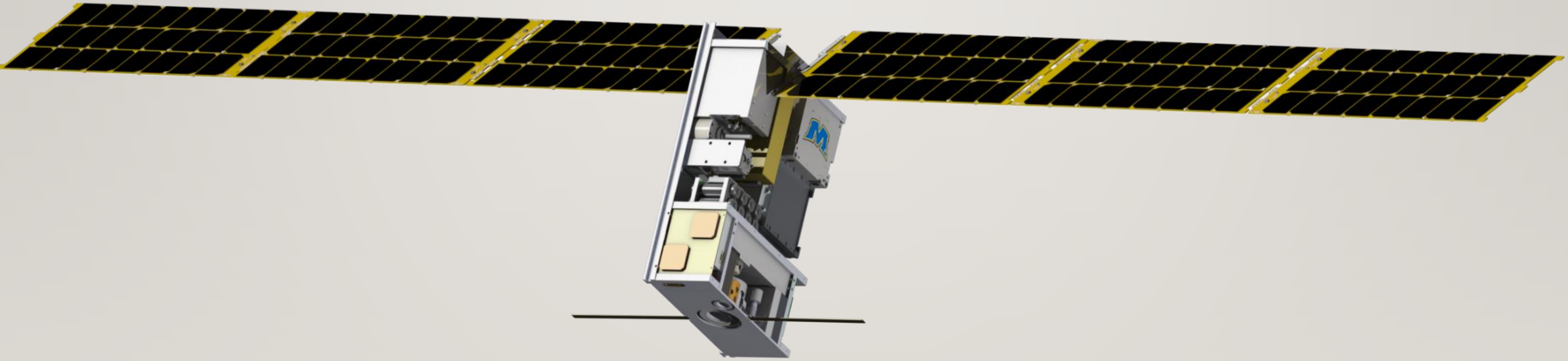
Thermal Management For Lunar IceCube

Dr. Boris Yendler (YSPM), Dr. Benjamin K. Malphrus, Nathan Fite (Morehead State University)



