



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

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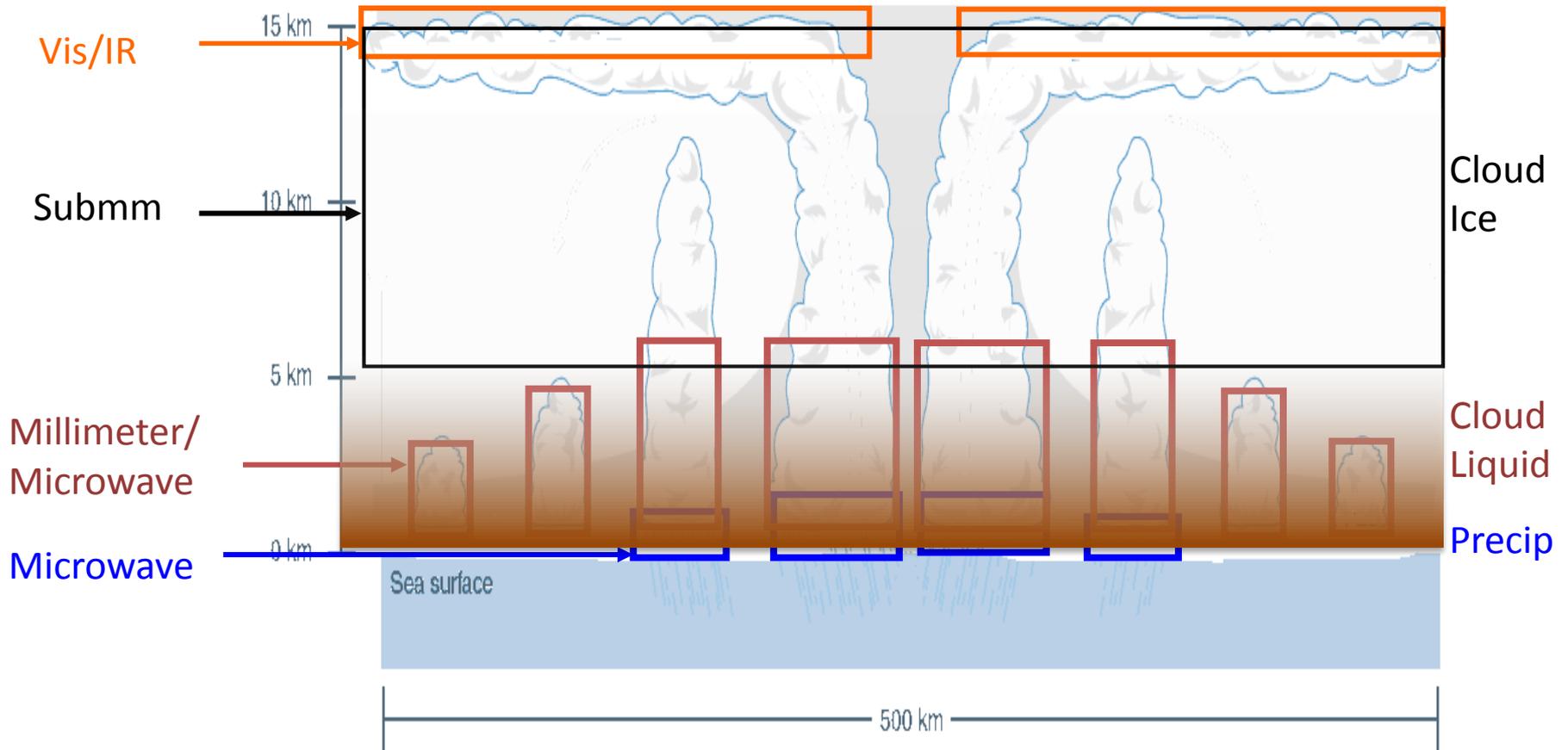
NASA Goddard Space Flight Center, Greenbelt, MD

Acknowledgements:

This research is sponsored by the NASA ESTO and SMD/ATIP Programs



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



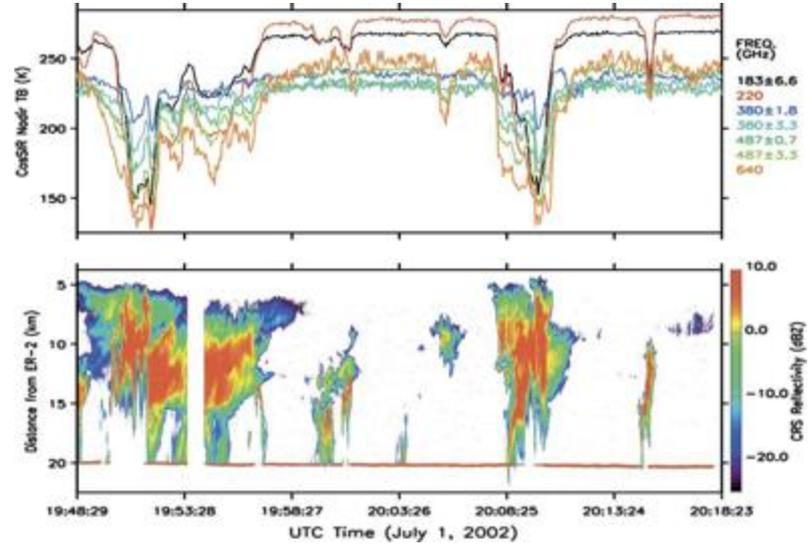


# Heritage: NASA/GSFC Airborne Instrument

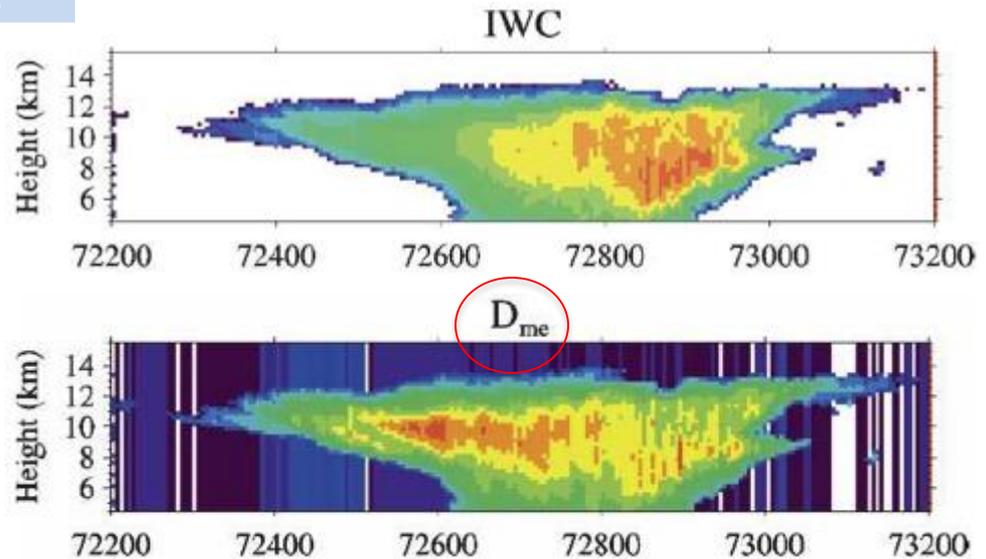
## Compact Scanning Submillimeter-wave Imaging Radiometer (CoSSIR)

