Jet Propulsion Laboratory
California Institute of Technology

6U Instruments for Weather

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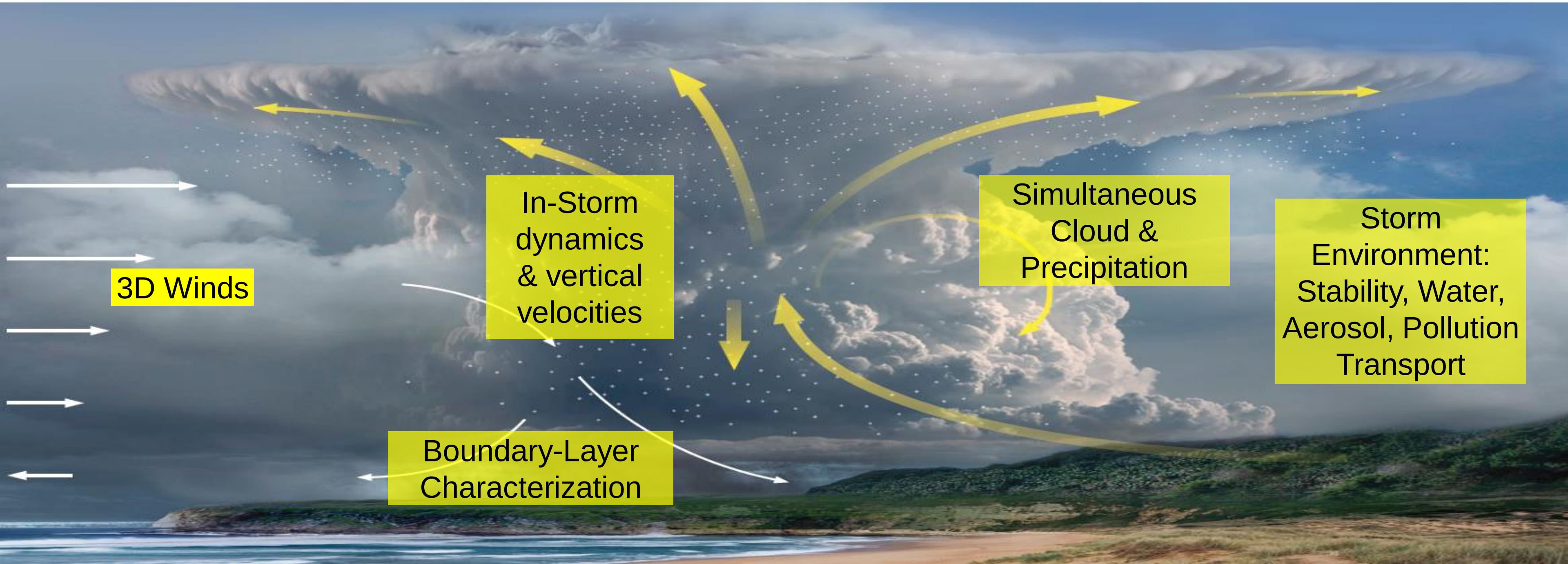
Complexity of Understanding Weather Science – Need for multiple measurements

- Constellations or GEO to monitor **storm evolution**
- Higher spatial resolutions to capture **mesoscale structure**
- Capture **microphysical processes** key to precipitation growth
- Advancing technology to characterize the atmospheric **boundary-layer**
- Improved atmospheric profiling to characterize the **storm environment**
- Characterizing storm dynamics and extremes with **Doppler radar**
- **Miniaturization** of sensors for **cubesats**, constellations and lower costs

