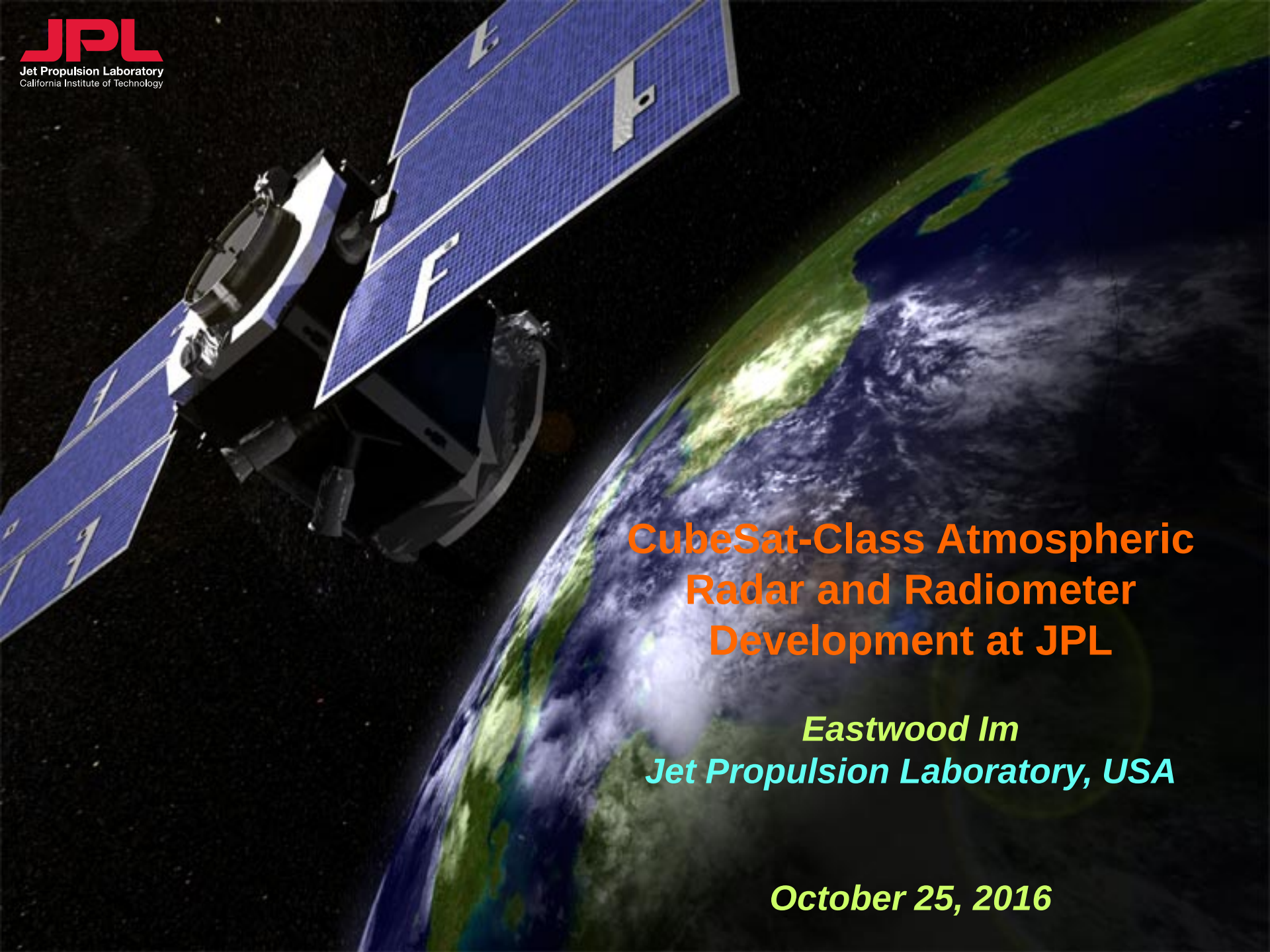


Jet Propulsion Laboratory
California Institute of Technology

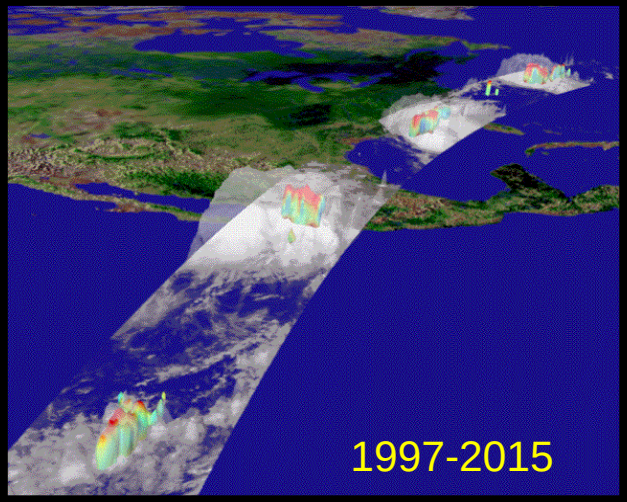
# CubeSat-Class Atmospheric Radar and Radiometer Development at JPL


