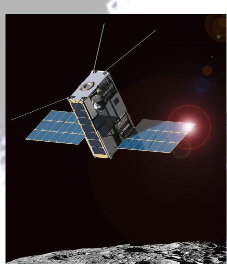
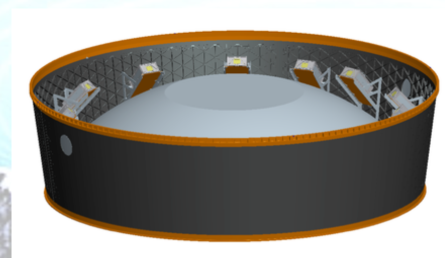
Lunar Ice Cube Orbiter:

Lunar Volatile Dynamics from a First Generation Deep Space CubeSat

P.E. Clark, CalTech/Jet Propulsion Laboratory, Science PI
B. Malphrus, Morehead State University, PI
NASA/GSFC Payload: D. Reuter, T. Hurford, R. MacDowall, N. Petro, W. Farrell, C. Brambora, D. Patel, S. Banks, P. Coulter
NASA/GSFC Flight Dynamics: D. Folta, P. Calhoun
Morehead State University Bus, Mission Ops, Ground Communication: B. Twiggs, Jeff Kruth, Kevin Brown, R. McNeill
Busek: M. Tsay, V. Hruby
Vermont Technical College: Carl Brandon, Peter Chapin





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

Science Goals

Understanding the role of volatiles in the solar system

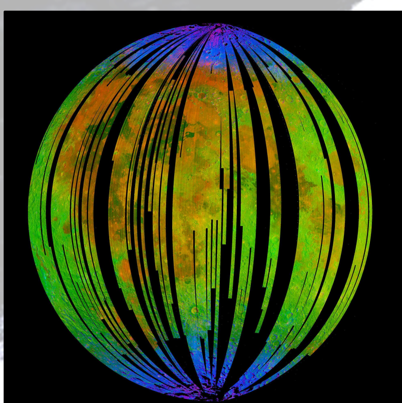
- Enabling broadband spectral determination of composition and distribution of volatiles in regoliths (the Moon, asteroids, Mars) as a function of time of day, latitude, regolith age and composition.
- Providing geological context by way of spectral determination of major minerals.
- Enabling understanding of current dynamics of volatile sources, sinks, and processes, with implications for evolutionary origin of volatiles.

IceCube addresses NASA HEOMD Strategic Knowledge Gaps related to lunar volatile distribution (abundance, location, transportation physics water ice).

IceCube complements the scientific work of Lunar Flashlight by by observing at a variety of latitudes, not restricted to PSRs

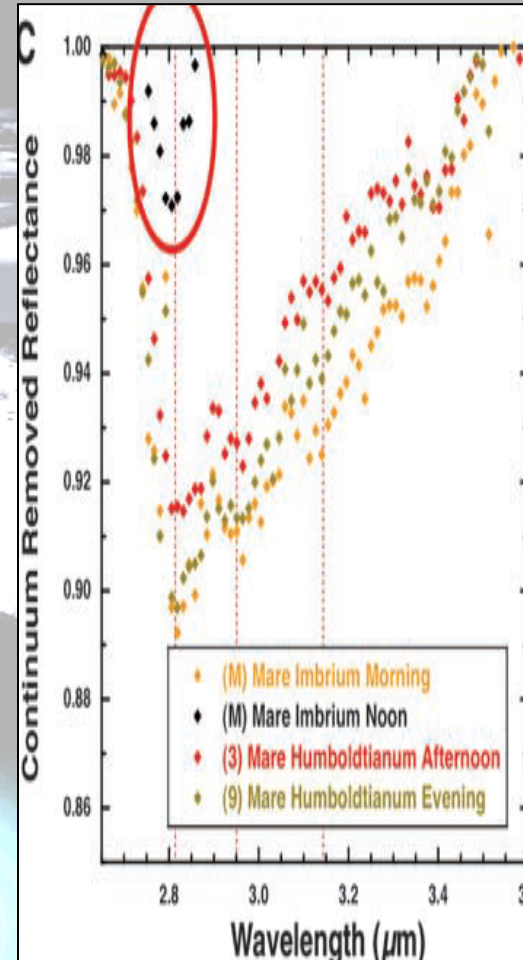
Lunar IceCube versus Previous Missions

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)	