byendler@yspm.net

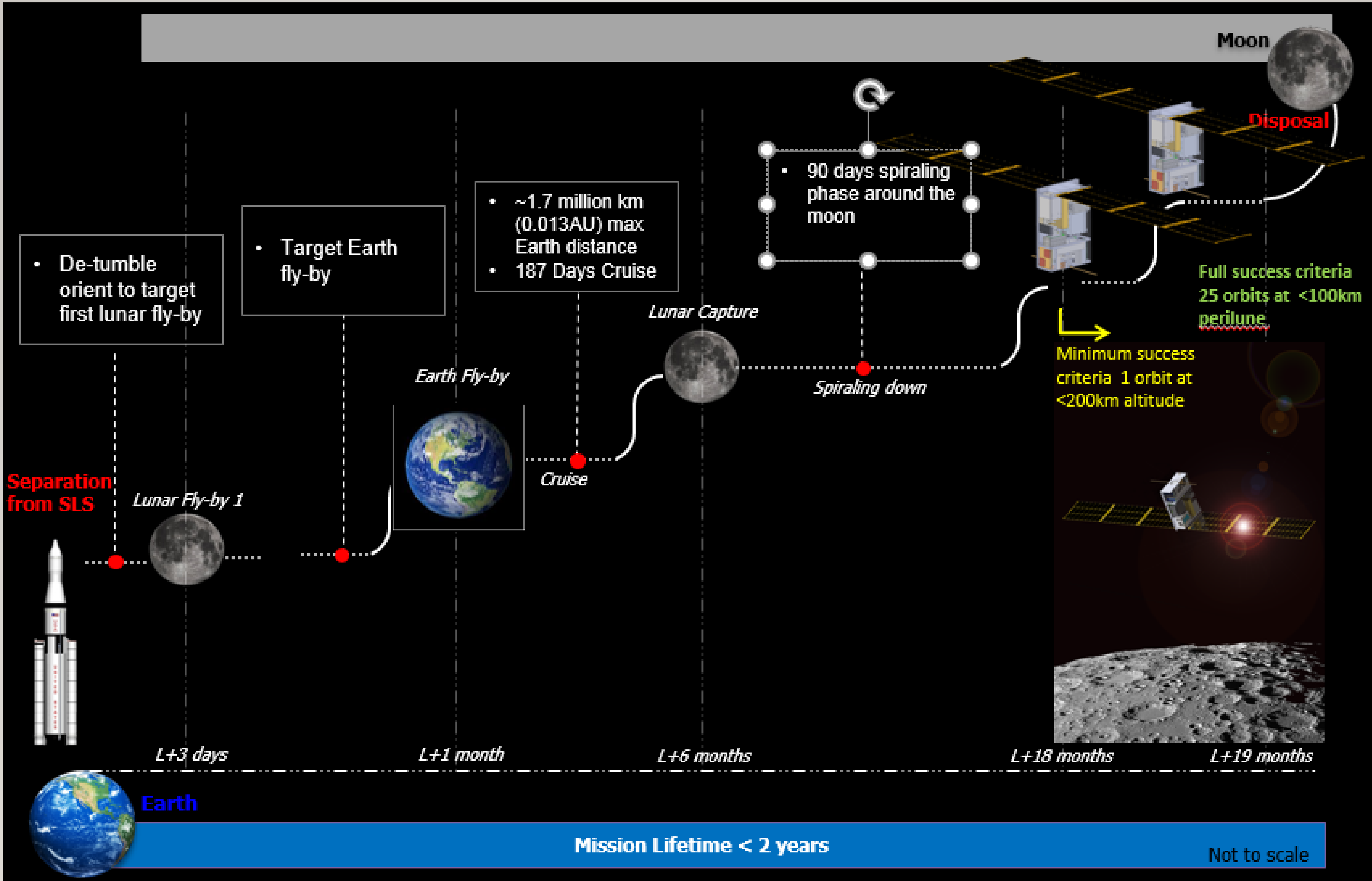
Agenda

- Mission Description
  - Mission lifetime
  - Lunar IceCube Design
- Development of Thermal Management System
  - Thermal Requirements:
    - Temperature
    - Power
    - operational constraints
- Thermal Model
  - Radiators
  - Simulation
- Discussion
- Conclusion

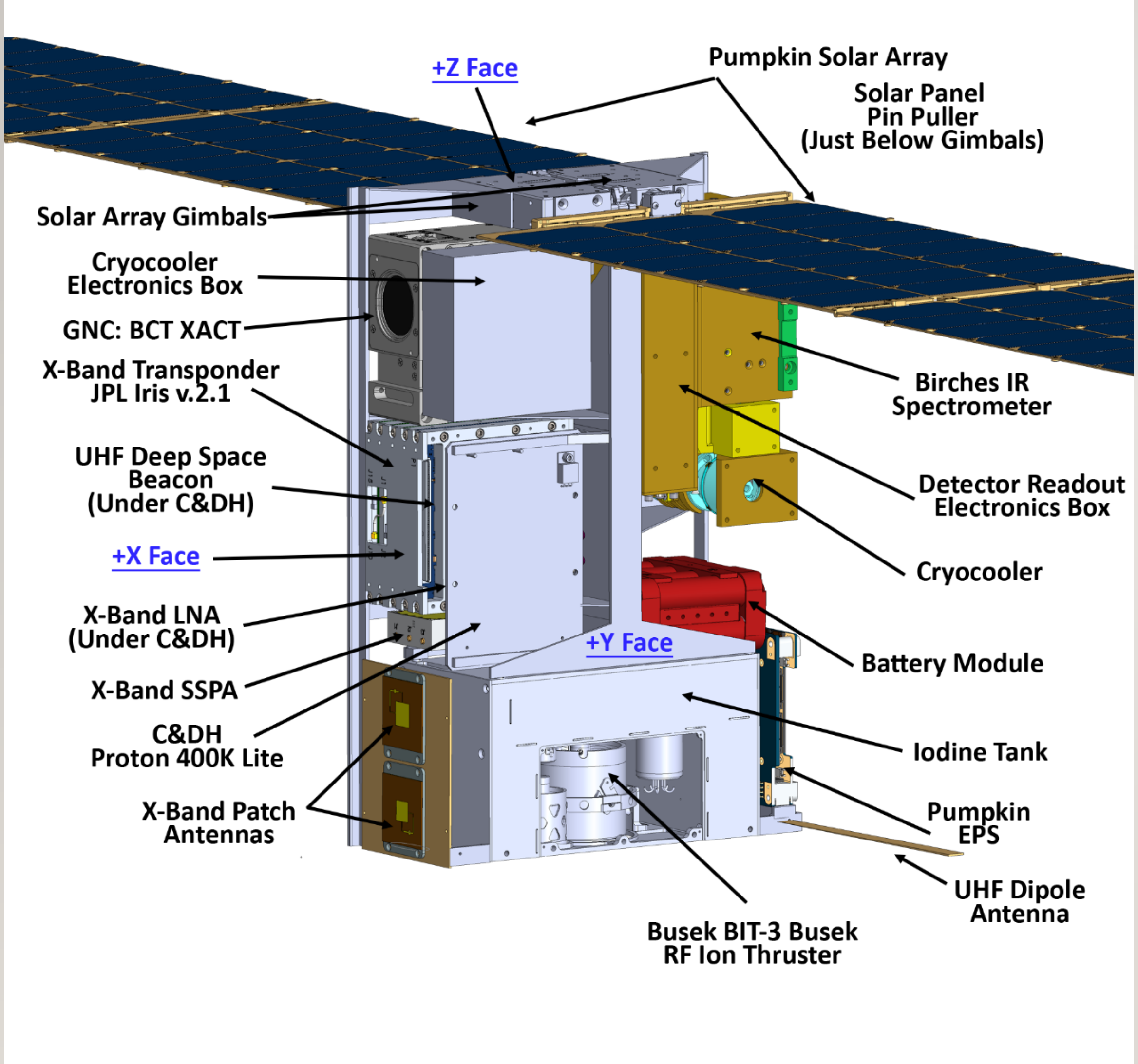
Lunar IceCube Mission

- NASA 6U cubesat mission to search for surface water ice and other volatiles from a 100 km x 5,000 km near-polar orbit
- Mission is one of several public-private partnerships chosen under NASA's Next Space Technologies for Exploration Partnerships (NextSTEP)
  - **Morehead State University** – 6U satellite bus development and testing, tracking and communication with DSS-17
  - **NASA Goddard Space Flight Center** – miniaturized instrument, the Broadband InfraRed Compact High Resolution Explorer Spectrometer (BIRCHES)
  - BIRCHES carries a 1,000,000-pixel detector that will sense infrared signals emanating from the lunar surface.
  - **JPL-** Iris transponder and flight communications systems
  - **NASA IV&V Center-** Flight Software Architecture
  - **Busek** - electric propulsion system based on Busek's RF Ion BIT-3 thruster, the world's only propulsion system powered with a solid-state iodine propellant,
- Getting there- using a low energy trajectory based on gravity wells of the sun, Earth and moon, looping around Earth a couple times and then to its destination. Propulsion system allows to naturally capture a lunar orbit.

