

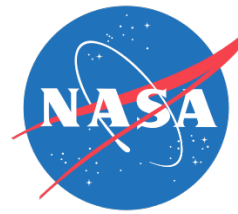
ADVANCING TECHNOLOGIES FOR CLIMATE OBSERVATION

NASA Goddard Space Flight Center

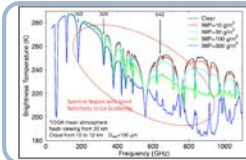
07/31/2014

D. Wu, J. Esper, N. Ehsan, T. Johnson, W. Mast,
J. Piepmeier, and P. Racette

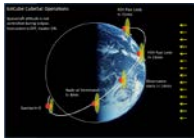
Outline



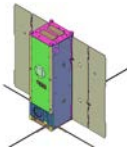
2



Objectives



Mission requirements



Mechanical configuration



Instrument

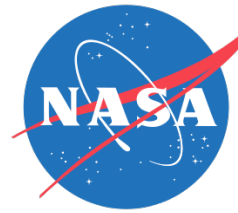


Results



Launch plan

Objectives



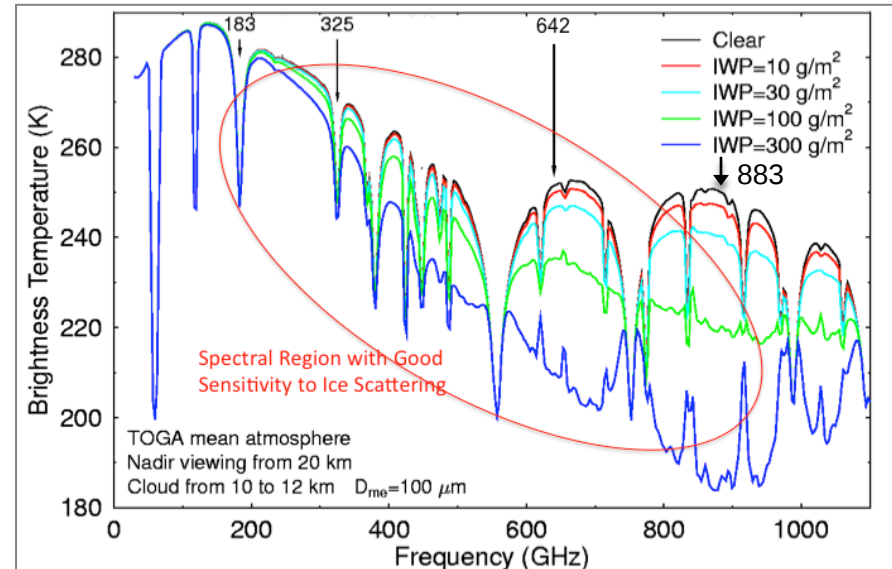
3

Climate research needs

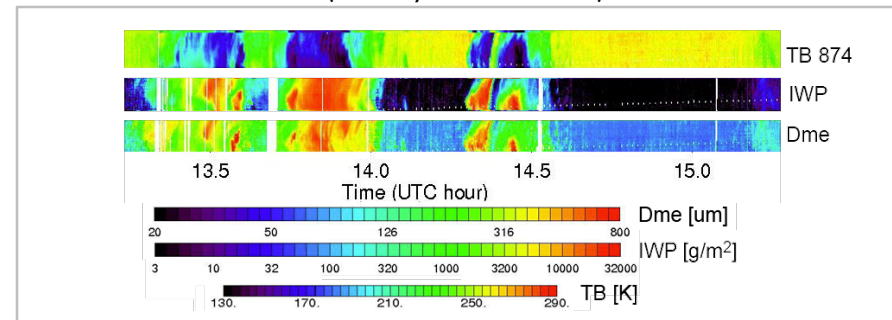
- Accurate global cloud ice measurements
 - ▣ Cloud ice properties are fundamental controlling variables of radiative transfer and precipitation
- Cost-effective, sensitive instruments for diurnal and wide-swath coverage
- Mature technology for space remote sensing

IceCube objectives

- Develop and validate a flight-qualified 883 GHz receiver for future use in ice cloud radiometer missions
- Raise TRL (5→7) of 883 GHz receiver technology
- Reduce instrument cost and risk by developing path to space for COTS sub-mm-wave receiver systems
- Enable remote sensing of global cloud ice with advanced technologies and techniques

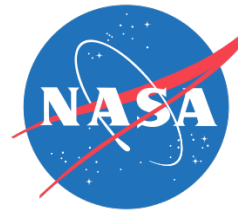


The spectral region with good sensitivity to ice cloud scattering
(courtesy of Frank Evans).



First-ever 874 GHz cloud measurements acquired by CoSSIR in 2008. CoSSIR measurements of ice clouds were used to successfully demonstrate retrieval of ice water path (IWP) and ice particle median mass-weighted ice particle size (D_{me}).

Mission Requirements



4

883 GHz measurement requirements:

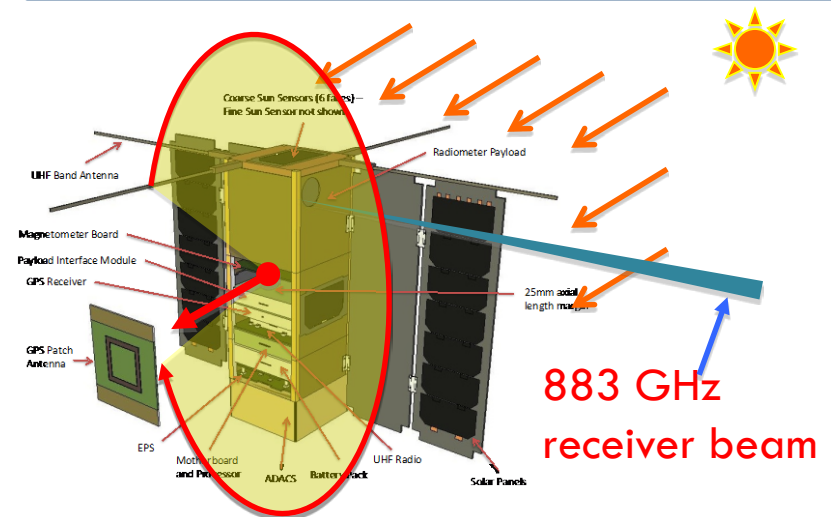
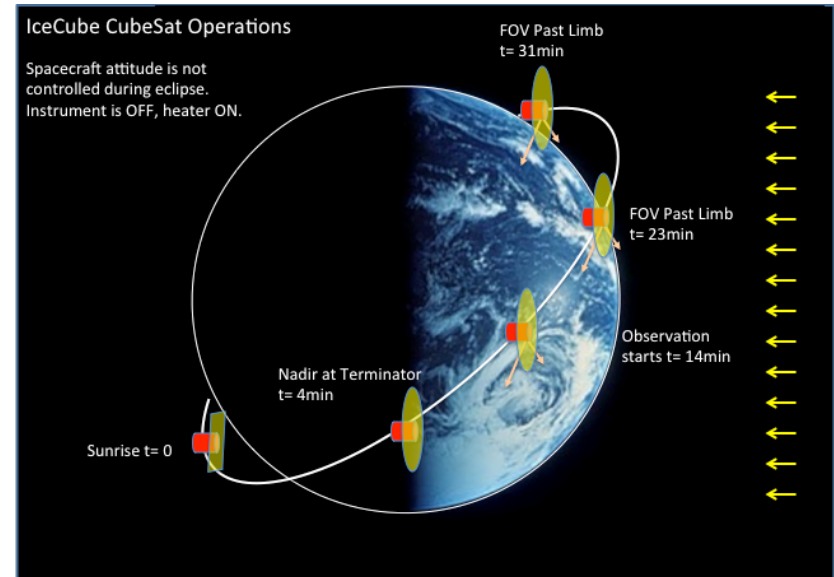
- Accuracy < 2 K
- Precision (NETD) < 0.2 K
- Spatial resolution < 15 km

Mission requirements:

- In-flight operation 28 days
- Periodic 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