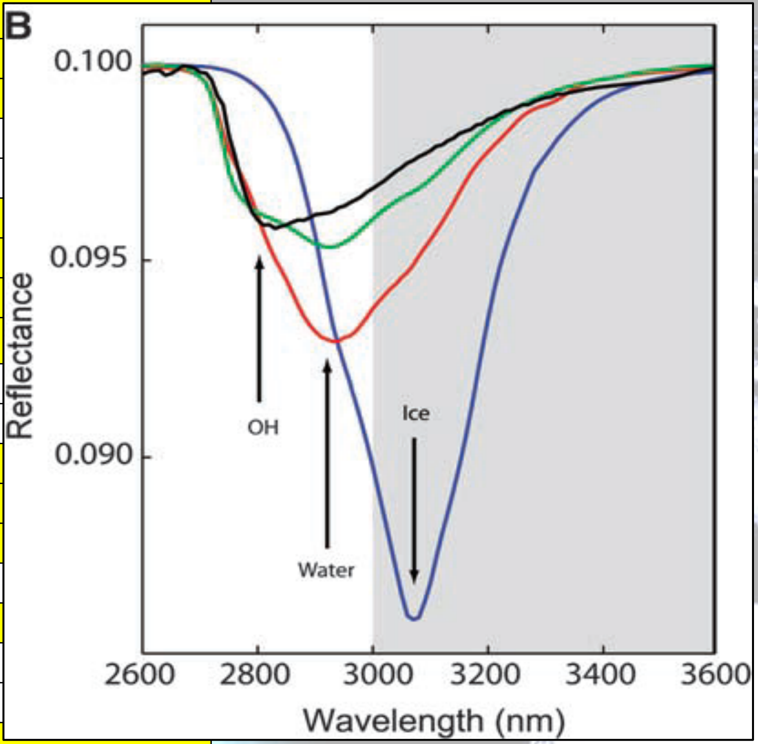
M3 'snapshot' lunar nearside indicating surface coating OH/H_2O (blue) near poles (Pieters et al, 2009)

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 H_2O
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 H_2O	2.85	Houck et al (Mars)
	3	H_2O of hydration
	2.95	H_2O stretch (Mars)
	3.14	feature w/2.95
adsorbed H_2O	2.9-3.0	R. Clark
ice	1.5	band depth-layer correlated
	2	strong feature
	3.06	Pieters et al
Other Volatiles		
NH_3	1.65, 2. 2.2	N-H stretch
CO_2	2, 2.7	C-O vibration and overtones
H_2S	3	
CH_4/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		



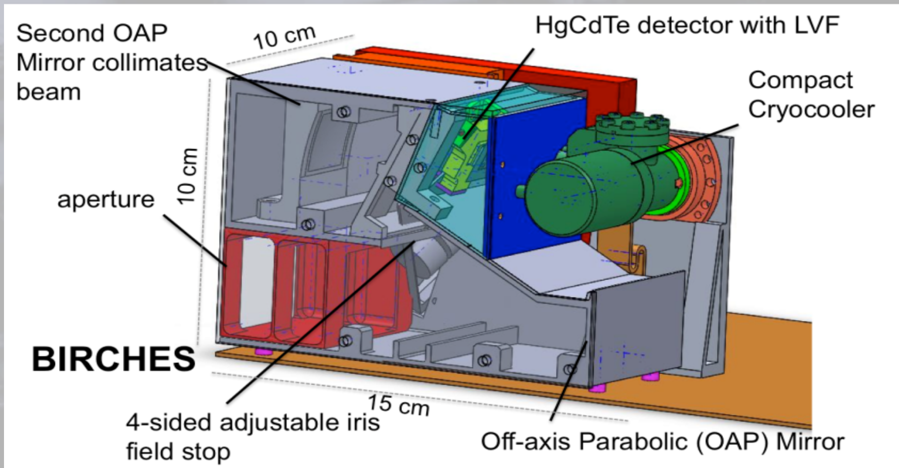
Ice Cube measurements will encompass the broad 3 um band to distinguish overlapping OH, water, and ice features. Will have near 10 nm resolution in this band

Yellow = water-related features in the 3 micron region

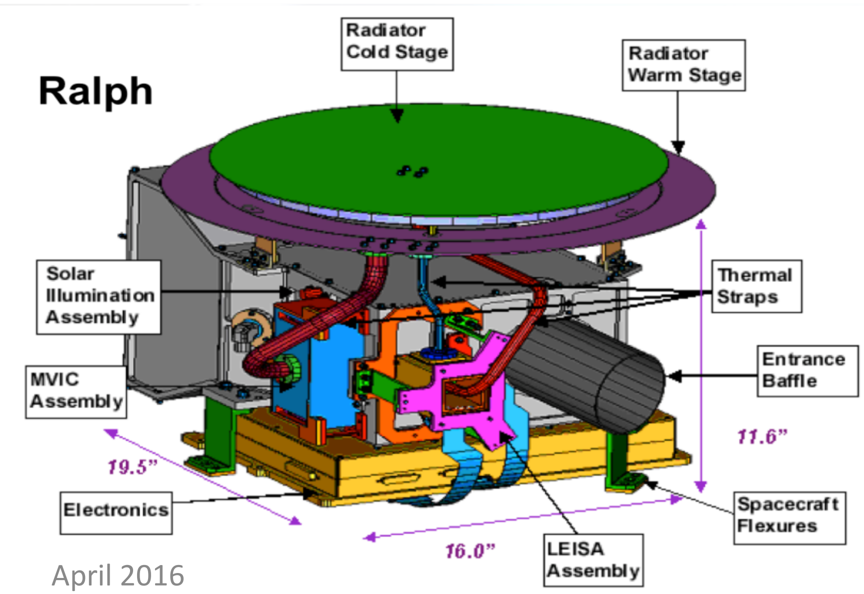
Influences on Measurable Signal at Volatile Bands	
Influences	**Effect**
Time of day	hydroxyl, water production/release as function of temperature, solar exposure
Latitude	greater impact of local topography near poles
Solar output	transient variations induced by solar output or events
regolith composition	variation in availability of OH, FeO
shadowing (slope orientation)	minimal or irregular illumination, lower temperature, potential cold trap
regolith maturity	variation in extent of space weathering induced reduction by hydrogen
feature type (impact or volcanic construct)	geomorphology induced cold trapping or internal volatile release
age	age-induced structural degradation reduces influence of local topography
major terrane (highland, maria)	combined age and composition effects

