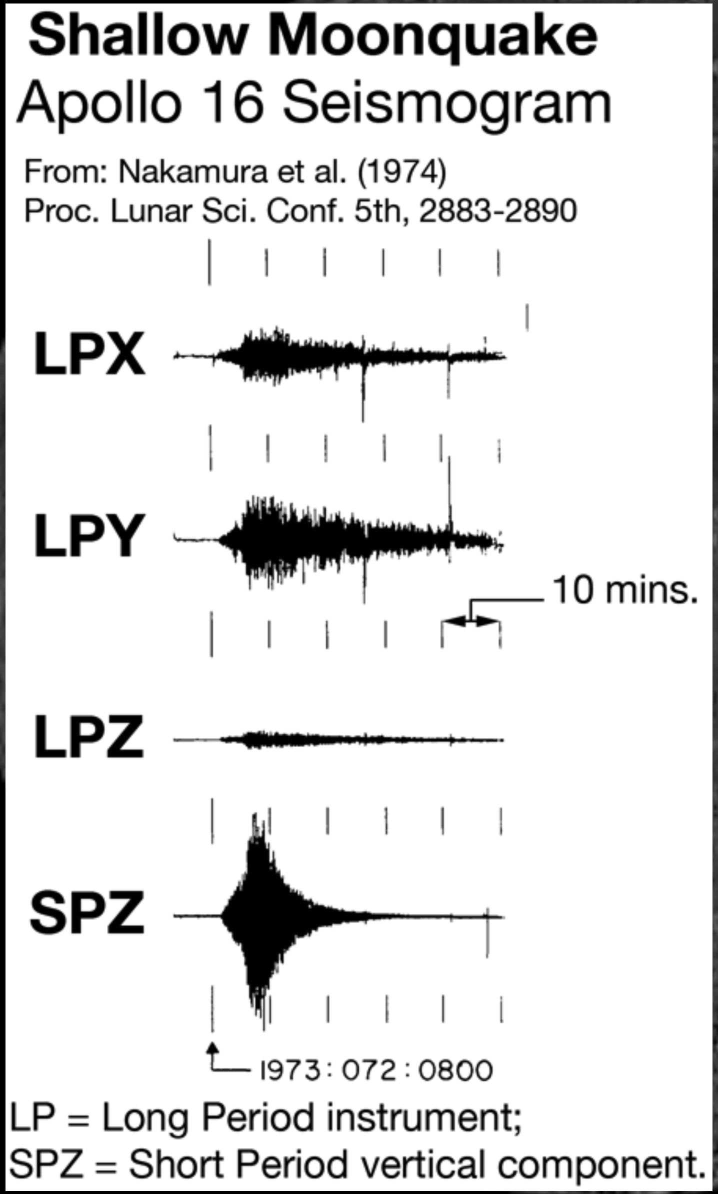
Present a potential significant risk to any proposed lunar outpost.

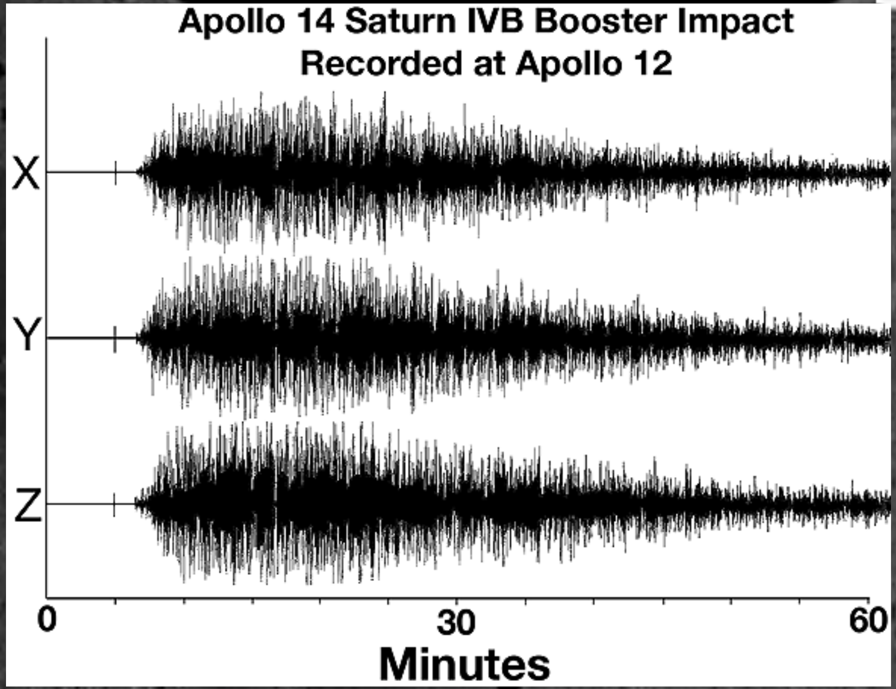




- **Shallow Moonquake** seismicity similar to intraplate seismicity on Earth.
- 28 **Shallow Moonquakes** recorded, **7** with magnitude > 5.