Mission Phases



IceCube Design



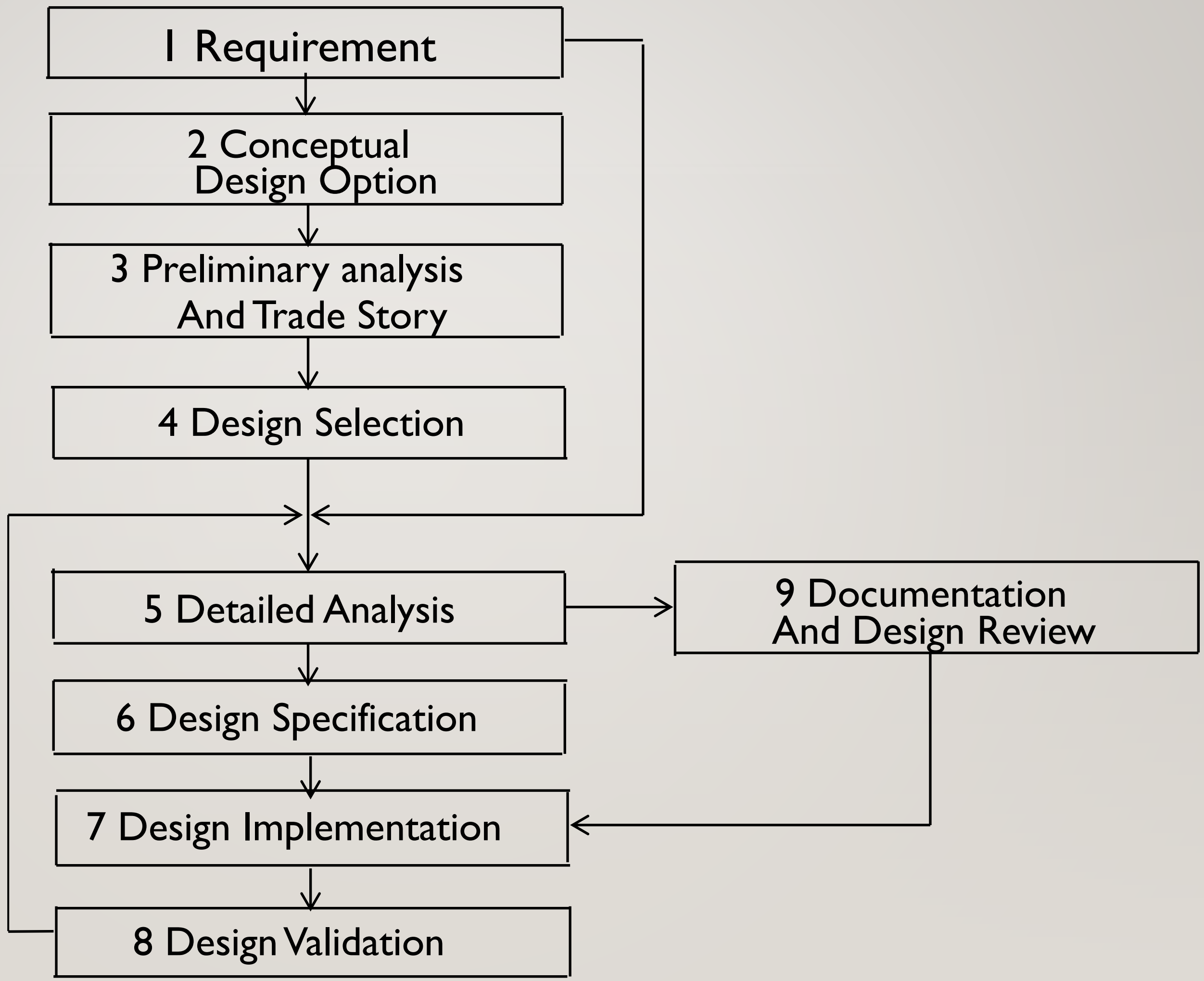
IceCube satellite is tightly packed :

- Thermal interaction between instruments
- Not easy routing of waste heat to space

Generally speaking :
All passengers share the same "boat": bad behavior of one affects all neighbors

