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IceCube: CubeSat 883-GHz Radiometry for Future Cloud Ice Remote Sensing

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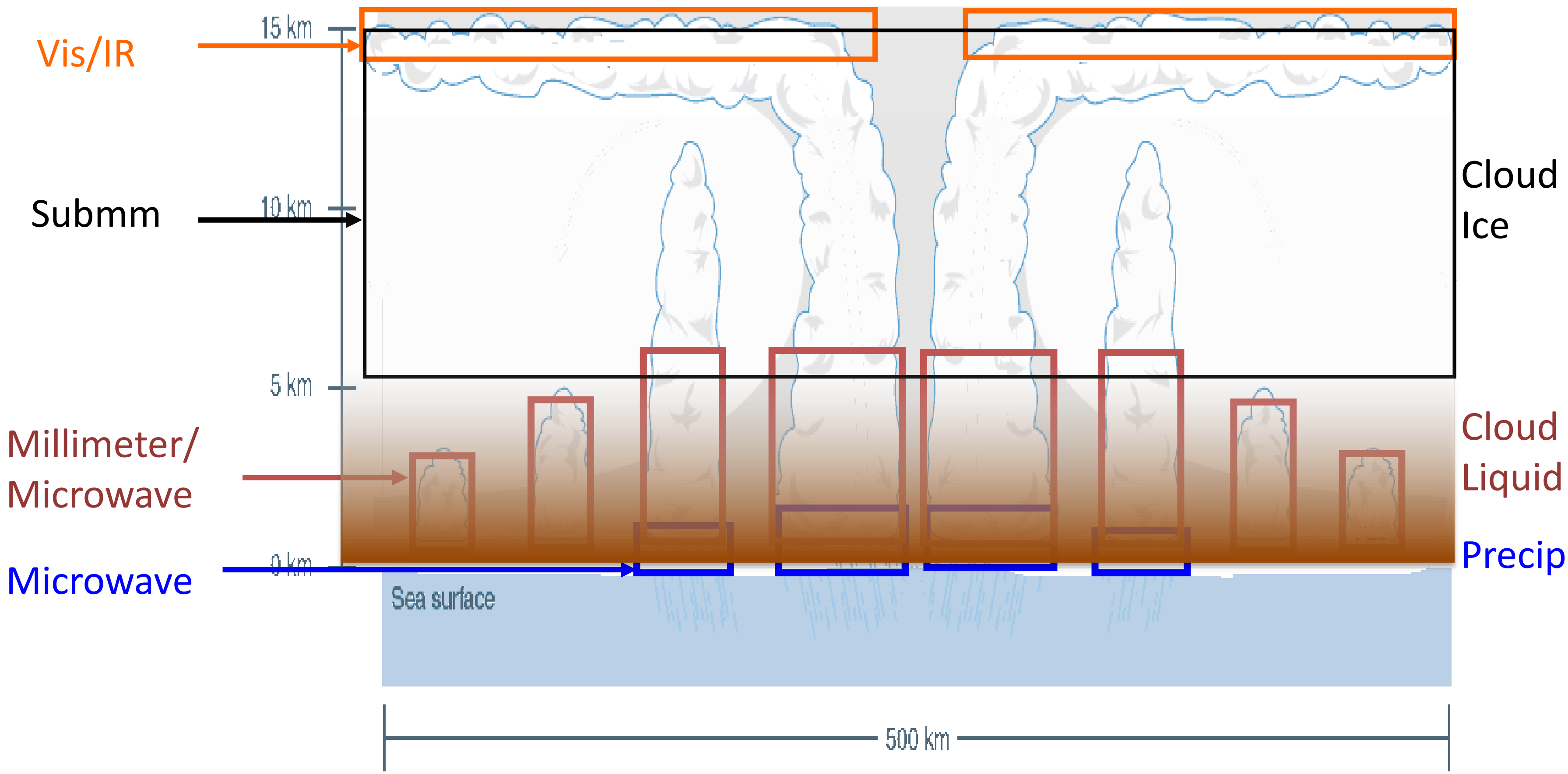
Why Submillimeter-Wave Radiometry?
- Critical Gap in Cloud Ice Measurements -

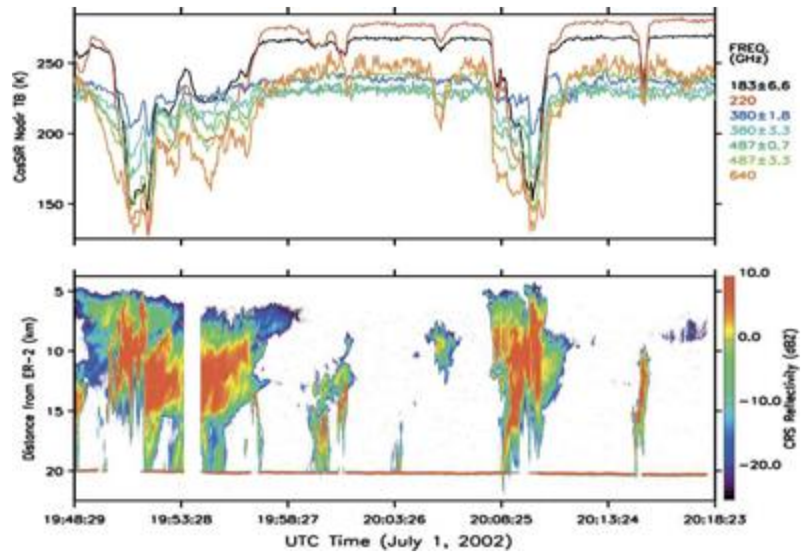


Heritage: NASA/GSFC Airborne Instrument

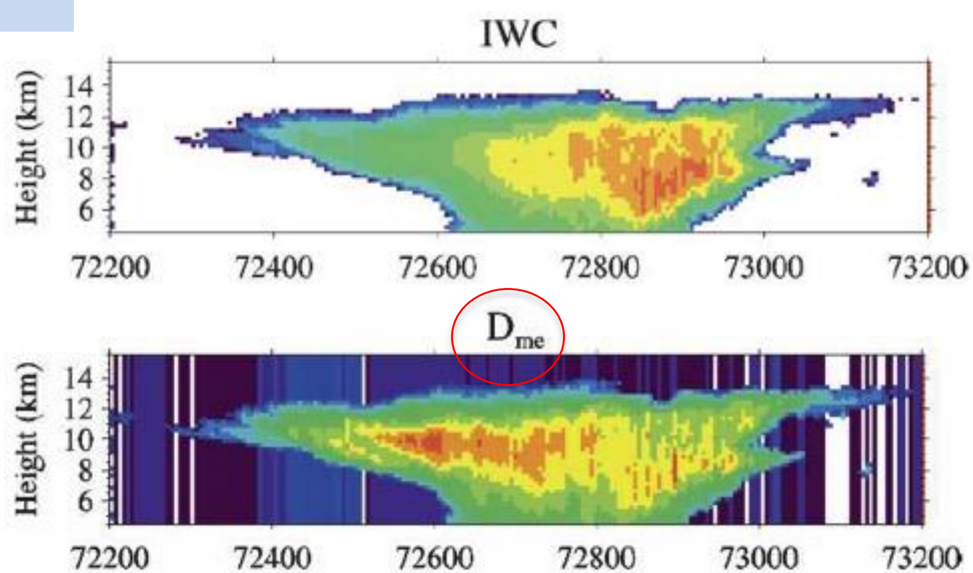
Compact Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

Evans et al. (2005)

Chn #	Freq. (GHz)	Offset (GHz)	BW(GHz)	Tsys (K)	NEDT (K)
1	183.3	1	0.5	2500	0.55
2	183.3	3	1.0	1390	0.23
3	183.3	6.6	1.5	1050	0.15
4	220	2.5	2.5	1760	0.16
5	380.2	0.8	0.7	3460	0.63
6	380.2	1.8	1.0	8440	1.23
7	380.2	3.3	1.7	4820	0.55
8	380.2	6.2	3.6	6670	0.52
9	487.25	0.8	0.35	4650	1.17
10	487.25	1.2	1.2	3890	0.85
11	487.25	3.3	2.9	4600	0.40
12	640	2.5	3.0	16000	1.33

