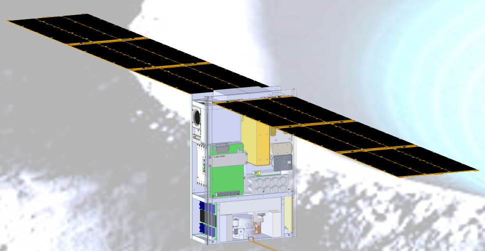
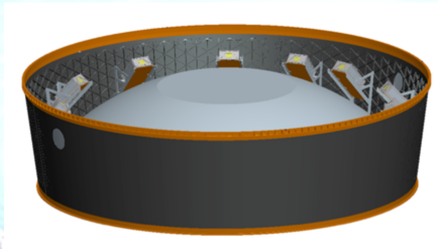
# Broadband InfraRed Compact High-resolution Exploration Spectrometer: Lunar Volatile Dynamics for the Lunar Ice Cube Mission

**P.E. Clark**, CalTech/Jet Propulsion Laboratory, Science PI
Morehead State University PI, Bus, Ground Communication, Science Operations: B. Malphrus (PI), B. Twiggs, Jeff Kruth, Kevin Brown, M. Coombs, R. McNeill;
NASA/GSFC Payload: C. Brambora, T. Hurford, R. MacDowall, D. Reuter, W. Farrell, D. Patel, S. Banks, E. Mentzell, R. Manriquez;
NASA/GSFC Flight Dynamics: D. Folta, P. Calhoun;
Busek Propulsion: M. Tsay, J. Frongillo;
Vermont Technical College Software: C. Brandon, P. Chapin





EM1 Deployment System for the 'lucky 13'

**National Aeronautics and Space Administration**

**Jet Propulsion Laboratory**
California Institute of Technology
Pasadena, California

www.nasa.gov



Government sponsorship acknowledged.

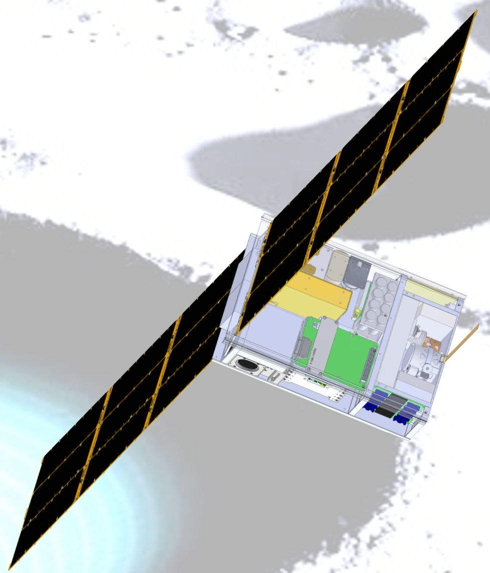
**Jet Propulsion Laboratory**
California Institute of Technology

# Lunar Ice Cube Science Goals

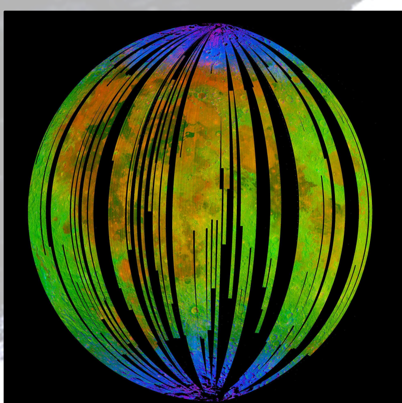
| Goals | Measurements | HEOMD SKG | NASA SP; AG roadmaps |
|---|---|---|---|
| Primary: Determine distribution of volatiles, including forms and components of water, and other volatiles such as $NH_3$, $H_2S$, $CO_2$, $CH_4$, to the extent possible, in lunar regolith as a function of time of day and latitude | IR measurements associated with volatiles in the 3 micron region at </= 10 nm spectral resolution to assess global scale variations in thermal and photometric conditions | **Water ice abundance, location,** transportation physics on lunar surface | Understand origin and role of volatiles. Measure, monitor, characterize areas associated with volatile activity. |
| Secondary: Consider impact of variations in surface properties (composition, slope, orientation) | Broadband (1-4 micron) NIR measurements associated with major minerals. Previous mission maps slope, maturity, mineralogy. | **Water ice** abundance, **location,** transportation physics on lunar surface | Understand origin and role of volatiles. Measure, monitor, characterize areas associated with volatile activity. |
| Secondary: Provide inputs to constrain models for volatile origin, production, and loss. | | **Water ice** abundance, location, **transportation physics** on lunar surface | Understand origin and role of volatiles. Measure, monitor, characterize areas associated with volatile activity. |

# Technology Goals
## Demonstrate Enabling Technologies for Interplanetary Cubesats

- Innovative Busek BIT-3 RF Ion Propulsion System
- Highly Miniaturized GSFC BIRCHES Point Spectrometer
- Inexpensive, Quasi-COTs, Radiation Tolerant Morehead State University 6U Interplanetary CubeSat bus
- Innovative Use of Low Energy Trajectories developed at GSFC FDF
- Robust Flight Software Systems written in Spark Ada by Vermont Tech

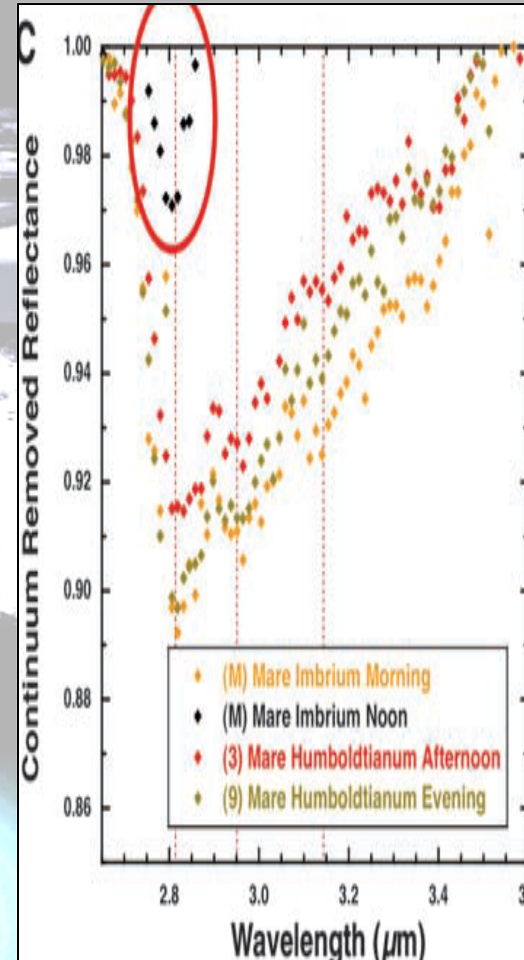


| Lunar IceCube versus Previous Missions | | |
|---|---|---|
| Mission | Finding | IceCube |
| Cassini VIMS, Deep Impact | surface water detection, variable hydration, with noon peak absorption | water & other volatiles, fully characterize 3 μm region as function of several times of day for same swaths over range of latitudes w/ context of regolith mineralogy and maturity, radiation and particle exposure, for correlation w/ previous data |
| Chandrayaan M3 | H2O and OH (<3 microns) in mineralogical context nearside snapshot at one lunation | |
| LCROSS | ice, other volatile presence and profile from impact in polar crater | |
| LP, LRO, LEND LAMP DVNR LOLA LROC, LADEE | H+ in first meter (LP, LEND) & at surface (LAMP) inferred as ice abundance via correlation with temperature (DIVINER), PSR and PFS (LROC, LOLA), H exosphere (LADEE) | |