Seismicity



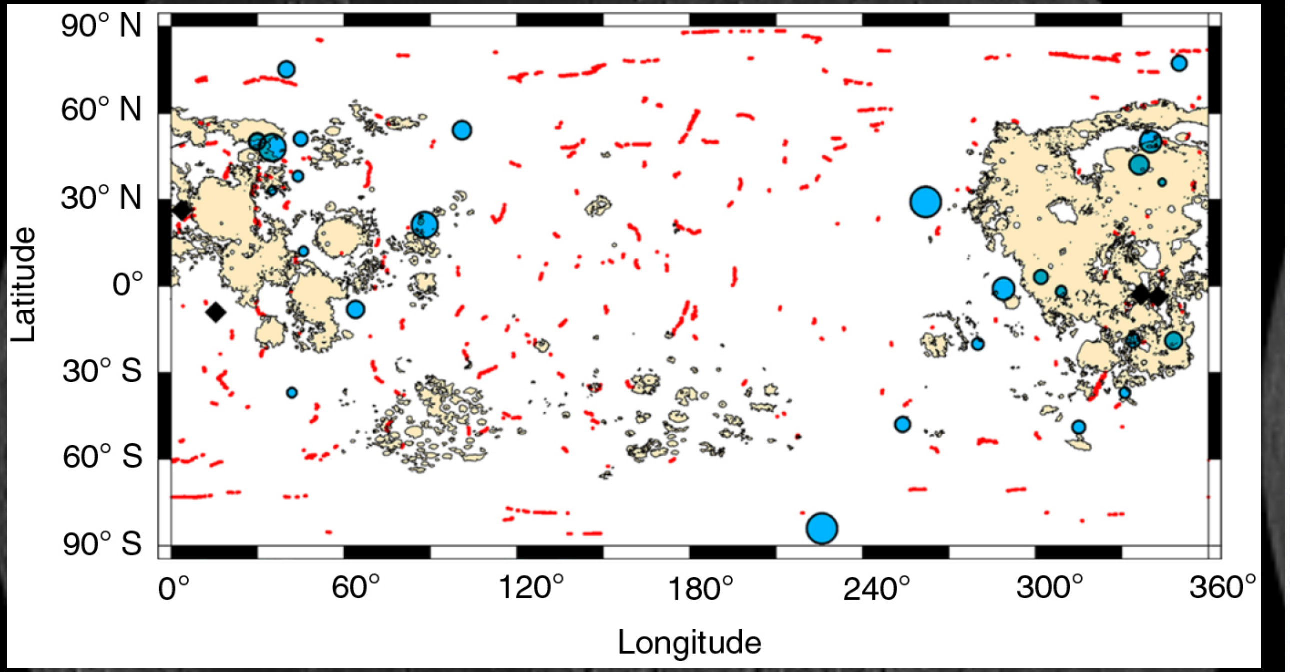


- Initial build-up phase;
- Long duration of energy tail off.
- Highest energy release over a period of ≥10 mins.

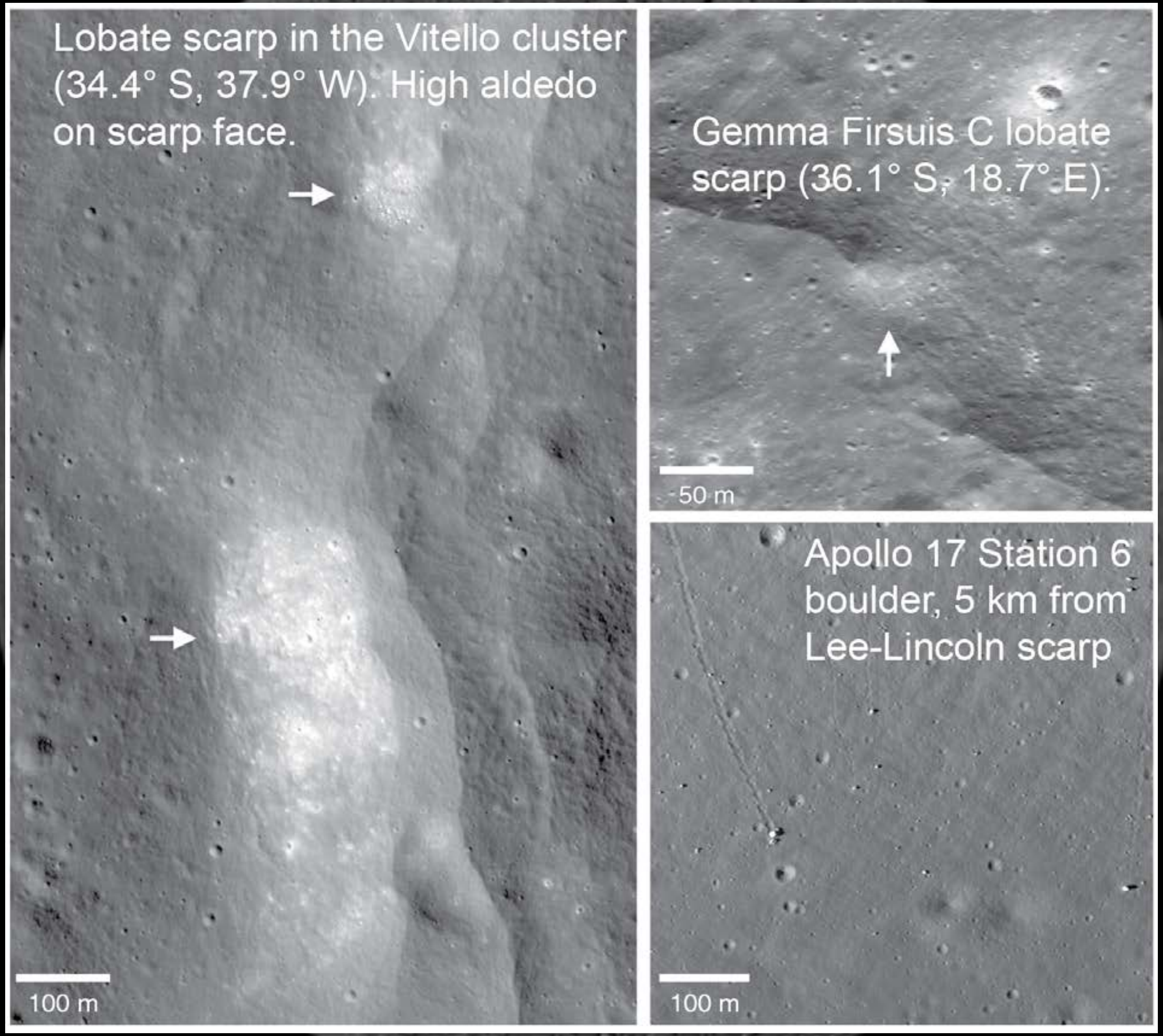
Lack of chemical alteration allows the Moon to “vibrate” for much longer than the Earth (high Seismic “Q”).

