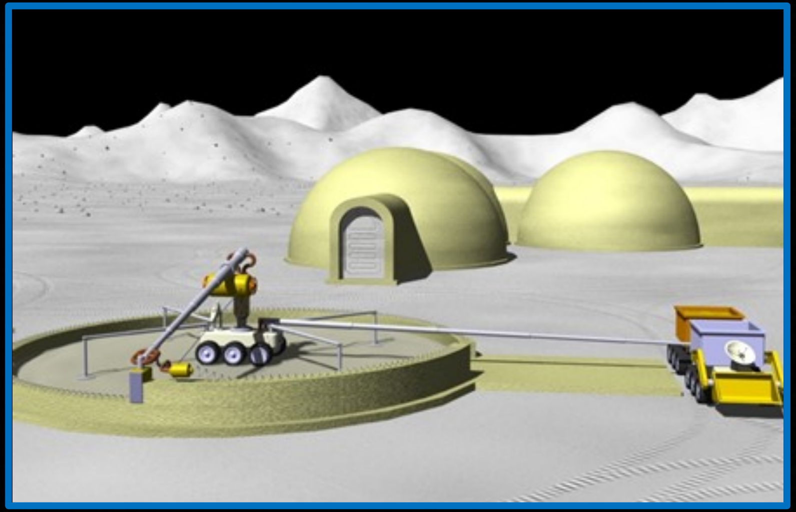
Challenges and Benefits of Excavation and Construction on the Moon

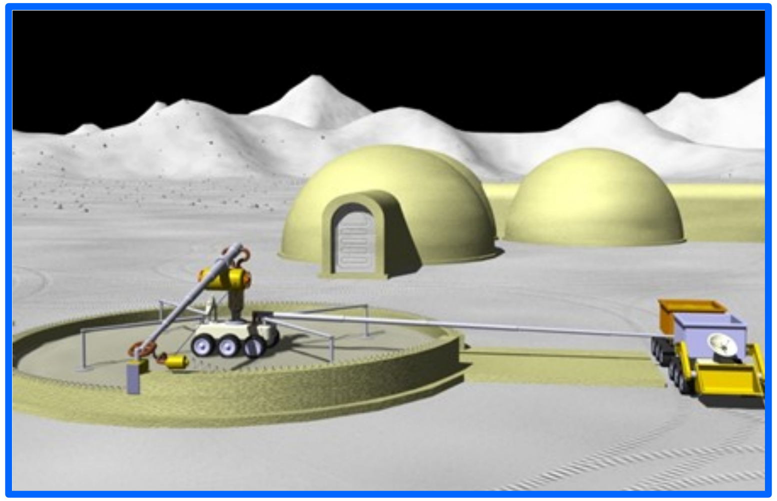


Dr. Jennifer Edmunson | 28 August 2020

Challenges

Benefits

Sustainable Human Presence on the Lunar Surface



There are many challenges in excavation and construction on the Moon

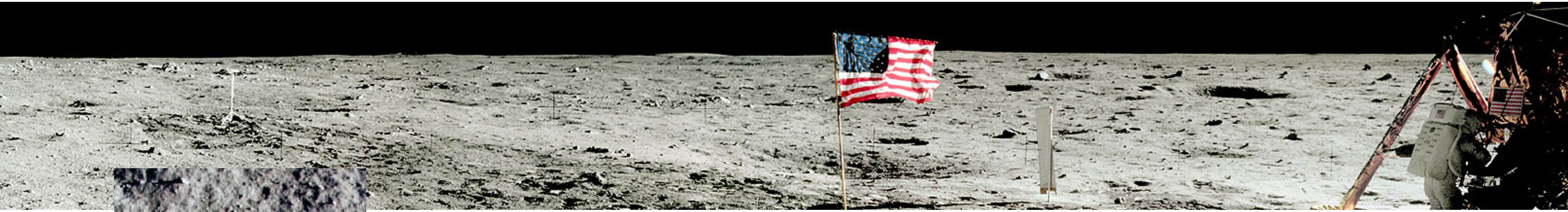
The Lunar Surface Environment

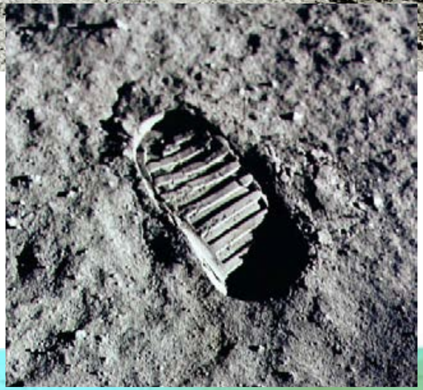
What Is Available In-Situ?

What Materials Should We Use?

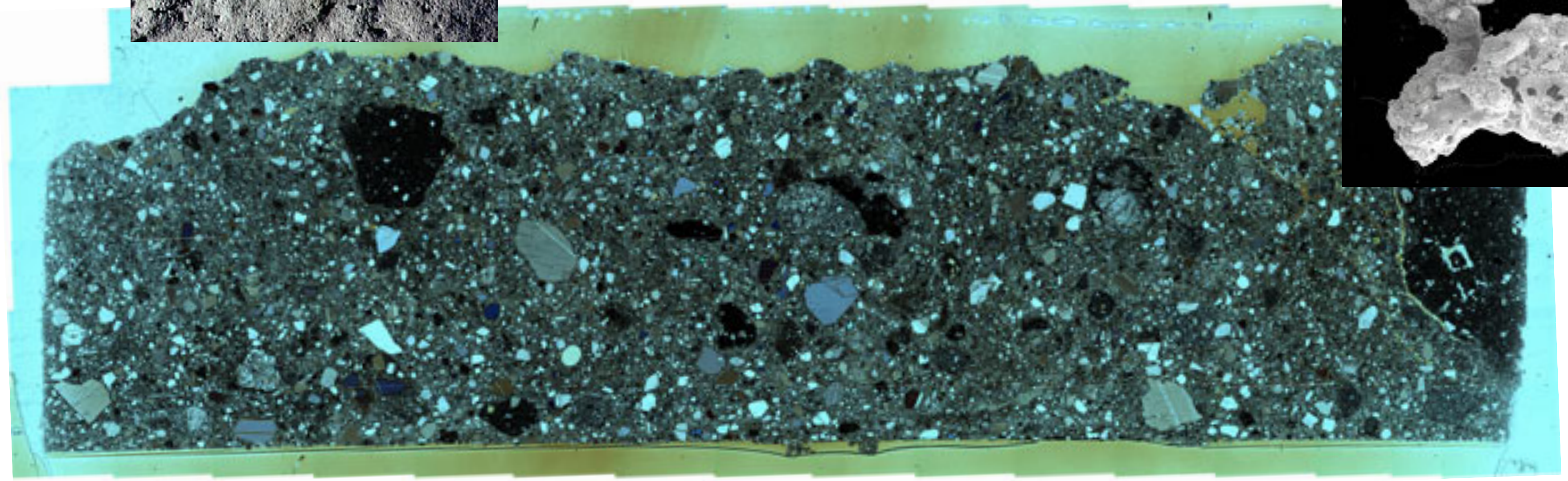
What Technologies Should We Mature?

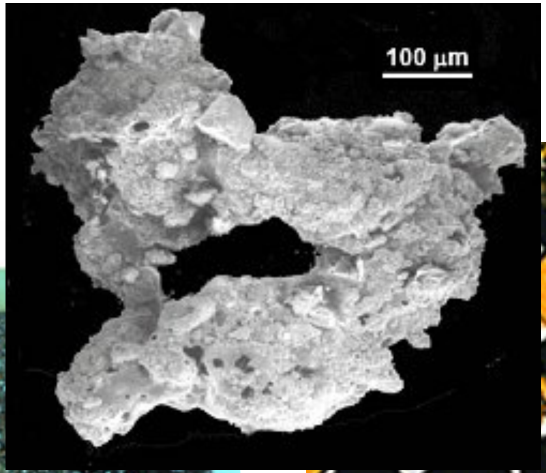
All missions indicated the lunar surface is covered with regolith

