IceCube: 883-GHz Cloud Radiometer Ready for its Space Journey

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ESTF Annapolis, MD June 14, 2016

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IceCube Status

- Launch date (Jan 2, 2017) at WFF
  - Manifest on OA-7
  - Contract mod and details in progress
- FM instrument (883-GHz cloud radiometer) delivered to WFF on May 25, 2016
  - Completed FM instrument TVAC and Vibe tests
  - Developed preliminary calibration algorithms from TVAC and Vibe data
  - FM instrument healthy and ready for spaceflight
- CubeSat system I&T in progress

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IceCube Spacecraft Bus Weekly Status 6-10-16

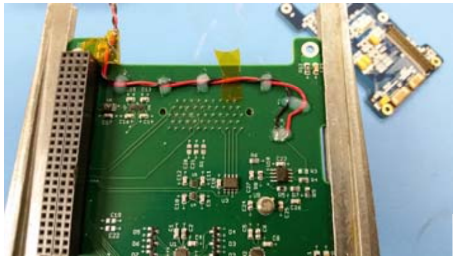
	Accomplishments	Risks/Issues
Power	The fixed body mount solar panel and one of two deployable solar panels have been received from Clyde and are undergoing bench testing. Clyde detected an issue of the third solar panel prior to delivery (they suspect the anomaly occurred during deployment tests) and elected to rebuild that panel. The EPS has been returned to Clyde and they are working the requested revisions to the switched power channel current limits. Both items are expected within 1-2 weeks.	- The anomaly that occurred at the factory with one of two of the deployable solar panels is not documented by the manufacturer. It raises the concern that deployment tests at Wallops may result in damage to the units.
ACS	BCT is working the XACT power board and expect to deliver within 1-2 weeks.	- Integration of the XACT 12V booster card adds scope to power, mechanical, and I&T, thus delaying schedule.
Com	Continuing with Cadet transceiver testing and debugging ground station command and data issues. Completed the second round of antenna pattern testing of the UHF antenna. Updated the link budget analysis and NTIA paperwork in preparation for license request resubmittal. Work is on-going to determine the extent and scope of the upgrades to the Wallops Island ground station (non IceCube task).	- Spectral license PFD limits result in reduced transmitter gain and periods of no TM link at low to mid angles of signal elevation. - The Wallops ground station upgrades may not be in place prior to delivery of IceCube.
Mech	The instrument calibration fixture has been received and the design of the Tvac mechanical fixtures are in work. Completed the design of the XACT power board mounting brackets and submitted for machining.	
S/W	Improvements to the Instrument, EPS, Cadet, and XACT flight software interfaces continue to be worked and tested. An internal review of the flight software mission mode architecture was completed and the mission mode code is being developed. An investigation into using the PIC FLASH in lieu of the SD card is also being worked.	- Amount of software development remaining may delay start of environmental testing.
Thermal	The TVac test plan continues to be worked, along with the associated thermal modeling to determine what test limits may be achieved.	- Some components exceed allowable flight temperature limits.
Harness	Staking of harness on the SIC and Pumpkin have been completed for flight. New, more flexible 0.086 coaxial cable has been received and soldered to a test GPS antenna for fit, finish, and functionality. Further testing will be conducted.	- Final flight lengths may not be obtained until spacecraft flight assembly is in process, requiring more time for assembly.
I&T	Documentation for Nanoracks integration is in work. The Tvac test plan review continues, as well as the post Tvac Instrument calibration process to be performed in the Tvac chamber. The EPS has been returned to Clyde for rework. Flight preparation of the SIC and Pumpkin have begun. The flight Instrument has been delivered and post shipment functional testing was completed.	- Start of environmental testing has slipped due to issues/risks above.

Component Status

Component	Received	In Test	Delivered	S/W Interface
EPS	✓	✓	✓	✓
EU Battery	✓	✓	✓	✓
Flight Battery	✓	✓	✓	✓
Solar Panels	✓	✓	0%	NA
XACT	✓	✓	✓	✓
GPS Rcvr	✓	✓	✓	✓
GPS Ant	✓	25%	0%	NA
Cadet	✓	✓	85%	85%
UHF Ant & Solar	✓	✓	90%	✓
Flight CPU	✓	✓	✓	NA
EU SIC	✓	✓	✓	NA
Flight SIC	✓	✓	✓	90%

I&T Status

	Progress
Component Integration	75%
Instrument Integration	42%
Flight S/W Development	67%
Flight Build	25%
Spacecraft Environmental	17%



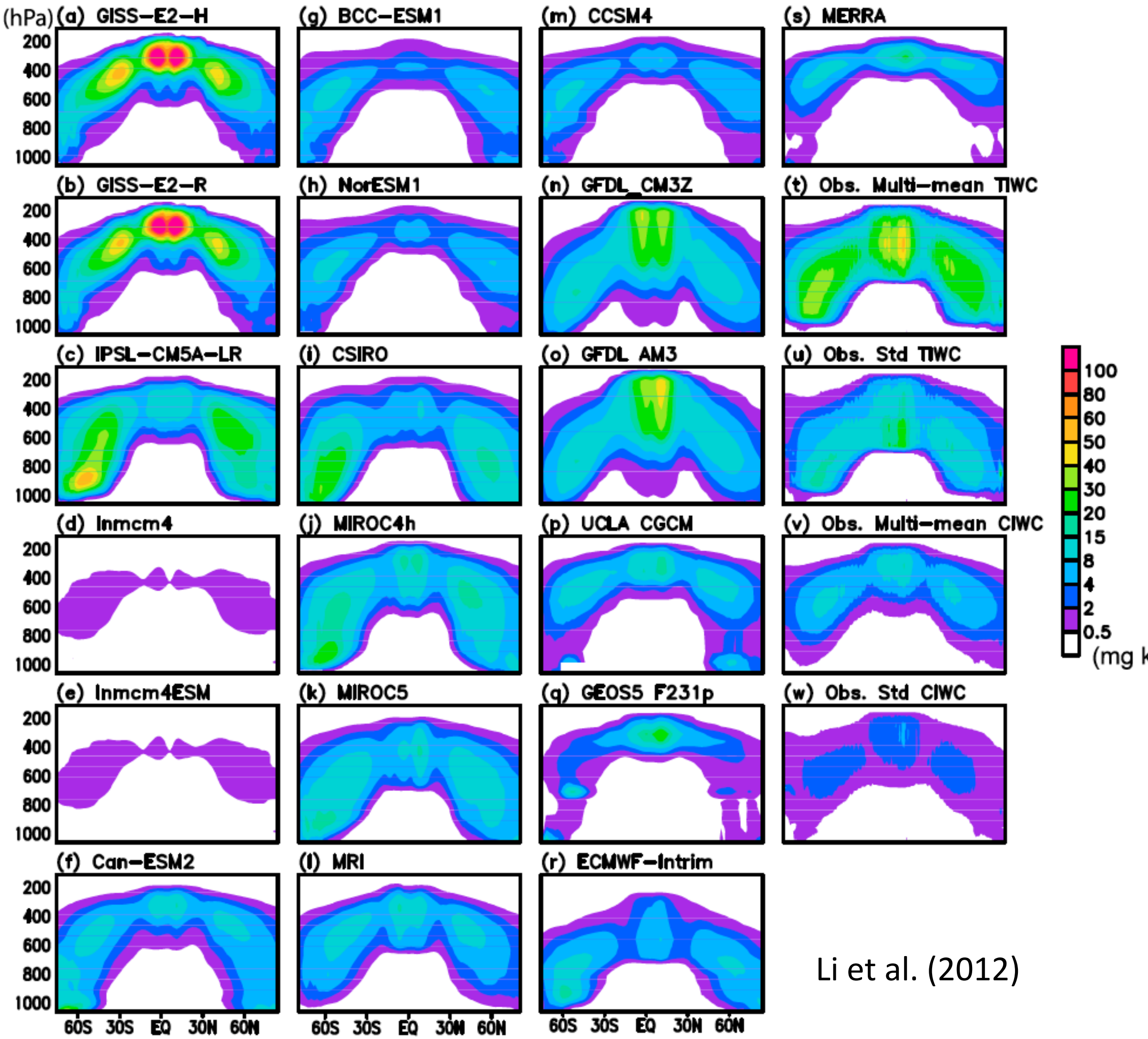
Staking of the Flight SIC in Progress

Courtesy of Brian Abresch

Science
Motivations and Objectives

Cloud Ice in Climate Models

- Clouds in climate models
  - Clouds as the major source of uncertainties in prediction
  - Cloud ice as a tunable parameter to balance the radiation at top and precipitation at bottom
  - Cloud ice different by 2x – 10x between models
- Needs for accurate cloud ice measurements highlighted in the Decadal Survey (DS) mission: Aerosol, Cloud and Ecosystem (ACE), which recommended submm and LWIR radiometers for cloud ice measurements.



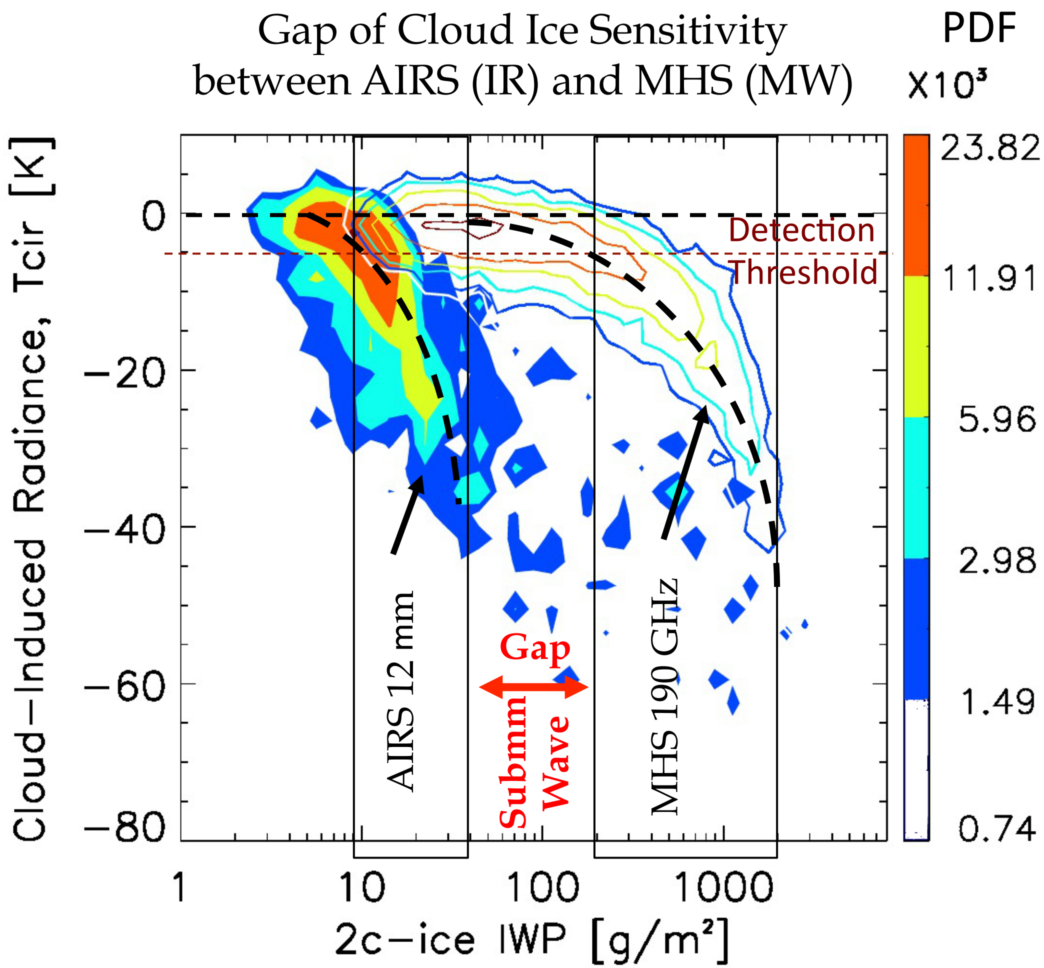
Li et al. (2012)