Development of Thermal Management

Best practice of Designing of Thermal Management



Thermal Requirements- Temperature

LUNAR ICE CUBE SUBSYSTEMS THERMAL RANGES			
Subsystem		In Space Temp Survival (°C)	In Space Temp Operations (°C)
C&DH	Proton 400K	-40ºC to +85ºC.	-24 to +61 °C
Electrical Power	Articulated Solar Array (Solar panels, gimbals & drive articulators)		-30 to +70 °C
	EPS		-40 to +85
	Batteries	-20 to + 40 degree C	Charge: 0 to +40°C Discharge: -20 to +60°C
AD&ACS	BCT XACT (Star Tracker, Reaction Wheels, Sun Sensor)	-30 to +70 °C	-30 to +35 °C Star Tracker degrades from +35°C to +65°C
Communications	JPL Iris, SSPA, LNA	-20 to + 50 °C	-20 to +50 °C
	X-Band Patch Antennas (LGAs)	-55 to + 125 °C	-50 to +125 °C
	UHF Beacon	-20 to +70 °C	-20 to +50 °C
Propulsion	Propulsion Subsystem	-30 to +80 °C	-20 to +70 °C
Payload	BIRCHES Spectrometer Optical BOX	-45 to +85 °C	-78 to -45 °C
	BIRCHES DRE (Detector Readout Electronics)	-20C to 70 C	-10 to 40°C
	BIRCHES detector assembly (FPA and LVF)	-20C to 70 C	110K to 115K
	Compact Cryocooler	-20C to 70 C	-10 to 40°C
	mLCCE	-20C to +70C	-10 to +40°C

Thermal Requirements – Power

Unit power

EPS	2.2
C&DH	13.3
UHF Beacon	21.4
BIT-3 Propulsion	35.0
ADS	2.8
ACS - Reaction Wheel	20.0
Solar Panel Gimbal	5.6
BIRCHES Payload	25.0
Xband -LNA	1.0
IRIS SSPA	27.0
IRIS	12.4

Operation Modes

		Heat (Watts)
Deployment and Early Ops (10days)	Deployment, Detumbling & Orientaion	38
	Recovery	17
	Ranging &System Checkout	70
	Heating Propellant	71
	Calibrating ACS	72
	Trust Vector Orientation	114
Cruise (73.5 days)	Thrusting	68
	Comm and Navigation	113
	Standby	81
Capture & Transition (293 days)	Periapsis lowering	101
	Nav and Tracking	113
	BIRCHES Calibration	109
Science Orbit - 7hrs (single)	BIRCHES Calibration&Data collection	71
	Nav and Tracking	87
	Communication	95
	Standby	59

"Back Envelope Calculations"

Problem

- Total heat dissipation ≈ 114 Watts
- Total radiator area needed ≈ 0.3 m^2
- Total surface area available ≈ 0.24 m^2 (optimistic)

Not enough radiator area to dump all wasted heat at reasonable temperature

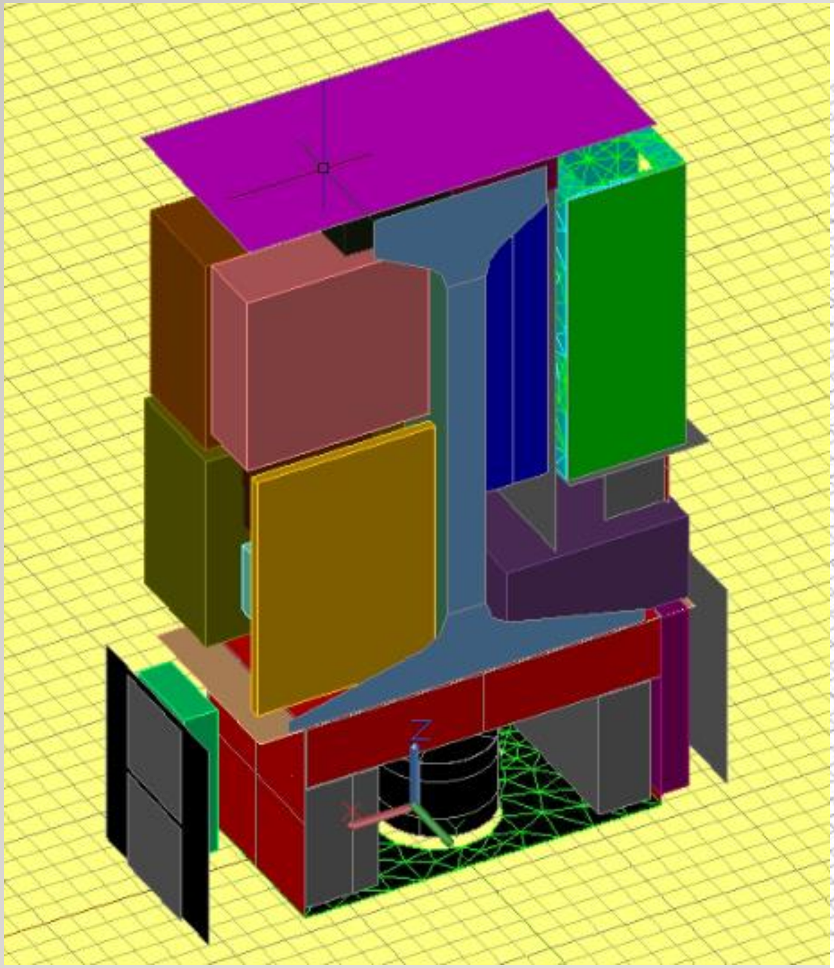
Solution(s)