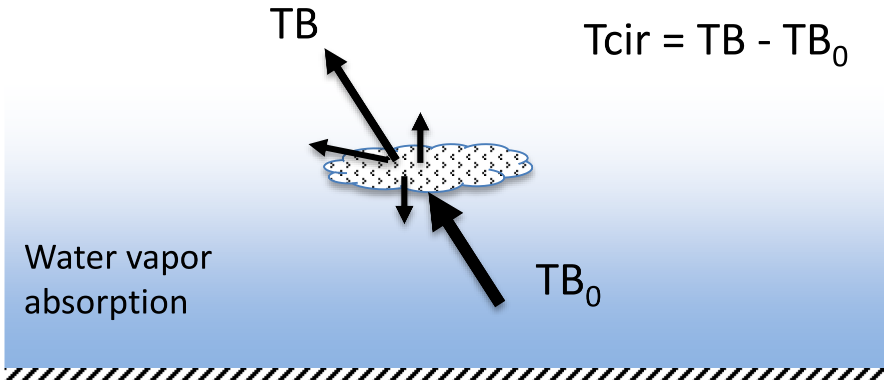


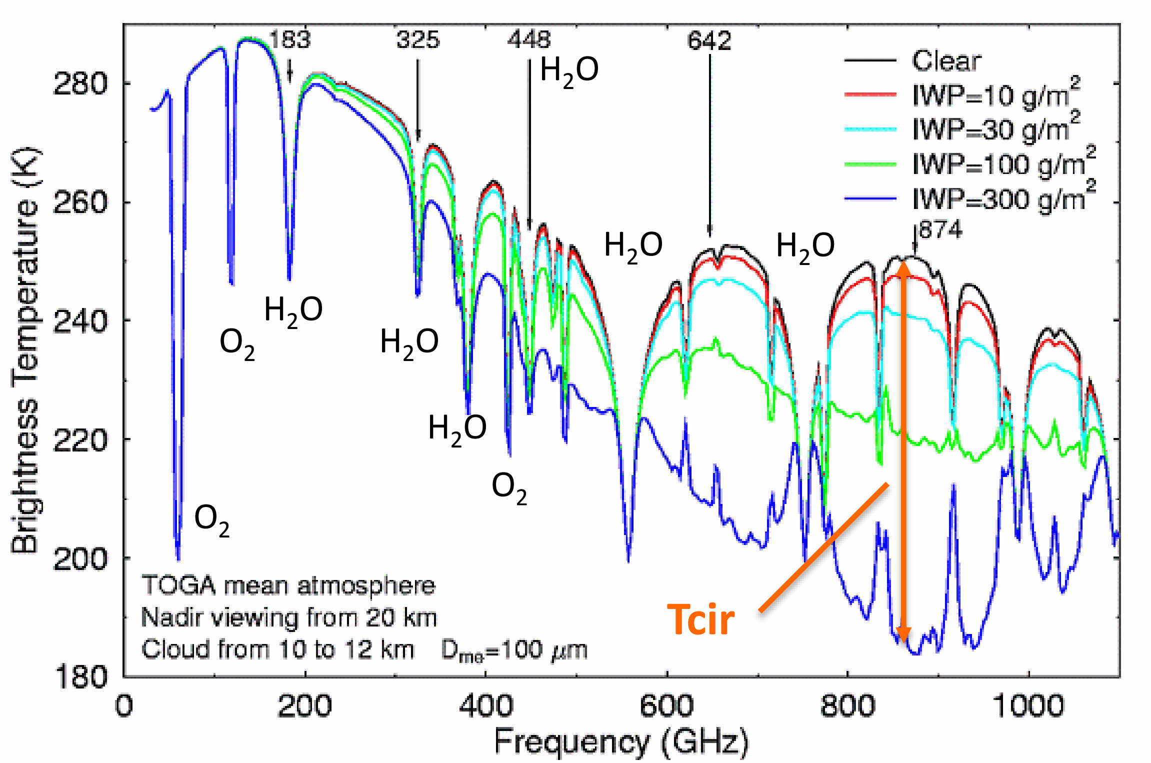
- CRYSTAL-FACE campaign near Florida in July 2002
- Co-flight of CoSSIR and 94-GHz Cloud Radar System (CRS)
- Simultaneous retrievals of ice water path (IWP) and particle size (D_{me}) from CoSSIR
- Simultaneous retrievals of ice water content (IWC) and D_{me} from CoSSIR + CRS



Ice Cloud Scattering Properties

- Higher sensitivity to cloud scattering at submm-wave
- Cloud-induce radiance, Tcir, proportional to cloud ice water path (CIWP)
- Cloud microphysical properties (i.e., particle size) from different frequencies
- Simultaneous retrievals with T, H_2O