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



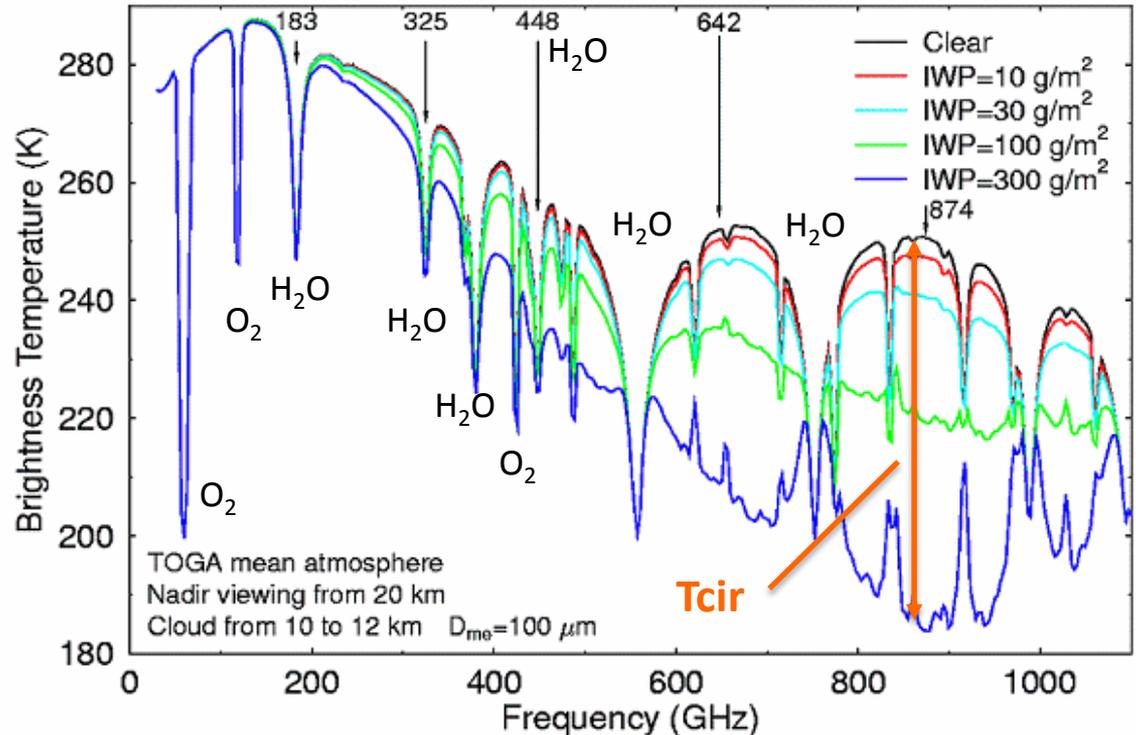
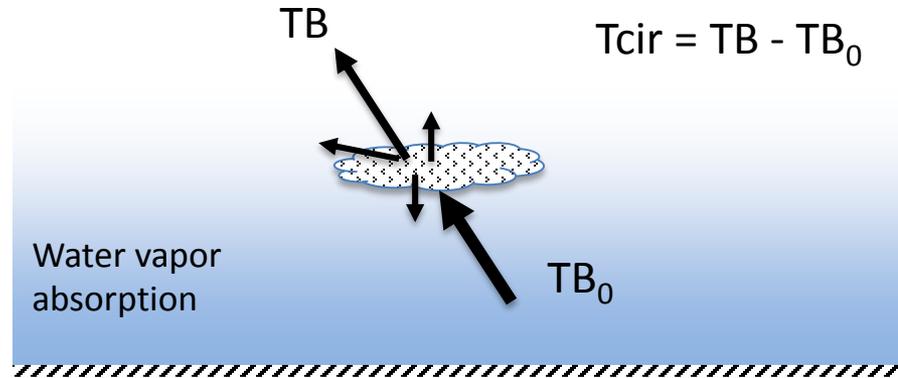
- CRYSTAL-FACE campaign near Florida in July 2002
- Co-flight of CoSSIR and 94-GHz Cloud Radar System (CRS)
- Simultaneous retrievals of ice water path (IWP) and particle size ( $D_{me}$ ) from CoSSIR
- Simultaneous retrievals of ice water content (IWC) and  $D_{me}$  from CoSSIR + CRS





# Ice Cloud Scattering Properties

- Higher sensitivity to cloud scattering at submm-wave
- Cloud-Induce radiance,  $T_{cir}$ , proportional to cloud ice water path (CIWP)
- **Cloud microphysical properties** (i.e., particle size) from different frequencies
- Simultaneous retrievals with  $T$ ,  $H_2O$