Gap in Cloud Ice Sensitivity

- Clouds, ice clouds in particular, as a major source of uncertainty in climate models
- Needs for accurate cloud ice measurements highlighted in the Decadal Survey (DS) mission: Aerosol, Cloud and Ecosystem (ACE), which recommended submm and LWIR radiometers for cloud ice measurements.
- Cloud microphysical properties (particle size and shape) account for ~200% and ~40% of measurement uncertainty, respectively.
- Sensitivity from nadir sensors:
  - 190-GHz IWP: 200-2000 g/m^2
  - 12-mm IWP: 10-40 g/m^2
  - Submm-wave: 30-300 g/m^2

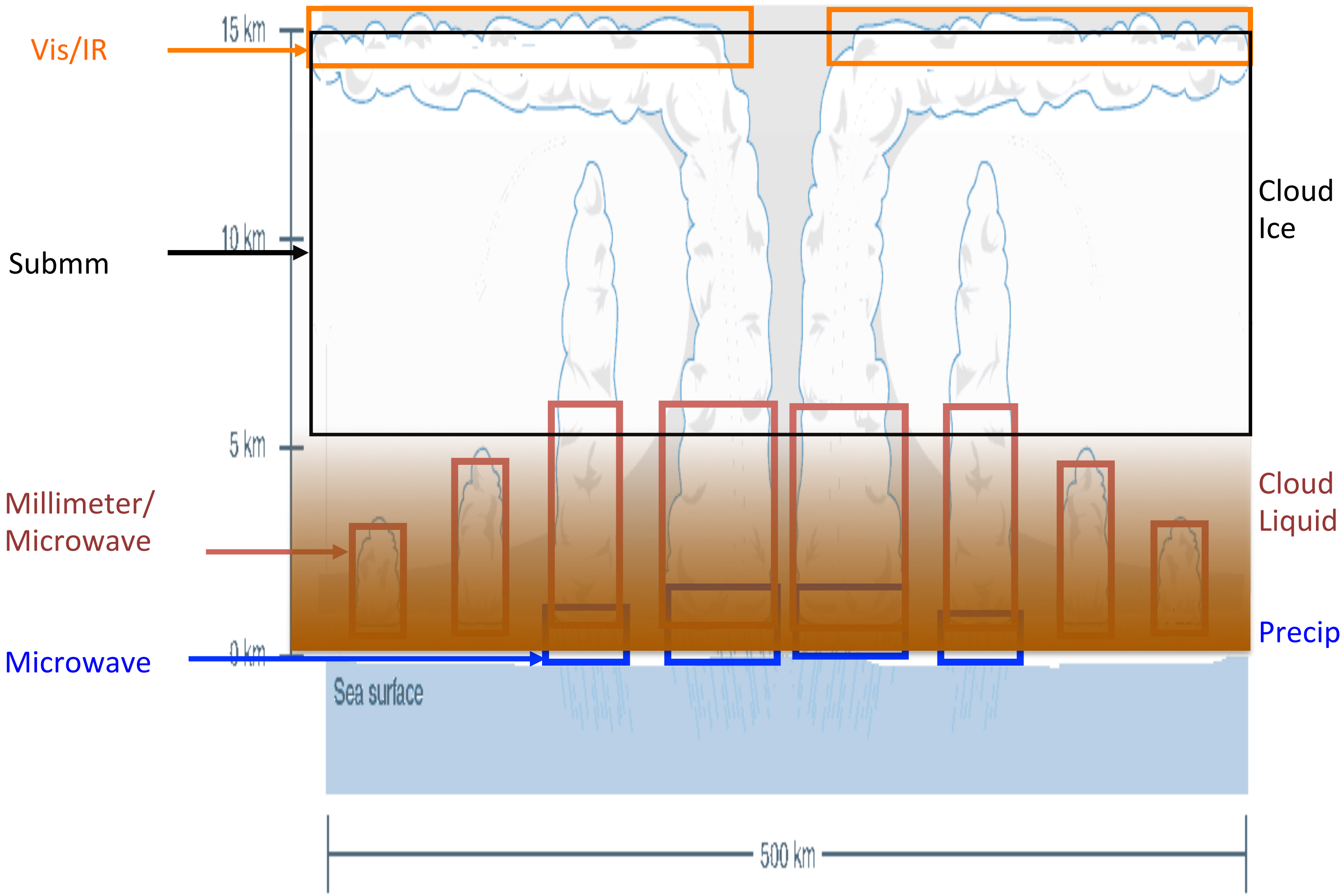
$$T_{cir} = T_b - T_{b\_clear}$$

Figure credit: J. Gong



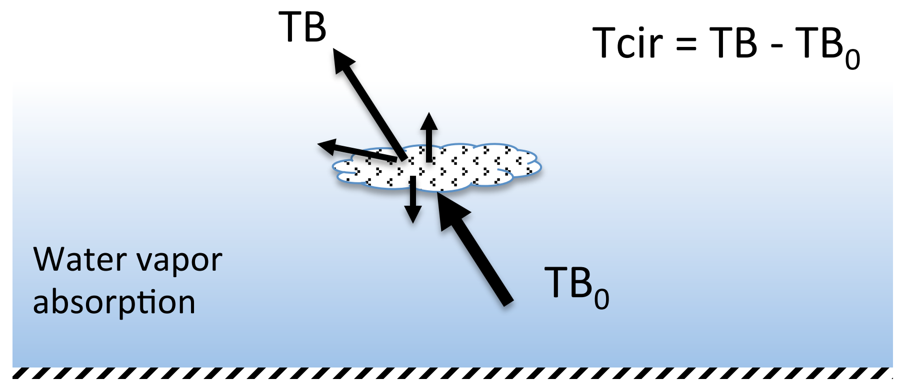
Ice Water Path (IWP) from CloudSat/CALIOP

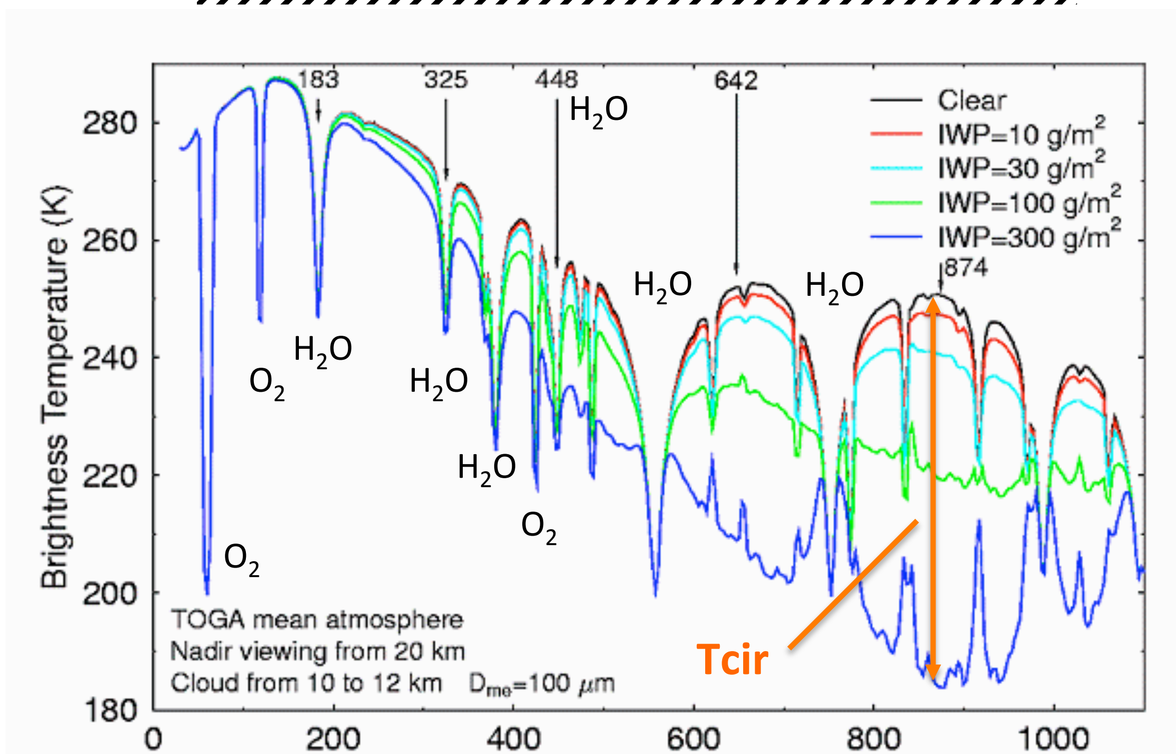
Gap = Unconstrained IWP in the Upper Tropopshere