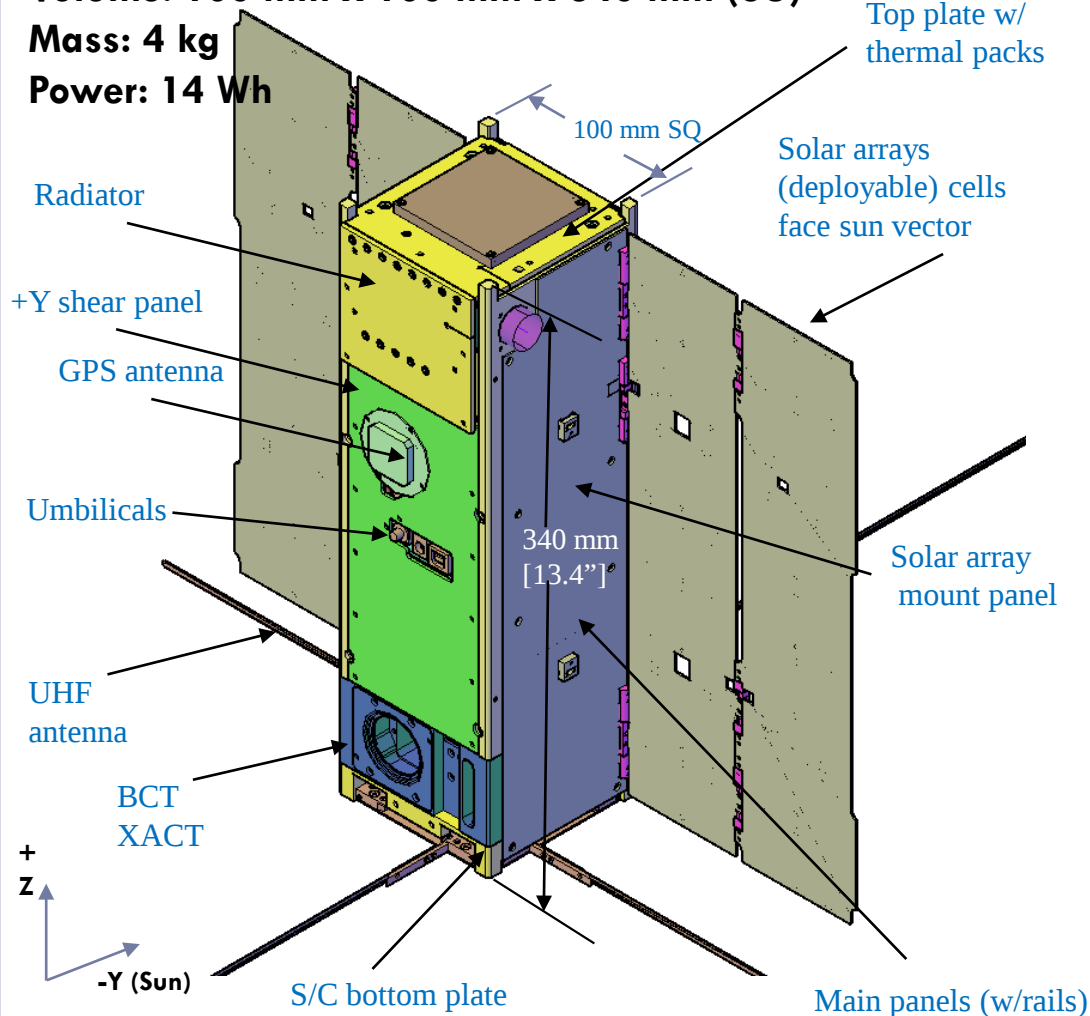
Flight Configuration

5

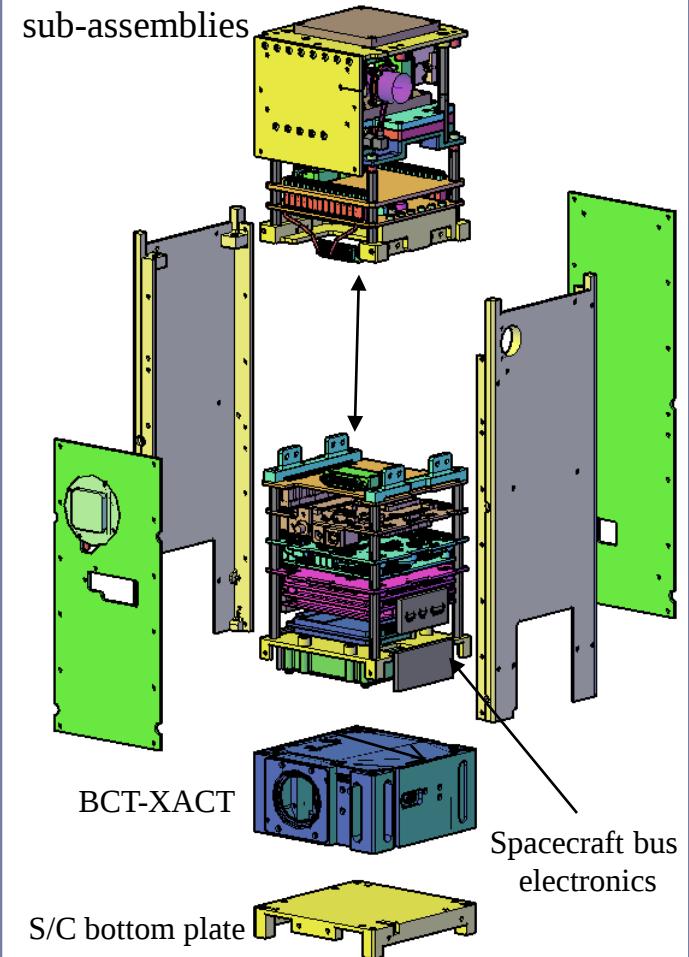
Volume: 100 mm x 100 mm x 340 mm (3U)

Mass: 4 kg

Power: 14 Wh



Instrument sub-assemblies





The diagram illustrates the Receiver architecture, which is divided into three main functional blocks: the Intermediate Frequency Assembly (IFA), the Mixer LO Assembly (MLA), and the Receiver Interface Card (RIC).

Intermediate Frequency Assembly (IFA): This block is enclosed in a blue dashed box. It receives an input signal (T3) and processes it through a 2nd Harmonic Mixer (T4) at 441.5 GHz. The signal then passes through a 3x frequency multiplier to 147.2 GHz, a 2x multiplier to 73.6 GHz, and a Power Amplifier (PA). The output of the PA is connected to the Mixer LO Assembly (MLA). The IFA also includes a Noise Source and a Noise Control (NS Ctrl) block. The signal path continues through a Coupler (20 dB), an Isolator (T1), a Low Noise Amplifier (LNA) with a gain of 25 dB, a Bandpass Filter (BPF) with a frequency range of 6-12 GHz, a Gain Equalizer, another LNA (25 dB), a second BPF (6-12 GHz), a Detector (T2), and finally a Video Amp.