- Increase surface - Deployable radiator

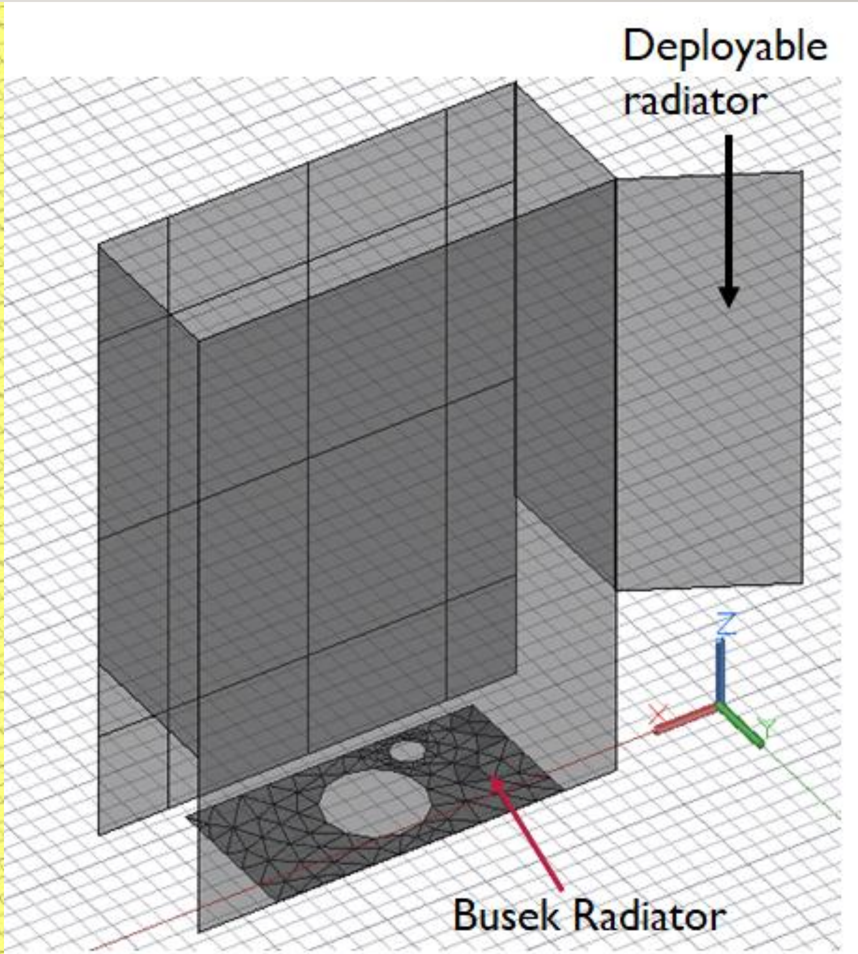
Or/And

- Increase radiator(s) temperature
  - Have several independent radiators
  - Connect components with similar temperature range to the same radiator
  - Raise radiator temperature to maximally allowable level
  - *Challenge:* heat generation by components changes during different operational modes. Therefore, heat generation in total for the same group can change that will lead to change of the radiator temperature.