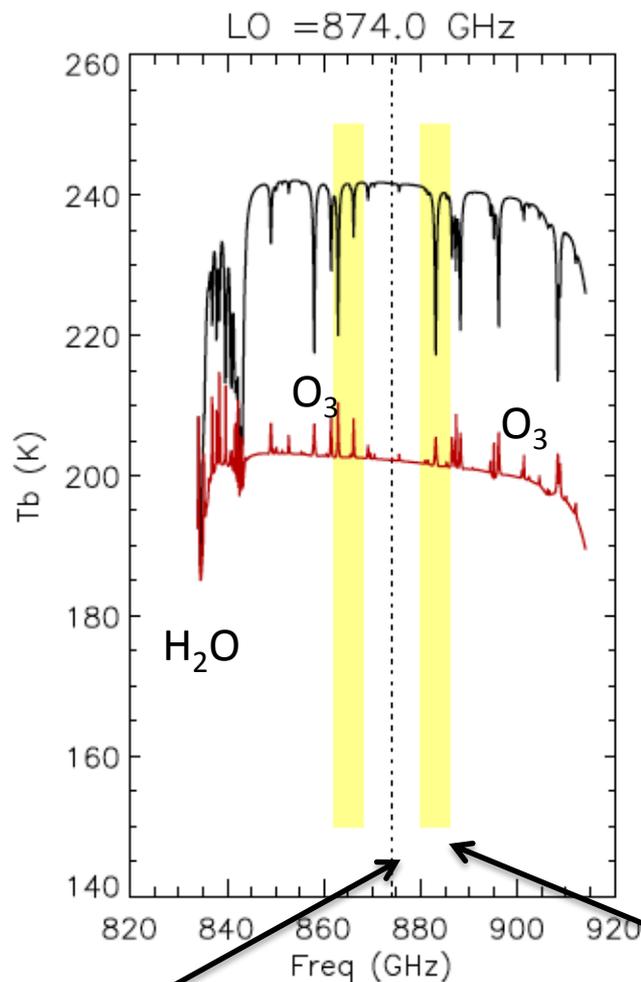




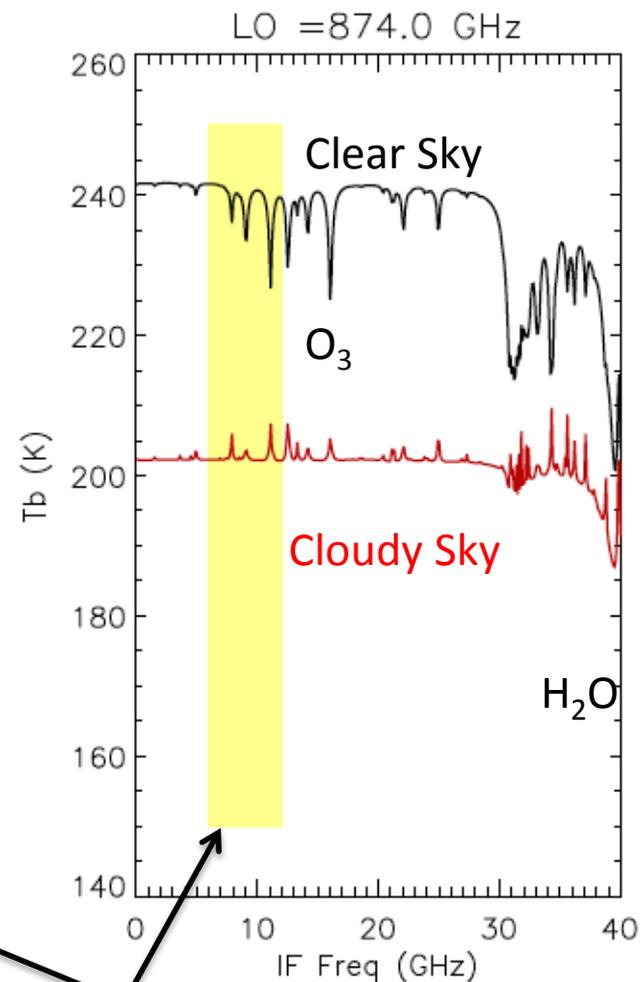
# LO Frequency Change: 874 -> 883 GHz

Molecules included in calculations

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



Local Oscillator (LO) Frequency



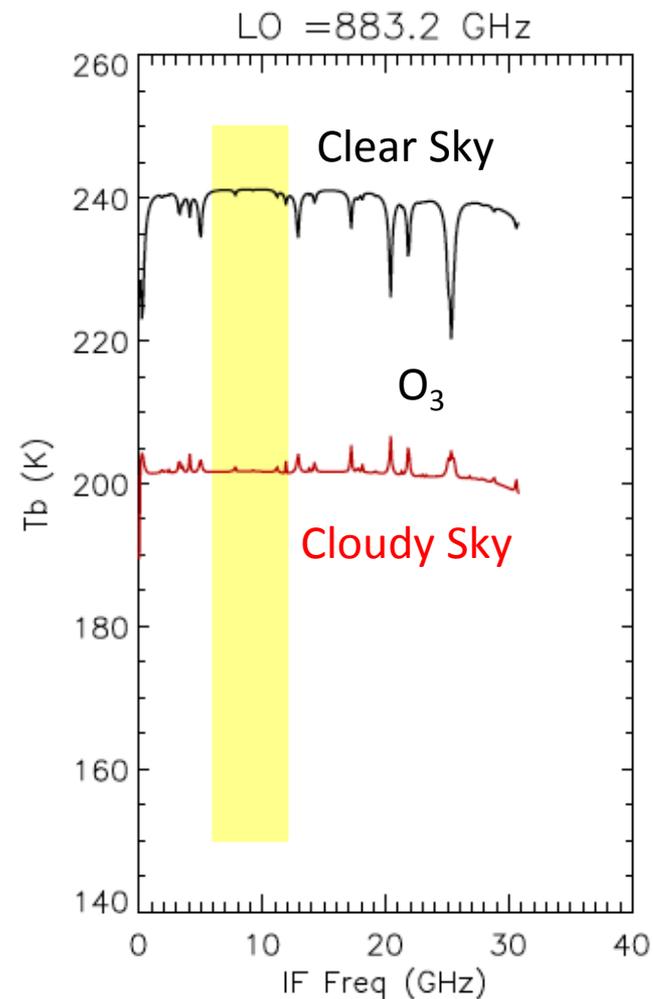
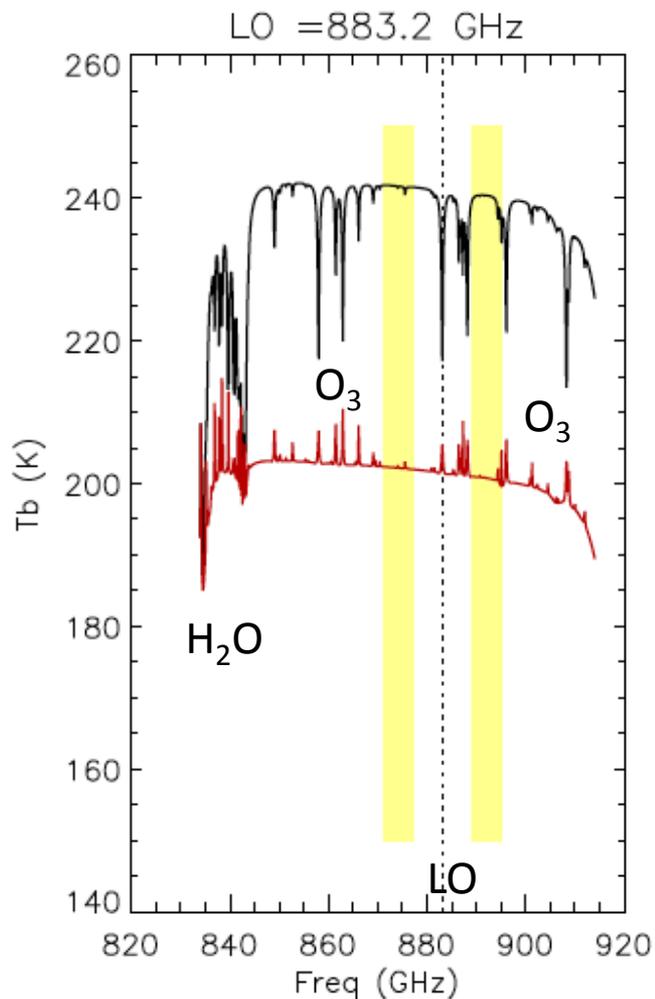
Intermediate Frequency (IF) Bandwidth (BW)



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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:

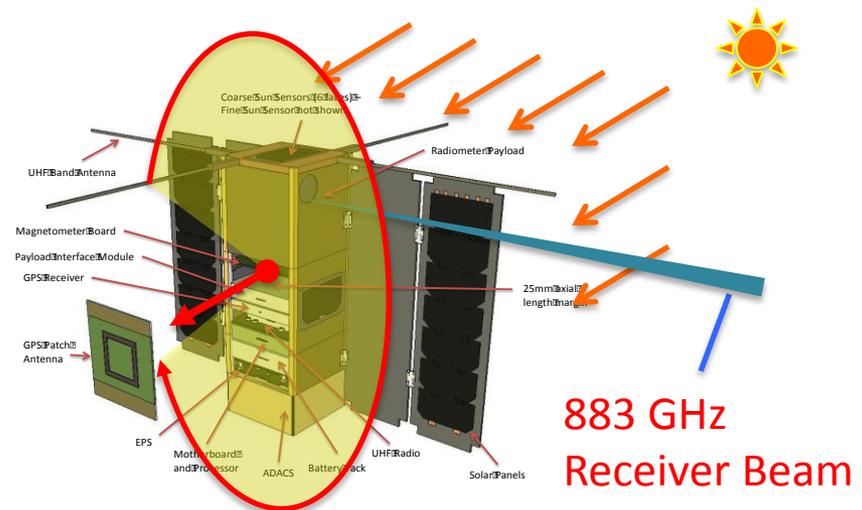
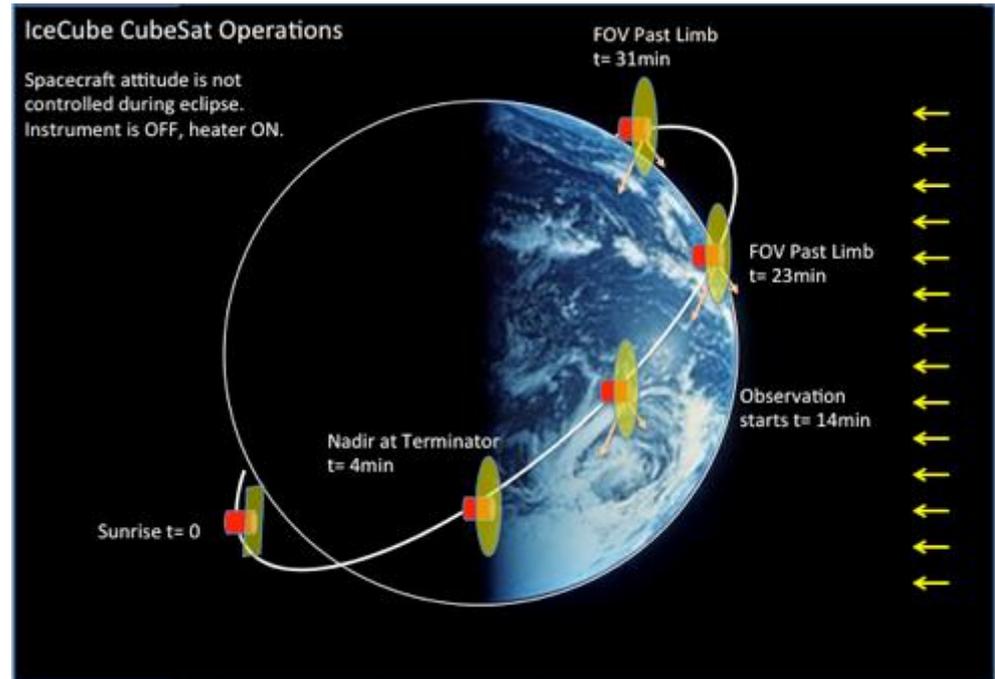
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