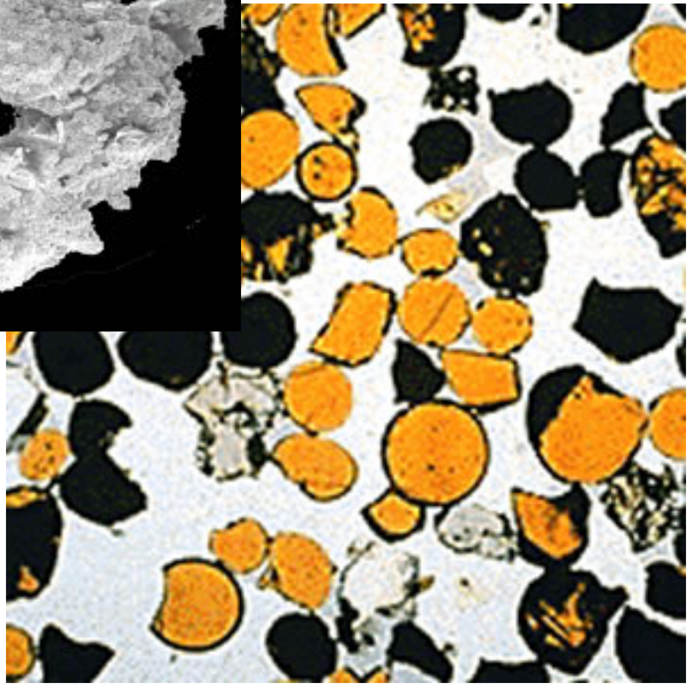




Thickness: <5m to 20m



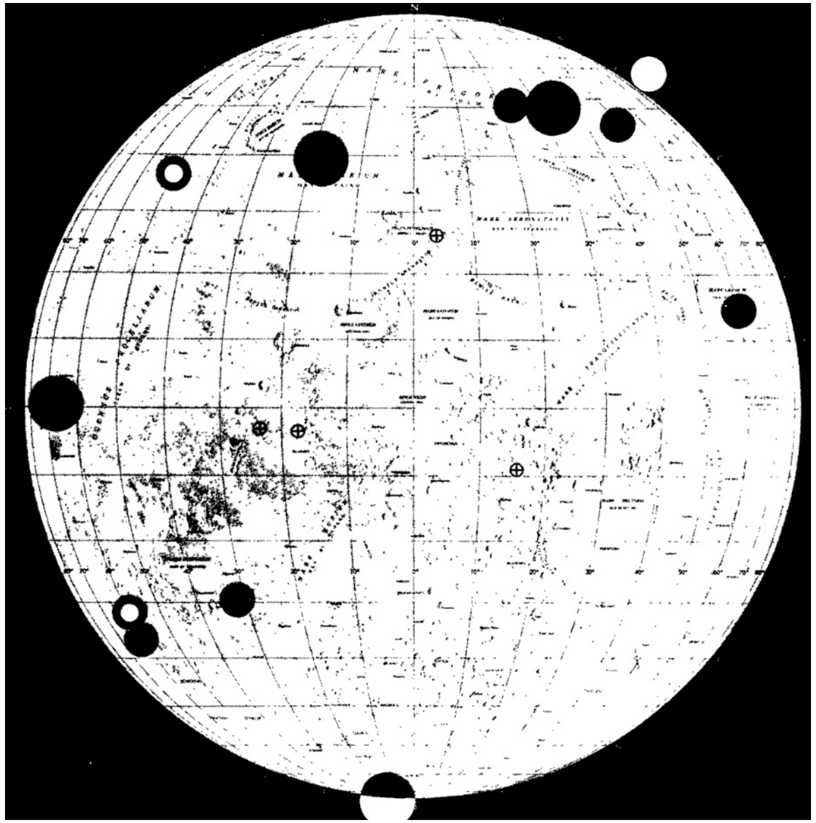




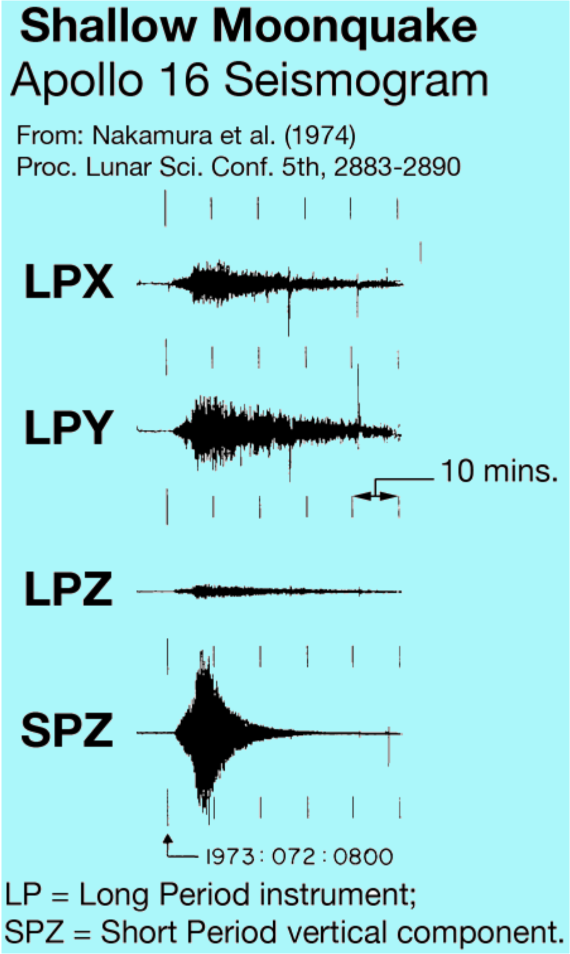
Dust – it will cover, and stick to, everything

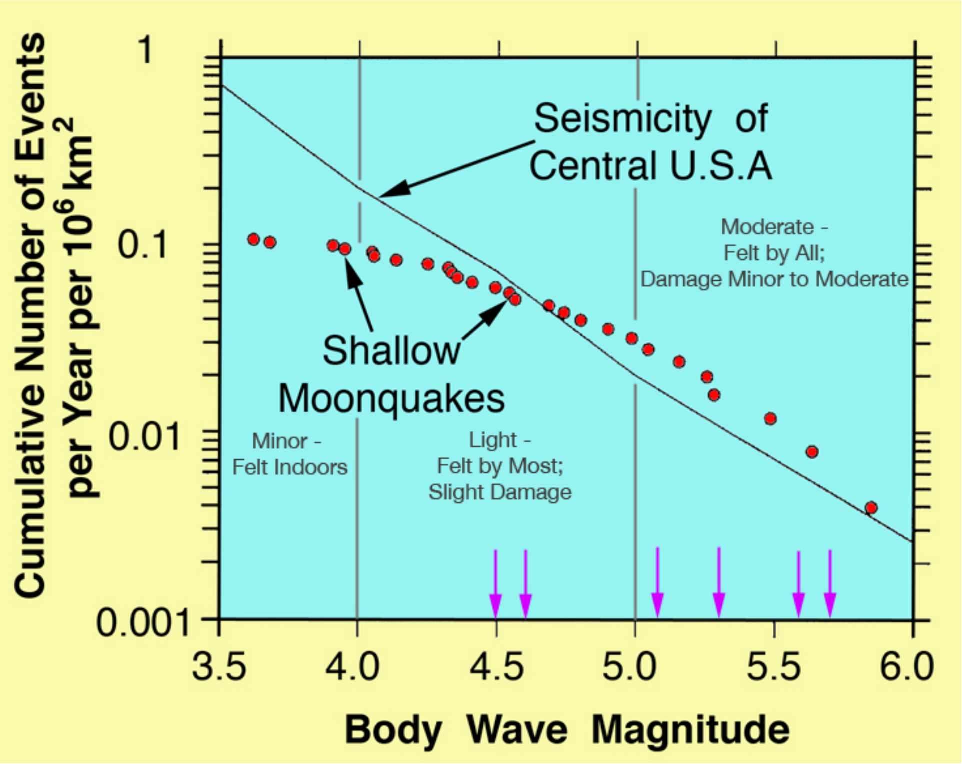
The Moon is seismically active

- Deep, Shallow, and Thermal Moonquakes



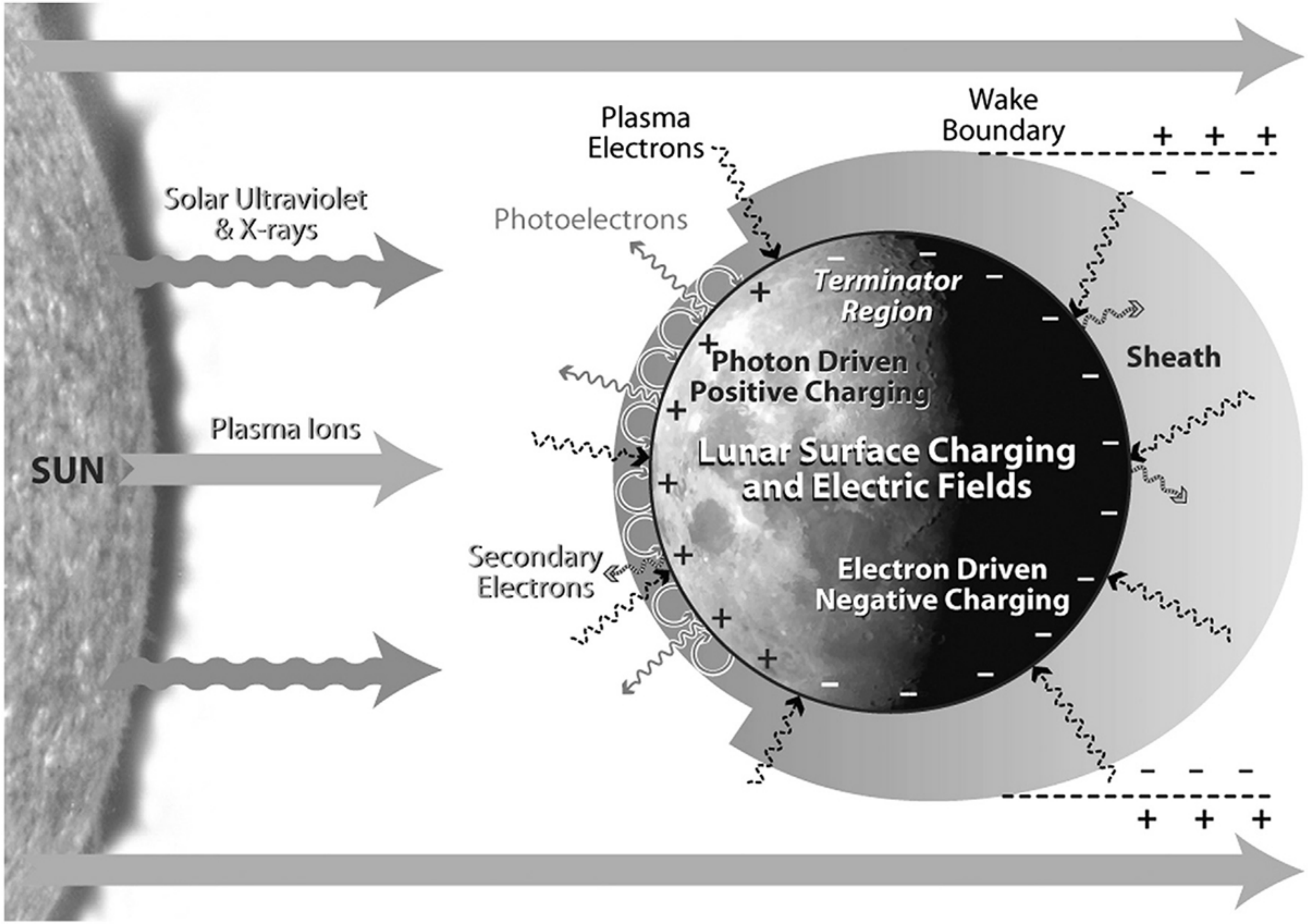
Nakamura et al. (1974) *LPSC* **5th**, 2883-2890
Shallow Moonquakes