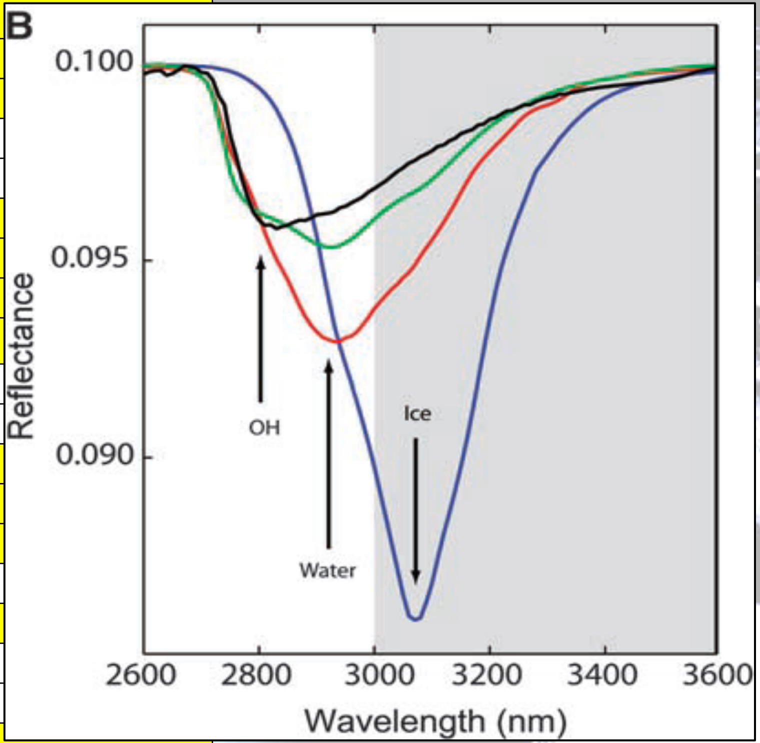
M3 'snapshot' lunar nearside indicating surface coating OH/$H_2O$ (blue) near poles (Pieters et al, 2009)

| Table B.2 IR measured volatile abundance in LCROSS plume (Colaprete et al, 2010) | | |
|---|---|---|
| Compound | Molecules $cm^{-2}$ | Relative to $H_2O$(g)* |
| H2O | 5.1(1.4)E19 | 100% |
| H2S | 8.5(0.9)E18 | 16.75% |
| NH3 | 3.1(1.5)E18 | 6.03% |
| SO2 | 1.6(0.4)E18 | 3.19% |
| C2H2 | 1.6(1.7)E18 | 3.12% |
| CO2 | 1.1(1.0)E18 | 2.17% |
| CH2OH | 7.8(4.2)E17 | 1.55% |
| CH4 | 3.3(3.0)E17 | 0.65% |
| OH | 1.7(0.4)E16 | 0.03% |
| *Abundance as described in text for fit in Fig 3C | | |




Early evidence for diurnal variation trend in OH absorption by Deep Impact (Sunshine et al. 2009) which will be geospatially linked by Lunar IceCube.

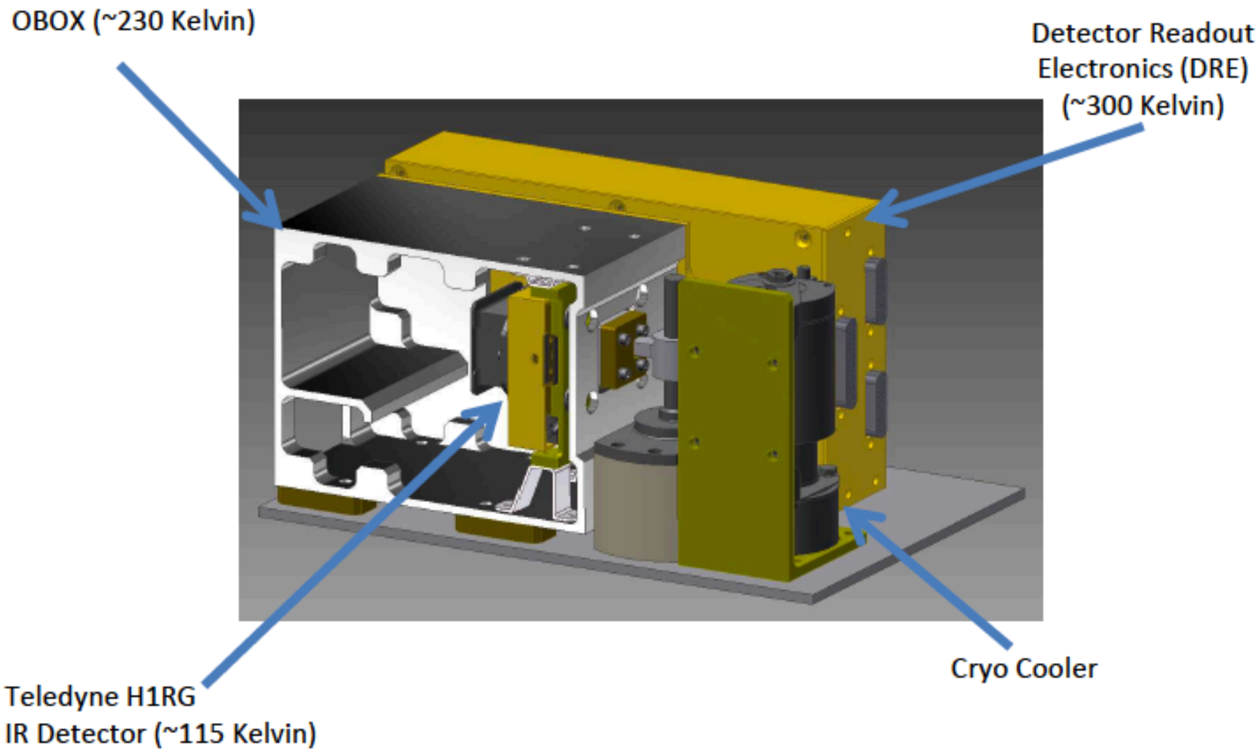
| Species | µm | description |
|---|---|---|
| **Water Form, Component** | | |
| water vapor | 2.738 | OH stretch |
| | 2.663 | OH stretch |
| liquid water | 3.106 | H-OH fundamental |
| | 2.903 | H-OH fundamental |
| | 1.4 | OH stretch overtone |
| | 1.9 | HOH bend overtone |
| | 2.85 | M3 Feature |
| | 2.9 | total H2O |
| hydroxyl ion | 2.7-2.8 | OH stretch (mineral) |
| | 2.81 | OH (surface or structural) stretches |
| | 2.2-2.3 | cation-OH bend |
| | 3.6 | structural OH |
| bound H2O | 2.85 | Houck et al (Mars) |
| | 3 | H2O of hydration |
| | 2.95 | H2O stretch (Mars) |
| | 3.14 | feature w/2.95 |
| adsorbed H2O | 2.9-3.0 | R. Clark |
| ice | 1.5 | band depth-layer correlated |
| | 2 | strong feature |
| | 3.06 | Pieters et al |
| **Other Volatiles** | | |
| NH3 | 1.65, 2. 2.2 | N-H stretch |
| CO2 | 2, 2.7 | C-O vibration and overtones |
| H2S | 3 | |
| CH4/organics | 1.2, 1.7, 2.3, 3.3 | C-H stretch fundamental and overtones |
| **Mineral Bands** | | |
| pyroxene | 0.95-1 | crystal field effects, charge transfer |
| olivine | 1, 2, 2.9 | crystal field effects |
| spinels | 2 | crystal field effects |
| iron oxides | 1 | crystal field effects |
| carbonate | 2.35, 2.5 | overtone bands |
| sulfide | 3 | conduction bands |
| hydrated silicates | 3-3.5 | vibrational processes |
| **anticipate wavelength of peak for water absorption band to be structural<bound<adsorbed<ice** | | |