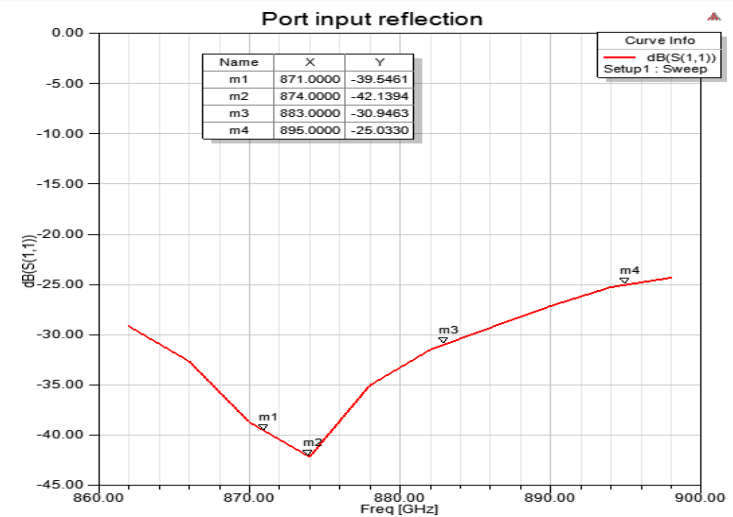
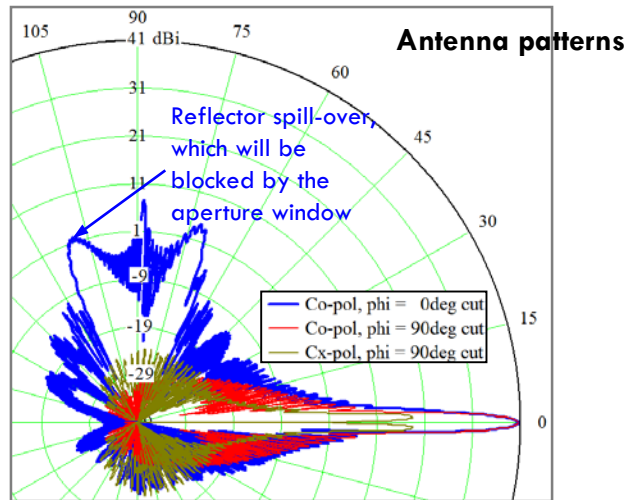
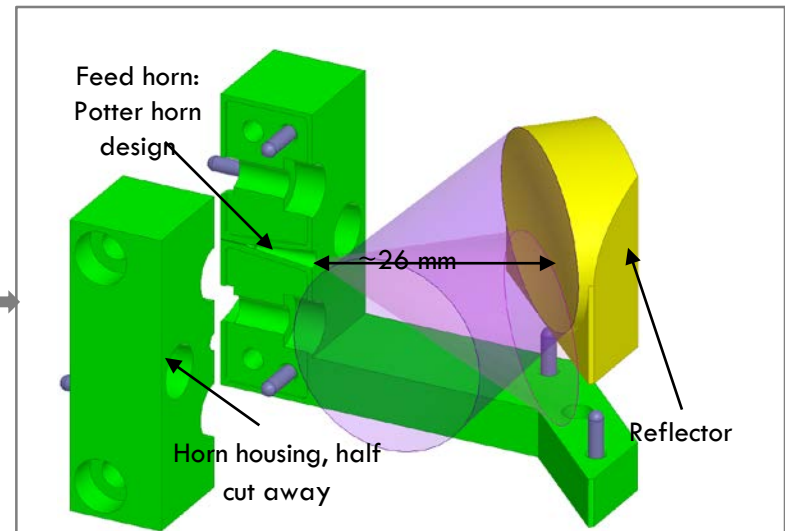
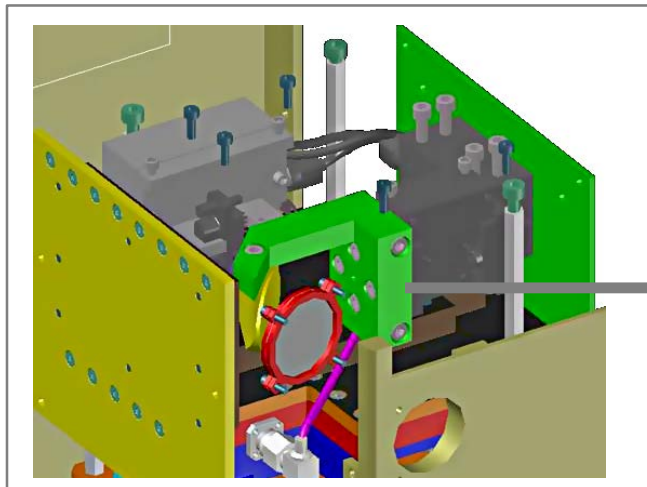
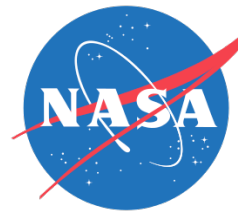
Mixer LO Assembly (MLA): This block is enclosed in a blue dashed box. It provides the local oscillator (LO) for the mixer. It consists of a 3x frequency multiplier, a Power Amplifier (PA), and a DRO (Dielectric Resonator Oscillator) operating at 24.52 GHz. The output of the PA is connected to the 2nd Harmonic Mixer (T4) in the IFA.

Receiver Interface Card (RIC): This block is enclosed in a green dashed box. It receives the signal from the IFA and processes it through a 14-bit ADC (ST 1401) and a Buffer. The output of the Buffer is connected to the Signal Conditioning Circuit. The RIC also includes a Power Distribution Unit (PDU) and a Telemetry output (8 bits).

Switching Sequence: A table showing the sequence of operations over time. The sequence is divided into three 10 ms intervals, each repeated 40 times. The operations are: A+N (Antenna Noise), A (Antenna), Ref (Reference), and R+N (Receiver Noise).

		Switching Sequence			
		10	10	10 ms	
40	1 sec	A+N	A	Ref	R+N
		A+N	A	Ref	R+N
		A+N	A	Ref	R+N
.....					
		A+N	A	Ref	R+N

Antenna



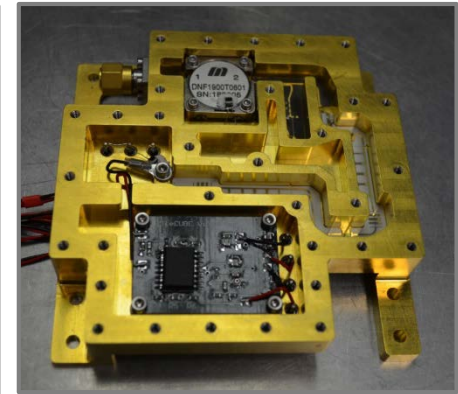
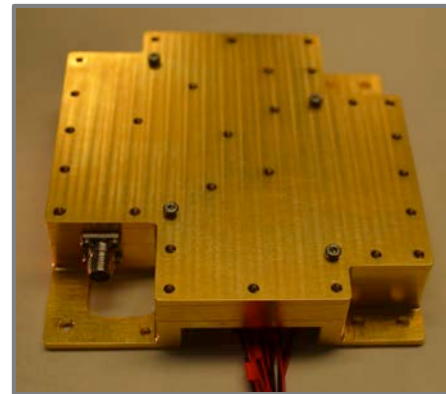
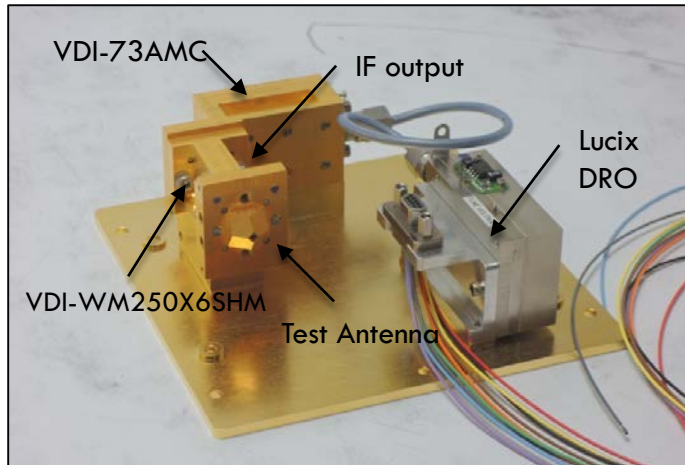
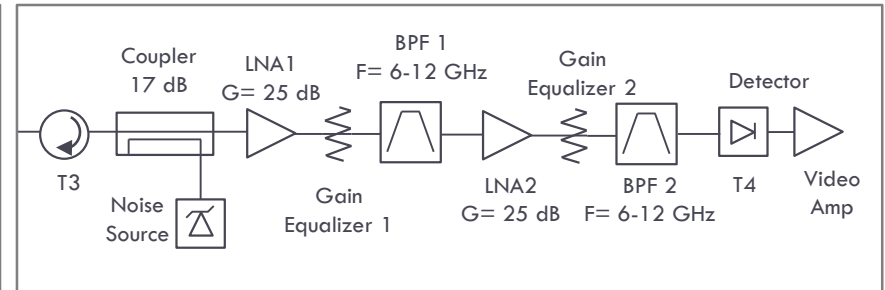
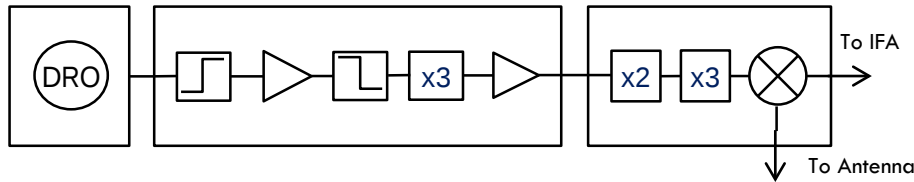
Instrument: MLA and IFA

8

Lucix LO-245-EC
 $F = 24.278 \text{ GHz}$
 $P_{\text{out}} = 7-10 \text{ dBm}$

VDI-73AMC ($P_{\text{out}} = 20 \text{ dBm}$)

VDI-WM250X6SHM



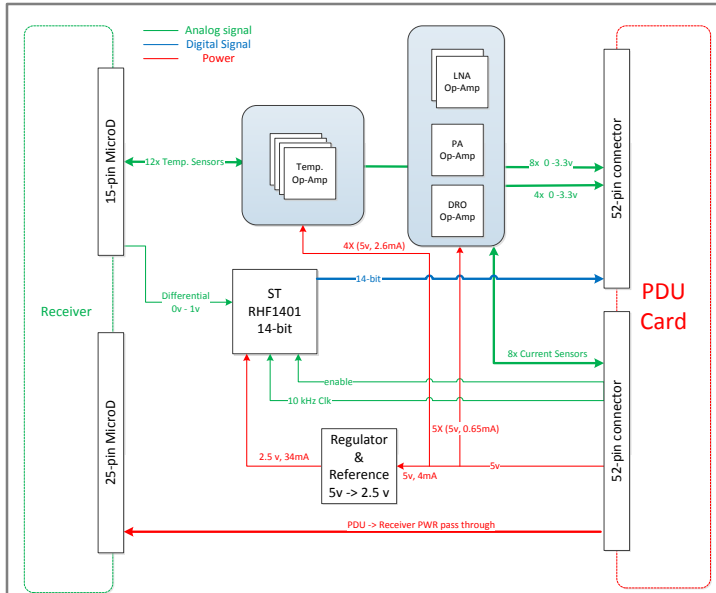
- MLA (Mixer LO Assembly):
 - ▣ Measured noise temperature: 4000 K
 - ▣ Measured conversion loss: 13 dB
 - ▣ Mass and volume: 150 g, 90 x 90 x 35 mm³
 - ▣ Power: 1.73 W