*Eastwood Im*
*Jet Propulsion Laboratory, USA*

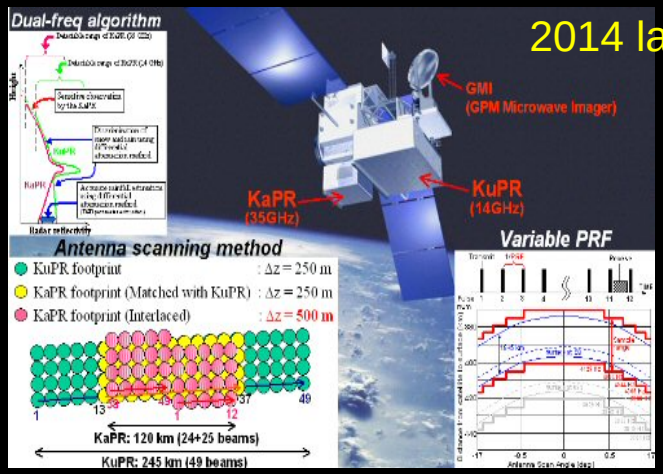

*October 25, 2016*

# First Two Generations of Spaceborne Weather Radars

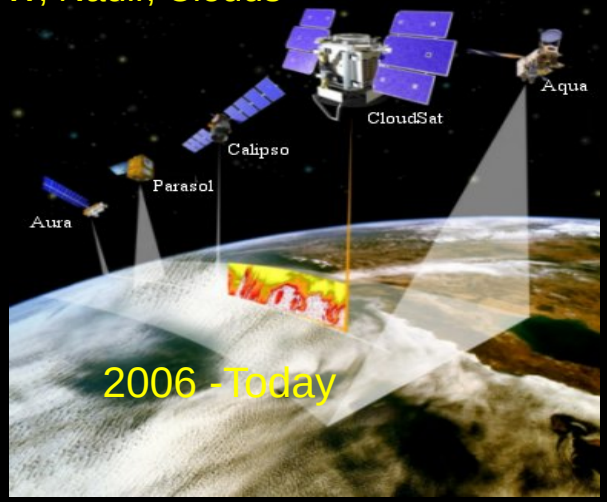
TRMM/PR – NICT/JAXA
Ku, Scanning, Tropical Rain

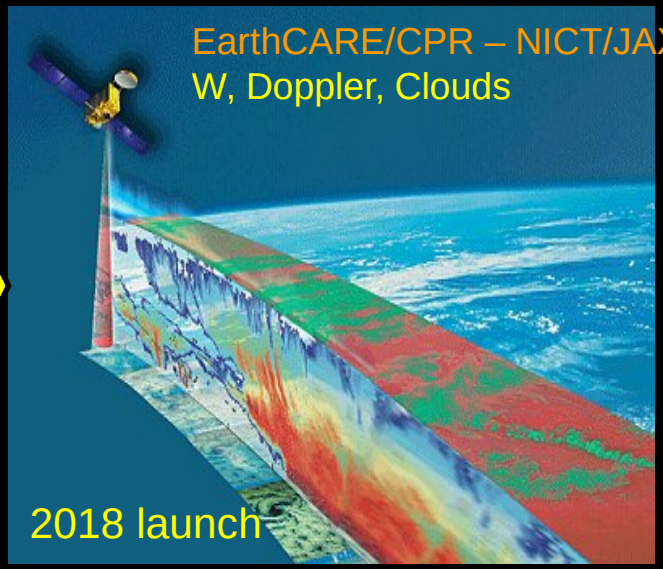



GPM/DPR – NICT/JAXA
Ku/Ka, Scanning, Precipitation




CloudSat/CPR – JPL/NASA/CSA
W, Nadir, Clouds

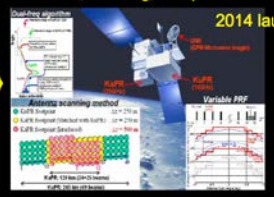


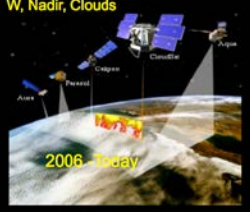
# Visions Beyond GPM & EarthCARE Radars

TRMM/PR – NICT/JAXA
Ku, Scanning, Tropical Rain

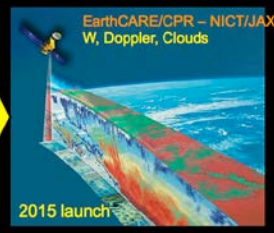
GPM/DPR – NICT/JAXA
Ku/Ka, Scanning, Precipitation