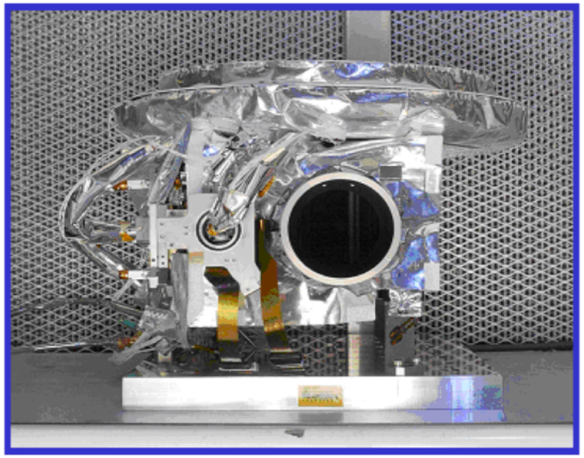
Mission Payload BIRCHES: Broadband IR Compact High Resolution Exploration Spectrometer

- Broadband (1 to 4 um) IR spectrometer with HgCdTe and compact line separation (LVF)
- Compact microcrycooler to ≤ 120K to provide long wavelength coverage
- compact optics box designed to remain below 220K
- OSIRIS Rex OVIRS heritage design

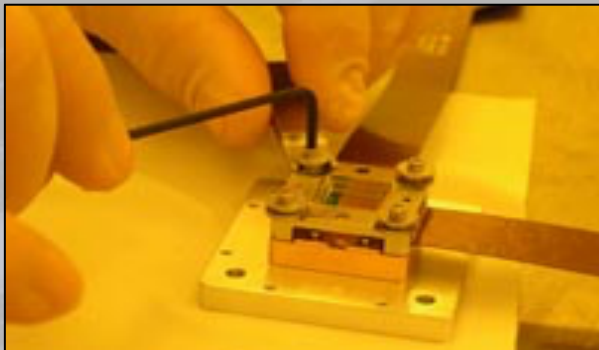


Property	Ralph	BIRCHES
Mass kg	11	2.5
Power W	5	#10-15 W
Size cm	49 x 40 x 29	10 x 10 x 15
# includes 3 W detector electronics, 1.5 W iris controller, 5-10 W cryocooler		