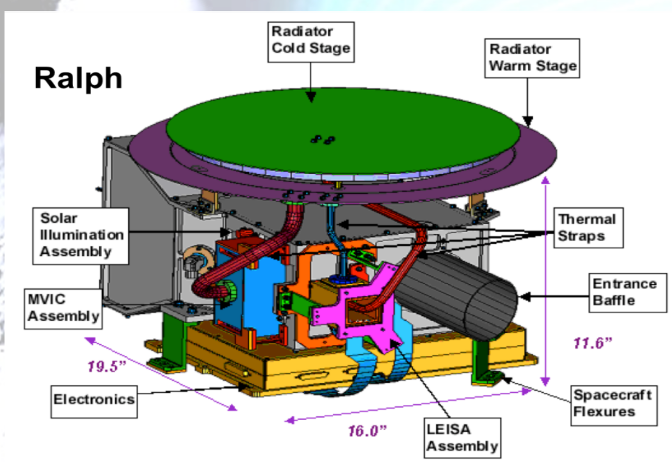



Ice Cube measurements will encompass the broad 3 um band to distinguish overlapping OH, water, and ice features. Will have near 10 nm resolution in this band

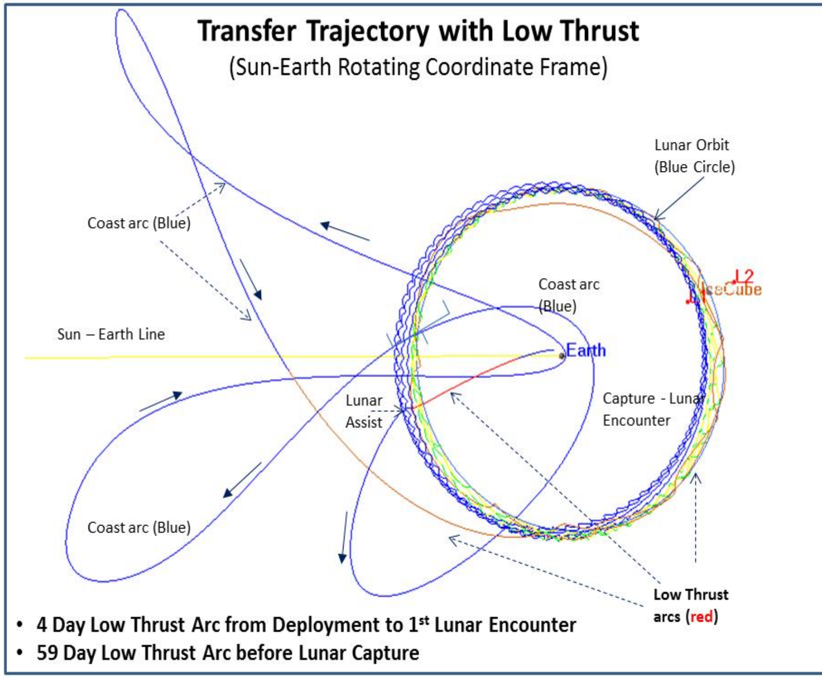
Yellow = water-related features in the 3 micron region

