NASA HEOMD NextSTEP Lunar Ice Cube Mission: CubeSat Lunar Orbiter with BIRCHES (Broadband InfraRed Compact High-Resolution Exploration Spectrometer)

NEXTSTEP EM1 Mission and Instrument Concept

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EM1 Selectees to Date			
Program	**Target, Description**	**Payload**	**Lead**
HEOMD NEXT STEP	Moon, orbiter, Ice Cube	broadband IR cryocooled.	Morehead State U/ NASA GSFC/JPL/ Busek
HEOMD AES	Lunar Flashlight orbiter. (Surface ices in permanently shadowed 'cold traps')	NIR instrument.	JPL/NASA MSFC
HEOMD AES	Near Earth Asteroid Scout	Imager to characterize asteroid dynamics and surface	NASA MSFC/JPL
HEOMD AES	BioSentinel	Radiation Exposure Induced Genetic Damage Experiment	NASA ARC
HEOMD NEXT STEP	Skyfire lunar flyby	Tech Demo, Thermography	Lockheed Martin
SMD SIMPLEx			
STMD Centennial Challenges			

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).

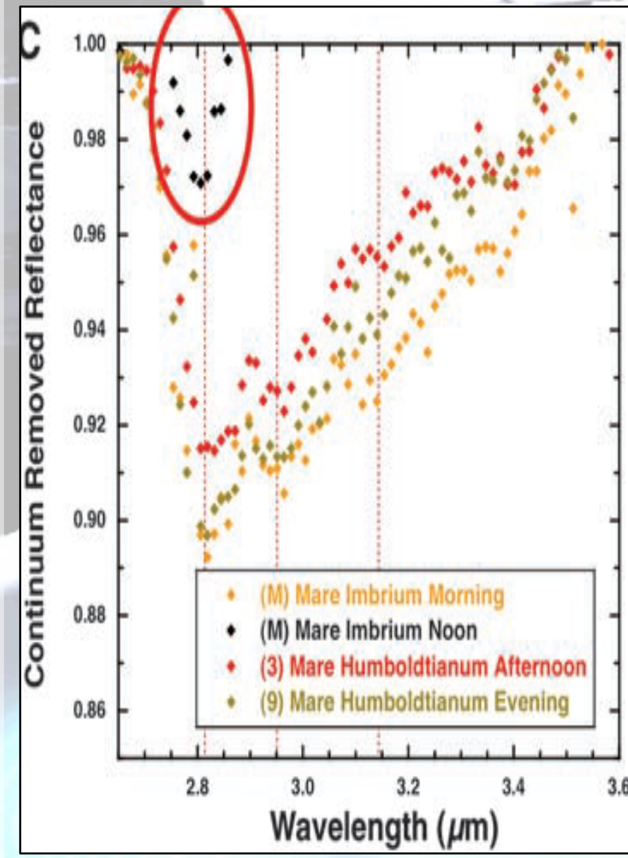
IceCube complements the scientific work of Lunar Flashlight by by observing at a variety of latitudes, not restricted to PSRs

While M3 provided a 'snapshot' mosaic of lunar nearside indicating surface coating of OH/H_2O (blue) near the poles,

Early evidence for diurnal variation trend in OH absorption (Sunshine et al. 2009)

LCROSS provided evidence of additional subsurface volatiles.

IceCube will extend 'snapshots' to geospatially linked time of day and latitude coverage.



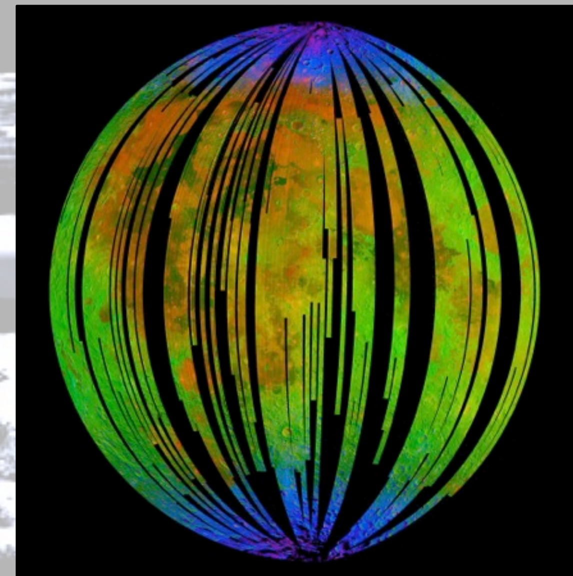


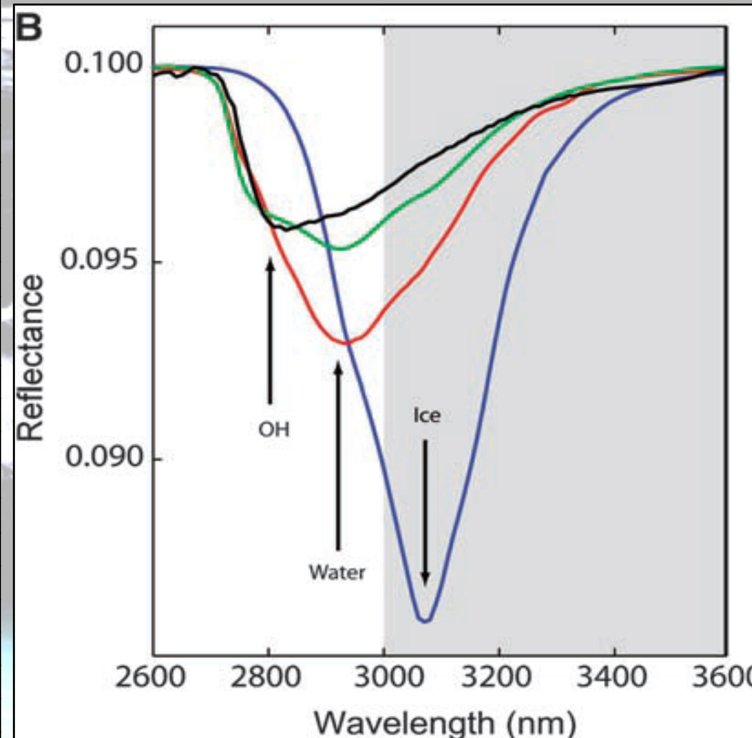
Table B.2 IR measured volatile abundance in LCROSS plume (Colaprete et al, 2010)