## 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





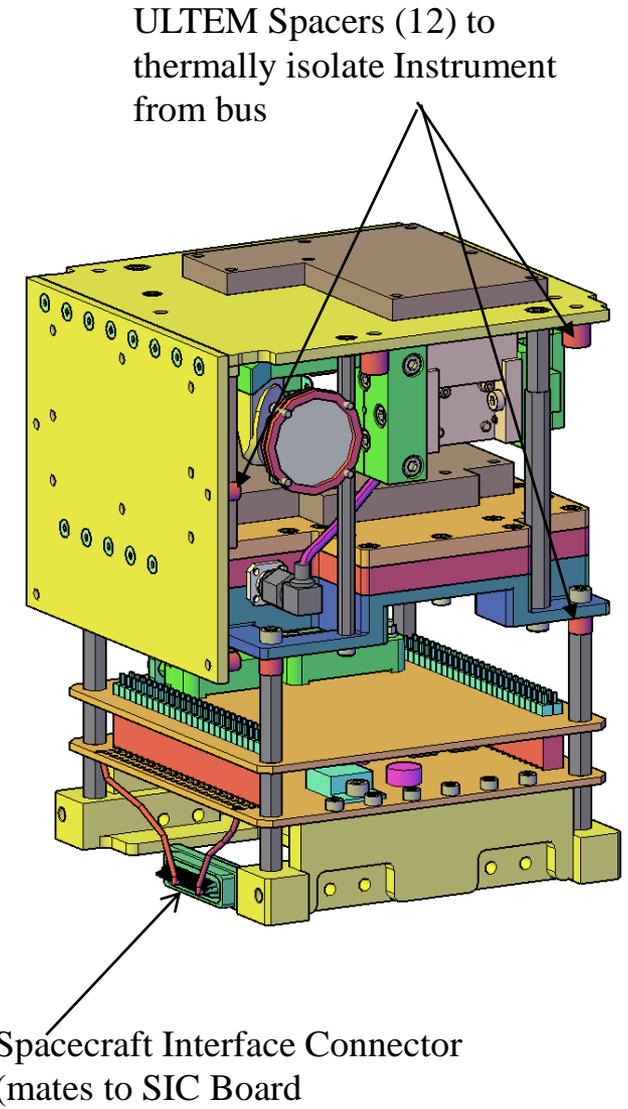
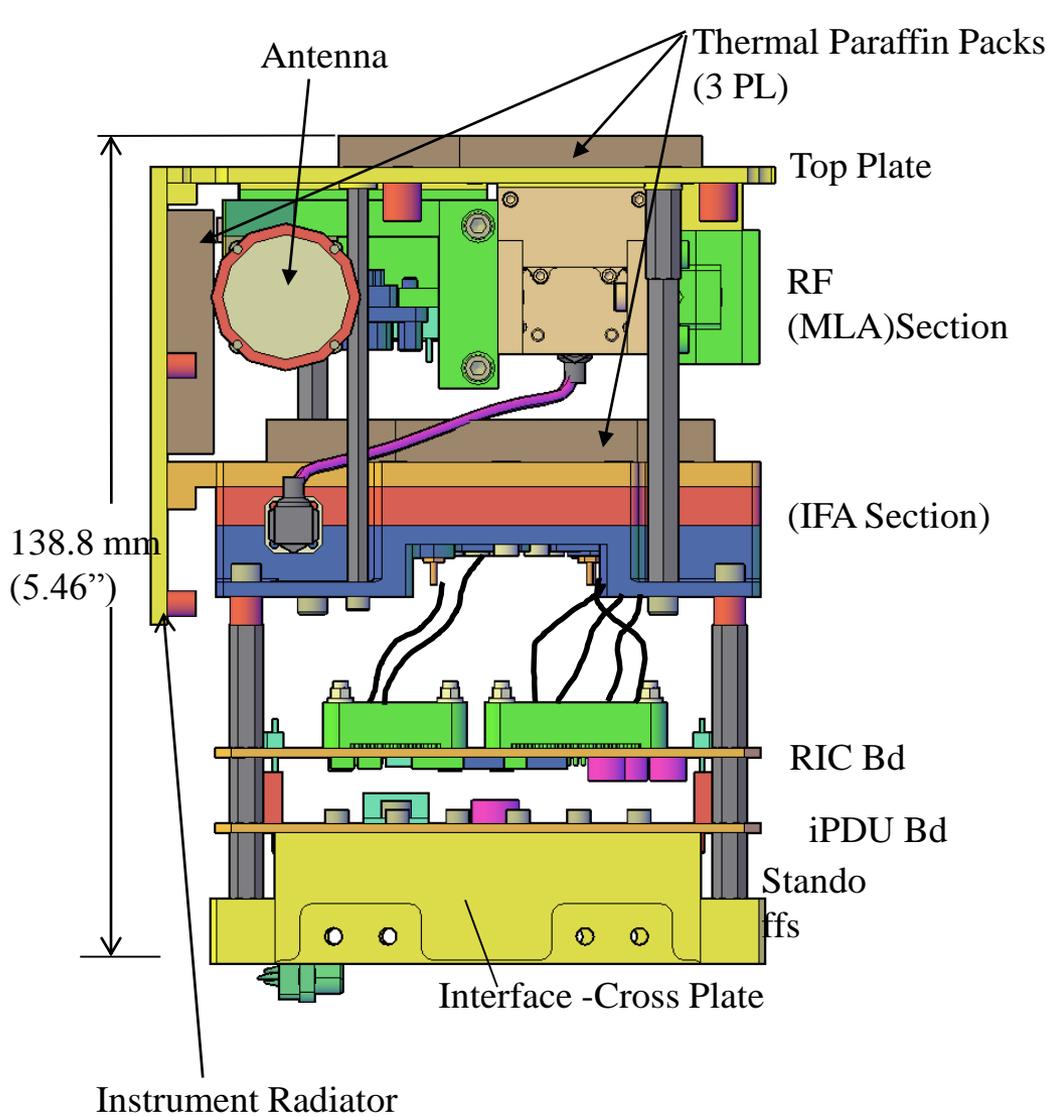
# Instrument Specification Summary

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	$\leq 1.3$ kg including 30 % contingency
Power	11.2 W including 30 % contingency