- IFA (Intermediate Frequency Assembly):
 - ▣ Estimated noise figure: 3-4 dB
 - ▣ Gain and bandwidth: 38.1 dB and 4 GHz
 - ▣ Mass: 200 g
 - ▣ Volume : 90 x 90 x 20 mm³
 - ▣ Power: 1.15 W

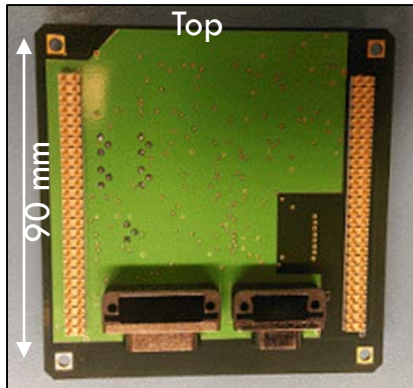
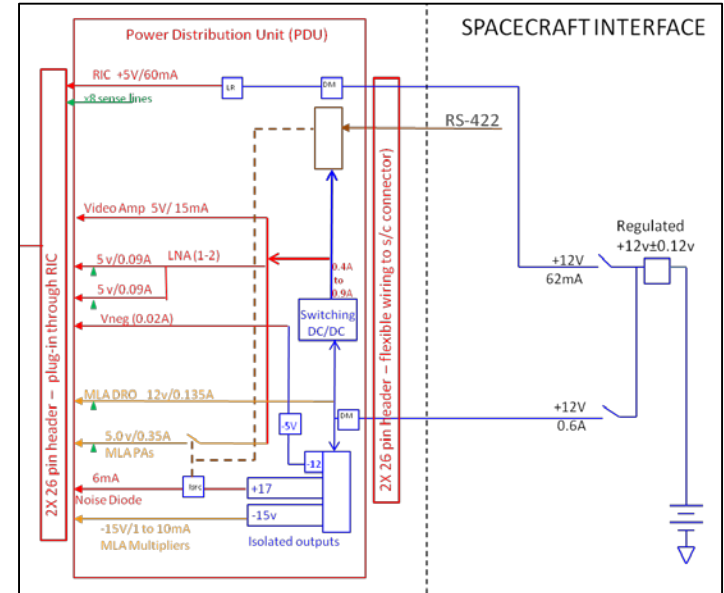
Instrument: RIC and iPDU

9

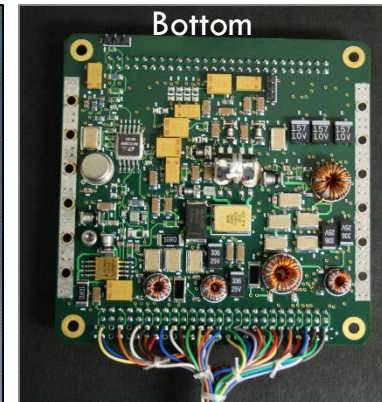
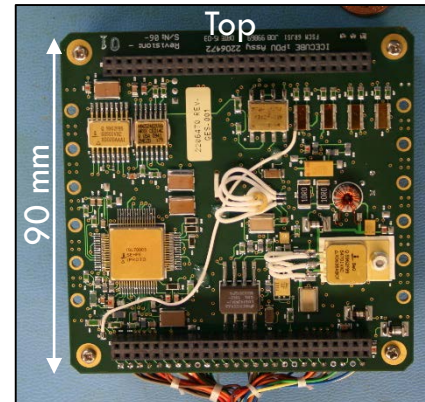
RIC (Receiver Interface Card)



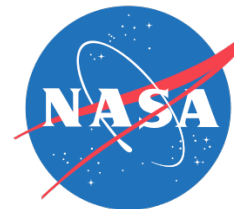
iPDU (instrument Power Distribution Unit)



Power: 0.3 W, Mass: 100.7 g



Power: 2.23 W, Mass: ~100 g



Power per Instrument Mode

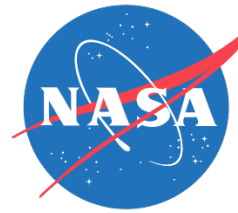
10

Based on integrated Engineering Model (EM) instrument measurements:

		- ND		all		- PA, -ND		-PA		
Load		Power Per Instrument Mode								
		ANT (10ms)		ANT+Noise (10ms)		REF (10ms)		REF+Noise (10ms)		RIC ON/PDU OFF
		Nom	+10%	Nom	+10%	Nom	+10%	Nom	+10%	
	Watts	6.56	7.22	6.44	7.08	3.94	4.33	3.88	4.26	0.38
non-sw	PDU logic									OFF
non-sw	Video Amplifier									OFF
non-sw	MLA_DRO									OFF
switched	MLA Power Amplifier					OFF		OFF		OFF
non-sw	LNA1									OFF
non-sw	LNA2									OFF
non-sw	deleted									OFF
switched	Noise Diode_Current Source	OFF				OFF				OFF
non-sw	MLA Multiplier									OFF
non-sw	Video amp NEG (linear reg)									OFF
non-sw	RIC									