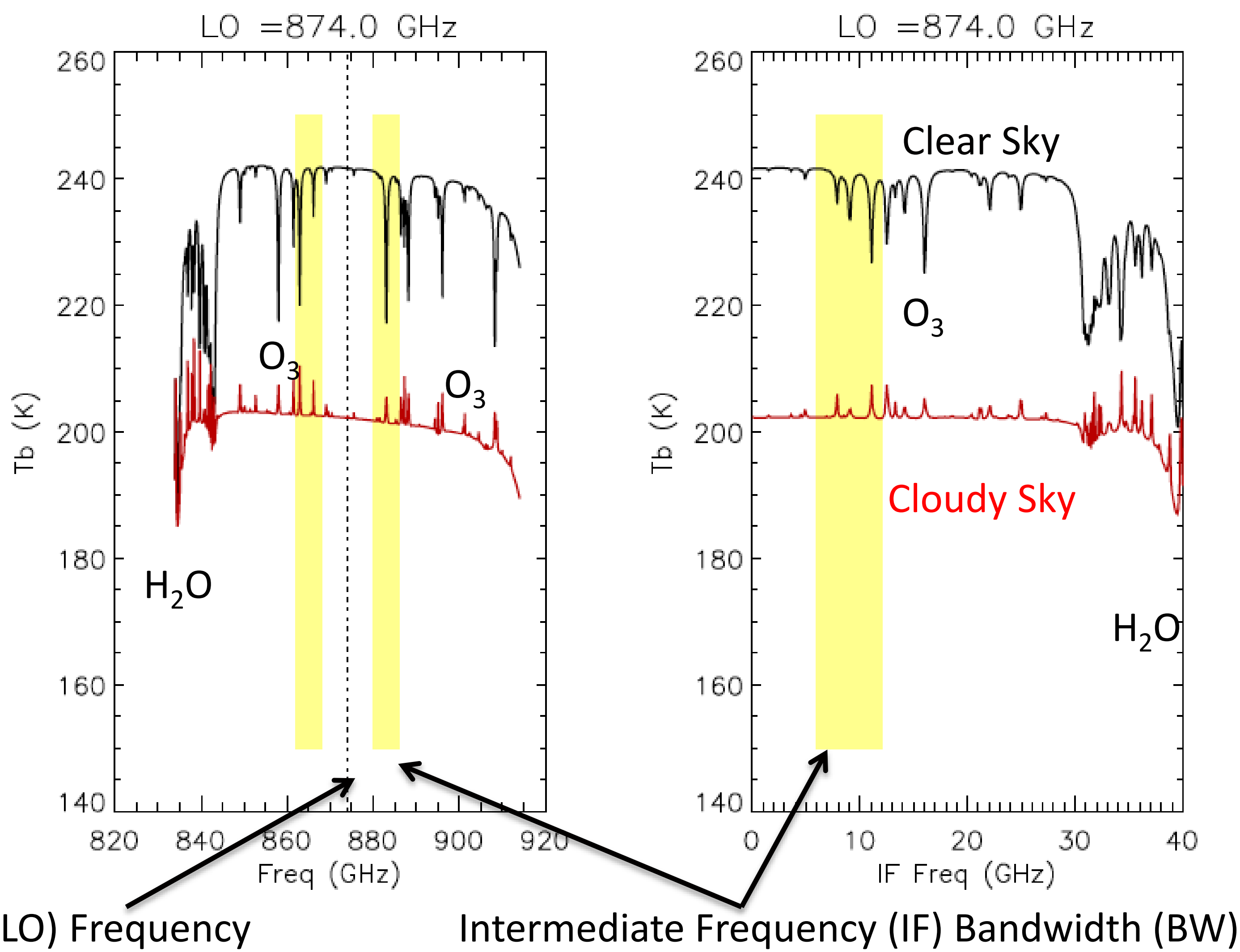




LO Frequency Change: 874 -> 883 GHz

Molecules included in calculations

- O_2
- H_2O
- O_3
- NHO_3
- $O^{18}O$



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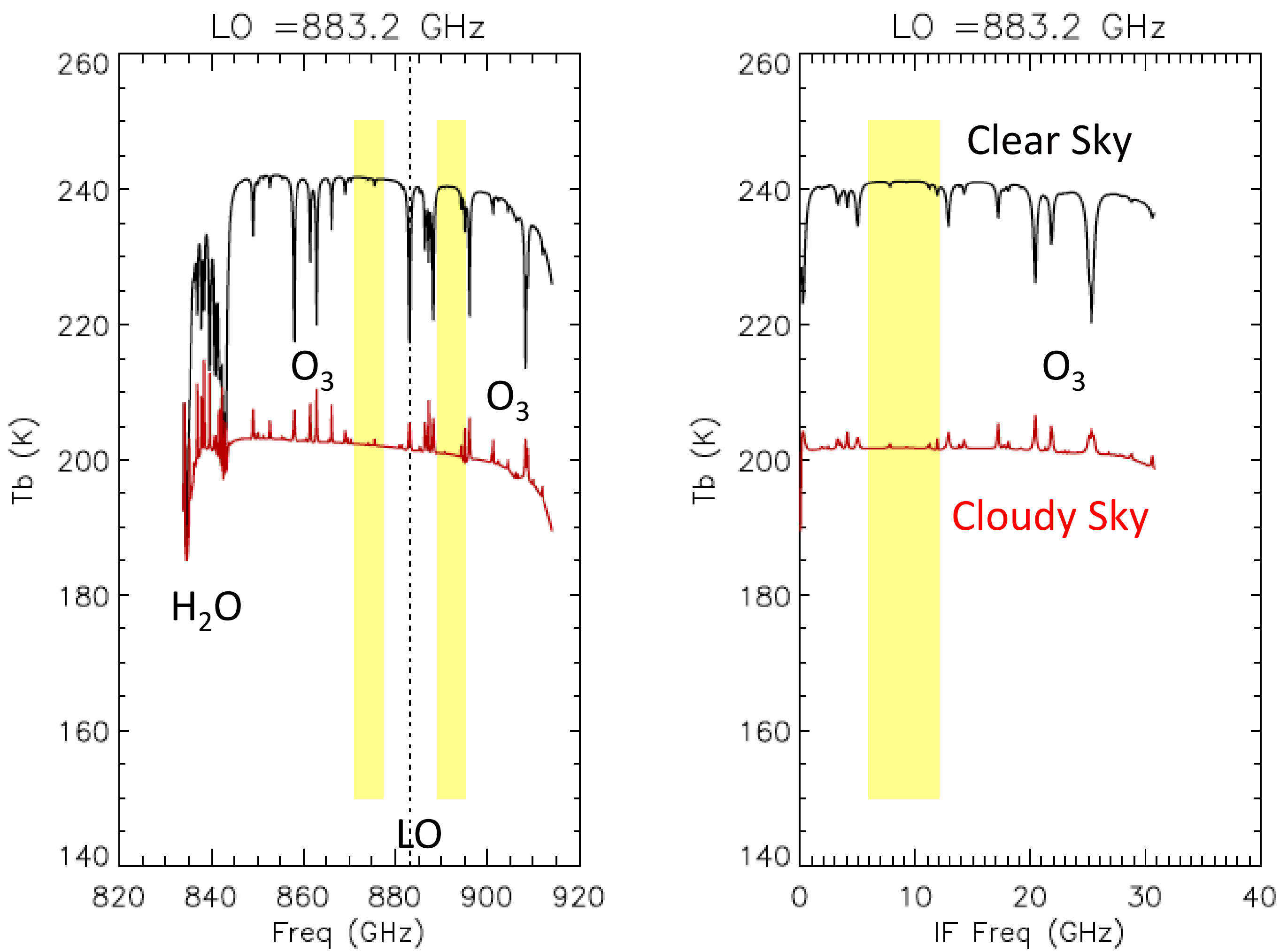


IceCube Objectives

- Enable remote sensing of global cloud ice from space with submm-wave technology
- Raise overall TRL (5->7) of 883-GHz receiver technology with spaceflight demonstration on 3U CubeSat

Common Goals and Benefits to NASA SMD science missions

- Miniaturize science payload for low-power and low-mass spaceborne sensors
- Reduce instrument/spacecraft cost and risk for future missions by developing efficient path-to-space with COTS receiver and CubeSat systems

Measurement and Mission Overviews

883-GHz measurement requirements:

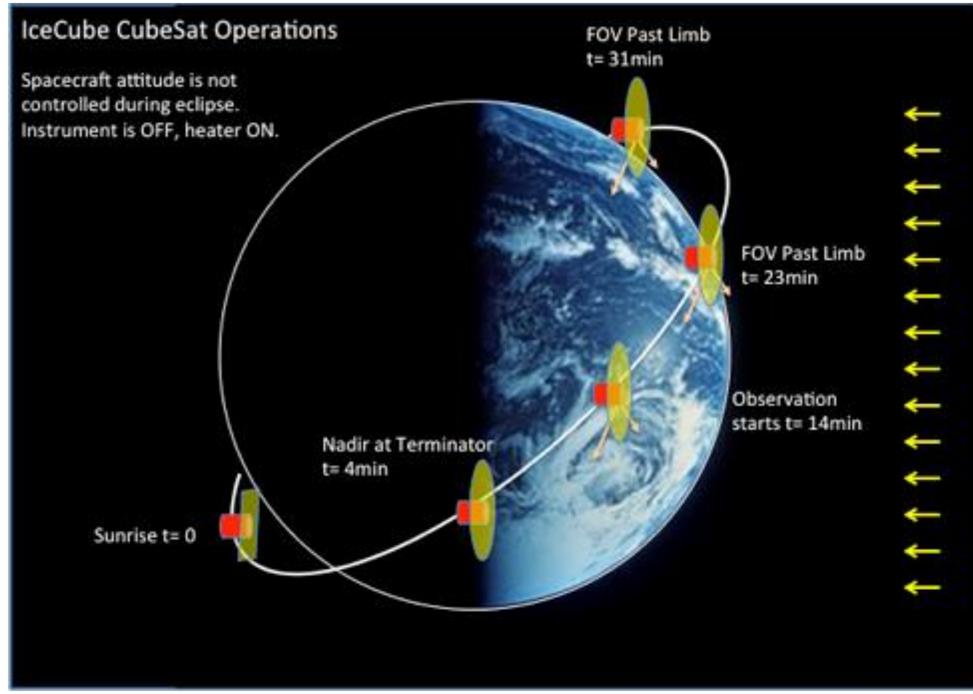
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

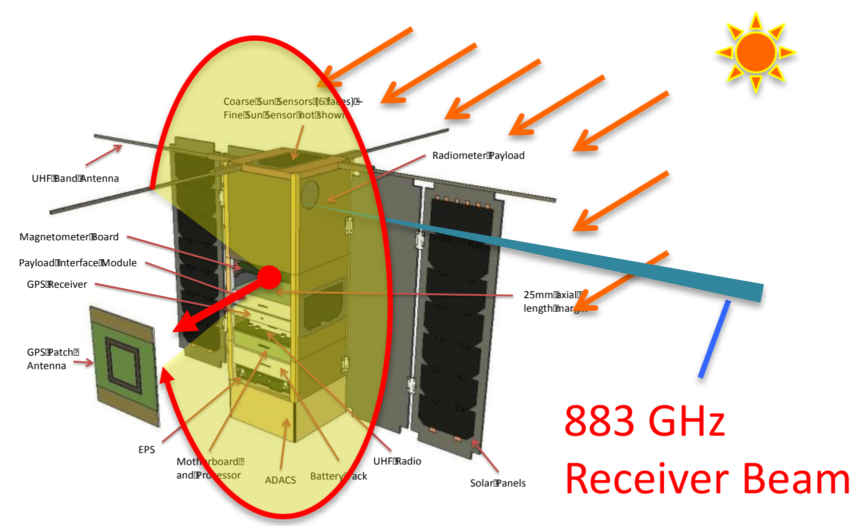
Mission requirements:

- In-flight operation 28 days
- Periodical views of Earth (science) and space (calibration) within an orbit
- Science data 30+% (8+h /day)
- Pointing knowledge < 25 km

Validation plan:

- Lab measurement and verification
- Modeled vs observed clear-sky radiances for accuracy verification
- Space-view radiances for precision





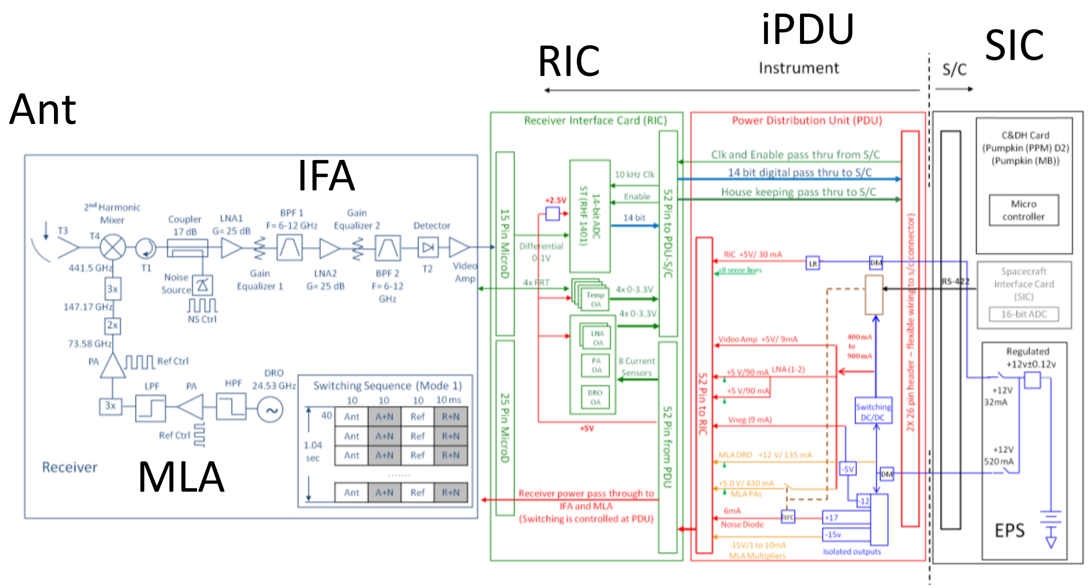
Instrument Specification Summary

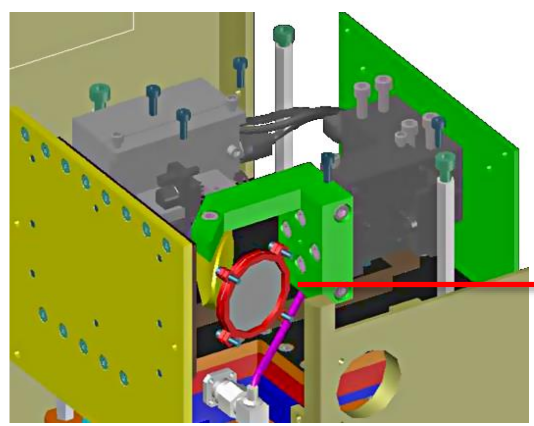
Category	Specification
Frequency band	871-895 GHz with f_0 = 883 GHz
Input RF channel	V polarization
NEDT	0.25 K
Calibration sources	Noise diode/reference load (internal)
IF 3 dB bandwidth	6-12 GHz
IF gain	30-40 dB
A/D sampling	10 kHz
Integration time	1 s
Mass	≤1.3 kg including 30 % contingency
Power	11.2 W including 30 % contingency