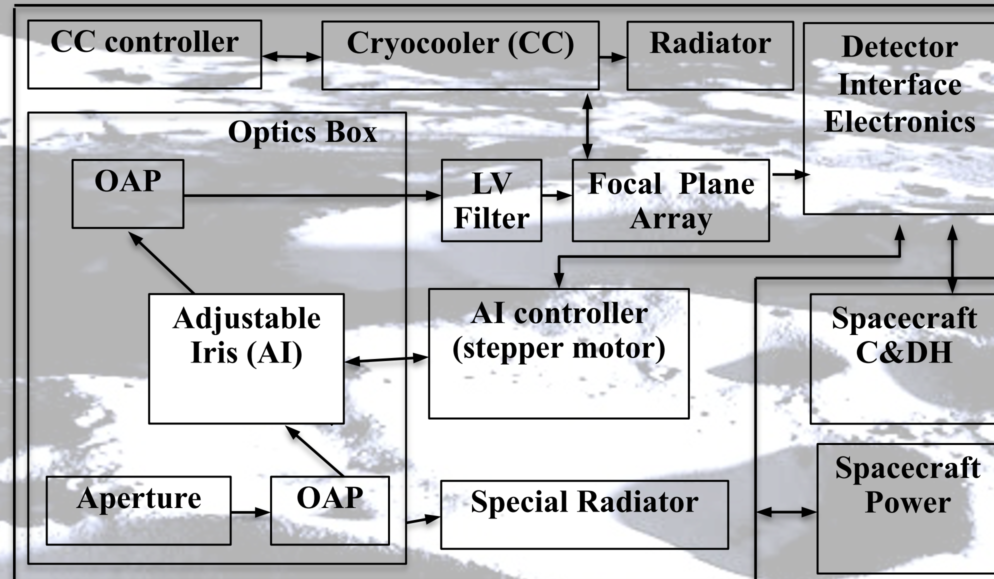




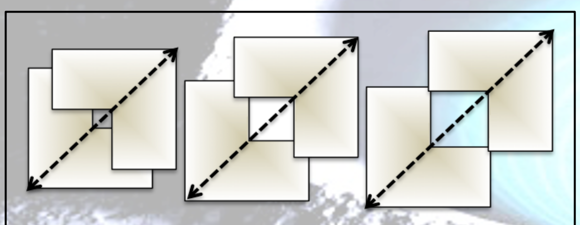
Spectrometer Components



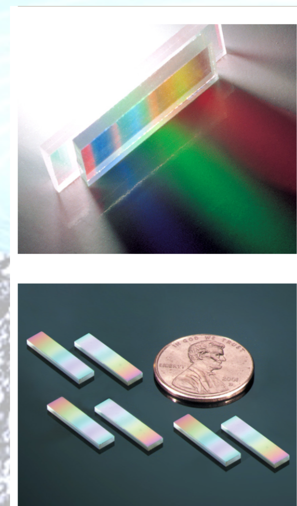
BIRCHES utilizes a compact Teledyne H1RG HgCdTe Focal Plane Array and JDSU linear variable filter detector assembly leveraging OSIRIS REx OVIRS.



BIRCHES block diagram illustrates simplicity and flexibility of design.

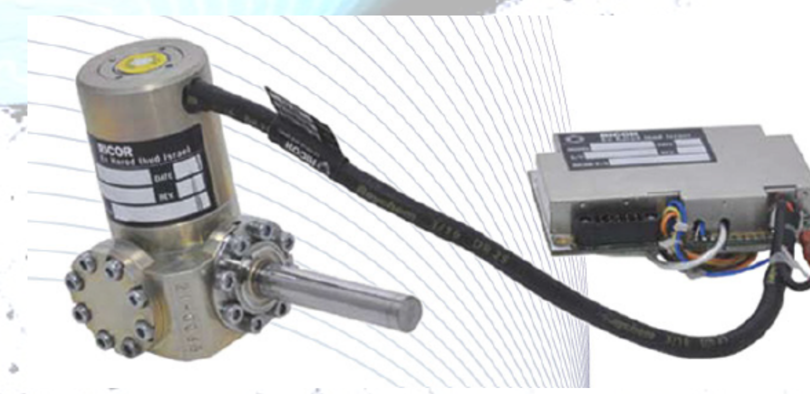


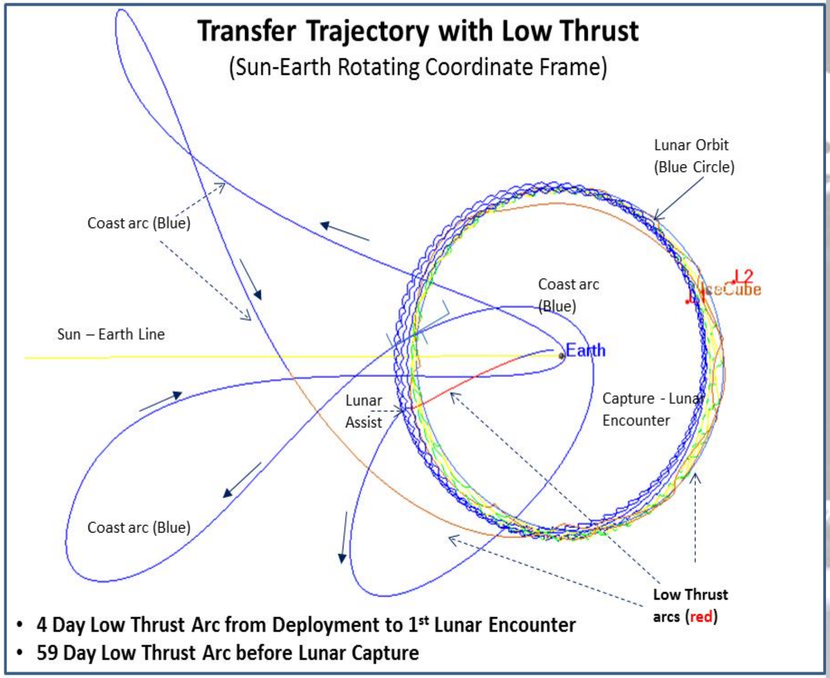
Adjustable Iris maintains footprint size at 10 km by varying FOV regardless of altitude