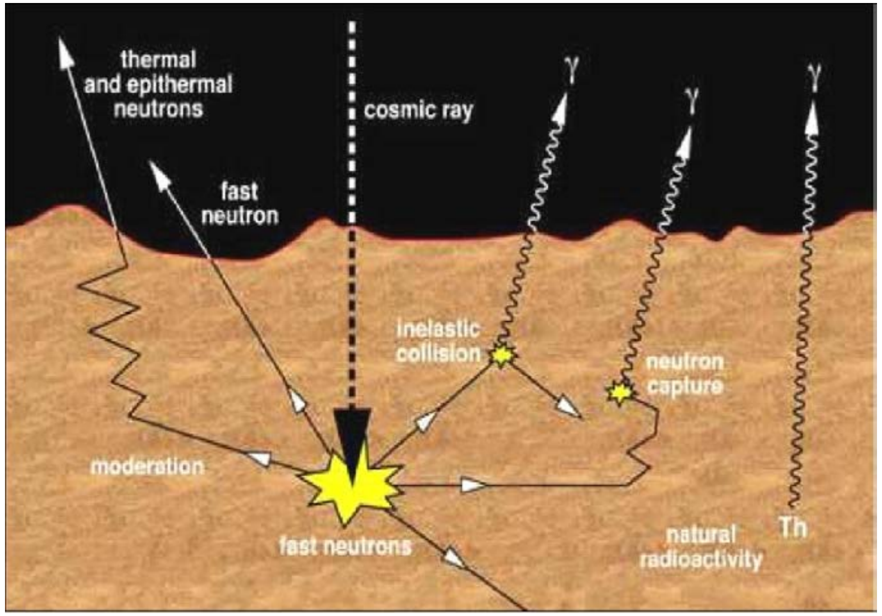


Oberst & Nakamura (1992) *Lunar Bases & Space Activities*, 231-233.

The lunar surface is a radiation-rich environment

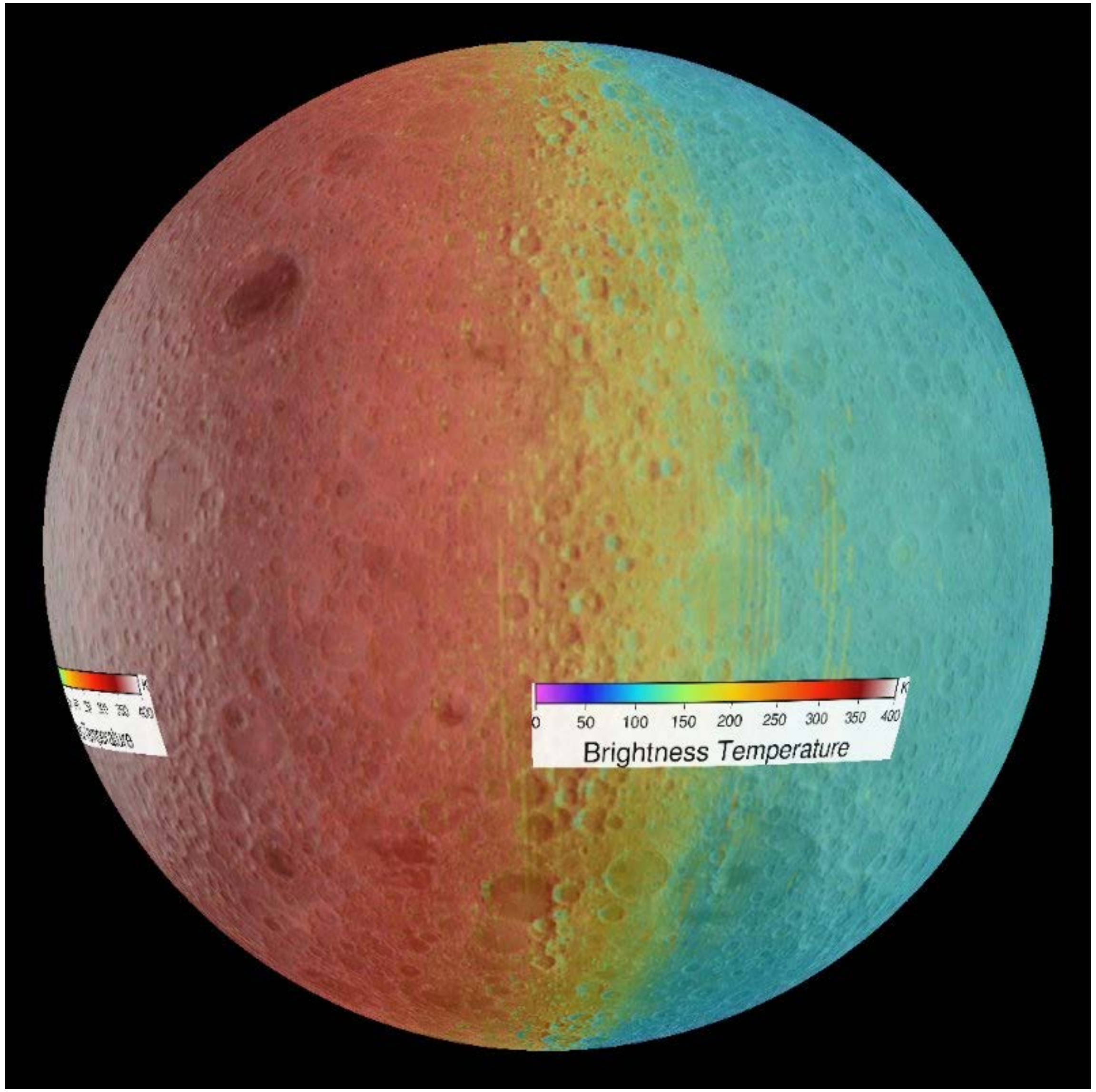


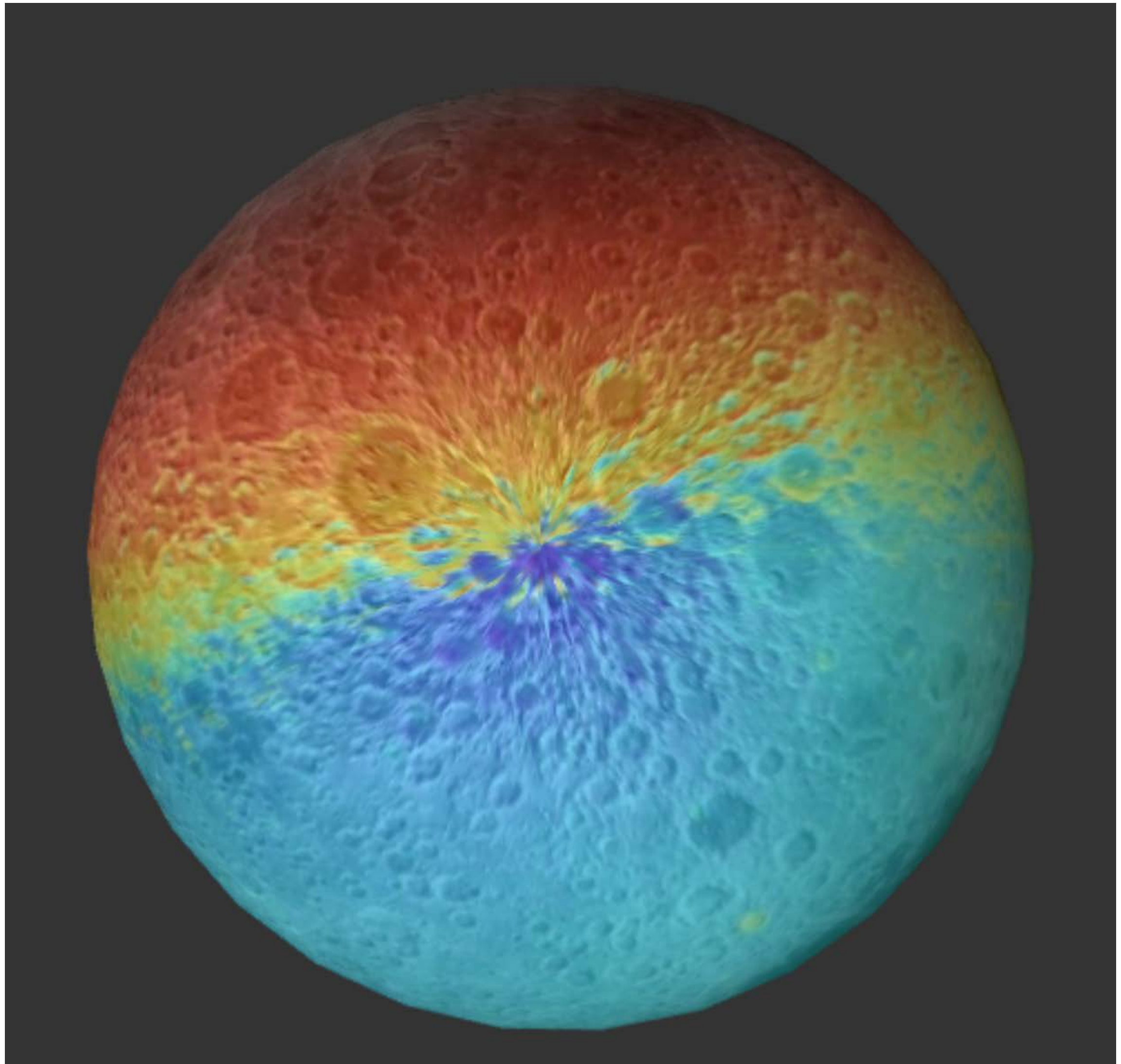
Stubbs et al. (2014) *Planet. Space Sci*. **90**, 10-27



