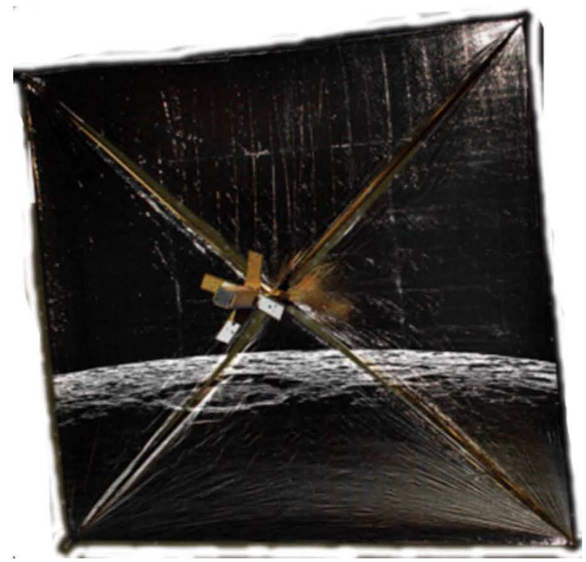
Lunar Flashlight: Mapping Lunar Surface Volatiles Using a Cubesat



Barbara Cohen, MSFC

Paul Hayne, Ben Greenhagen, JPL

David Paige, UCLA

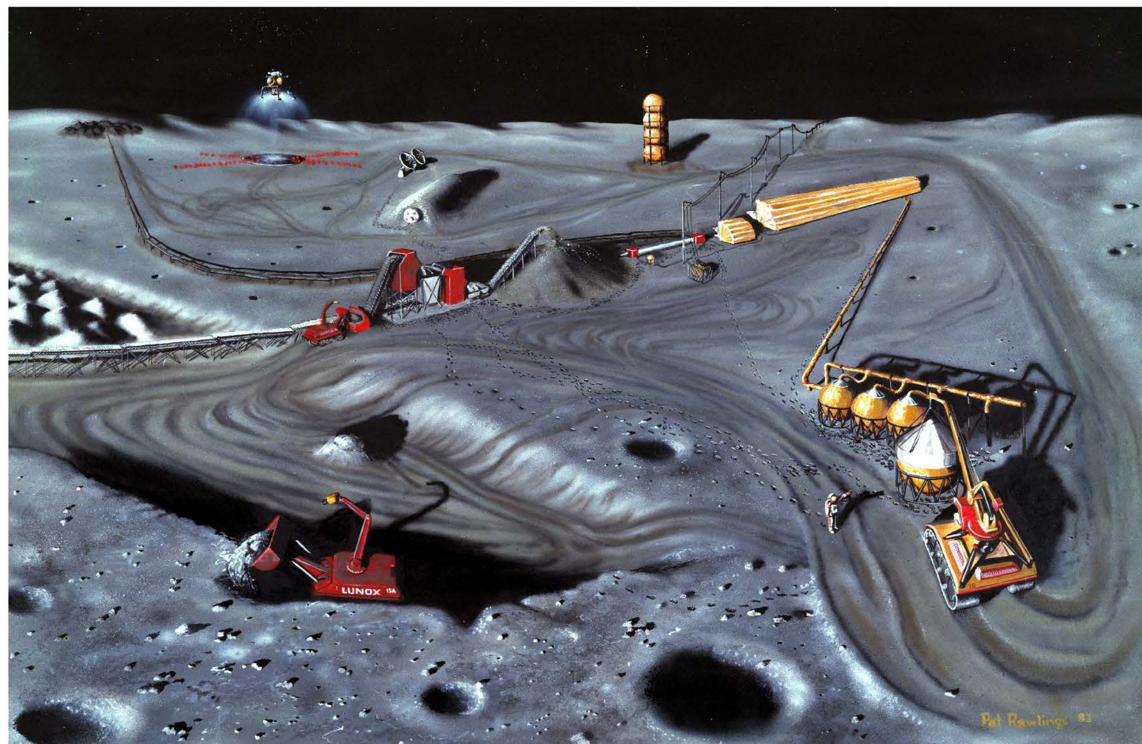
EM-1 Secondary Selection

- 19 NASA center-led concepts were evaluated and 3 were down-selected by the Advanced Exploration Systems (AES) program
- Primary selection criteria:
  - Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
  - Synergistic use of previously demonstrated technologies
  - Life-cycle cost and optimal use of available civil servant workforce
- Other secondary payloads will be added
  - NASA SMD and STMD may be interested
  - Possibly others – universities, research centers, etc?