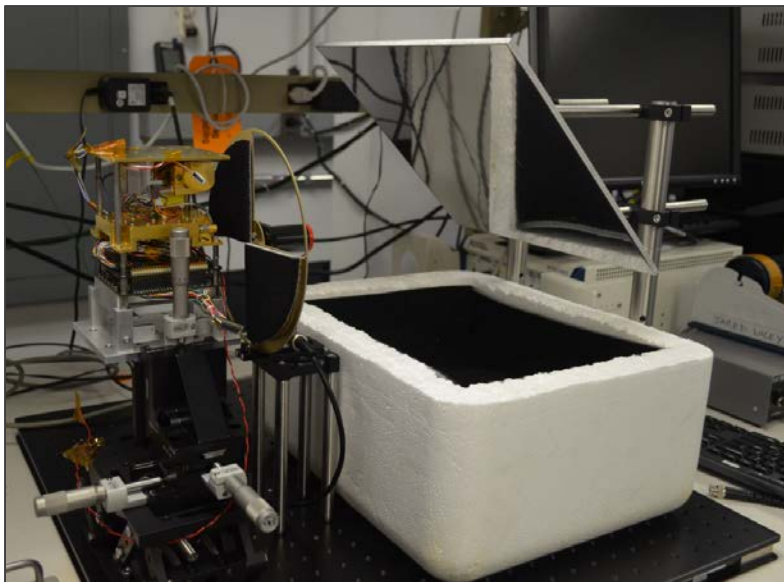
Courtesy of Amri Hernandez-Pellerano

Instrument Integration & Test

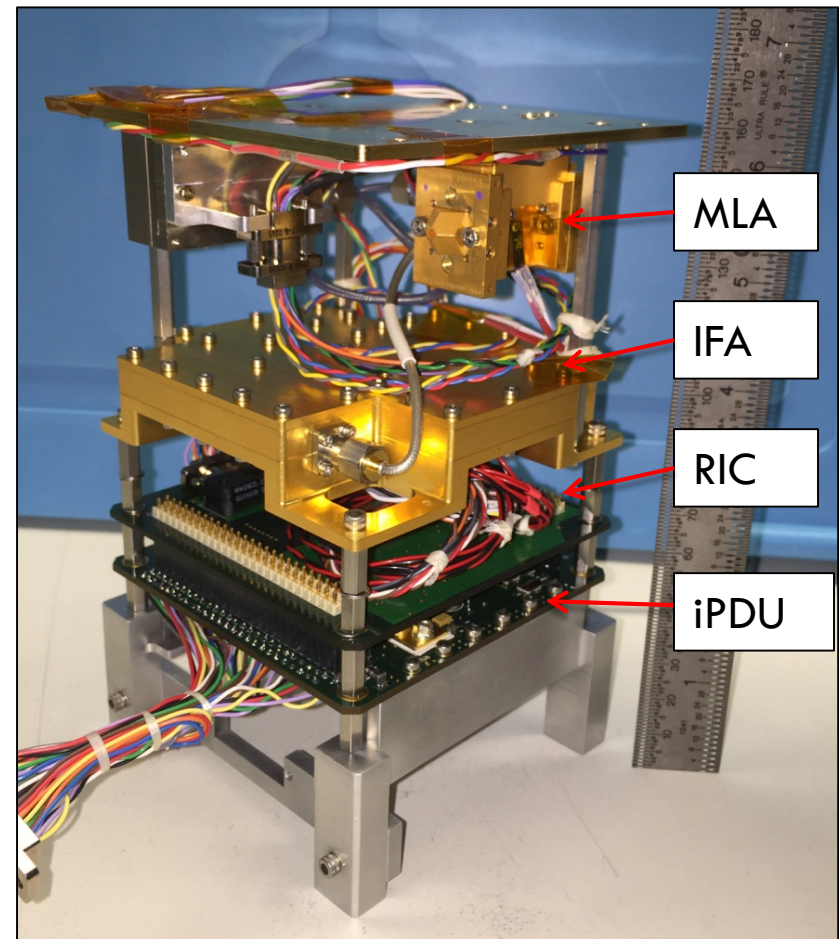


11

- Verification has been done via alternating between room temperature and LN₂ target
- Ambient setup includes:
 - Chopper wheel with room temperature absorber
 - 12" x 12" mirror
 - GSE spacecraft simulator
 - LN₂ absorber (Eccosorb AN 72)
- The instrument will be tested over temperature with a Thermal Vacuum Chamber (TVAC)



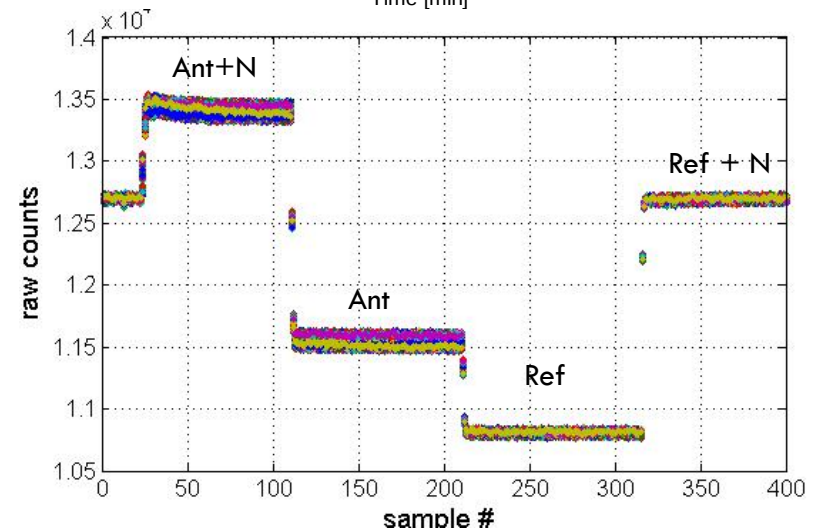
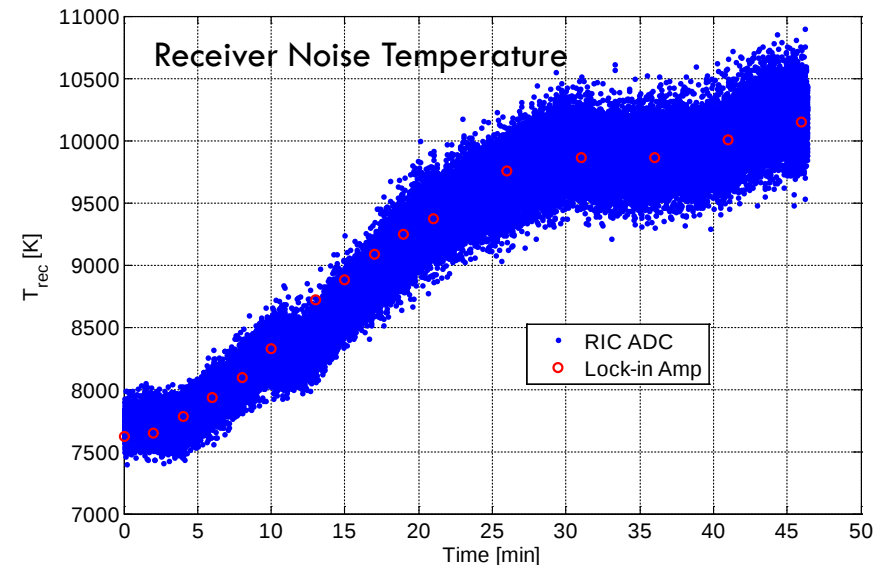
Engineering Model IceCube Instrument



Ambient Test Results

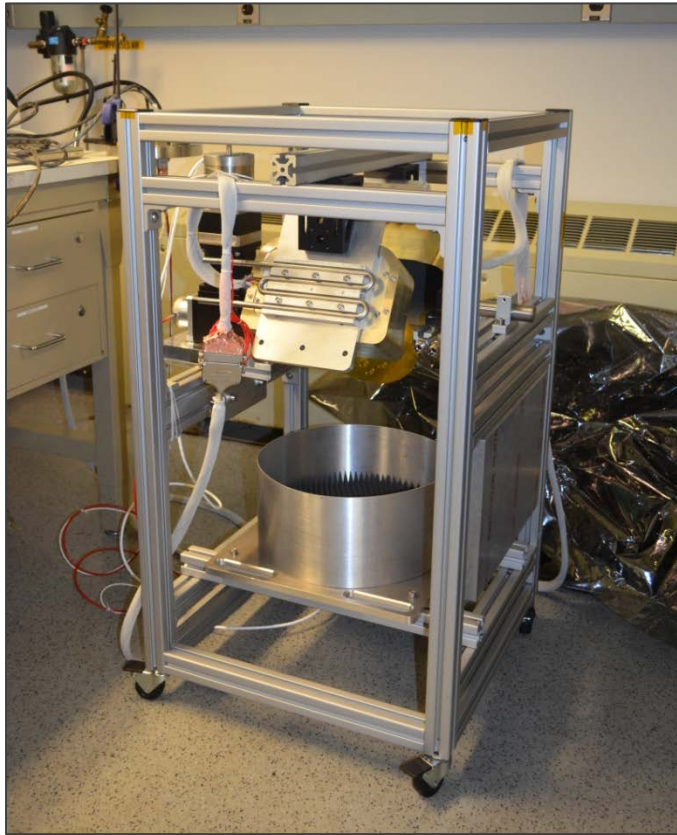
12

- Receiver noise temperature has been measured via Y-factor measurement both with lock-in amplifier and RIC in the antenna mode.
- The instrument noise temperature varies between 7500 K to 10500 K in 45 mins due to thermal effects.
- The flight instrument has thermal control to stabilize the temperature of the instrument.
- The instrument is switching states every 10 ms for calibration.

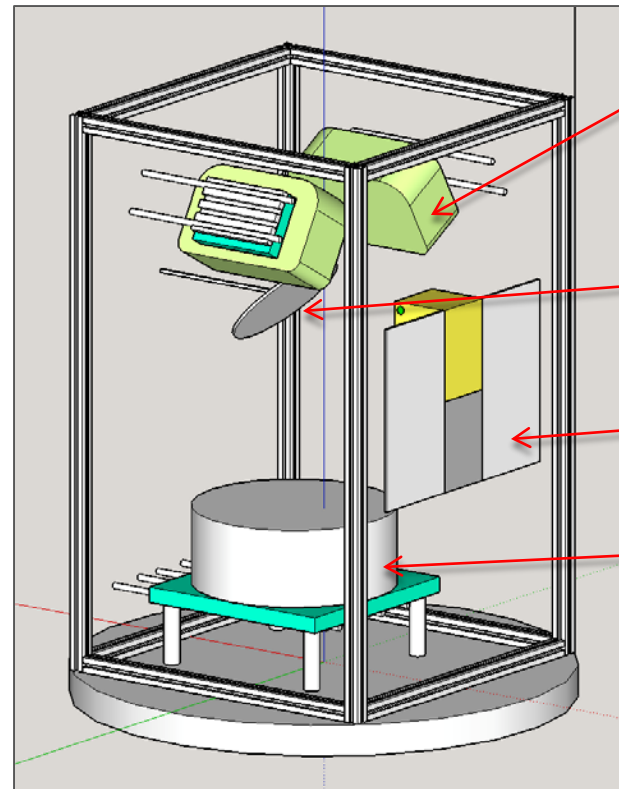


Instrument TVAC

13



Courtesy of Kevin Horgan, 555 (inspired by MIT Lincoln Laboratory MicroMAS TVAC structure)



Sub-MMW blackbody cold target (100 K) & hot target (300 K) for external calibration; tolerance ± 1 K

45deg-offset rotating mirror to alternate observed scene/target

Instrument/IceCube

Sub-MMW blackbody target (variable 100-300 K); tolerance ± 1 K

IceCube Calibration Fixture
(mounting hardware not shown)
(22.6" x 22.6" x 36")

Launch Opportunity and Orbit

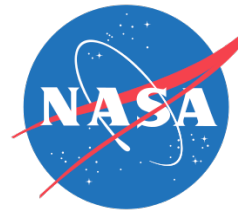
14

- NASA CubeSat Launch Initiative (CSLI)
 - ▣ Coordination of upcoming launches
 - ▣ 1U, 2U, 3U, or 6U

- International Space Station (ISS)
 - ▣ Secondary cargo payload on ISS resupply missions
 - ▣ Mid 2016
 - ▣ 350-450 km, 51.6° inclination near-circular orbit
 - ▣ β angle variation: 0-75°

- 3U CubeSat Launchers
 - ▣ NanoRacks CubeSat Deployer from ISS





Questions?