>=3 missions in order to provide all measurements



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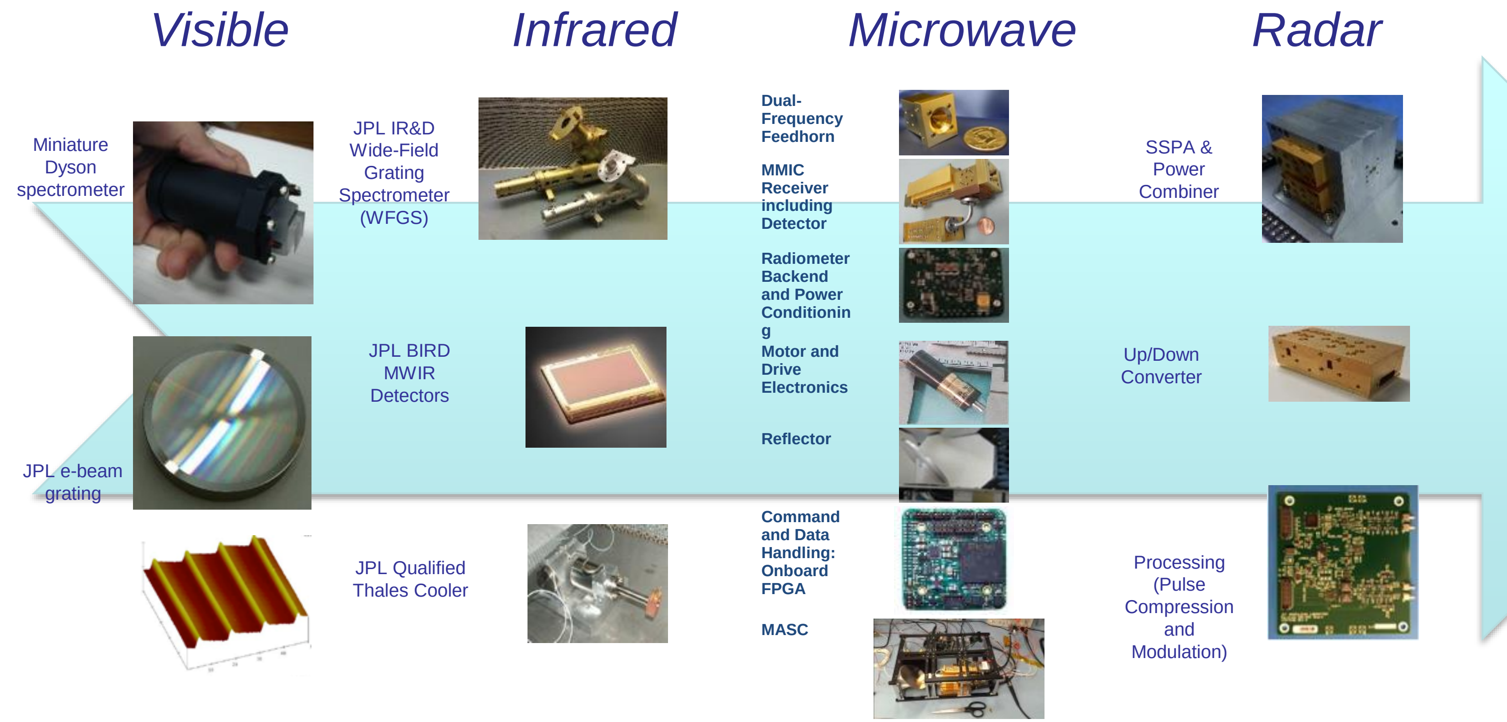
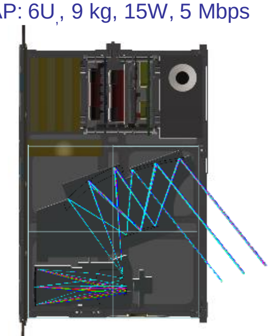
JPL's Miniaturized Weather Instruments

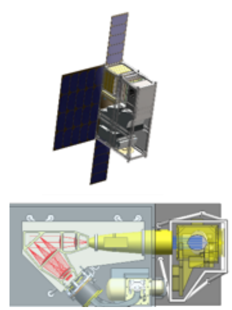


MicroGRACE Gravity Measurement
Spatial: submm accuracy
SWAP: 6U, 20 kg, 30 W, <1 Mbps

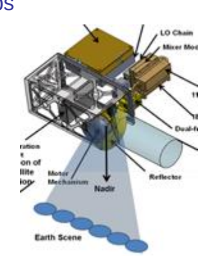
Snow and Water Imaging Spectrometer
Spatial: ±5°, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 µm
SWAP: 6U, 9 kg, 15W, 5 Mbps



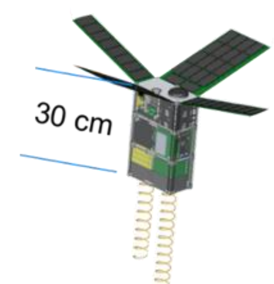
CubeSat Infrared Atmospheric Sounder (CIRAS)
Spatial: ±48.3°, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 µm
SWAP: 6U, 20 kg, 30 W, 1 Mbps



Microwave Atmospheric Sounder on CubeSat (MASC)
Spatial: ±45°, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: <0.01 m^3, 3 kg, 7 W, 10 kbps



RaInCube: Precipitation Profiler
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps