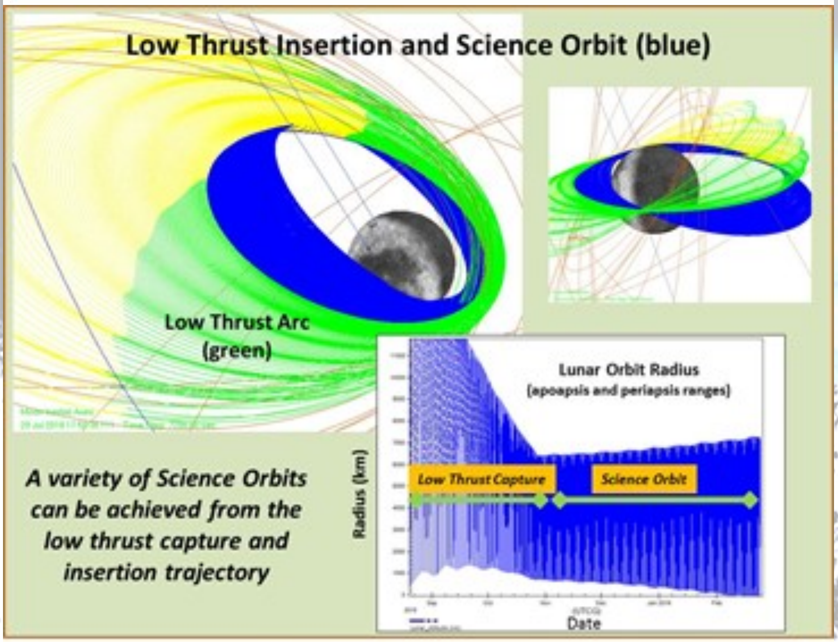
JDSU LV filters

Off the shelf tactical cryocooler with cold finger to maintain detector at ≤120K

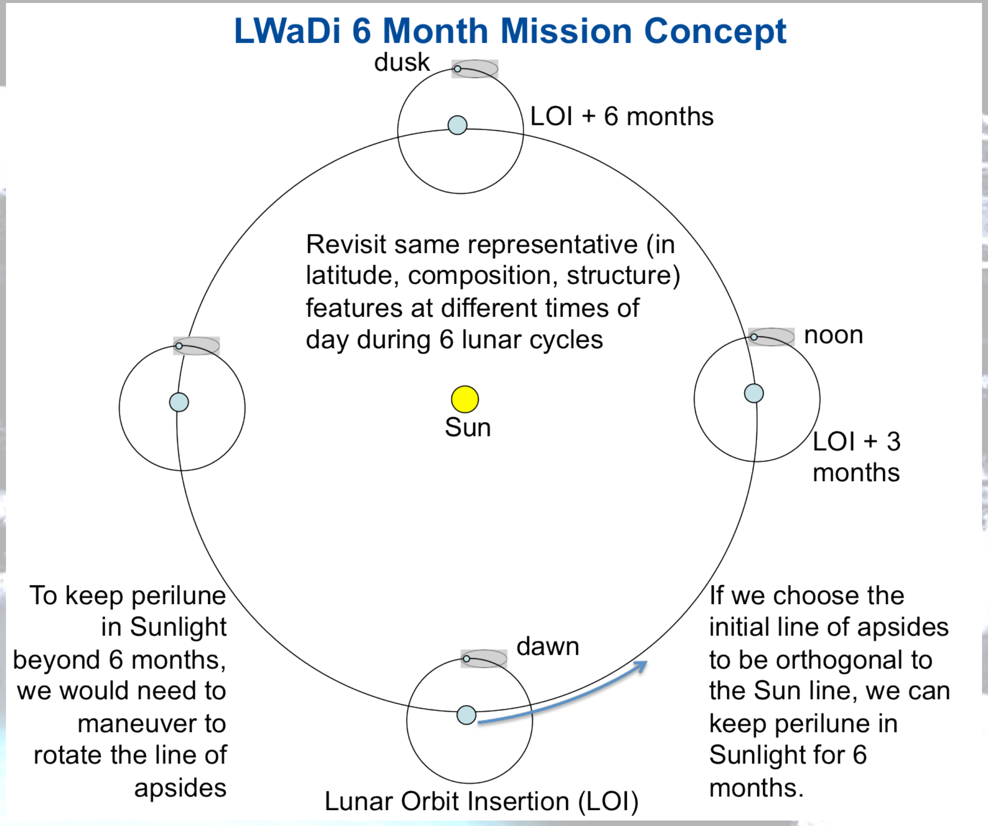




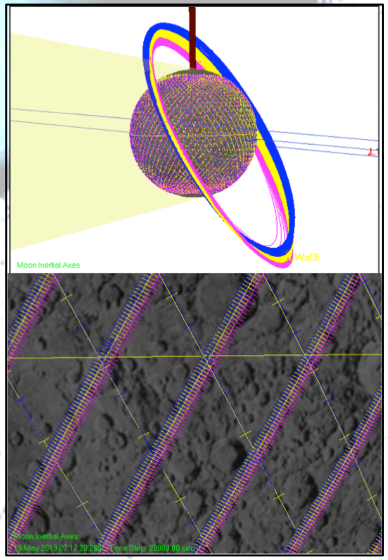
Transfer Trajectory with Low Thrust
(Sun-Earth Rotating Coordinate Frame)
Lunar Orbit
(Blue Circle)
Coast arc (Blue)
Coast arc
(Blue)
L2
Sun – Earth Line
Earth
Lunar
Assist
Capture - Lunar
Encounter
Coast arc (Blue)
Low Thrust
arcs (red)
• 4 Day Low Thrust Arc from Deployment to 1st Lunar Encounter
•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