Thermal Model



Space craft

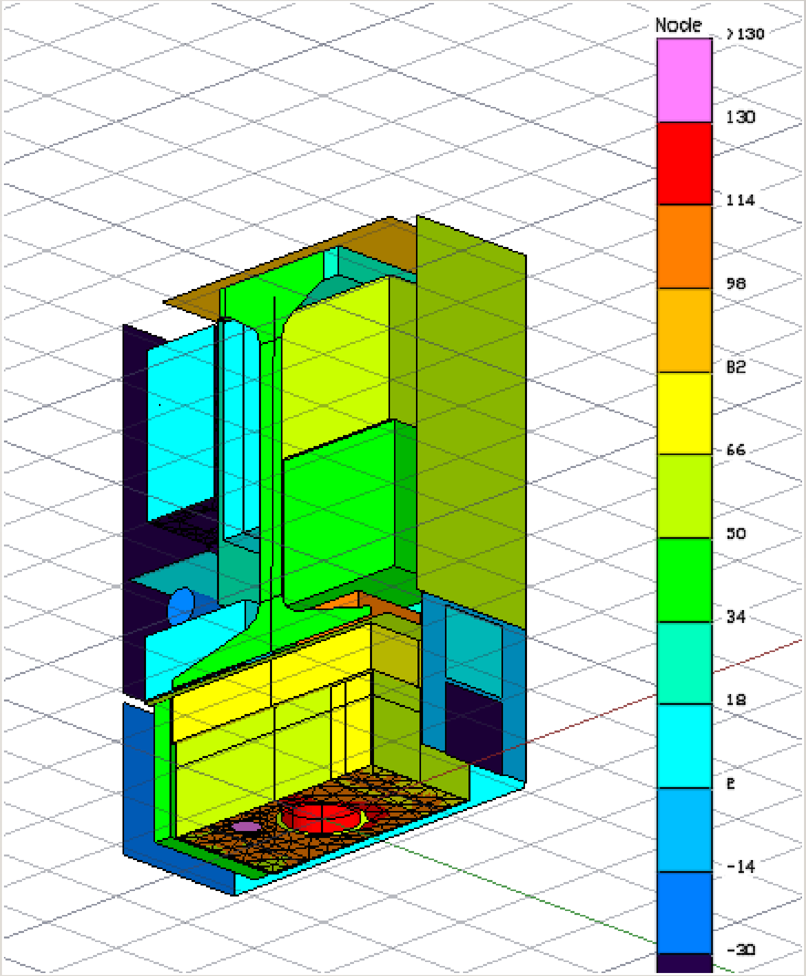


Six Radiators

Design Options- Radiator Assignment

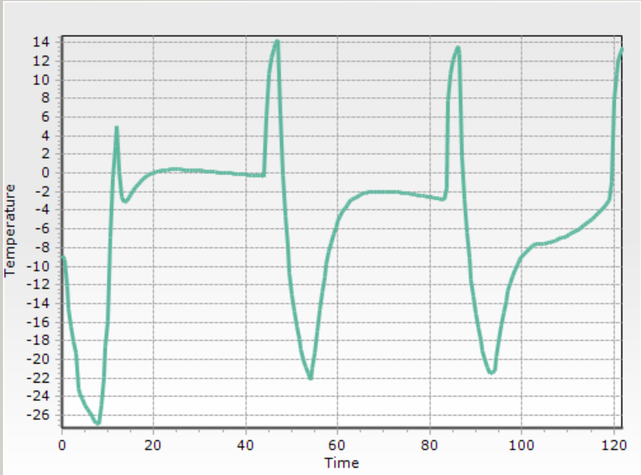
radiator	component	Rad temp.
-X (fixed)	Optical Box	-80 C
-X (deployable)		
+X	ADS_ACS	+18 C
	reaction wheel	
-Y	Sol Array Gimbals	+25 C
	reaction wheel	
	IRIS	
	IRIS SSPA	
	BIT3 Chassis	
-Z	BIT3	–20 +50 C
+Y	C&DH PR_N 400K	+30 C
	BIT3 Chassis	
	reaction wheel	
	IRIS SSPA	
	BAT_PAK	
	EPS	
	Detector Electronics	
	CryoCooler & cold finger Mounting	

Spectrometer could not achieve 110K without deployable radiator

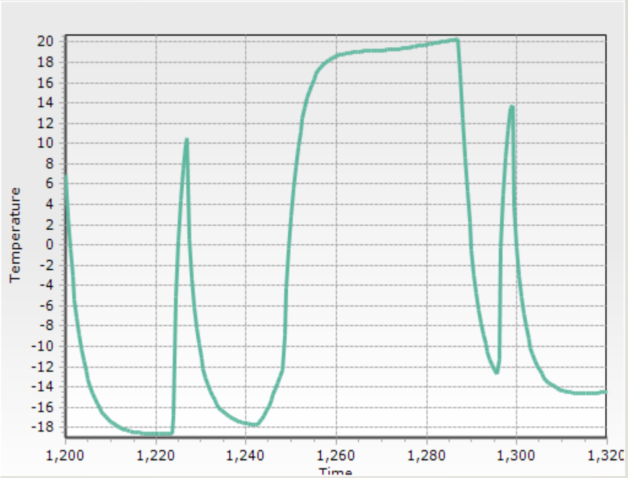


Radiators are not shown

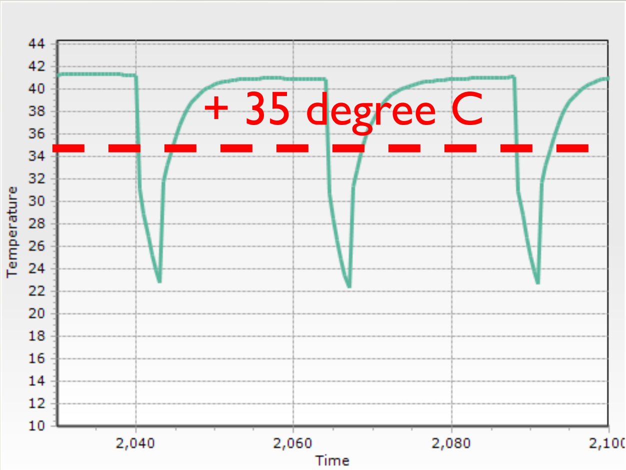
Operation Modes (example- Reaction Wheel)