15

□ NASA ESTO, SMD and CSLI supports

□ IceCube Team

PI

Deputy PI

Tech Lead

Wu, Dong (GSFC, 613)

Piepmeyer, Jeffrey (GSFC, 555)

Esper, Jaime (GSFC, 592)

Instrument (GSFC)

Inst. And Sys. Lead Ehsan, Negar (555)

Inst. Scientist Racette, Paul (555)

Antenna Du Toit, Neils (555)

Integration & Test Horgan, Kevin (555)

Calibration Alg. Hudson, Derek (555)

IF subassembly Lucey, Jared (555)

Assembly Tech. Macmurphy, Shawn (562)

Pathways Intern Cooke, Caitlyn (555)

Power Lead Hernandez, Amri (563)

Power Ortiz-Acosta, Melyane (563)

Mechanical Solly, Michael (562)

Parts Support Fetter, Lula (560)

RIC Lead Wong, Mark (564)

Video Amp/RIC Lu, Daniel (555)

GSE Software Topper, Alyson (561)

CubeSat, Ground System, Op (WFF, GSFC)

Mission Sys Engr. Mast, William (WFF, 598)

Mgt. Support Johnson, Tom (WFF, 8000)

Power Systems Purdy, Christopher (WFF, 569)

Power Systems Corbin, Brian (WFF, 569)

Software/Avionics Daisey, Ted (WFF, 589)

Software/Avionics Lewis, Christopher (WFF, 569)

Mechanical/Thermal Hudeck, John (WFF, 548)

GN&C Heatwole, Scott (WFF, 598)

SIC Duran-Aviles, Carlos (GSFC, 564)

SIC Rush, Kurt (GSFC, 564)

Thermal Analysis Choi, Michael (GSFC, 545)

874 GHz Receiver (Virginia Diode, Inc)

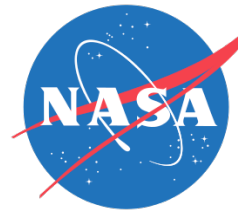
Tech POC Hesler, Jeff

LO Drive Module Design Bryerton, Eric

Integration and Testing Retzliff, Steven

CAD and Mechanical Neff, Chuck

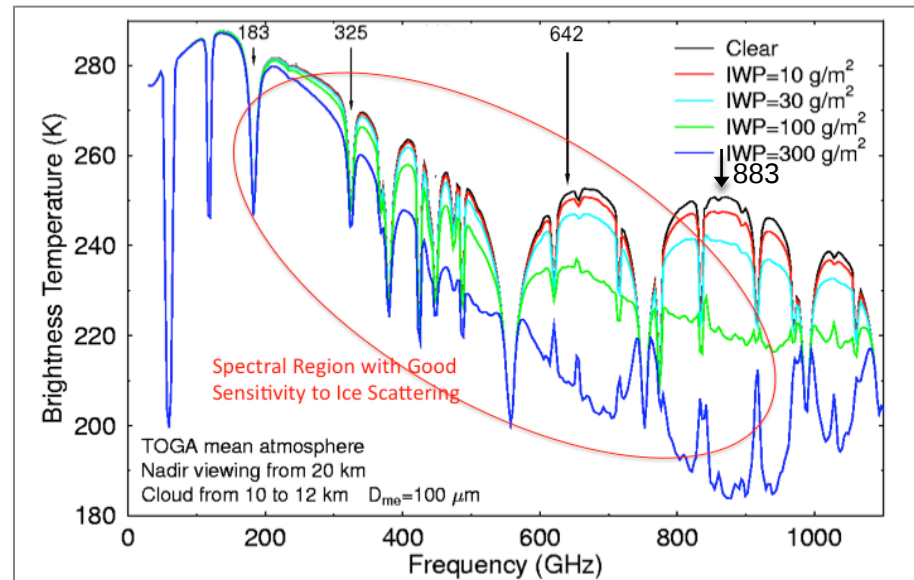
Back-Up



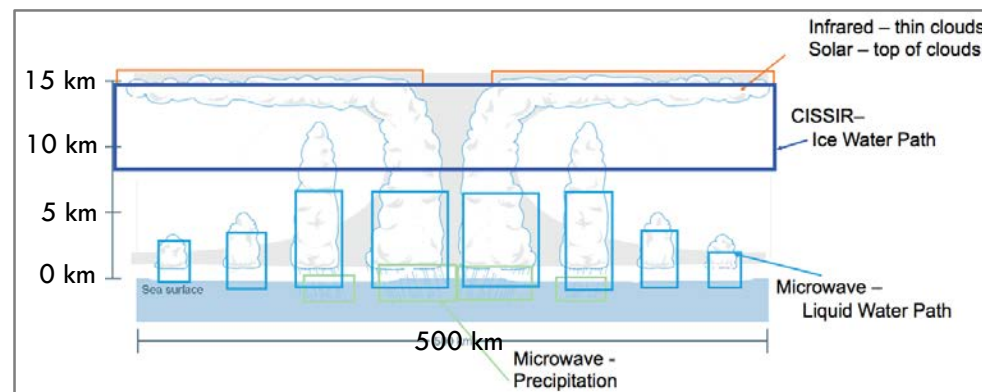
Motivation and Science Drive

17

- Cloud ice properties are fundamental controlling variables of radiative transfer and precipitation
- Large discrepancies in ice water path (IWP) exist in global circulation models
- Limited availability of data and poor assumptions about the cloud micro- and macro-physical properties of clouds are principle contributors to the discrepancy
- No ice cloud measurements currently exist for the intermediate altitudes
- mm- and submm-wave radiometry offers great potential to fill the measurement gap in the middle and upper troposphere



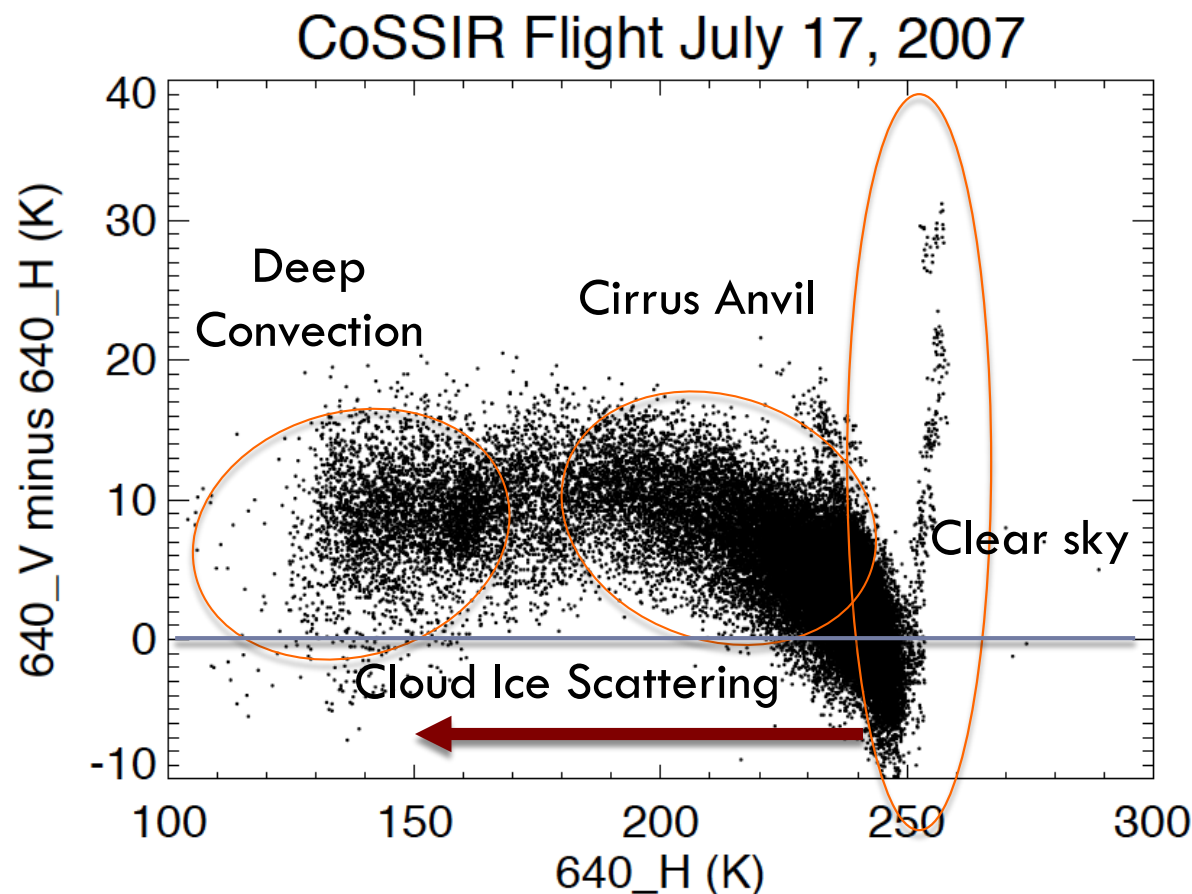
The spectral region with good sensitivity to ice cloud scattering (courtesy of Frank Evans).