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



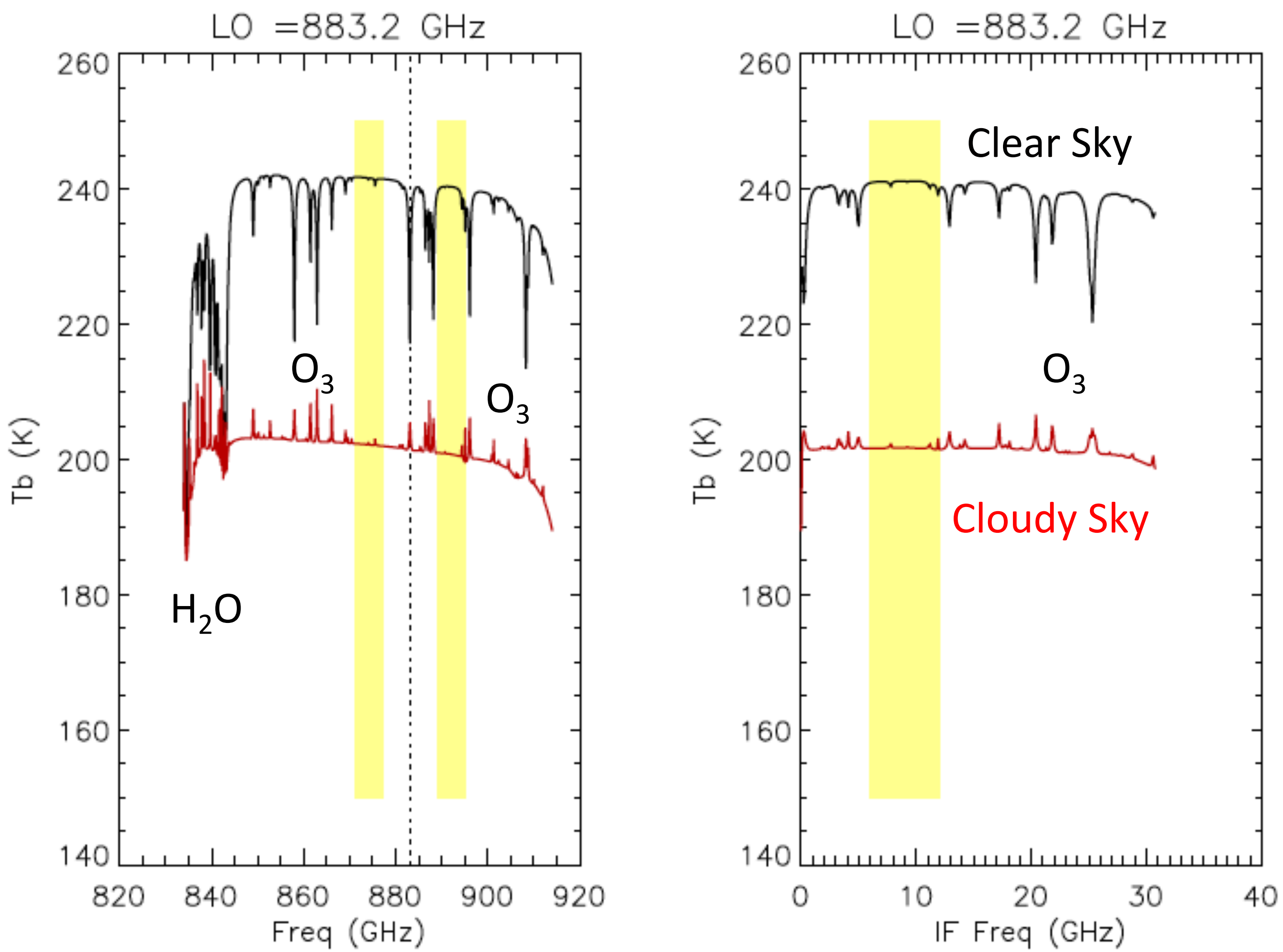


Credit: F. Evans

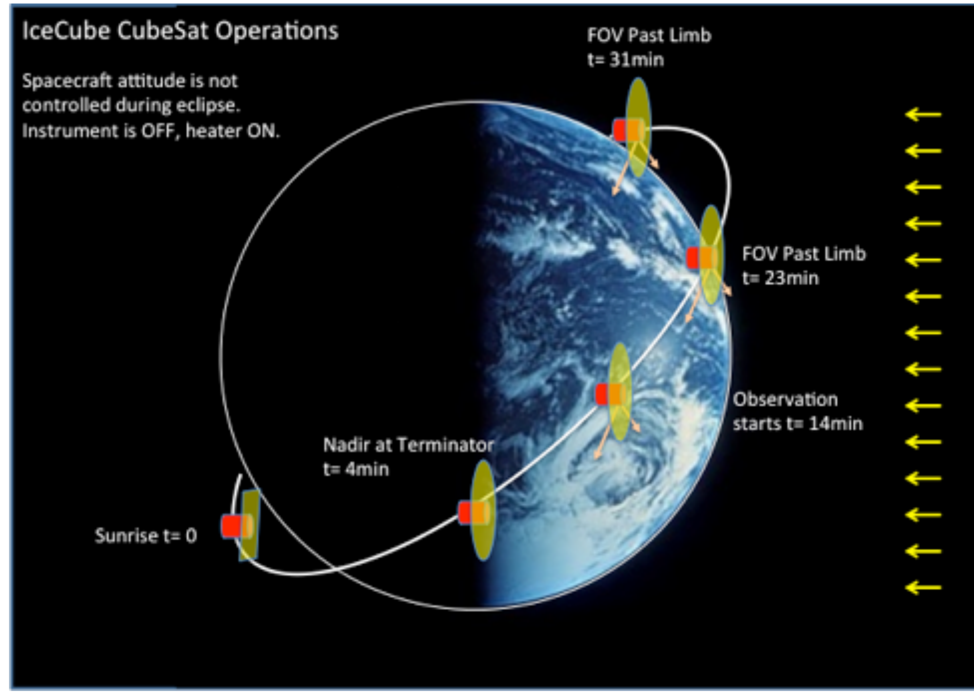
Frequency Change: 874 -> 883 GHz

Molecules included in calculations

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



Measurement and Mission Requirements



883-GHz measurement requirements:

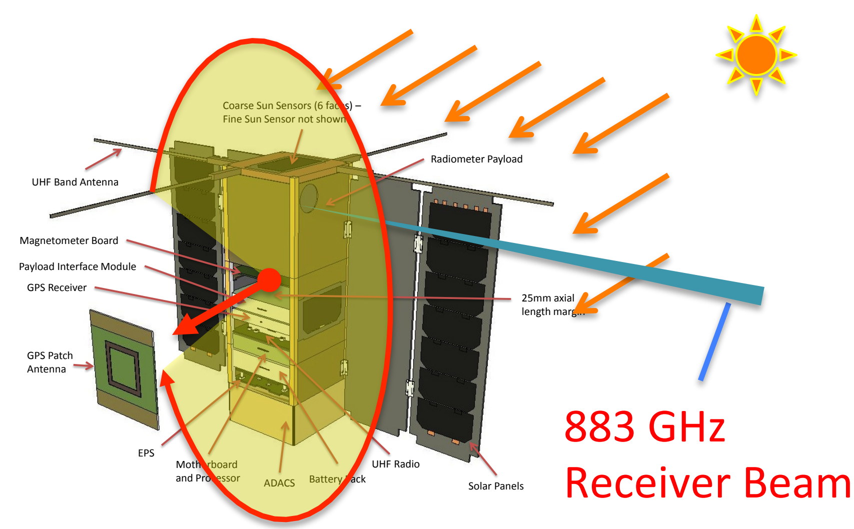
- Accuracy < 2 K
- Precision (NEdT) < 0.25 K
- Spatial resolution < 15 km

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

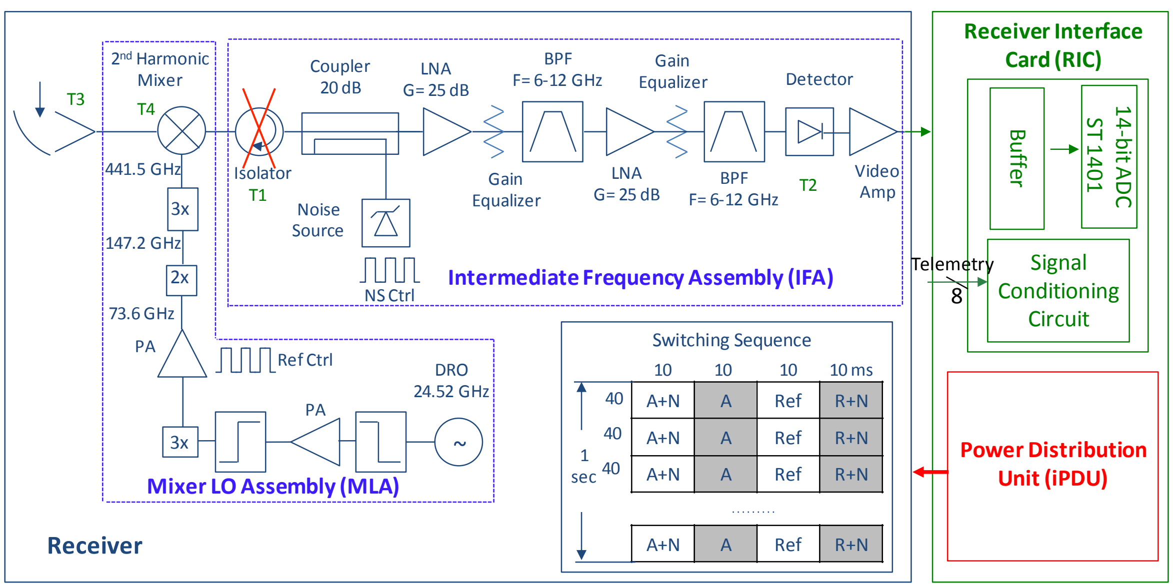


IceCube
FM Instrument/Payload

IceCube Instrument: 883 GHz Cloud Radiometer

Objective: Develop and validate a flight-qualified 883 GHz receiver to reduce cost and risk in future missions and enable cloud remote sensing at sub-mm wavelengths

Instrument Block Diagram

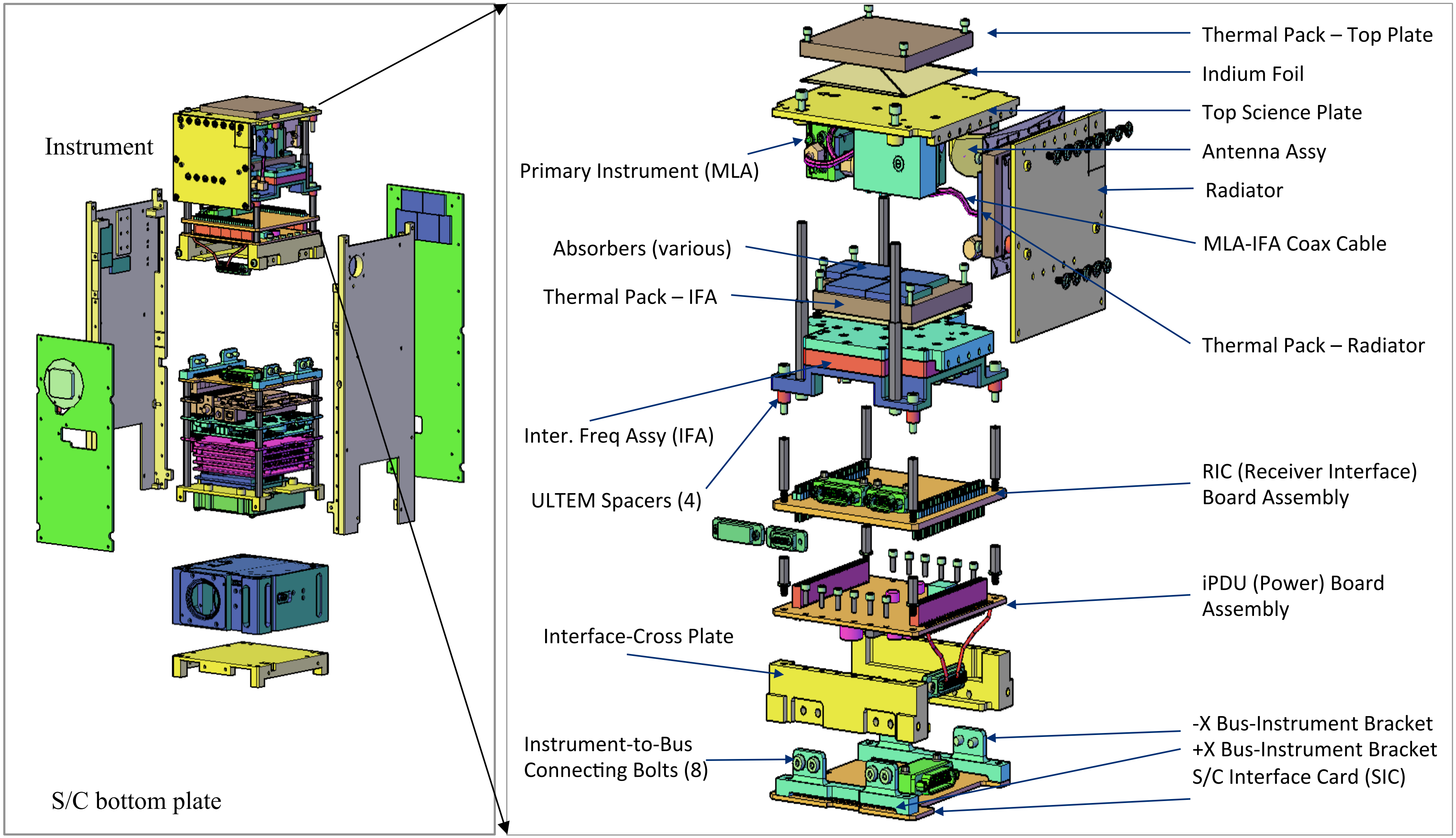


High level requirements:

- Advance TRL of commercial (Virginia Diodes Inc) 883 GHz receiver technology from 5 to 6
- Integrate a heterodyne receiver at center frequency (f_0) 883 GHz with 6 GHz pass-band centered at ± 9 GHz from f_0
- Measure the atmosphere with nadir footprint of ≤ 15 km from ISS orbit
- NEΔT< 0.25 K for 1 s integration time
- Calibration accuracy of < 2 K

Courtesy of Negar Ehsan (GSFC/555)

