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


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)

<table>
<thead>
<tr>
<th>Chn #</th>
<th>Freq. (GHz)</th>
<th>Offset (GHz)</th>
<th>BW(GHz)</th>
<th>Tsys (K)</th>
<th>NEDT (K)</th>
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<td>3.0</td>
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<td>1.33</td>
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</table>

- 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-induced 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:

- $\text{O}_2$
- $\text{H}_2\text{O}$
- $\text{O}_3$
- $\text{NHO}_3$
- $\text{O}^{18}\text{O}$

Local Oscillator (LO) Frequency

Intermediate Frequency (IF) Bandwidth (BW)

Clear Sky

Cloudy Sky
Molecules included in calculations

- $\text{O}_2$
- $\text{H}_2\text{O}$
- $\text{O}_3$
- $\text{NHO}_3$
- $\text{O}^{18}\text{O}$
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
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

883 GHz Receiver Beam
# Instrument Specification Summary

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

- **Antenna**
- **Thermal Paraffin Packs**
  - (3 PL)
- **Top Plate**
- **RF (MLA) Section**
- **RIC Bd**
- **iPDU Bd**
- **Standoffs**
- **Interface - Cross Plate**
- **138.8 mm**
  - (5.46”)
- **Spacecraft Interface Connector**
  - (mates to SIC Board)
- **ULTEM Spacers (12)**
  - to thermally isolate Instrument from bus

*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


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

- Paraffin Packs x4
- PDU-SIC Interface Connector
- Instrument RF
- Instrument IF
- Instrument RIC
- Instrument PDU
- Spacecraft Interface Card (SIC)
- Pumpkin Motherboard
- Pumpkin Processor
- Clyde Space EPS
- Clyde Space Battery Pack (40whr)
- Novatel GPS Receiver
- L3 Cadet Radio
- BCT XACT
- ISIS UHF Antenna
External Layout (1/2)

- Paraffin Packs x2
- Instrument View Port
- GPS Antenna
- RBF Pin
- EGSE Port
- BCT XACT
- Star Tracker
- Double Deploy 3U
- Solar Panel x2
- Deployable UHF Antenna
External Layout (2/2)

- Coarse Sun Sensor Pyramid
- (5) Cell 2U Solar Panel
- (2) Cell Solar Panel
- Spring Plunger x2
- Deployment Switch x2
Concept of Operations

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

Operations

- Sunrise t=0. Spacecraft attitude/roll rate remains controlled.
- Instrument powers on Observations Start.
- Terminator t=4min
- FOV Past Limb near equator crossing
- FOV Past Limb Instrument turns off
- ACS Remains on t=31min
- Continuous Observations spacecraft revolving about sun vector

Science only in Sun  Limit  
20% DOD

<table>
<thead>
<tr>
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<th>Sun W</th>
<th>Eclipse W</th>
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<tbody>
<tr>
<td>Instrument</td>
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<tr>
<td>GN&amp;C/C&amp;DH</td>
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<tr>
<td>Com</td>
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<td>0.32</td>
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<tr>
<td>Power</td>
<td>0.31</td>
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<td>EPS Losses 16%</td>
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<td>Total out</td>
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<td>5.713</td>
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<td>Arrays</td>
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<td>PDU losses 20%</td>
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<tr>
<td>Total in</td>
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<tr>
<td>Cell Temp Loss 20%</td>
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<tr>
<td>Total in</td>
<td>16</td>
<td>0</td>
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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, H2O)

- Tropical measurements: well-defined atmospheric thermal structures

- Slant-to-nadir conversion using

\[ T_b = T_{b0} + a \ln[\cos \theta] \]
<table>
<thead>
<tr>
<th>Event</th>
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<tbody>
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<td>Project start</td>
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<tr>
<td>System Requirements Review (SRR)</td>
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<tr>
<td>Table Top Design Review</td>
<td>10/23/14</td>
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<tr>
<td>Critical Design Review (CDR)</td>
<td>4/28/15</td>
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<tr>
<td>Instr. Integration &amp; Test begins</td>
<td>9/16/15</td>
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<tr>
<td>Pre-Environmental test Review (PER)</td>
<td>10/16/15</td>
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<tr>
<td>Pre-Ship Review (PSR)</td>
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<td>Flight Readiness Review (FRR)</td>
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<td>Launch</td>
<td>4/14/16</td>
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<tr>
<td>Flight Operation ends</td>
<td>5/25/16</td>
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<tr>
<td>Data Analysis ends</td>
<td>8/19/16</td>
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<td>TRL(in) = 5; TRL(out) = 7</td>
<td>9/1/16</td>
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