Lunar Ice Cube: All Dressed up and Ready to Go

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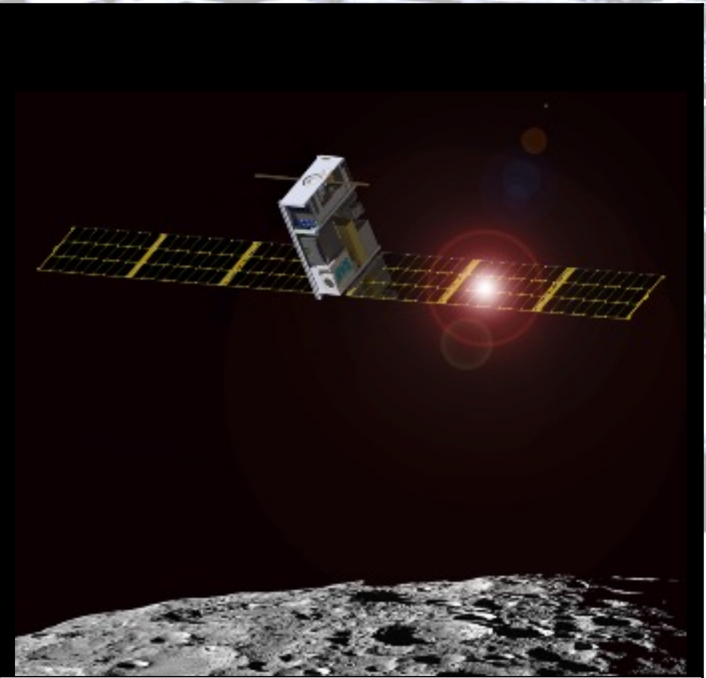
NextSTEP - Lunar IceCube Mission

Mission Description and Objectives

Lunar IceCube is a 6U small satellite whose mission is to prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, inclined lunar orbit using a compact IR spectrometer. **1.)** Lunar IceCube will be deployed by the SLS on EM-1 and **2.)** use an innovative RF Ion engine combined with a low energy trajectory to achieve lunar capture and a science orbit of 100 km perilune.



Strategic Knowledge Gaps

1-D Polar Resources 7: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H2O deposits toward PSR retention

1-D Polar Resources 6: Composition, Form and Distribution of Polar Volatiles

1-C Regolith 2: Quality/quantity/distribution/form of H species and other volatiles in mare and highlands regolith (depending on the final inclination of the Lunar IceCube orbit)

Technology Demonstrations

- **Busek BIT 3** - High Isp RF Ion Engine
- **NASA GSFC - BIRCHES** Miniaturized IR Spectrometer - characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μm)
- **Space Micro C&DH-** Inexpensive Radiation-tolerant Subsystem
- **JPL Iris v. 2.1** Ranging Transceiver
- **BCT- XACT** ADCS w/ Star Tracker and Reaction Wheels
- **Custom Pumpkin**- High Power (120W) CubeSat Solar Array