Total Identified Here: 72kg, 112W, 8 Mbps

RainCube & MASC First Airborne Observations of Clouds and Precipitation during the PECAN Experiment (June-July 2015)

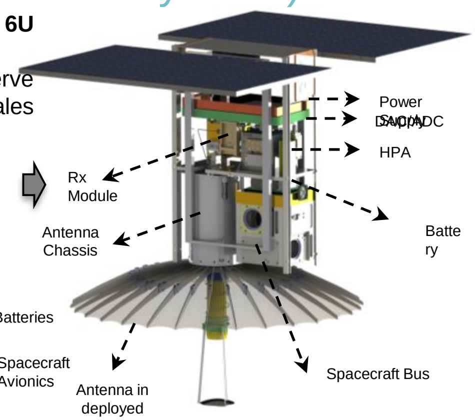
RainCube & MASC are instruments developed at JPL for deployment in **6U CubeSats**.

They will enable **affordable LEO constellations** to observe **cloud and precipitation processes** as they evolve at the timescales needed to validate and improve weather and climate models.

RainCube

PI: Eva Peral

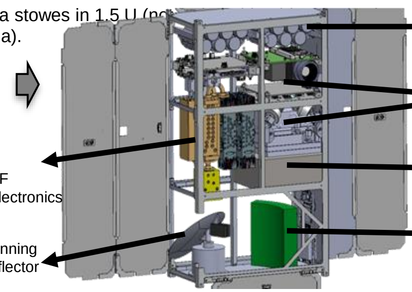
- nadir-pointing Ka-band precipitation radar (35.7 GHz)
- novel architecture to achieve the required sensitivity with low-power radar electronics that fit in 2U
- High-performance pulse compression to reduce surface clutter contamination and achieve sensitivity and range resolution.
- Lightweight Deployable antenna stowes in 1.5 U (no replaced by a horn-lens antenna).



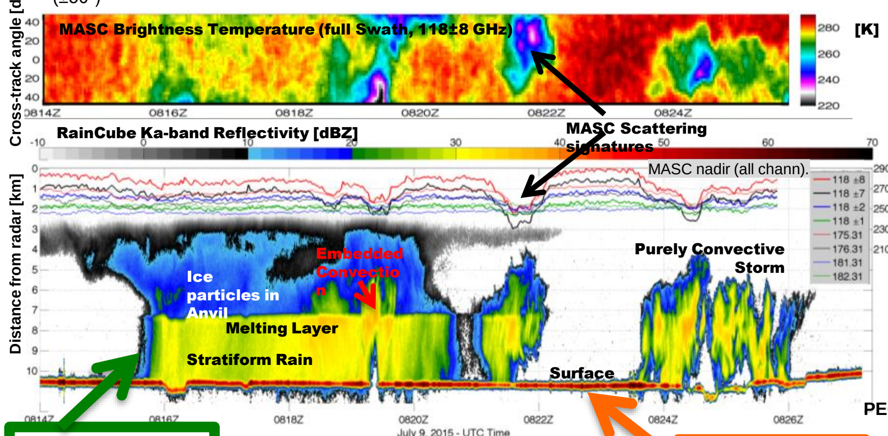
MASC (Microwave Atmospheric Sounder on CubeSat)

PI: Sharmila Padmanabhan

- 8 channel mm-wave radiometer (4 channels near 118GHz, 4 channels near 183 GHz)
- Cross-track scanning (±50˚)

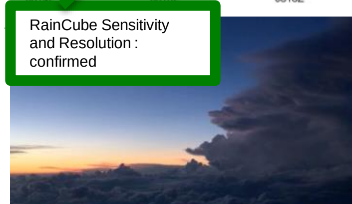


Both operated successfully on the NASA DC-8 for their **first airborne test and demonstration during PECAN (Jun. 28 – Jul. 11, 2015)**



RainCube Sensitivity and Resolution: confirmed

RainCube Pulse Compression performance: confirmed



- No faults or glitches from first flight to last flight.
- Fine calibration and science analysis: in progress.
- Coordinated operations with ground based weather radars

PECAN = Plains Elevated Convection At Night

https://www.eol.ucar.edu/content/pecan-iss
http://asr.science.energy.gov/meetings/stm/2013/presentations/PECAN-update.pdf
http://www.nssl.noaa.gov/projects/pecan

Acknowledging:

- **AFRC**: excellent coordination and rapid implementation
- **PECAN** Science Leadership: outstanding flexible and creative collaboration
- **OU ARRC**: coordinated deployment of X-band ground based weather radars
- **Weather Focus Area** Leads: additional flight hours to PECAN for RainCube and MASC
- **Kansas City Star** picture gallery: http://www.kansascity.com/news/local/article27710704.html