Importance of polarization in cloud ice measurements

18

- Determining ice crystal orientation is important for accurate cloud ice retrieval.
- Depending on V or H to use, cloud ice scattering signals can differ by 20-50% for cirrus anvil.
- Global properties of Ice crystal orientation and their variations with cloud type remain unclear.





The diagram illustrates a Receiver system and its associated Switching Sequence.

Receiver Block Diagram:

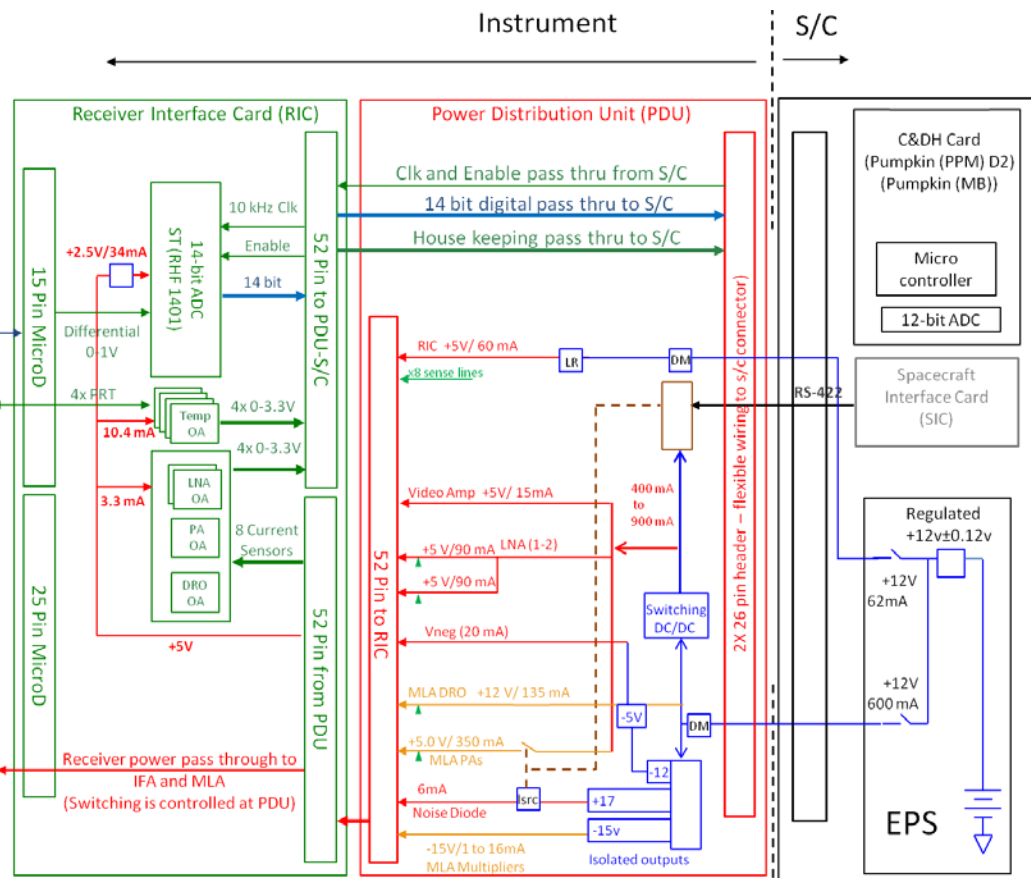
- The input signal enters through a circulator (T1) and is split into two paths.
- Upper Path (Main Signal Path):**
 - The signal passes through a 2nd Harmonic Mixer (T2) where it is mixed with a 437 GHz signal (3x).
 - The resulting signal (145.7 GHz, 2x) passes through a Coupler (T3) and a Noise Source (NS Ctrl).
 - It then enters LNA1 (G=25 dB) followed by Gain Equalizer 1.
 - The signal passes through BPF 1 (F=6-12 GHz) and LNA2 (G=25 dB).
 - It then passes through Gain Equalizer 2 and BPF 2 (F=6-12 GHz).
 - The signal is then detected by a Detector (T4) and amplified by a Video Amp.
- Lower Path (Reference Path):**
 - The signal from the 2nd Harmonic Mixer (T2) is also mixed with a 72.8 GHz signal (3x) to create a reference signal.
 - This signal passes through a PA (Power Amplifier) and a Ref Ctrl (Reference Control) block.
 - The reference signal is then processed by a 3x multiplier, an LPF (Low Pass Filter), a PA, and an HPF (High Pass Filter) to produce a 24.3 GHz DRO (Dielectric Resonator Oscillator) signal.

Switching Sequence:

The switching sequence is defined by a table with 4 rows and 4 columns. The columns are labeled 10, 10, 10, and 10 ms. The rows are labeled 40, 1 sec, and 1 ms. The sequence is as follows:

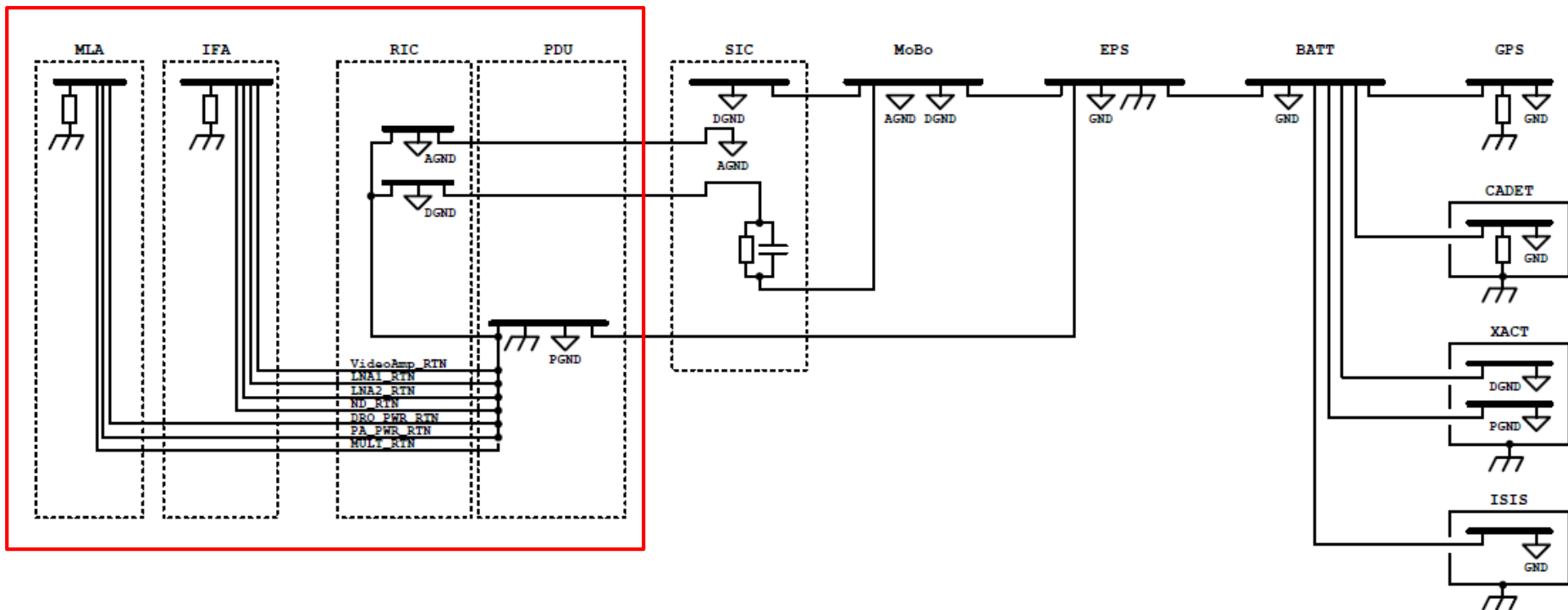
	10	10	10	10 ms
40	Ant	A+N	Ref	R+N
1 sec	Ant	A+N	Ref	R+N
1 ms	Ant	A+N	Ref	R+N
	Ant	A+N	Ref	R+N

The sequence is repeated for 40, 1 sec, and 1 ms durations.