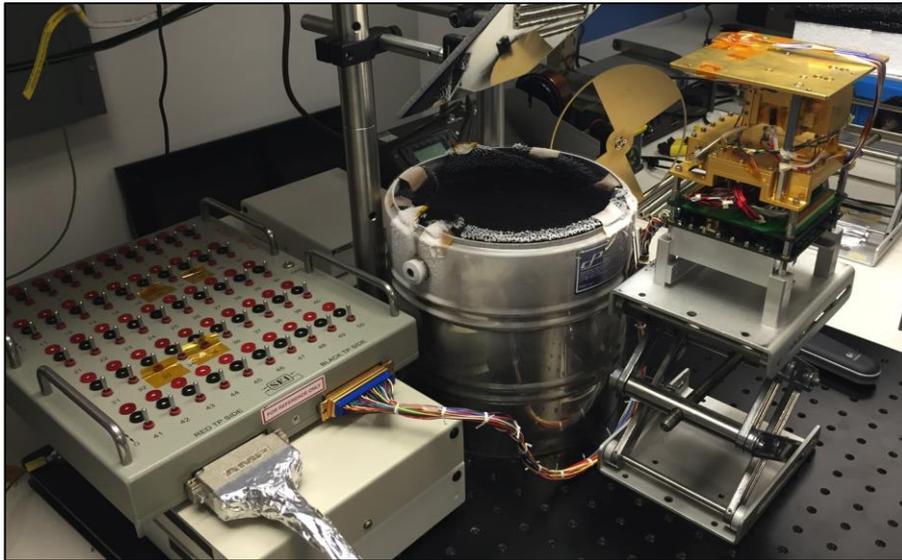
# Instrument Mechanical Structure



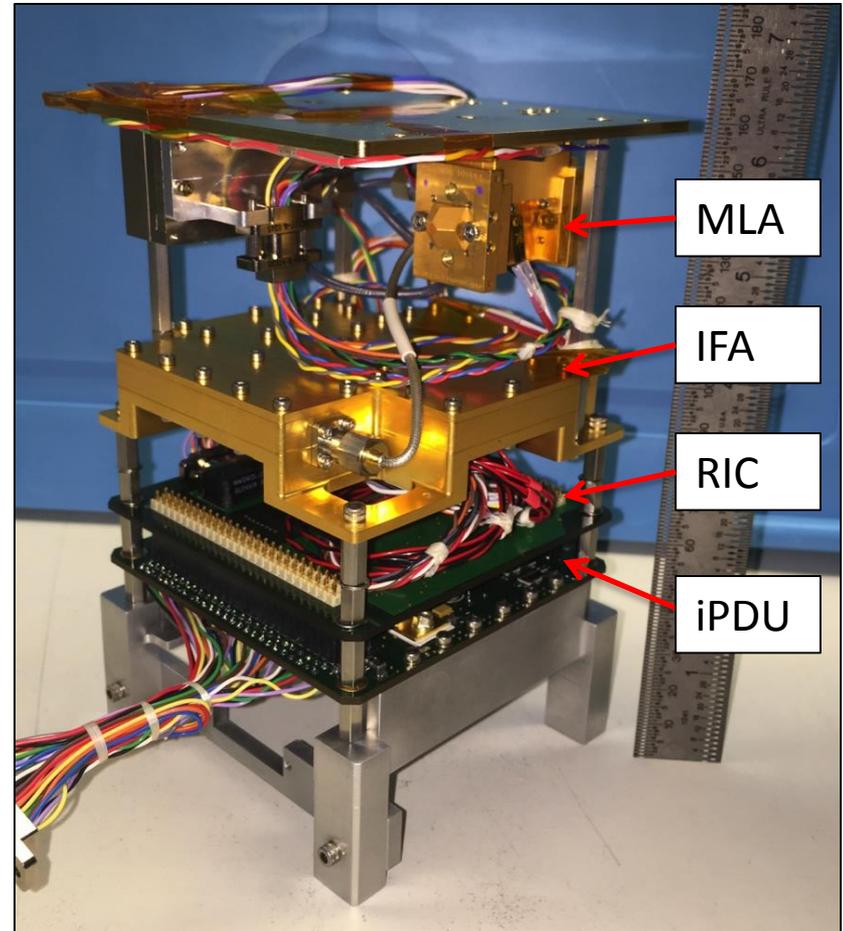


# Engineering Model (EM) I&T

An Instrument Integration & Test (I&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