Ground shakes for a long time!

Seismicity



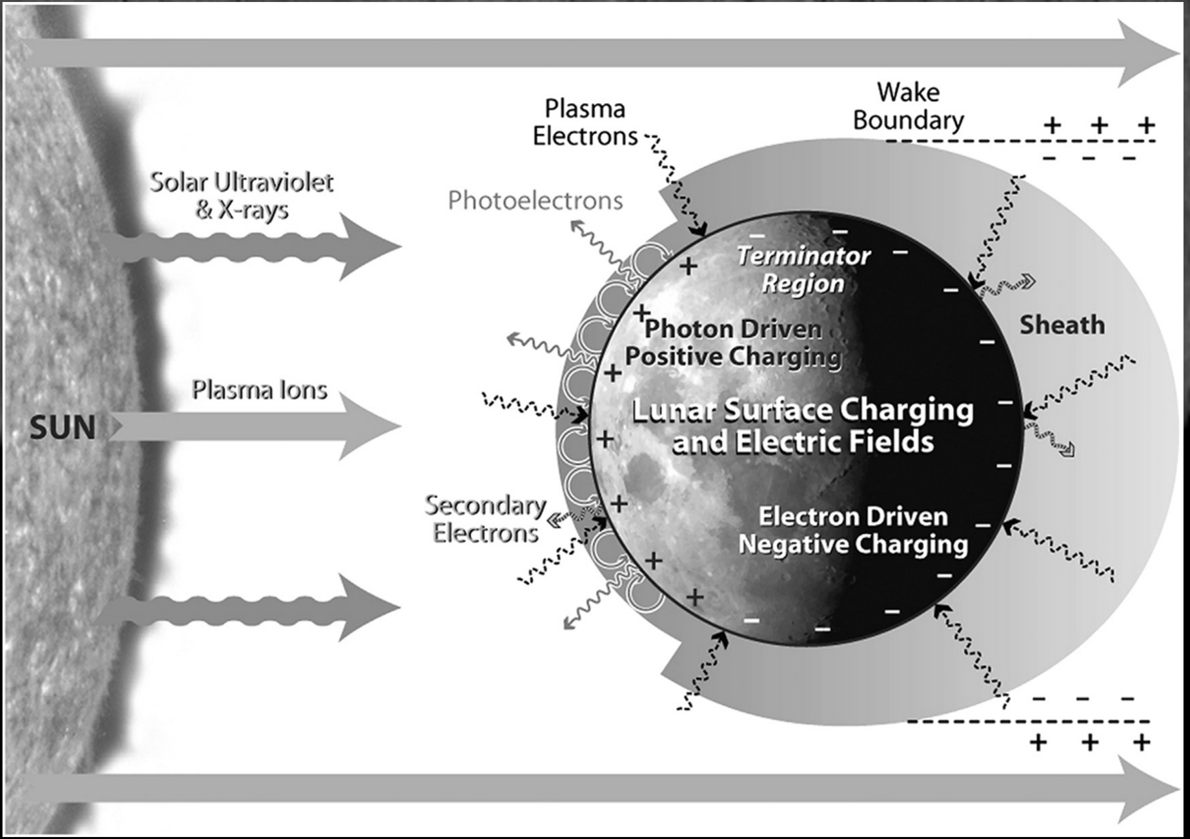
Watters et al. (2019) *Nat. Geosci.* **12**, 411-417



Plasma Environment

Plasma is a cloud of protons, neutrons and electrons where all the electrons have come loose from their respective molecules and atoms, giving the plasma the ability to act as a whole rather than as a bunch of atoms.

Solar wind plasma flows ~horizontally in near-terminator regions of the Moon. At the polar regions, presence of "frost" in PSRs requires a dynamic flux of water molecules in to replace those lost by ion sputtering.
Zimmerman et al., (2013) *Icarus* **226**, 992-998