CloudSat/CPR – JPL/NASA/CSA
W, Nadir, Clouds



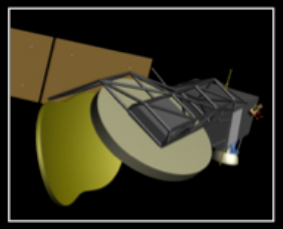

EarthCARE/CPR – NICT/JAXA
W, Doppler, Clouds




## Examples of radar concepts under study by the international community

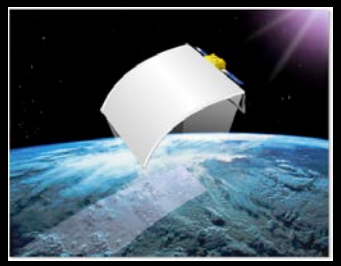
For US Decadal ACE meas. concept

**ACERAD**
W/Ka, Scanning Ka, Doppler

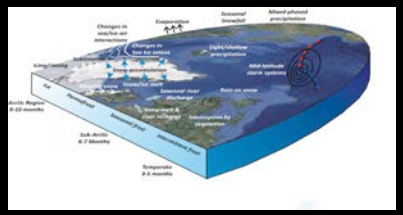


**Reflectarray Radar**
W/Ka, Scanning Ka, Doppler

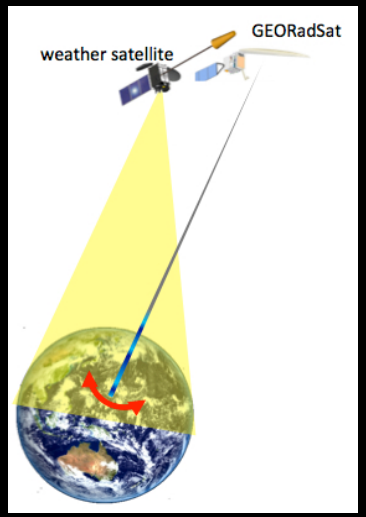
GPCM Radar Ku/Ka/W, Doppler, Scanning



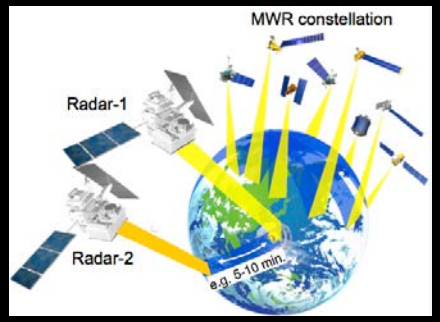
SnowSat / PPM
W/Ka, Doppler



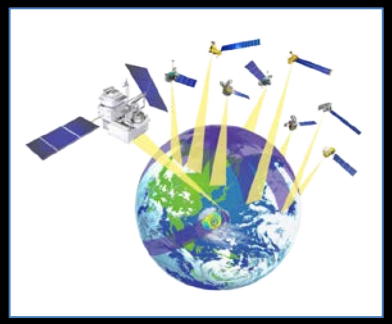
GEORadSat
W, Scanning, Doppler, GEO

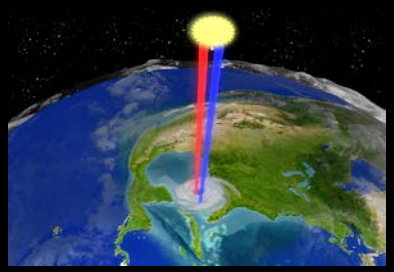



GPM w/ Radar in Train Formation
Radar 1 & 2: Ku/Ka/W, Scanning




RadarGPM Constellation
Core S/C: Ku/Ka/W, Scanning
SmallSat: One freq radar





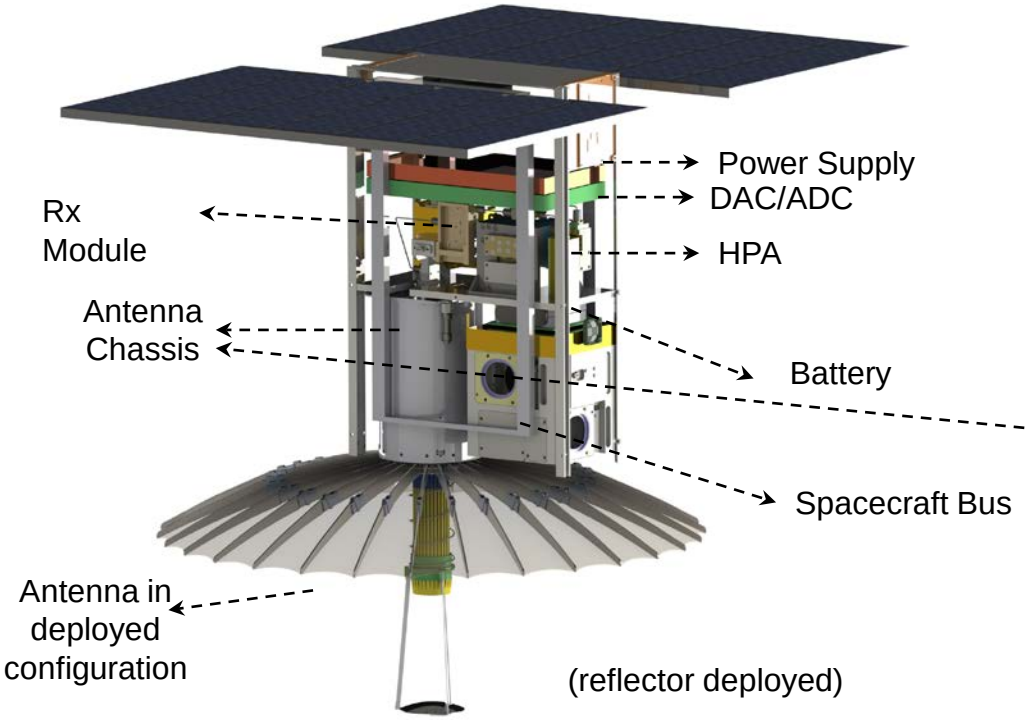
NEXRAD-In-Space
W/Ka, Scanning, Doppler, GEO

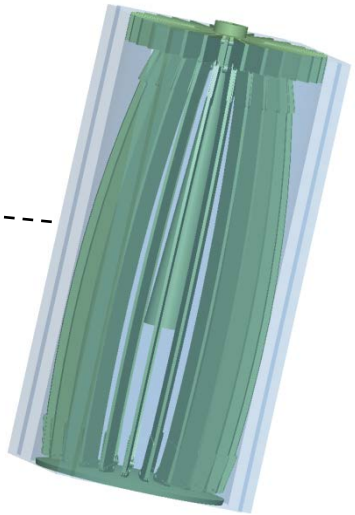
# Objective of Today's Presentation

- Focuses on JPL's new and emerging instrument capabilities in studying weather and atmospheric processes that are compact and low cost
  - RainCube
  - TEMPEST-D
  - MASC

# RainCube: Key to miniaturization and cost reduction

- JPL has developed a novel radar architecture for a Ka band (35.75 GHz) precipitation profiling radar for operation in a 6-U CubeSat platform
  - Digital electronics 0.5U
  - RF electronics 0.5U
  - SSPA 1U
  - Deployable antenna 1.5U