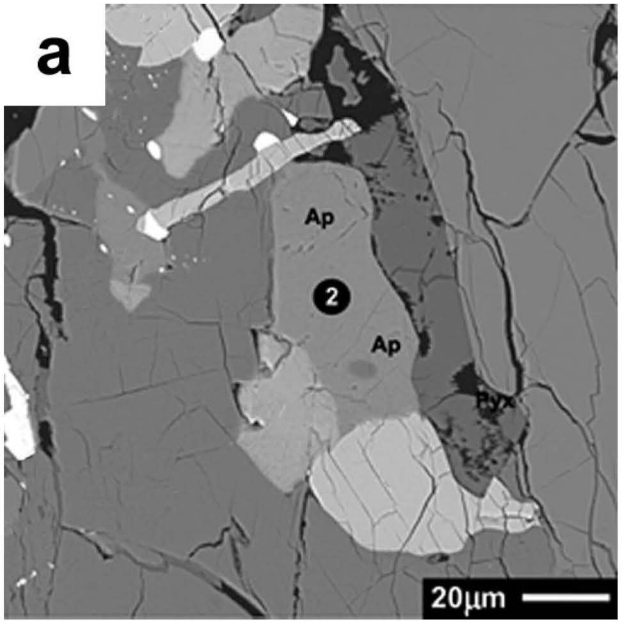
Payload *NASA Centers*	**Strategic Knowledge Gaps Addressed**	**Mission Concept**
BioSentinel ***ARC**/JSC* 	**Human health/performance in high-radiation space environments** • Fundamental effects on biological systems of ionizing radiation in space environments	Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth
Lunar Flashlight ***JPL**/MSFC/MHS* 	**Lunar resource potential** • Quantity and distribution of water and other volatiles in lunar cold traps	Locate ice deposits in the Moon's permanently shadowed craters
Near Earth Asteroid (NEA) Scout ***MSFC**/JPL* 	**NEA Characterization** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Slow flyby/rendezvous and characterize one NEA in a way that is relevant to human exploration

Why look for water ice?

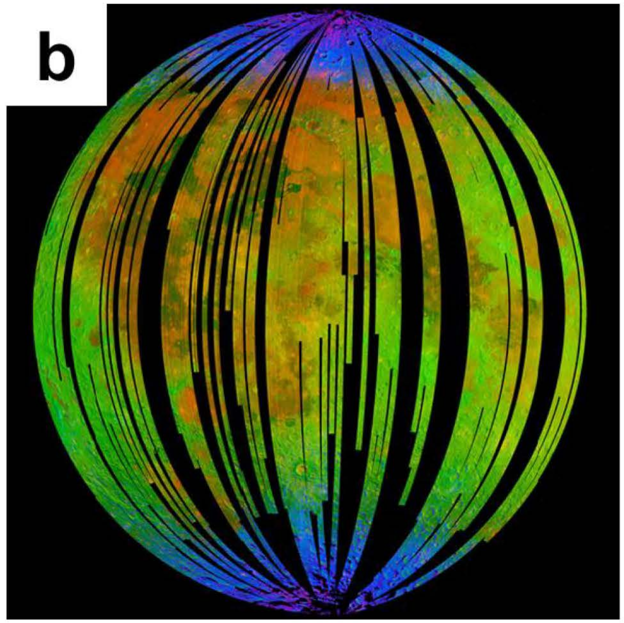
- The Moon is highly depleted in volatile compounds, especially water
- Humans exploring the Moon will need water:
  - Option 1: Carry it there. ↵ expensive (at $10K/lb, 1 gal H_2O=$80K)
  - Option 2: Use water that may be there already. ↵ “live off the land”
- Can mine O_2 from minerals and H from solar wind implantation, however, this is very energy intensive
- **Life would be much easier and cheaper if we could use H_2O from the Moon**
  - At the surface or near surface
  - In “operationally useful” quantities