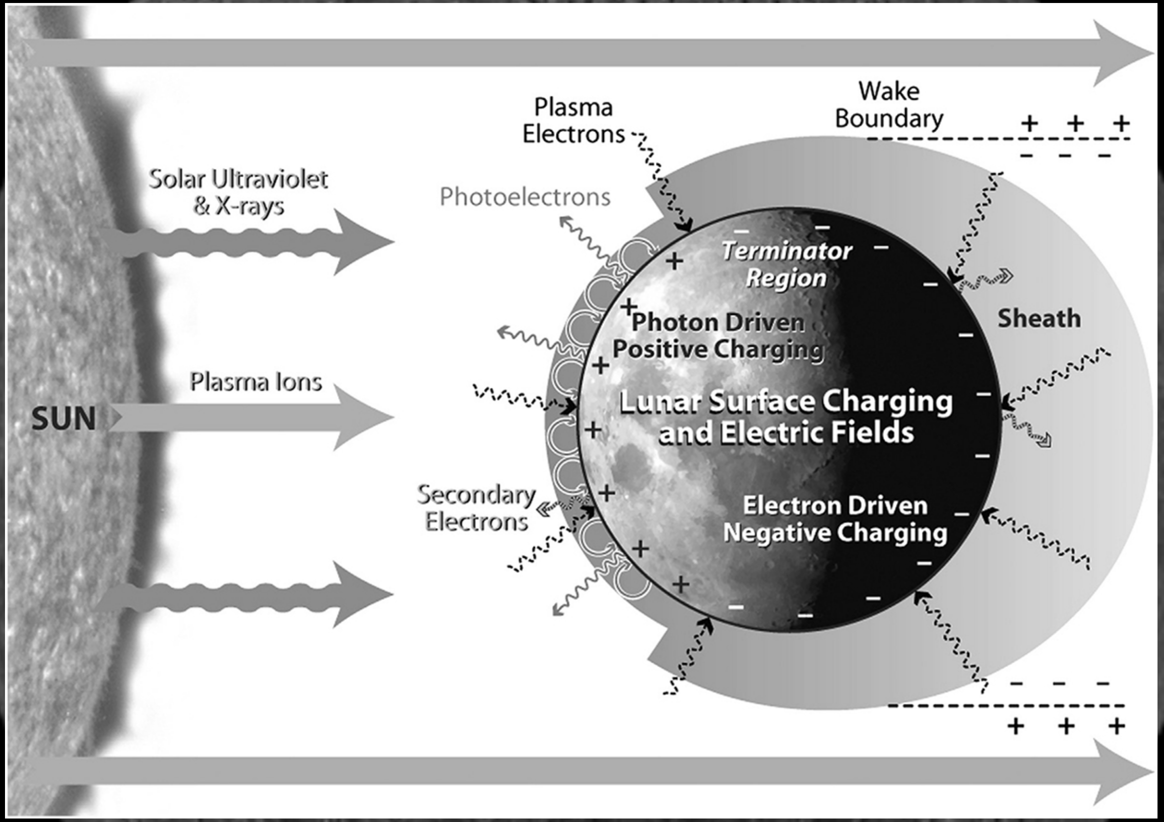
Apollo 14 Suprathermal Ion Detector Experiment. Give ground-truth to remote-sensing orbiter observations of the plasma environment.
Collier et al. (2017) *Geophys. Res. Lett.* **44**, 79-87

Plasma Environment

The influence of surface charging pervades the lunar environment. Three major sources dominate surface charging on the lunar dayside:

- Photoemission of electrons by solar UV and soft X-rays,
- Plasma electrons,
- Plasma ions.

Stubbs et al. (2014) *Planet. Space Sci*. **90**, 10-27



Plasma Environment

Further reading:

Vorburger, A., P. Wurz, S. Barabash, Y. Futaana, M. Wieser, A. Bhardwaj, M. B. Dhanya, and K. Asamura (2016) Transport of solar wind plasma onto the lunar nightside surface, Geophys. Res. Lett., 43, 10,586–10,594, doi:10.1002/2016GL071094.

Popel S.I., Zelenyi L.M., Golub A.P., Dubinskii A.Yu. (2018) Lunar dust and dusty plasmas: Recent developments, advances, and unsolved problems. Planetary and Space Science 156, 71-84

Kallio E et al. (2012) Kinetic simulations of finite gyroradius effects in the lunar plasma environment on global, meso, and microscales. Planetary and Space Science 74, 146-155.

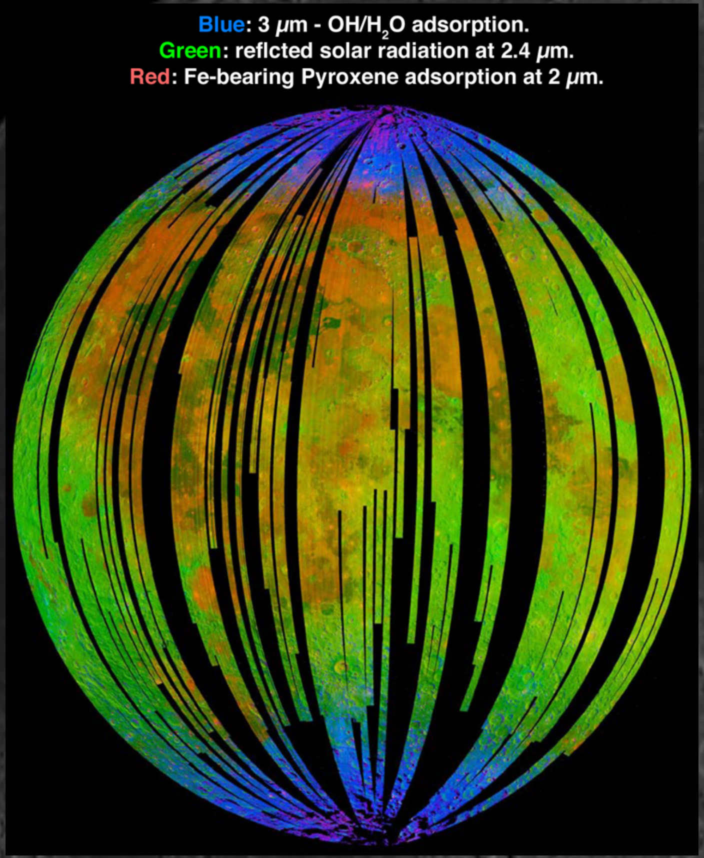
Halekas J.S., Saito Y., Delory G.T., and Farrell W.M. (2011) New views of the lunar plasma environment. Planetary and Space Science 59, 1681-1694.