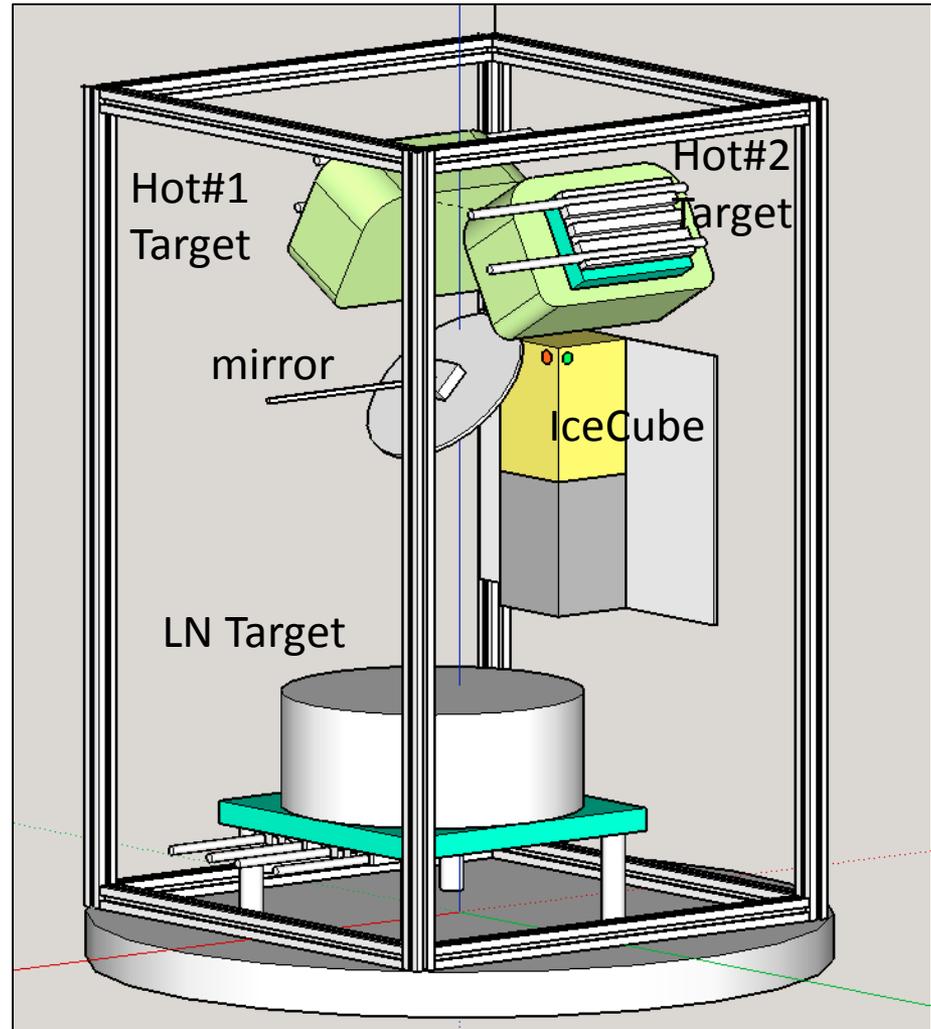


Engineering Model IceCube Instrument, May 2015



# 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

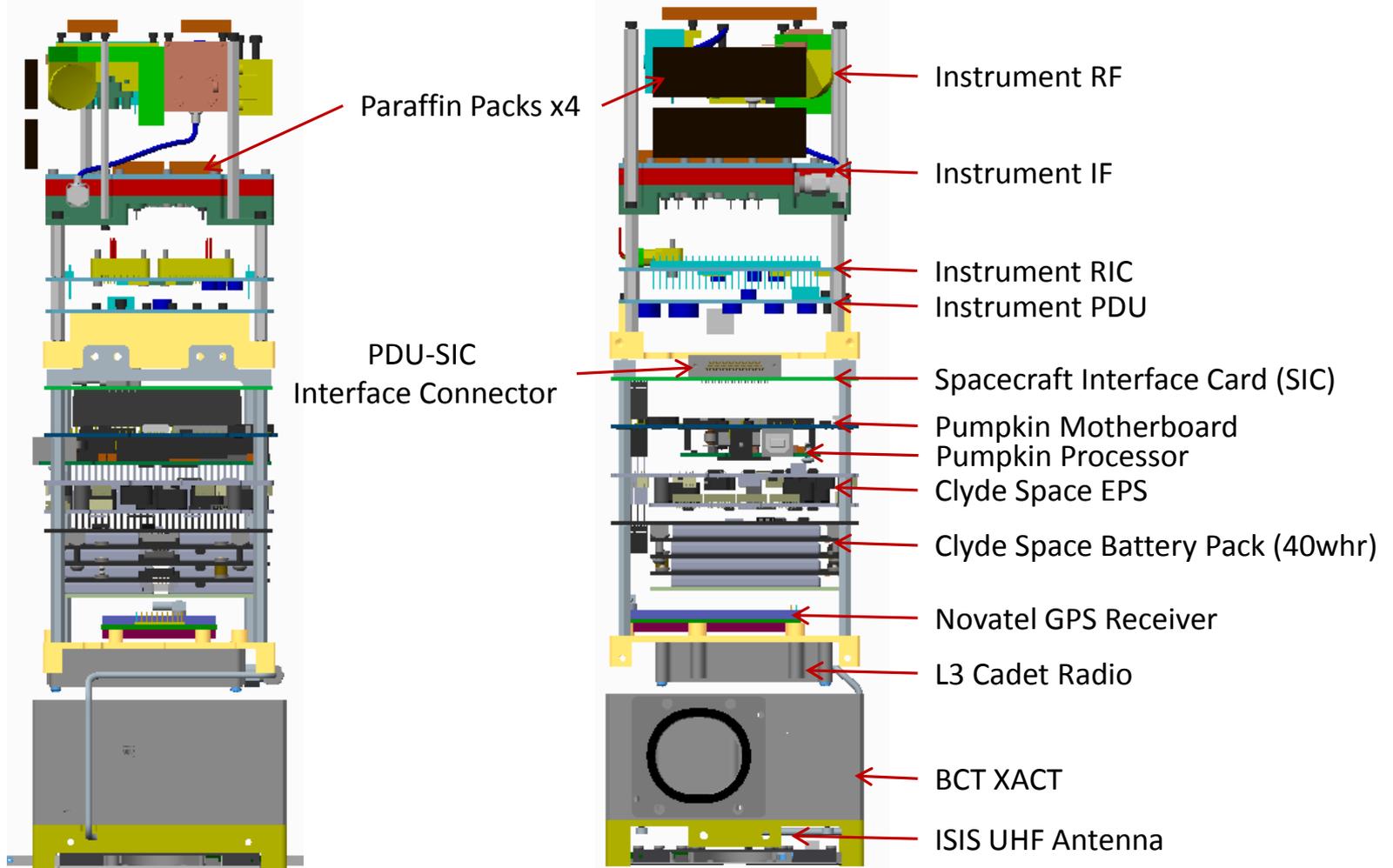


# Spacecraft Subsystems

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

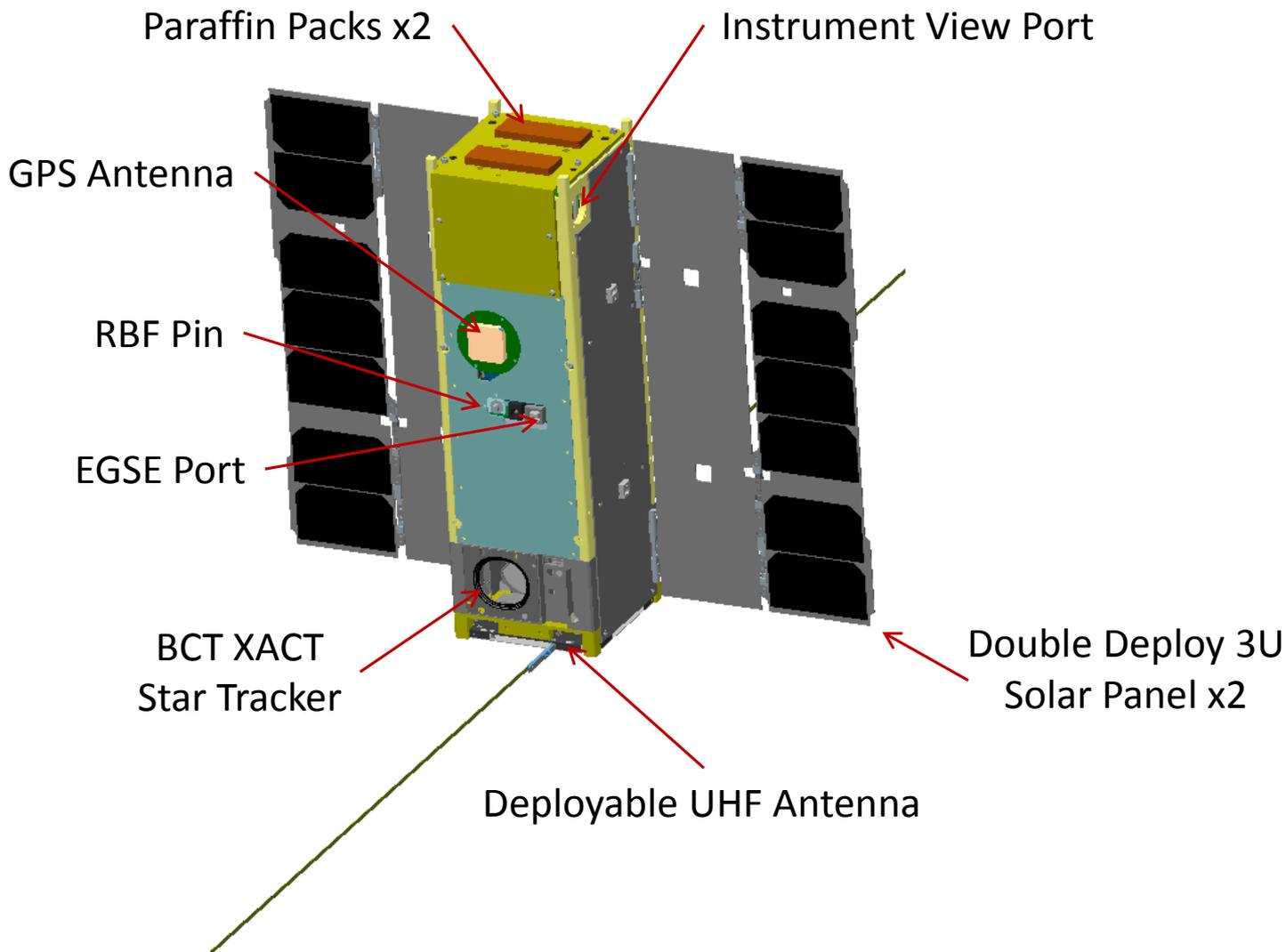


# Internal Layout



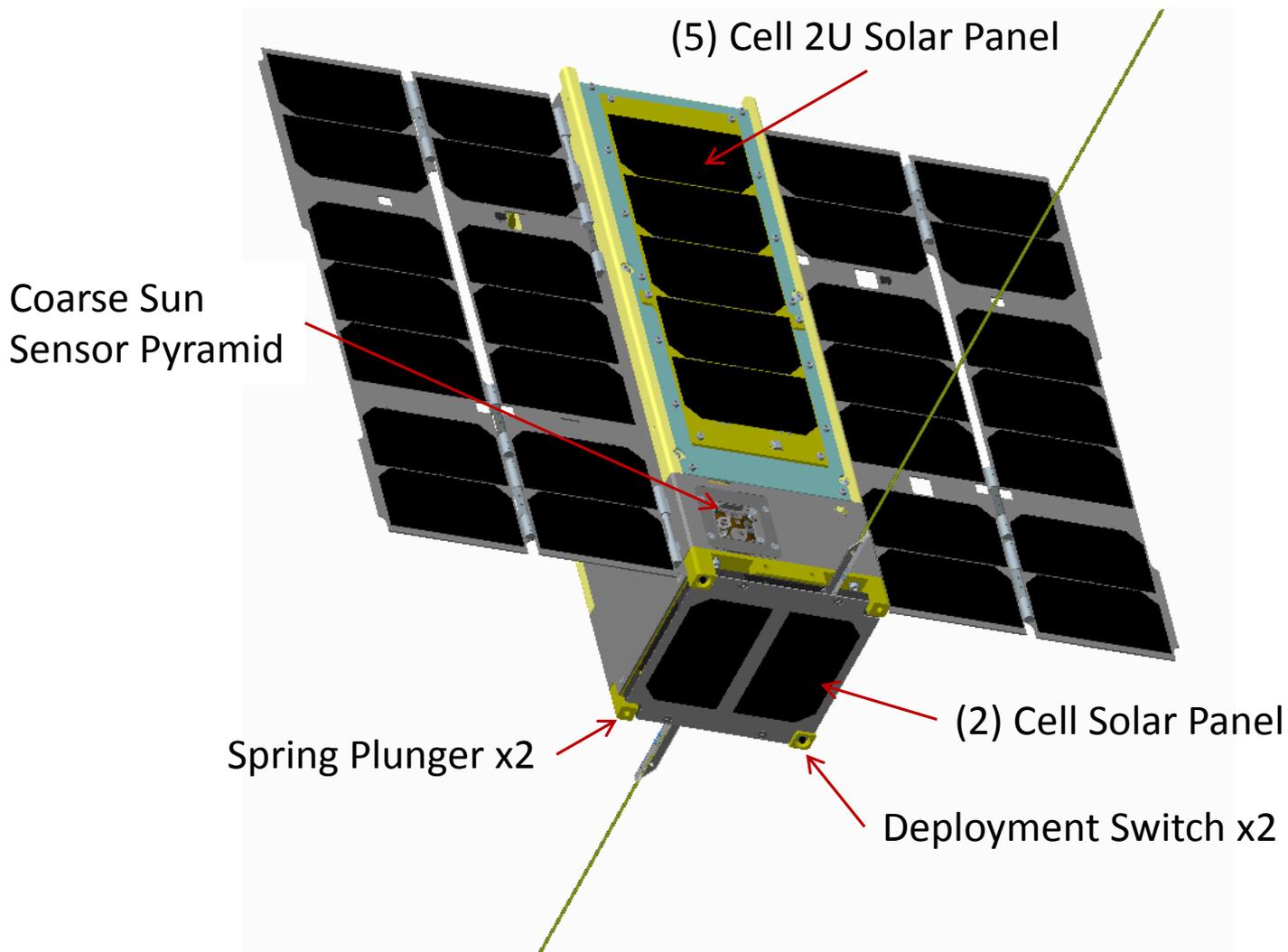


# External Layout (1/2)





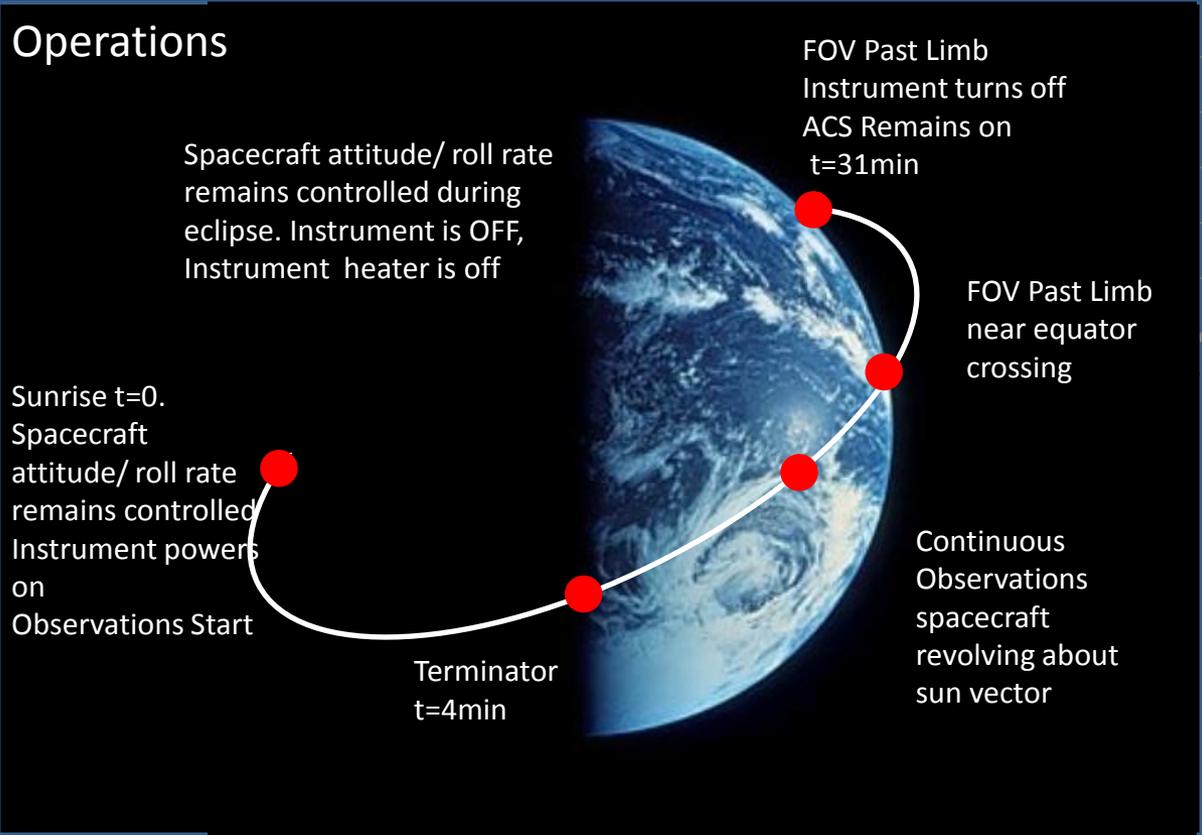
