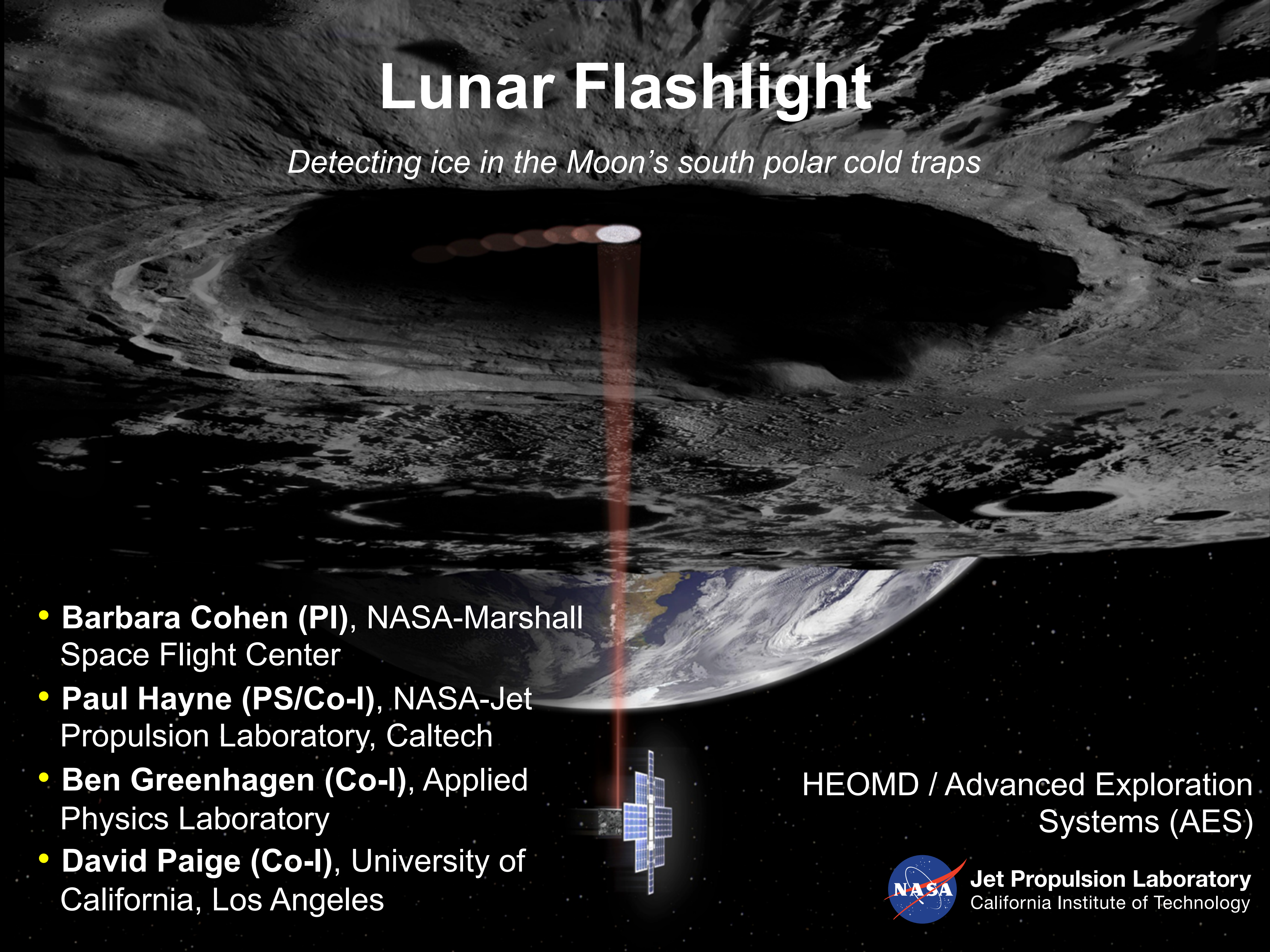

Lunar Flashlight

Detecting ice in the Moon's south polar cold traps

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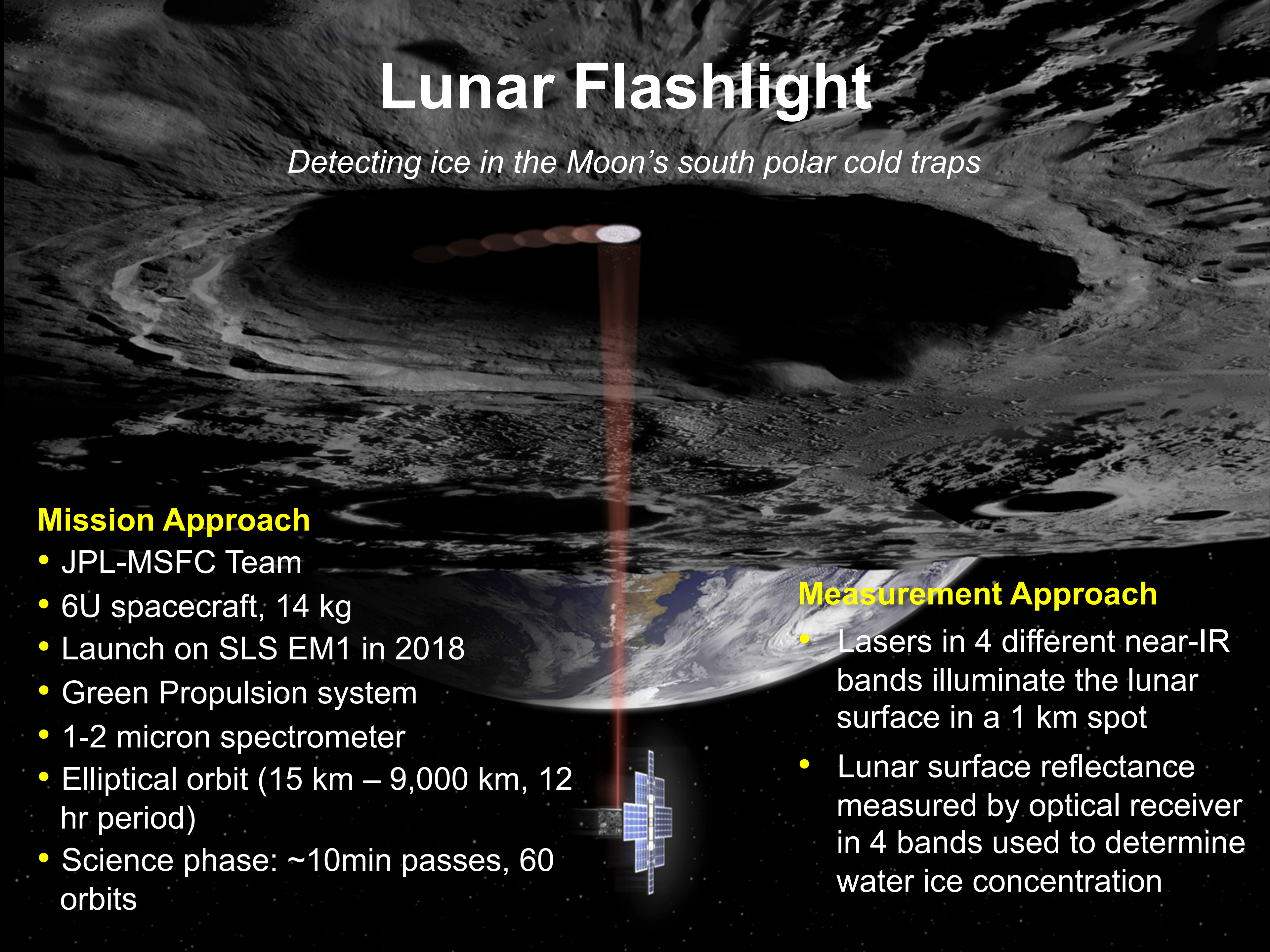
HEOMD / Advanced Exploration Systems (AES)