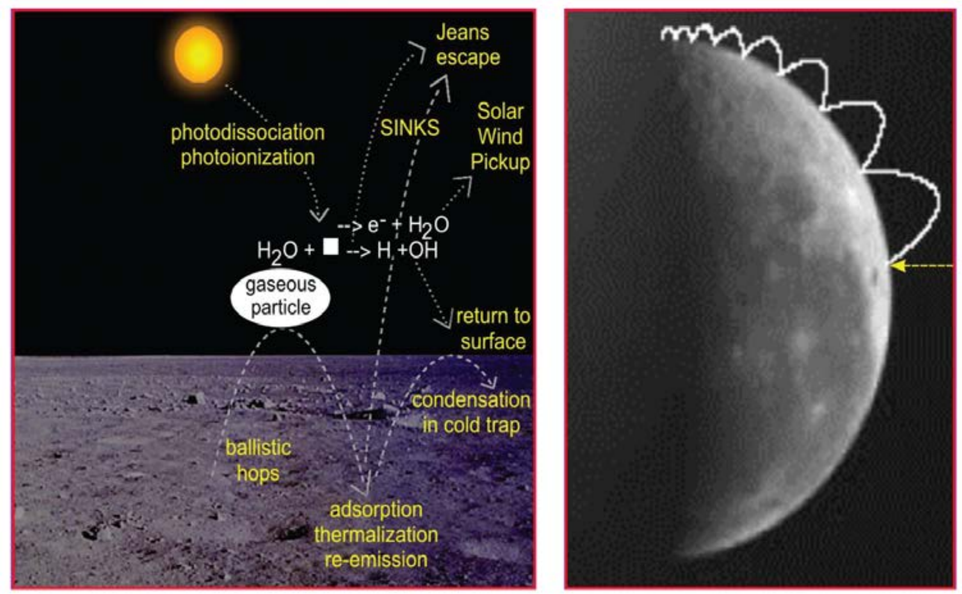
Farrell W.M., Poppe A.R., Zimmerman M.I., Halekas J.S., Delory G.T., and Killen R.M. (2013) The lunar photoelectron sheath: A change in trapping efficiency during a solar storm. J. Geophys. Res. 118, 1114-1122, doi:10.1002/jgre.20086

Farrell W.M., et al. (2012) Solar-Storm/Lunar Atmosphere Model (SSLAM): An overview of the effort and description of the driving storm environment. J. Geophys. Res. 117, E00K04, doi:10.1029/2012JE004070

Farrell W.M., et al. (2010) Anticipated electrical environment within permanently shadowed lunar craters. J. Geophys. Res. 115, E03004, doi:10.1029/2009JE003464

Exosphere





Hurley-Crider & Vondrak (2000) *J. Geophys. Res.* **105**, 26773-26782

Diurnal surface OH/H_2O

Pieters et al. (2009) *Science* **326**, 568-572

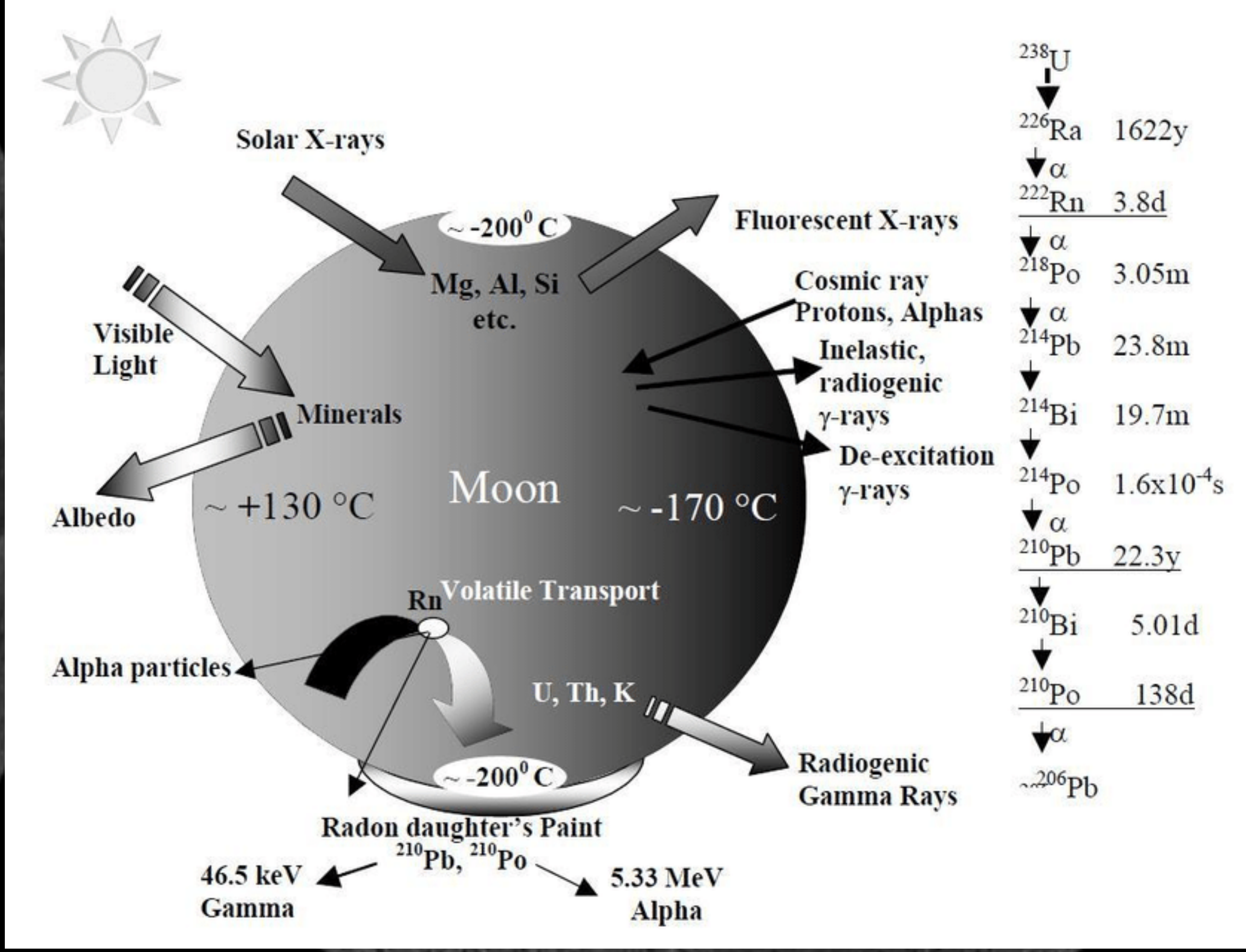
Solar wind plasma flows almost horizontally in near-terminator regions of the Moon. At the polar regions, presence of “frost” in PSRs requires a dynamic flux of water molecules in to replace those lost by ion sputtering.