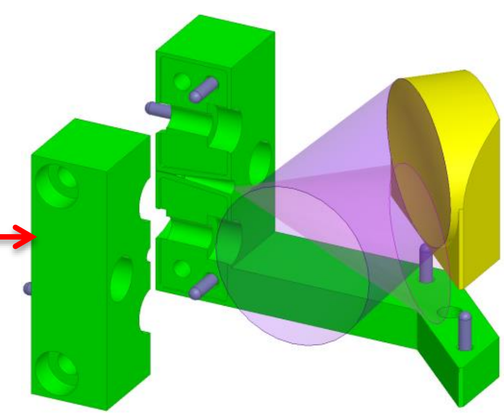
Key Instrument Subsystems

- Antenna (Ant)
- Mixer LO Assembly (MLA)
- Intermediate Frequency Assembly (IFA)
- Receiver Interface Card (RIC)
- Power Distribution Unit (iPDU)

- Mechanical structure
- Instrument EM and flight I&T

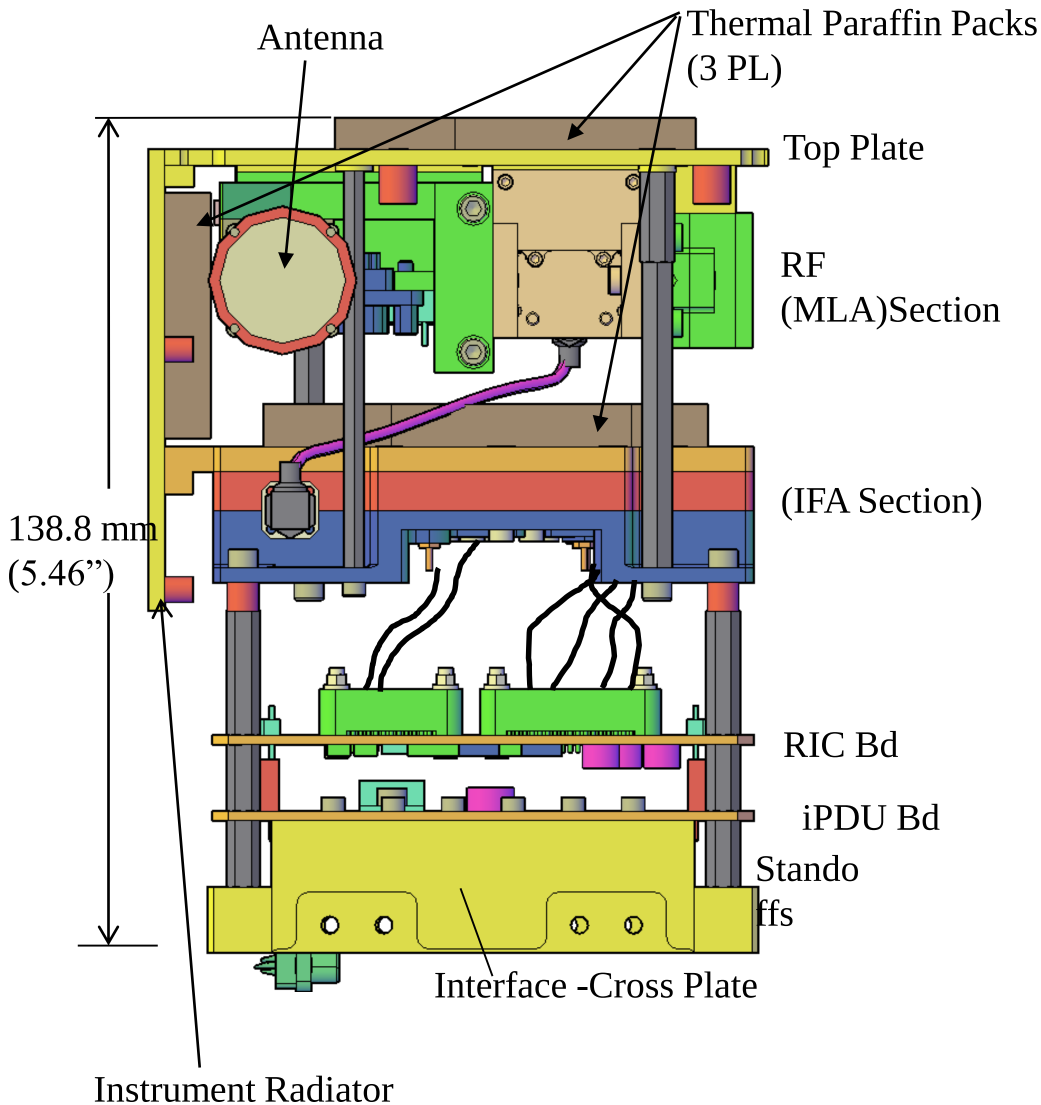


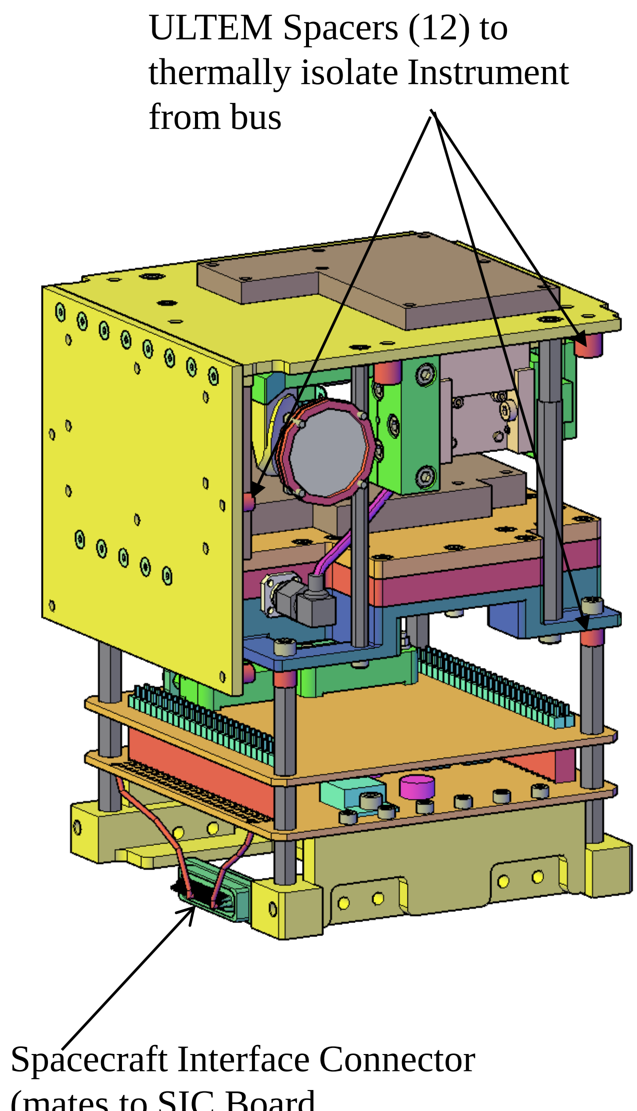




IceCube Antenna Design

Instrument Mechanical Structure

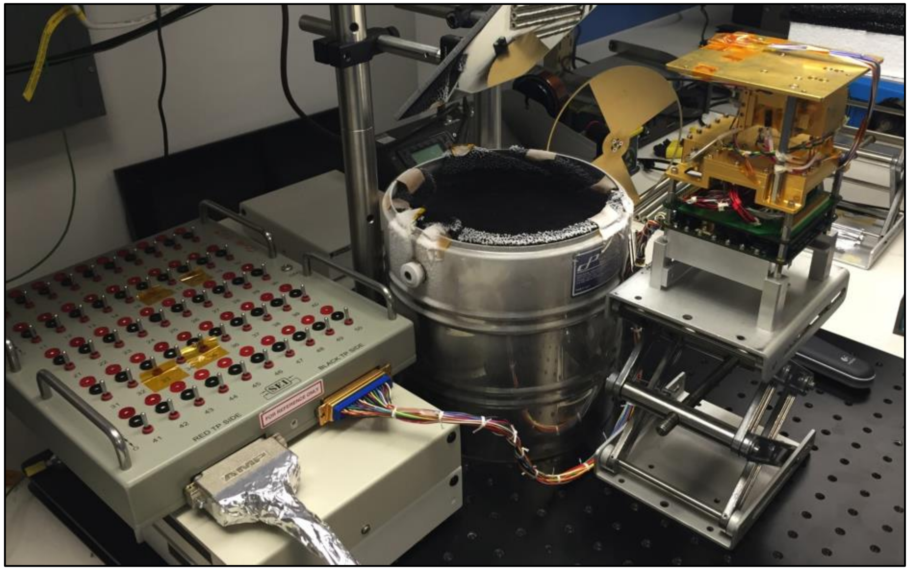




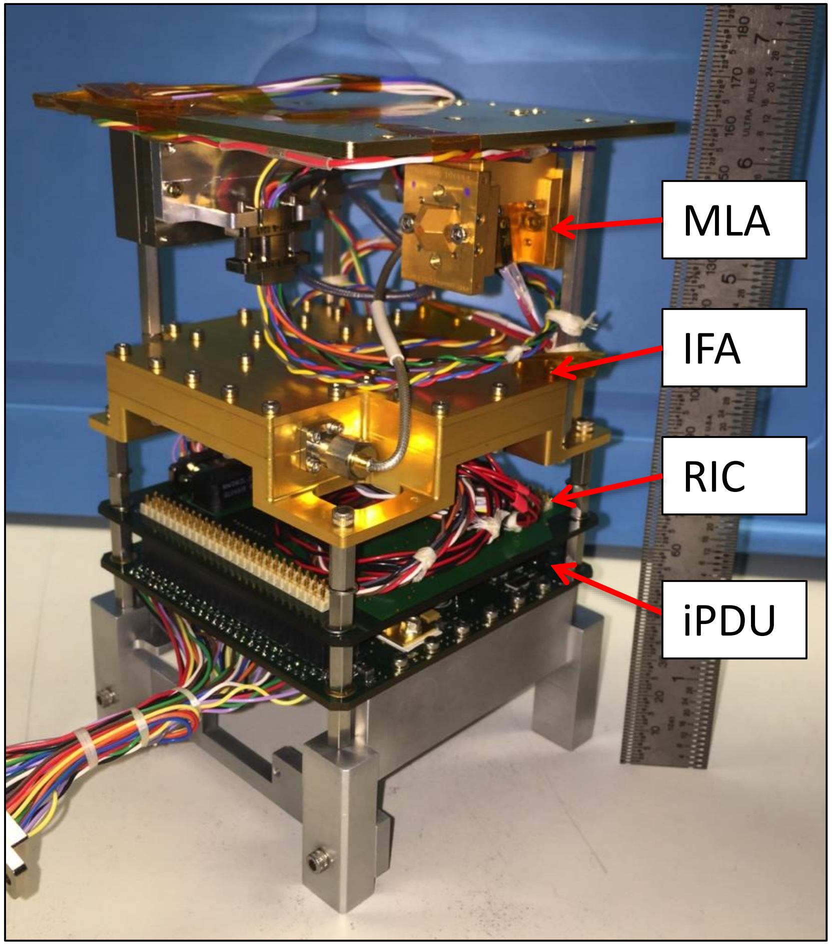
Courtesy of Mike Solly Code 562

Engineering Model (EM) I&T

An Instrument Integration & Test (II&T) was conducted in April 2015 on an Engineering Model (EM) Instrument. This I&T was to verify instrument interfaces, calibration GSE interfaces, and assess preliminary instrument performance and calibratability.