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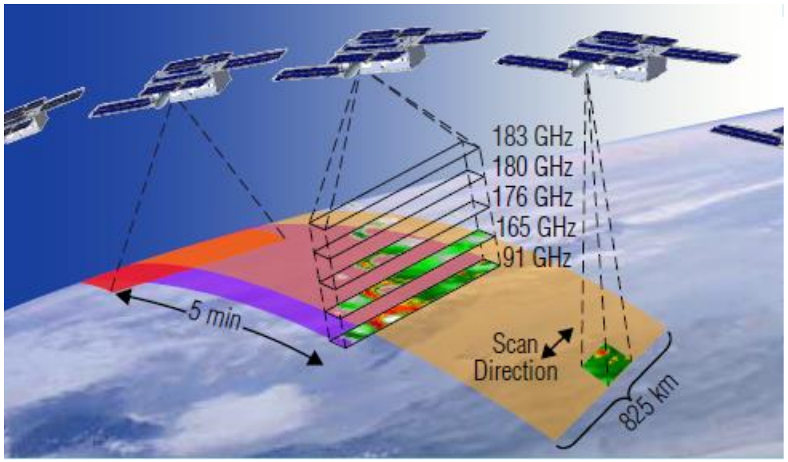
Constellation of CubeSats: Calibration



Instrument performance flow-down from science requirements.

Characteristic	Instrument Capability	From Science Requirement
Half-Power Beamwidth (HPBW)	2.9° (118 GHz) 1.8° (183 GHz)	<4° (118 GHz) <3° (183 GHz)
Intersatellite Precision	0.6 K	1.2 K
Absolute Tb Accuracy	3 K	4 K

Instrument Thermal Stability Requirements

Component	Operating Temp	Thermal Stability
Calibration target	20°C–40°C	±3.0°C/orbit
Receiver electronics	0°C–40°C	±1.5°C/orbit
Back-end electronics	20°C–40°C	±5.0°C/orbit

The science requirements are

- **a precision among all CubeSats of 2 K and**
- **an absolute accuracy of 4 K**

The 2 K precision requirement has two major components:

(1) instrument noise, including calibration uncertainty and antenna pattern knowledge, and

(2) observation noise due to sampling and Earth incidence angle (EIA) errors. We allocate 1.2 K to instrument noise and 1.6 K to observation noise (for an RSS of 2 K).

Instrument error allocation for intersatellite precision requirement.

Error Allocation	118 GHz	183 GHz
Measurement noise (NEΔT, 1/f, 2 Instruments)	0.48 K	0.61 K
Residual antenna temperature error	0.1 K	0.1 K
Residual brightness temperature calibration	0.15 K	0.15 K
RSS total error allocation	0.51 K	0.64 K
Flowed down from Science Requirement	1.2 K	1.2 K

Mission Trade

	Ocean focus – Cubesat	Ocean focus	Coasts focus - Cubesat	Coasts focus	Land focus	Landsat-like
Spatial Res	1 km	1 km	200 m	200 m	60 m	30 m
Global Revisit	1 day	1 day	9:30 AM + 3:30 PM Daily	9:30 AM + 3:30 PM Daily	10 day	16 day
Global Coverage each revisit	100%	100%	8%	40%	100%	100%
# of Satellites	30	4	18	4	4	12
FOV [deg]	40	40 x2	12 (36 FOR)	30	9	1.5
# of Launches	3	1	2	1	1	3
Altitude [km]	561	561	561	561	626	619
Instrument dimensions	0.01x0.02x 0.01 m	(0.01x0.02x 0.01 m) x2	0.01x0.02x 0.01 m	0.3x0.2x 0.2 m	0.6x0.45x 0.45 m	0.3x0.2x 0.2 m
# of x-track detector elements	400	600 x2	600	1600	1600	600
F stop	F 1.8	F 1.8	F 1.8	f 1.8	f 1.8	f 3
Spacecraft class	Cubesat	SSTL 150 class	Cubesat	SSTL 150 class	SSTL 300 class	SSTL 300 class

Recommendation

- Define science missions only CubeSat can solve with the lower cost
  - Temporal sampling and heterogeneous instruments
- Miniaturized science instruments that are fully self calibrated
- Establishment of a reliable ground network
- Class C spacecraft
- Industry driven – propulsion, communication, avionics, power