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


NASA Goddard Space Flight Center, Greenbelt, MD

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Pasadena, CA
June 25, 2015
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>
<td>16000</td>
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- 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)
LO Frequency Change: 874 -> 883 GHz

Molecules included in calculations

- $O_2$
- $H_2O$
- $O_3$
- $NHO_3$
- $O^{18}O$
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
# 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>≤1.3 kg including 30 % contingency</td>
</tr>
<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
Instrument Mechanical Structure

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

138.8 mm (5.46”)

Courtesy of Mike Solly Code 562
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.
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.
# Spacecraft Subsystems

<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)</td>
<td>C. Duran-Aviles</td>
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<tr>
<td></td>
<td>PDU-SIC interface</td>
<td></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</td>
<td>C. Purdy</td>
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<tr>
<td></td>
<td>EPS, Solar panels, Battery 40Whr</td>
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<td>Thermal control</td>
<td>Passive paraffin packs</td>
<td>M. Choi</td>
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<td></td>
<td>Radiating surfaces</td>
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<tr>
<td>Communication</td>
<td>L2 Cadet radio</td>
<td>B. Corbin</td>
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<tr>
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<td>ISIS UHF Antenna</td>
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<tr>
<td>Flight software</td>
<td>Pumpkin Motherboard, CPU</td>
<td>T. Daisey</td>
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<tr>
<td></td>
<td>Modified DICE flight software</td>
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<tr>
<td></td>
<td>Beacon telemetry</td>
<td></td>
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<tr>
<td>Ground system</td>
<td>WFF 18m, GMSEC/DICE design</td>
<td>R. Stancil</td>
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</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

9/4/2015
External Layout (2/2)

- Coarse Sun Sensor Pyramid
- Spring Plunger x2
- Deployment Switch x2
- (5) Cell 2U Solar Panel
- (2) Cell Solar Panel
**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 during eclipse.
  - Instrument is OFF,
  - Instrument heater is off
- Terminator t=4min
- Continuous Observations spacecraft revolving about sun vector
- FOV Past Limb near equator crossing
- FOV Past Limb Instrument turns off
- ACS Remains on t=31min

**Science only in Sun Limit**
- 20% DOD

**Graph**

**Table**

<table>
<thead>
<tr>
<th></th>
<th>Sun</th>
<th>Eclipse</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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<td>4.145</td>
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<td>Com</td>
<td>0.32</td>
<td>0.32</td>
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<td>Power</td>
<td>0.31</td>
<td>0.46</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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<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
  \[ T_b = T_{b0} + a \ln[\cos \theta] \]
IceCube Project Schedule

- Project start: 4/14/14
- System Requirements Review (SRR): 7/29/14
- Table Top Design Review: 10/23/14
- 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