Current Status

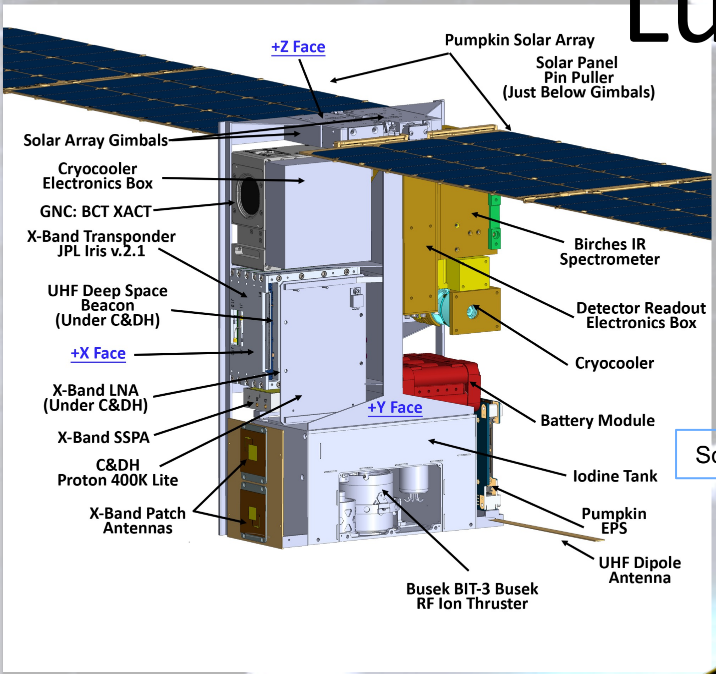
V&V Complete
Vehicle Delivered to KSC

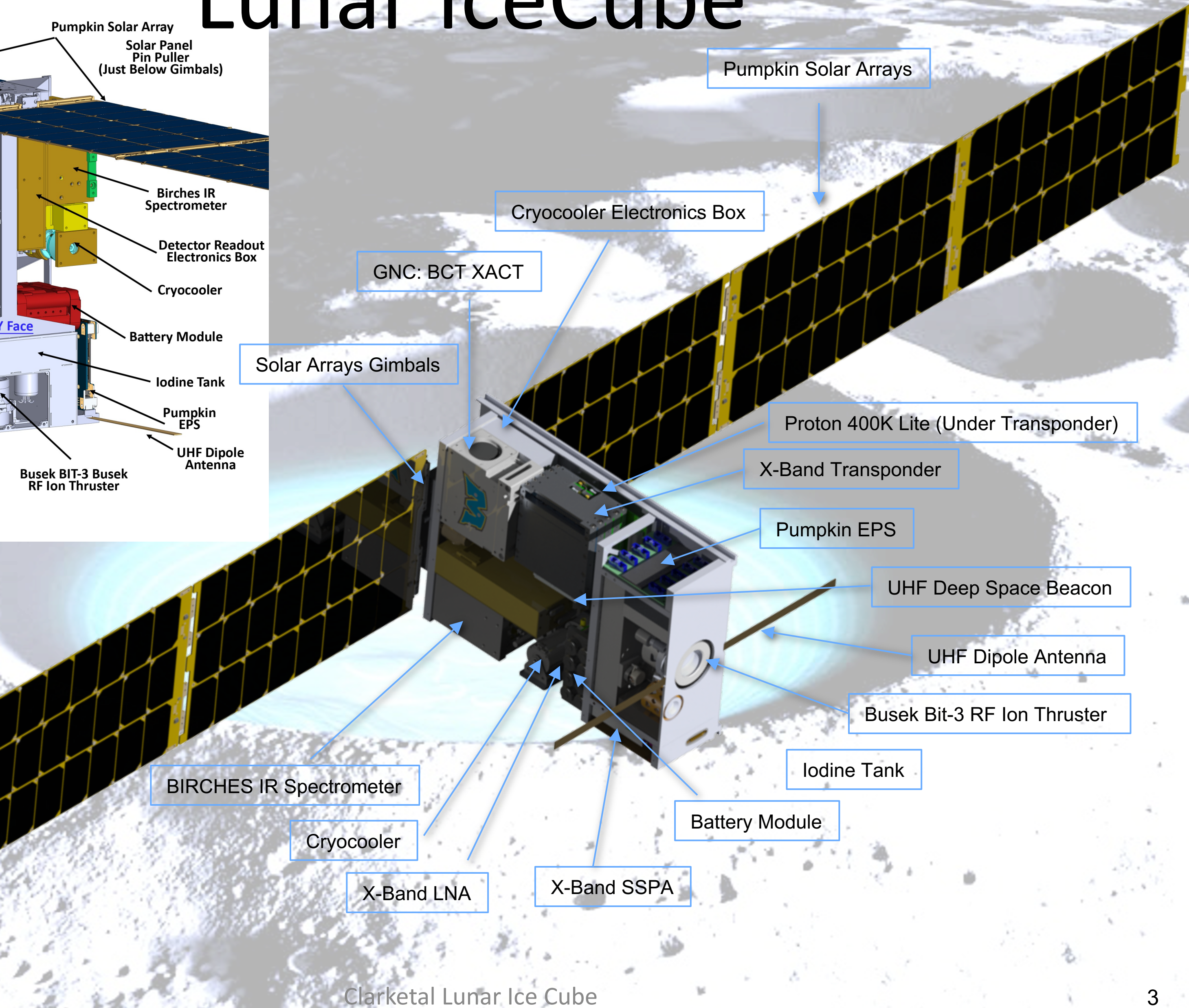
Preparing for Operational Readiness

Navigation and Trajectories Models and Processes Evolving

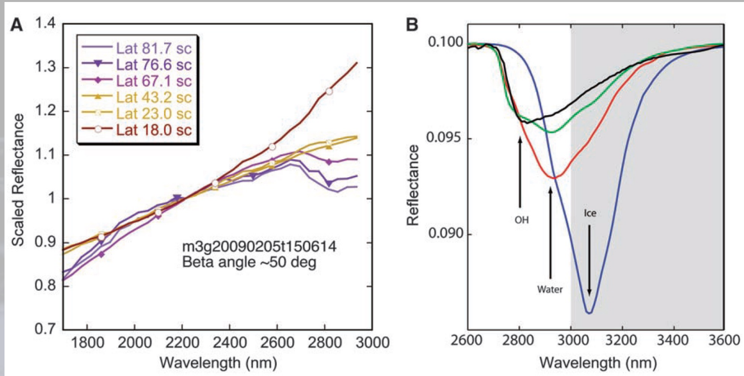
PDR	Phase 1	CDR/ΔCDR	Phase 2	Phase 3	IRR	FRR	ORR	Launch	Mission Ops	Mission Duration	Project Closure
05/19/2016	06/20/2016	05/16/17 3/14/18	04/26/2018	5/23/2019	11/04/2020	**7/28/2021**	04/14/2022	June 2022	2022-2024	2 years incl. ext.	2024

Lunar IceCube

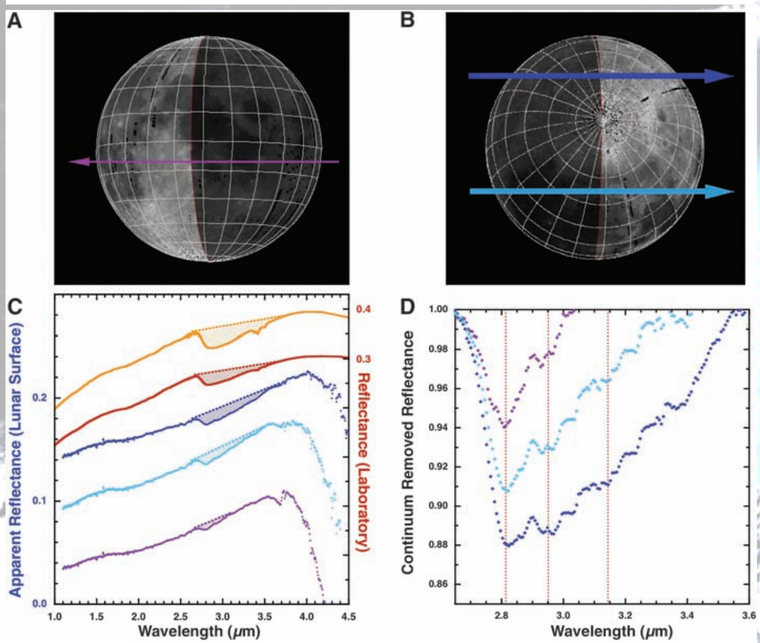




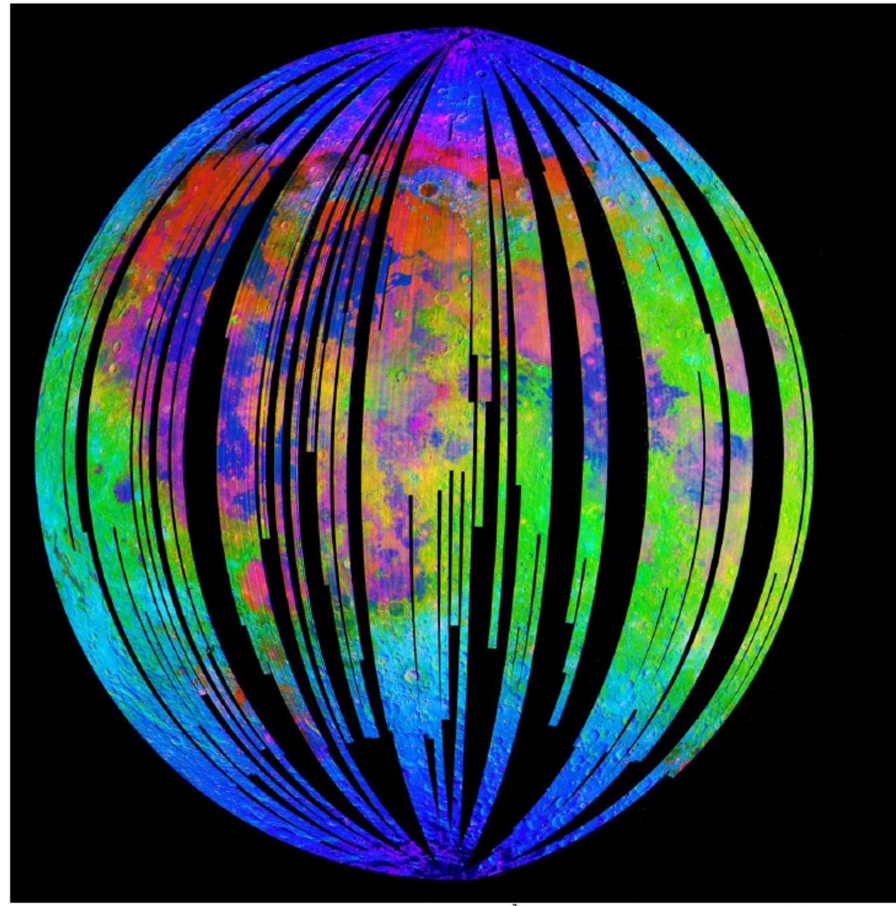
Evidence for Water



Reflectance spectra showing water and hydroxyl aborption features (near 3 microns) depth as a function of latitude. Chandrayaan M3, Pieters et al 2009

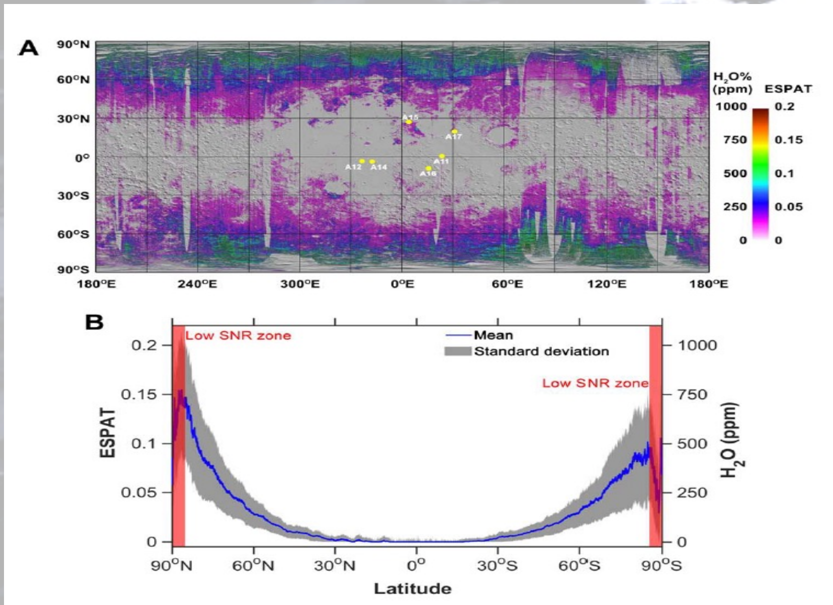


Reflectance spectra with absorption feature strength correlated with time of day. Deep Impact Epoxi. Sunshine et al 2009