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

Table C.1 Water-, Volatile-, and Mineral-Related Bands

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 would be structural<bound<adsorbed<ice		

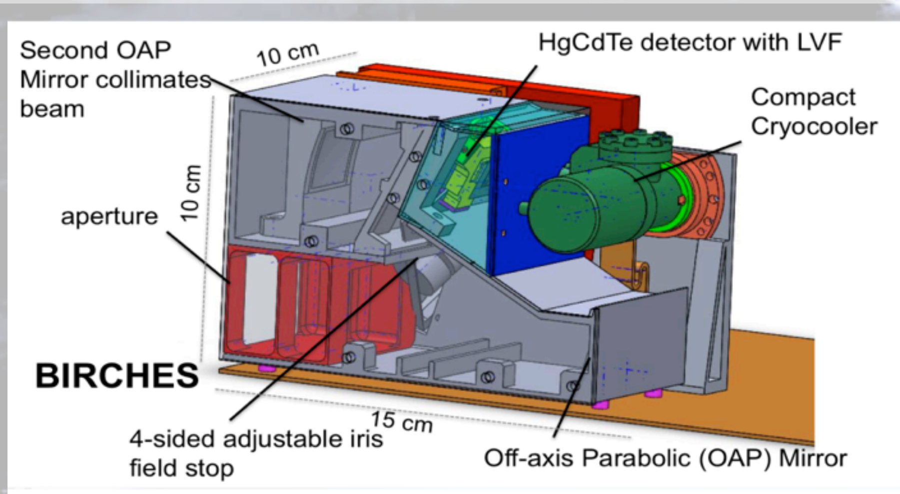


Ice Cube measurements will not cut off (Pieters et al. 2009) but encompass the broad 3 um band to distinguish overlapping OH, water, and ice features.

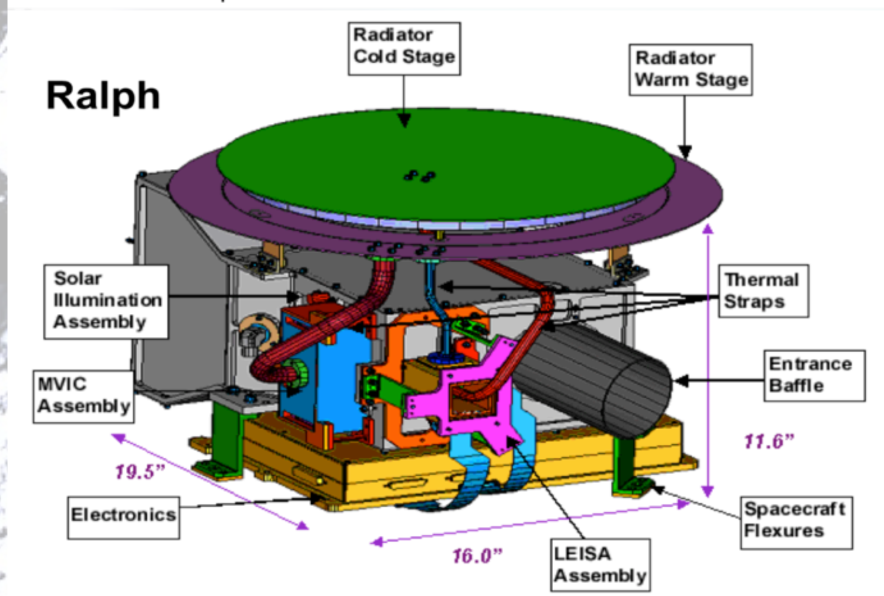
IceCube versus Previous Missions

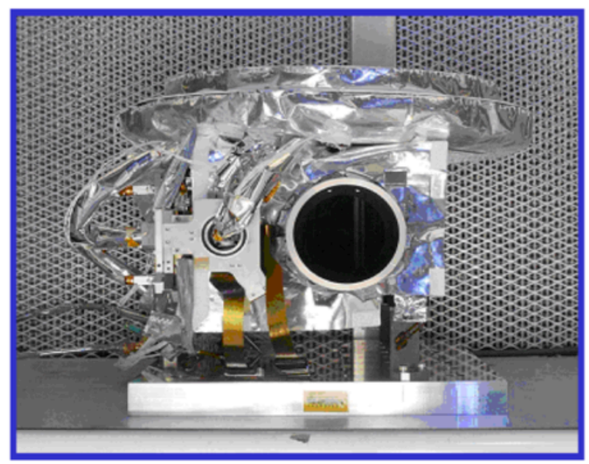
Mission	Finding	IceCube
Cassini VIMS, Deep Impact	surface water detection, variable hydration	water & other volatiles, fully characterize 3 μm region as function of several times of day for same swaths over range of latitudes w/ context of regolith mineralogy and maturity, radiation and particle exposure, for correlation w/ previous data
Chandra 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)	

- Broadband 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

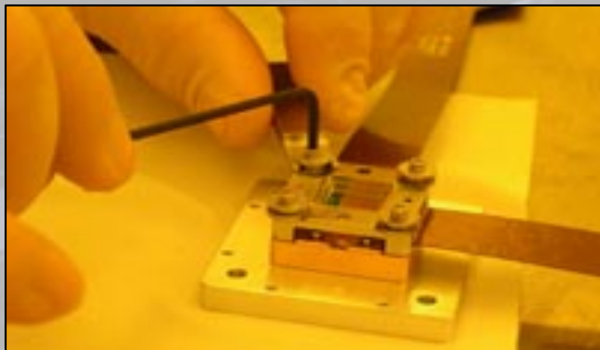


Property	Ralph	BIRCHES
Mass kg	11	2
Power W	5	<5#
Size cm	49x40x29*	10x10x15
*19.5x16.0x11.6 inches equivalent		
#includes 3W cryocooler		