Zimmerman et al., (2013) *Icarus* **226**, 992-998

Radiation

Three major types:

- Solar Wind,
- Solar-Flare-associated particles (AKA Solar Energetic Particles), and
- Galactic Cosmic rays.



The radiation consists mainly of protons and electrons with some heavier nuclei. These particles interact with the Moon in different ways, depending on their energy and composition, resulting in penetration depths that vary from micrometers to meters.

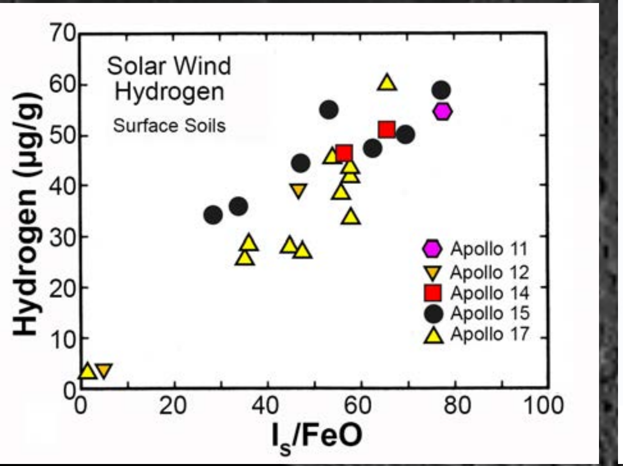
Radiation

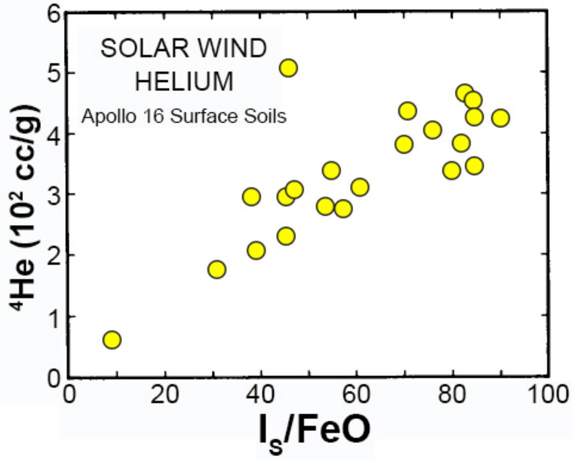
Solar Wind Particles:

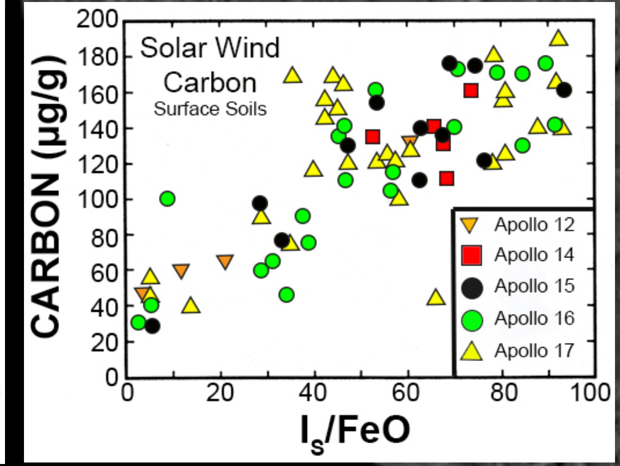
- Have an average energy of 1 keV/amu
- Penetrate to about 150 nm (0.15 µm) in lunar materials
- Interact with atoms in target crystals - forms an amorphous outer layer.