# BIRCHES Instrument

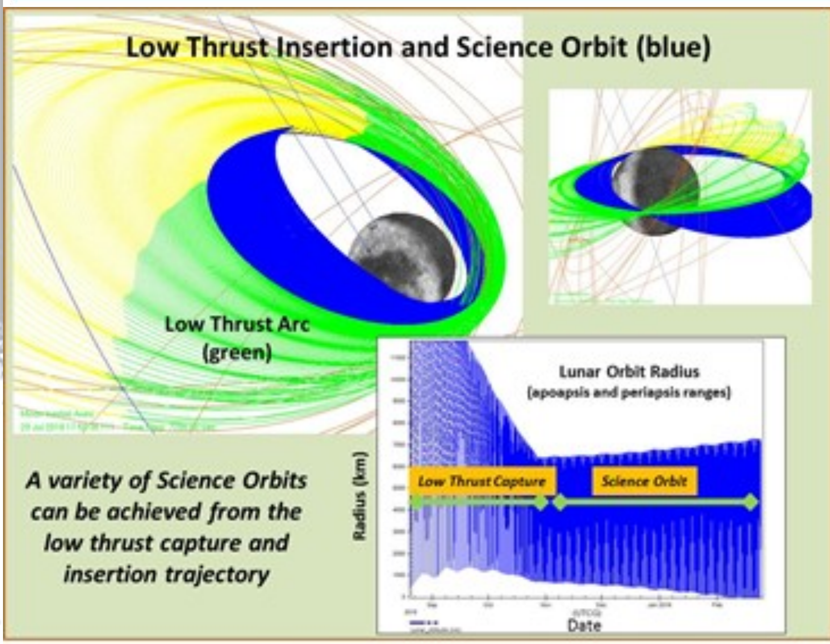


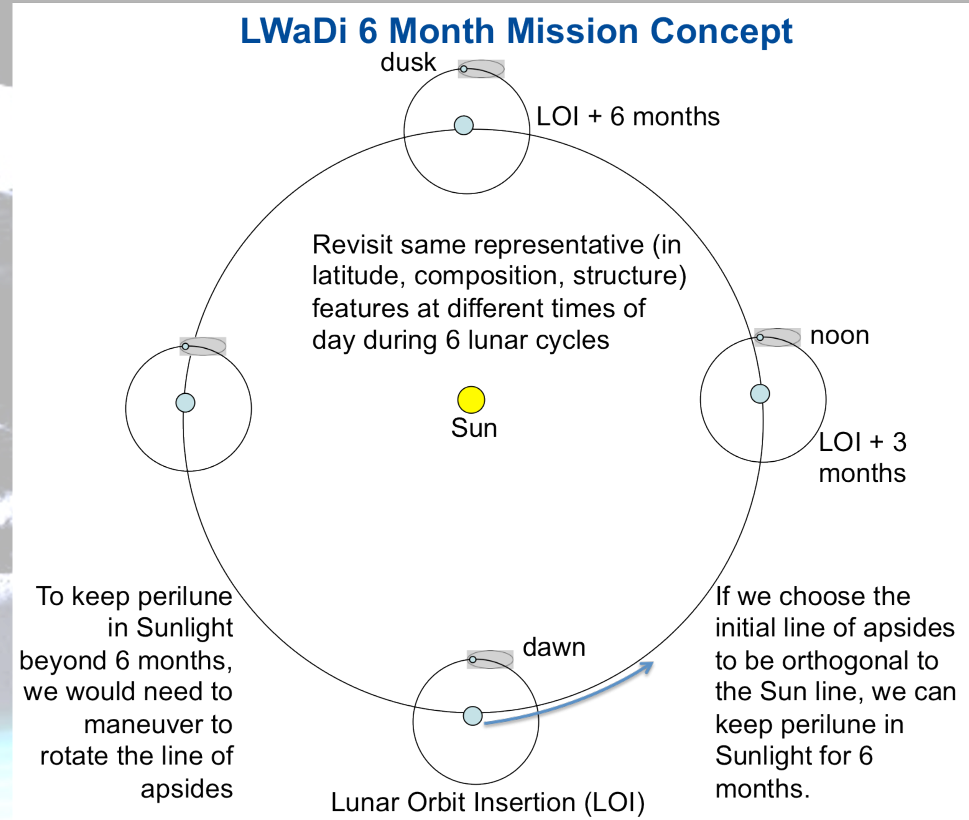

| BIRCHES compactness | | |
|---|---|---|
| Property | Ralph | BIRCHES |
| Mass kg | 11 | 3 |
| Power W | 5 | #10-20 W |
| Size cm | 49 x 40 x 29 | 10 x 10 x 15 |
| # includes 3 W detector electronics, 1.5 W AFS controller, 5-10 W cryocooler | | |



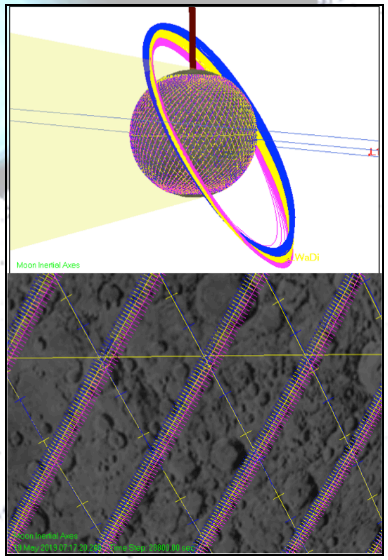
Transfer Trajectory with Low Thrust
(Sun-Earth Rotating Coordinate Frame)
Lunar Orbit
(Blue Circle)
Coast arc (Blue)
Coast arc
(Blue)
L2
IceCube
Sun – Earth Line
Earth
Lunar
Assist
Capture - Lunar
Encounter
Coast arc (Blue)
Low Thrust
arcs (red)
• 4 Day Low Thrust Arc from Deployment to 1st Lunar Encounter
• 59 Day Low Thrust Arc before Lunar Capture

Low Thrust Insertion and Science Orbit (blue)
Low Thrust Arc
(green)
A variety of Science Orbits
can be achieved from the
low thrust capture and
insertion trajectory
Lunar Orbit Radius
(apoapsis and periapsis ranges)
Radius (km)
Low Thrust Capture
Science Orbit
Date

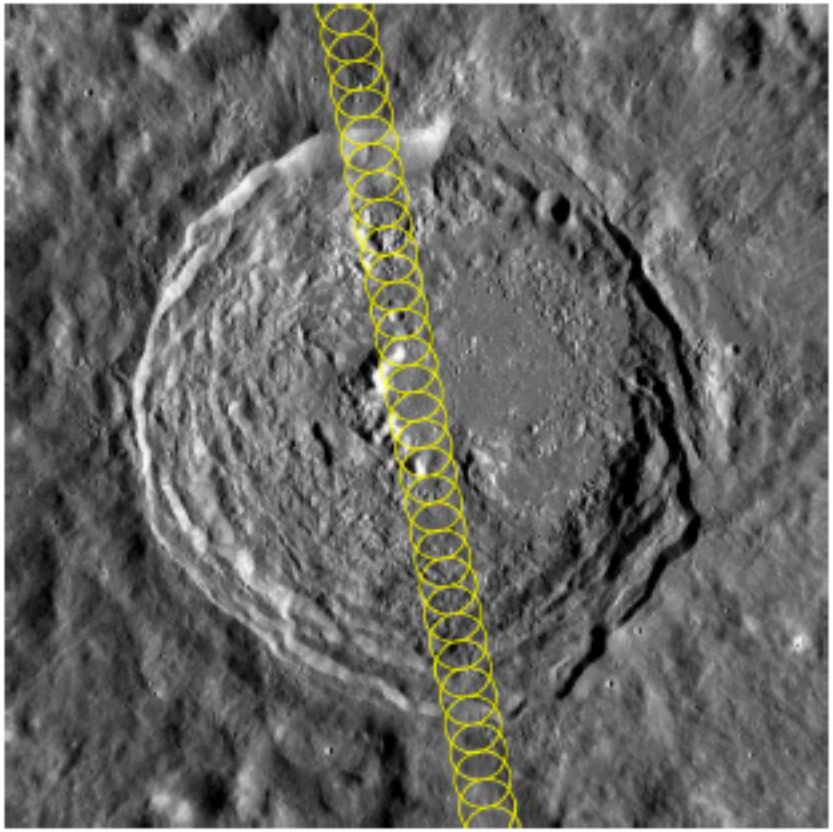
LWaDi 6 Month Mission Concept
dusk
LOI + 6 months
Revisit same representative (in latitude, composition, structure) features at different times of day during 6 lunar cycles
noon
Sun
LOI + 3 months
To keep perilune in Sunlight beyond 6 months, we would need to maneuver to rotate the line of apsides
dawn
If we choose the initial line of apsides to be orthogonal to the Sun line, we can keep perilune in Sunlight for 6 months.
Lunar Orbit Insertion (LOI)