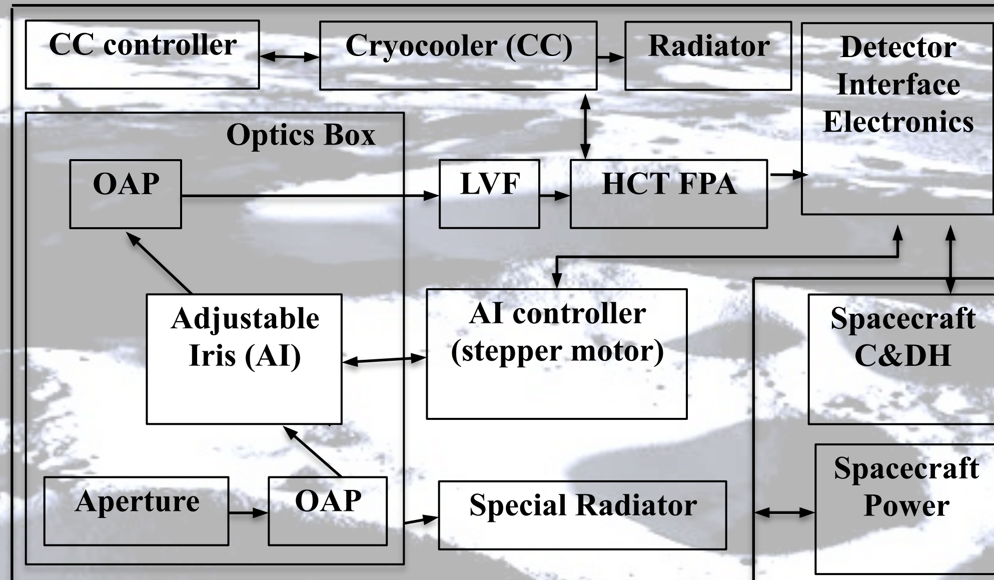




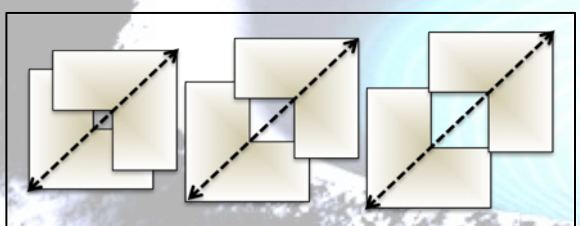
Spectrometer Components



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



BIRCHES block diagram illustrates simplicity and flexibility of design.

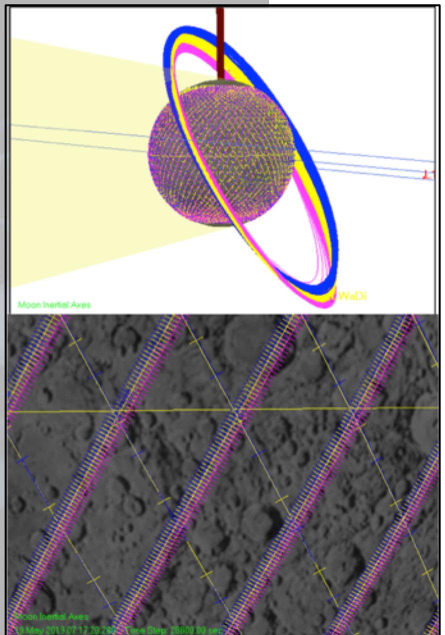


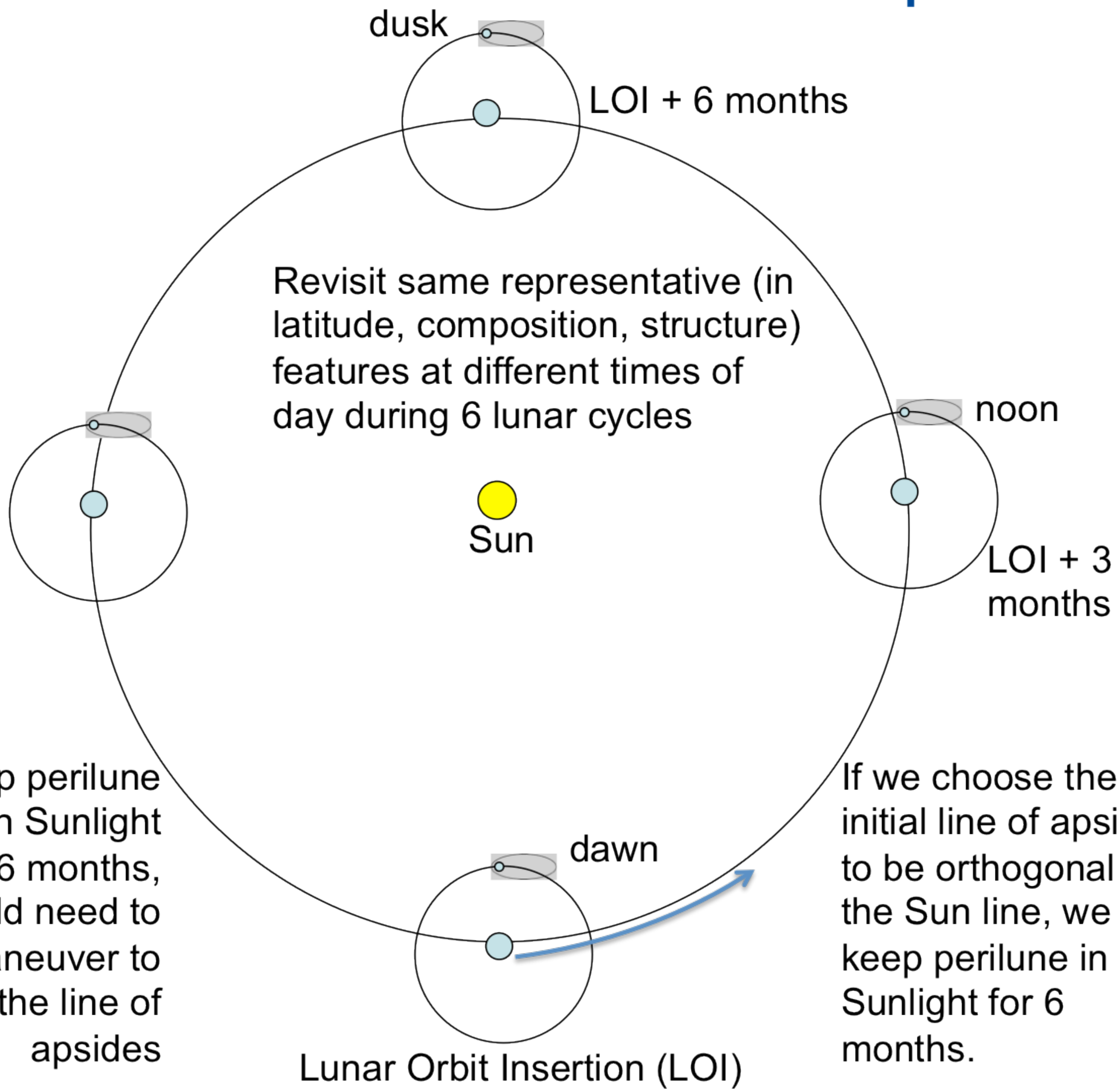
Adjustable Iris maintains footprint size at 10 km by varying FOV regardless of altitude