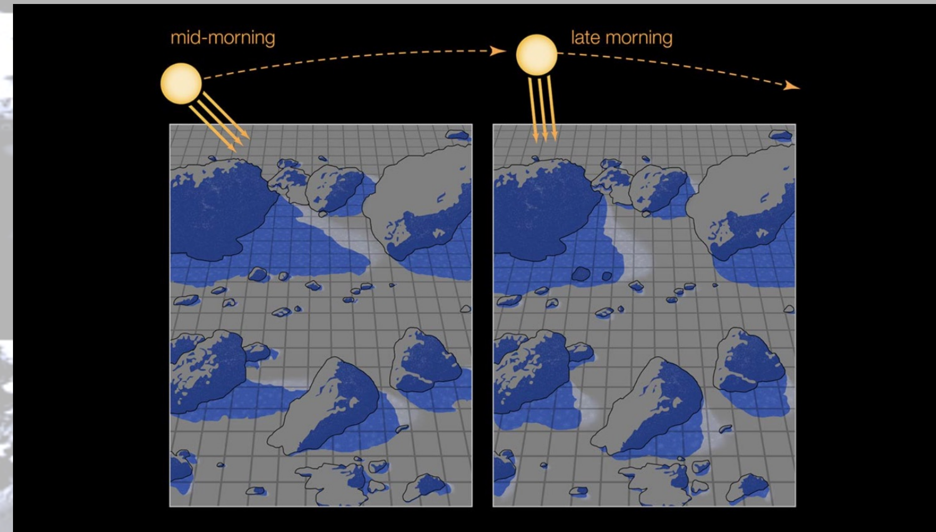


Water and Hydroxyl on Moon. Combined Red (Pyroxene), Green (Reflectance continuum), Blue (water and hydroxyl absorption) bands. Blue, Cyan, Magenta, Pink water indicators. Chandrayaan M3, Pieters et al 2009

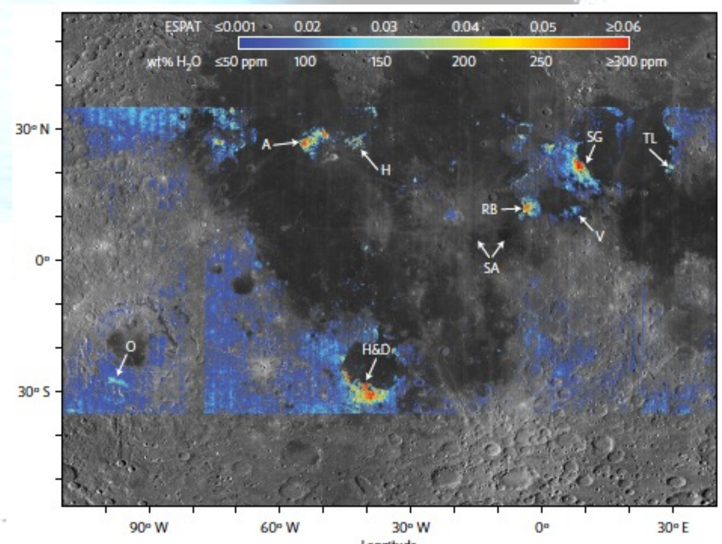
Further Evidence for Water



M3 calculated ESPAT estimated water content (Apollo landing sites in yellow) map (A), all longitude-averaged latitude profile (B), and +/- 35 degree latitude-averaged longitude profile (C). Li and Milliken, 2017.



This illustration zooms in on the area of detail indicated in the previous photo, showing how shadows enable water ice to survive on the sunlit lunar surface. When shadows move as the Sun tracks overhead, the exposed frost lingers long enough to be detected by spacecraft. Credit: NASA/JPL-Caltech



Map of 2.85 u Effective Single Particle Absorption Thickness (ESPAT) derived from M3 at low lunar latitudes. Features apparently associated with pyroclastic deposits, lending credence to hypothesis of volatile-rich (hundreds ppm) sources in mantle. A aristarchus; O orientale, RB Rima Bode, SG Sulpicius Gallus, TL Taur-Littrow. Milliken and Li, 2017.

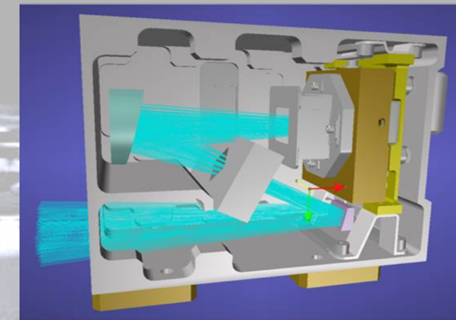
Science Goal and Objectives

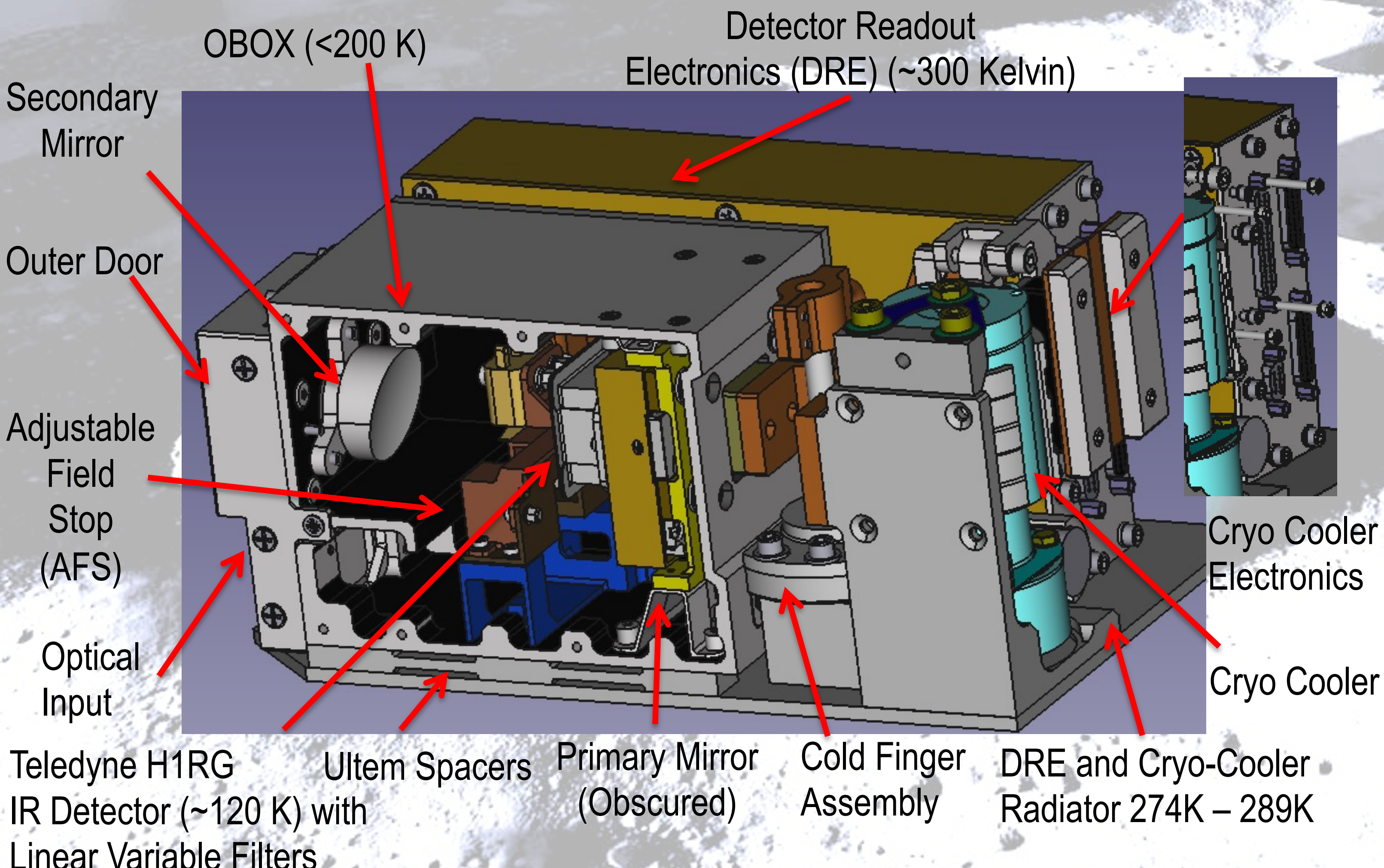
Verify hypothesis that lunar water (forms and components) production is an ongoing global distribution process, thus water (forms and components) are 'cold trappable' and observable as a function of temperature

Goal Lunar Ice Cube Science Payload: Utilize a compact IR spectrometer on a 6U platform to obtain measurements of water-related absorption features from lunar orbit over several lunar cycles to address the HEOMD SKG requiring improved understanding of physics driving the spatial and temporal distribution of all forms of water on the Moon.