NASA illustration

Thermal swings on the lunar surface are large





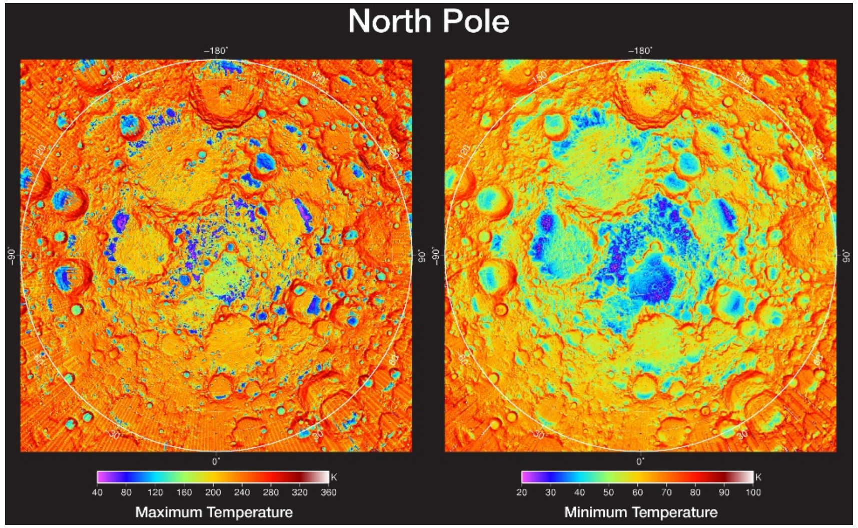
https://sos.noaa.gov/datasets/moon-surface-temperature/

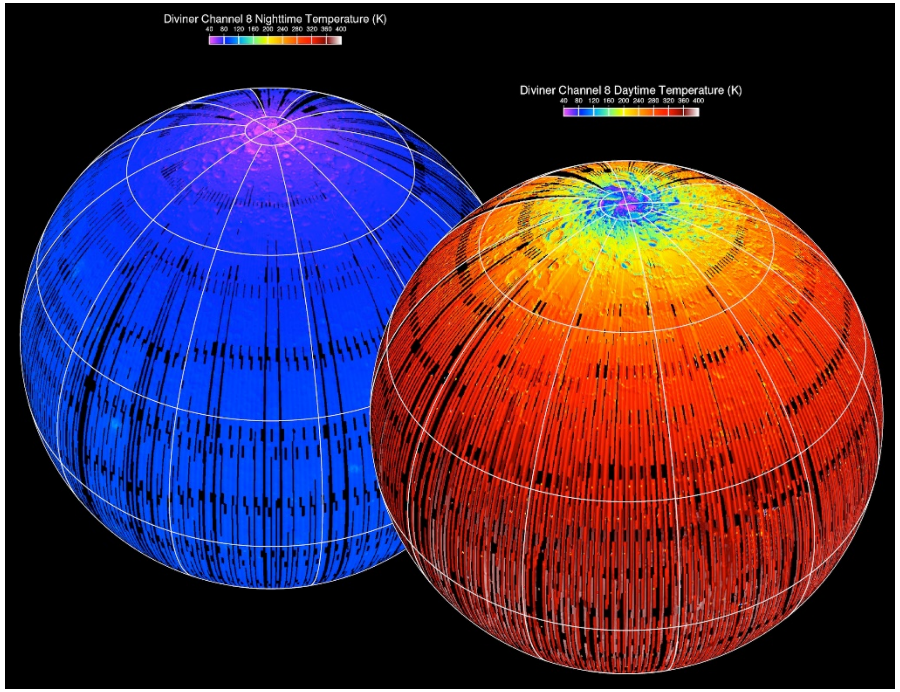
The Permanently Shadowed Regions (PSRs) are VERY cold

- Apollo 15
  - Day = 374K (101°C)
  - Night = 92K (-181°C)
- Apollo 17
  - Day = 410K (137°C)
  - Night = 103K (-170°C)

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

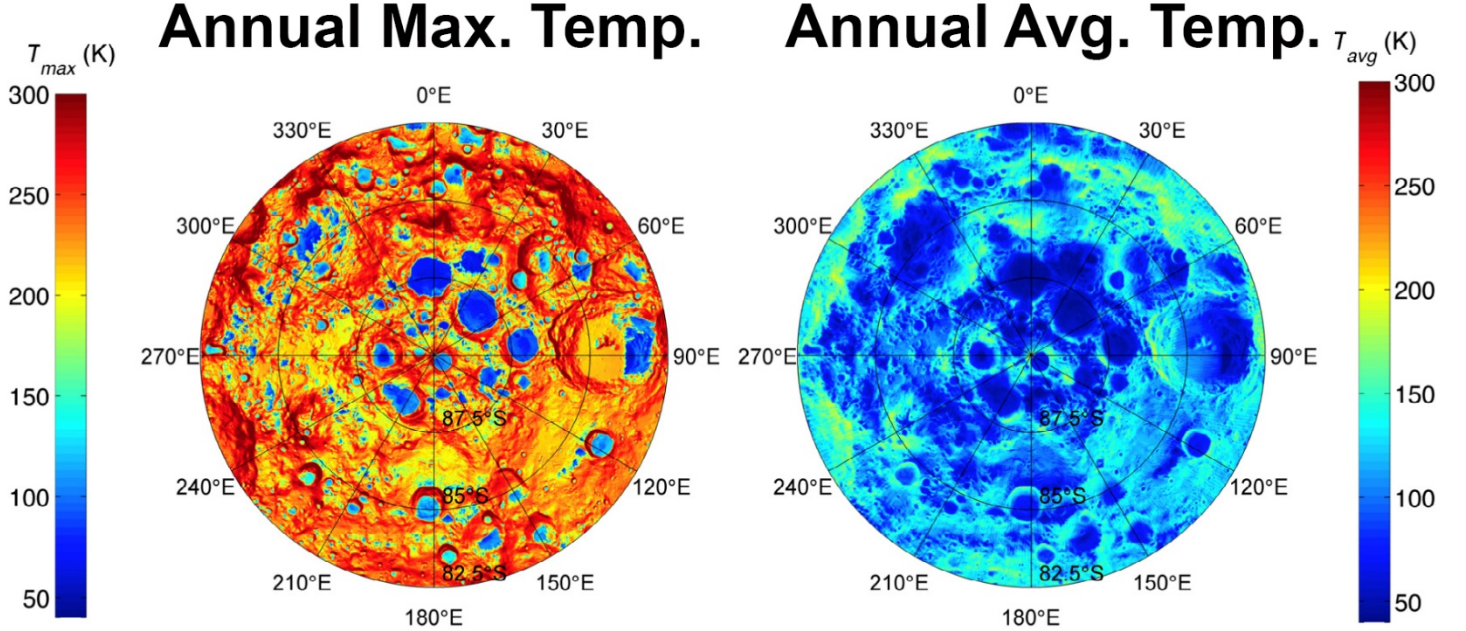
- Diviner (LRO)
  - Ridge = up to 300K (27°C) or over (388K, 115°C)
  - PSR = as low as 25K (-248°C) (average 40K, -233°C)