Jet Propulsion Laboratory
California Institute of Technology



Lunar Flashlight
Detecting ice in the Moon's south polar cold traps
Mission Approach
• JPL-MSFC Team
• 6U spacecraft, 14 kg
• Launch on SLS EM1 in 2018
• Green Propulsion system
• 1-2 micron spectrometer
• Elliptical orbit (15 km – 9,000 km, 12 hr period)
• Science phase: ~10min passes, 60 orbits
Measurement Approach
• Lasers in 4 different near-IR bands illuminate the lunar surface in a 1 km spot
• Lunar surface reflectance measured by optical receiver in 4 bands used to determine water ice concentration

Objectives and Priorities

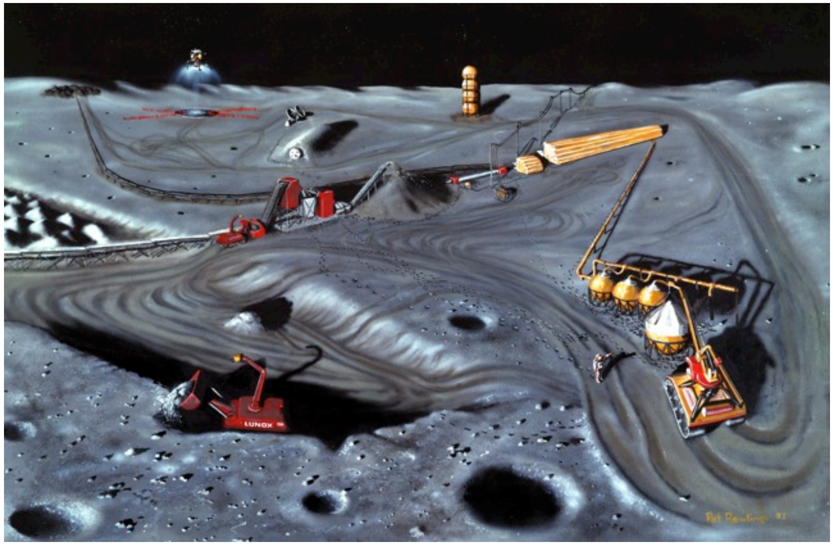
***LUNAR FLASHLIGHT* SHALL DEMONSTRATE THE CAPABILITY TO LOCATE SURFACE ICE DEPOSITS IN THE MOON'S PERMANENTLY SHADOWED CRATERS**

- Full Success Criteria: Identify and map the concentration of surface water ice within the permanently shadowed regions of the lunar south pole
- Minimum Success Criteria: Determine the presence or absence of surface water ice in the permanently shadowed regions of the lunar south pole
- Rationale: This requirement addresses Strategic Knowledge Gap (SKG) 1D, to understand the composition, quantity, distribution, and form of water and other volatiles associated with lunar cold traps. The data obtained will guide landing site selection for future *in situ* resource utilization by robotic and human missions.

Rationale and Context

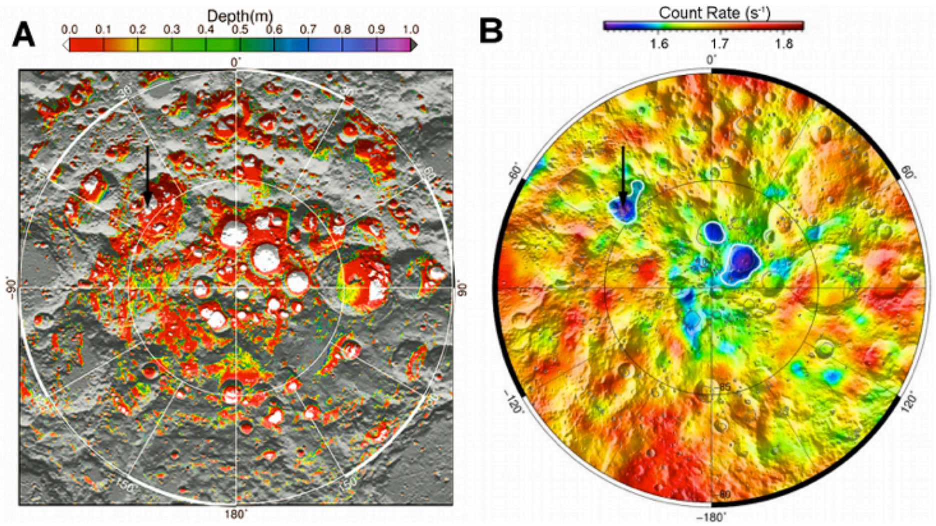
- The Moon is highly depleted in volatile compounds, especially water
- Humans exploring the Moon will need water:
  - Option 1: Carry it there. ← expensive (at $10K/lb, 1 gal H_2O=$80K)
  - Option 2: Use water that may be there already. ← “live off the land”
- Can mine O_2 from minerals and H from solar wind implantation → very energy intensive