Science Objectives	
#	Objective
L1-1	Primary: Determine distribution of forms and components of water in lunar regolith as a function of time of day and latitude
L1-2	Secondary: Determine impact of variations in surface properties (composition, slope, orientation) on water distribution
L1-3	Secondary: Provide inputs to constrain models for Lunar volatile origin, production, and loss.

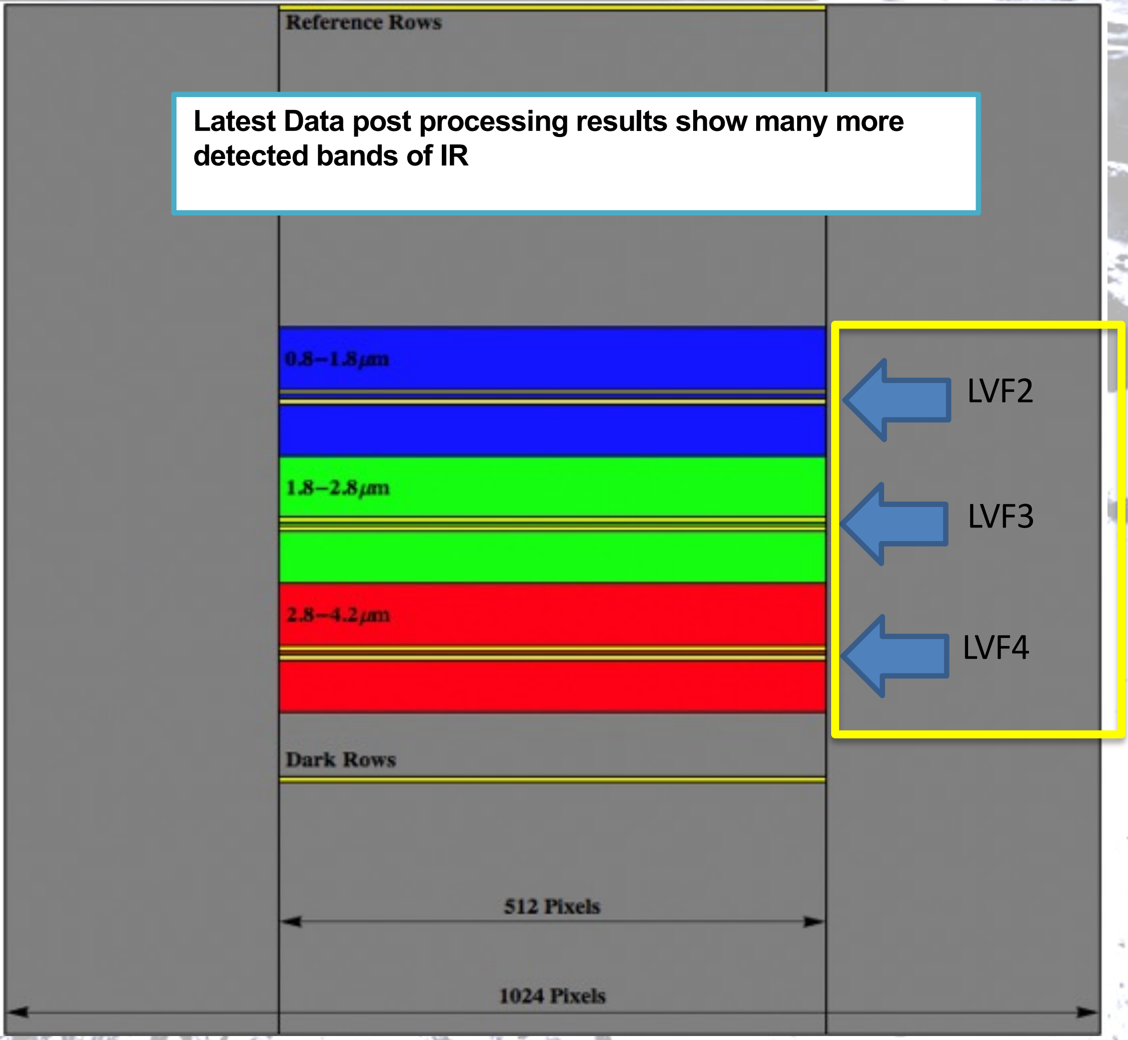
BIRCHES IR Spectrometer HW Architecture





Detector Linear Variable Filter Details

Table 1: BIRCHES measurable IR bands	
Form	μ
Water	
Water Vapor	2.663
	2.738
Liquid Water	1.4
	1.9
	2.85
	2.9, 2.903
	3.106
Hydroxyl	2.2-2.3
	2.7-2.8, 2.81
	3.6
Bound H2O	2.85
	2.95
	3
	3.14
Adsorbed H2O	2.9-3.0
Ice	1.5
	2
	3.06
Other Volatiles	
Organics	1.2, 1.73, 2.3
NH3	1.65, 2
CO2	2.7
H2S	3
CH4	3.3
Mineral Bands	
Pyroxene	0.95-1
Olivine	1, 2, 2.9
Iron Oxides	1
Carbonate	2.35, 2.5
Sulfide	3
Hydrated Silicates	3-3.5
	LVF 2
	LVF 3
	LVF 4



Latest Data post processing results show many more detected bands of IR

LVF – Linear Variable Filter

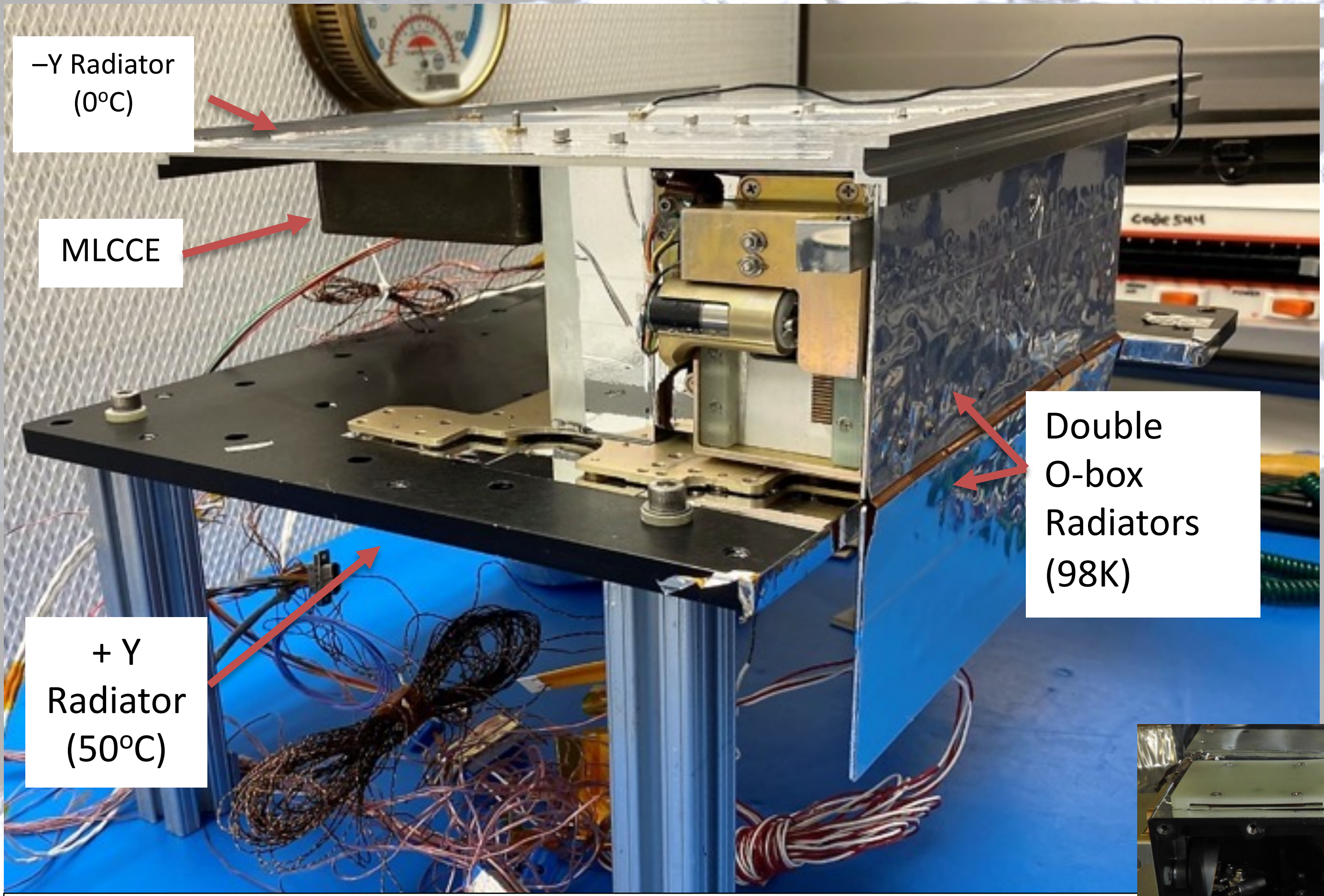
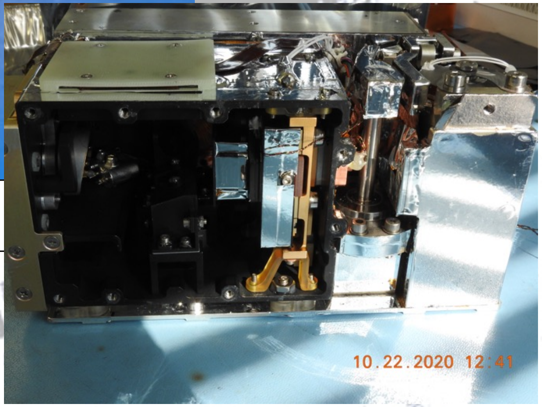