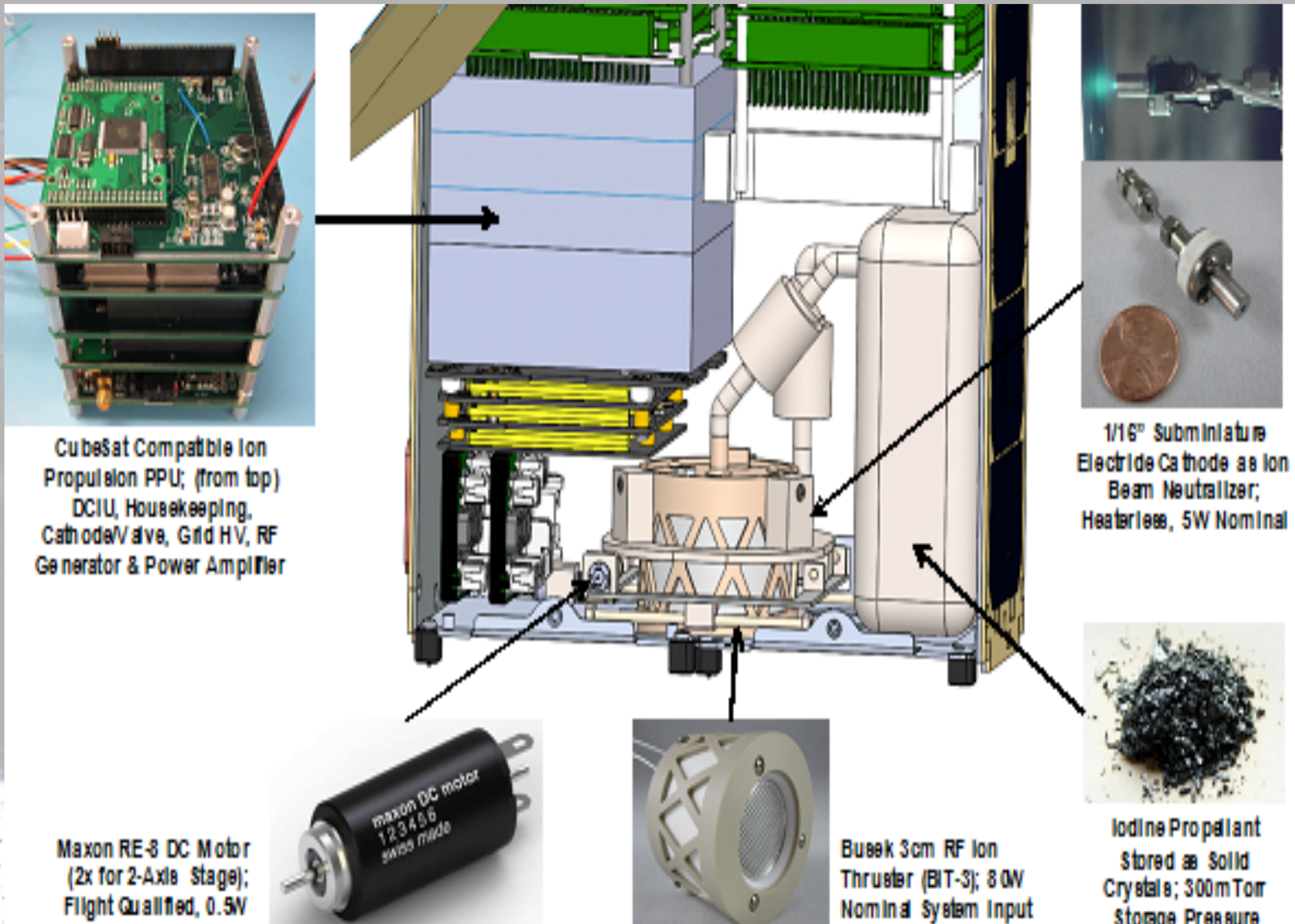
Low Thrust Insertion and Science Orbit (blue)
Low Thrust Arc
(green)
A variety of Science Orbits
can be achieved from the
low thrust capture and
insertion trajectory
Lunar Orbit Radius
(apoapsis and periapsis ranges)
Radius (km)
Low Thrust Capture
Science Orbit
Date



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)



Busek Iodine ion propulsion system (EP)

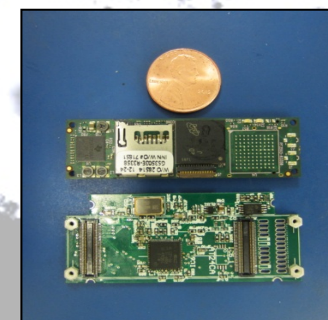


-External electron source to offset charge build-up Volume ~ 2 U, EM life testing 2016

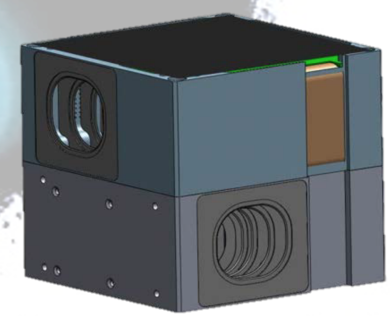
Bus Components

Thermal Design: with minimal radiator for interior the small form factor meant that interior experienced 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 ~ 50 kb/s