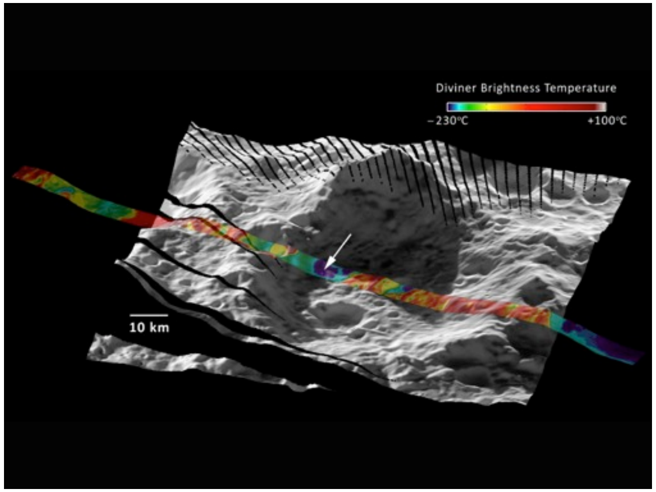
- **Life would be much easier and cheaper if we could just find H_2O on the Moon**
  - At the surface or near surface
  - In “operationally useful” quantities, **> 0.5wt%**



Rationale and Context

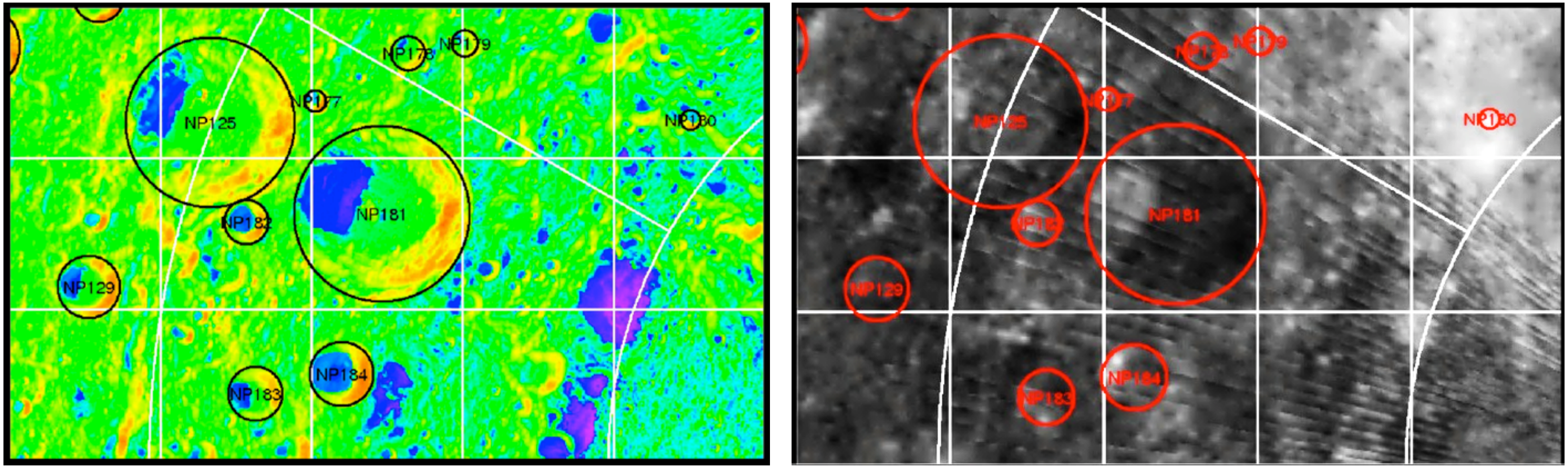
Evidence for water ice on the Moon:





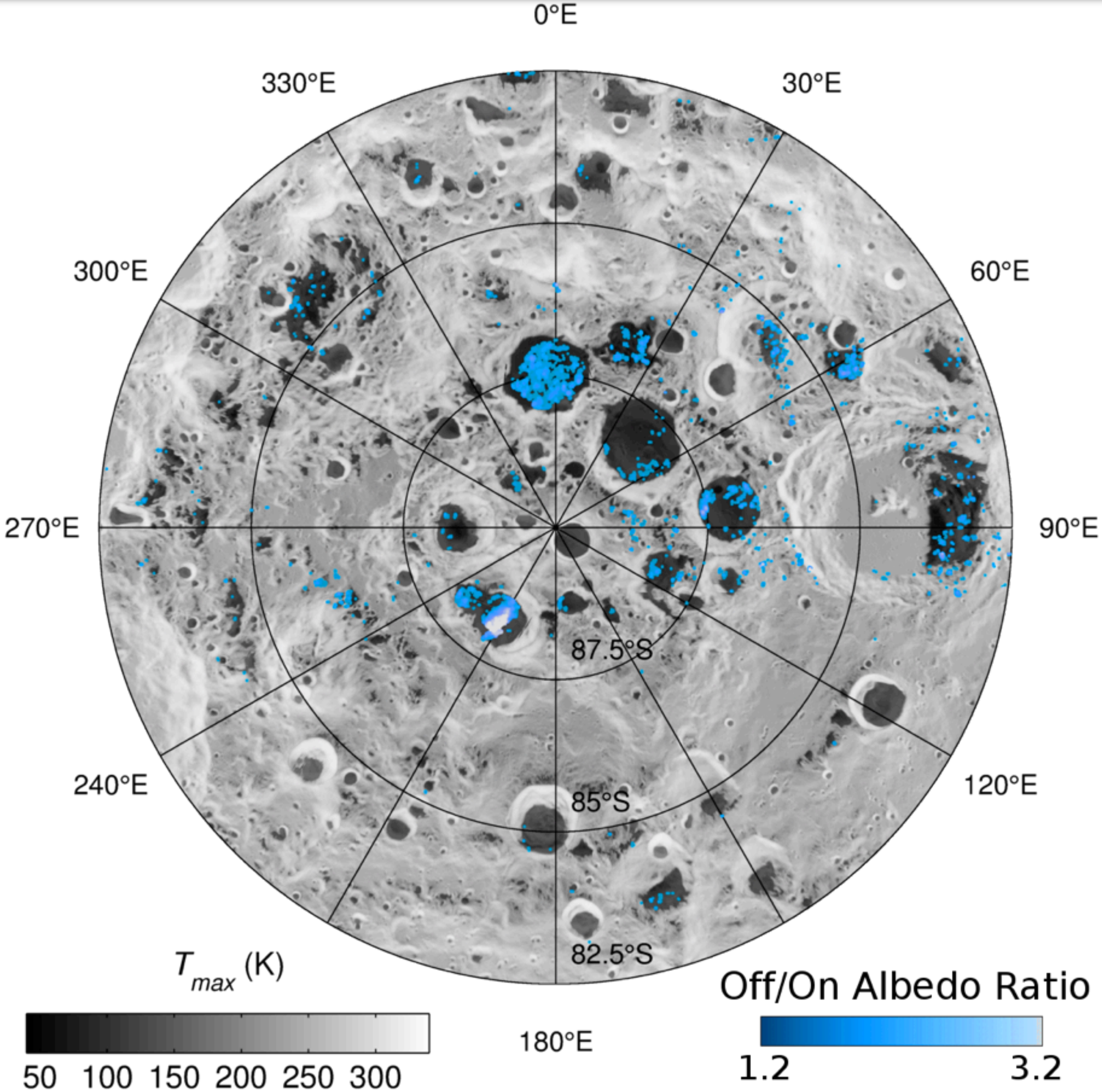
- Craters near the poles are observed to be cold enough (< 110 K) for water ice to be stable essentially indefinitely
- Hydrogen concentrations measured by neutron detectors suggest presence of H_2O deposits in some of these craters
- The LCROSS mission impacted into one of the coldest places on the Moon (~40 K) and measured [H_2O] ~ 2-7% by mass, within upper ~2-3 m