Figure 5-2 BIRCHES Integrated Test Configuration



PreFlight Calibration Data

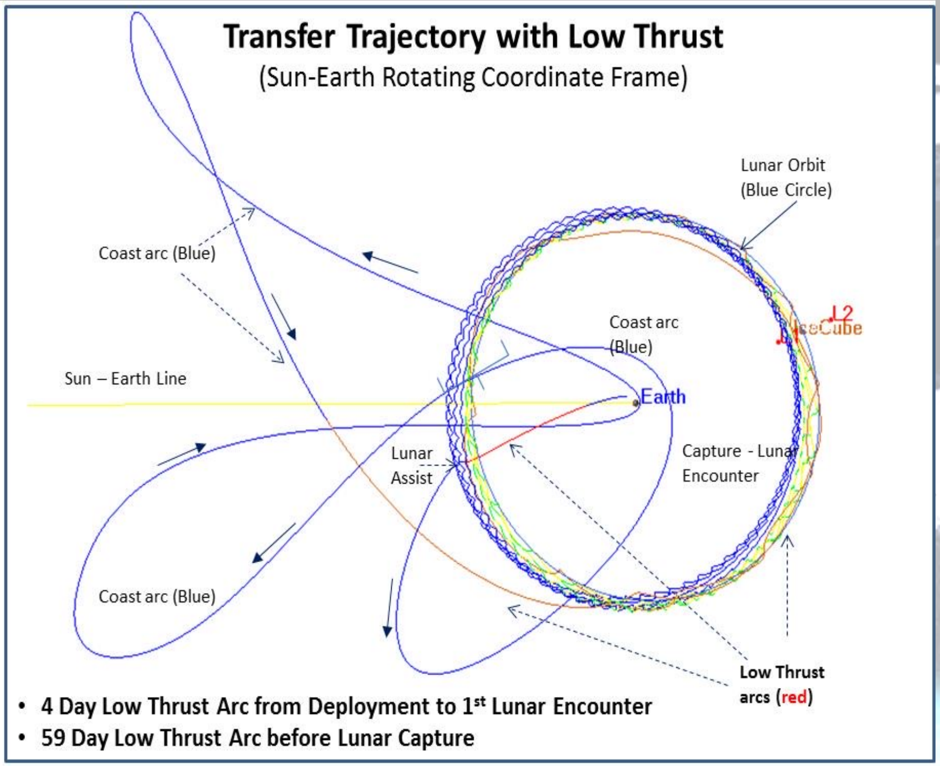
Activity	Status	Current DataSets	Who
Detector Characterization (readout settings)	Preflight calibration gain, Vclp. To be verified by model and observation during Inflight calibration.	Sharepoint, raw mode files, Data Table	Brambora
Adjustable Field Stop Settings	Preflight calibration. In flight verification.	Sharepoint, Spreadsheet	Brambora
Bad Pixel map and Detector Row Selection	Preflight calibration. To be verified Inflight calibration (rows 1-4, 385-388, 424-427, 511-514, 547-550). Report on data reduction method.	Sharepoint, raw mode files (with bad pixels), report	Hewagama
Optical/Spatial (FOV, alignment to S/C)	Preflight calibration. To be verified Inflight calibration	Sharepoint, data table, report	Brambora
Detector Characterization (dark noise vs temperature)	Preflight calibration at two BIRCHES temperatures. To be verified inflight at minimum three temperatures.	Sharepoint, raw mode files, report	Brambora
Spectrometry (wavelength assignment, spectral resolution)	Wavelength/pixel map for LVF2, LVF3, LVF4, measured resolution: 57.2 nm LVF2; <53.8 nm LVF 3; 92.9 nm LVF4	Sharepoint, raw mode files, wavelength map file, report (figures and equation). See Spectroscopic slide below.	Hewagama
Out of Band Correction	In flight calibration needed.		Hewagama
Radiometry (counts to luminance vs temperature)	Preliminary (0.008 ergs/s/cm^{-1}/cm^2/count at 135 K), InFlight calibration at two other Temperatures. Working on conversion to radiance units.	Sharepoint, raw mode files, report (figures and equation). See Radiometric slide below.	Hewagama
Observation and Raw modes	Modification FPGA code to correct bug in observation mode (V68-2) during preflight testing. Verify at room T only. To be verified inflight calibration.	Sharepoint, observation and raw mode files.	Brambora

Raw mode: Complete 1024 x 1024 FPA readout; Observations modes: readout central 512 x 512 with LVF segments with and without pause and second read