EM Instrument observing LN2 target – May, 2015

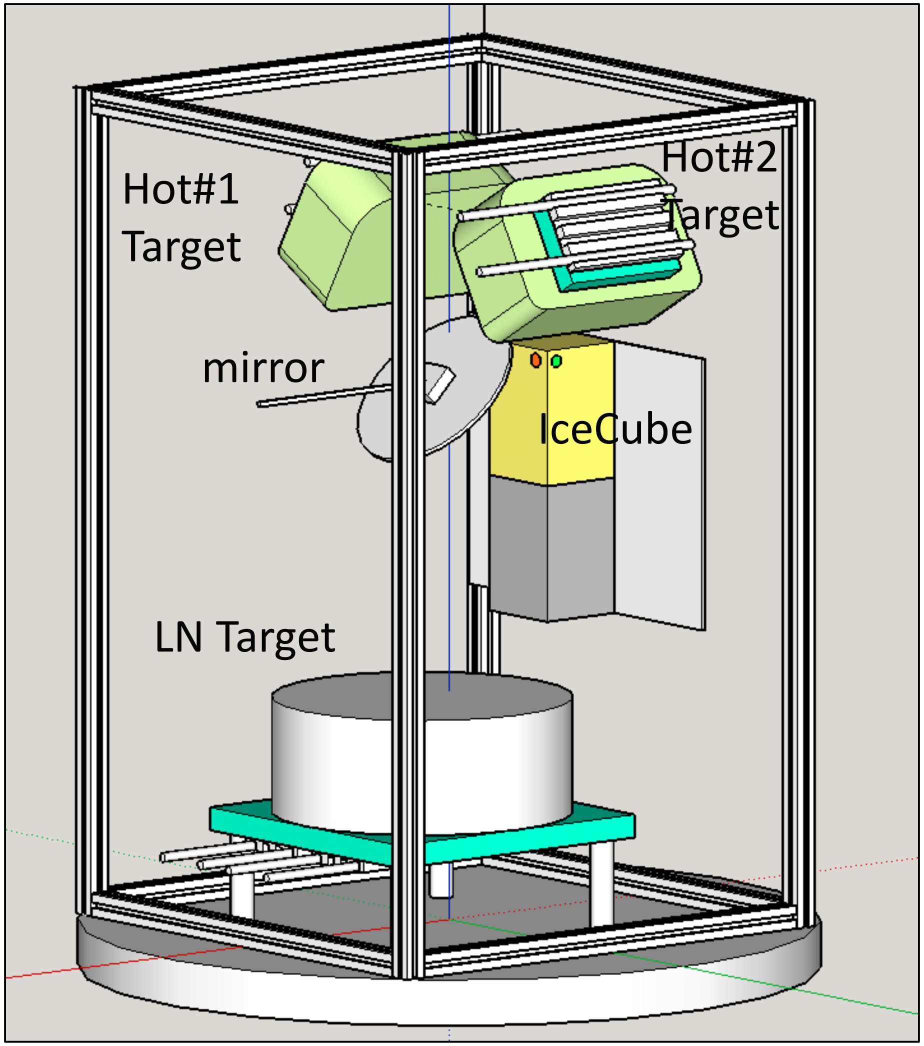


Engineering Model IceCube Instrument, May 2015

Courtesy of Kevin Horgan Code 555

II&T T-VAC Calibration Fixture

- Calibration fixture, similar to one used for MIT/Lincoln Labs (MIT/LL) MicroMAS-1, is being developed for IceCube microwave payload in a 3U CubeSat.
- A rotating mirror will be used to direct the instrument's field-of-view to three thermal targets of different temperatures. The calibration will be performed in GSFC Greenbelt or WFF facility.
- Table-top and critical design reviews were conducted for II&T and calibration activities.



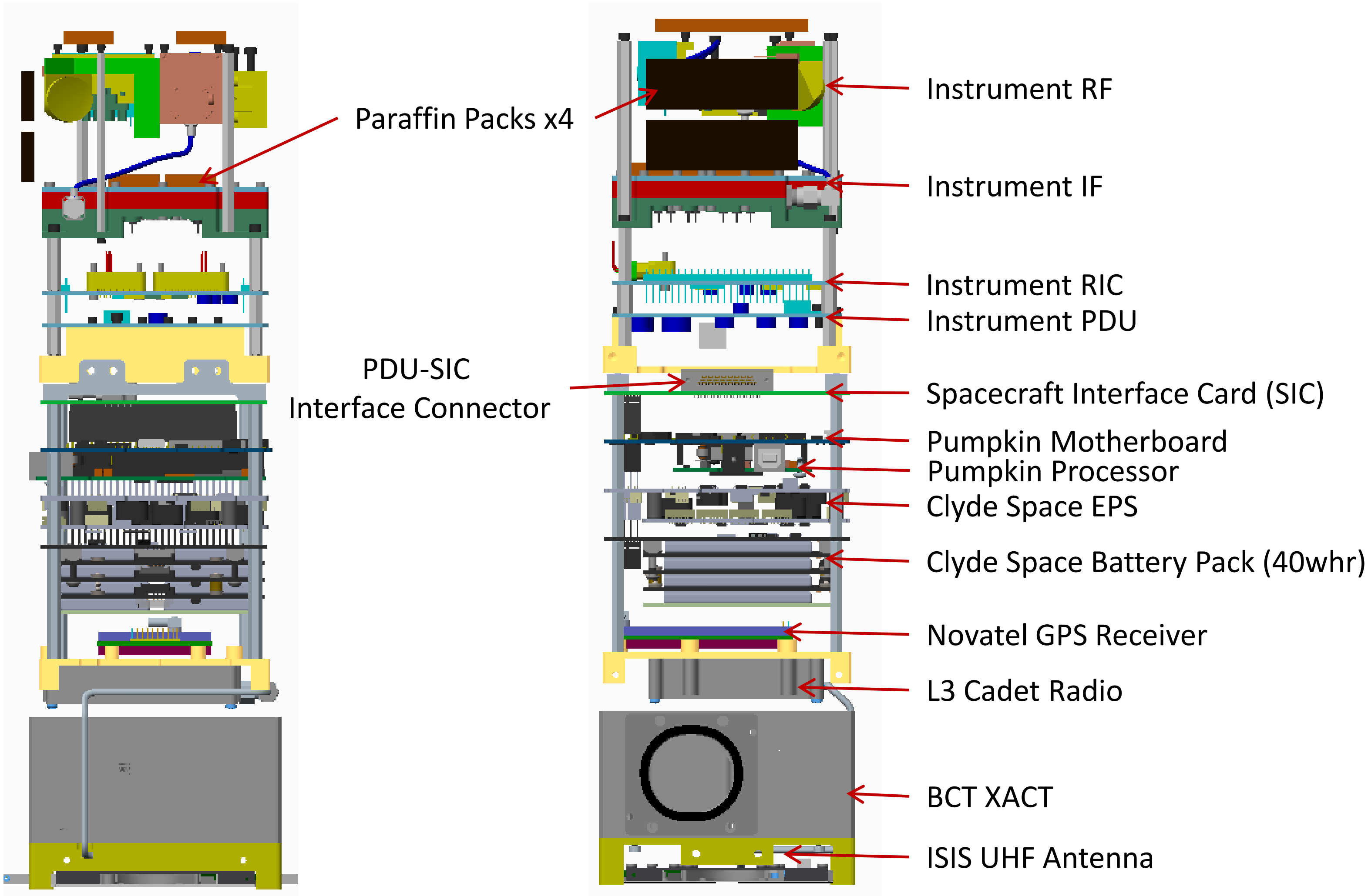
Model of IceCube Calibration Fixture w/ CoSSIR & 330 mm Targets

