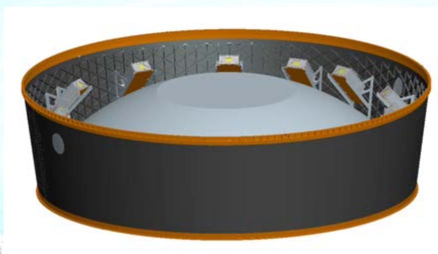
Broadband InfraRed Compact High-resolution Exploration Spectrometer: Lunar Volatile Dynamics for the Lunar Ice Cube Mission

P.E. Clark, CalTech/Jet Propulsion Laboratory, Science PI
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, Flight Software: Carl Brandon, Peter Chapin



EM1 Deployment System for the 'lucky 13'

Jet Propulsion Laboratory
California Institute of Technology

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

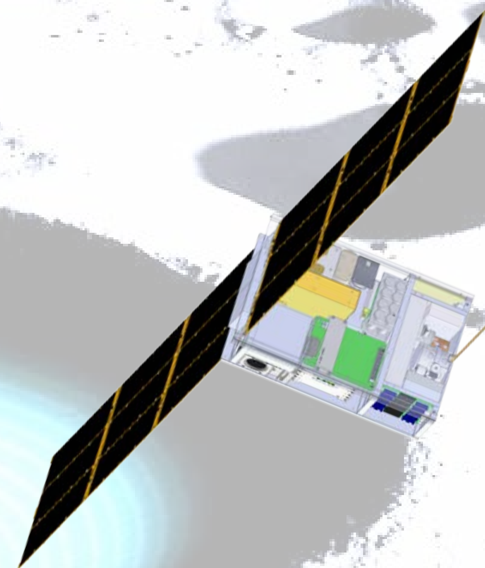
Government sponsorship acknowledged.

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 NH3, H2S, CO2, CH4, 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.

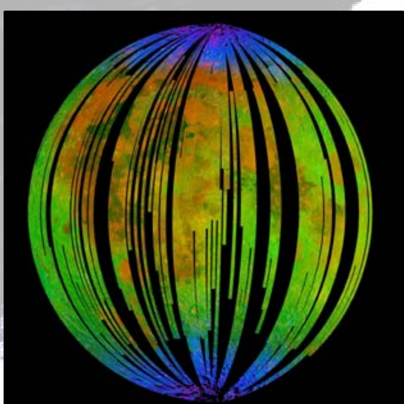
Technology Goals
Demonstrate Enabling Technologies for Interplanetary Cubesats

- 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
- Modified eHaWK Power Array- highest power >90W CubeSat



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)	

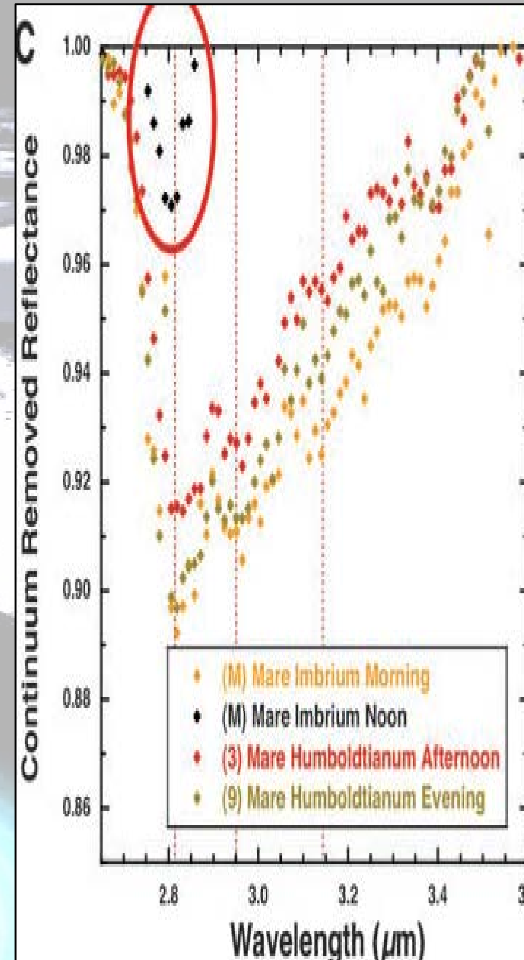


M3 'snapshot' lunar nearside indicating surface coating OH/H_2O (blue) near poles (Pieters et al, 2009)

Table B.2 IR measured volatile abundance in LCROSS plume (Colaprete et al, 2010)

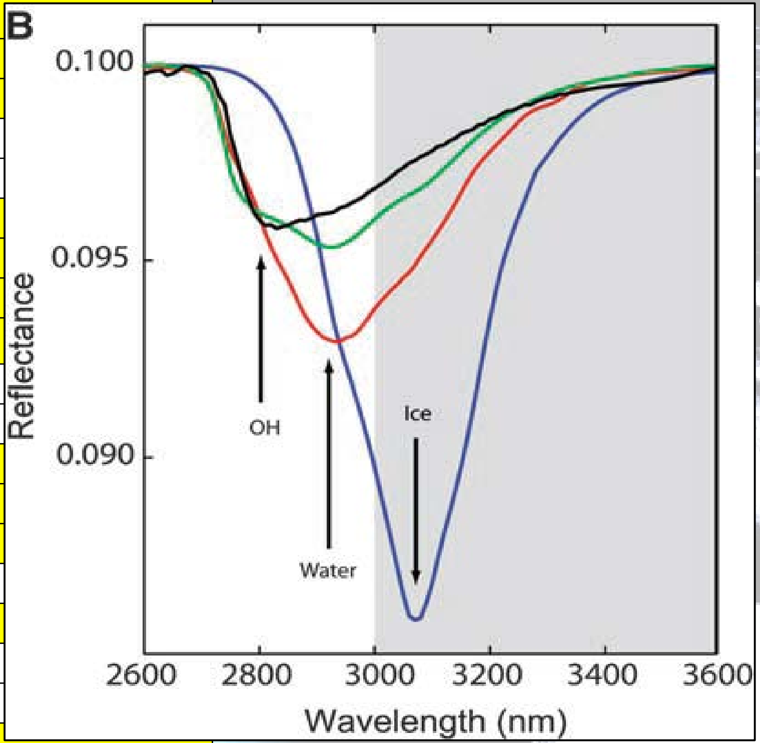
Compound	Molecules cm^{-2}	Relative to $H_2O(g)$*
H2O	5.1(1.4)E19	100%
H2S	8.5(0.9)E18	16.75%
NH3	3.1(1.5)E18	6.03%
SO2	1.6(0.4)E18	3.19%
C2H2	1.6(1.7)E18	3.12%
CO2	1.1(1.0)E18	2.17%
CH2OH	7.8(4.2)E17	1.55%
CH4	3.3(3.0)E17	0.65%
OH	1.7(0.4)E16	0.03%

*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.