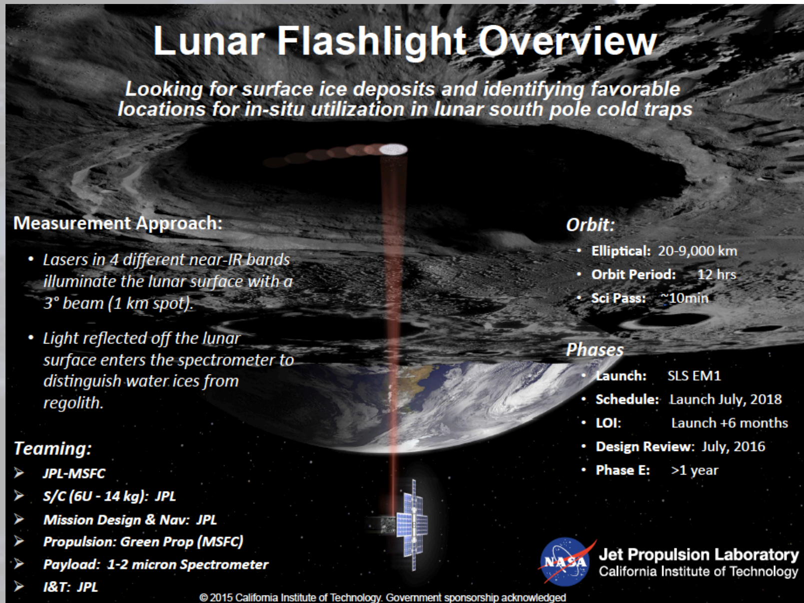


C&DH: very compact and capable Honeywell DM microprocessor, at least one backup C&DH computer (trade volume, complexity, cubesat heritage, live with the fact this hasn't flown in deep space)



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)

Other EM1 Mission Complimentarity



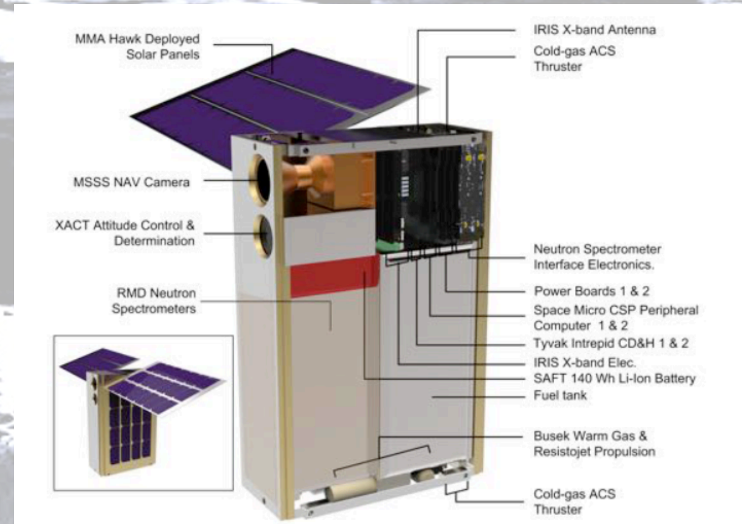


Figure 1: LunaH-Map cut-away showing spacecraft components and configuration. Inset image shows LunaH-Map deployed configuration.

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.

Current status and issues

Data Access and Archiving: Discussions with LMMP on arrangements for data access and archiving. Proposal to PDART.

Volume: Additional volume accommodation for Iris radio and propulsion system. Building compact electronics.