Evidence for Water Frost



Diviner temperatures show well-defined cold traps, where LOLA often sees high-albedo deposits, consistent with surface frost
(D. Paige, Lunar Flashlight Co-I, Diviner PI)

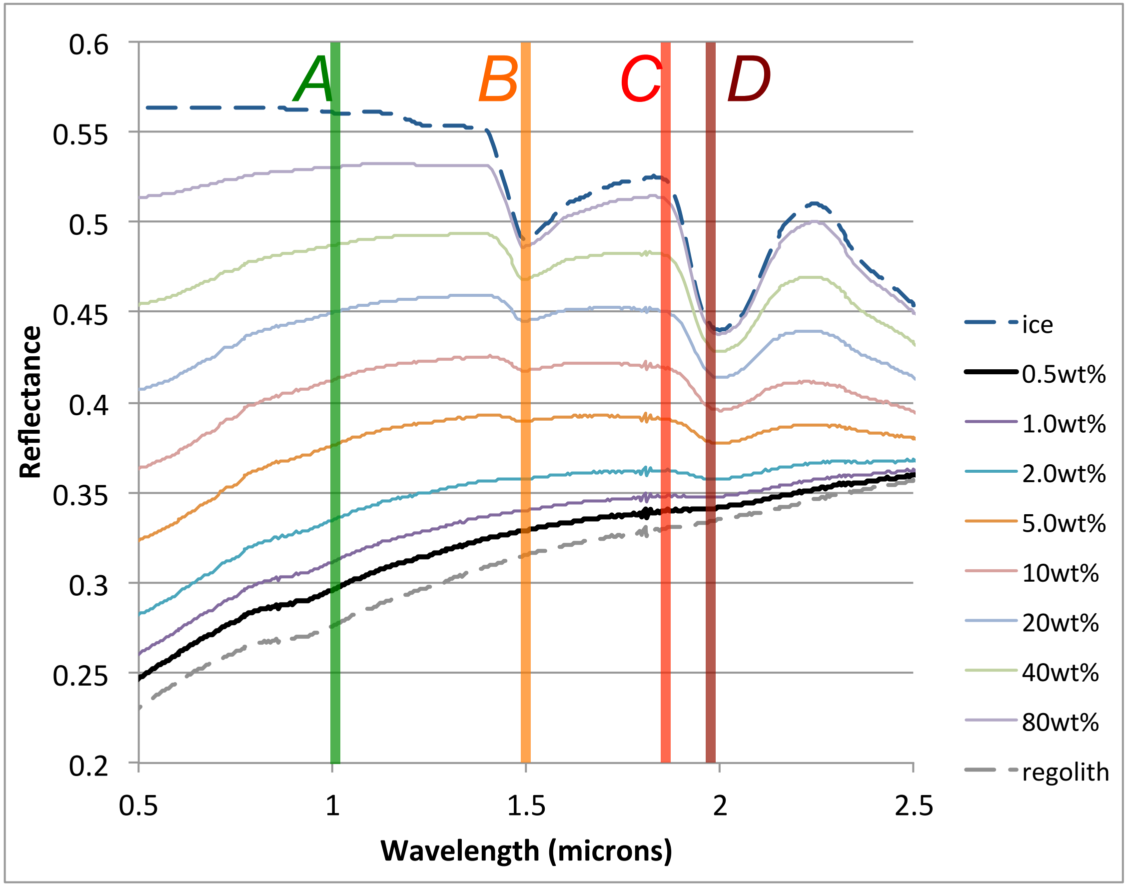
Evidence for Water Frost



Ultraviolet spectroscopy consistent w/ patchy ice at 1-10% level (Gladstone et al., 2012; Hayne et al., 2015)