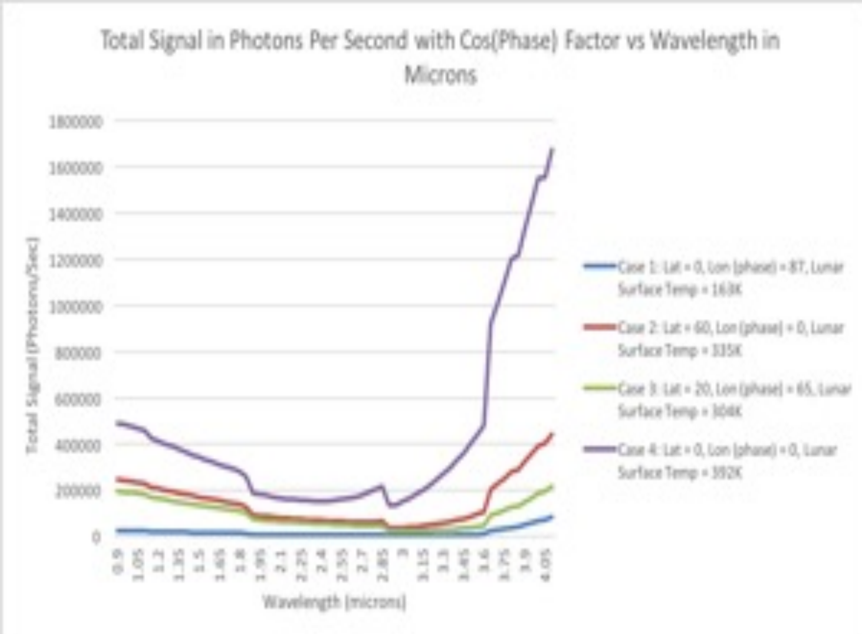
# BIRCHES Observation Requirements

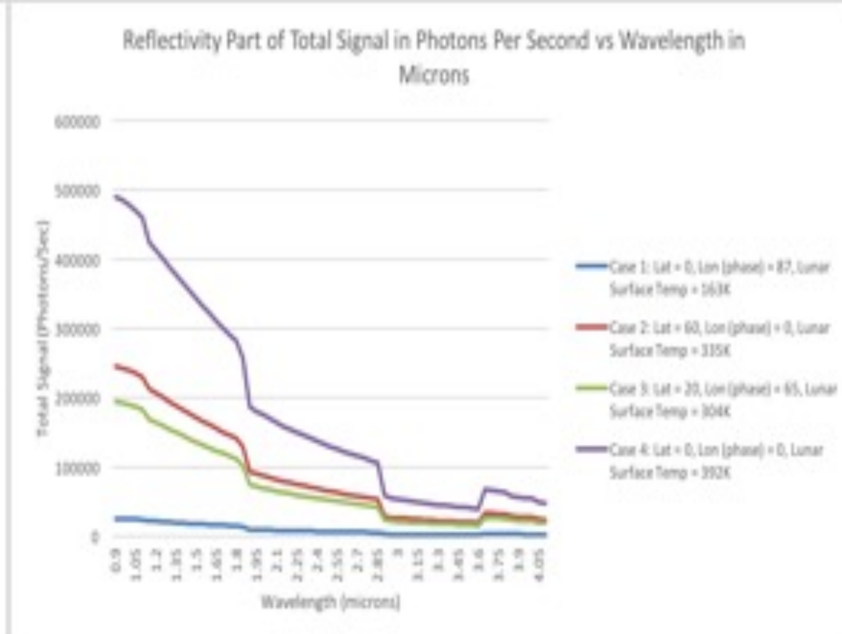
| Requirement |
| --- |
| A footprint of 10 km from an altitude of 100 km |
| **Footprint 10 km in along track direction regardless of altitude, consecutive observations separated by a couple of kilometers; greater overlap of consecutive tracks at poles, separted by a couple of kilometers** |

- FOV of the instrument will be 100 mrad (6°)
- An Adjustable Field Stop (AFS) shall maintain the FOV to 10 km in size
- Based on spacecraft velocity exposures shall be taken at intervals of 2.7 seconds (TBC)



Vavilov Crater:
100 km in diameter
1° S, 138° W




| Case | Lat | ToD | Temp K | Reflectivity @ 3um photons/sec | Total Signal | SNR | Band depth/PPM water | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.1/1000 | 0.05/500 | 0.01/100 |
| 1 | 0 | 87 | 163 | 3254 | 2760 | 52 | 276 | 138 | 27 |
| 2 | 60 | 0 | 335 | 39045 | 26400 | 162 | 2640 | 1320 | 264 |
| 3 | 20 | 65 | 304 | 24279 | 20963 | 145 | 2096 | 1480 | 210 |
| 4 | 0 | 0 | 395 | 150777 | 52800 | 230 | 5280 | 2640 | 528 |

## Current Challenges

Thermal Design: major cubesat challenge. Thermal models indicate dedicated radiator maintains temperature of optics box <220K, BIRCHES instrument maintained within operational range. All aluminum design of optical bench minimizes impact of terminator-equator temperature variation. Calibration of optical system will allow anticipated minimal effects to be removed. Microcryocooler maintains detector <115 K.

Optics: Cover will be needed to prevent sunlight from entering instrument. Minimal mass and volume impact solutions being explored. Adjustable Field Stop design allows window spot size to be maintained over changes in altitude from 10 to 100 km.

Human-rated launch vehicle challenges: Very high Vibration and Shock survival in original requirements documents: deployer design will mitigate and original margins were very high
Very large survival temperature range in requirements documents: partially mitigated by 'rolling' spacecraft once Orion deployed +1.5 hours) Solutions being negotiated.

Radiation issue: Attention being paid to NEPP by entire team thanks to efforts of Cliff Brambora

Communication, navigation and tracking: DSN developing new capabilities for multiplexing communication. Iris version 2 provides much improved bandwidth at expense of power.

Data Management: PDS requirement at PDR presents major challenge.