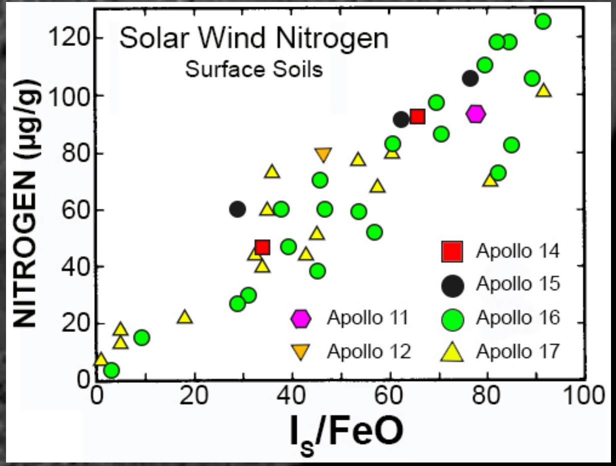
Quantifiable solar-wind elements limited to the volatile elements (e.g., H, He, Ne, Ar, Kr, Xe, C, and N) - lunar materials have very low volatile contents.

Saturation value is reached in ~100 yr, balanced between implantation and loss by sputtering Borg et al., 1980 The Ancient Sun: Fossil Record in the Earth, Moon and Meteorites, pp. 431–461. Pergamon.







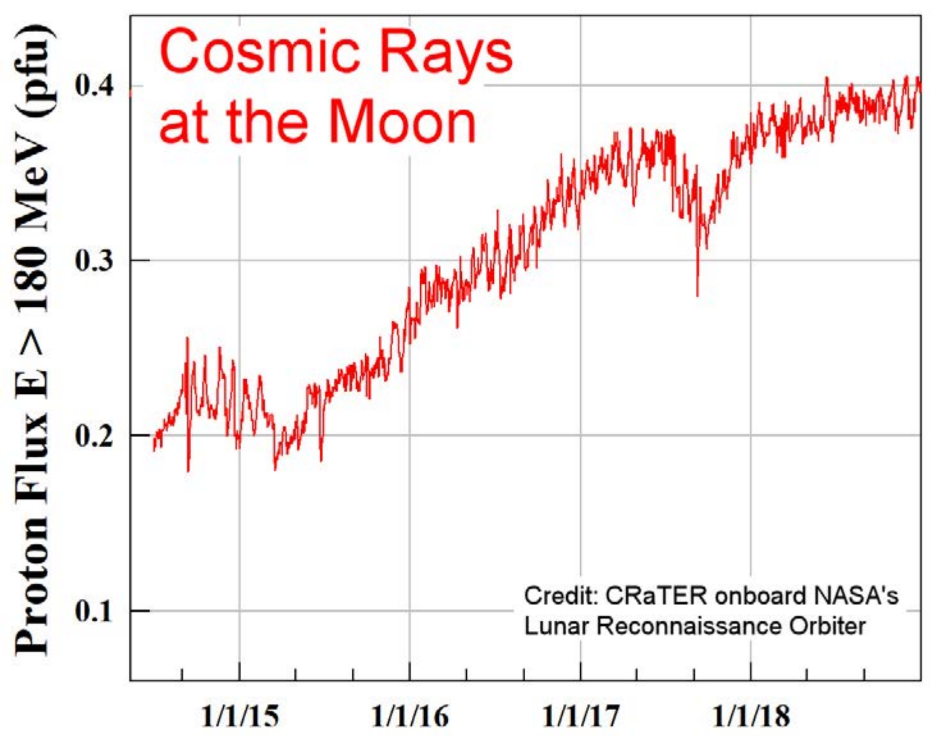


I_S/FeO – a measure of metallic Fe to oxidized Fe quantified by ferromagneitc resonance.

Radiation

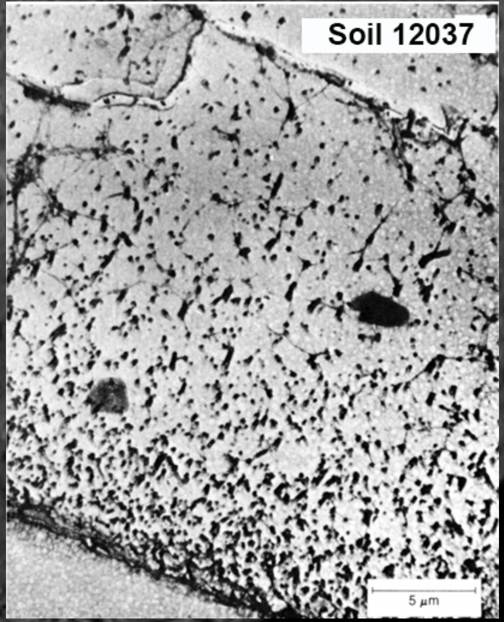
Cosmic-ray protons and neutrons:

- Energies >1 GeV/amu
- Penetrate into lunar materials to



Solar-Flare Particles:

- Energies 10^4 to 10^8 eV/amu,
- Penetrate few mm to several cm into lunar materials.
- Lower flux than solar-wind particles,
- Density of tracks = indicator of the exposure age.



Radiation

The current knowledge about the radiation environment on the surface of the Moon is exclusively based on calculations using radiation transport models with input parameters from models for the galactic cosmic ray spectra and for solar particle events.