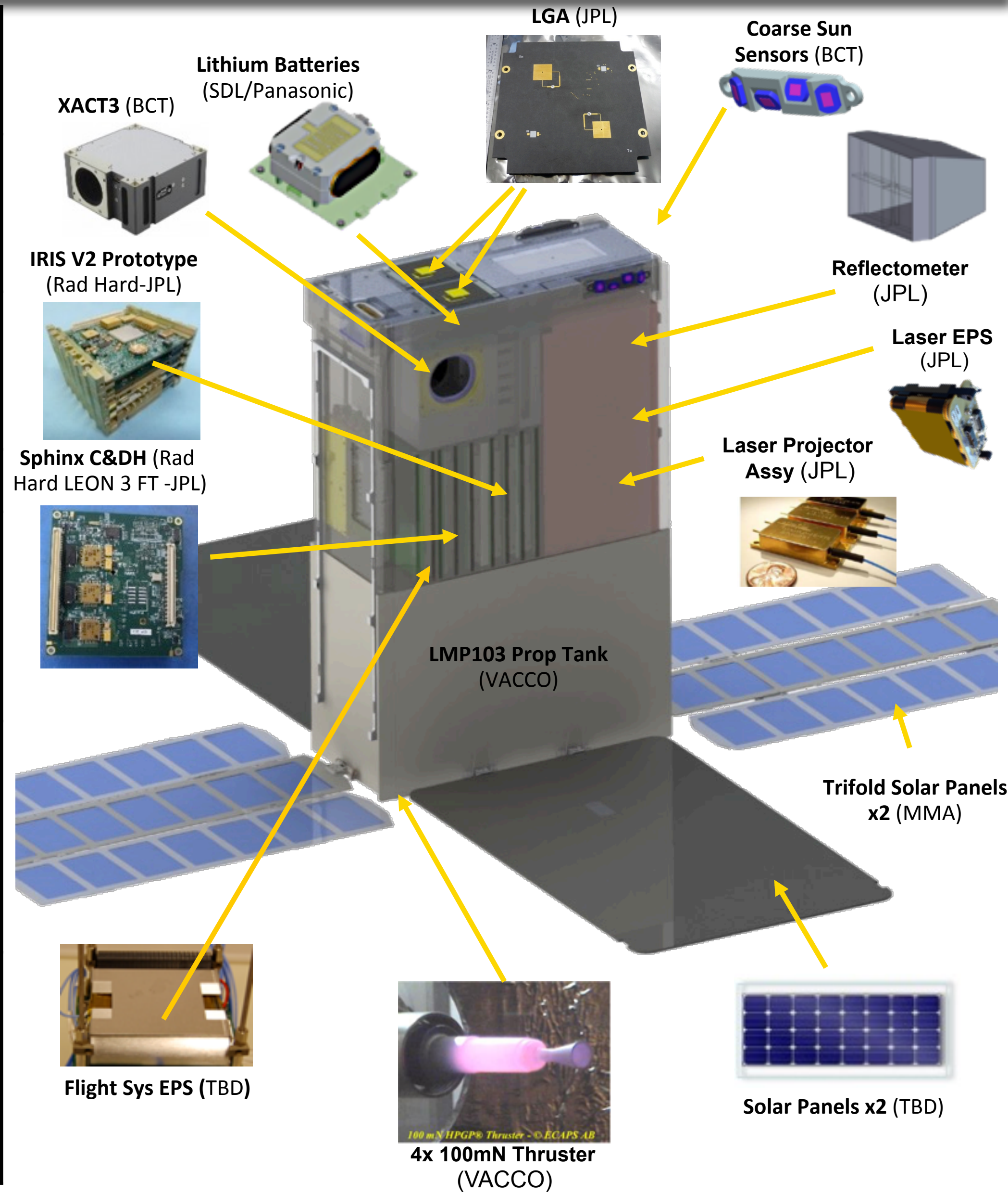
Measurement Goal

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

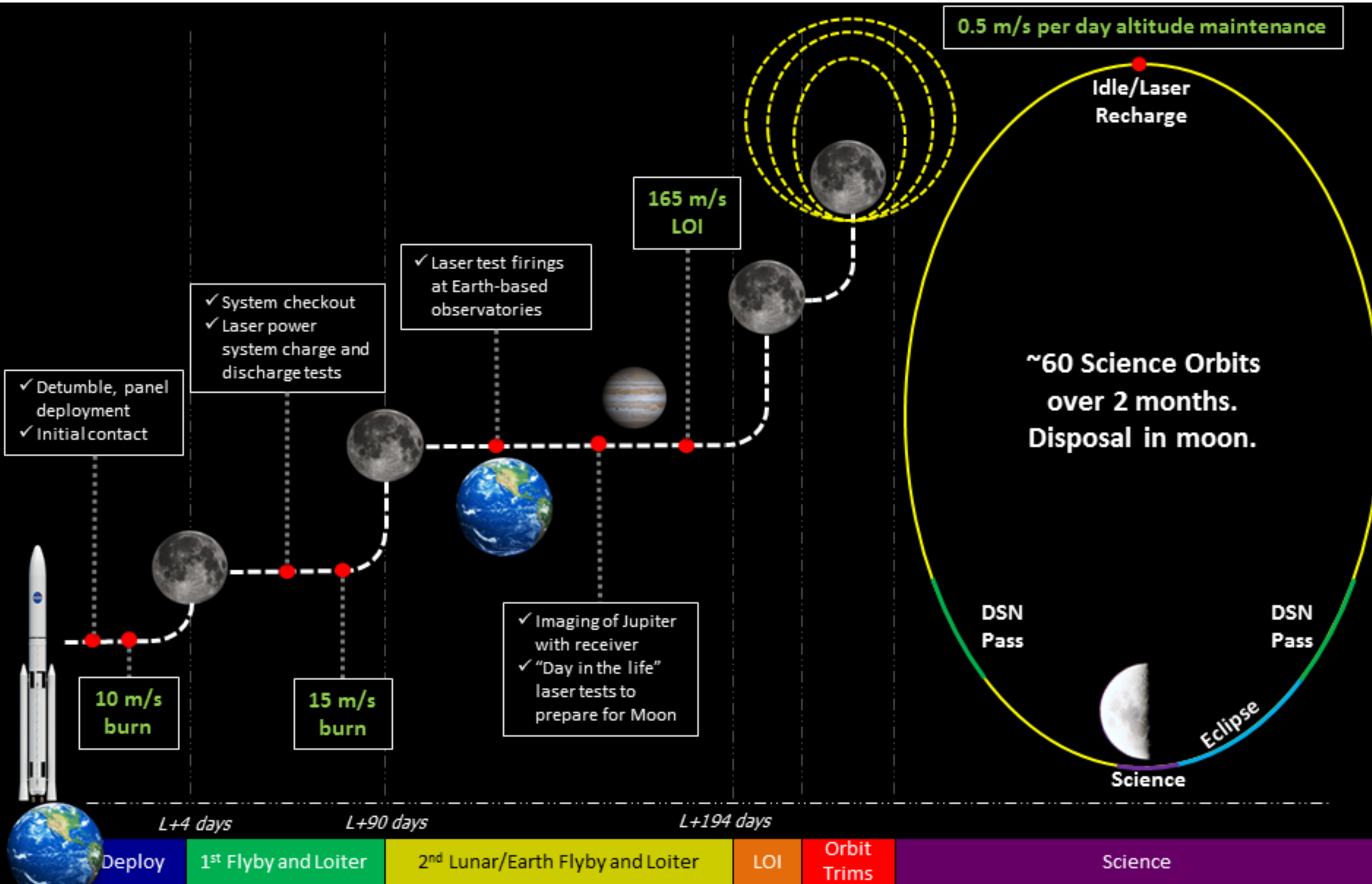


Lunar Flashlight Flight System Overview

Payload	• 4-band Laser Projector (LP) @ ~25-50W per band with custom hybrid power source • Lunar Reflectometer (LR) covering 1-2μm
Mechanical & Structure	• "6U" CubeSat form factor • <14 kg total launch mass • Modular flight system concept
Propulsion	• 290 m/s of delta-v • 4 x 100 mN thrusters • Utilizes LMP-103S green mono-propellant
Avionics	• Radiation tolerant LEON3-FT architecture
Electrical Power System	• 2x Trifold deployable solar arrays and 2x simple deployable solar arrays with UTJ GaAs cells (~51.2 W EOL at 1 AU) • 6.2 Ah Battery (3s2p 18650 Li-ion Cells) • 9 -12.3 V unregulated, 5 V/3.5 V regulated
Telecom	• JPL Iris 2.0 X-Band Transponder; 4 W RF output power supports Doppler, ranging, and D-DOR • 2 pairs of INSPIRE-heritage LGAs (RX/ TX)
Attitude Control System	• BCT XACT3 integrated ACS unit contains: 50 mNm-s (x3) RWAs, Nano StarTracker, & MEMS IMU for attitude determination • Receives data from 4 coarse sun sensors • Controls VACCO green propulsion system