Off the shelf tactical cryocooler with cold finger to maintain detector at ≤140K

4/23/15 Clark etal CDW Spring 2015 IceCube 8

LWaDi 6 Month Mission Concept



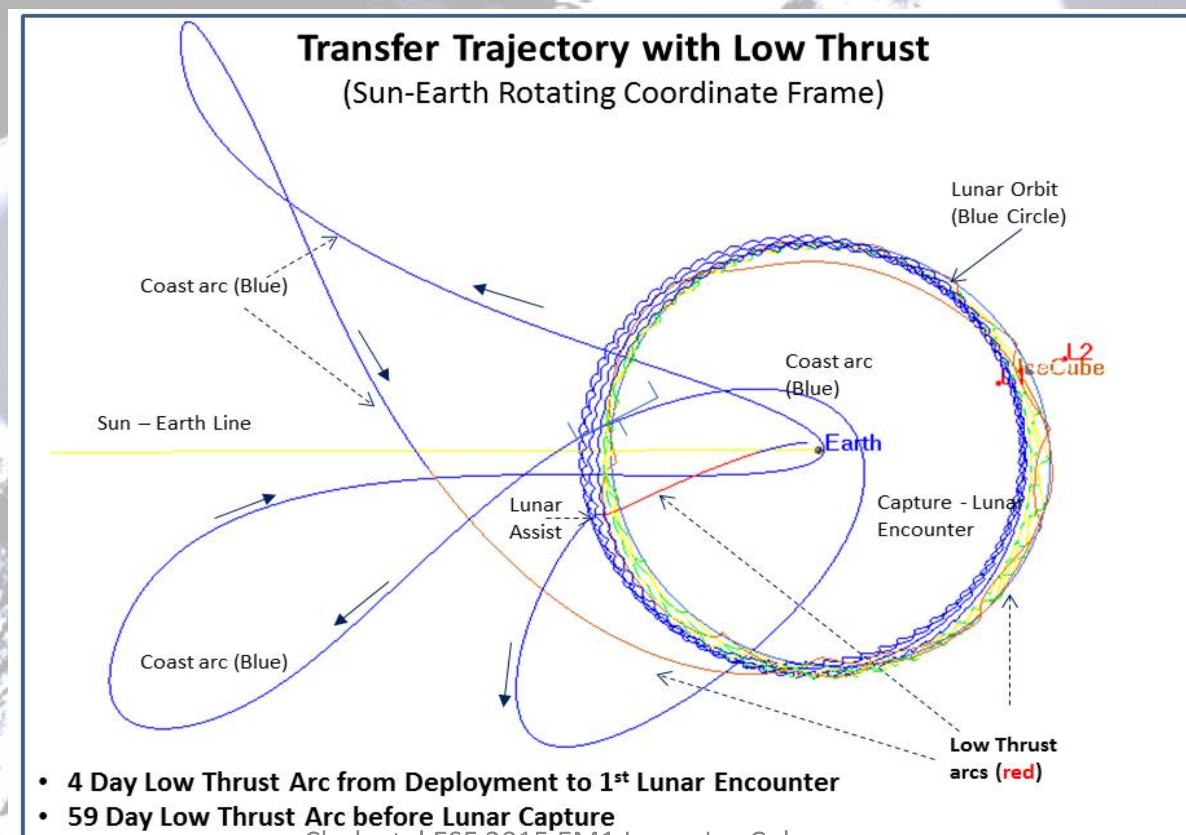


To keep perilune in Sunlight beyond 6 months, we would need to maneuver to rotate the line of apsides

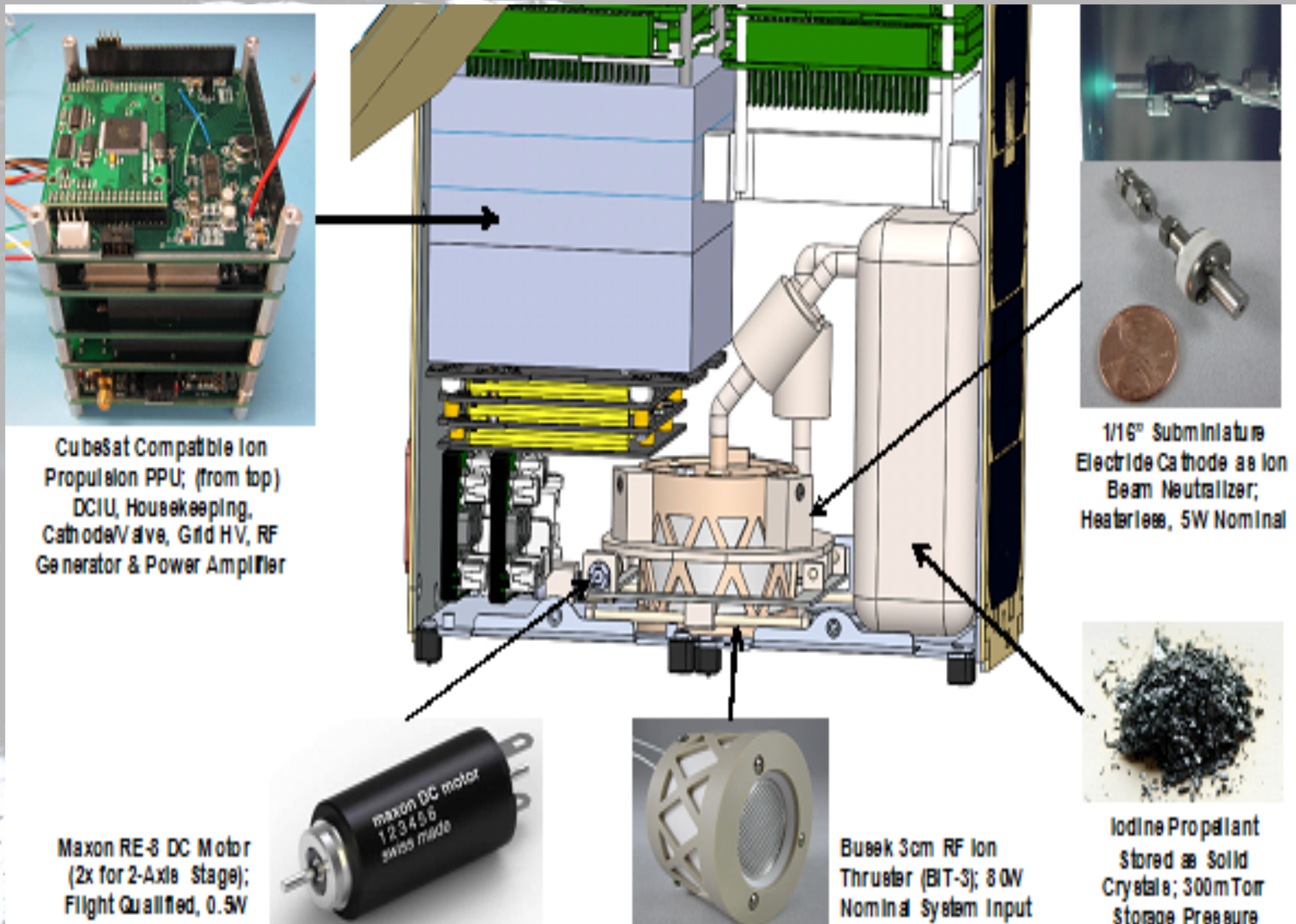
If we choose the initial line of apsides to be orthogonal to the Sun line, we can keep perilune in Sunlight for 6 months.