Instrument Mechanical

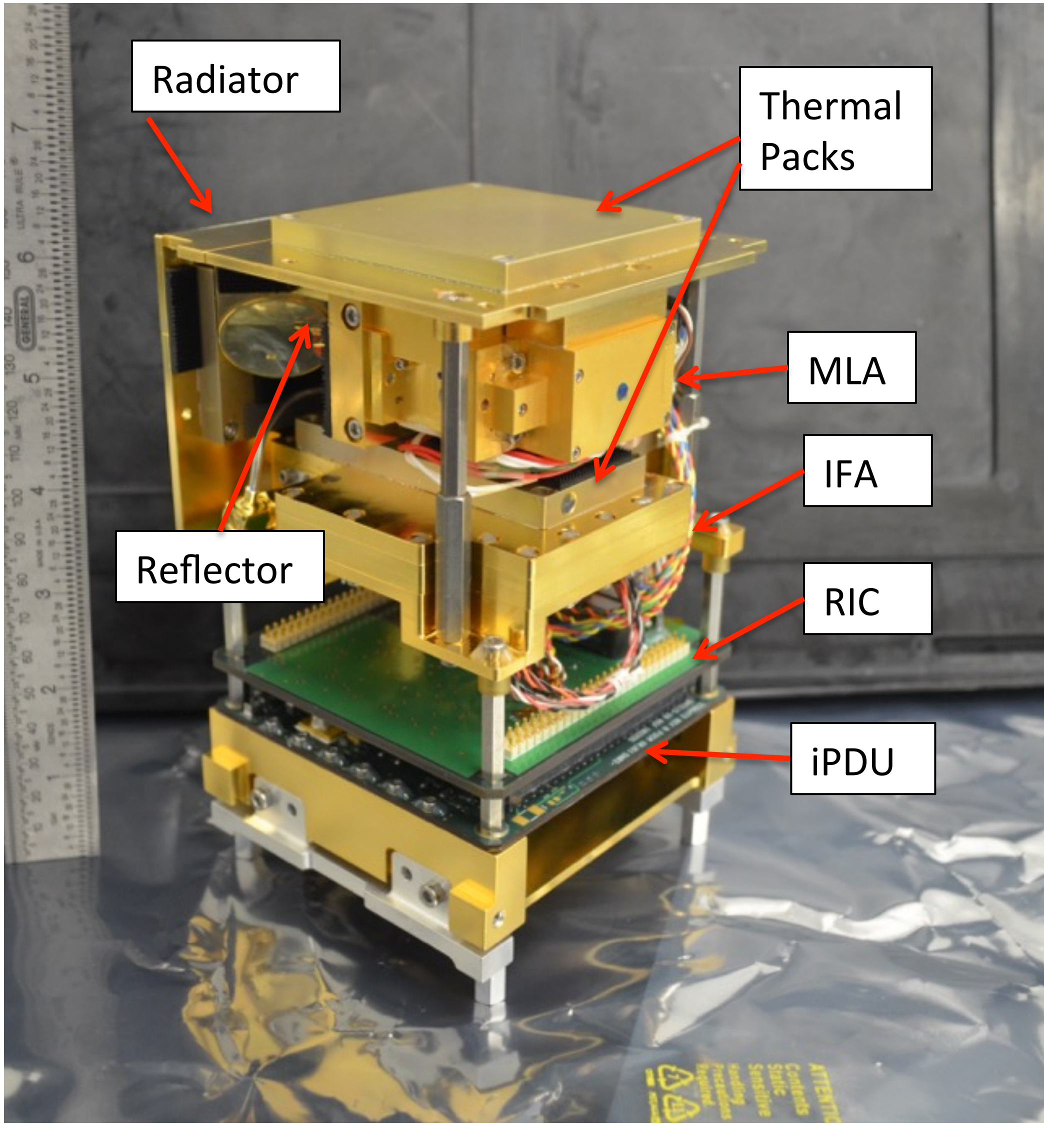


Instrument mass and volume: 1.033 kg, 1.3 U

Courtesy Michael Solly (GSFC/562)

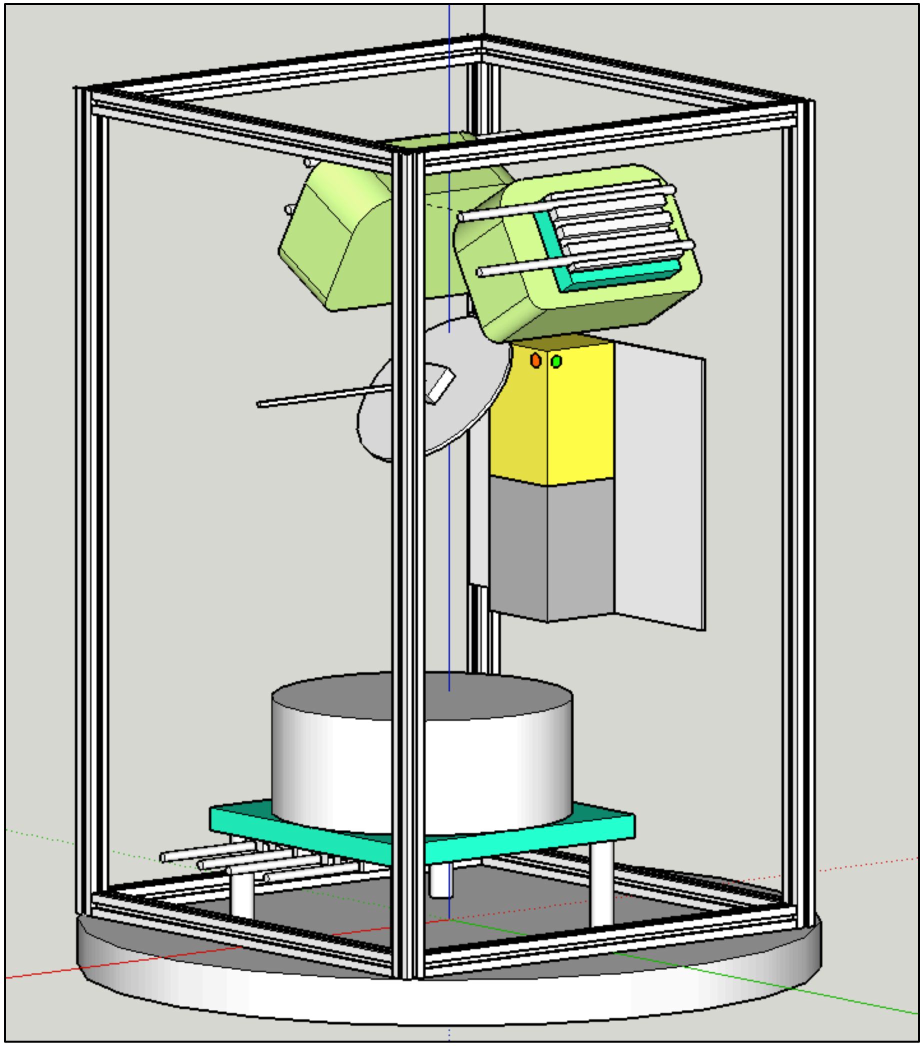
FM Instrument

- MLA: Assembled, tested and delivered by VDI, along with DRO. Amplifier and mixer blocks fabricated and tested.
- IFA: Built by Jared Lucey and Shawn Macmurphy. Video amplifier board assembled and tested; Board functions as expected.
- iPDU: Built, assembled, and tested. Card functions as expected and the board delivered to the flight I&T by Amri Hernandez and Melyane Ortiz.
- RIC: Built, assembled, and characterized by Mark Wong and Daniel Lu.
- Mechanical components such as top science plate, interface cross plate, thermal packs all designed by Mike Solly; and the components have been fabricated.



TVAC Calibration Fixture

- In Nov 2014, MIT/Lincoln Labs (MIT/LL) design a calibration fixture for MicroMAS-1, with a similar microwave payload in a 3U CubeSat.
- IceCube built a three-target fixture, with the instrument's field-of-view determined by a rotating mirror. This fixture can be accommodated in Goddard B4 Dynavac and in WFF F-7 TVAC chambers.
- IceCube FM TVAC tests were conducted in December 2015.

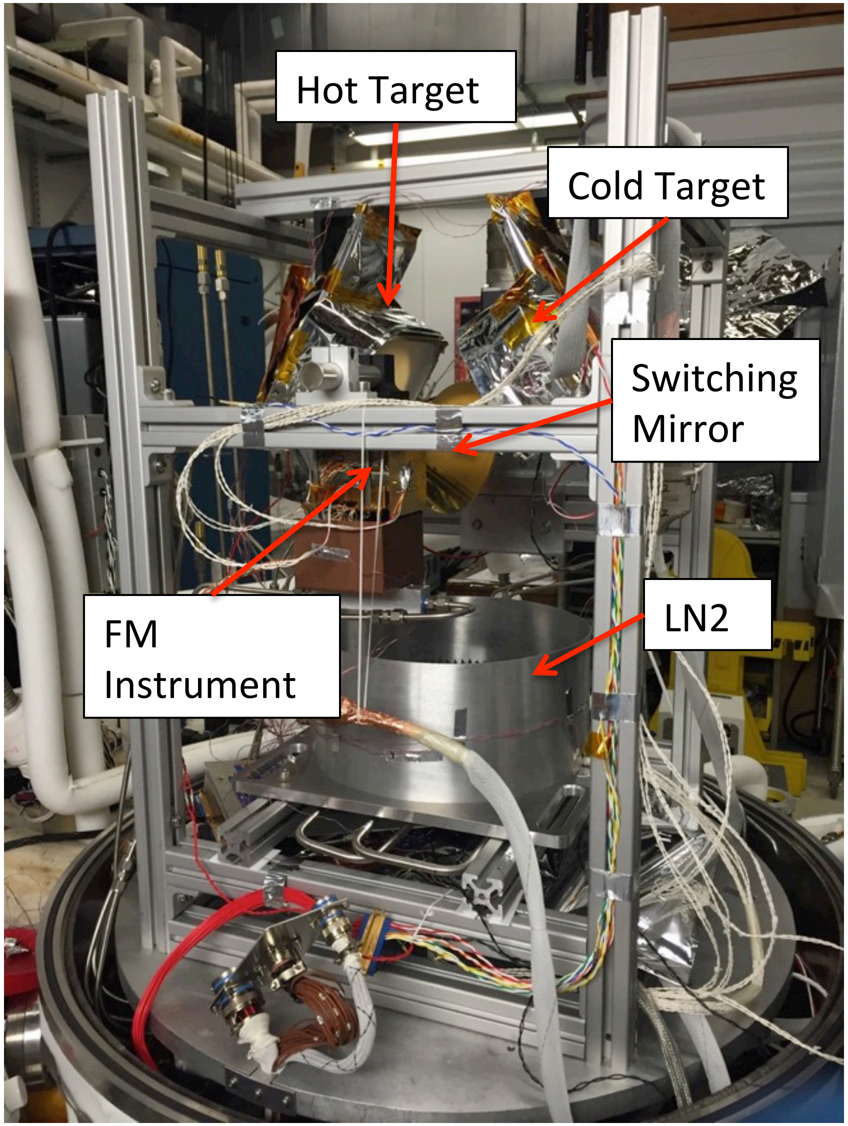


Model of IceCube Calibration Fixture w/ CoSSIR & 330 mm Targets

Courtesy of Kevin Horgan (GSFC/555)