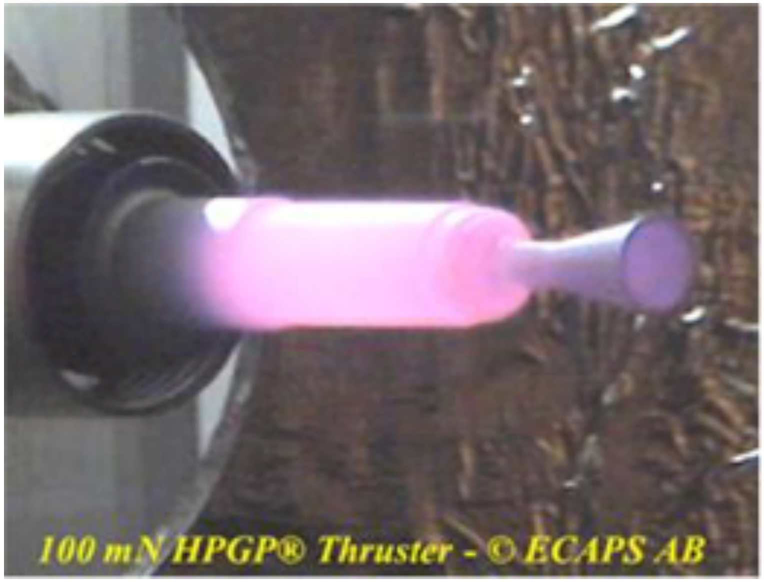


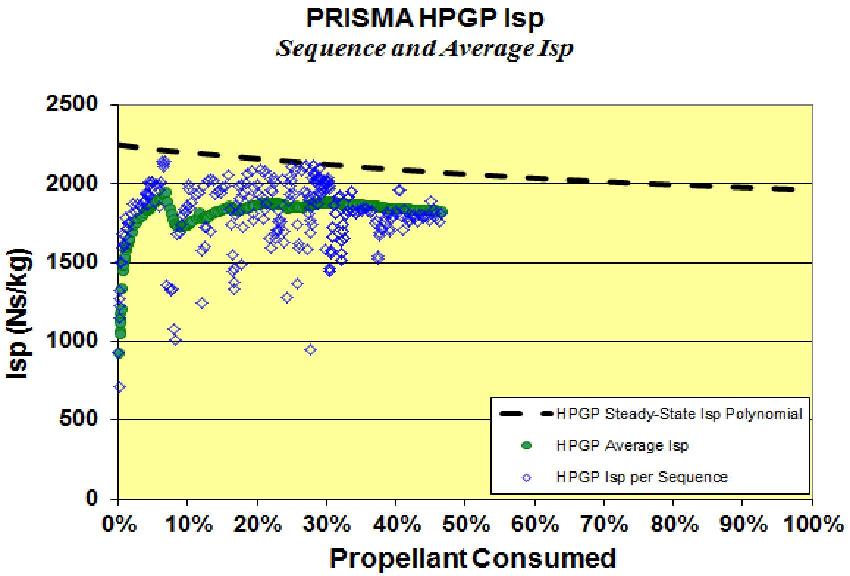
Lunar Flashlight ConOps



Green Propulsion Technology

- Overall propulsion system design based on refrigerant gas systems delivered for multiple users
- Fuel and 1N thruster flight proven on PRISMA (currently in its 5th year on-orbit)
    - Further qualified for Skybox satellites
- Characterization complete for 0.5N, 1N, 5N, 22N, 50N, 220N thrusters
- 100mN thruster has been hot-fired, and will soon begin more testing and characterization





Laser Illumination

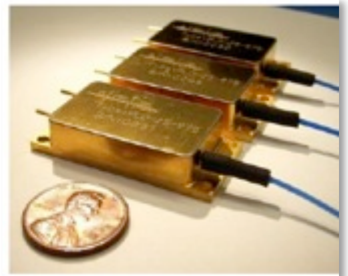
Derived illumination requirements for 3-sigma detection of ice: ~5x10^-6 W/m^2 within each 200-nm wide spectral band

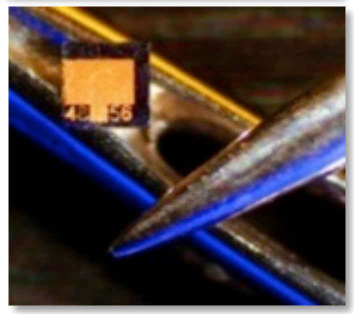
Wavelengths
A: 1.064 (-0.060 / + 0.230) micron
B: 1.495 (-0.015 / +0.015) micron
C: 1.850 (-0.030 / +0.020) micron
D: 1.990 (-0.020 / +0.025) micron

Illumination power: 25W each (A&B); 50W each (C&D) [to be confirmed]
Divergence: <10 mrad after collimation

Volume: Illumination source, lenses, and electronics fit inside 10 x 10 x 10 cm cube. Power will be supplied at 28V.