Courtesy of Kevin Horgan Code 555

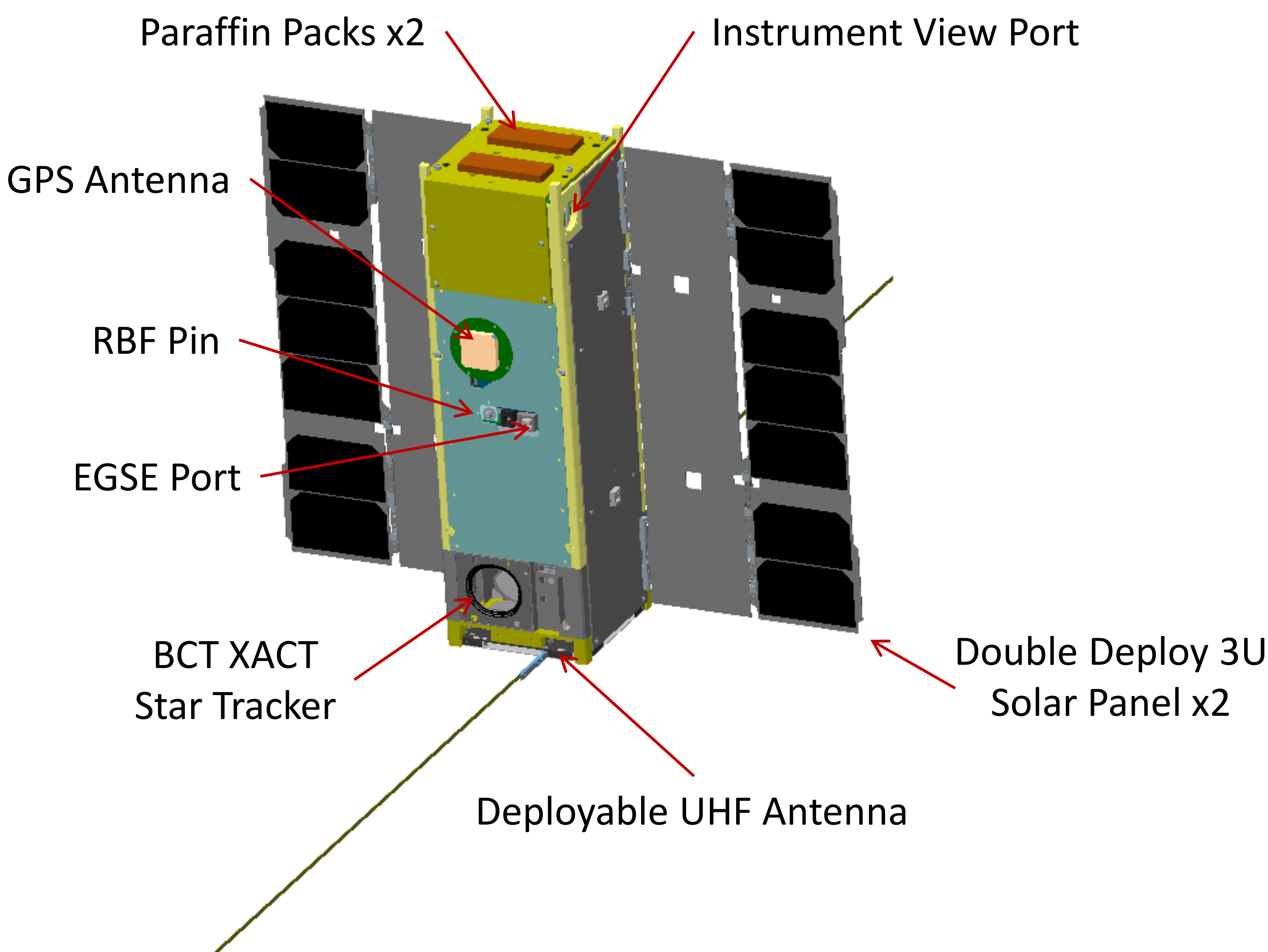
Spacecraft Subsystems

Subsystem	Design	POC
Electrical system	Spacecraft Interface Card (SIC) PDU-SIC interface	C. Duran-Aviles
Mechanical structure	3U	J. Hudeck
GPS	Novatel GPS Receiver	T. Johnson
Navigation and Control	BCT EXAT	S. Heatwole
Power system	Clyde Space EPS, Solar panels, Battery 40Whr	C. Purdy
Thermal control	Passive paraffin packs Radiating surfaces	M. Choi
Communication	L2 Cadet radio ISIS UHF Antenna	B. Corbin
Flight software	Pumpkin Motherboard, CPU Modified DICE flight software Beacon telemetry	T. Daisey
Ground system	WFF 18m, GMSEC/DICE design	R. Stancil

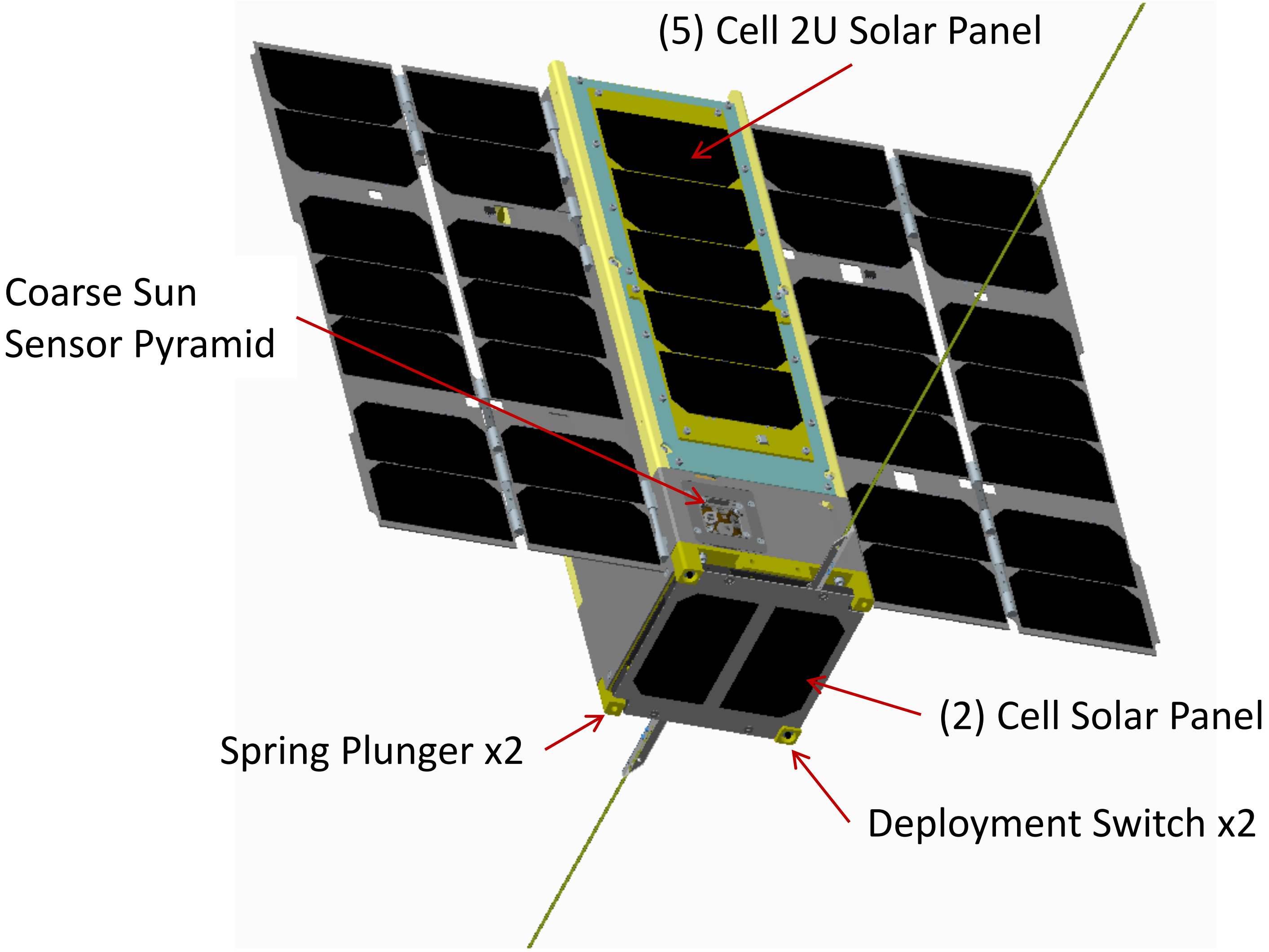
Internal Layout



External Layout (1/2)