Mission Profile – Transfer Orbit

- Based on EM-1 heliocentric escape trajectory initial conditions (Interim Cryogenic Propulsion Stage (ICPS) disposal state)
- Low-thrust Busek 1.2 mN propulsion system achieves alternate lunar flyby
- Based on a roboust multi-body dynamical design for a ballistic lunar return
- Design provide for a 9-hr post deployment check out, low fuel mass, reduced radiation environment, and targets the required science orbit
- Transfer duration of ~182 days with only two low-thrust arcs
- Operationally demonstrated by the ARTEMIS mission with a similar trajectory



Busek Iodine ion propulsion system

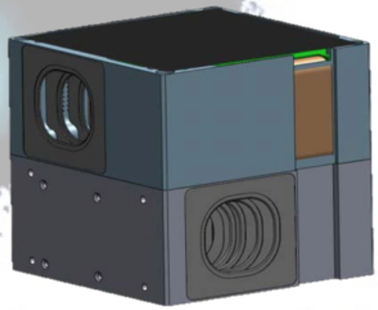


Bus Components

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.

Communication, Tracking: X-band, JPL Iris Radio, dual X-band patch antennas, X-band dish (trade availability, cost, dB, and DSN compatibility, live with the fact this hasn't flown in deep space)

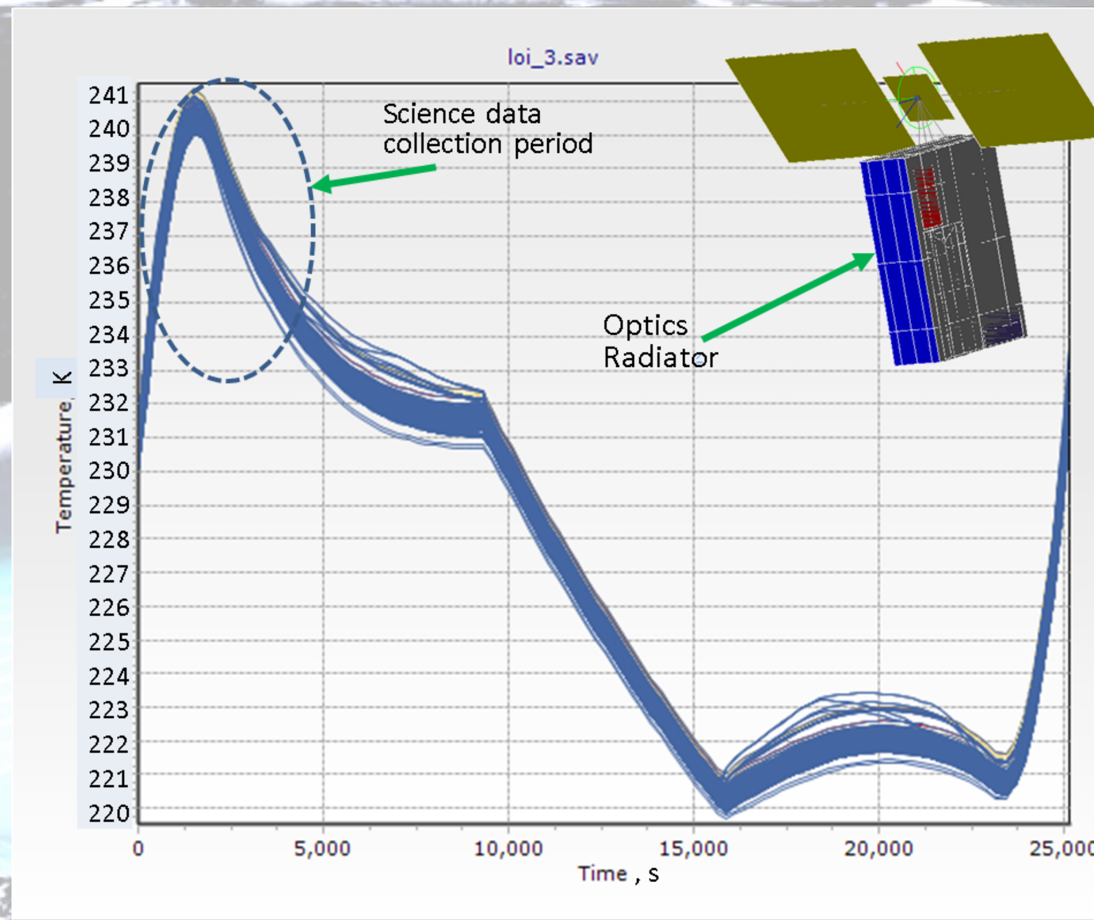
C&DH: very compact and capable Honeywell DM microprocessor, at least one backup C&DH computer (trade volume, complexity, cubesat heritage, live with the fact this hasn't flown in deep space)



GNC/ACS: 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)

Thermal Design

- The biggest challenge on LWADi was maintaining temperature of the optics box at 240K +/-5K, due to parasitic and environmental heat.
- Thermal isolation between the radiator and chassis provides the lowest optics box temperature.
- The plot to the right shows temperature of the optics radiator during LOI+3 orbit.