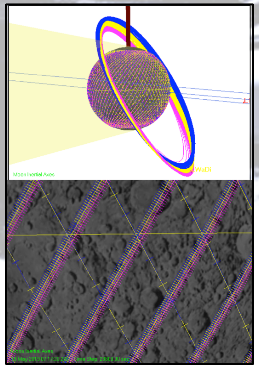
In-Flight Calibration: Steps in order

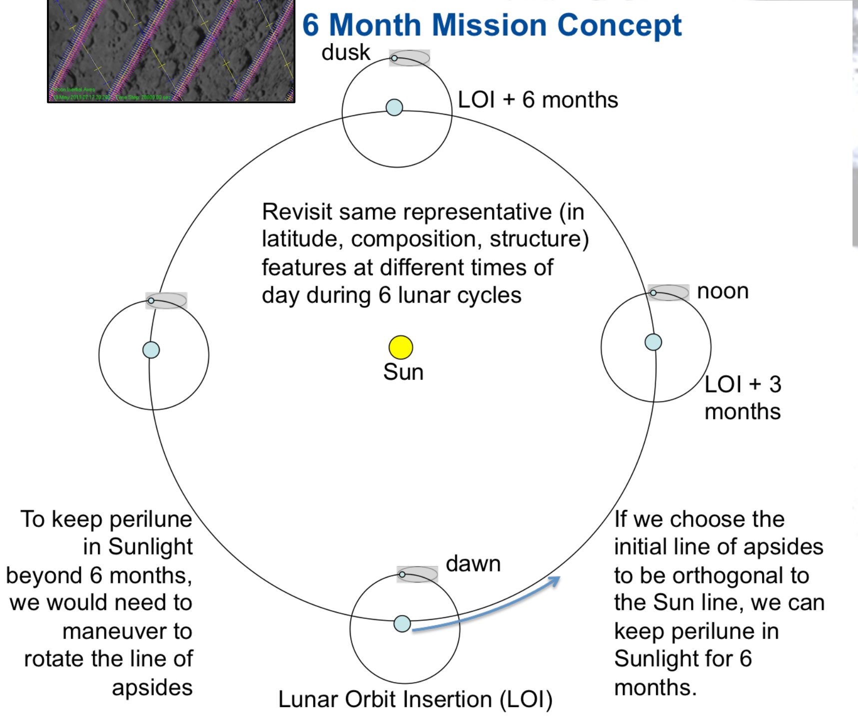
0) 24 hours+ direct sunlight on Obox radiator for decontamination ending by performing 1) below (mid-June)
1) Verify relationship between S/C T sensors, Obox T, cold finger T (from mid-June and then monitor)
2) Verify cryocooler settings (time, voltage) required to achieve maximum detector (cold finger) temperature (performed along with 1)
3) Verify relationship between Obox T and Cold Finger T whenever taking data
4) Verify Boresight on available target (limb/terminator/limb) to verify BIRCHES pointing offset (June/July with 5)
5) Verify Boresight on available target (limb/terminator/limb) to determine FOV as function of AFS setting (with 4)
6) Verify Vclp and Gain settings as function of illumination and temperature (two or more targets and phases) (raw mode) (July/August with 7)
7) Verify bad pixels as function of degree of illumination (from door closed) and temperature (raw mode) (with 6)
8) Determine relationship between Counts/Sec and radiance as function of temperature (with 6, 7, 9, 10)
9) Verify pixel wavelength position and resolution from target with known spectral signature (while performing radiometry with 8)
10) Determine out of band correction as a function of temperature (while performing radiometry with 8)

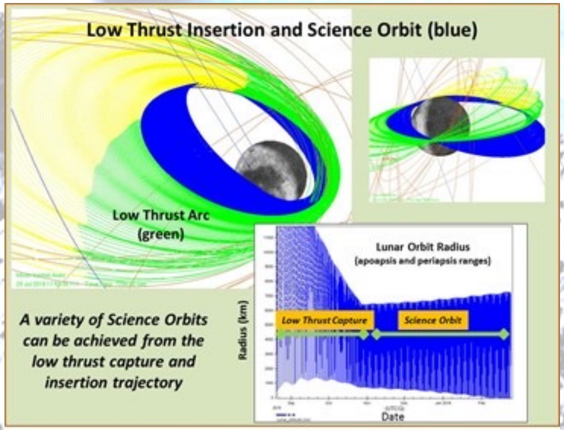
Lunar Ice Cube MIssion Concept



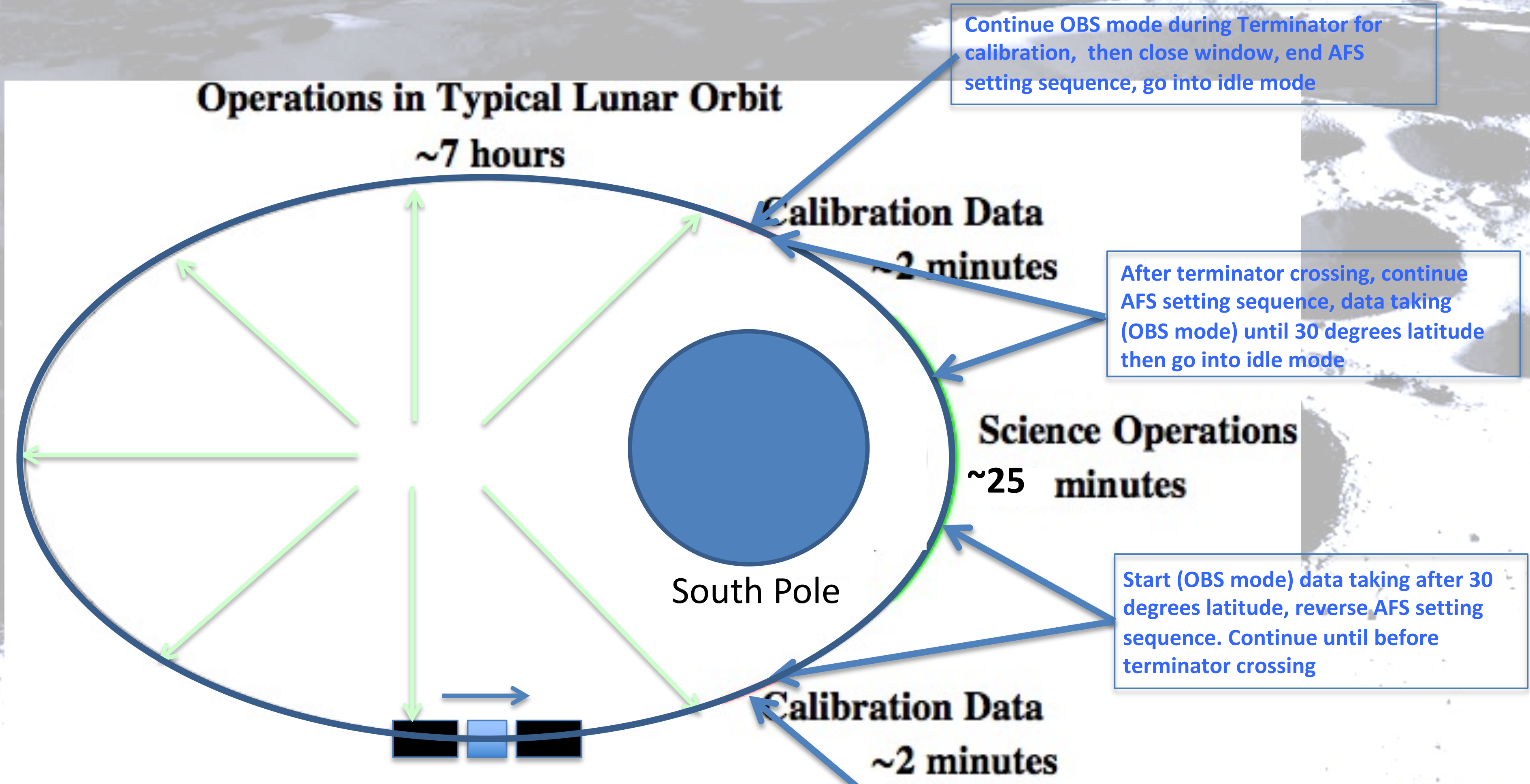
- 4 Day Low Thrust Arc from Deployment to 1st Lunar Encounter
- 59 Day Low Thrust Arc before Lunar Capture