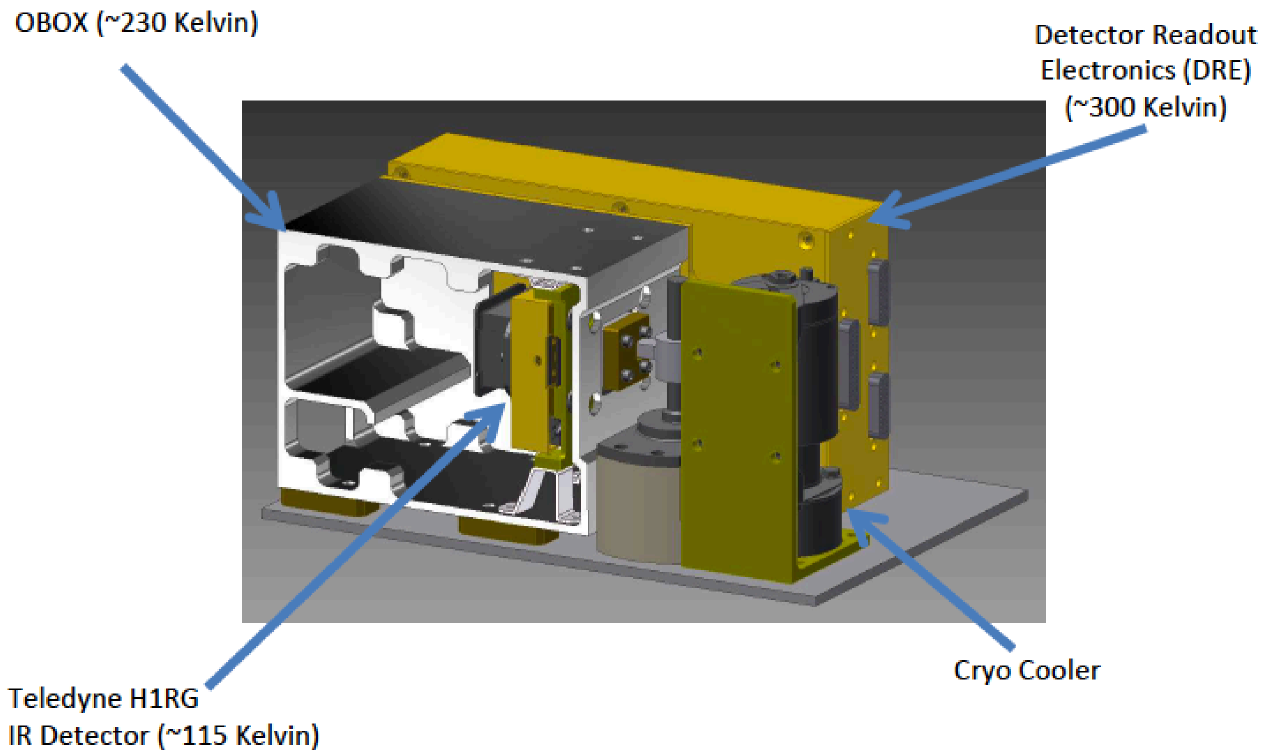
Species	µm	description
Water Form, Component		
water vapor	2.738	OH stretch
	2.663	OH stretch
liquid water	3.106	H-OH fundamental
	2.903	H-OH fundamental
	1.4	OH stretch overtone
	1.9	HOH bend overtone
	2.85	M3 Feature
	2.9	total H2O
hydroxyl ion	2.7-2.8	OH stretch (mineral)
	2.81	OH (surface or structural) 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		

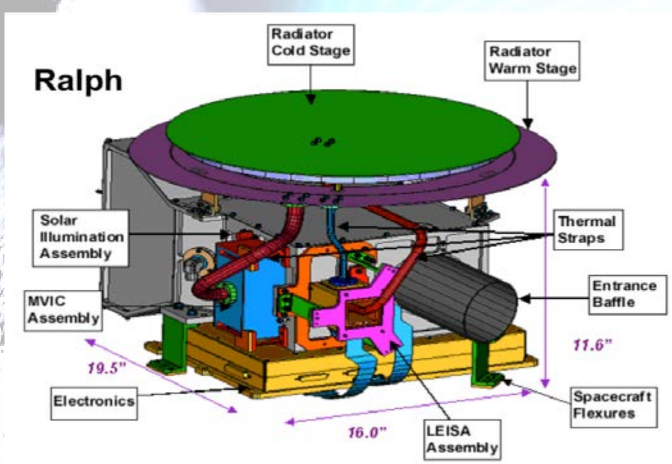


Ice Cube measurements will encompass the broad 3 um band to distinguish overlapping OH, water, and ice features. Will have near 10 nm resolution in this band