IceCube Concept: Morehead CubeSat Bus

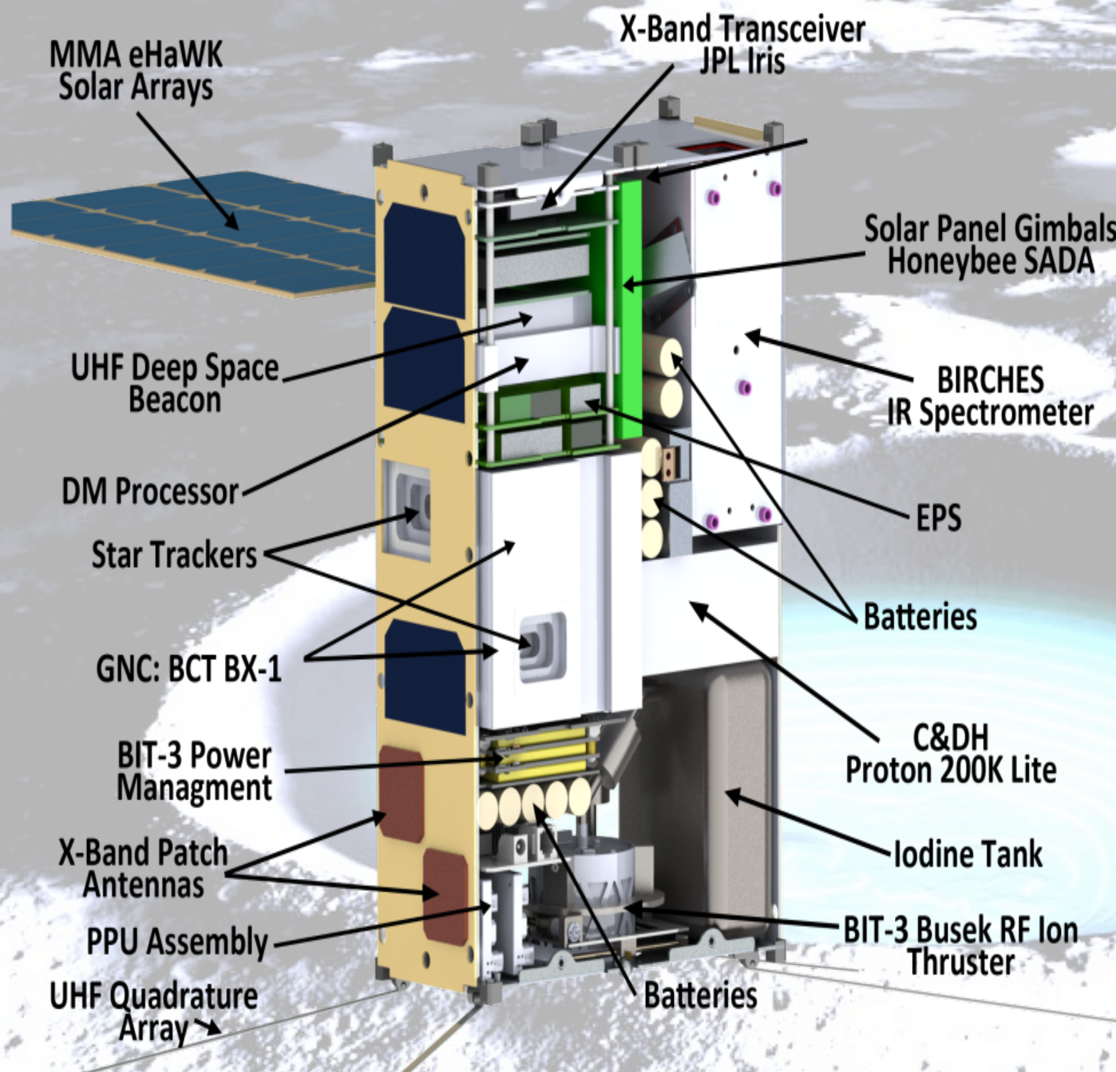


Table 4: Lunar IceCube Subsystems

System	Mass	Volume (in Us)	Power Use	Rad Tolerance	Dollars*	Source
Structures, Thermal Management	1.2 kg	6U Exterior & Rings	N/A	N/A	69K	MSU
C&DH: Proton 200K Lite/ Custom Daughter BCT XB1 for ACS Control	0.36 kg	0.75 U	5 W	>100 krad	240K	Space Micro BCT XB1 MSU
Harnesses, cables, coatings, elastomerics	0.5 kg	Conformal w/in structure	N/A	N/A	12K	MSU
Power (Solar panels & Gimbals MMA HaWK 72 W Array	0.340kg x 2 Deployed 0.190kg x 2 Fixed (Side)	Deployable panels intrude 10 mm into structure (each)	N/A	TBD	185K	MSU + MMA
Solar Panel Drive Articulators HoneyBee SADA	0.40 kg x 2	10 x 10 x 0.65 cm (Each) (0.25U)	5 W	10 krad	Included Above	Honeybee Robotics-MMA
EPS + Batteries MSU + TBD	2.4 kg	0.5 U	Quiescent Draw = 10 mW	> 10 krad	36K	MSU
Propulsion: Busek BIT-3cm RF Ion Iodine	2.5 kg	2U	60W	TBD	1,000K	Busek
ACS/GNC: BCT XB1	2.1 kg	0.75 U	6.3W Cont.	TBD	250K	BCT XB1
Comms: JPL Iris	0.5 kg	0.5U + Antennas	12.8 W- Transponder 6.4 W- Receive	50 krad	500 K	JPL IRIS
IR Spectrometer	0.62 kg	1.5 U	<5 W	TBD	In budget	GSFC
Payload Processor: DM	0.350 kg	10 x 10 x 4 cm (0.25U)	2 W per processor continuous	Multiple processors (8) & middleware	68K	MSU/Honey well


Opening the Lunar Frontier
5th International Workshop on LunarCubes
October 6 - 9, 2015 - San Jose, CA.