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

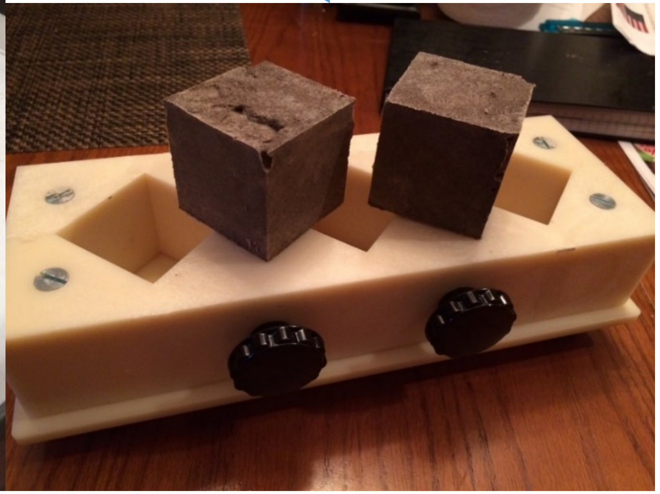
Hayne et al. (2015) *Icarus* **255**, 58-69

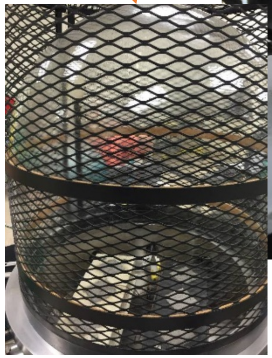


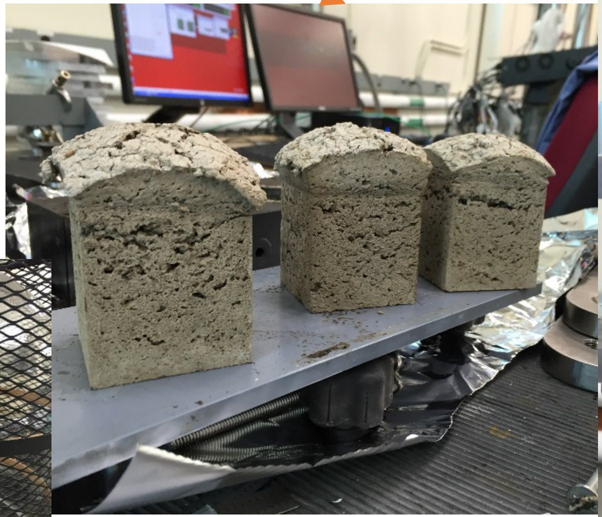
Surface pressure can have a large effect due to material vapor pressure

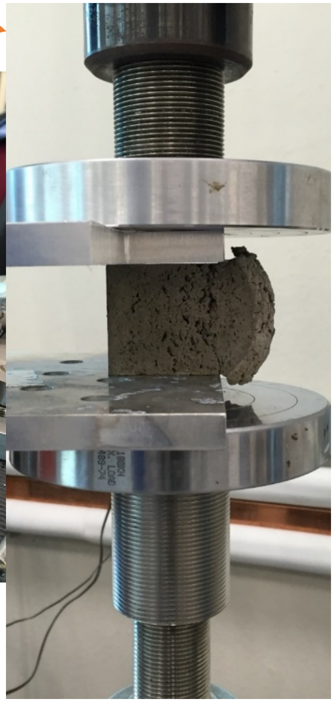
Earth	Mars	Moon
760 Torr	3-6.8 Torr	10^{-10} to 10^{-12} Torr

?









Through the Yet2 search company, NASA released a list of desired material attributes to the public for crowdsourcing solutions in materials that will survive on the lunar surface

TechNeed

Overview:
NASA is seeking materials that can withstand the lunar surface environment. These materials will ideally be used for large structures, such as habitats, but are not limited to these applications. Materials made from locally sourced constituents (e.g. lunar dust/regolith, crewed mission waste) are of highest interest.

Background:
NASA is working to establish a permanent human presence on the Moon within the next decade to uncover new scientific discoveries and lay the foundation for private companies to build a lunar economy. In order to build infrastructure elements on the lunar surface, it is important to identify materials that are capable of withstanding the lunar surface environment. Therefore, NASA is seeking materials suitable for use in the lunar environment that are:

1. Able to survive the lunar environment
2. Can be made from locally sourced materials. The bulk chemical composition of lunar regolith/dust varies across the lunar surface, but is about 50% SiO_2, 15% Al_2O_3, 10% CaO, 10% MgO, 5% TiO_2 and 5-15% iron with lesser amounts of sodium, potassium, chromium, and zirconium. Other materials, such as crewed mission waste, could also be used.

Constraints:
Required material attributes:

- Capable of tolerating thermal shocks/large temperature swings (ΔT = ~400°C)
- Low coefficient of thermal expansion (less than 20x10^-6/°C)
- Materials will ideally be made from locally sourced constituents (e.g. lunar dust/regolith, mission waste)

Desired material attributes:

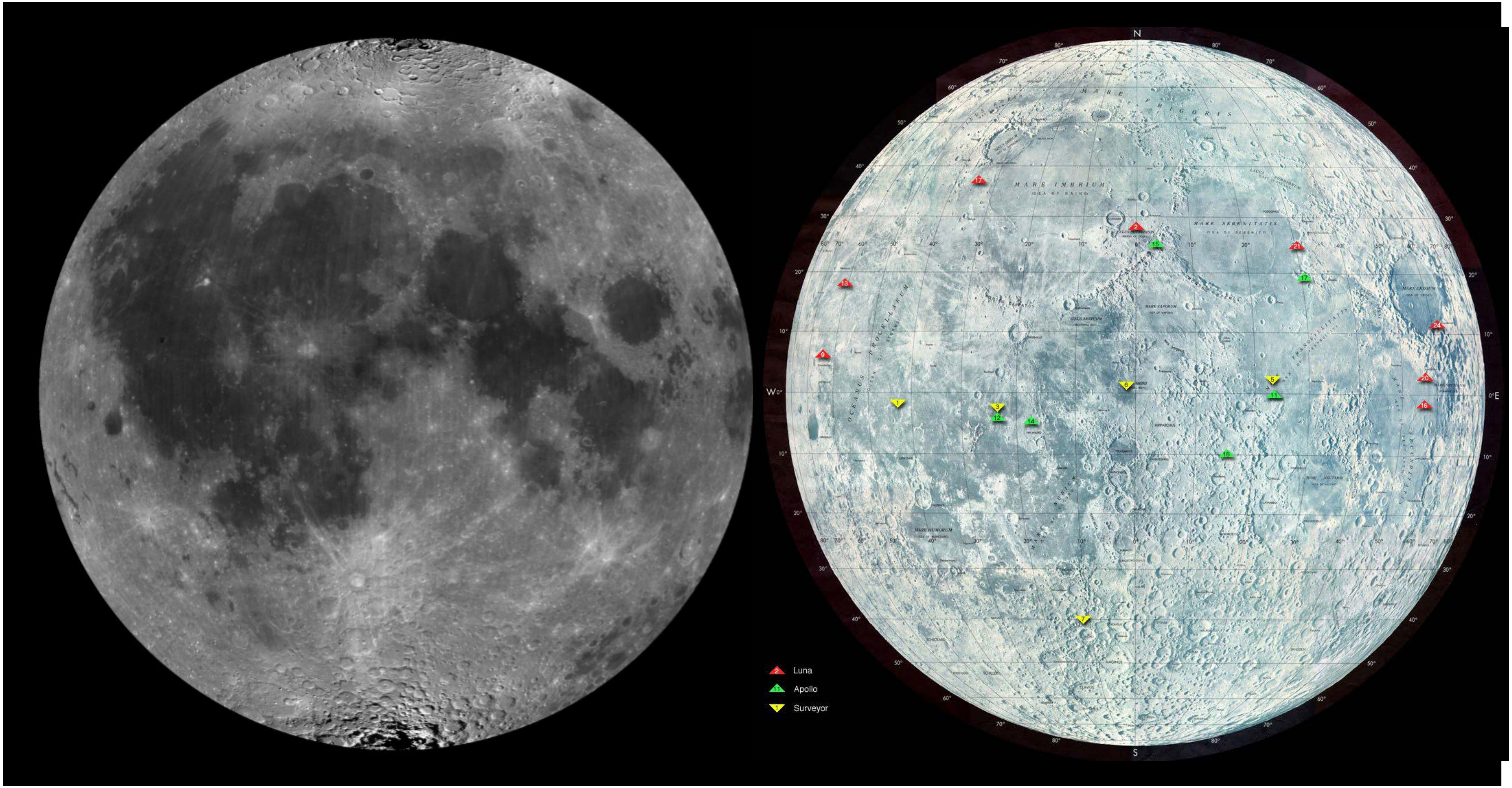
- Able to dissipate heat and accommodate the lack of atmospheric convective heat transfer
- Resistant to micrometeorite impact (i.e. cannot shatter)
- Resistant to multiple forms of radiation (solar wind and galactic cosmic ray bombardment)
- Materials do not need to be made of the same composition throughout
- Can be readily repaired (self-healing is ideal)
- Non-toxic if humans are exposed to it (or human byproducts like oxygen, carbon dioxide, or water)
- 3000psi and above in compressive strength
- Resistance to “aging” in the lunar environment (degradation over time due to exposure to the thermal environment, radiation (including UV light), dust, etc.)
- Prevents the growth of microbes/bacteria
- Ideally able to accommodate small changes in the chemistry of the local feedstock material

Possible Solution Areas:

- Materials for extreme environments (i.e. oil and gas, industry, aerospace, etc.)
- Metal alloys
- Recyclable materials
- Highly durable ceramics

Field of use and intended applications:
Establish sustainable infrastructure for permanent human presence on the Moon.