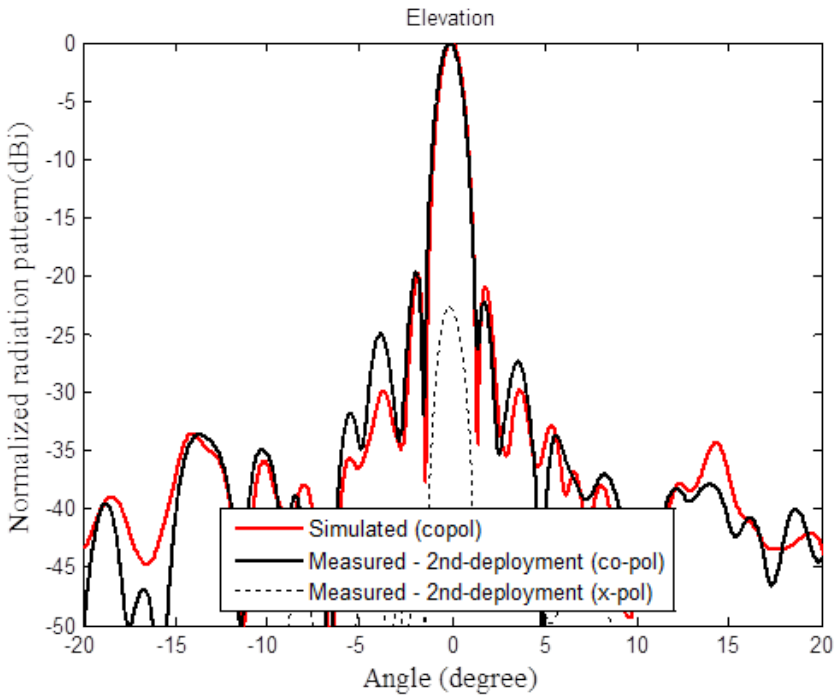
# RainCube Antenna Capability Demonstrated

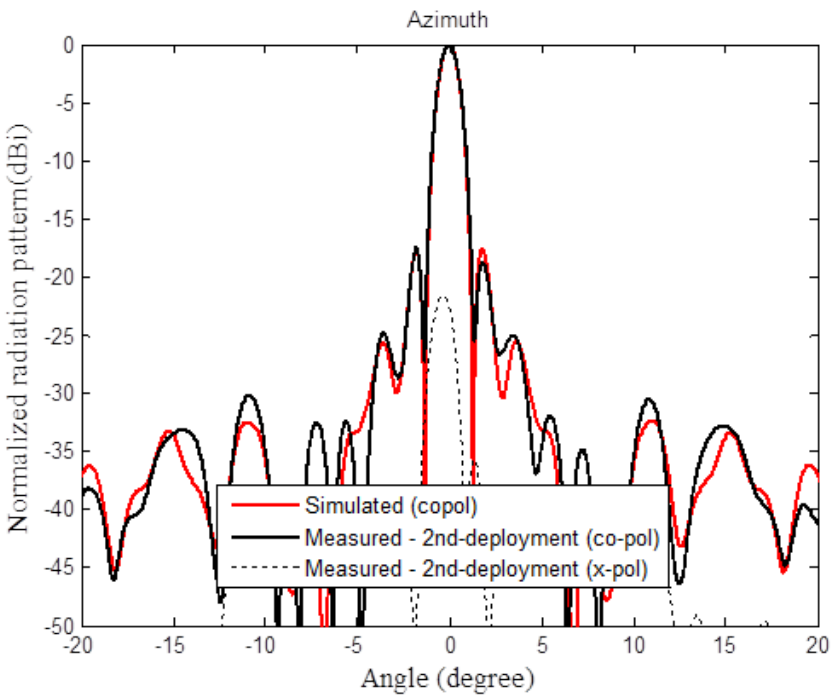
- Deployable antenna
  - 0.5m class antenna has been built, and RF performance demonstrated

  - 1m class antenna under development
    - 6U deployable antenna demo: summer 2016
    - 6U deployable antenna qualification: winter 2016/2017
    - Next-generation antenna design completion (scanning): 2017