Lunar Science Illuminating the Universe
1st International Workshop on Scientific Opportunities in Cislunar Space
Cassini
VIMS
ISS
Equator
Temperature
Water
Hydroxyl
November 9th, 2014 - Tucson, AZ

Why Lunarcubes?

Using the Cubesat paradigm to build user requirements driven ‘pathfinders’ for low-cost multi-platform mission concepts that will ultimately provide next generation exploration through the use of temporal and spatially distributed measurements.

Providing access to deep space via the Moon as nearby analogue, technology testbed, and gateway to the solar system.

Providing a low-cost alternative for high science yield missions at a time of declining funding and increasing costs for conventional missions.

Taking advantage of the decade long evolution of the cubesat model from standardized kits to science-driven, multi-institutional, multi-platform collaborations for LEO applications.

Examining the use of cubesat hardware/software for missions that are a representative cross-section of lunar, Mars, and other applications at varying degrees of difficulty (flyby, probe, orbiter, lander).

identifying modifications and new technology needed to support a science-driven deep space mode.

NASA has expanded the CubeSat Launch Initiative which provides launch opportunities for cubesats to LEO as secondaries at no cost, to GEO and beyond.

Designing a deep space prototype bus, and prototype for a lunar orbiter missions.

Building on the exploding interest in cubesat as seen in our LunarCubes Workshops over the last 4 years.

Deep Space CubeSats to date:

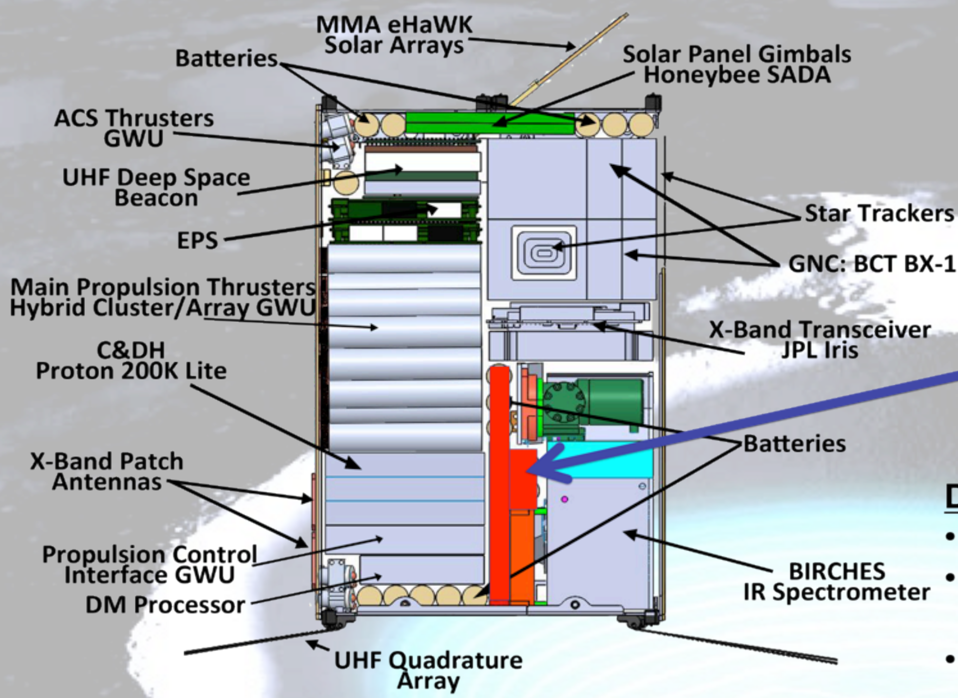
Announced: INSPIRE (2 3U); 11 EM1 releases (6U) including 3 HEOMD AES selected (Lunar Flashlight, NEA Scout, BioSentinel) plus 8 others TBS (SMD PDS SIMPLEx (1), SMD Heliophysics HTIDS (1), HEOMD NextStep (1), OCT Centennial Challenges (several)); Europa mission secondaries
Likely: Surviving GLXP/Catalyst lander deck, leg, or orbit secondaries; Mars mission secondaries; Deep Space Scouts from 100 EM1 proposals pent-up demand

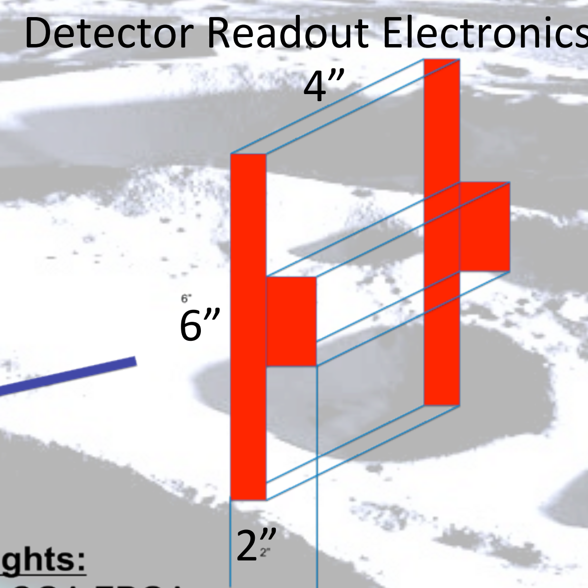
As in NASA's first decade, all 'prototypes' of these 'shoeboxes' must, to get beyond LEO (launch, orbit, orbital formation flying), demonstrate the following:

Operate in Deep Space Radiation Environment
Operate in Extreme Target Thermal Environment (particularly the Moon)
Manage Deep Space Communication
Manage Deep space Navigation and Tracking
Perform Deep Space Maneuvers, Orbital Insertion and Orbit Maintenance
Manage a variety of onboard propulsion systems: (solar sail, ion drive, microcathode, electrospray)
Manage onboard active attitude control systems
Perform Onboard Processing
Find Capable yet Compact, Low-Cost, Low-power Payloads
Harness CubeSat (Class D) development model