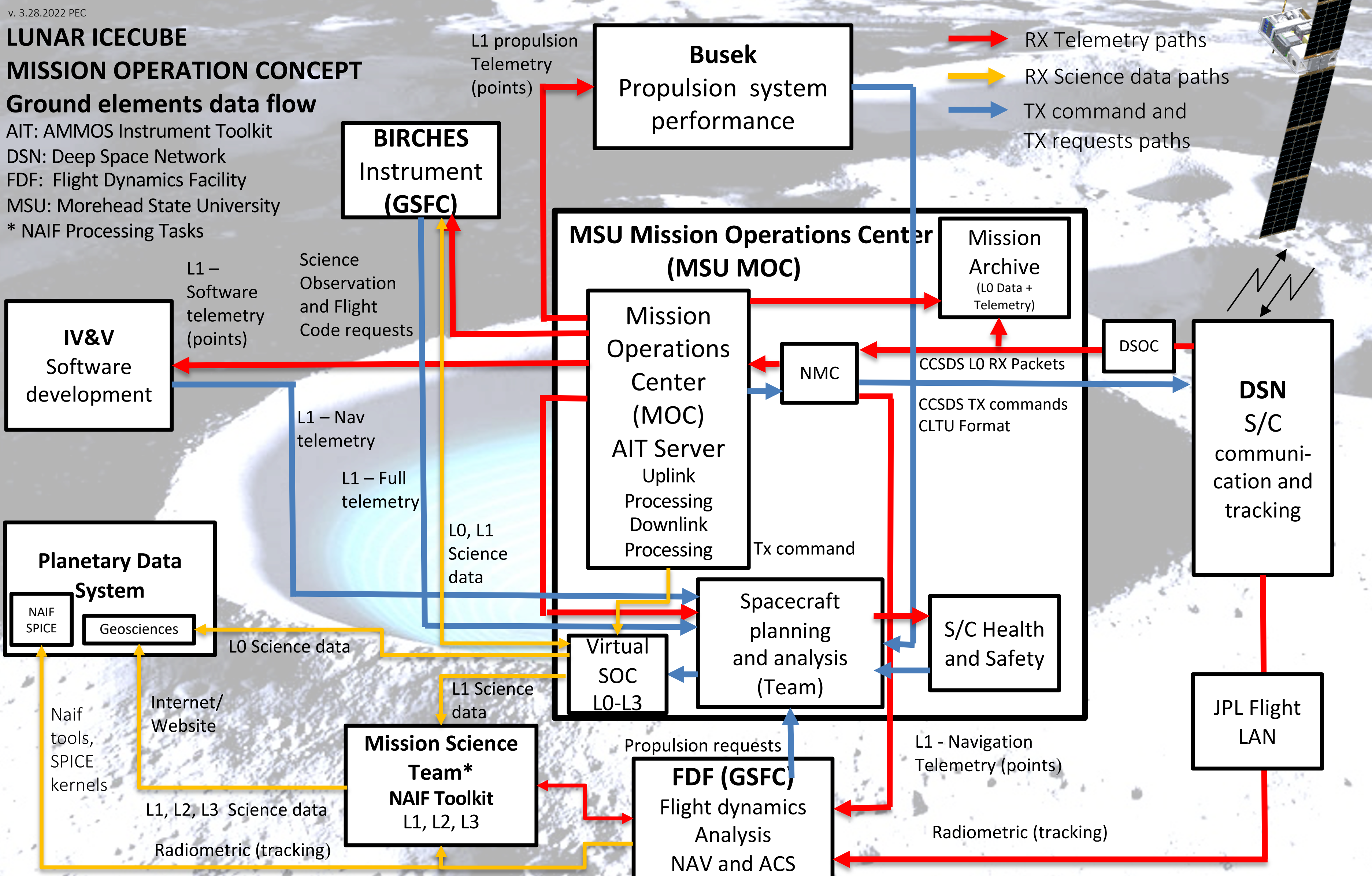


Science Mode Operations



Altitude (100Km – 1000Km – 100Km over the 40 min science Observation) with a +-10Km variability.

Ground Elements Data Flow



Challenges Summary

Challenges and Mitigations

Shutdown limited resources and time available to complete planned calibration process. In future, a Plan B for alternate testing and integration plan (outside of NASA centers) should be required.

Thermal design (on-orbit heat removal an issue for 6U, and on-surface heat retention during lunar night an issue if minimum resource (including cost) solutions sought: In future, take advantage of High performance thermal solutions now being developed. Additional work (remove some stand offs, modify detector surfaces, add small dedicated deployable radiator, variable thickness radiator) to reduce heat transfer to detector to reduce pixel saturation without increasing mass. Go to 12U for future cubesats.

Development process: version controlled design and interface control documentation, and scheduled essential reviews and deliverables. Learning curve for ‘early cubesat deep space qualification'. Define 'threshold' early and go to threshold as cost cap issues arise.

Team membership: high turn over and no guaranteed backups for student team. In future, would appoint staff thermal engineer, mission operations, ground data system managers.

Non-scalable (in cost and schedule) development and operation: Support and utilize design, subsystem simulation and driver tools, operating systems, operations facilities, and data delivery pipeline tools already developed or under development for cubesats.

Conclusions

- Lunar Ice Cube is the most operationally complex cubesat to date.
- Lunar Ice Cube goal to provide measurements from which liquid water, ice, OH distribution across the lunar surface can be derived to understand function of time of day (temperature and illumination) at a variety of representative locations.
- Regardless of the degree of overlap with other missions (LunaH-Map and Lunar Ice Cube) in space or time, these measurements when combined will provide far more systematic understanding of the water cycle, and the accessibility of water as a resource on the Moon.
- We are doing what cubesats are supposed to do: creating an innovative and tailored solution with a standard platform.
- Serious challenges for thermal design in 6U volume must be addressed (go to 12U) for next round of deep space opportunities.

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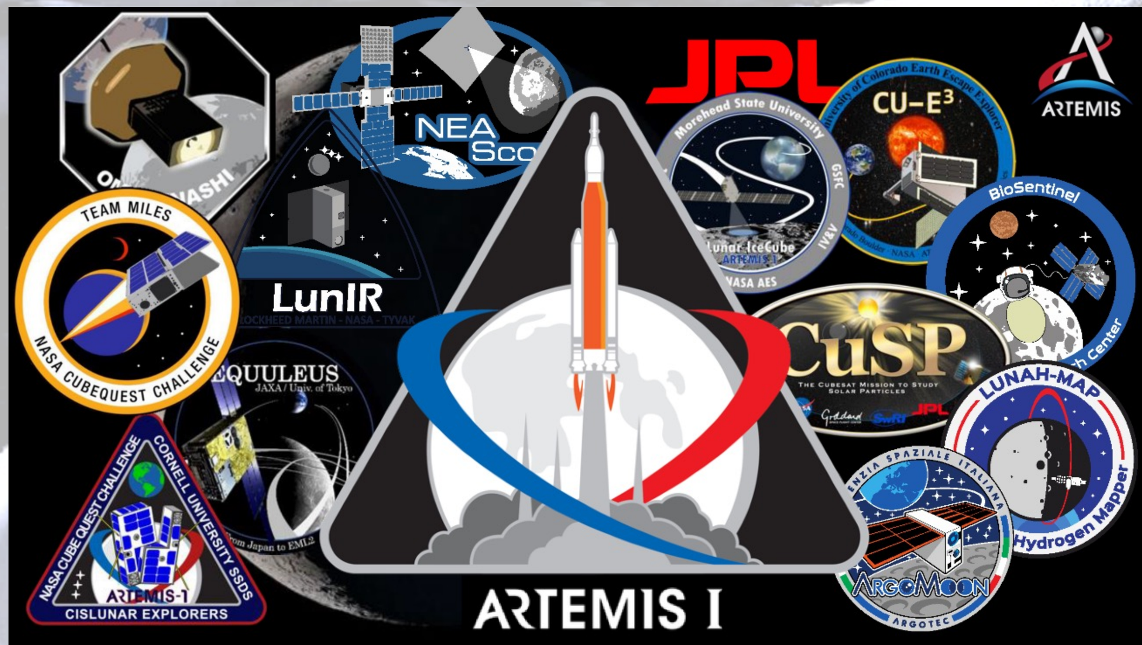
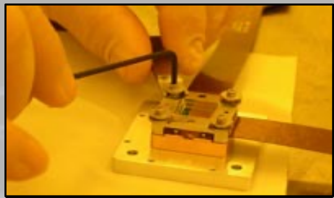
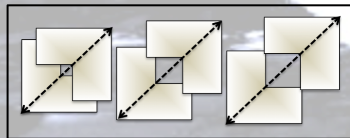


Cubesats are Ready to Go!