Apollo, Lunokhod, and Surveyor missions provided us with ground truth on the makeup of the lunar surface, but only on the near side and in equatorial regions

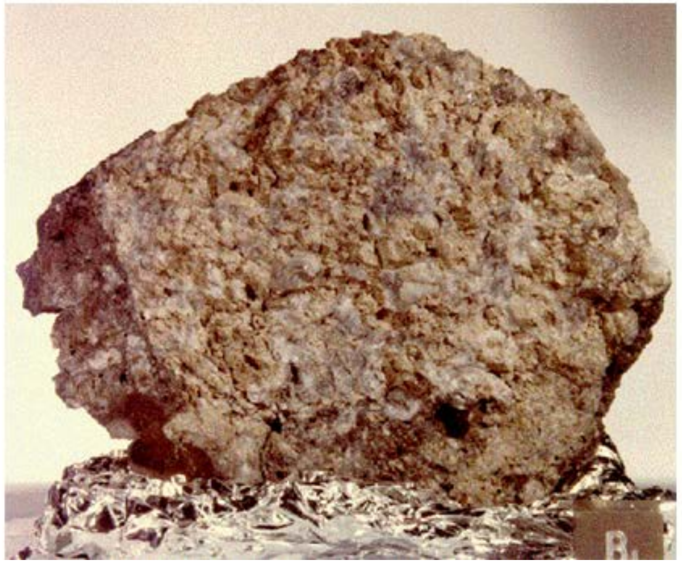


The missions found rock types that we can find on Earth

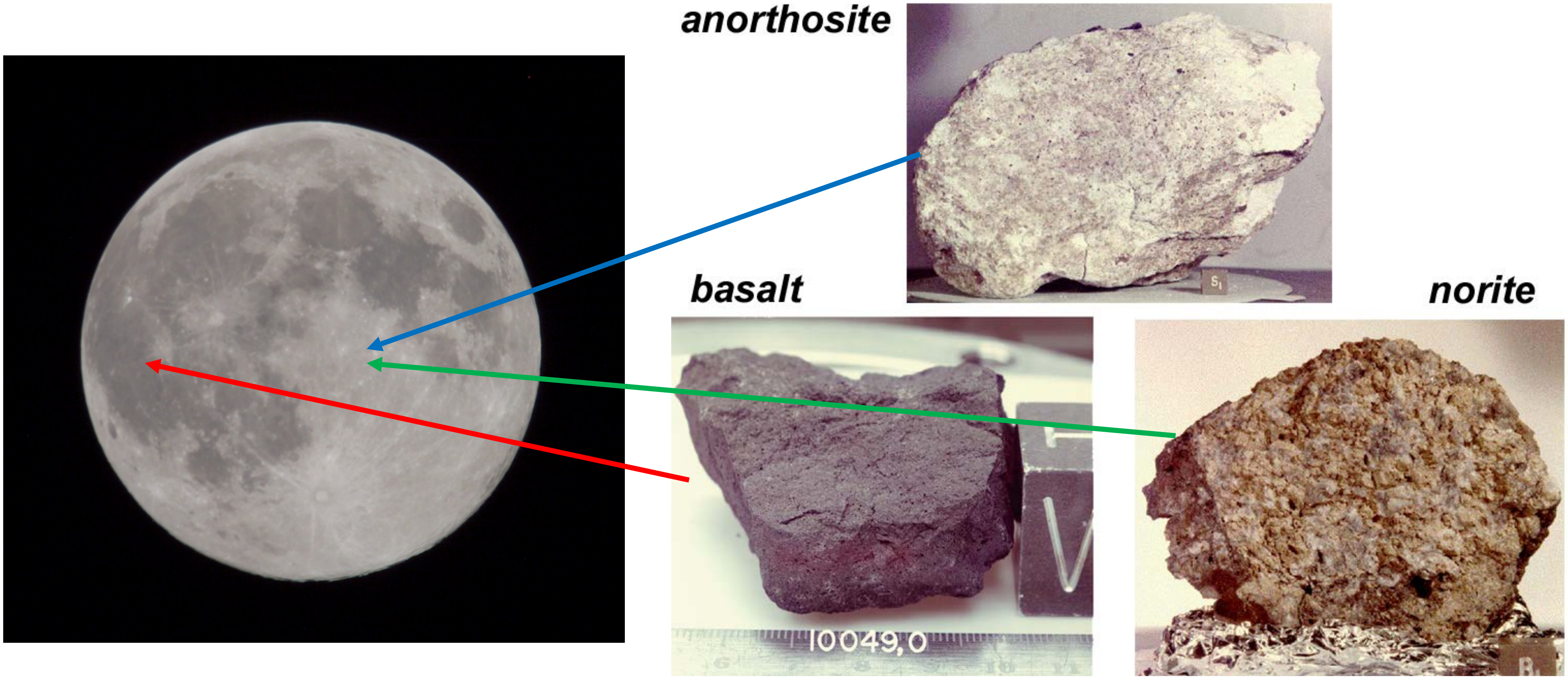
anorthosite

basalt

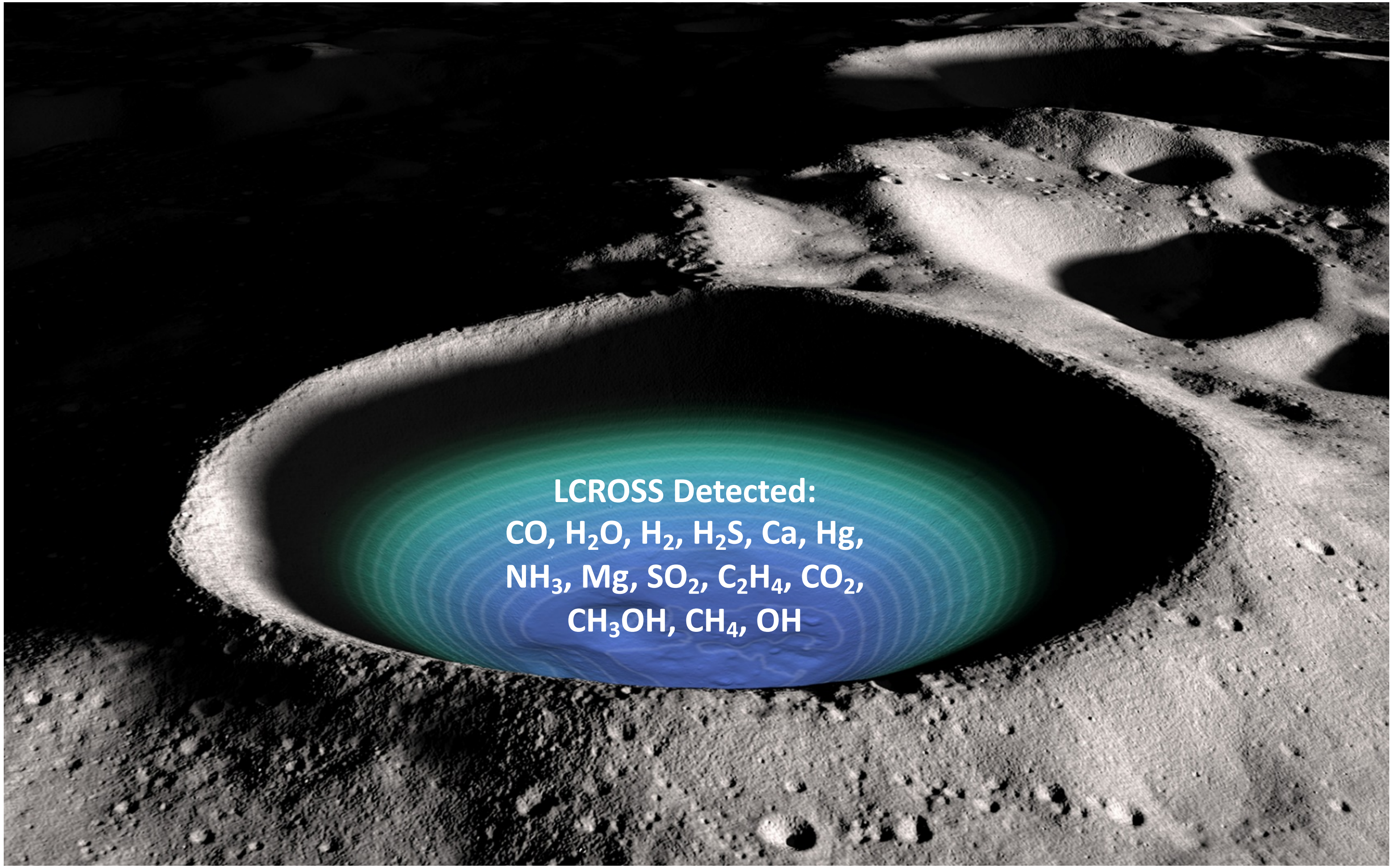
norite



The missions found rock types that we can find on Earth



The Lunar CRater Observation and Sensing Satellite (LCROSS) mission detected numerous volatiles, including water



Lunar **CR**ater **O**bservation and **S**ensing **S**atellite (2009)

There are many technologies that need to be matured to help with excavation and construction on the lunar surface