Yellow = water-related features in the 3 micron region

BIRCHES Instrument



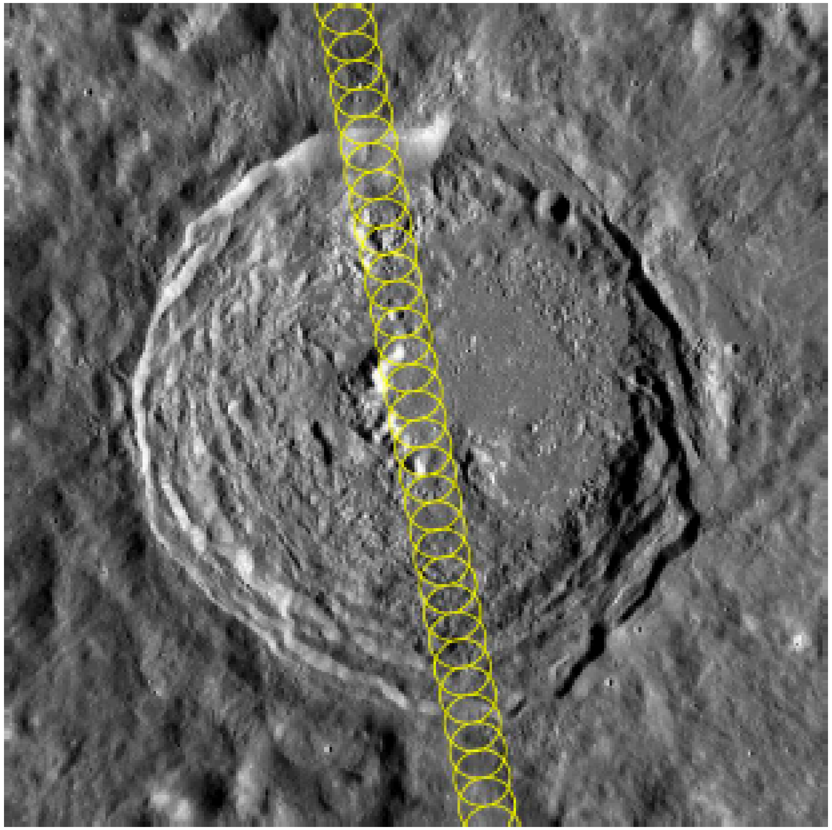


BIRCHES compactness		
Property	Ralph	BIRCHES
Mass kg	11	2.5
Power W	5	#10-15 W
Size cm	49 x 40 x 29	10 x 10 x 15
# includes 3 W detector electronics, 1.5 W AFS controller, 5-10 W cryocooler		

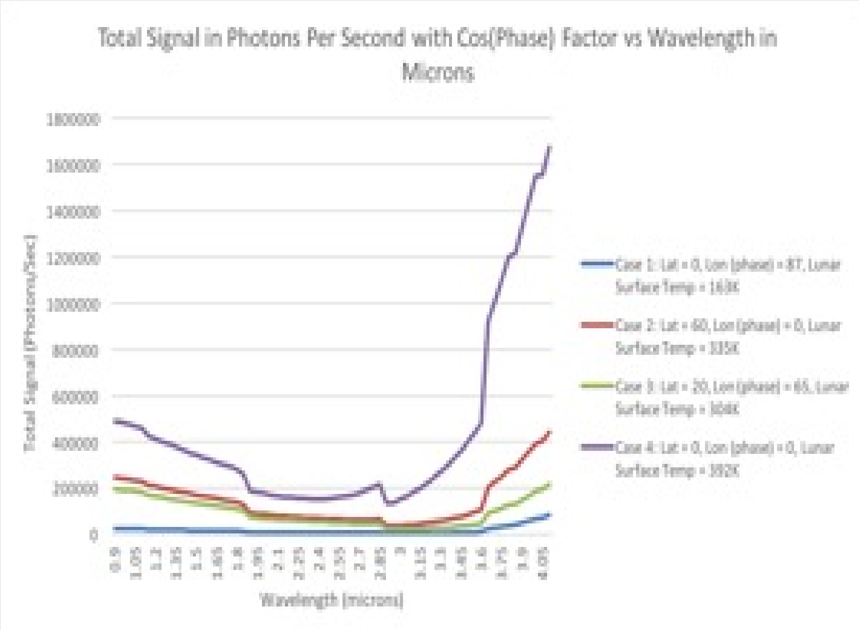
BIRCHES Observation Requirements

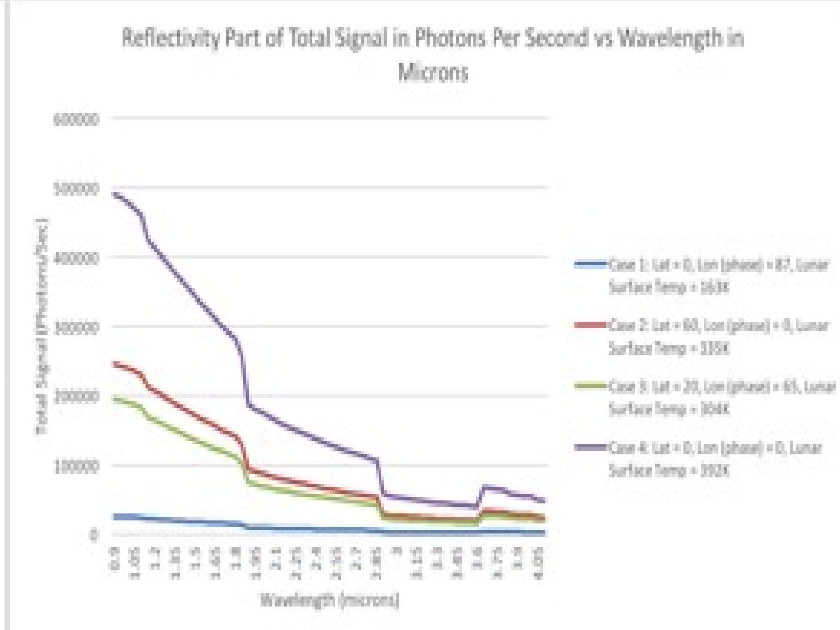
Requirement
A footprint of 10 km from an altitude of 100 km
Footprint 10 km in along track direction regardless of altitude, larger in crosstrack direction above 250 km
Nyquist sampling of the surface

- 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)