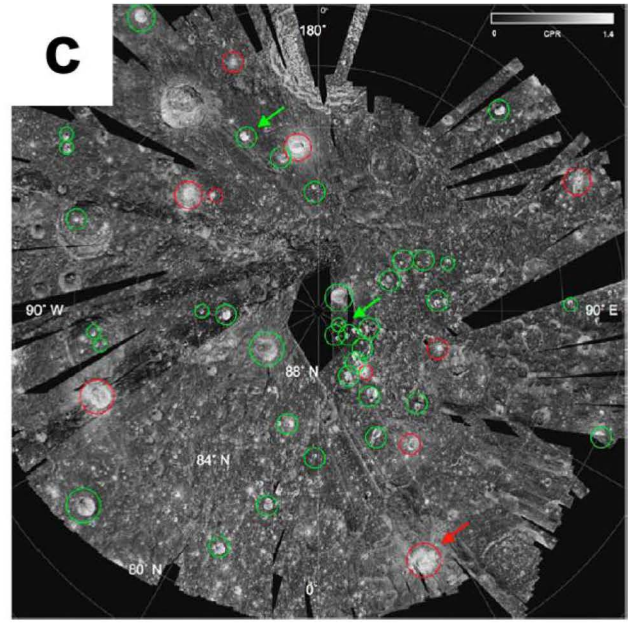
Water on the Moon



Magmatic samples contain trace amounts of water (5-1000 ppm) as part of the mineral structures (e.g., Saal et al. 2008; McCubbin et al. 2010, 2013). *Too little.*

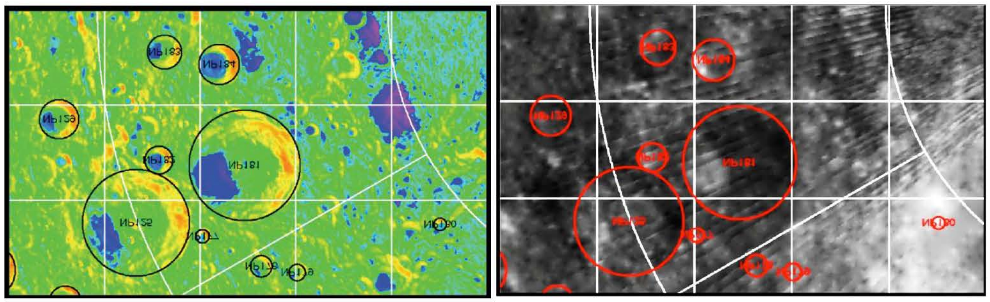


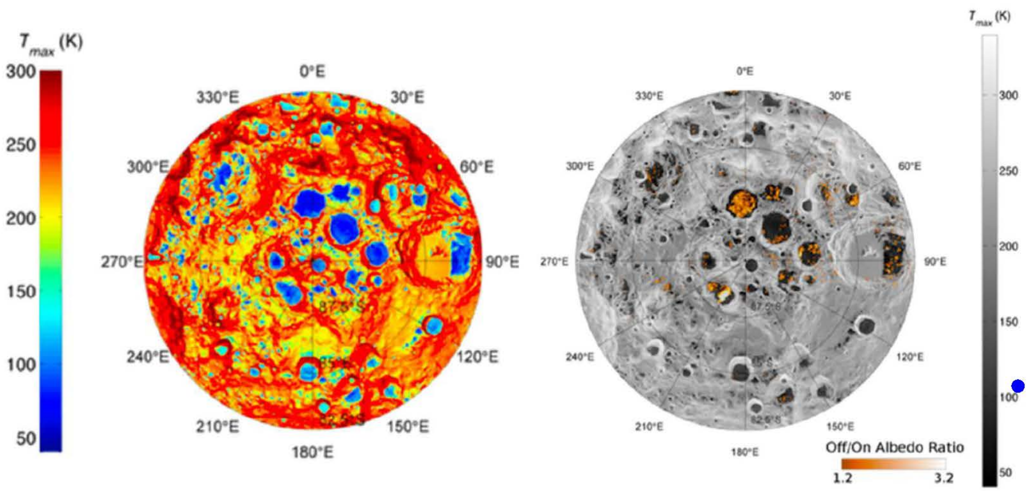
Trace H_2O and OH on the lunar surface near the poles, as a monolayer on lunar dust grains or bound into the mineral structures of surface materials (Pieters et al., 2009; Sunshine et al., 2009; Clark, 2009). *Too little.*



Multiple ground-based and space assets (Clementine, Lunar Prospector, LRO, LCROSS, Kaguya) have suggested water ice resides in permanently-shadowed regions (PSRs) at the lunar north and south poles. *Too deep.*

Lunar surface frost





- Locations where Diviner measures the coldest year-round temperatures also show high albedo in LOLA at 1.064 μm
  - most likely due to diminished effects of space weathering, but could be water ice in the upper regolith (Zuber et al., 2012)
  - If water ice frost, abundance of ~3-14% (Lucey et al. 2014)
  - or perhaps bright anorthosite (Haruyama et al., 2013)
- Ultraviolet albedo data from LAMP also show evidence for water ice at the lunar surface (Hayne et al. 2014), but are not yet definitive