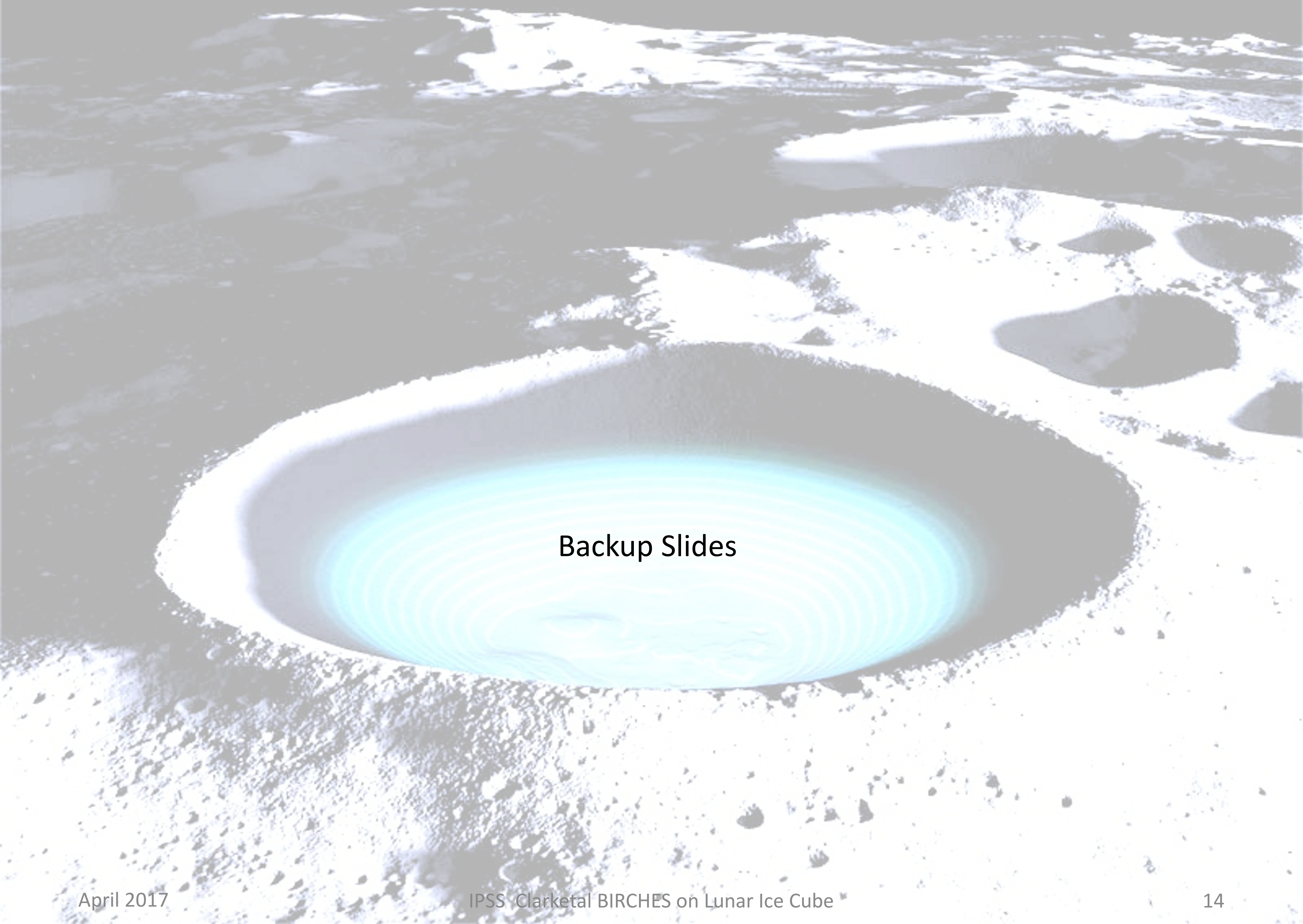
| Baseline Success Criteria | |
|---|---|
| Lunar Surface Coverage for same swaths as function of 3 or more times of day | Minimum 10% near equator, 100% at poles for 6 month mission |
| Polar regional coverage for overlap with two other orbiters | TBD |
| Equatorial periapsis for symmetrical coverage | 100 km +/- 5 km vertical/horizontal |
| Footprint | <300 sq km |
| Spectral resolution @ 3 µm | 10 nm |
| Avoid 3 micron region saturation | preflight loaded and tested software to control adjustable aperture size. combine integration periods as necessary. |
| Downlink of collected data | 128 kbps to downlink all science data daily |
| dynamic range in water-related abundances | Four orders of magnitude |
| Access to Phase 1 and 2 data (last slide) | Deliver to PDS EDRs. Incorporate NAIF/SPICE for positioning and pointing information. Level 1 products to include calibrated data, more as resources permit, leveraging community resources |

# Conclusions

- IceCube to place an IR spectrometer in lunar orbit to look for surface OH, water, other volatiles
- Examines changes in surface volatile content as function of temperature and illumination conditions to get at dynamics issues! (like Sunshine et al., 2009 observation)
- Utilizes MSU cubesat bus with Busek propulsion and commercial subsystems modified for deep space, GSFC payload and flight dynamics expertise with low energy manifolds to lunar capture, and JPL science PI and deep space communication expertise
- Creating a tailored solution with a standard platform.
- Our goal is to deliver high priority measurements on lunar volatiles via a HEOMD NextSTEP mission selected to demonstrate technology for propulsion and compact volatile-detecting instrument capability

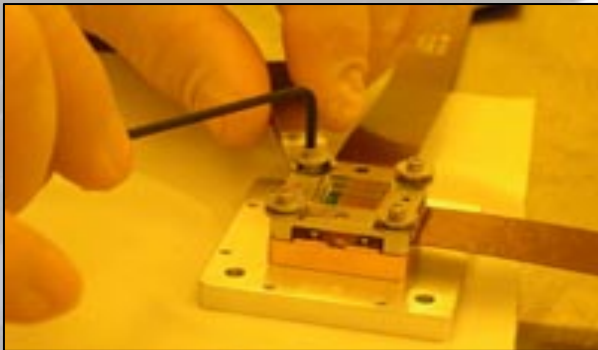
# LunarCubes Are Here!!!!

pamela.e.clark@jpl.nasa.gov

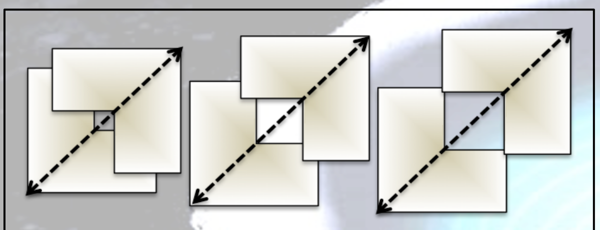


# Backup Slides

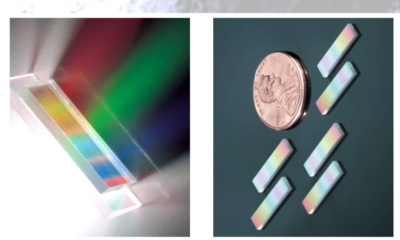
# Spectrometer Schematic and Components



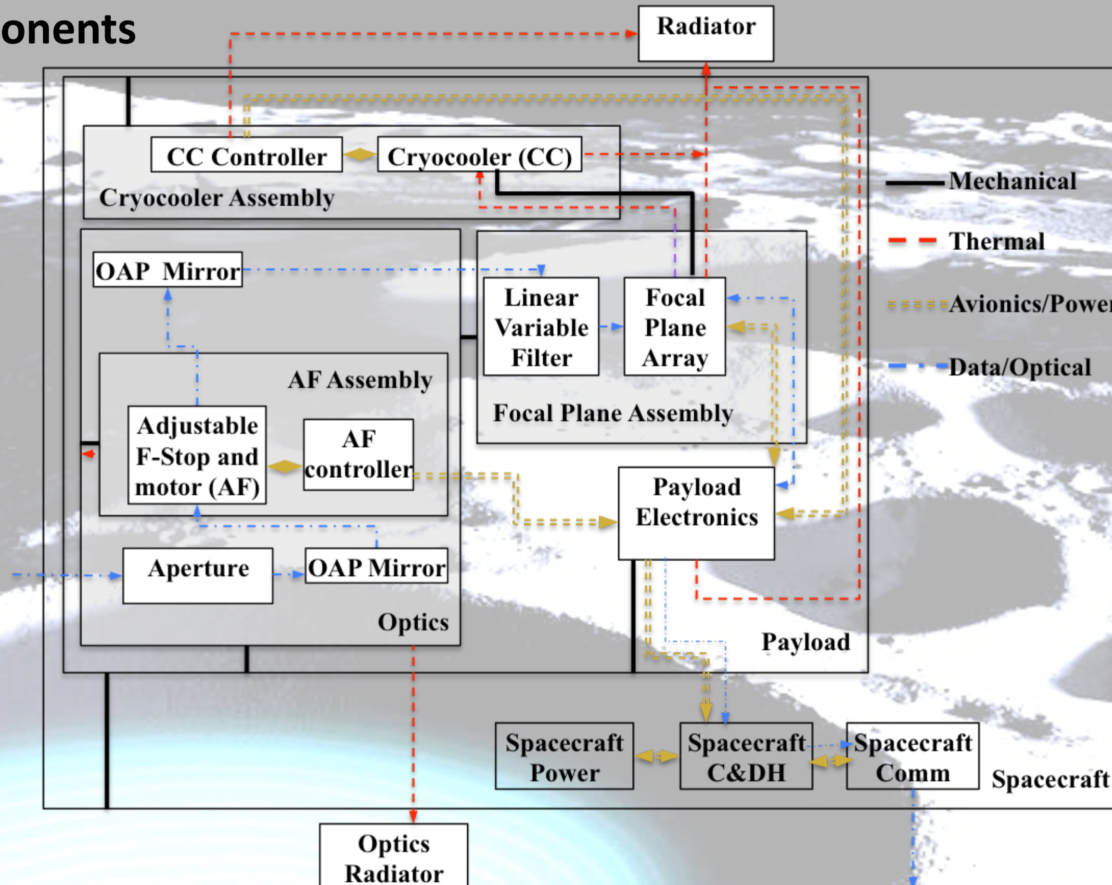
BIRCHES utilizes a compact Teledyne H1RG HgCdTe Focal Plane Array and JDSU linear variable filter detector assembly leveraging OSIRIS REx OVIRS.