Excavation

Construction

Size Sorting

Conveyance

Autonomy/Telerobotics

Beneficiation

Mobility

Materials Processing

Robotics

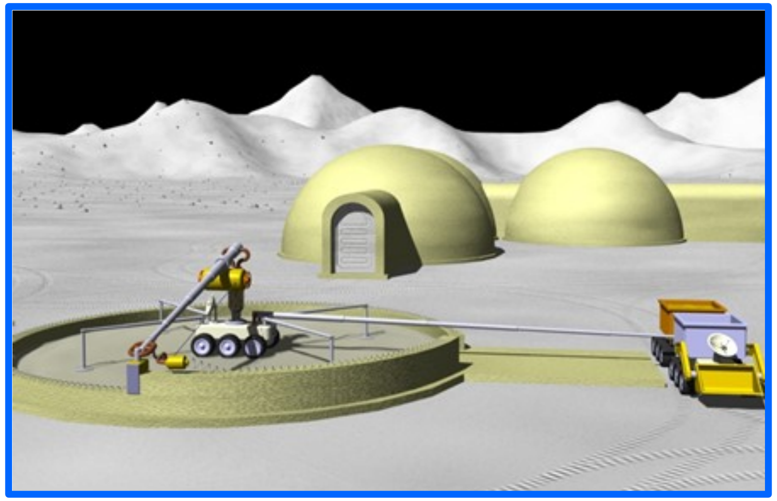
Geolocation

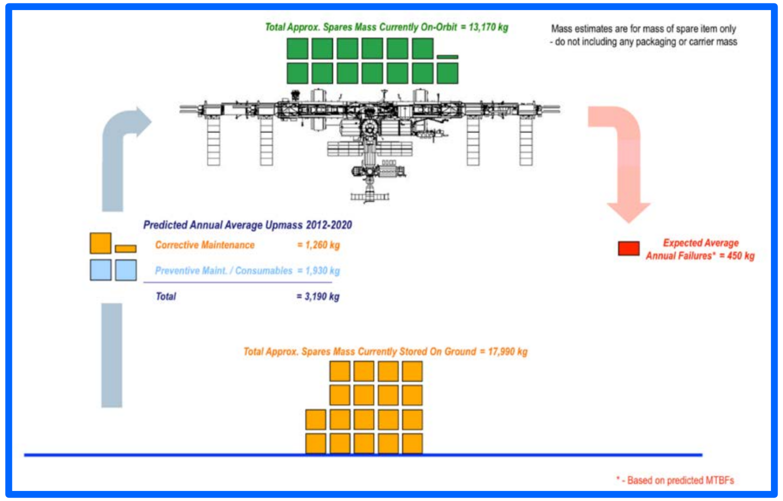
Etcetera

There are many benefits to excavation and construction on the Moon

ISRU and Sue's Car

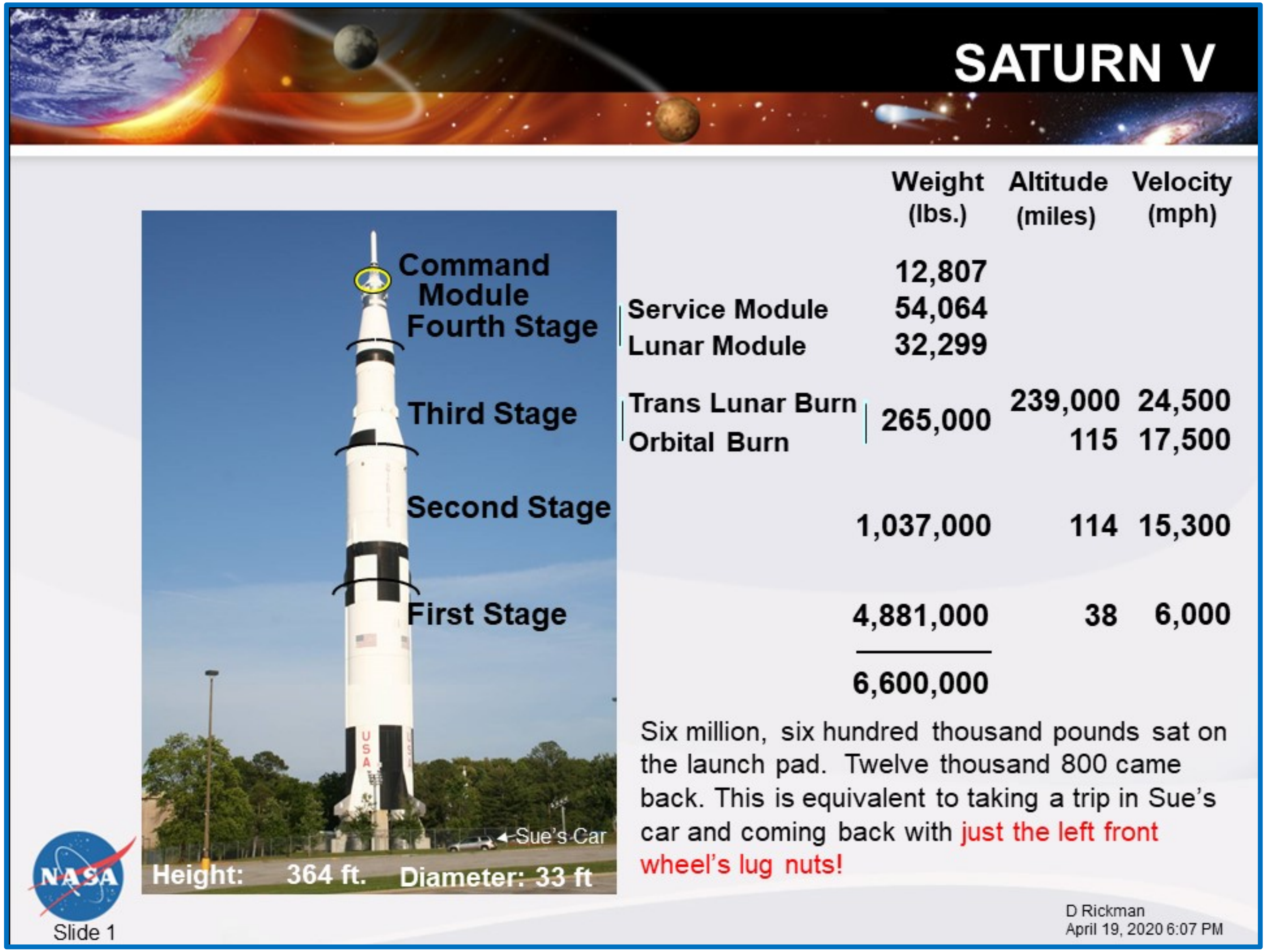
Sustainable Human Presence on the Lunar Surface



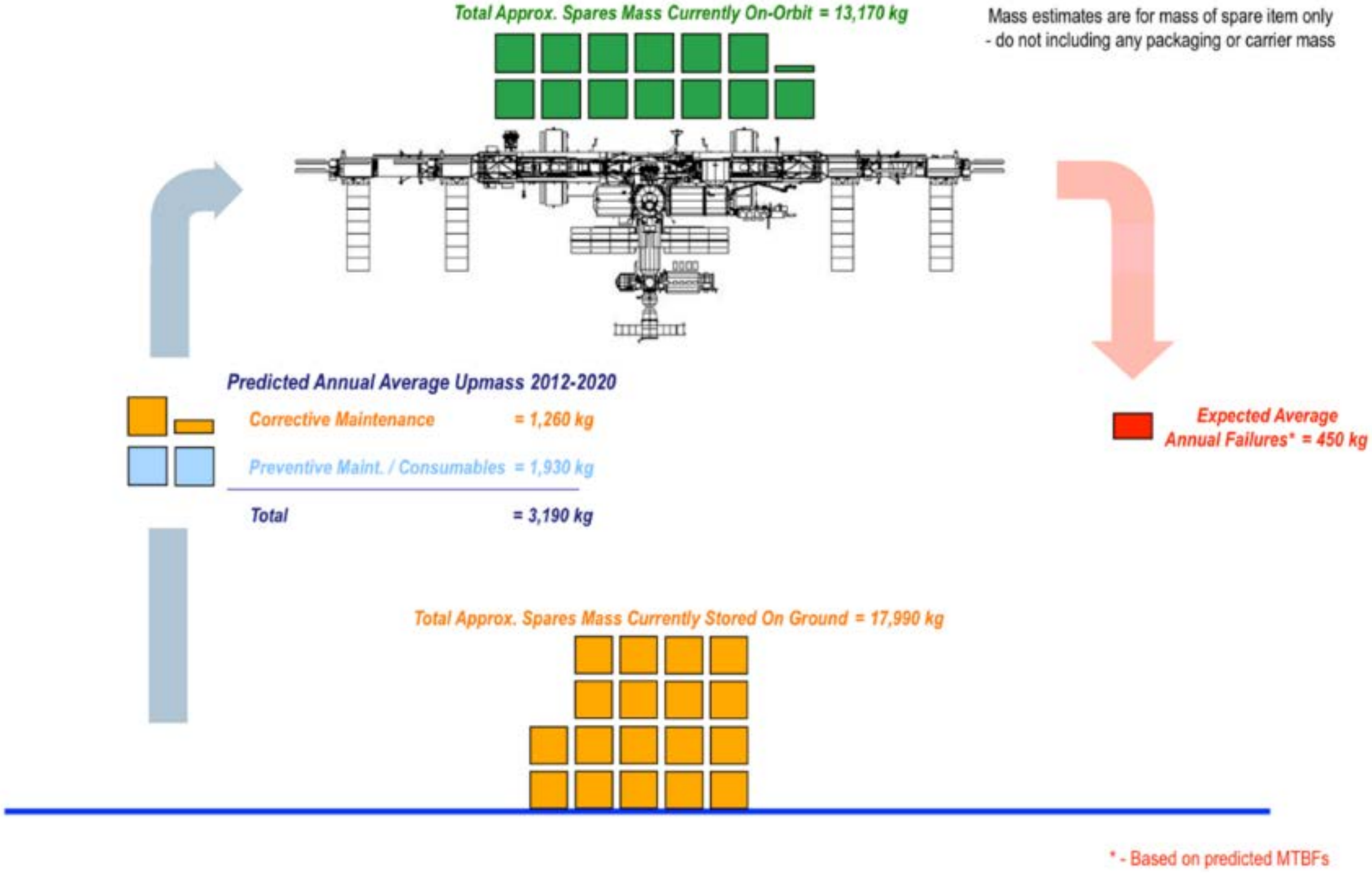


Changing the ORU Paradigm

It takes a great amount of fuel to get out of Earth's gravity well, and at great expense, so it is important to launch only what is required to originate on Earth