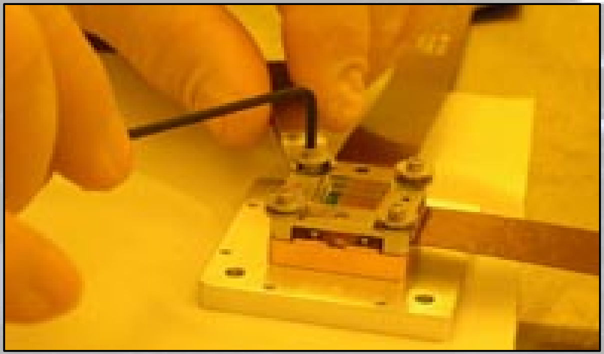
Vavilov Crater:
100 km in diameter
1° S, 138° W



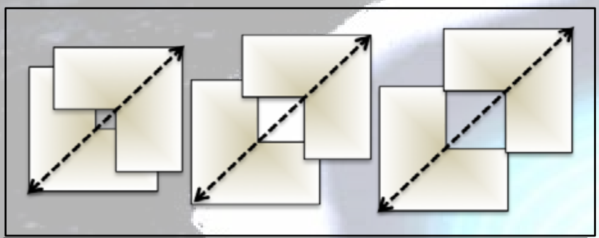


Case	Lat	ToD	Temp K	Reflectivity @ 3um photons/sec	Total Signal	SNR	Band depth/PPM water		
							0.1/1000	0.05/500	0.01/100
1	0	87	163	3254	2760	52	276	138	27
2	60	0	335	39045	26400	162	2640	1320	264
3	20	65	304	24279	20963	145	2096	1480	210
4	0	0	395	150777	52800	230	5280	2640	528

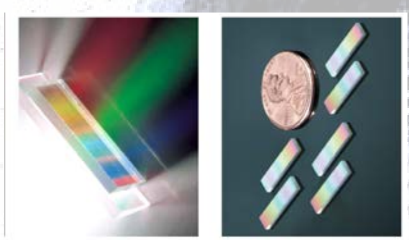
Spectrometer Schematic and Components



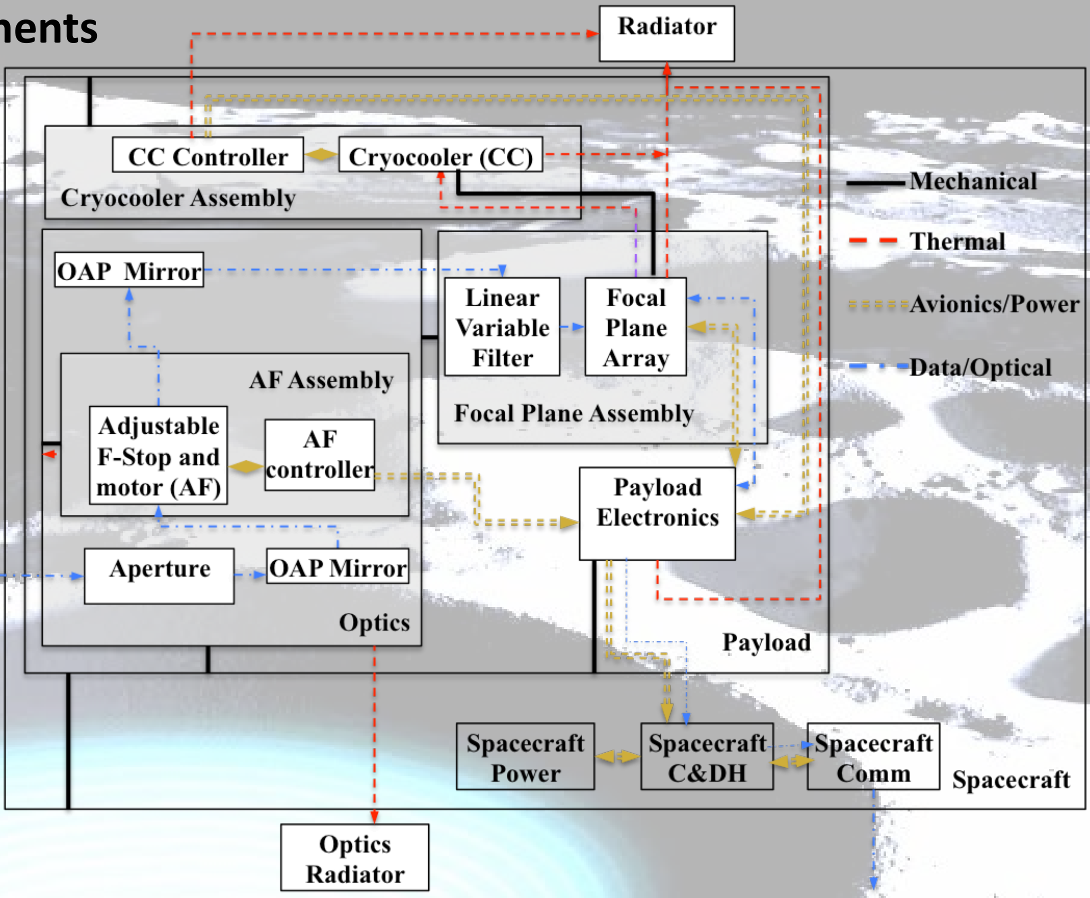
BIRCHES utilizes a compact Teledyne H1RG HgCdTe Focal Plane Array and JDSU linear variable filter detector assembly leveraging OSIRIS REx OVIRS.