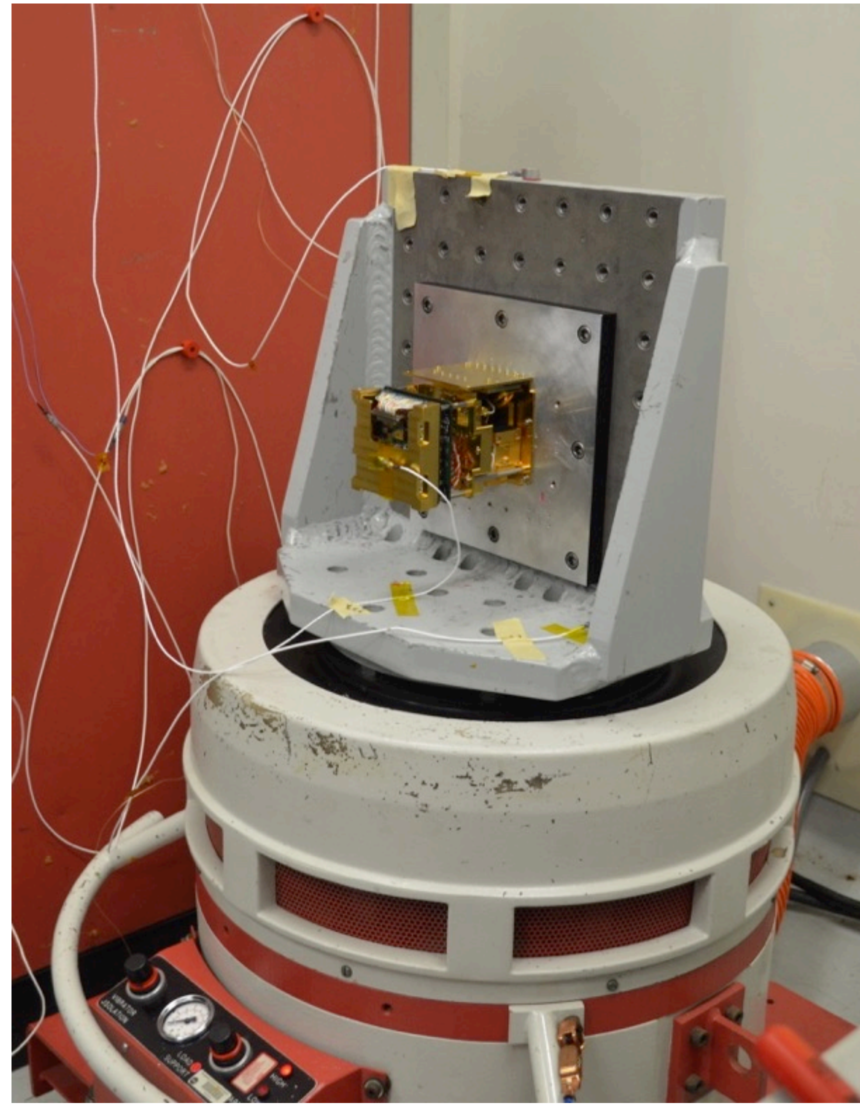
FM Instrument TVAC Test

- SIC was not present in the test since the S/C software and the GSE required to connect to SIC were not ready.
- Paraffin packs were not tested in TVAC, and no side solar panels were present.
- Aperture cover (Zitex G) was not included in TVAC since it is part of the S/C side panels, as designed.
- During TVAC-1 after absorber tile installation the instrument antenna and antenn+noise count were lost.
  - Diagnosis pointed the problem to the FM MLA.
  - The problem was resolved by disconnecting and reconnecting the 2.92 mm cable between the amplifier block and the DRO in the FM MLA.

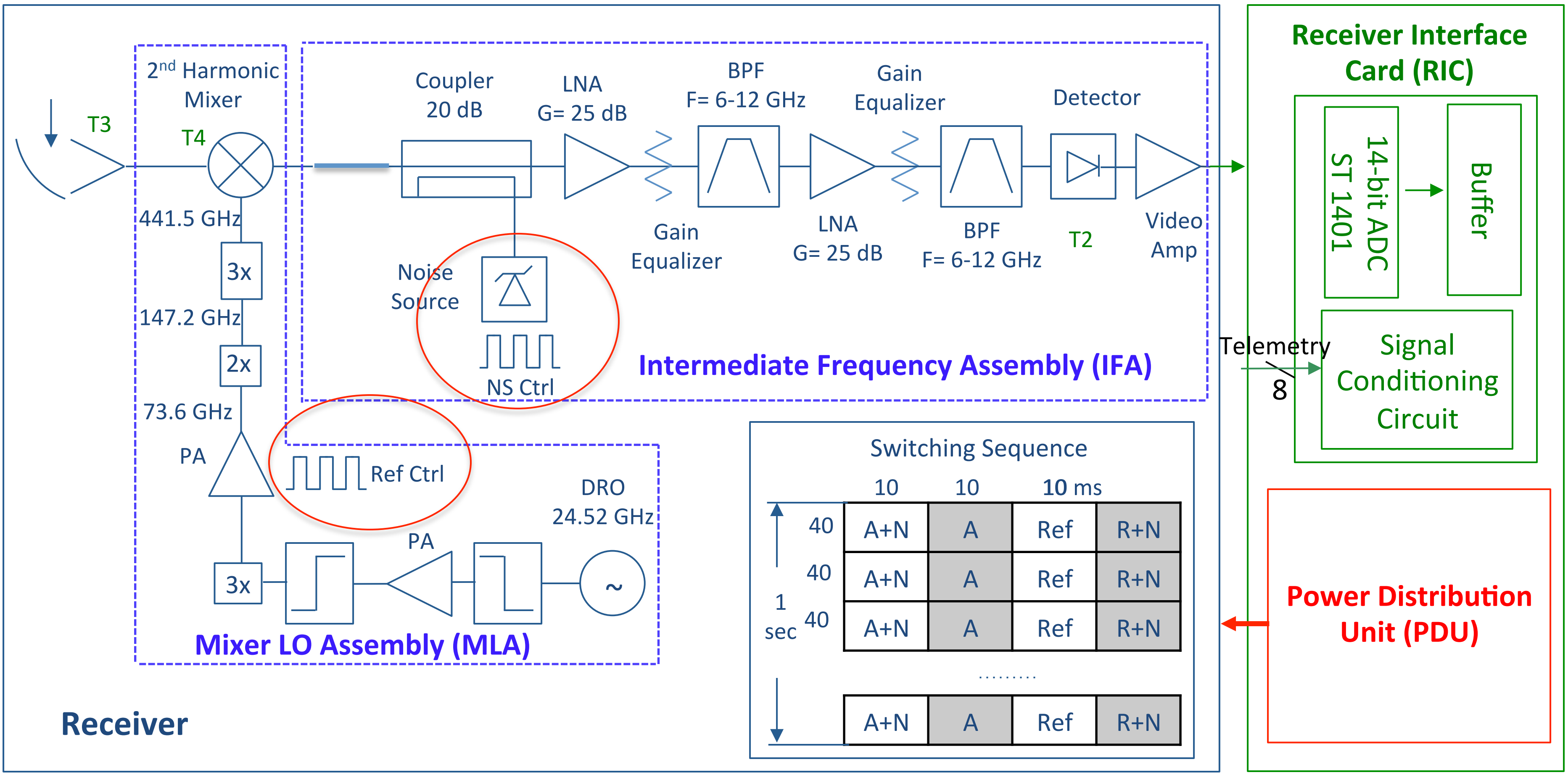


FM Instrument Workmanship Vibration Test

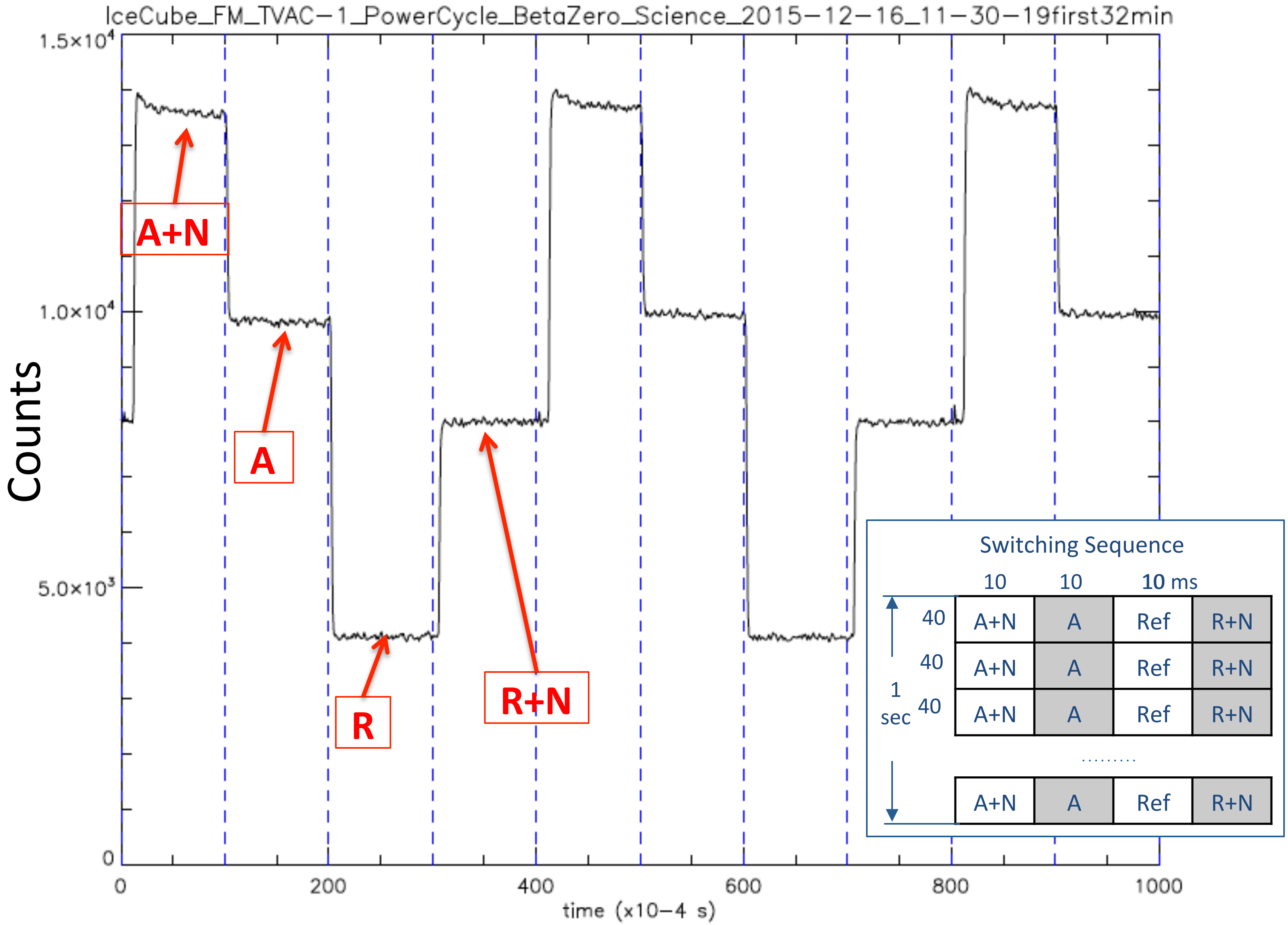
- FM instrument vibration test successfully conducted without modification to HW.
- MLA cable tested with PNA and X-ray before vibration and no issue was found.
- Highest frequency shift in the y-axis pre/post sine sweep is about 2.2%.
- FM instrument mechanically healthy. The instrument gain variation is within 2% before and after the vibe tests.
- No glitches observed in the data.
- TVAC and pre/post vibe data analyzed by Derek Hudson.