Adjustable Iris maintains footprint size at 10 km by varying FOV regardless of altitude



JDSU LV filters

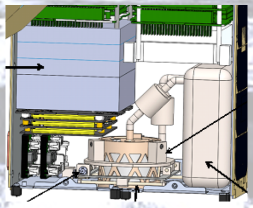




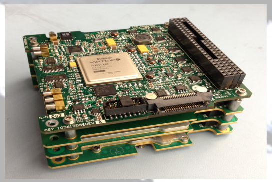
COTS AFRL developed AIM SX030 microcryocooler with cold finger to maintain detector at ≤115K and iris controller

# Bus Components

**Propulsion:** 2U Busek Gimbaled Iodine Ion Propulsion Drive (EP) with external e- source to offset charge build up. Models indicate no contamination problem.

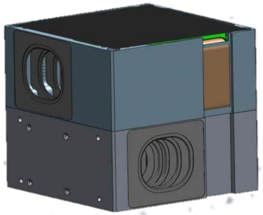


**Thermal Design:** with minimal radiator for interior the small form factor for BIRCHES means that interior experiences temperatures well within 0 to 40 degrees centrigrade, except for optics box which has a separate radiator. Thermal modeling funded via IRAD work.



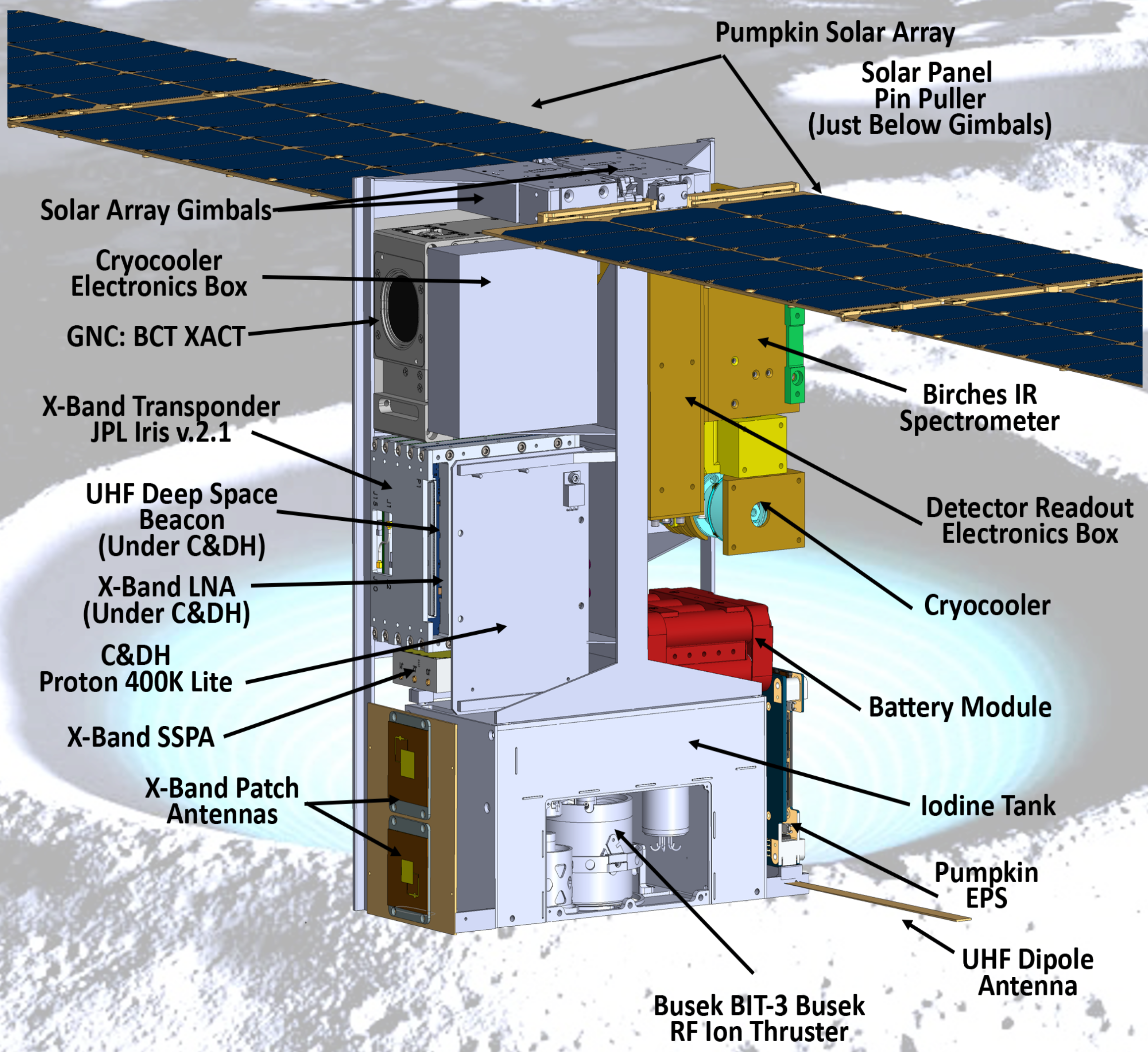
**Communication, Tracking**: X-band, JPL Iris Radio, dual X-band patch antennas. MSU has 21-m dish that is becoming part of the DSN. Anticipated data rate 128 kb/s

**C&DH**: very compact and capable proton 400K (trade volume, complexity, cubesat heritage, live with the fact this hasn't flown in deep space)