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

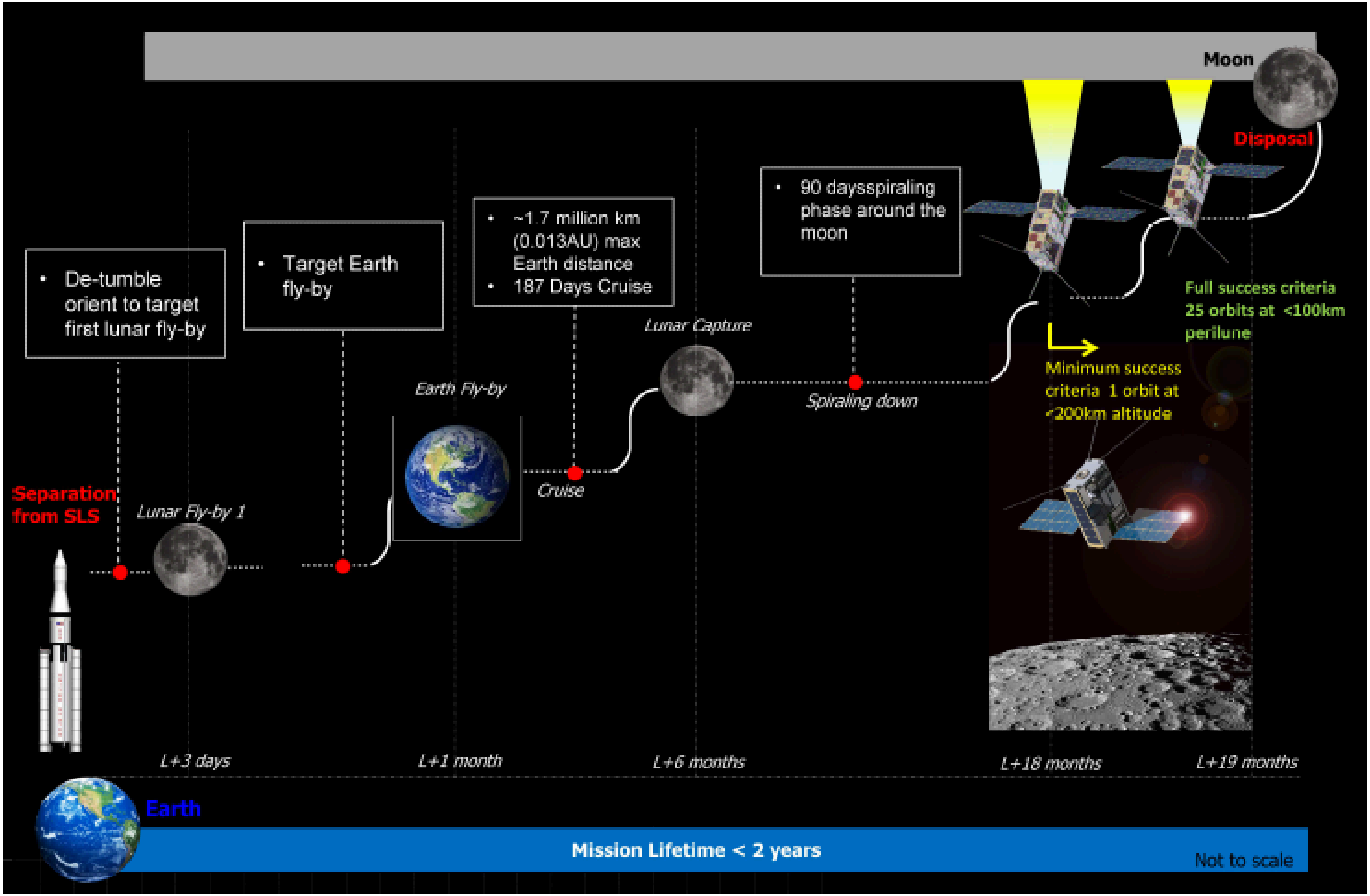


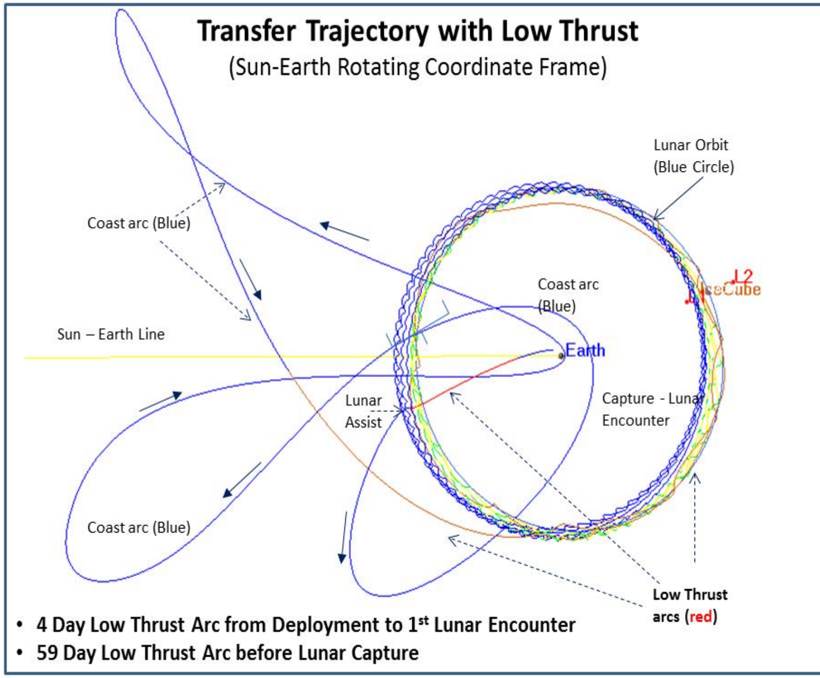
JDSU LV filters

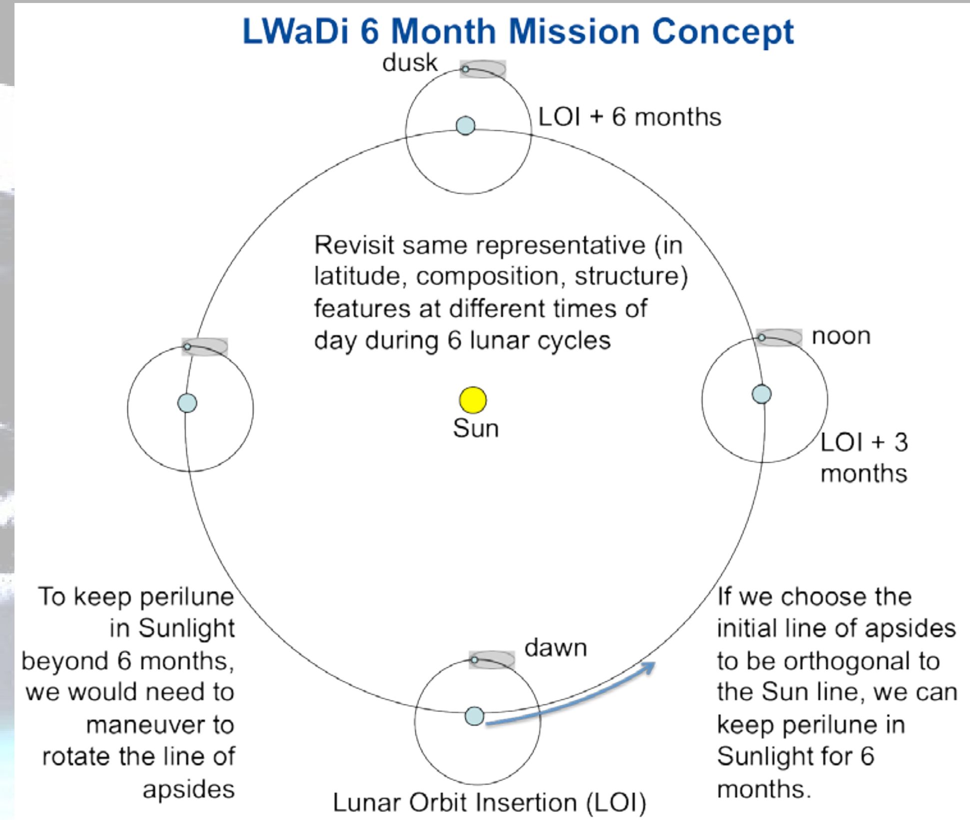


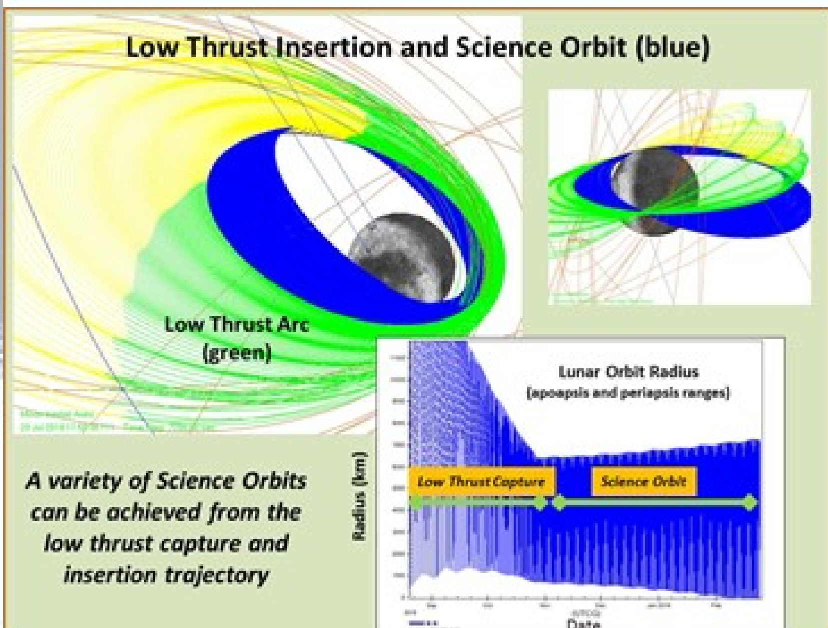
COTS AFRL developed AIM SX030 microcryocooler with cold finger to maintain detector at ≤115K and iris controller

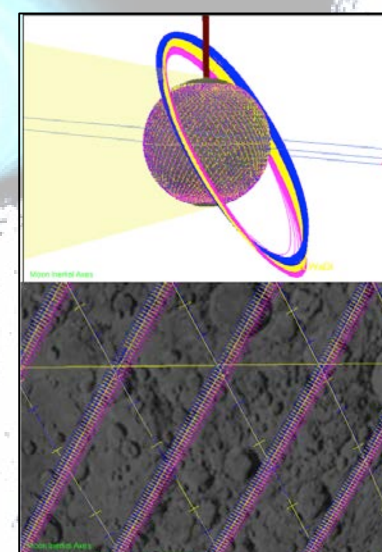
Lunar IceCube ConOps




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

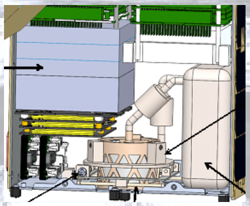

LWaDi 6 Month Mission Concept
dusk
LOI + 6 months
Revisit same representative (in latitude, composition, structure) features at different times of day during 6 lunar cycles
noon
Sun
LOI + 3 months
To keep perilune in Sunlight beyond 6 months, we would need to maneuver to rotate the line of apsides
dawn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


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



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.

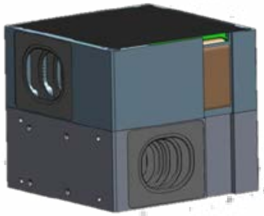


Thermal Design: with minimal radiator for interior the small form factor meant that interior experienced temperatures well within 0 to 40 degrees centrigrade, except for optics box which has a separate radiator. Thermal modeling funded via IRAD work.