# RainCube Antenna Capability Demonstrated

- Antenna radiation pattern



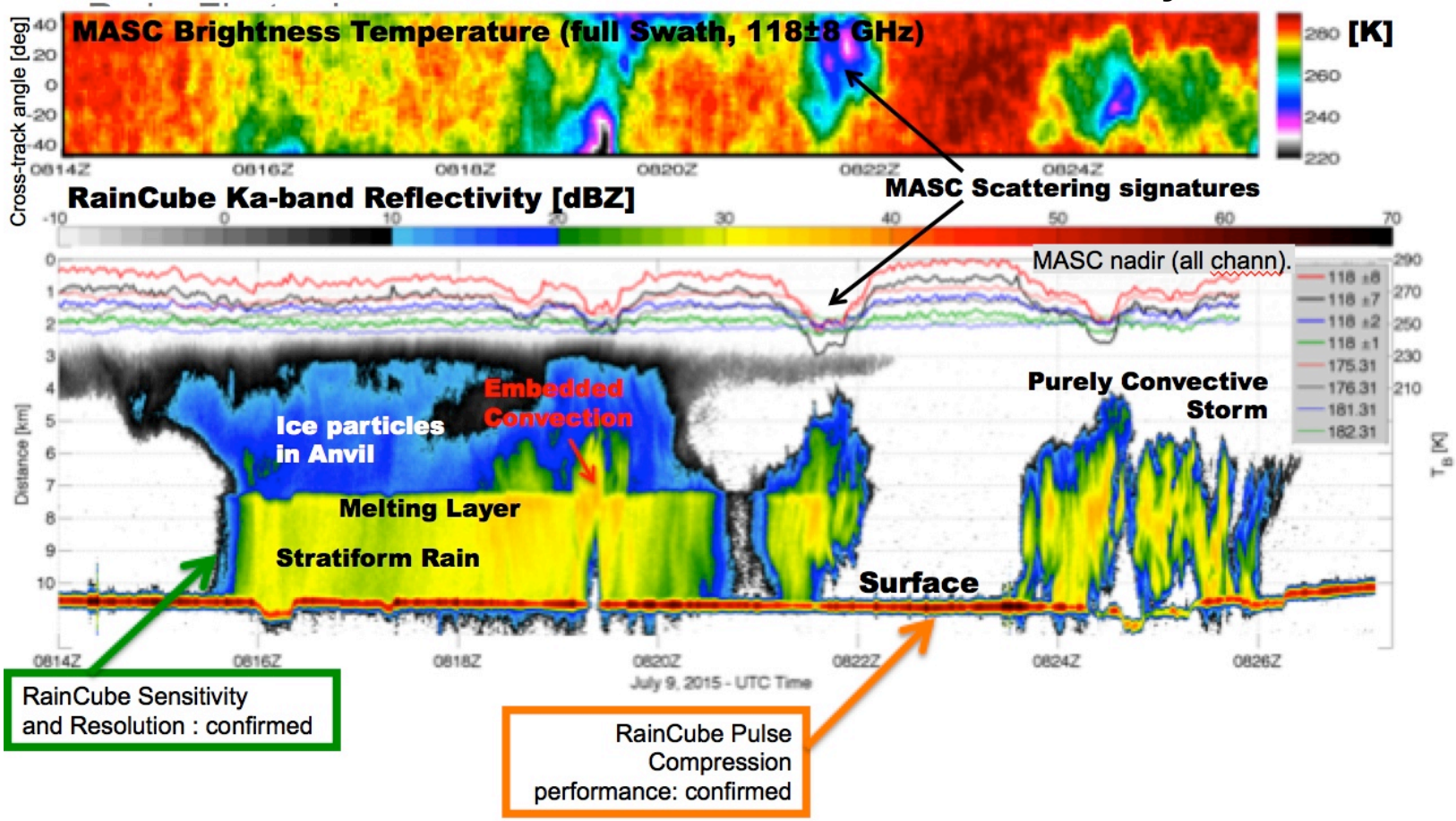




- Gain: 42.7 dBi
- Stowed size: 1.6 U
- Mass: 1.4 kg

# RainCube Radar Electronics Capability Demonstrated

- Radar Electronics
  - Breadboard developed, tested and performance characterized.
  - Airborne flights have demonstrated performance
  - Hardware T/VAC & Vibe Qualifications done

**Radar-Sounder observations of PECAN storms in July 2015**



# RainCube Status

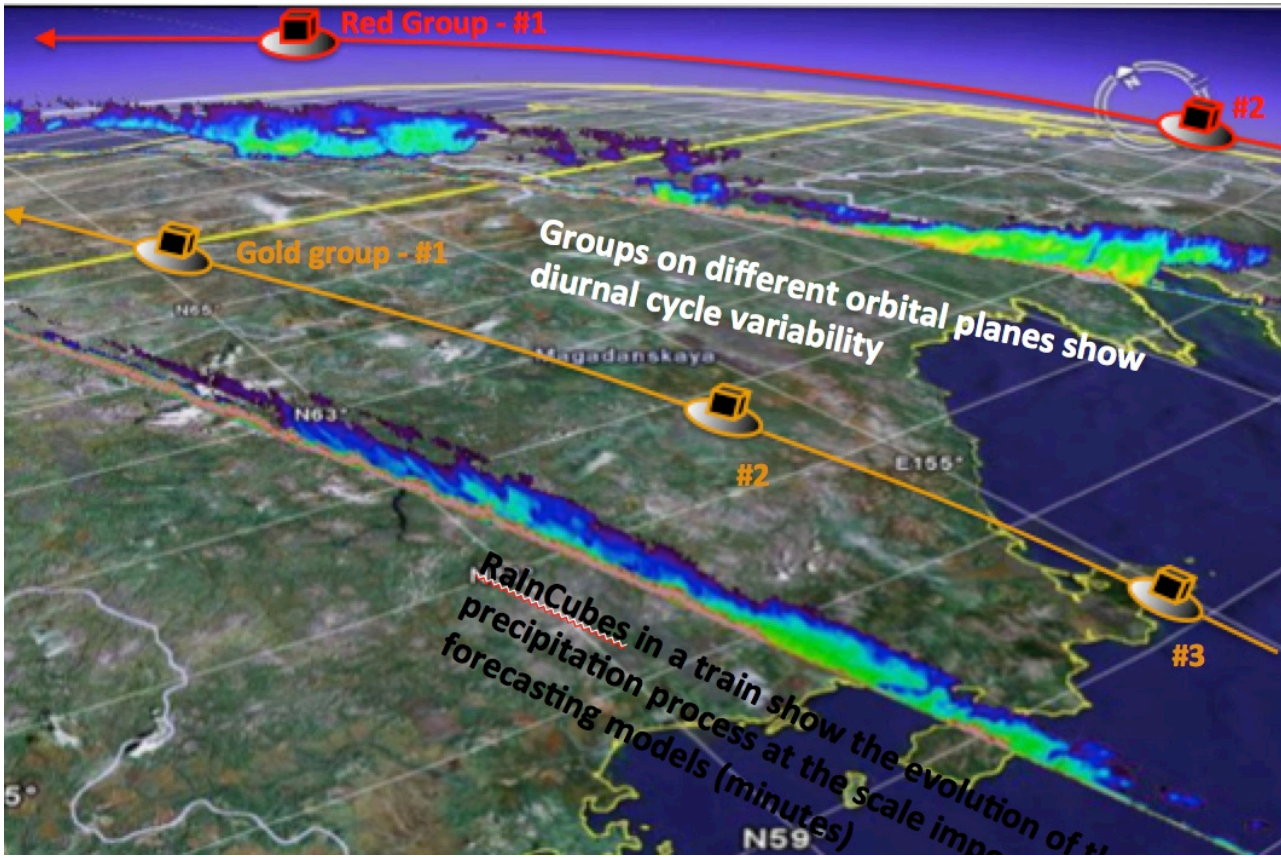
- The 1st-generation RainCube tech demo unit is being developed, and will be ready for launch in early 2018
  - Plan for space operation for at least 6 months