What we need to know

Lunar Strategic Knowledge Gaps

I. Understand the lunar resource potential

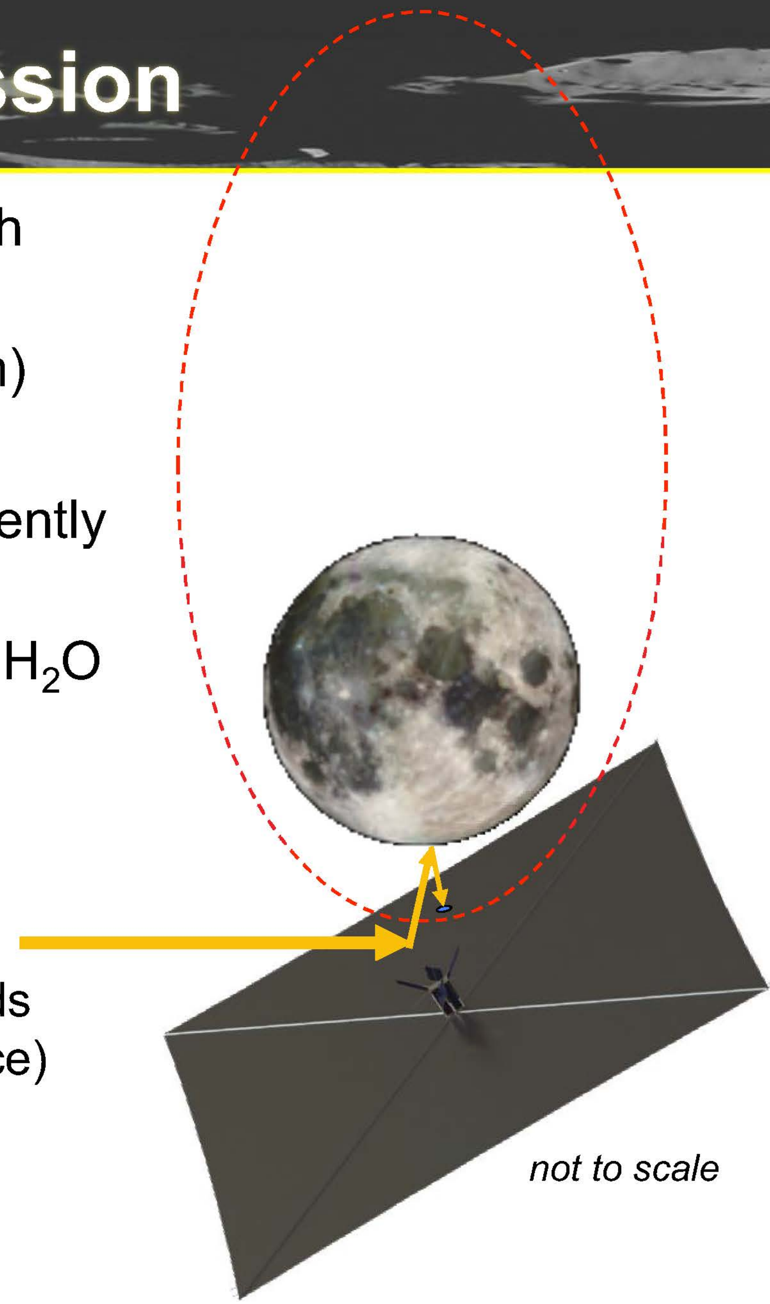
D. Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps.

Narrative: Required "ground truth" in-situ measurement within permanently shadowed lunar craters or other sites identified using LRO data. Technology development required for operating in extreme environments. Enables prospecting of lunar resources and ISRU. Relevant to Planetary Science Decadal survey.