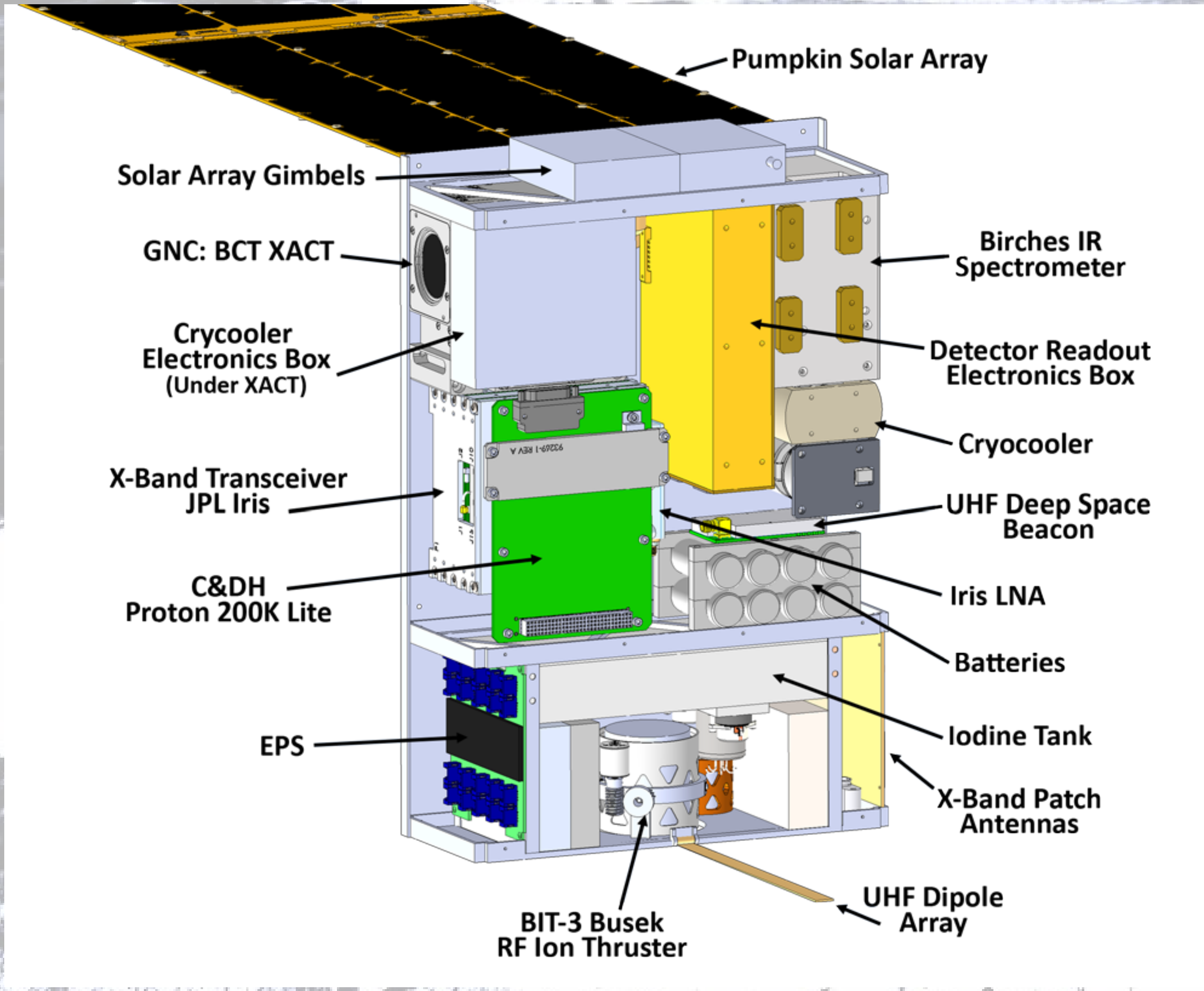
Communication, Tracking: X-band, JPL Iris Radio, dual X-band patch antennas. MSU has 21-m dish that is becoming part of the DSN. Anticipated data rate ~ 50 kb/s

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)



Lunar Ice Cube Bus



Current status and issues

Thermal Design: major cubesat challenge. Using dedicated radiator to minimize temperature of optics box <230K. Using microcryocooler to maintain detector <115 K.

Volume: A chronic problem. Accommodations needed for instrument for more robust microcryocooler and adjustable field stop controllers and propulsion systems especially.

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)

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.

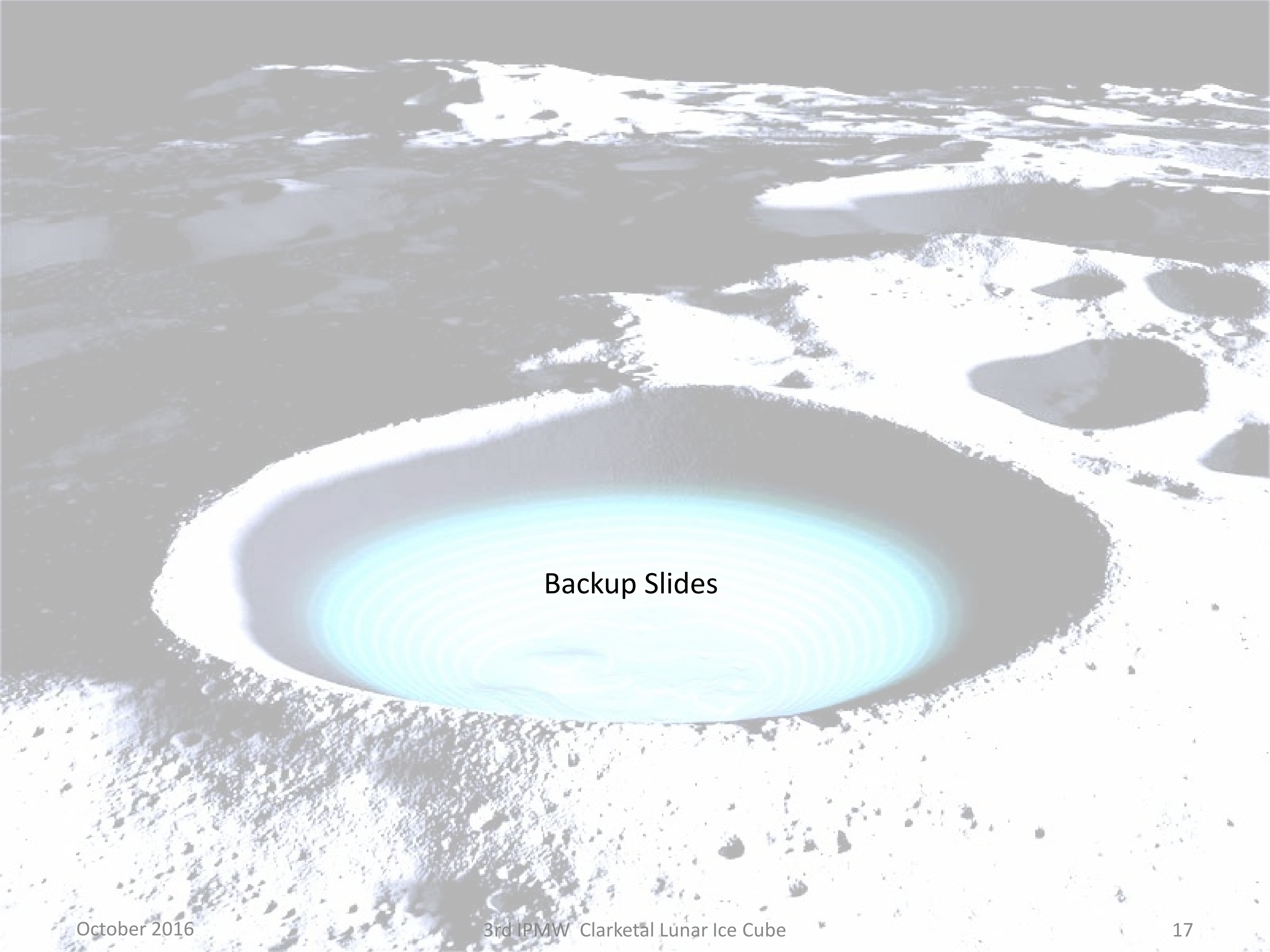
Data Access and Archiving: subsidized cubesat tool developed underway for stream-lined pipelining and archiving process.