# External Layout (2/2)



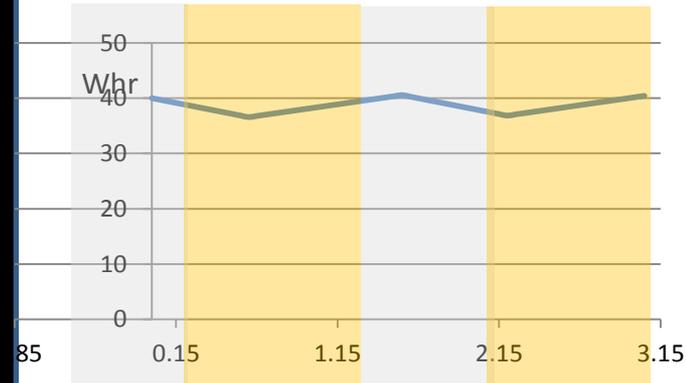


# Concept of Operations

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



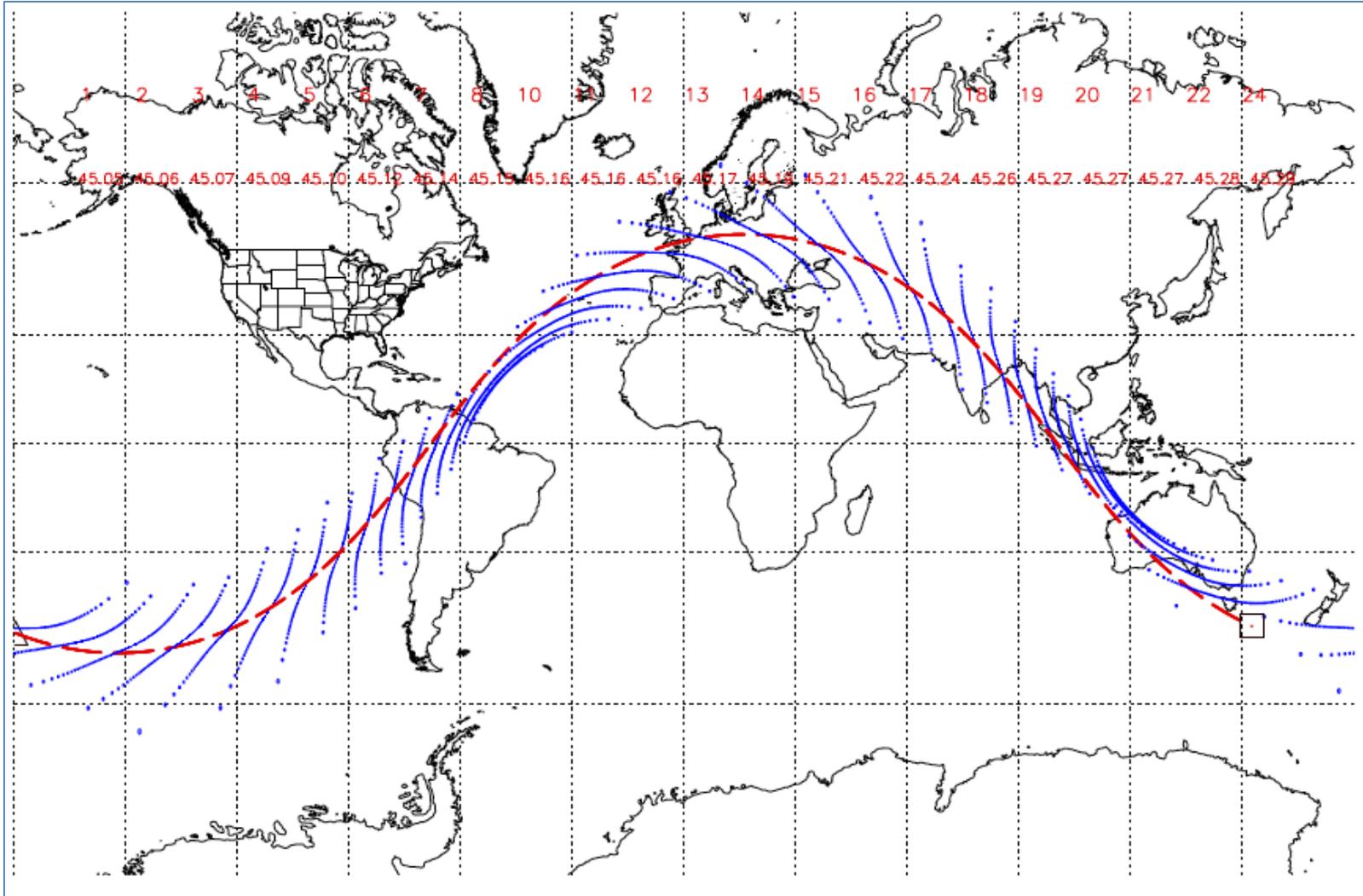
## Science only in Sun Limit 20% DOD



	Sun <u>W</u>	Eclipse <u>W</u>
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
<b>Total out</b>	<b><u>11.803</u></b>	<b><u>5.713</u></b>
Arrays	25	0
PDU losses 20%	-5	0
<b>Total in</b>	<b>20</b>	
Cell Temp Loss 20%	-4	
<b>Total in</b>	<b><u>16</u></b>	<b><u>0</u></b>