Duty cycle: Near continuous for <10 minutes per 12 hour orbit



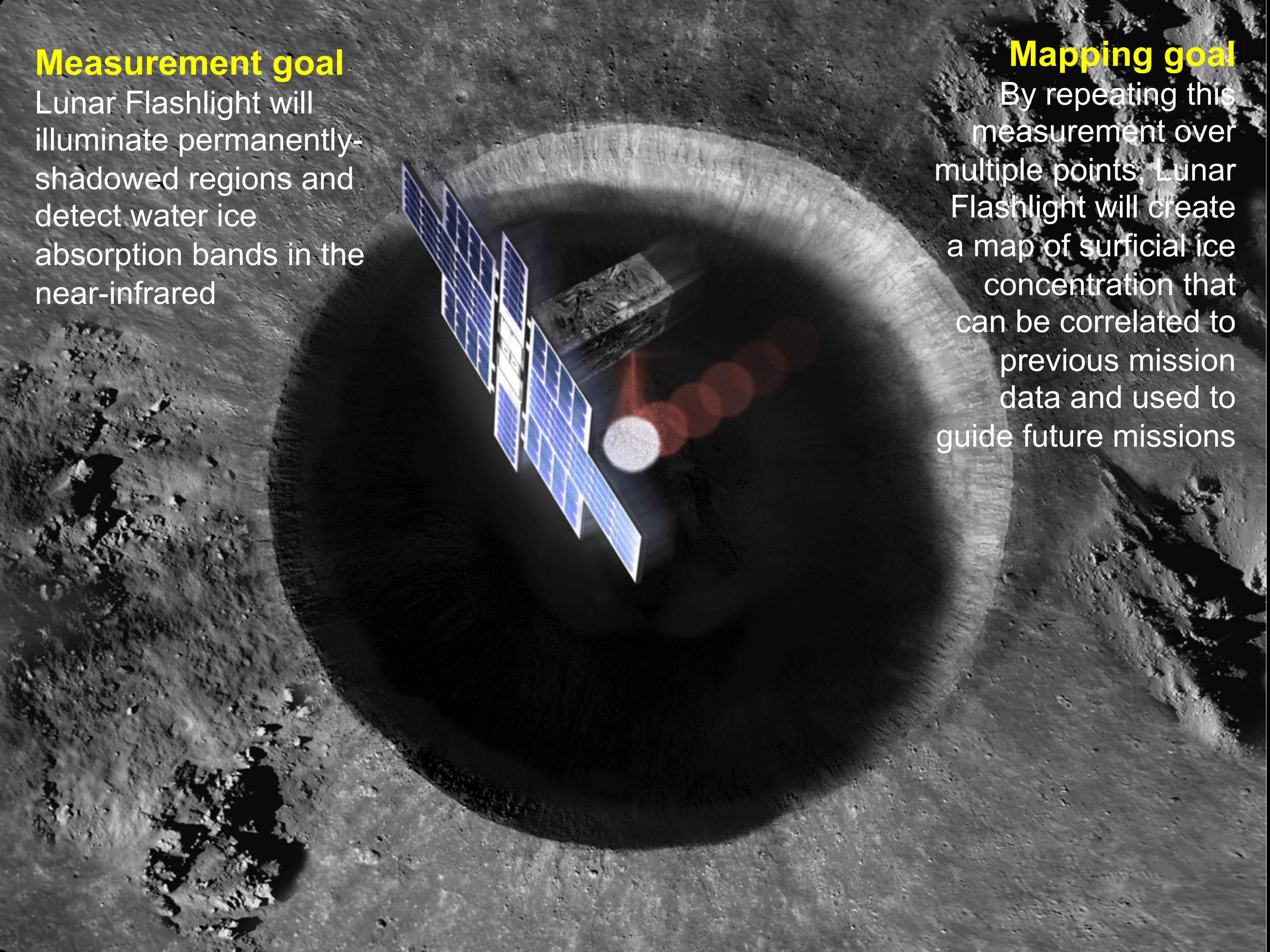


Single Element Diodes

- Single emitter packages are small and can offer small fiber output
- These devices have a space qualified fiber pigtailed package
- Other wavelengths have flown on many LiDAR missions
- Devices in series -> Lower current requirements, higher voltage requirements
- A single failure will not significantly diminish power output
- Pulsed in series w/ 5 ms cycle during science pass

Power Source

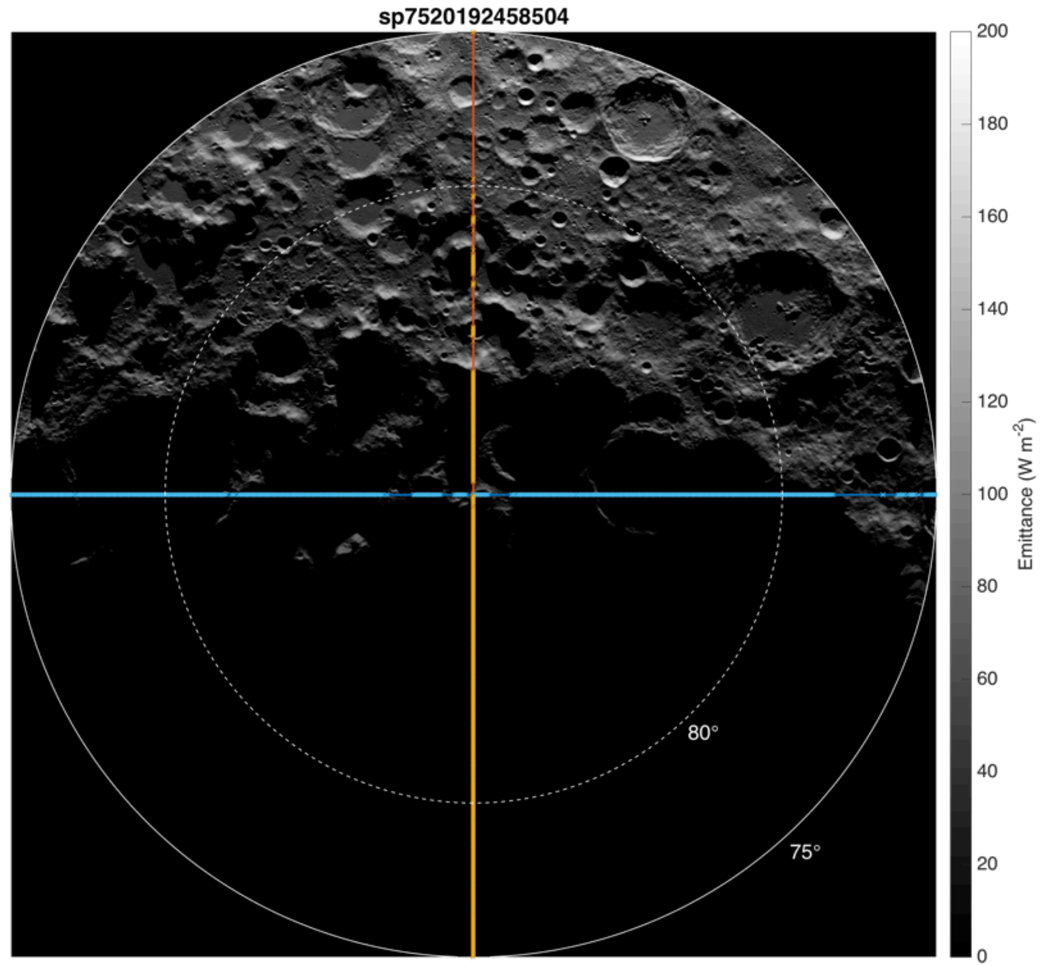
- Powered by Li-Ion/ Supercapacitor hybrid system developed at JPL
- Capable of delivering this power and energy with small mass and volume (<700g, <1U)
- Currently TRL 5, similar system set to launch from ISS in March 2016



Measurement goal
Lunar Flashlight will illuminate permanently-shadowed regions and detect water ice absorption bands in the near-infrared
Mapping 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

- 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.