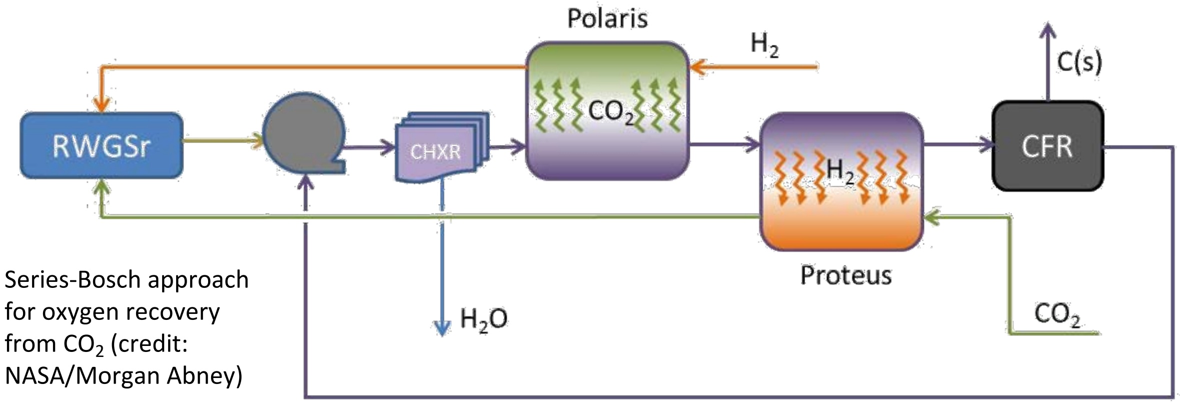
Each square represents 1000 kg



- Based on historical data, 95% of spares will never be used
- Impossible to know which spares will be needed
- Unanticipated system issues always appear, even after years of testing and operations

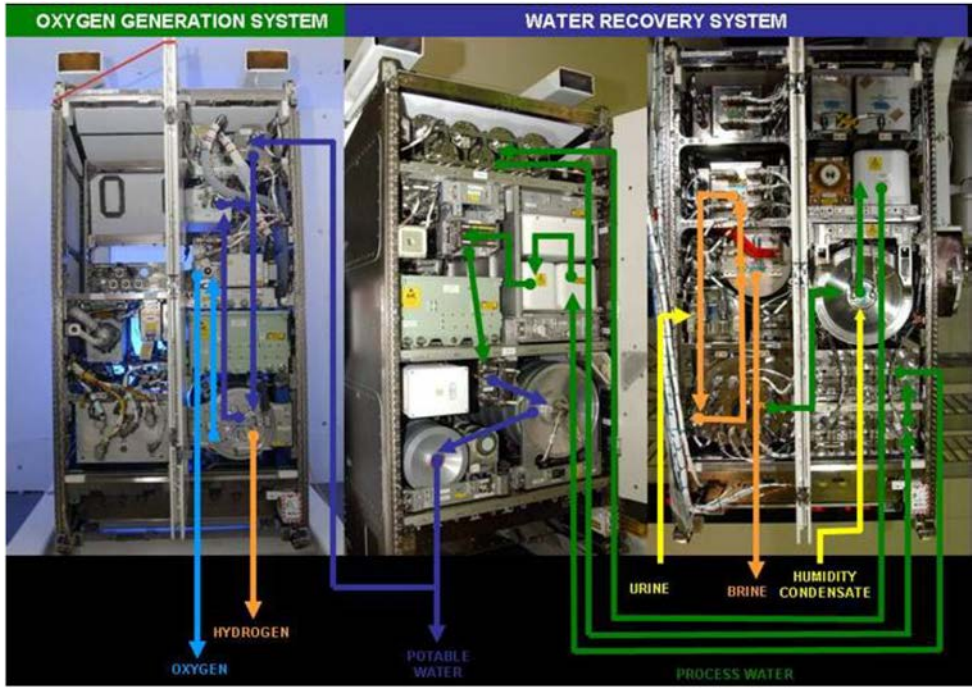
Image credit: Bill Cirillo (LaRC) and Andrew Owens (MIT)

In-situ resources on the International Space Station (ISS) include Environmental Control and Life Support System (ECLSS) carbon, waste/trash, and used parts

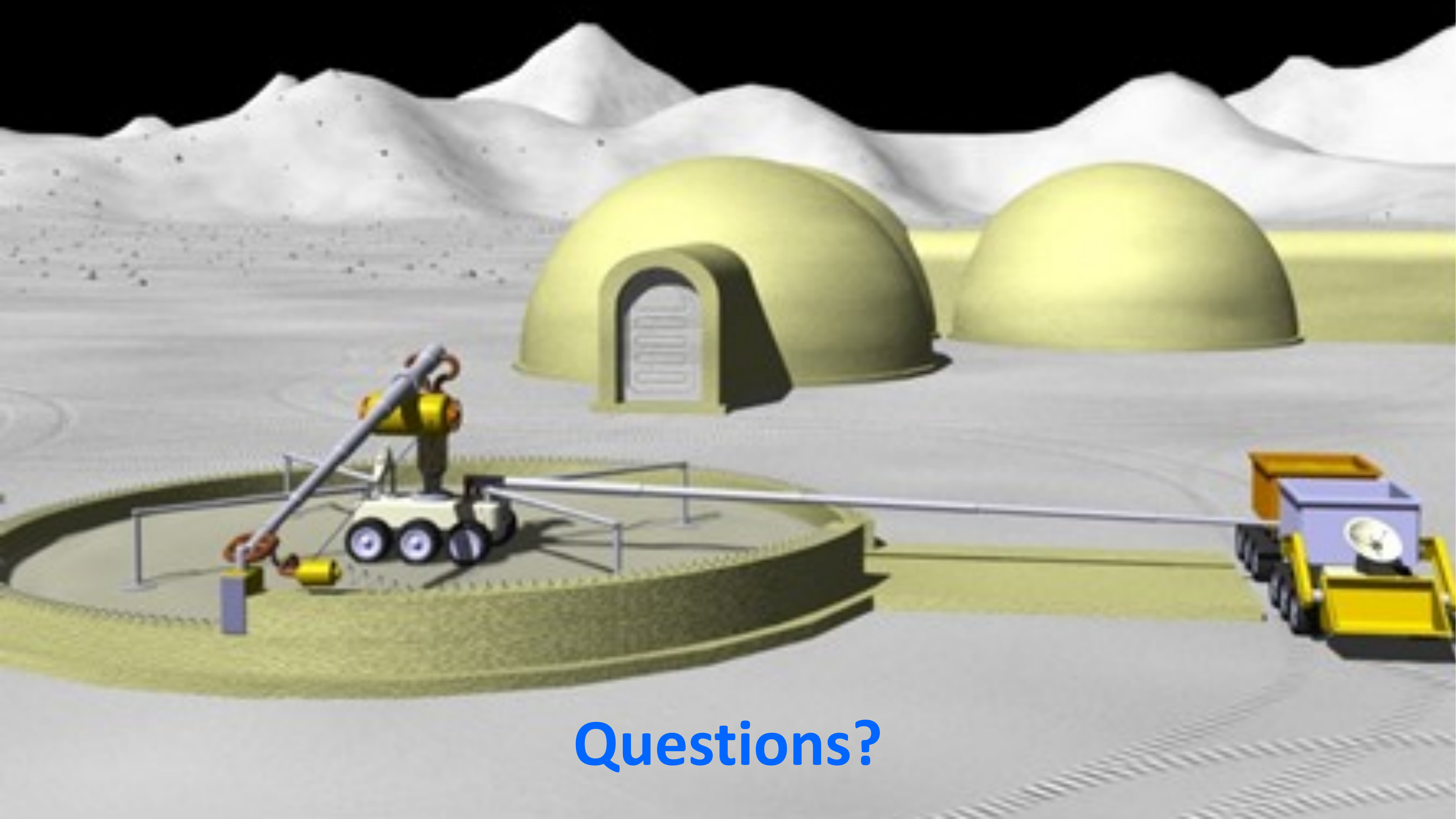


Series-Bosch approach for oxygen recovery from CO_2 (credit: NASA/Morgan Abney)

ISS crewmember Mike Fossum holding a "trash football". Currently all waste on ISS is downmassed via Cygnus. (credit: NASA)



Oxygen and water recovery systems on the ISS are based on Orbital Replacement Units (ORUs) (credit: NASA/Layne Carter)



Questions?