Instrument: Block Diagram and Calibration



A = Antenna
N = Noise
R = Reference



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1/*f* noise
or
Pink noise

TIME DOMAIN		FREQUENCY DOMAIN	LOG-LOG	PHASE
$\alpha = 2.0$	t^{2}	ω^{-3}	-3.0	$\phi = -3\pi/2$
$\alpha = 1.0$	t^{1}	ω^{-2}	-2.0	$\phi = -\pi$
$\alpha = 0.5$	$t^{0.5}$	$\omega^{-1.5}$	-1.5	$\phi = -3\pi/4$
$\alpha = 0.0$	t^{0}	ω^{-1}	-1.0	$\phi = -\pi/2$
$\alpha = -0.25$	$t^{-0.25}$	$\omega^{-0.75}$	-0.75	$\phi = -3\pi/8$
$\alpha = -0.5$	$t^{-0.5}$	$\omega^{-0.5}$	-0.50	$\phi = -\pi/4$
$\alpha = -0.75$	$t^{-0.75}$	$\omega^{-0.25}$	-0.25	$\phi = -\pi/8$
$\alpha = -1.0$	t^{-1}	ω^{0}	0.0	$\phi = 0$
$\alpha = -1.50$	$t^{-1.5}$	$\omega^{0.5}$	0.5	$\phi = \pi/4$
$\alpha = -2.0$	t^{-2}	ω^{1}	1.0	$\phi = \pi/2$

LINEAR

Instrument Operation Modes

IceCube instrument operated in an unusual way, compared to most radiometers:

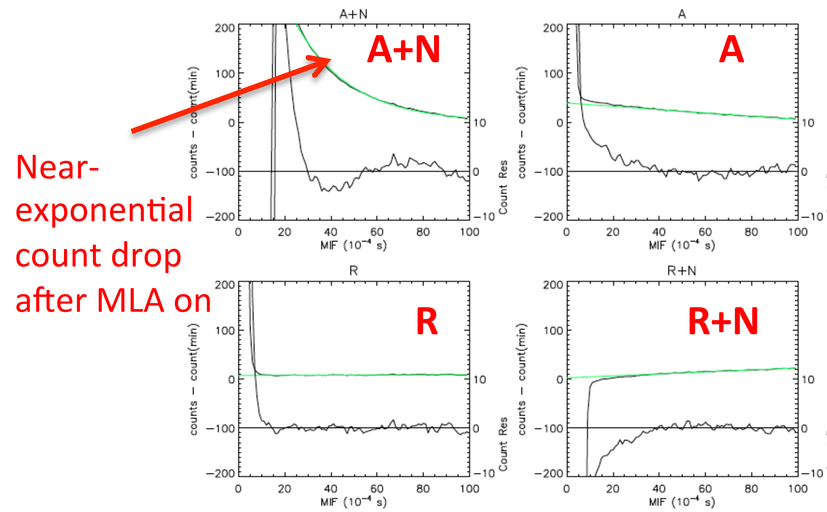
- MLA on and off in every 20 ms
- IFA not in an equilibrium state
- Gain (count-to-radiance) model very different

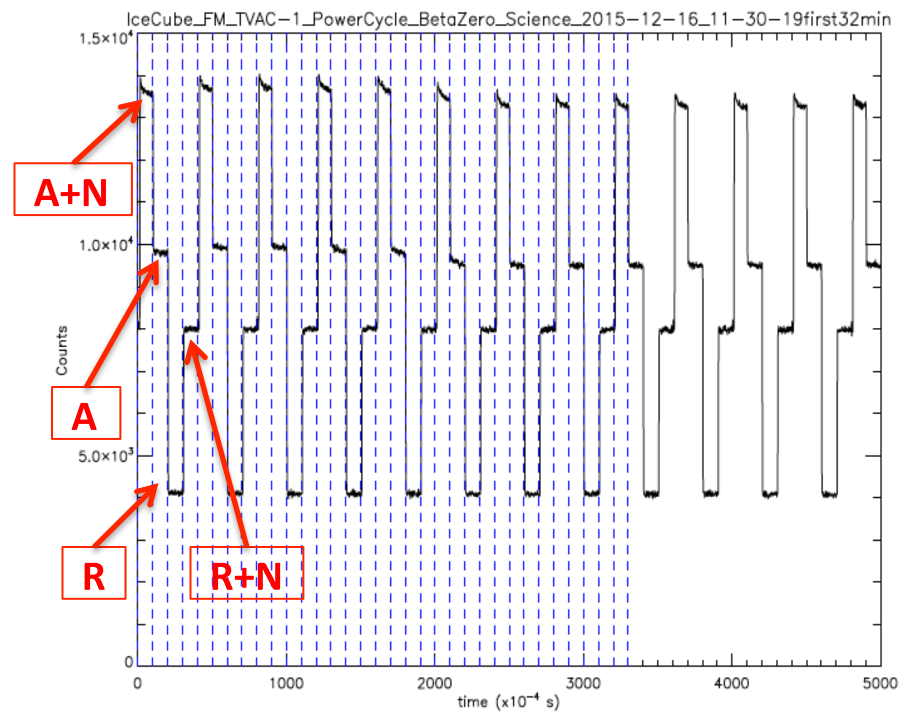
Mode 1 (nominal)

- Periodically switching between 4 states
  - Antenna + Noise (A+N) 10 ms
  - Antenna (A) 10 ms
  - Reference (R) 10 ms
  - Reference + Noise (R+N) 10 ms
- For each 10 ms, sum up counts (sampled every 0.1 ms) to downlink
  - Mean count and standard deviation

Mode 2 (experimental)

- Periodically switching only between 2 antenna states
  - Antenna + Noise (A+N) 10 ms
  - Antenna (A) 10 ms
- More DC power (6.5 W vs 5.2 W) than mode 1 operation





Effects of Count Response Functions

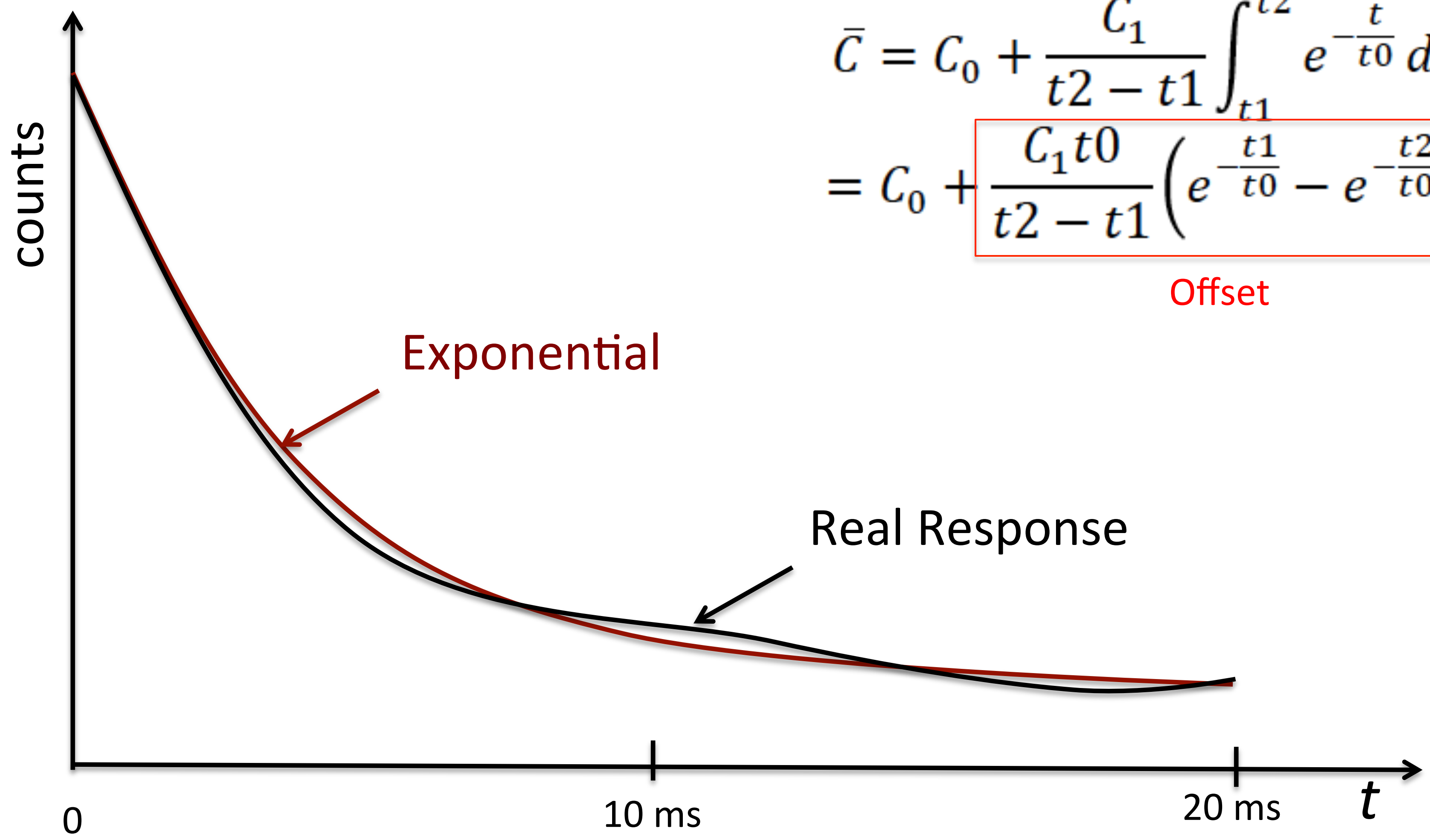
$$C = C_0 + C_1 e^{-t/t_0}$$

Exponential

$$\bar{C} = C_0 + \frac{C_1}{t2 - t1} \int_{t1}^{t2} e^{-\frac{t}{t0}} \, dt$$

$$= C_0 + \frac{C_1 t0}{t2 - t1} \left(e^{-\frac{t1}{t0}} - e^{-\frac{t2}{t0}} \right)$$

Offset

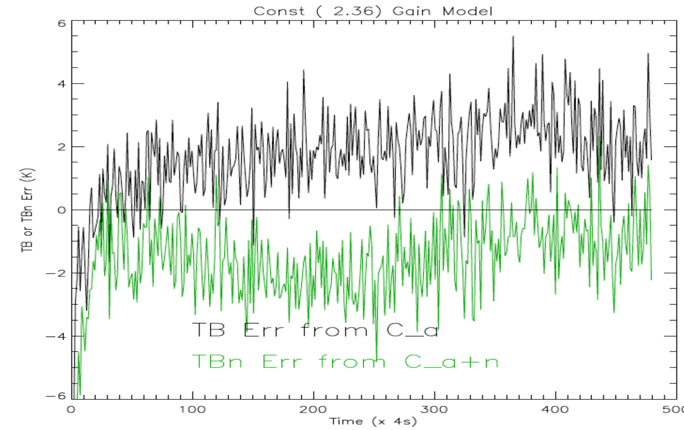


Instrument Test Results and Calibration Algorithms

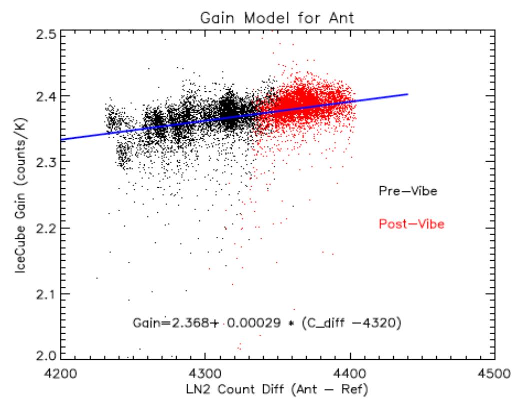
- A constant gain model

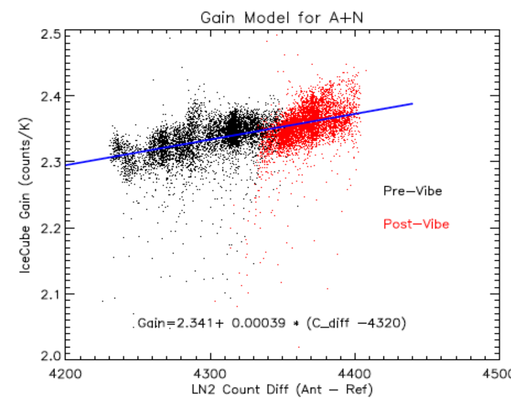
Gain = 2.36 counts/K

Radiance error: +/- 4 K



- Modified constant-gain model from pre- and post-vibe tests





For A+N counts:

Gain = 2.341 + 0.00039*(Cdiff-4320)

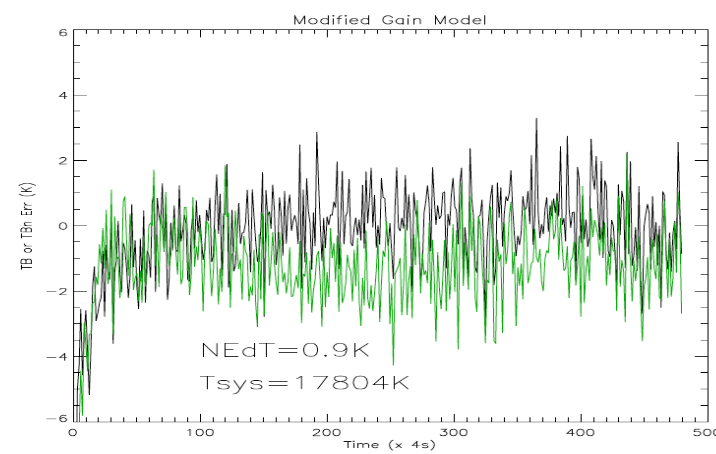
For A counts:

Gain = 2.368 + 0.00029*(Cdiff-4320)

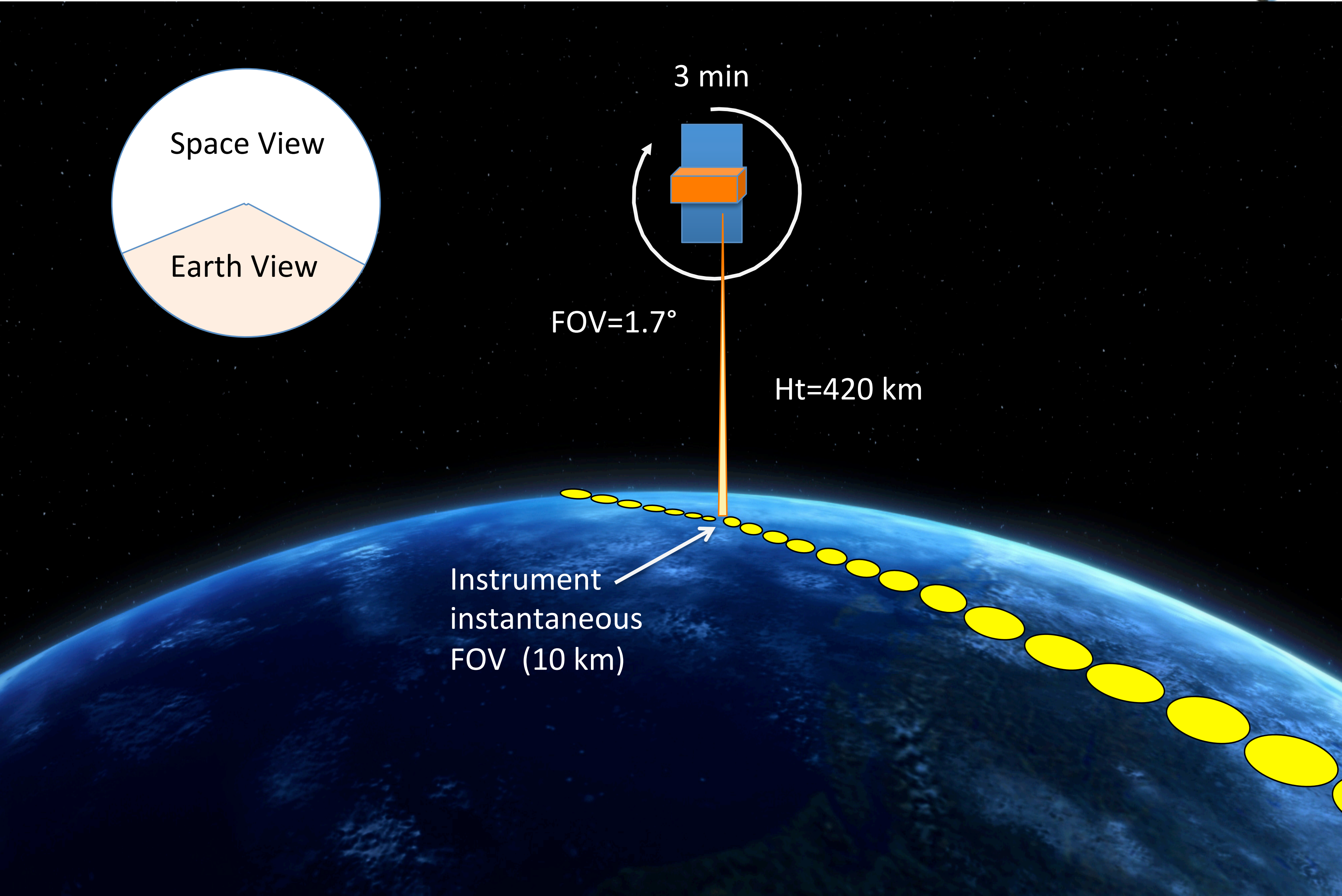
where $C_{diff}=(C_{A\_LN2} - C_{R\_LN2})$

Radiance error: +/- 2K

(ignore first 3-min data)



IceCube Operation Concept



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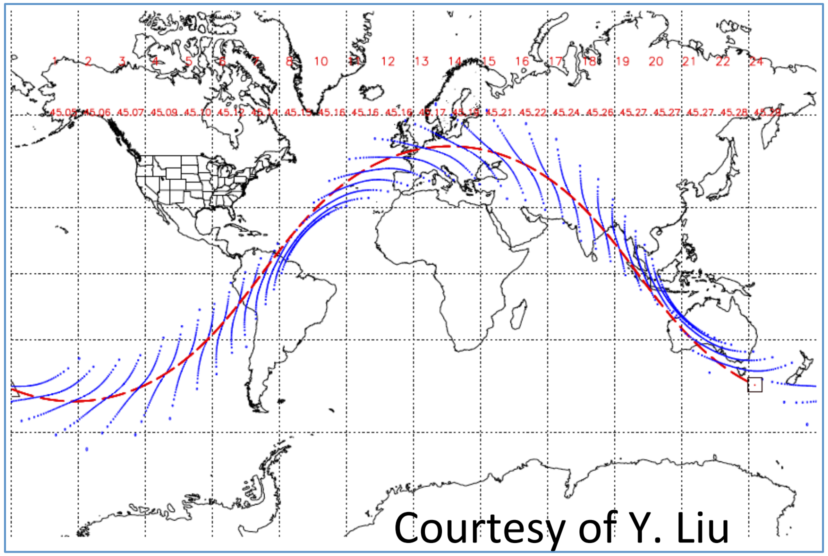
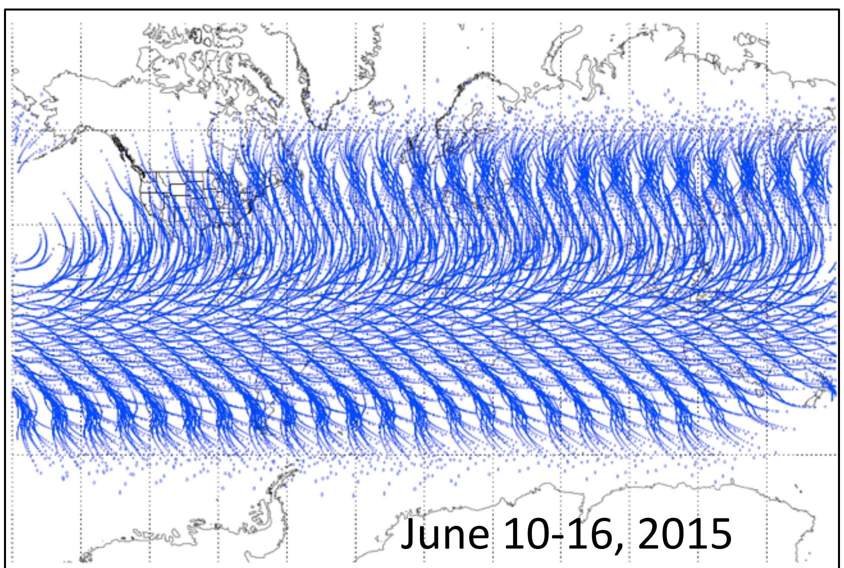
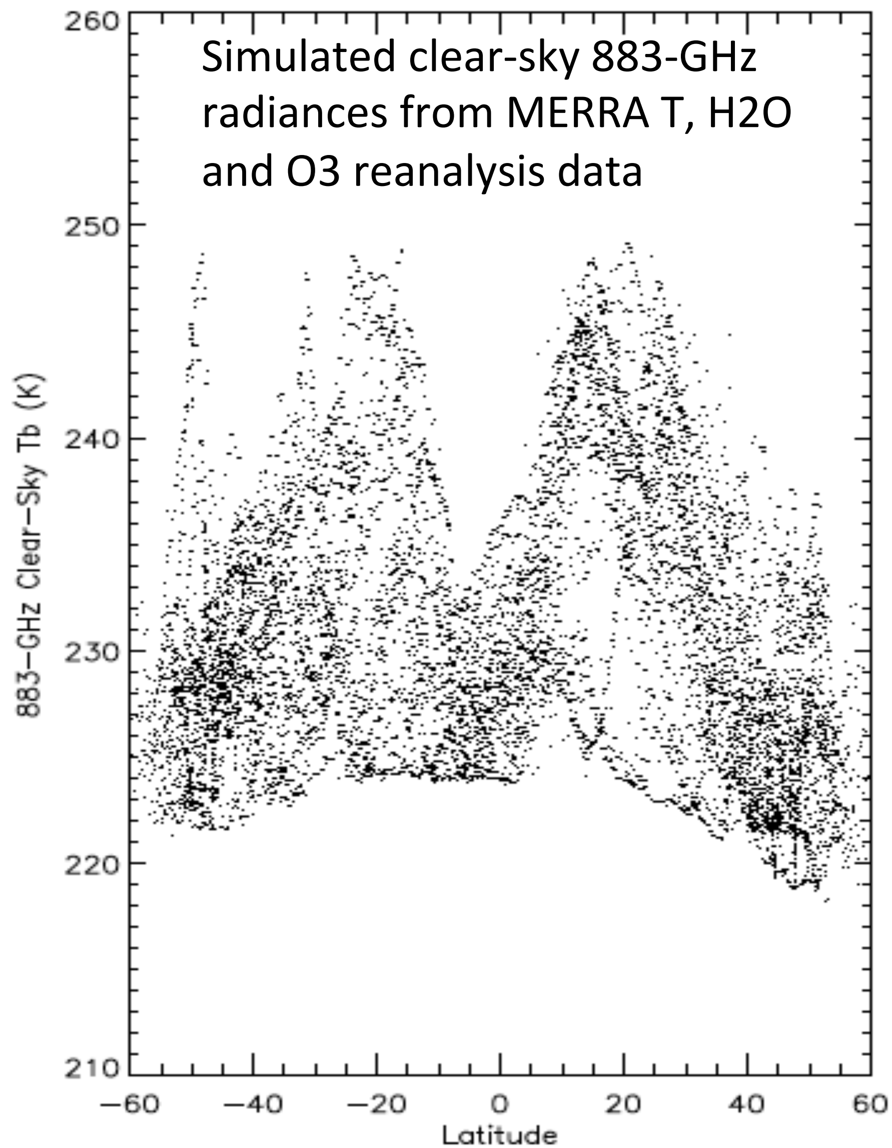
Simulated IceCube Daytime-Only Sampling