- JPL is also developing technologies for the 2nd- and 3rd-generation RainCube concepts
  - 1-m or larger deployable
  - W-band
  - Cross-track scanning
  - Doppler
  - Adaptation to 6-12U cubsats, and smallsats.

# RainCube Constellation Concepts

**Science Goal: to profile precipitation down to near-surface, at all latitudes and at various sub-daily scales.**

- Nadir pointing profiling radar at **Ka band**
- Horizontal resolution: **5 km**
- Range resolution: **250 m**
- Sensitivity: **5 dBZ** (0 dBZ goal)
- Range sidelobe suppression **better than 70 dB @ 500 m altitude** for ground clutter contamination control.
- **4-6 CubeSats on 2-6 orbital planes in LEO**
  - Observe the same cloud at very short intervals (e.g., 30-240 seconds)
  - Observe the same region at different times of the day during the same month



# TEMPEST-D: TEMPoral Experiment for Storms and Tropical systems - Demonstration

Jet Propulsion Laboratory
California Institute of Technology

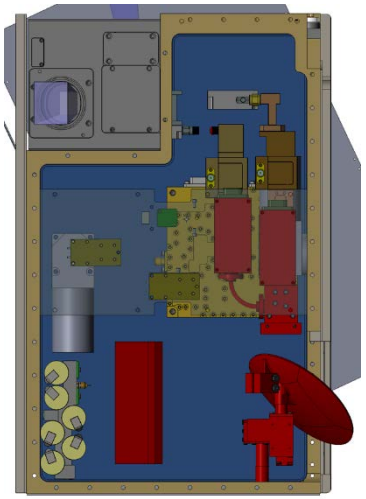
## Objectives

- Reduce the risk, cost, and development time for a future TEMPEST mission to provide the first temporal observations of cloud and precipitation processes on a global scale to improve understanding of cloud processes vital to climate change prediction.
- Demonstrate a 6U spacecraft with a millimeter-wave radiometer measuring five frequencies from 89 to 182 GHz, all calibrated with a radiometric precision of 2 Kelvin or better.
- Demonstrate cross-calibration with at least one other orbiting radiometer to 2 Kelvin inter-satellite precision.
- Demonstrate feasibility of orbital drag maneuvers to control 6U spacecraft altitude to 100 m or better.

## Instrument Highlights:

- Cross-track scanning
- Five channels at 89, 165, 176, 180 and 182 GHz
- Spatial resolution of 13 km (182 GHz) to 25 km (89 GHz)

| | Instrument w/ contingency | Spacecraft |
|---|---|---|
| Mass | 2 kg | 4.8 kg |
| Power | 6.5 W | 5 W |
| Volume | 3 U | |
| Precision | 0.5 K (CBE) | |
| Accuracy | 1.0 K (CBE) | |



## Approach

- JPL will provide the five-channel millimeter-wave radiometer instrument from 89 to 182 GHz
- Spacecraft vendor will:
  - provide spacecraft bus with all subsystems
  - integrate and test instrument with the bus
  - deliver spacecraft to launch provider (desired orbit is from 350-450 km altitude and inclination of 30-91°)
  - provide for spacecraft operations

## Development Team

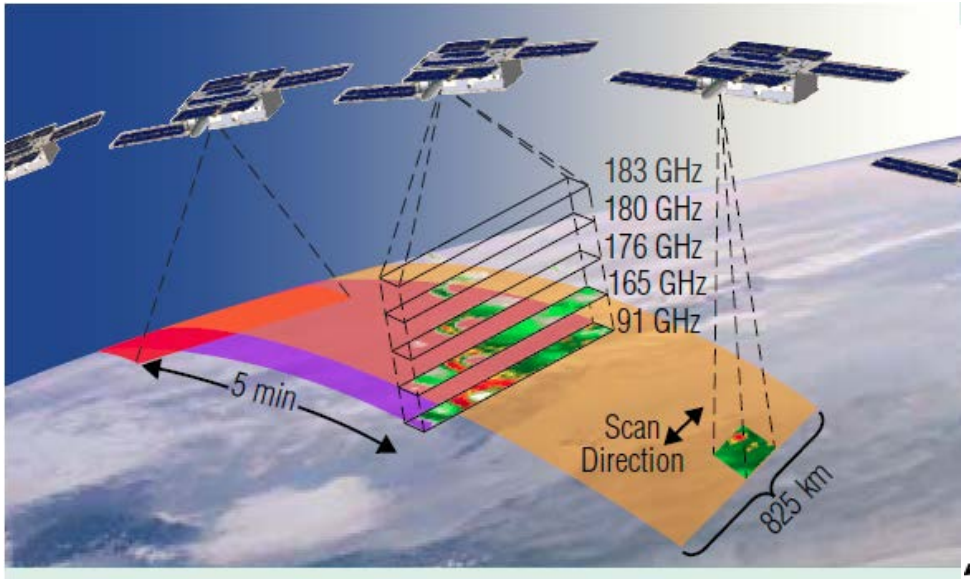
- PI: Steve Resing (CSU)
- Project Manager: Todd Gaier (JPL)
- CSU Key Team Members:
  - V. Chandrasekar, C. Kummerow
- JPL Key Team Members:
  - S.T. Brown, B. Lim, S. Padmanabhan, C. Heneghan