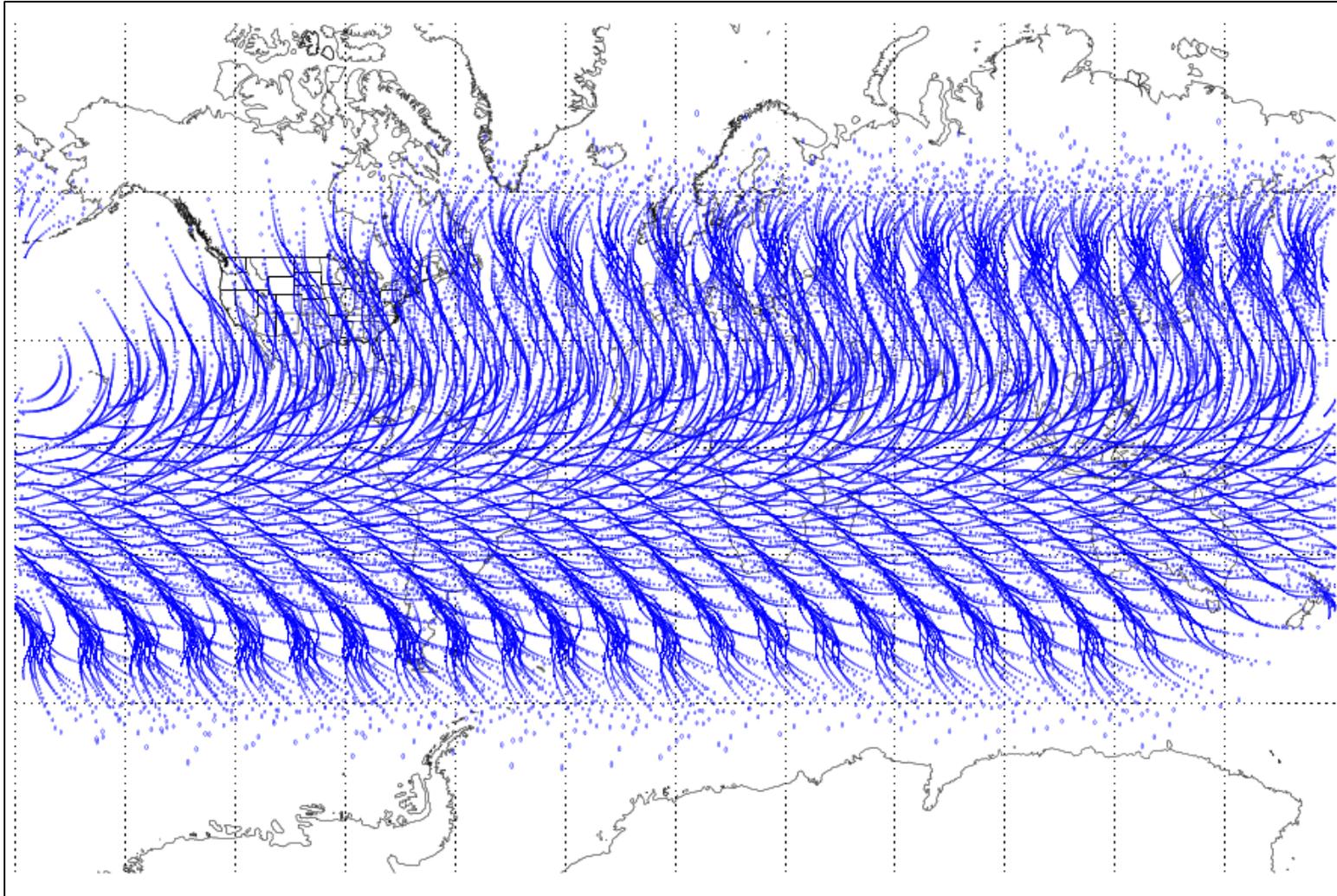
# Simulated IceCube Sampling for Feb 25, 2015



(Courtesy of Y. Liu, SSAI)



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



(Courtesy of Y. Liu, SSAI)

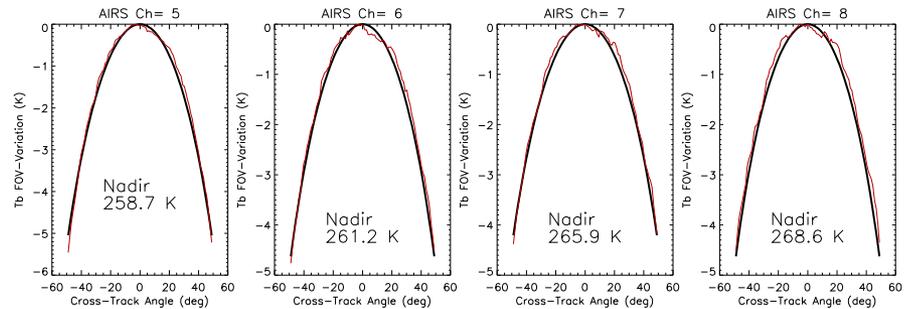


# Validation of IceCube 833-GHz Radiances

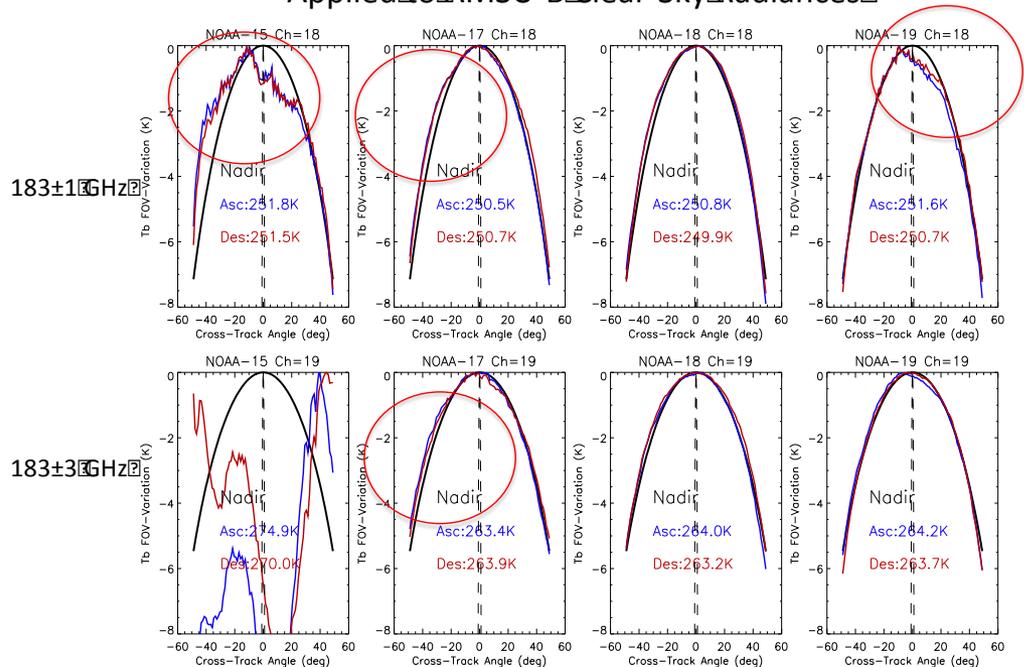
- Comparison between modeled and observed clear-sky radiances
- MLS Radiative transfer model [Wu et al., 2006], and inputs from MERRA data (e.g., P, T, H<sub>2</sub>O)
- Tropical measurements: well-defined atmospheric thermal structures
- Slant-to-nadir conversion using

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

Applied to AIRS Radiances



Applied to AMSU-B Clear-Sky Radiances



Scan Angle from Nadir (degrees)



# IceCube Project Schedule

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