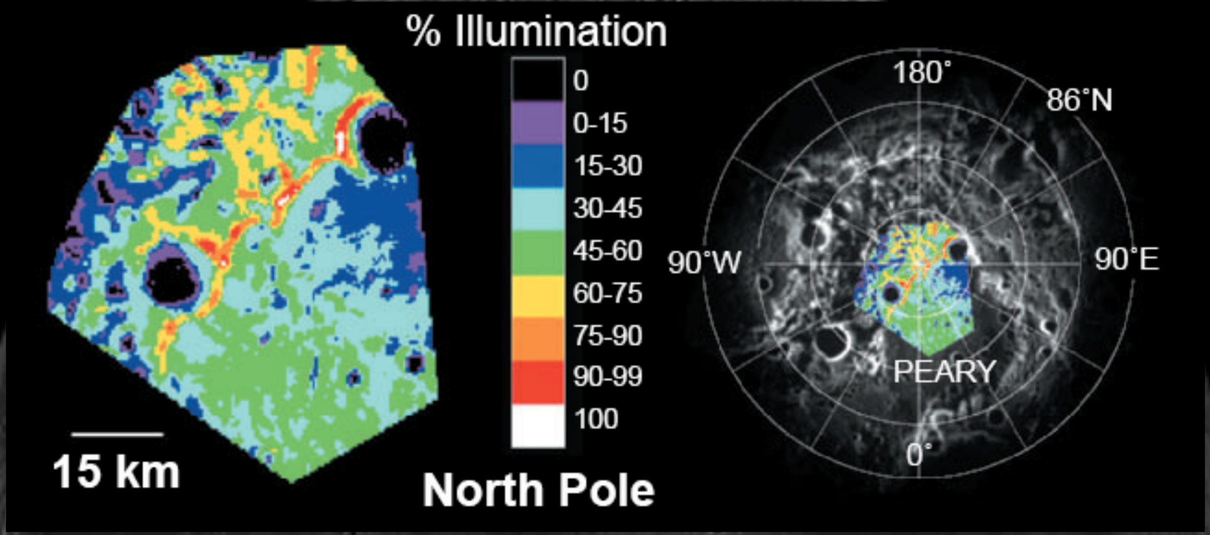
Reitz et al. (2012) *Planet. Space Sci.* **74**, 78-83

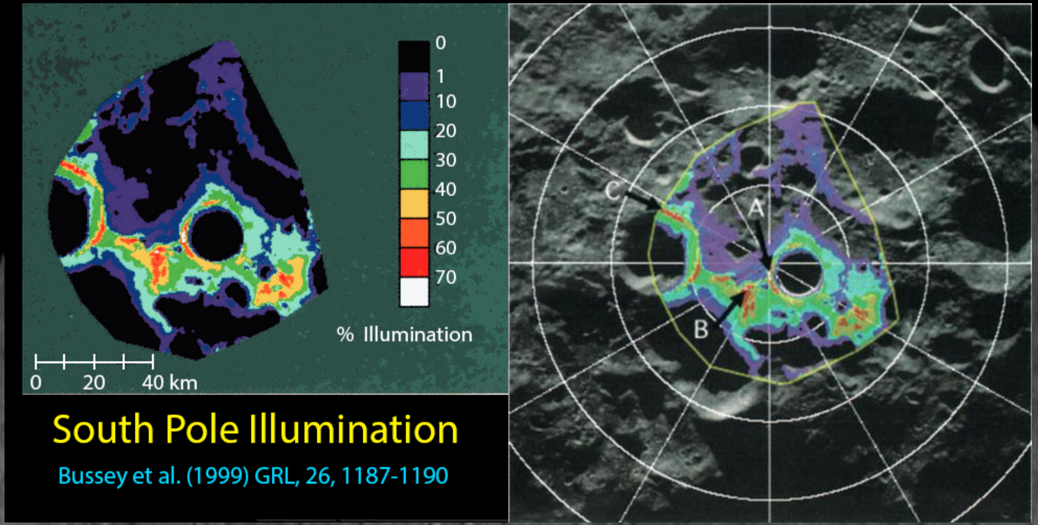
- Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on LRO.
- Sun has not been very active but Galactic Cosmic Ray levels are high.
- *The time to 3% risk of exposure-induced death (REID) in interplanetary space was less than 400 days for a 30 year old male and less than 300 days for a 30 year old female*.
- As the Sun's activity increases, this time will decrease.

Schwadron et al. (2014) *Space Weather* **12**, 622-632

Radiation environment on the lunar surface is more severe due to secondaries.

Polar Illumination





Bussey et al. (2005) Constant illumination at the lunar North Pole. *Nature* **434**, 842.

Bussey et al. (1999) Illumination conditions at the lunar south pole. *Geophys. Res. Lett.* **26**, 1187-1190.

Identified localized regions at the North and South Poles where the lunar surface remains illuminated for nearly 94% of the year with the longest eclipsed period lasting only 43 hours.

Speyreer & Robinson (2013) Persistently illuminated regions at the lunar poles: Ideal sites for future exploration. *Icarus* **222**, 122-136.

Summary

- The surface is subject to continual macro and micro-meteoroid bombardment, which has produced the cratered appearance and the lunar regolith.
- The continual bombardments ground the regolith into fine grained angular dust, which is hazardous to humans and machinery.
- The Moon has an exosphere, not an atmosphere.

Summary

- Diurnal temperatures are extreme, although some of the coldest places in the Solar System are in the polar permanently shadowed craters.
- The Moon is seismically active. Meteoroid impacts and shallow moonquakes are hazards for humans living and working on the Moon.
- The lack of atmosphere produces a plasma environment that can charge materials.
- Low gravity will impede mobility
- The radiation environment requires mitigation measures to ensure human survival.