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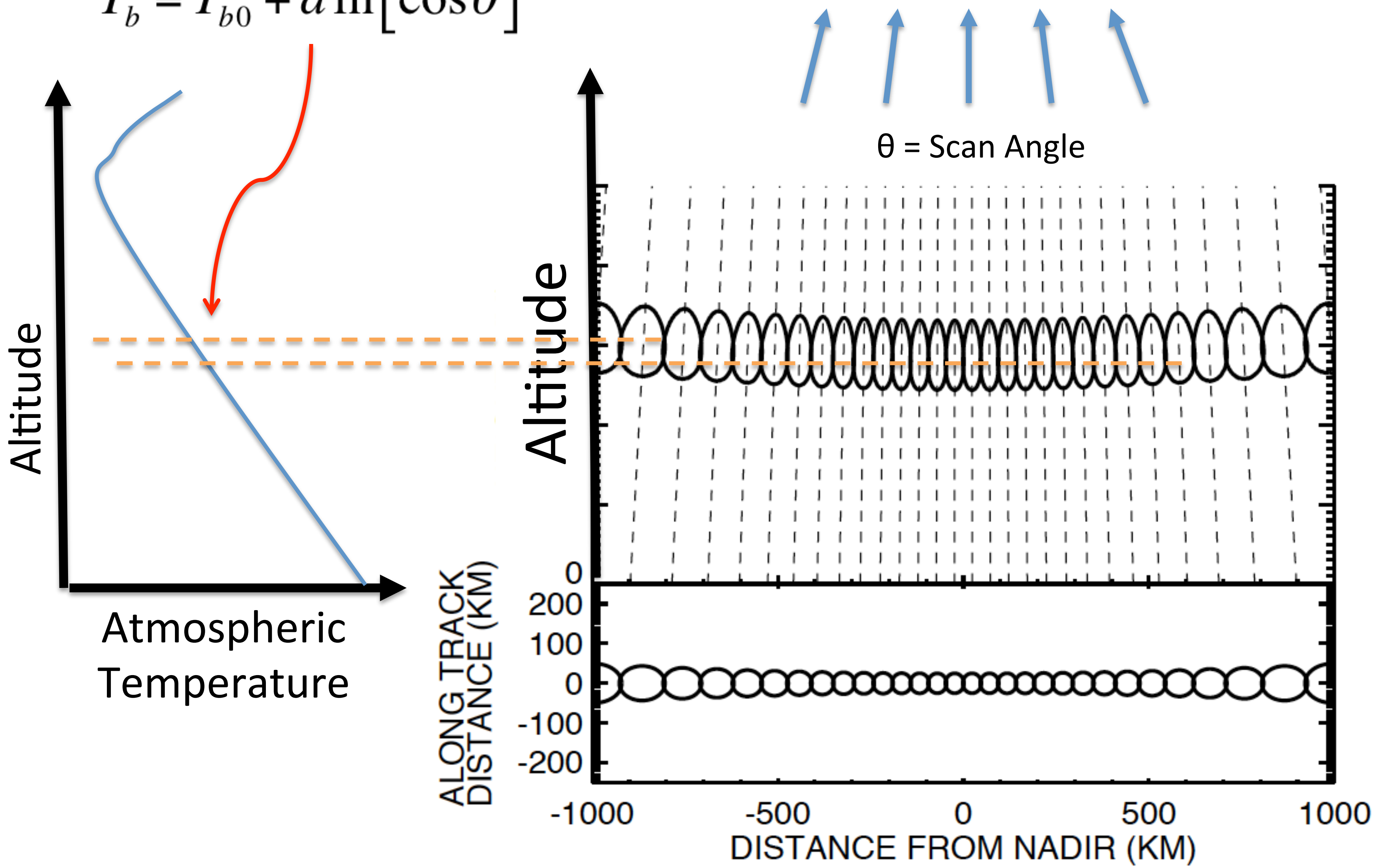
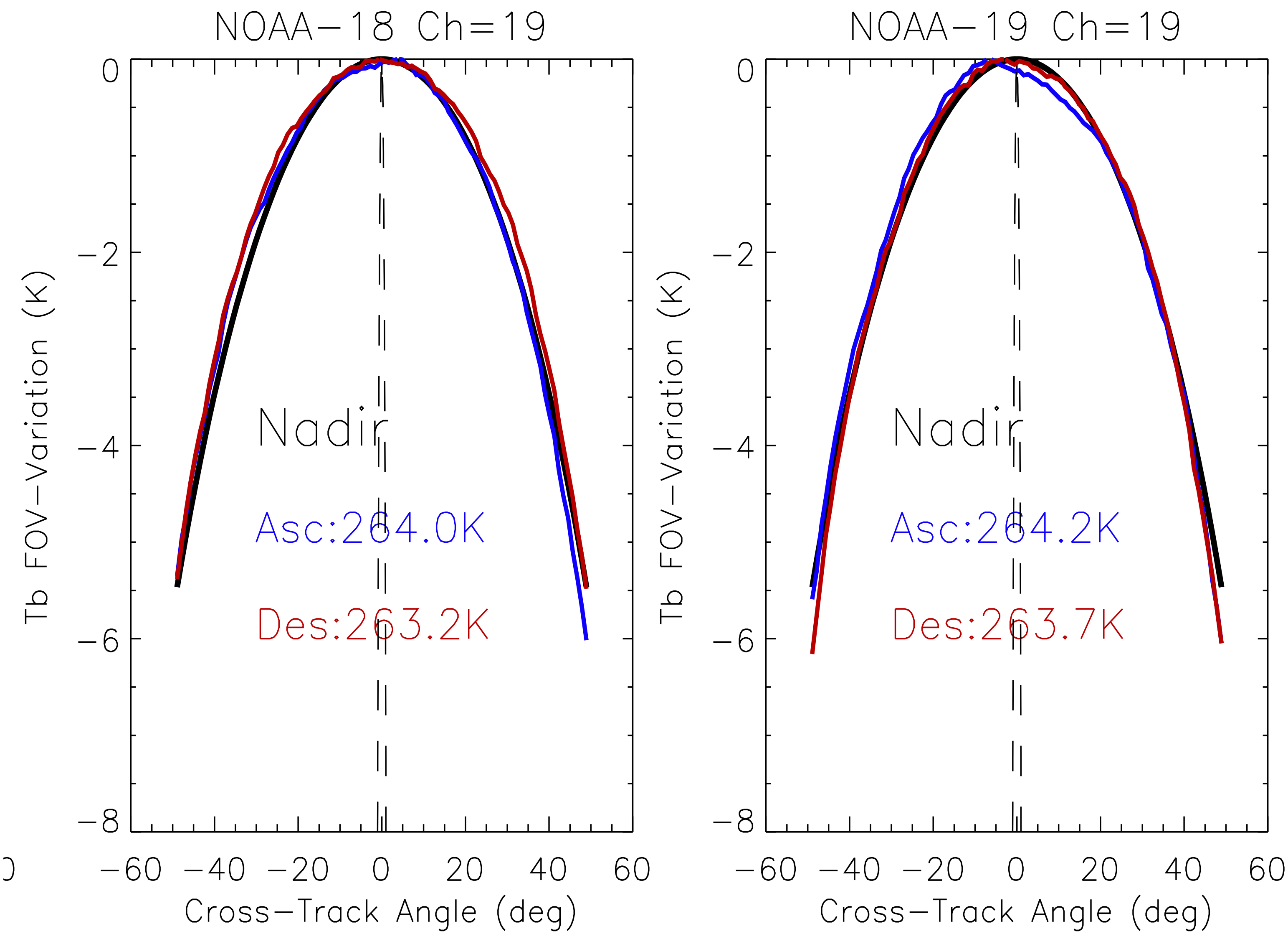
IceCube

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

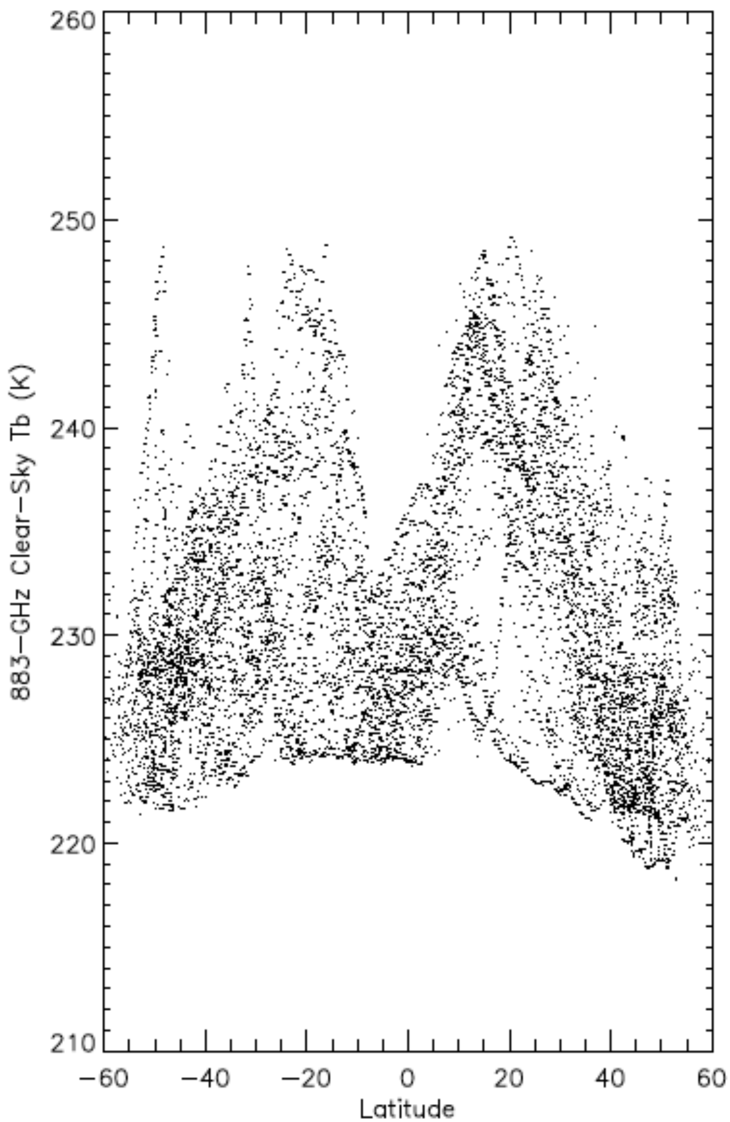


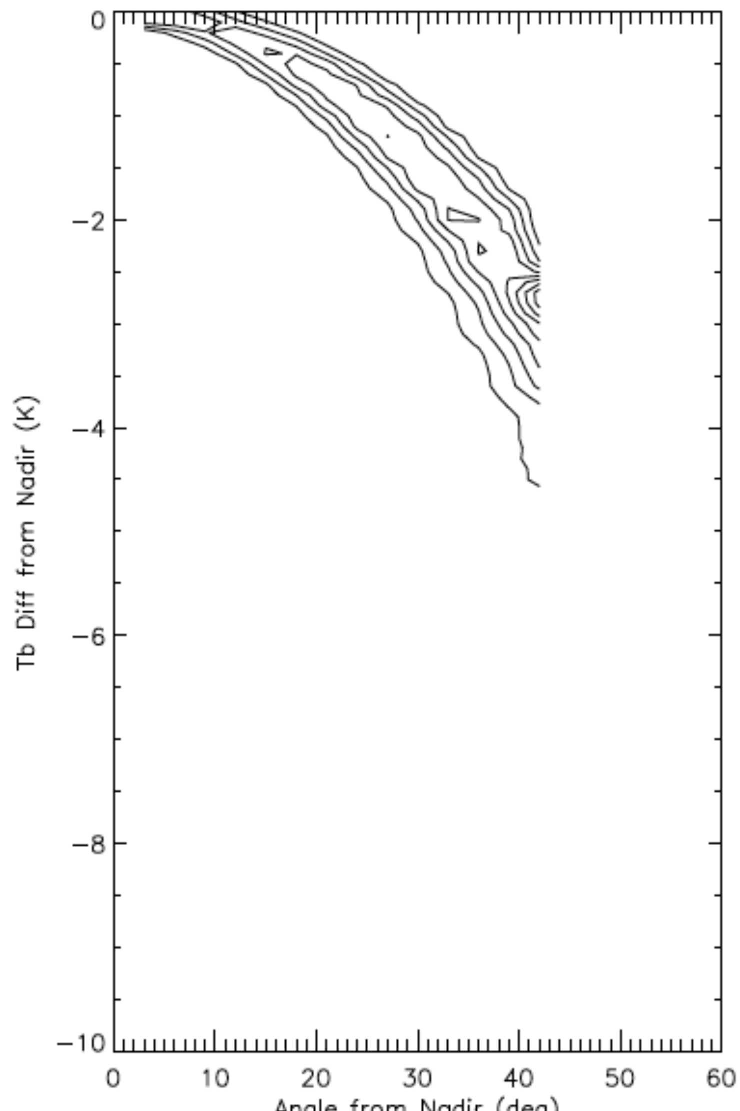
$$T_b = T_{b0} + a\ln[\cos\theta]$$

AMSU-B 183±3 GHz Clear-Sky Radiances



Slant-to-Nadir Radiance Conversion at 883 GHz





Summary

- IceCube 883-GHz cloud radiometer (FM) has been built and tested mechanically and thermally.
- The receiver appears to operate at a stage with significant 1/f noise, but calibratable to +/- 2K.
- The instrument FM is to be integrated to 3U CubeSat for a final system-level thermal-vacuum test.
- IceCube instrument is ready to fly, manifested on OA-7 for ISS on January 2, 2017.