Instrument Ground Diagram

20

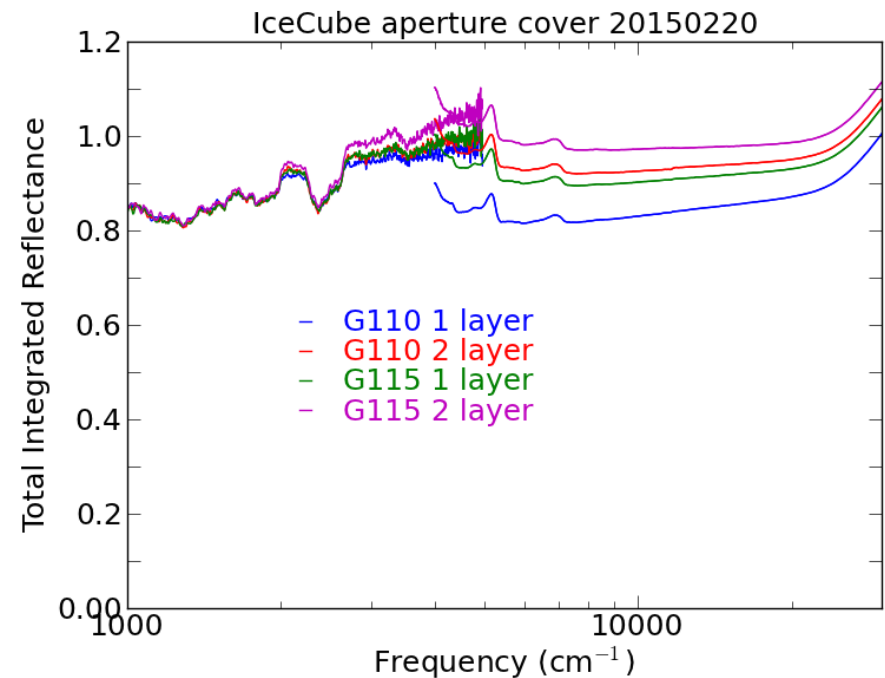
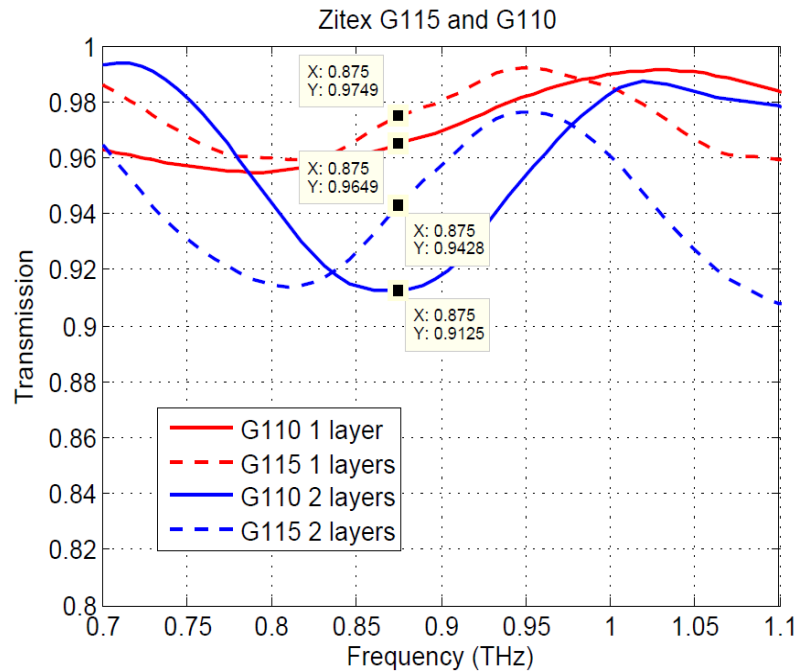


- MLA and IFA are isolated from chassis (there is a high resistive connection to chassis to prevent charge build up). The return path of the loads will be only through iPDU.
- RIC is grounded through iPDU to chassis.

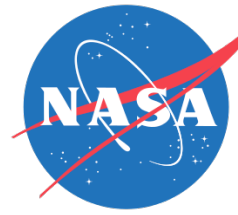
Antenna Aperture Window Cover

21

Two samples based on porous PTFE have been measured by Kevin Miller using FTS: Zitex G110 and Zitex G115 (recommended by Ed Wollack).

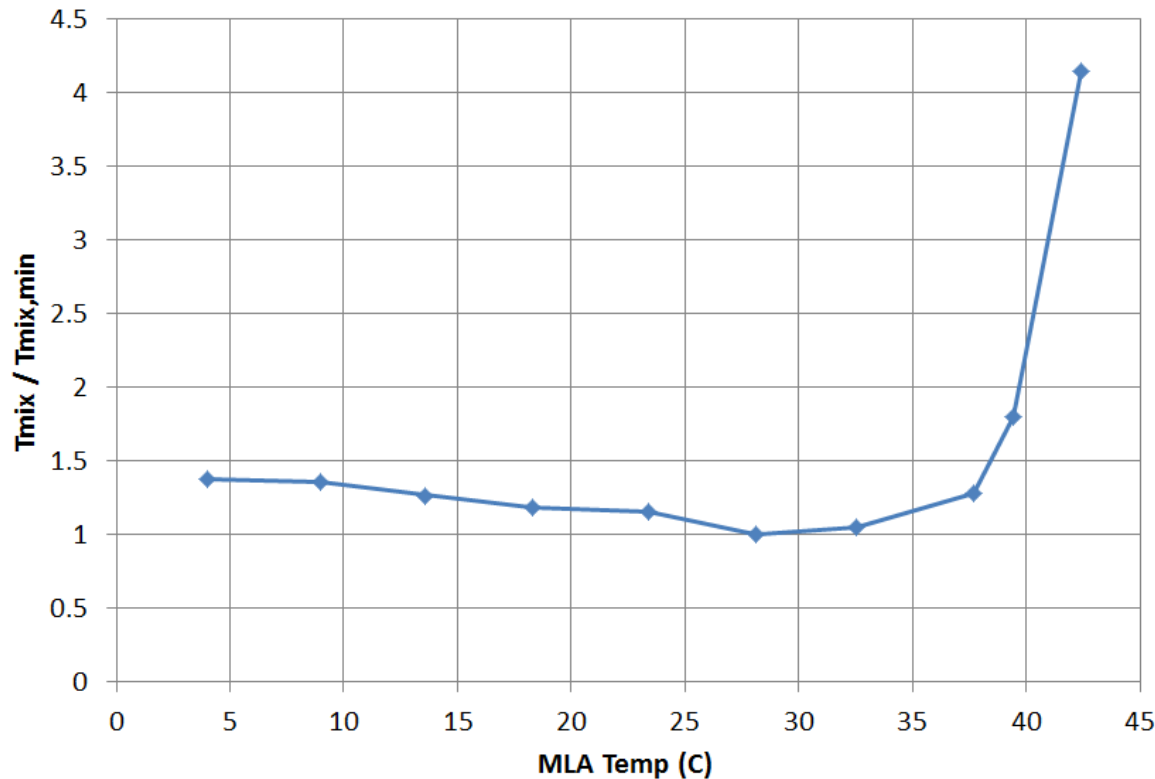


- Fitted material constants $\epsilon_r = 1.4 + i0.0001$ (Courtesy of Ed Wollack)
- Both G110 and G115 would perform optimally if the thickness could be increased by 1.4mils.
- G115 was selected based on its superior mechanical strength.

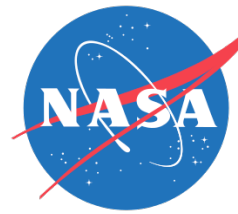


Back-UP: Mixer Noise vs Plate Temperature

22



- LO=883 GHz, 8-11 GHz IF
- Relative measurement, T_{min} higher due to loss of taper and WR-10 waveguide
- Optimized for 28 ± 10 C
- LO power inversely proportional to temperature, so above ~ 40 C, mixer underpumped
- Better to be too cold than too hot!
- This curve can be shifted to right or left with change of resistor in 73AMC bias circuit



Mixer Loss vs Plate Temperature

23