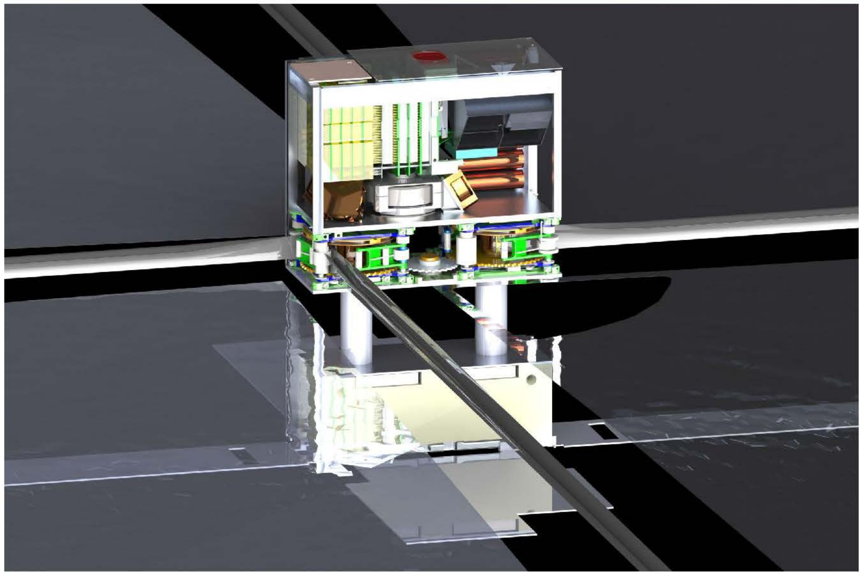
- Lunar Flashlight will illuminate permanently-shadowed and detect water ice absorption bands in the near-infrared – **Measurement goal**
- By repeating this measurement over multiple points, Lunar Flashlight will create a map of surficial ice concentration that can be correlated to previous mission data and used to guide future missions **– Mapping goal**

The Lunar Flashlight mission

- Secondary payload on the Space Launch System test flight (EM1, 2018)
- 6U Cubesat (form factor 10 x 20 x 30 cm)
- Orbits the Moon
- ~80 m^2 sail reflects sunlight into permanently shadowed regions
- IR 4-band point spectrometer measures H_2O absorption & continuum
- Teaming: JPL & MSFC
  - MSFC Solar sail development expertise (NanoSail-D, Sunjammer, LightSail-1)
  - JPL CubeSat developments and standards (INSPIRE, university & industry experience)



LF Flight System Overview



Bus: JPL Deep Space NanoSat Bus (leveraging INSPIRE)

Propulsion: MSFC ~80 m^2 Solar Sail (based on NanoSail-D)