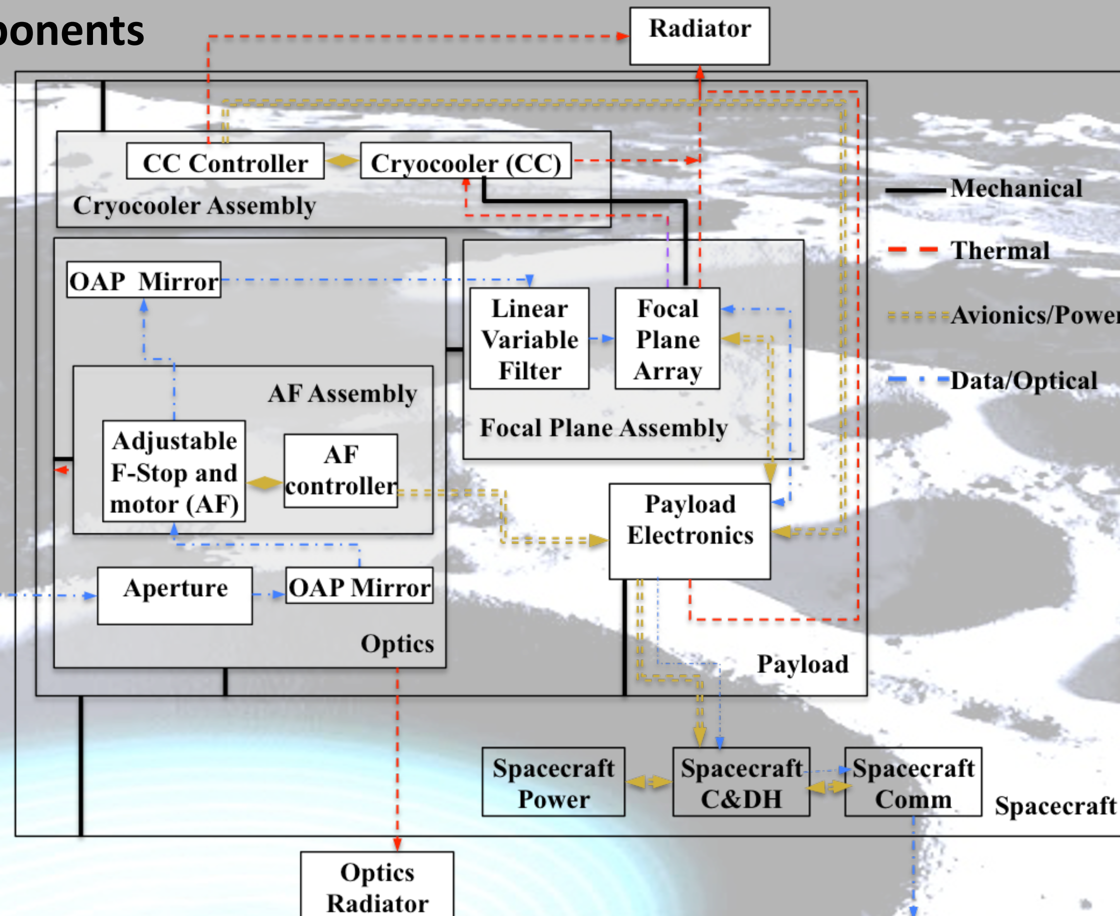
Spectrometer Schematic and Components

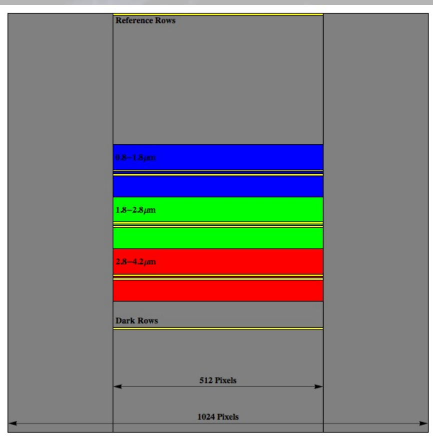


BIRCHES utilizes a compact Teledyne H1RG HgCdTe Focal Plane Array and JDSU linear variable filter leveraging OSIRIS REx OVIRS.

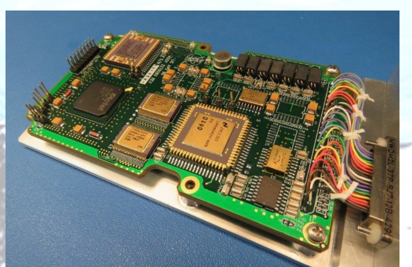


Adjustable Iris maintains footprint size at 10 km by varying FOV regardless of altitude





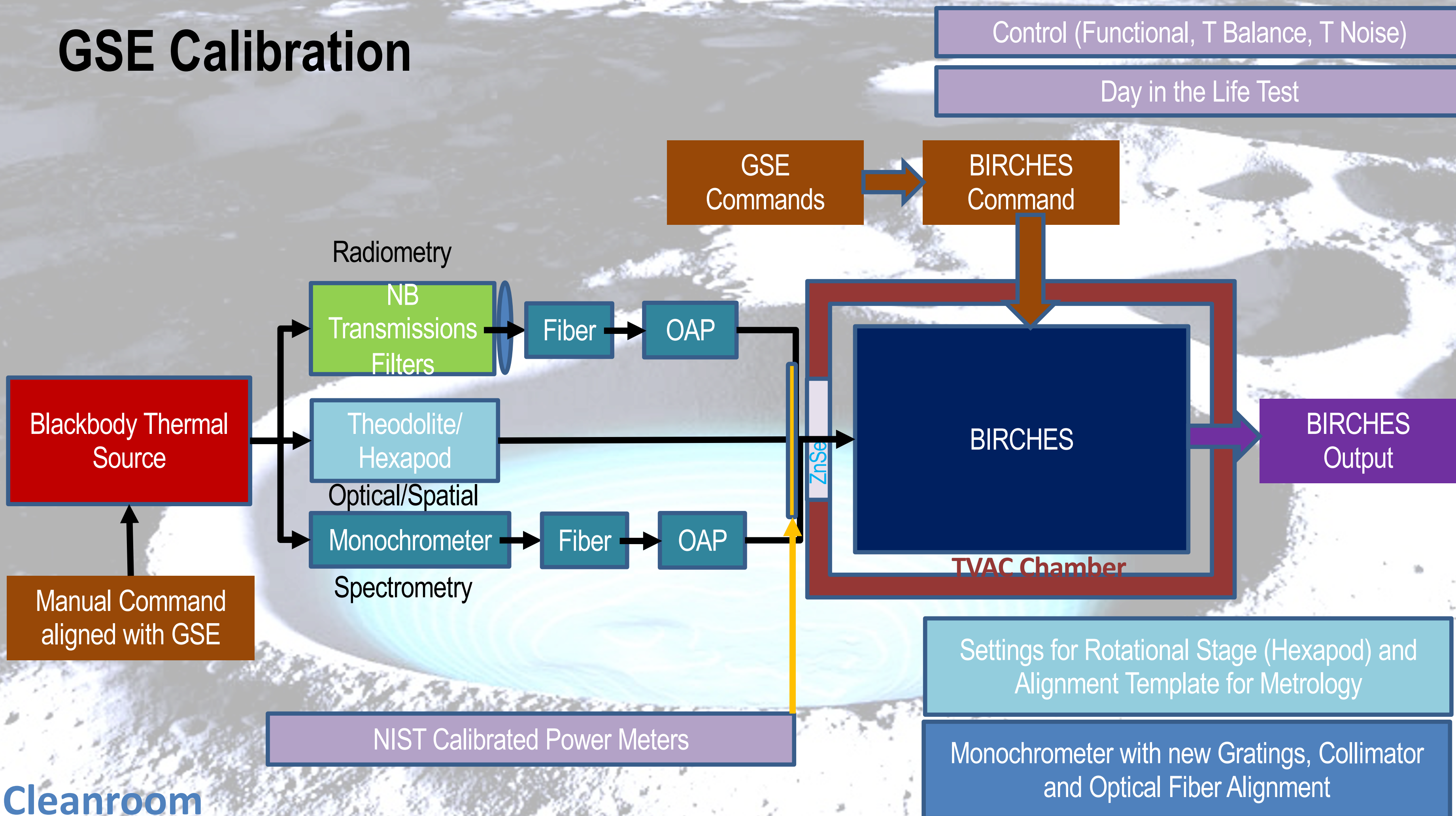
Linear Variable Filter Segments over H1RG focal plane array with reference, dark, segment 1, segment 2, and segment 3 rows (yellow lines) superposed.



BIRCHES Analog Processing Unit (APU) (top)

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

GSE Calibration



Cleanroom