Conclusions

- IceCube to place an IR spectrometer in lunar orbit to look for surface OH, water, other volatiles
- Examine changes in surface volatile content 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

LunarCubes Will Return!!!!

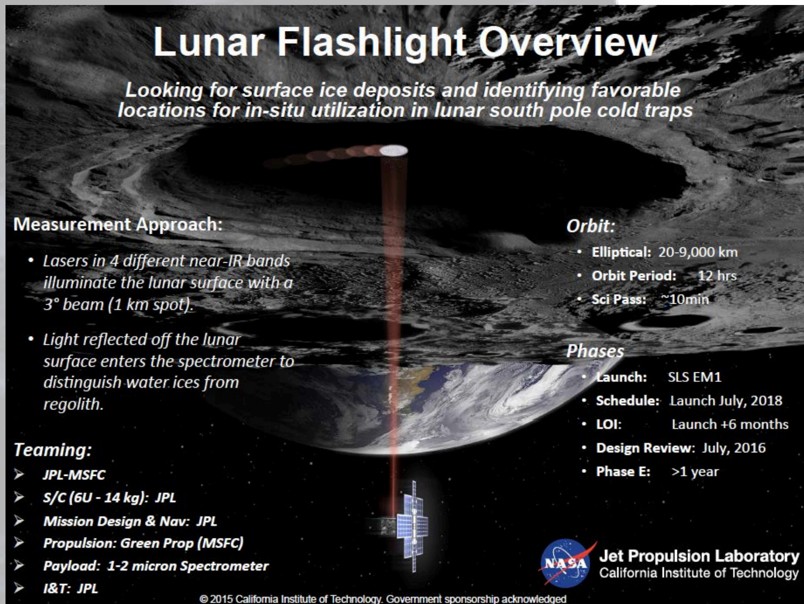
pamela.e.clark@jpl.nasa.gov



Backup Slides

Influences on Measurable Signal at Volatile Bands		
Influences	**Effect**	**Source of Data**
Time of day	hydroxyl, water production/release as function of temperature, solar exposure	Lunar Ice Cube
Latitude	function of temperature, solar exposure, rougher topography/shadowing near poles	Lunar Ice Cube, Lunar Flashlight, LunaH Map
Solar output	transient variations induced by solar output or events	LunaH Map
regolith composition	variation in availability of OH, FeO	M3, Kaguya
shadowing (slope orientation)	minimal or irregular illumination, lower temperature, potential cold trap	LOLA, LEND, Lunar Flashlight, LunaH Map
regolith maturity	variation in extent of space weathering induced reduction by hydrogen	M3
feature type (impact or volcanic construct)	geomorphology induced cold trapping or internal volatile release	Lunar Geology Maps
age	age-induced structural degradation reduces influence of shadowing	Lunar Geology Maps
major terrane (highland, maria)	combined age and composition effects	Lunar Geology Maps

Other EM1 Mission Complimentarity



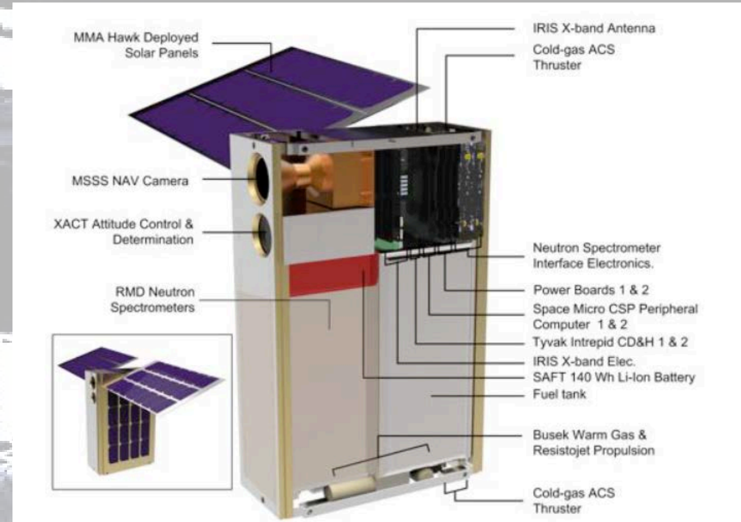


Figure 1: LunaH-Map cut-away showing spacecraft components and configuration. Inset image shows LunaH-Map deployed configuration.

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.