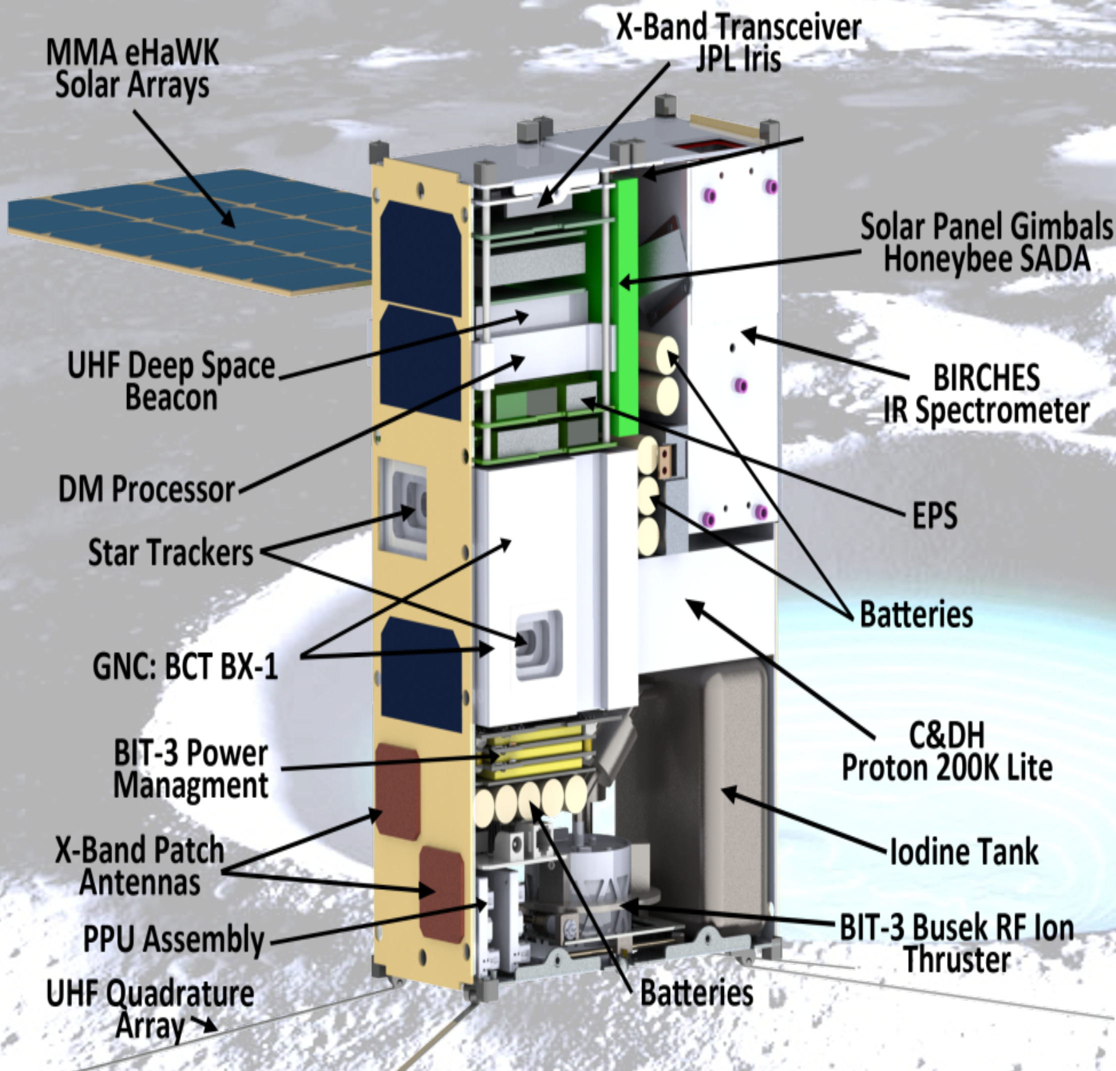
Very high Vibration and Shock survival in requirements documents: deployer design will mitigate considerably and original margins are very high

Very large temperature range survival in requirements documents: partially mitigated by 'rolling' spacecraft once Orion deployed +1.5 hours).

Radiation issue: Deployment opportunity starts in the second lobe of the Van Allen Belt: 8 to 11 hours to get out…however only relatively small Total Ionizing Dose to deal with.

Thermal Design: major cubesat challenge. Using dedicated radiator to minimize temperature of optics box (<240K). Using microcryocooler to maintain detector at 120K.

IceCube Concept: Morehead CubeSat Bus



Conclusions

- IceCube to place an IR spectrometer in lunar orbit to look for surface OH, water, other volatiles
- Correlate volatiles with surface mineralogy, surface temperature, illumination, solar wind, etc
- Examine changes in surface volatile content to get at dynamics issues! (like Sunshine et al., 2009 observation)
- Uses MSU cubesat bus, with Busek propulsion
- Enabling GSFC flight dynamics: Use of low energy manifolds to get into lunar capture
  - Propulsion solution and flight dynamic requirements uniquely solved in a self-consistent way
  - Creating a tailored solution with a standard platform

Seattle, WA is the place and it's all about space at LunarScene 2016!

We've combined our highly regarded technical workshops on Lunar Surface Applications and LunarCubes with our Space Entrepreneur workshop and Hack the Moon hackathon for one spectacular, 10 day event.

September 26-27, 2016
The 6th International Workshop on Lunar Surface Applications

There are major opportunities for scientists and space entrepreneurs alike to get new hardware and instruments flying relatively soon and at low cost through privately funded platforms. Learn more about the latest technology, and the recent science and business plans that will fuel the Lunar Renaissance and open the Lunar Frontier, as private companies continue their push to explore space.

September 28-29, 2016
The 6th International Workshop on LunarCubes

Join the best space scientists, engineers, entrepreneurs and investors from around the world to discuss, explore, and redefine the technology, collaboration and commercial strategies required to make the most of LunarCubes, an unprecedented opportunity in space exploration.

September 30, 2016
Entrepreneur Day

Let's hear it for the Entrepreneur! Topics include Entrepreneurship for the Lunar Frontier, Collaboration & Partnerships in New Space and Funding for Space Companies - Tried and True vs. All That's New. This is a hands on training day with experts in the field ... crowd funding, crowd sourcing, and equity funding are just a few of the topics that will be discussed.

October 1-2, 2016
Hack the Moon

At Hack the Moon, students and space enthusiasts have the opportunity to come up with creative solutions to space-related problems, while New Space startups can create and launch their own successful Kickstarter campaigns. This is a hands on workshop - create one or more solutions to a real space problem and you and your team will be eligible for prizes.

www.lunarworkshops.com **pamela.e.clark@jpl.nasa.gov**

Join us September 26 - October 2, 2016 for the Lunar Workshop of The Year - LunarScene 2016!