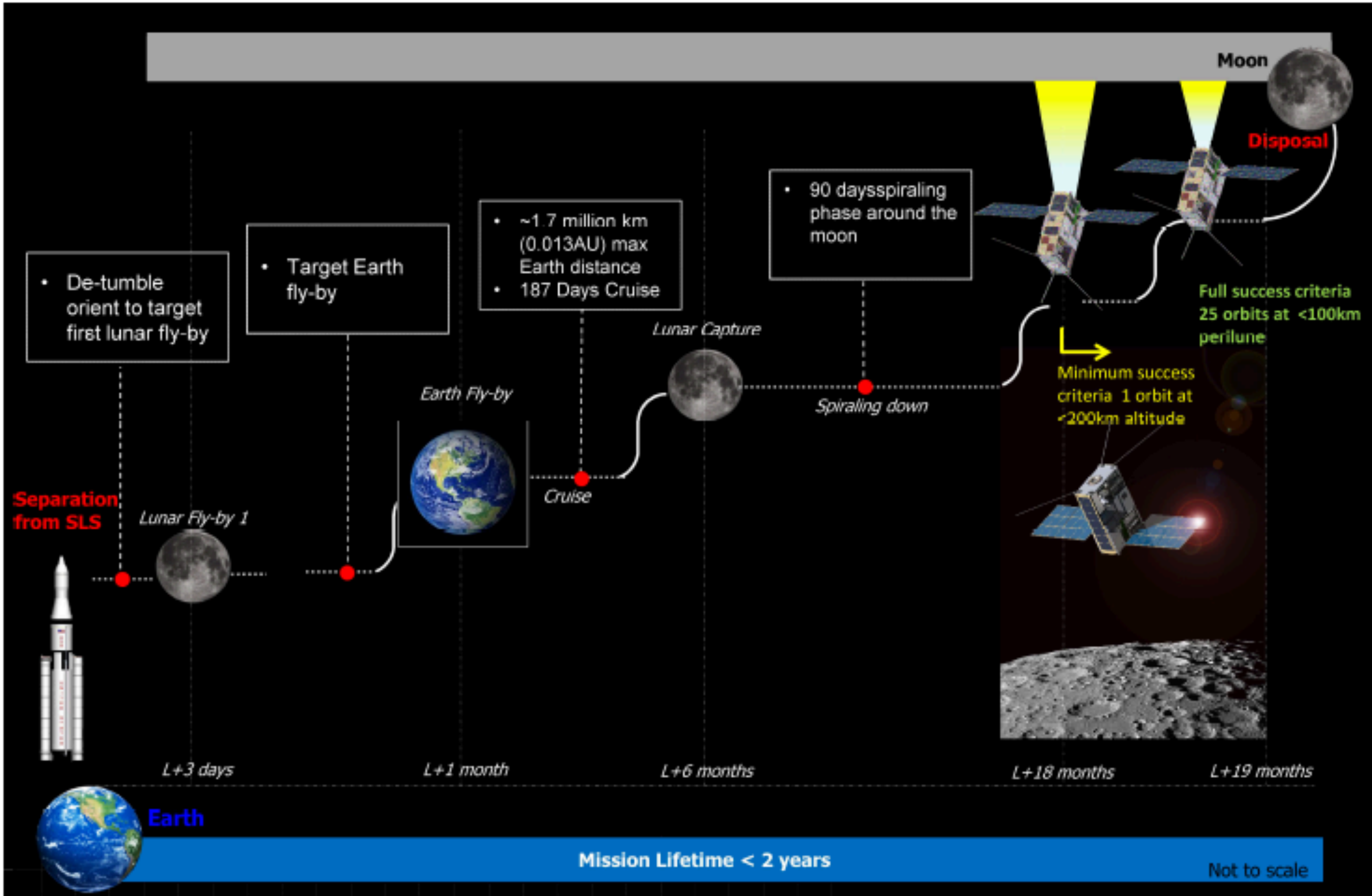


**GNC/ACS**: Modified Blue Canyon system. Multi-component (star trackers, IMU, RWA) packages with heritage available, including BCT XB1, which can interface with thrusters (trade cost, volume, cubesat heritage, live with the fact this hasn't flown in deep space)

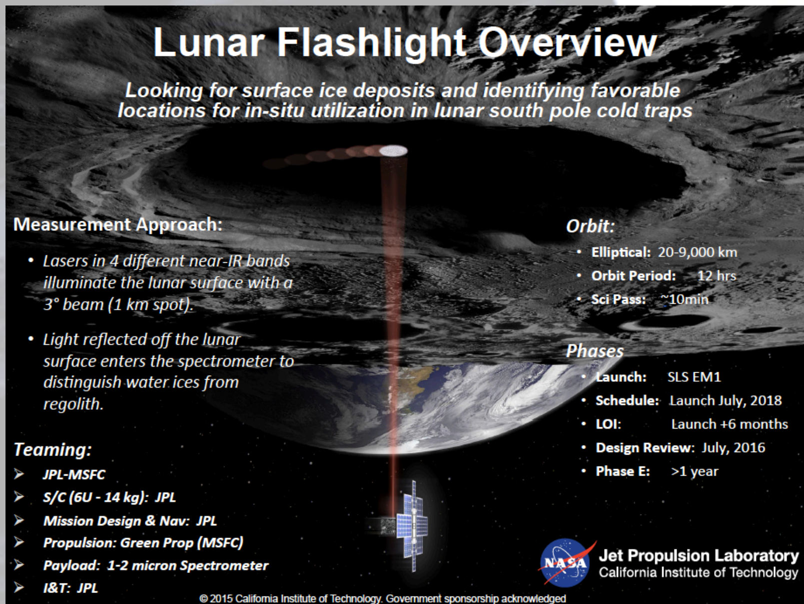
# Lunar Ice Cube Bus



# Lunar IceCube ConOps



# Other EM1 Mission Complimentarity



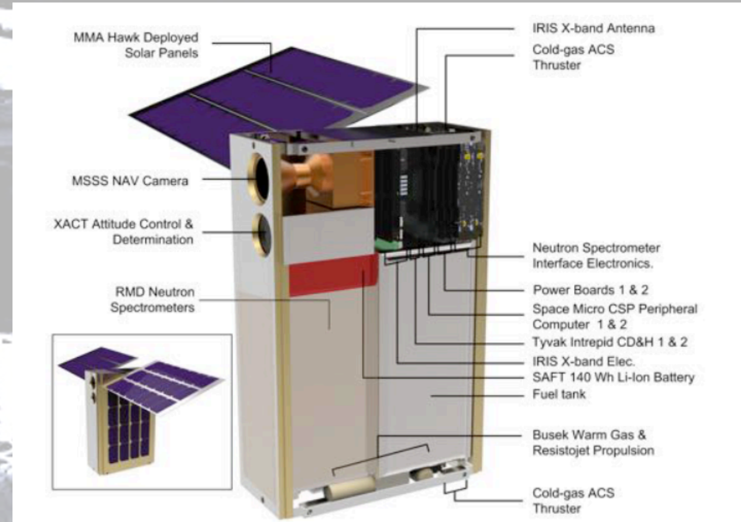




**Figure 1:** LunaH-Map cut-away showing spacecraft components and configuration. Inset image shows LunaH-Map deployed configuration.

Lunar Flashlight: Detect surface ice for PSRs polar region by measuring laser stimulated emission at several ice-associated lines.

LunaH Map: Detect ice in top layer (tens of centimeters) of regolith for PSRs polar region by measuring decrease in neutron flux (anti-correlated with protons) using neutron spectrometer.

Lunar IceCube: Determine water forms and components abundances as a function of time of day, latitude, and lunar regolith properties using broadband point spectrometer.