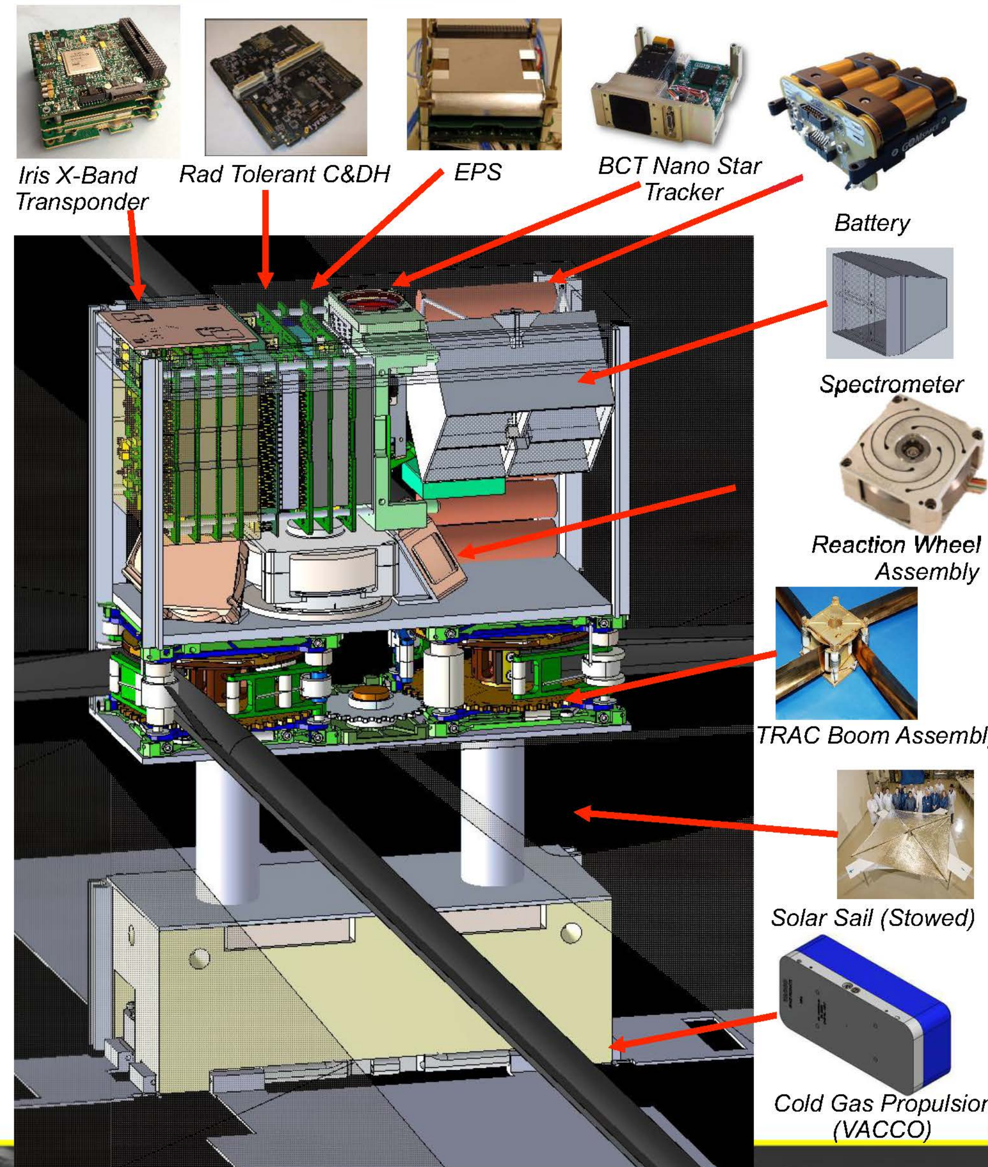
Payload: COTS 4-band spectrometer

C&DH: Rad Tolerant LEON-3 architecture, JPL Protos FSW

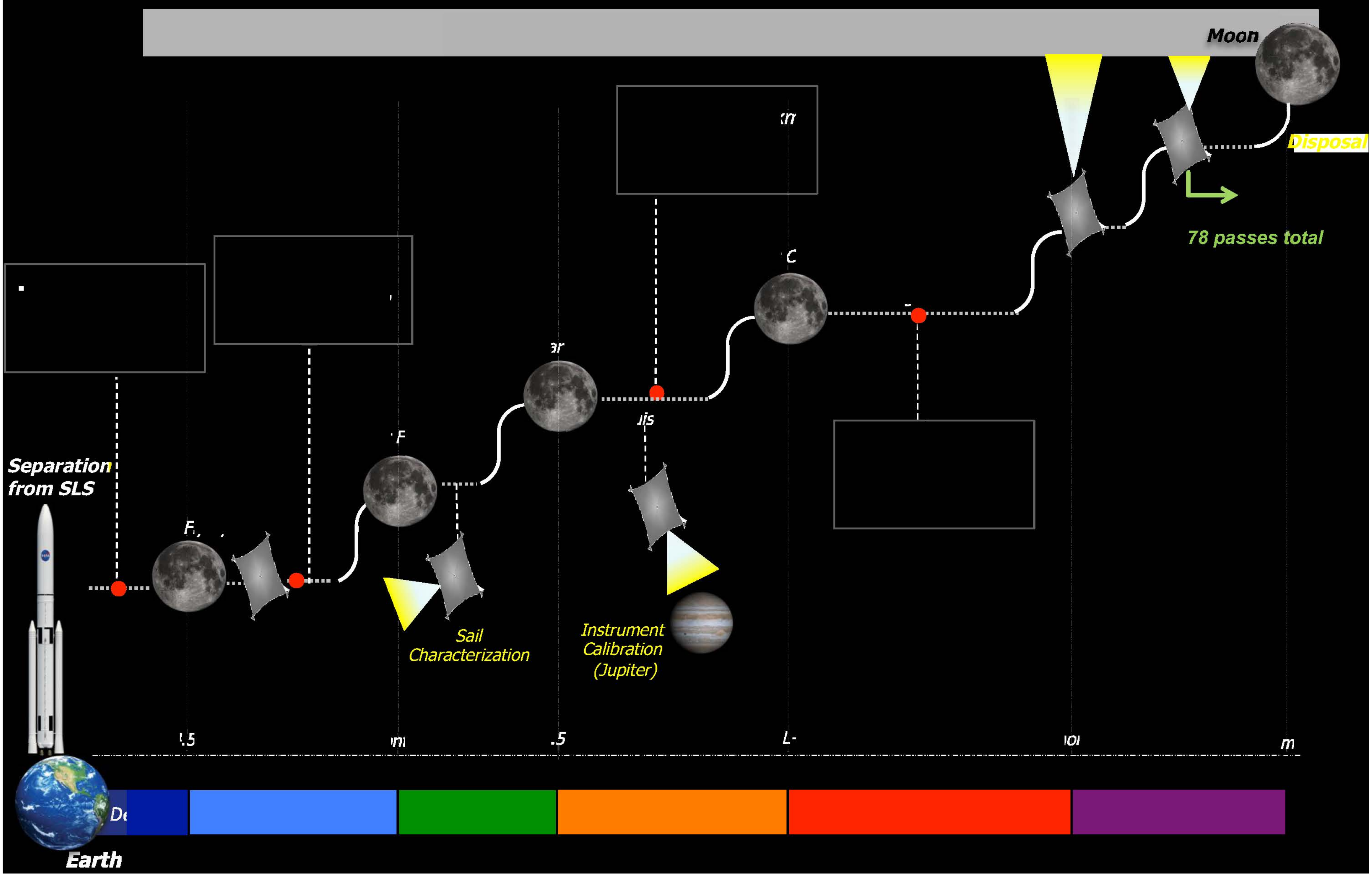
ADCS: COTS Cold Gas, RWA, SRU, IMU, CSS

Power: ~44W

Telecom: JPL Iris X-Band Transponder + Patch Antenna (~1 kbps nominal @ Lunar Distance with DSN State)