## Key Milestones

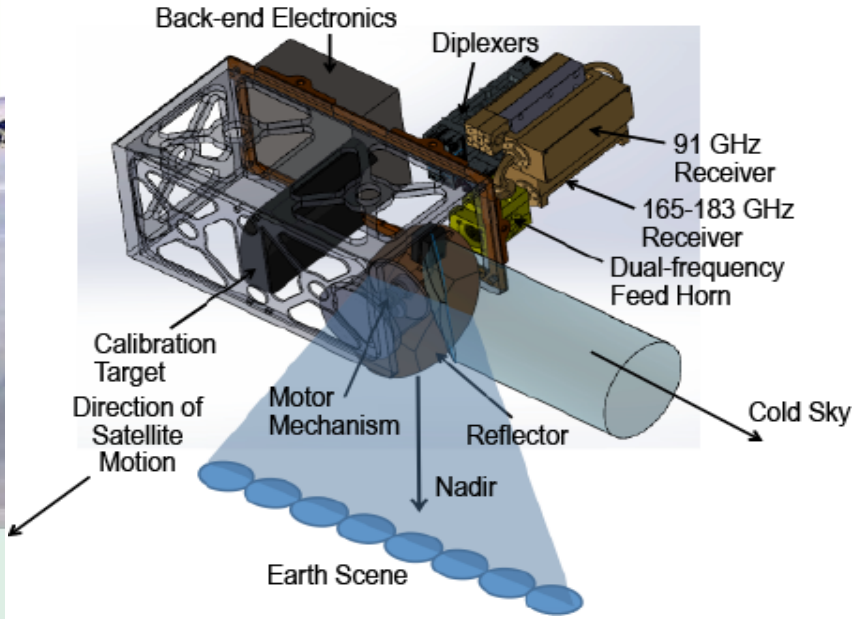
| | |
|---|---|
| System Requirements Review (SRR) | 11/15 |
| CubeSat provider under contract with CSU | 02/16 |
| Preliminary Design Review (PDR) | 02/16 |
| Critical Design Review (CDR) | 07/16 |
| Ground-Support Equipment completed | 09/16 |
| Instrument delivered to BCT | 04/17 |
| Pre-Ship Review (PSR) | 07/17 |
| Complete CubeSat delivered to launch provider | 08/17 |
| Launch Readiness Date (under Venture Class Launch Service) | 03/18 |
| On-orbit operations complete | L + 3 mos. |
| Data analysis and validation summary complete | L + 5 mos. |

*Pre-Decisional Information -- For Planning and Discussion Purposes Only.*

# TEMPEST – The constellation mission concept



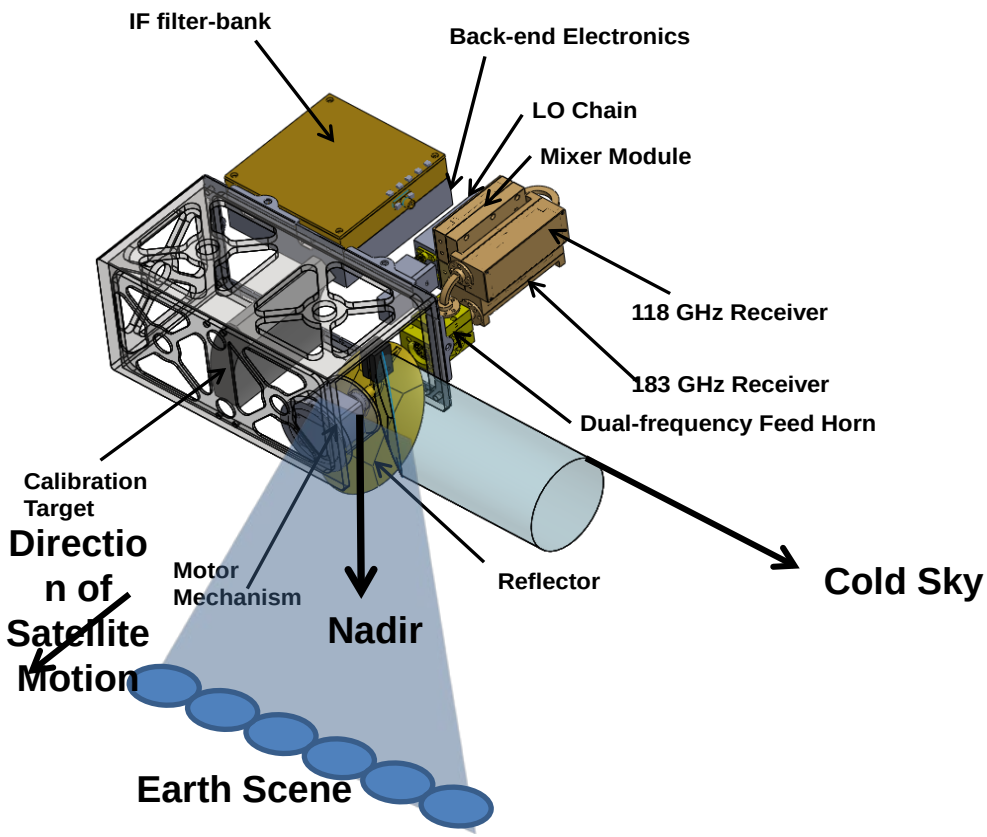

*5 identical 6U CubeSats, each with an identical 5-channel radiometer, flying 5 minutes apart*