Deployment and Early Ops

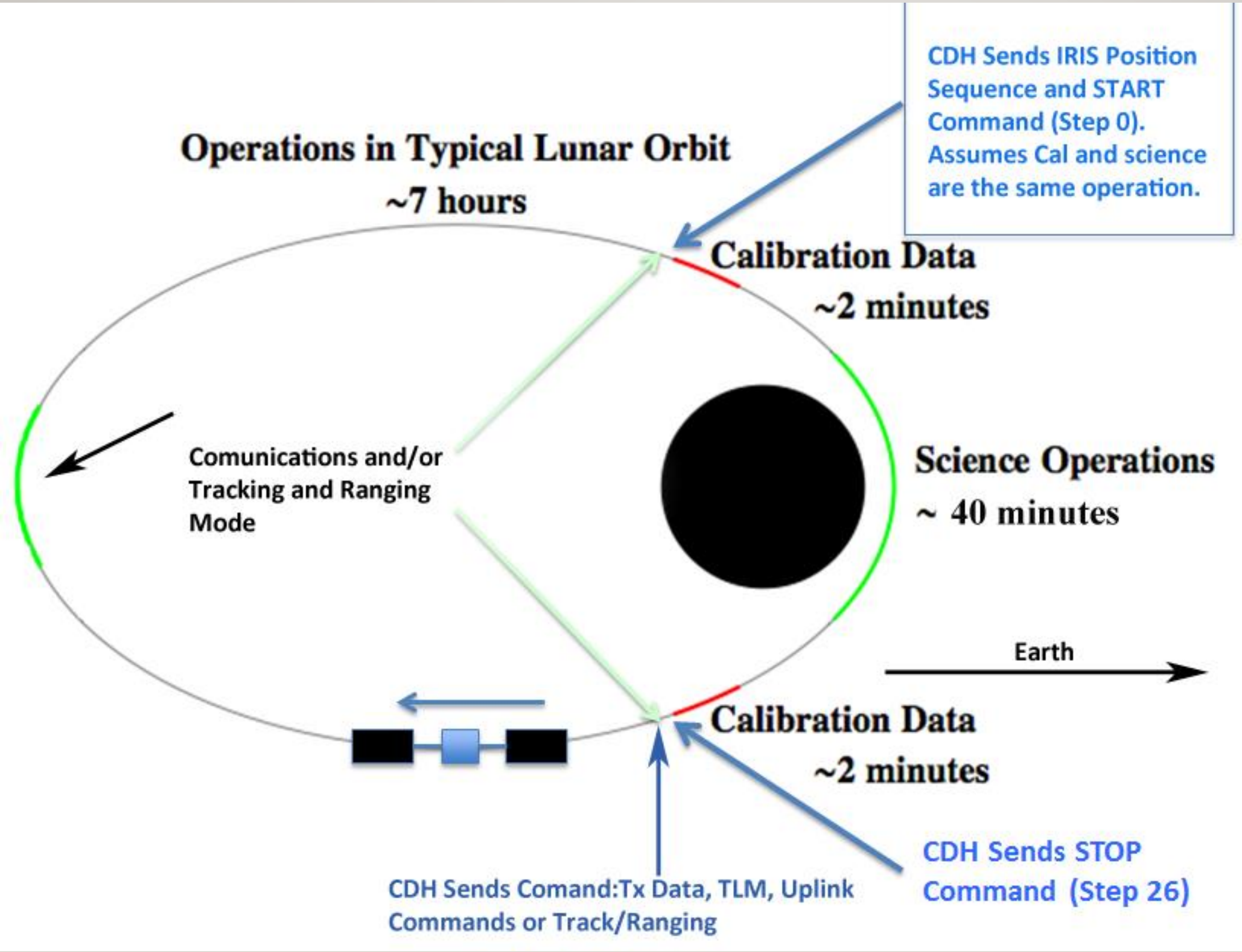


Cruise



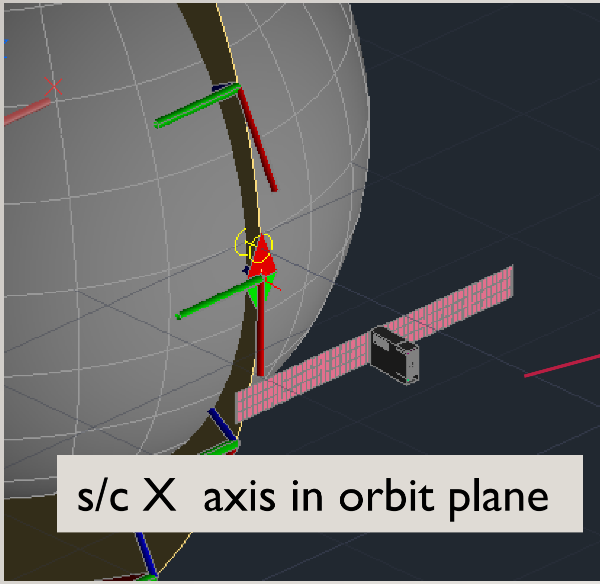
Capture and Transfer to Science

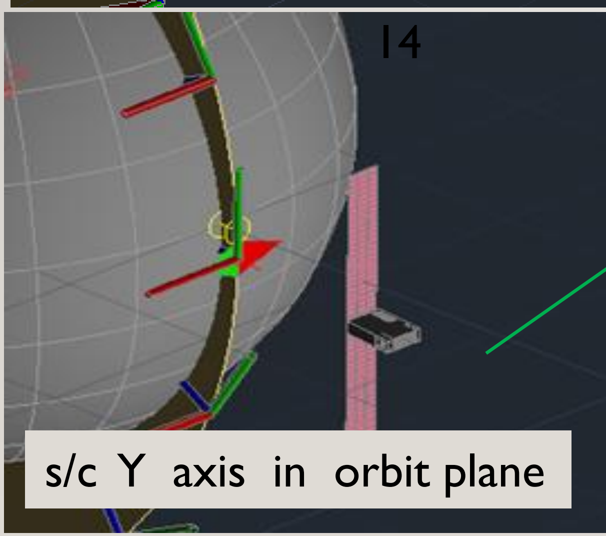
Science Orbit



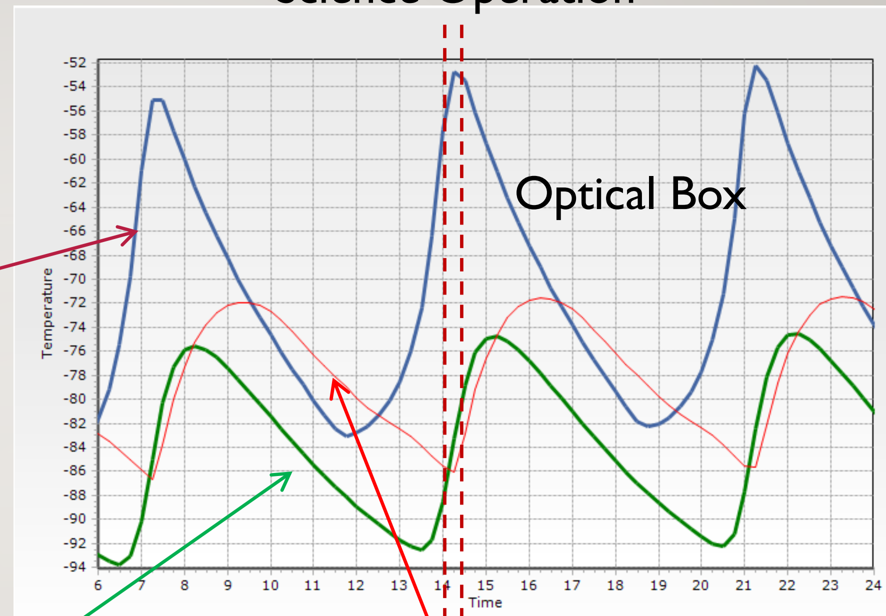
During daytime Lunar surface temperature can exceed 100C

