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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</table>

- CRYSyAL-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, Tcir, proportional to cloud ice water path (CIWP)
- Cloud microphysical properties (i.e., particle size) from different frequencies
- Simultaneous retrievals with T, H$_2$O
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
- \(\text{O}_2\)
- \(\text{H}_2\text{O}\)
- \(\text{O}_3\)
- \(\text{NHO}_3\)
- \(\text{O}^{18}\text{O}\)
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
**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

<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>
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<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>
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<tr>
<td>A/D sampling</td>
<td>10 kHz</td>
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<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>
</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**
- **ULTEM Spacers (12) to thermally isolate Instrument from bus**
- **Spacecraft Interface Connector (mates to SIC Board)**
- **138.8 mm (5.46”)**
- **Interface -Cross Plate**
- **Instrument Radiator**
- **Standoffs**
- **iPDU Bd**
- **RIC Bd**

*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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<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 EPS, Solar panels, Battery 40Whr</td>
<td>C. Purdy</td>
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<tr>
<td>Thermal control</td>
<td>Passive paraffin packs, Radiating surfaces</td>
<td>M. Choi</td>
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<tr>
<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>
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</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
- (5) Cell 2U Solar Panel
- Spring Plunger x2
- (2) Cell Solar Panel
- Deployment Switch x2
Concept of Operations

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

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

**Science only in Sun Limit**

<table>
<thead>
<tr>
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<th>Sun</th>
<th>Eclipse</th>
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<tbody>
<tr>
<td>Instrument</td>
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<td>GN&amp;C/C&amp;DH</td>
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<td>4.145</td>
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<tr>
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<td>Power</td>
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<td>EPS Losses 16%</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>
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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
  \[ T_b = T_{b0} + a \ln[\cos \theta] \]

![Graphs showing radiances vs. scan angle from nadir](image)
IceCube Project Schedule

Project start 4/14/14
System Requirements Review (SRR) 7/29/14
Table Top Design Review 10/23/14
Critical Design Review (CDR) 4/28/15
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