- **Spatial Resolution: 13 km (183 GHz) – 25 km (89 GHz)**
- **Swath Incidence Angle Range: ±45°**
  **Spectral Resolution: 5 Channels from 89-183 GHz**
- **Size, Weight and Power: 6U, <7 kg, <14 W, 10 kbps**

# Microwave Atmospheric Sounder on CubeSat (MASC) Prototype

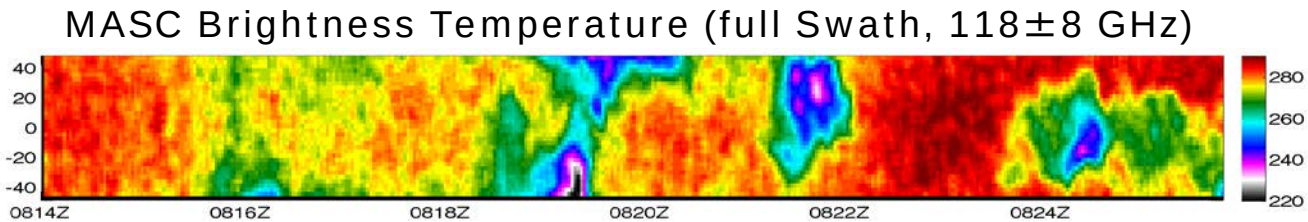
- JPL is developing a 6-U MASC prototype to demonstrate the technology readiness for a constellation of low-cost, miniature, self-calibrating microwave radiometers to provide near-continuous global microwave sounding of temperature and humidity
  - MASC instrument heritage is being used for TEMPEST-D development.

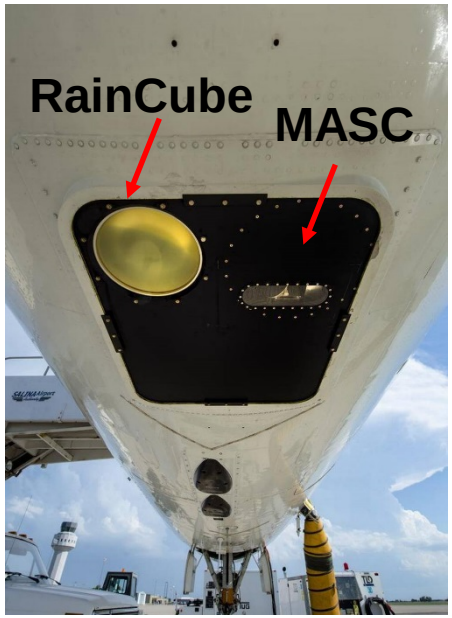


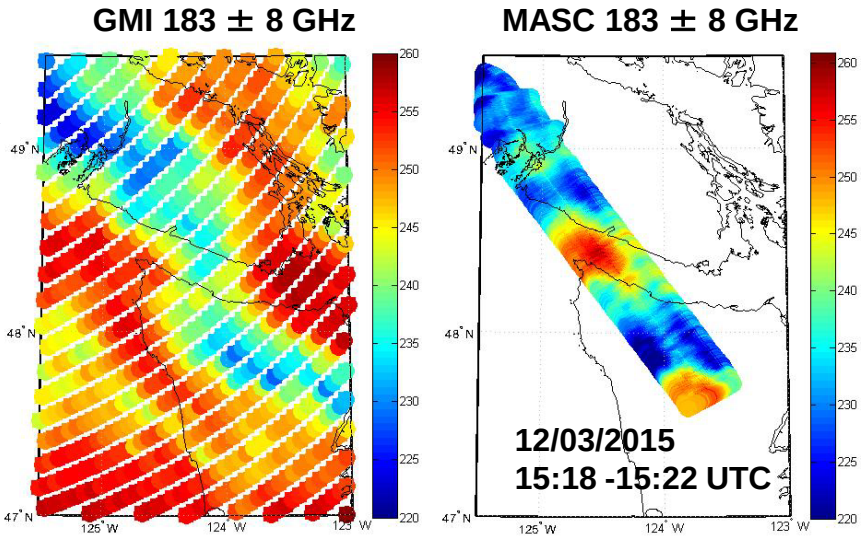

| | 118 GHz | 183 GHz |
|---|---|---|
| System noise temperature | < 900 K | < 700 K |
| Minimum # of channels | 4 | 4 |
| Minimum spectral resolution | 350 MHz | 350 MHz |
| IF Channels | ±1, ±2, ±7 and ±8 GHz | ±1, ±2, ±7 and ±8 GHz |
| Minimum Spatial resolution | 24 km at nadir (orbit:400 km) | 13 km at nadir (orbit:400 km) |
| Minimum Beam efficiency | >90% | >90% |
| Mass | <5 kg | |
| Power | 6.5 W CBE | |
| Volume | 3U | |
| Data Rate | 10 kbps | |

# (MASC) Airborne Demonstration

- MASC completed its maiden airborne flight in July 2015.
  - Packaged in a 6U, integrated in the NASA DC-8 and flew (together with RainCube) in PECAN experiment (Plains Elevated Convection At Night).
  - MASC performance validated.




- MASC was deployed on the NASA DC-8 from Nov 10 to Dec 22, 2015 for OLYMPEX The Olympic Mountains Experiment (OLYMPEX)
  - Ground validation of GPM's radiometer (a.k.a. GMI) measurements