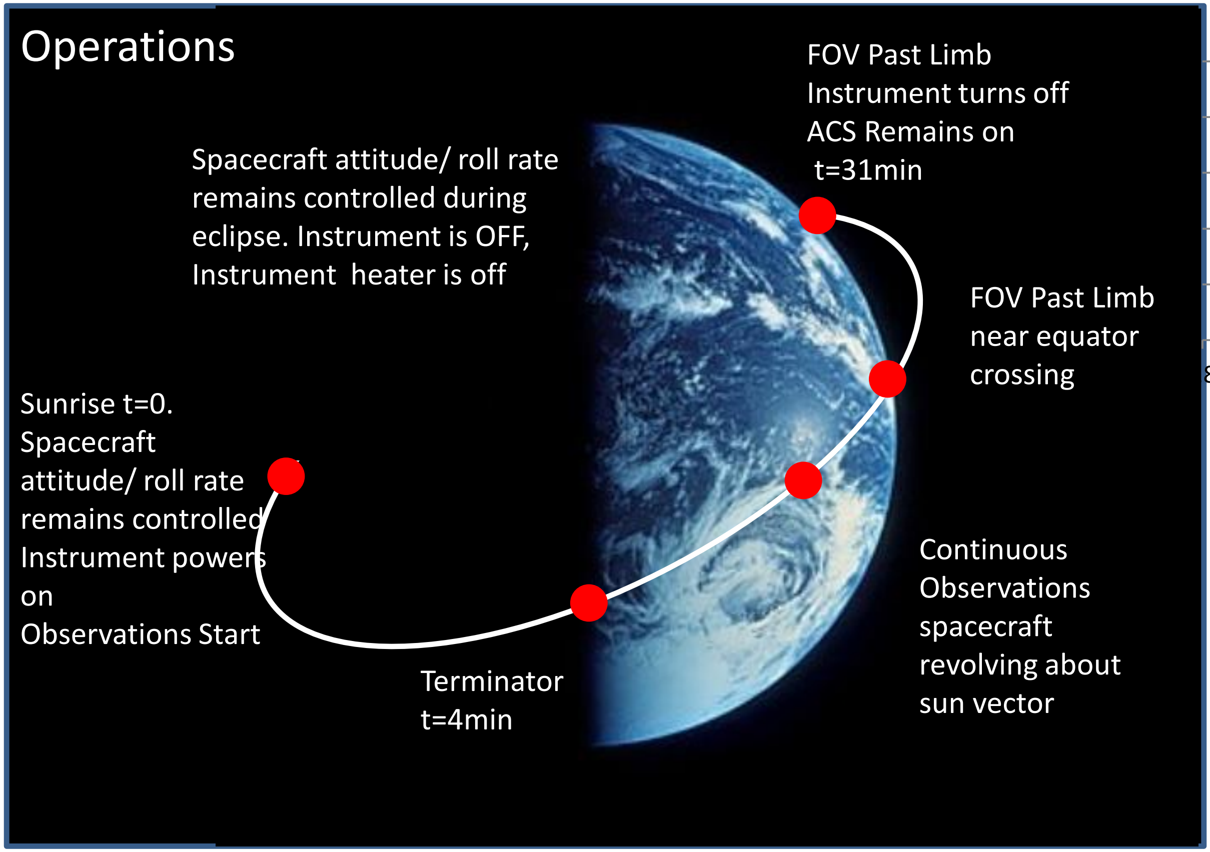


External Layout (2/2)

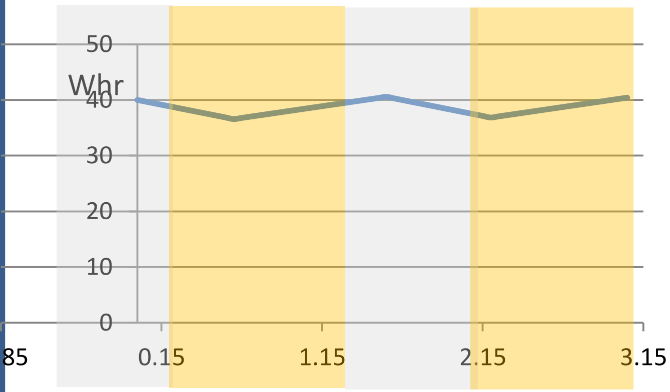


Concept of Operations

NASA CRS/COTS Orbit Baseline
Altitude = 424-422 km   Period = 90.5 min   Inclination = 51.65°

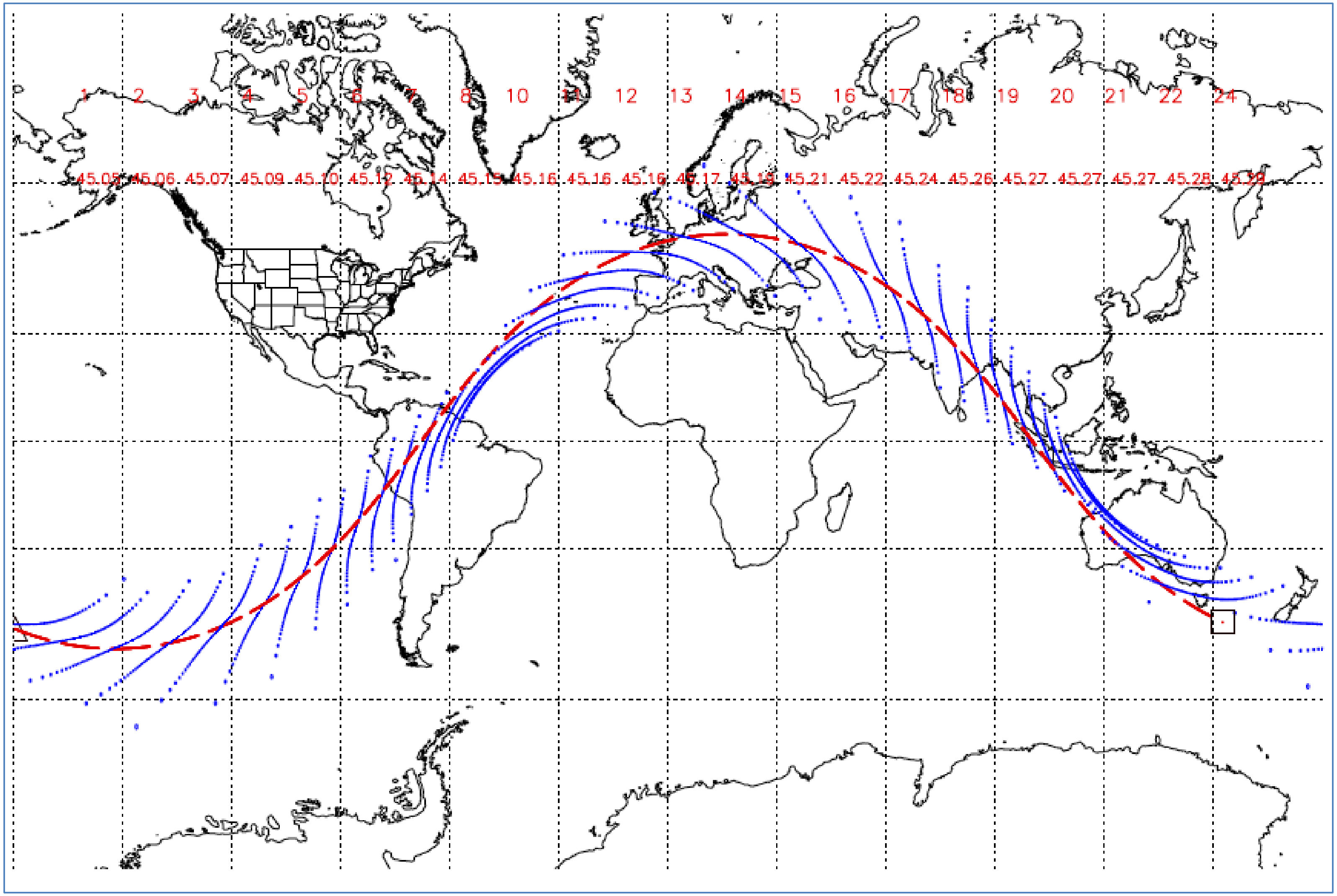


Science only in Sun Limit 20% DOD



	Sun	Eclipse
	W	W
Instrument	5.4	0
GN&C/C&DH	4.145	4.145
Com	0.32	0.32
Power	0.31	0.46
EPS Losses 16%	1.628	0.788
Total out	11.803	5.713
Arrays	25	0
PDU losses 20%	-5	0
Total in	20	
Cell Temp Loss 20%	-4	
Total in	16	0