Lunar Ice Cube

Detector Readout Electronics (DRE) Summary





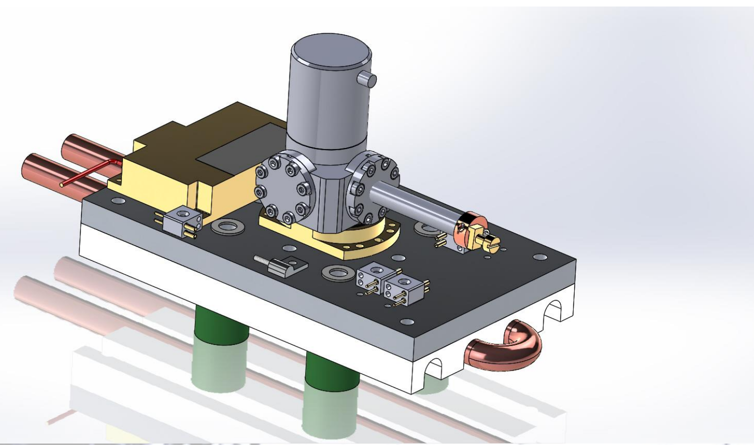
Design Highlights:

- RTAX 2000 CGA FPGA
- 2 Discrete Detector Analog Video Input channels
- Dedicated 14 Bit ADCs (100 – 200 kHz Sampling)
- 3 (TBR) Adjustable Biases for the H1RG Detector
- IRIS Stepper Motor Control
- Frame Averaging (CDS)
- RS-422 (or Space Wire, TBD) for Science/Telemetry out and Commands in.
- PWR +5V, +12V, -12V (TBR) provided by SC
- Low Power compact design.
- Aluminum Chassis
- Targeting Radiation Hardened Components

Cryocooler: Ricor K562S

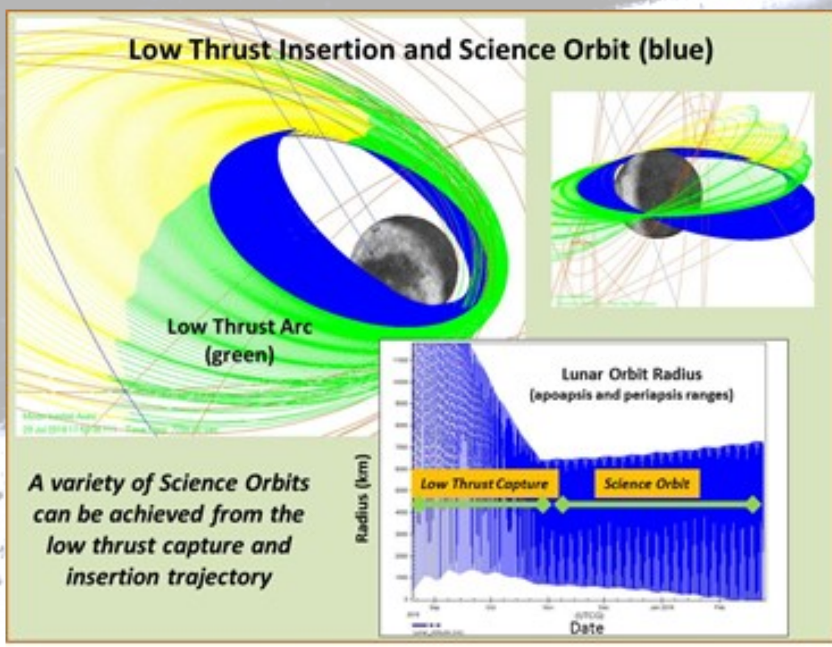
- Model K562S represents the ultimate miniaturization of Ricor's integral rotary Stirling mini micro coolers.
- Weighing only 185 grams and consuming less than 3 Watt, this cooler was specially developed to support miniature IR systems where the IR detector operates at temperatures of 95K and above.
- The basic design concept is based on Ricor's renowned integral rotary coolers known for their battle proven reliability and ruggedness.
- Specifications include a weight (without controller) of 185 gr, an input voltage of 12 VDC and steady state input power (without controller) of < 2.3WDC for 150mW @110K @23°C
- Ambient temperature range is -40°C to +71°C,
- MTTF > 8,000 hours (goal) and it meets environmental conditions per MIL STD-810.

K562S Test Stand



Mission Profile – Science Orbit

- Capture into a weakly stable lunar orbit that has a several month lifetime
- Sequentially lowering apoapsis to achieve inclined science orbit with equatorial periapsis
- Many lunar orbit parameters (sma, inclination, periapsis location, orbit alignment wrt to Earth, stability, shadowing, etc.) can be achieved and corrected
- Orbit shown is 6400 x 600km altitude with a 6 month decreasing periapsis altitude profile
- Transfer duration from capture to science orbit is ~ 80 days
- Orbit design goal to minimize shadows, achieve stable orbit, minimize fuel



Events and Parameters

Events / Parameter	Baseline
Initial Mass (Kg)	12
Thrust Level (mN)	1.2
Total DV (m/s)	790
EM1 Lunar Correction DV (m/s)	33
Lunar Flyby Radius (km) (EM1 nominal = 3065)	9239
Transfer DV (m/s)	517
Max Transfer Range (km)	1.34 e6
Total Transfer Duration (days) to Return Lunar Encounter	182
Total # of Low Thrust Maneuvers in Transfer	2
Total Duration of Low Thrust Transfer Arcs (days)	59
Total Duration of Low Thrust Lunar Arc (days)	80
Maximum Eclipse Duration (hrs) (Lunar Eclipse)	4
Lunar Orbit Radius (Km) after 59 Days of Thrusting (Apoapsis x Periapsis)	6364 x 600 (any available)
Lunar Orbit Inclination (deg)	70 (Any available)

Overarching Question: Considering the science priorities and resulting range of science investigations, and the range of potential payloads, what should a 'lunarcube' platform and infrastructure look like? 6U, needs robust propulsion system (>1.5 km/sec delta V) mostly to achieve desired orbit from lunar capture, can carry up to 2U payload, >60W power desirable, needs robust thermal protection design, requires 1 year plus operation, great increase in bandwidth desirable

Some Design Challenges Cubesat Concepts to Cubesat Missions: Applied to this concept

1) 'Lessons Learned' from this round deep space cubesat proposals and selected missions (Clark)

2**) Comparison viable (Earth-based and onboard) communication infrastructure models to support upcoming deep space cubesat (and conventional) missions (Duncan)**

3) Building the deep space internet (Rilee)

4) Overcoming challenges in design and development of radiation tolerant components and subsystems (Morse)