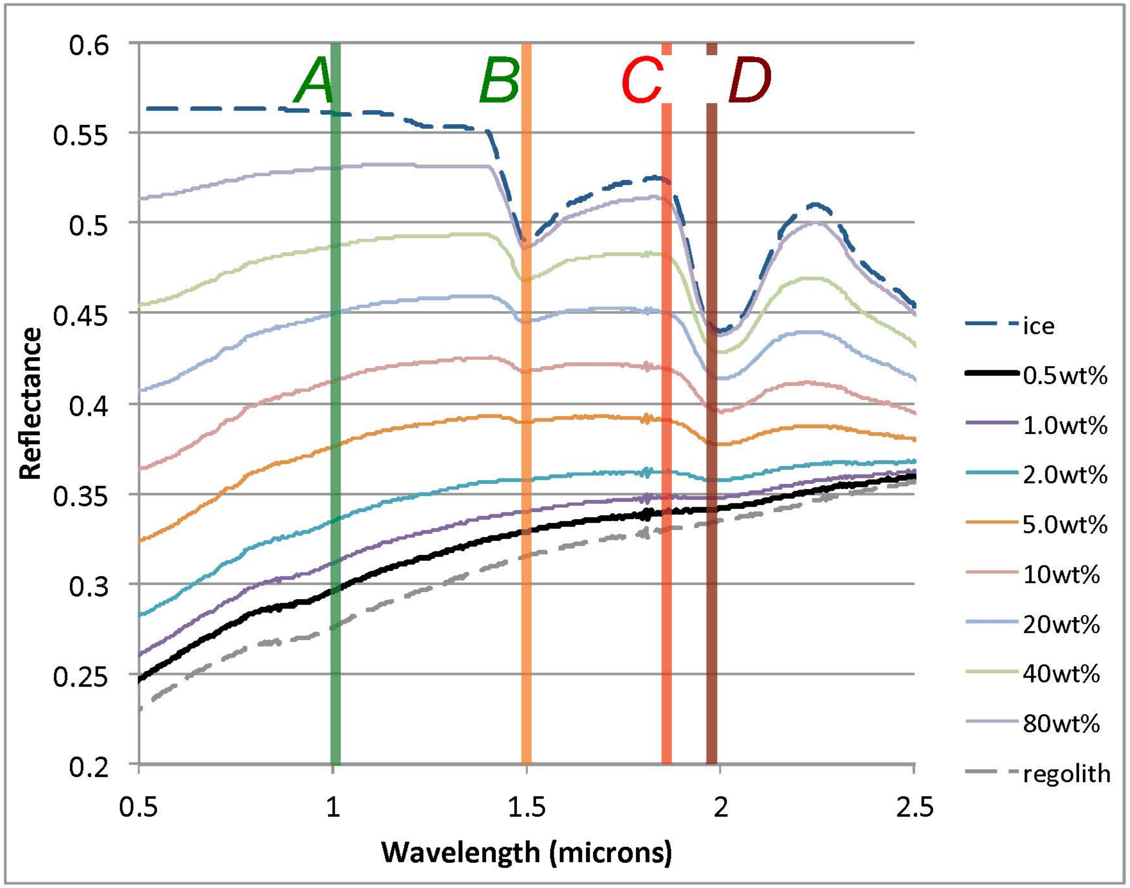


LF Concept of Operations



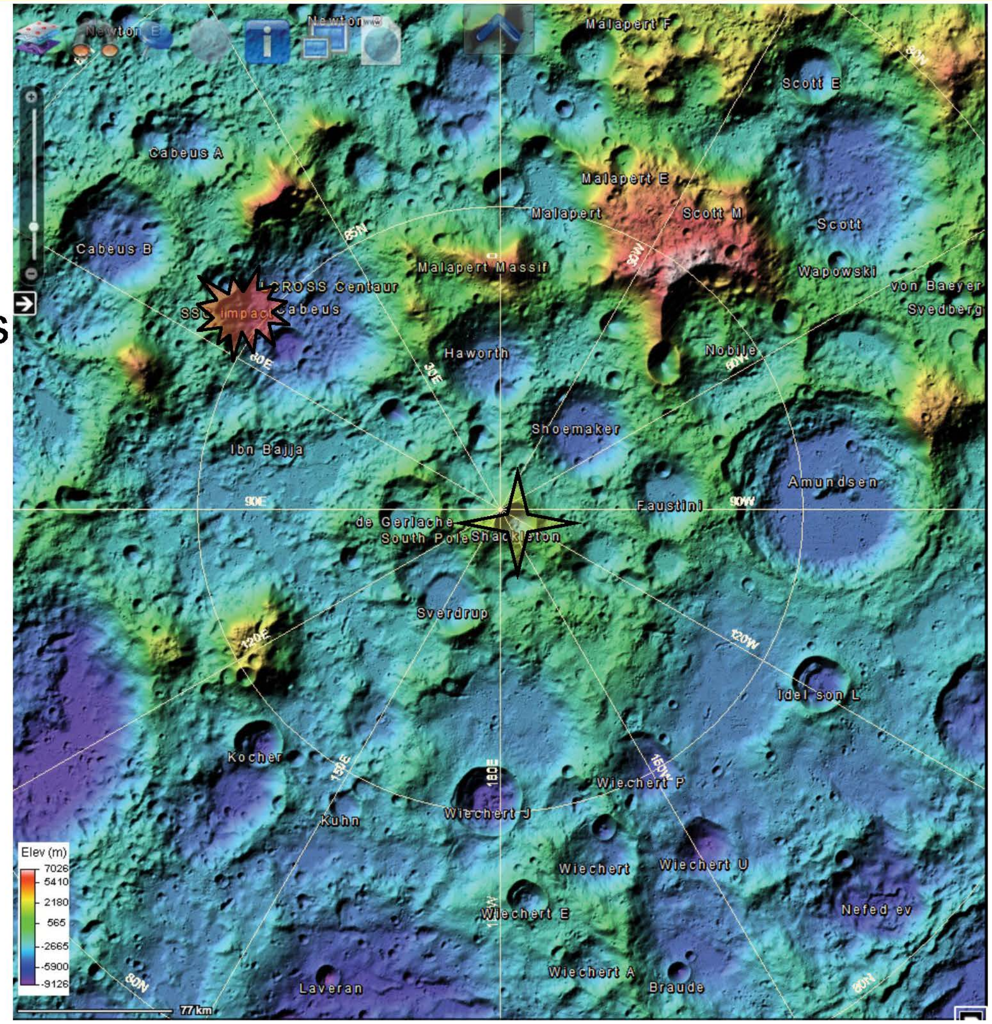
Objective 1: Measurement

- Reflectance spectroscopy is the standard technique for identifying molecular "fingerprints" from a distance
- Measure absorption and continuum to understand ice abundance



Objective 2: Mapping

- Measure water ice at multiple locations within PSRs at one pole at ~1-2 km footprint per spot
- This is an *operationally useful* scale for future landers and rovers
- Enables prediction of other ice deposits by correlating data with other mapped geologic characteristics, including latitude, temperature, topography, lighting, proximity to young fresh craters, etc.



LOLA topographic map for the South Polar region from 80S showing large craters and PSRs

Lunar Flashlight summary

- Cost-constrained Cubesat+ (nanosat) mission to detect and map lunar surface ice in permanently-shadowed regions of the lunar south pole
- Furthering the maturity of CubeSats
  - Long-lived CubeSat bus for deep space missions (C&DH, EPS, ADCS, Deep Space Transponder)
  - Further characterization of deep space environment effects on CubeSats (building on INSPIRE)
  - Mature CubeSat Solar Sail propulsion
- Future potential of small missions for science & exploration
  - Part of 1st generation of cubesat-style planetary missions to conduct real science measurements
  - Secondary spacecraft hosted on interplanetary missions