Simulated IceCube Sampling for Feb 25, 2015

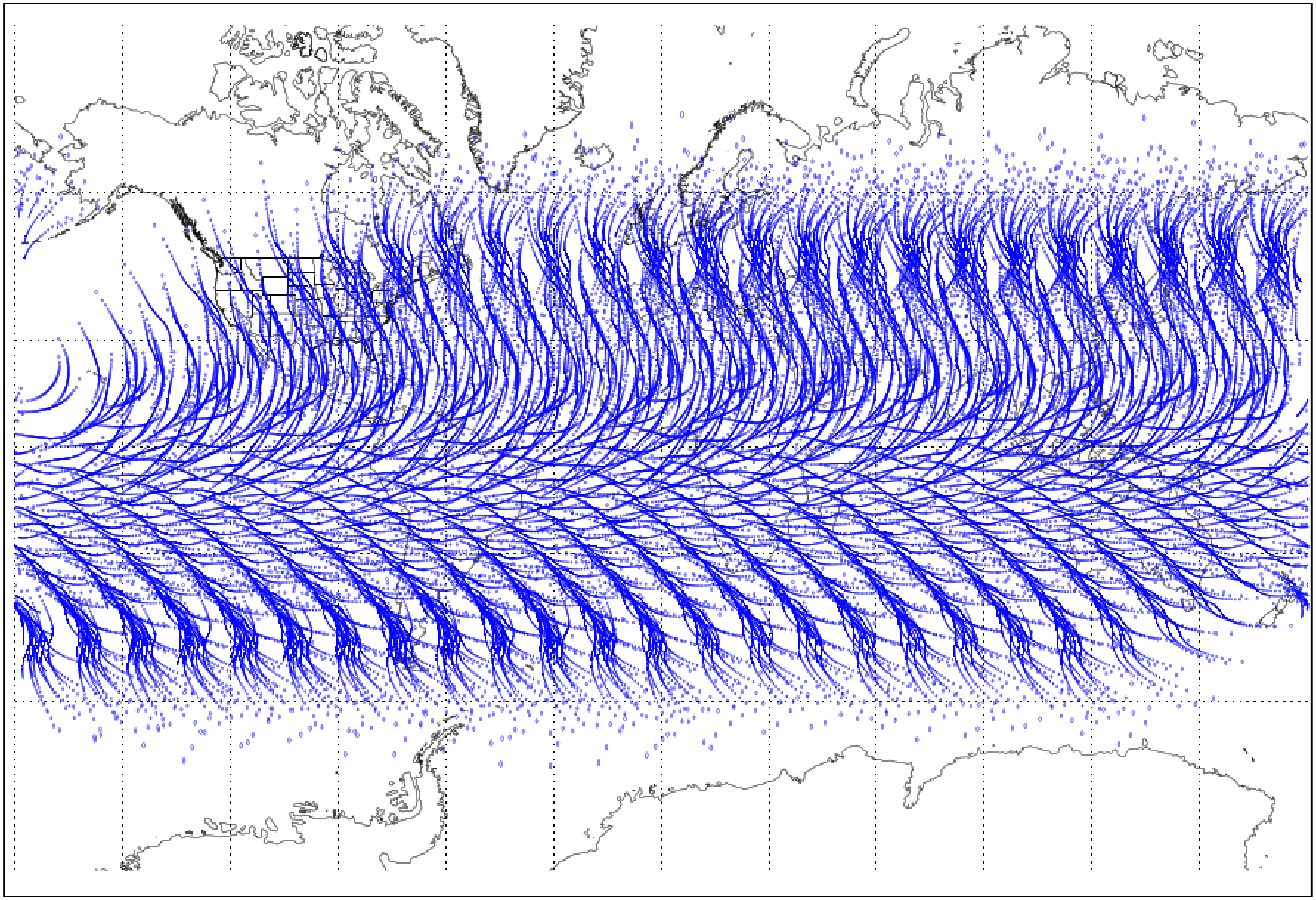


(Courtesy of Y. Liu, SSAI)

National Aeronautics and Space Administration

Goddard Space Flight Center

Simulated Sampling for June 10-16, 2015 (Daytime-Only)



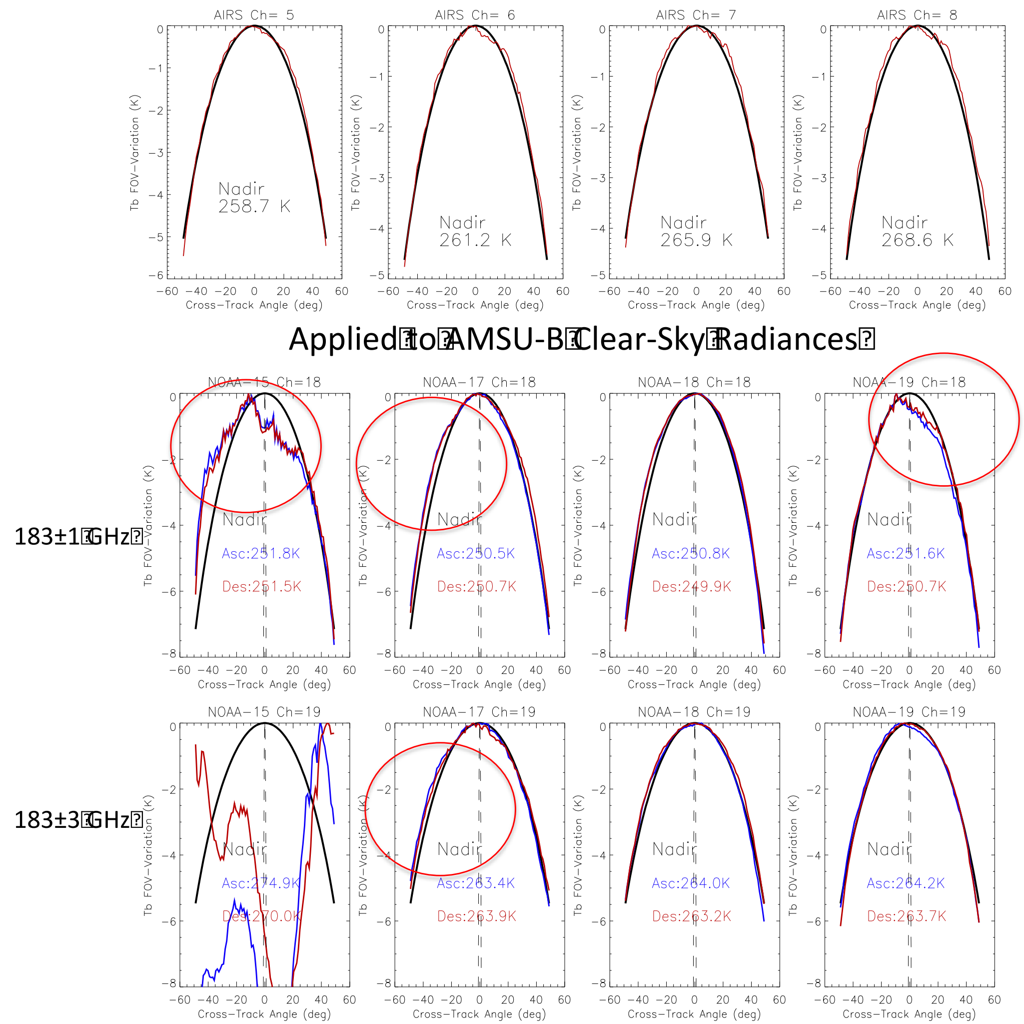
(Courtesy of Y. Liu, SSAI)

Validation of IceCube 833-GHz Radiances

- Comparison between modeled and observed clear-sky radiances
- MLS Radiative transfer model [Wu et al., 2006], and inputs from MERRA data (e.g., P, T, H2O)
- Tropical measurements: well-defined atmospheric thermal structures
- Slant-to-nadir conversion using

$$T_b = T_{b0} + a \ln[\cos\theta]$$

Applied to AIRS Radiances



Scan Angle from Nadir (degrees)

IceCube Project Schedule

Project start	**4/14/14**
System Requirements Review (SRR)	**7/29/14**
Table Top Design Review	**10/23/14**
Critical Design Review (CDR)	**4/28/15**
Instr. Integration &Test begins	**9/16/15**
Pre-Environmental test Review (PER)	**10/16/15**
Pre-Ship Review (PSR)	**12/22/15**
Flight Readiness Review (FRR)	**1/14/16**
Launch	**4/14/16**
Flight Operation ends	**5/25/16**
Data Analysis ends	**8/19/16**
TRL(in) = 5; TRL(out) = 7	**9/1/16**