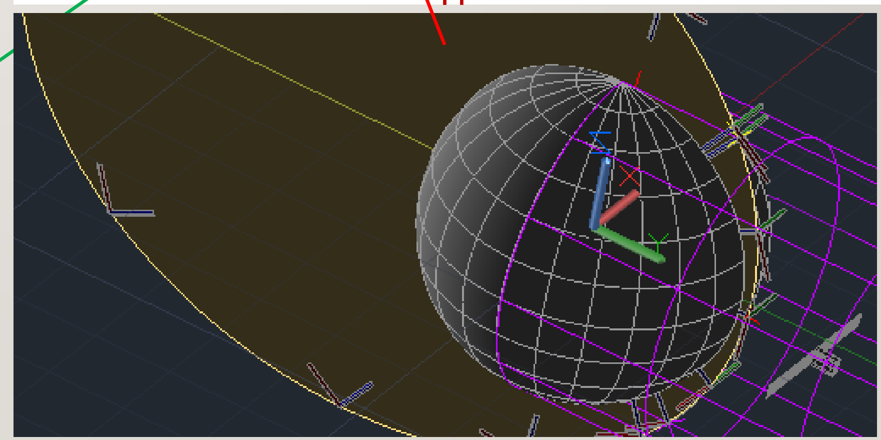
Lunar Orbit with eclipse



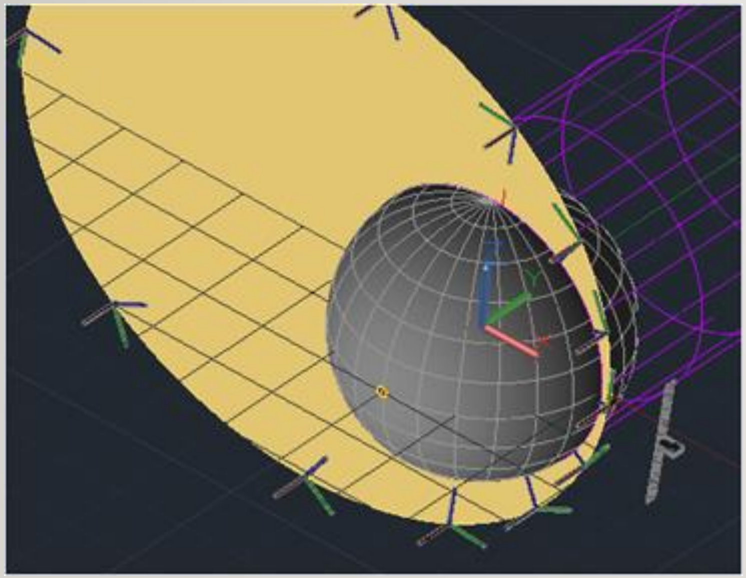


Science Operation





Science Orbit – sunsynk



s/c X axis in orbit plane

	min [C]	max [C]
mLCCE	4.3	29.8
battery	14.4	30.8
IRIS	0.0	33.6
SSPA	4.6	49.4
REACTION wheel	4.7	32.1

s/c Y axis in orbit plane

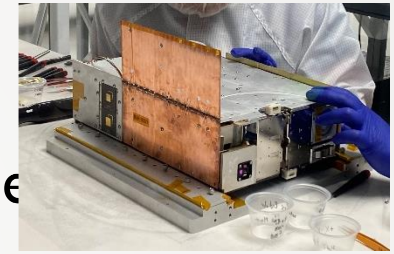
	min [C]	**max [C]**
CRYO_ELC_BOX	**3.3**	**26.8**
battery	**2.7**	**19.2**
IRIS	**2.0**	**38.7**
SSPA	**6.6**	**55.0**
REACTION wheel	**8.5**	**36.7**

Discussion

- Typically, high power cubesats run into problems of having not enough surface to reject waste heat into space at a reasonable temperature. Lunar IceCube represents an example
- Need to satisfy different requirements on different phases of mission timeline makes design of the temperature control system more complicated
- In contrast to large satellites, where all heat generated components are mounted directly on radiators, components in cubesat are mounted on “shelfs”. This leads to increase of temperature difference between heat source and radiator and larger radiator
- Spacecraft orientation could affect significantly thermal performance of the satellite.

CONCLUSION

- Independent radiators with different operating temperature increased s/c capability to reject waste heat into space.
- A deployable radiator was added because body-mounted radiators could not satisfy the thermal requirements



- S/c thermal model should be built at the beginning of the project and used as a tool of design optimization, in particular, in cases when instruments are supplied by multi- vendors with considerably dissimilar thermal requirements