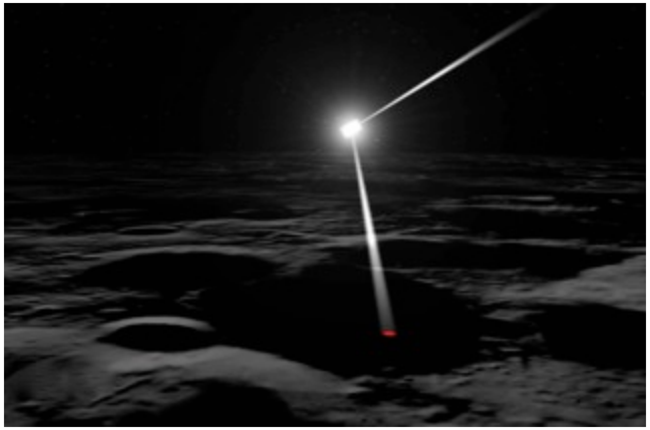


Summary

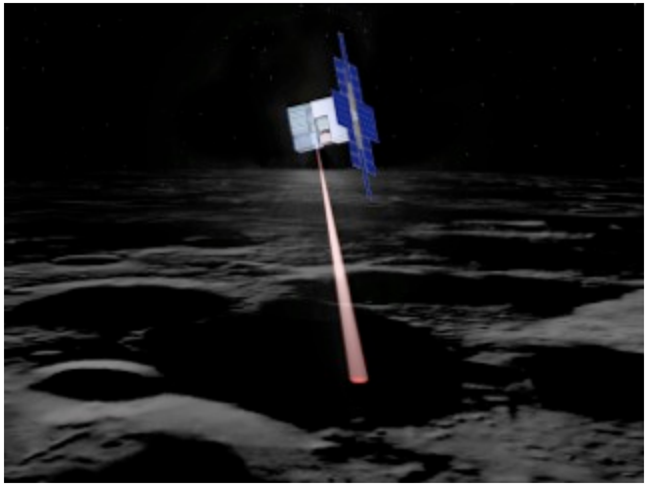
- Water on the Moon is a complex topic that traces origin and evolution of the Earth-Moon system, solar wind interaction, and delivery of volatiles by impacts
- Water is a human-exploitable resource with very large potential economic impact
- Lunar Flashlight is a low-cost nanosat mission to detect and map lunar surface ice in permanently-shadowed regions of the lunar south pole
- **Lunar flashlight will demonstrate potential of small missions for science & exploration on the Moon and beyond**

Extra Slides

Change from Sail to Active Prop/Illumination



- Solar sail design exceeds 12 kg; sail area yields insufficient thrust to capture and maintain lunar orbit
- No available orbits with dark-to-light passes, affecting Instrument thermal performance
- Insufficient spacecraft thermal radiator area for avionics power dissipation
- Sail reflectance distribution unlikely to satisfy illumination requirements

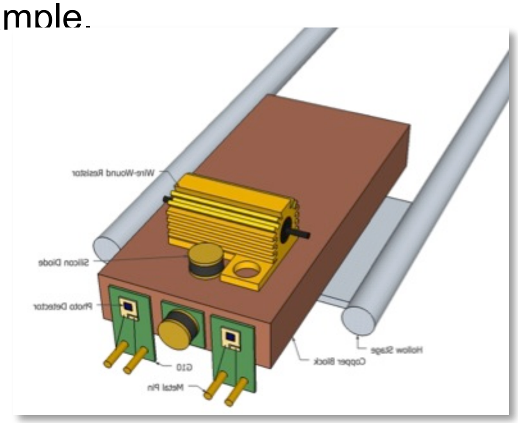


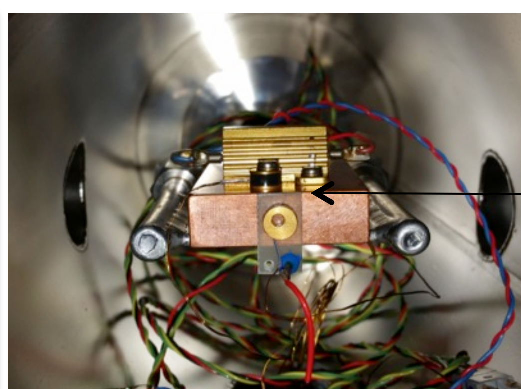
- Green propulsion provides viable lunar transfer and orbit trajectories for s/c mass of 13 kg
  - Better orbits, no spiral-down
  - Shorter mission reduces risk and cost
- Laser illumination provides enhanced science performance:
  - Coalignment of illuminated spot and spectrometer field of view
  - Simplification of receiving optics
  - Constant (zero-phase) illumination angle

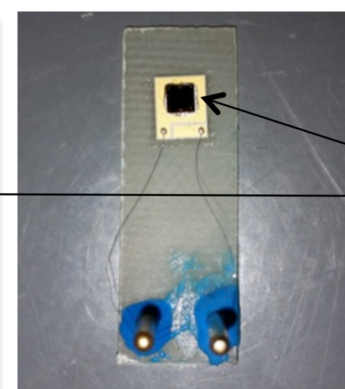
Since last LEAG - Science

Instrument Performance Model developed for Lunar Flashlight, in order to evaluate its capability to meet the mission requirements. This model (written in Matlab and Excel) takes as input all of the fundamental instrument parameters: aperture, detector and optical efficiencies, spectral bandpasses, focal plane temperature, etc. The model output is the signal-to-noise ratio for a single measurement, which can be converted readily to an equivalent weight-percentage of H2O ice. Due to its inherent flexibility, the instrument performance model has been used to evaluate both the solar sail and laser illumination measurement approaches.

Detector Performance Testing We designed and fabricated a system consisting of two silicon diode temperature sensors, two distinct InGaAs photodetectors, and a copper block that serves as a heat exchanger between a 25-Watt wire-wound resistor and a liquid-nitrogen-cooled hollow stage. The photodiodes will be cooled to 77 K by allowing LN2 flow through the hollow stage. Our set up allows us to have full control over the temperature of our system. This set-up is currently running under a cryogenic and vacuum environment to test the performance of our detectors. Future experiments include replacing the integrating sphere with a laser source and shinning its beam to lunar regolith simulant and detecting the reflected light of the sample.







LF Detector