Jet Propulsion Laboratory
California Institute of Technology

The Next Generation of Spaceborne Radars for Cloud and Precipitation Measurements

Eastwood Im, Eva Peral, Mauricio Sanchez-Barbetty, Simone Tanelli
Jet Propulsion Laboratory, California Institute of Technology
USA

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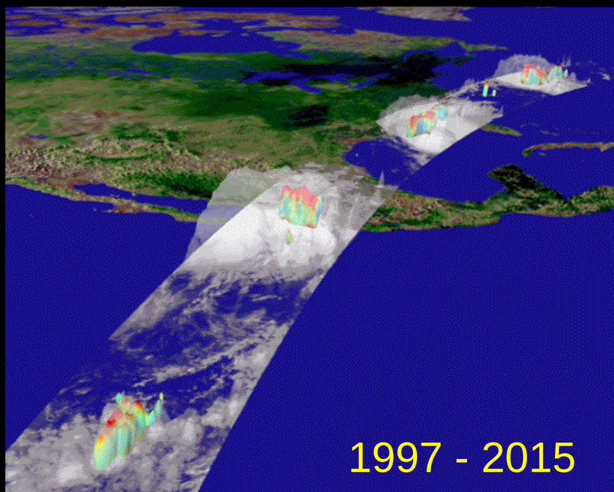
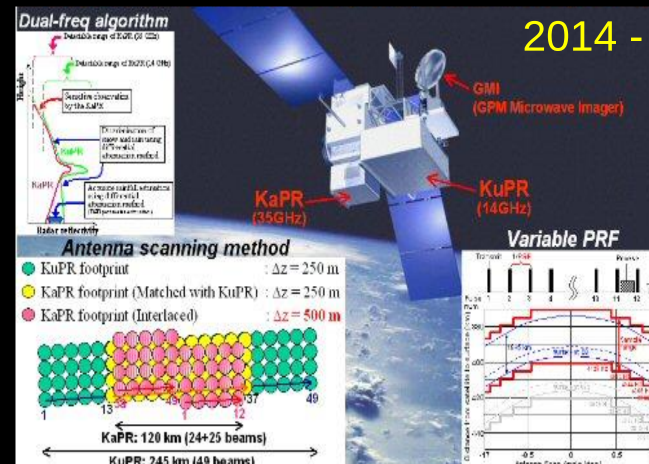
First Two Generations of Spaceborne Weather Radars

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



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



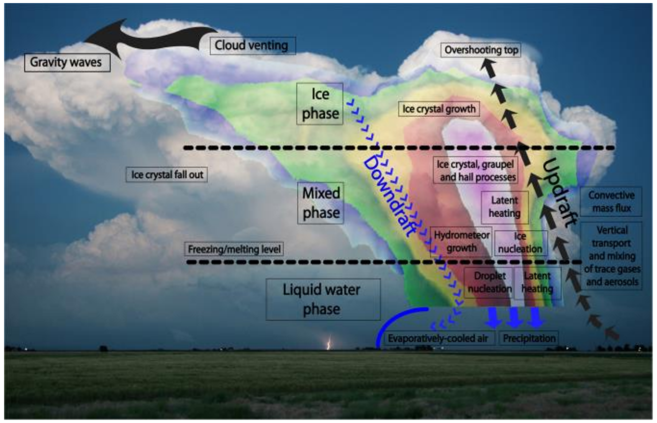
2014 - on-going

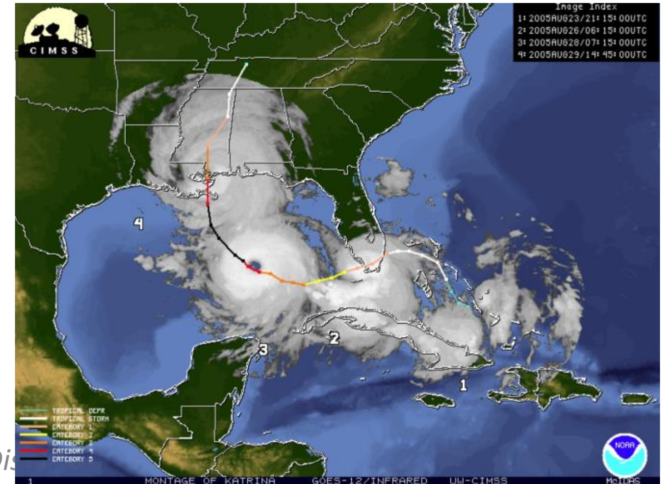
CloudSat/CPR – JPL/NASA/CSA
W, Nadir, Clouds

2006 - on-going

Science Driver on Next-Generation Atmos Radars – Process Study

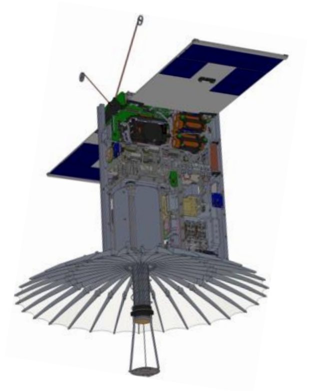
- CloudSat→EarthCARE and TRMM→GPM measure vertical profiles of two 'types' of hydrometeors (clouds and precipitation) separately.
- In recent community workshops/meetings and reports (e.g., 2010 WCRP GEWEX Paris Workshop, 2011 Spaceborne Snowfall Measurement Workshop, 2013 Global Preicp & Cloud Meas. Workshop), it is generally recognized that the next set(s) of space measurements should put more emphasis on process studies
  - Capture the comprehensive cloud/precip process as much as possible
    - Multi-frequency radar to increase measurement dynamic range and study microphysics
    - Simultaneous measurements of Doppler velocity to associate dynamics to the hydrometeor contents
  - Capture time evolution processes
    - GEO radars for studying life cycle of cyclones
    - LEO radar constellation
      - In train formation
      - In general constellation





Objective of Today's Presentation

- Through the sponsorship from NASA's Earth Science Technology Office (ESTO), JPL is developing two innovative spaceborne radar instruments for studying weather and atmospheric processes
  - **RainCube (Radar in a CubeSat)**
    - Miniaturized and low cost Ka-band radars in 6U CubeSats
    - Enable constellations of CubeSats for fine-resolution temporal sampling of processes
      - Study time evolution, capture life cycle
      - Study diurnal cycle



  - **MASTR (Multi-Application Smallsat Tri-band Radar)**
    - Compact, SmallSat-class, Ku/Ka/W-band scanning radar
    - Enable simultaneous clouds and precipitation measurements at 3 frequencies for studying
      - Cloud microphysics and drop size distribution
      - Cloud transition to precipitation

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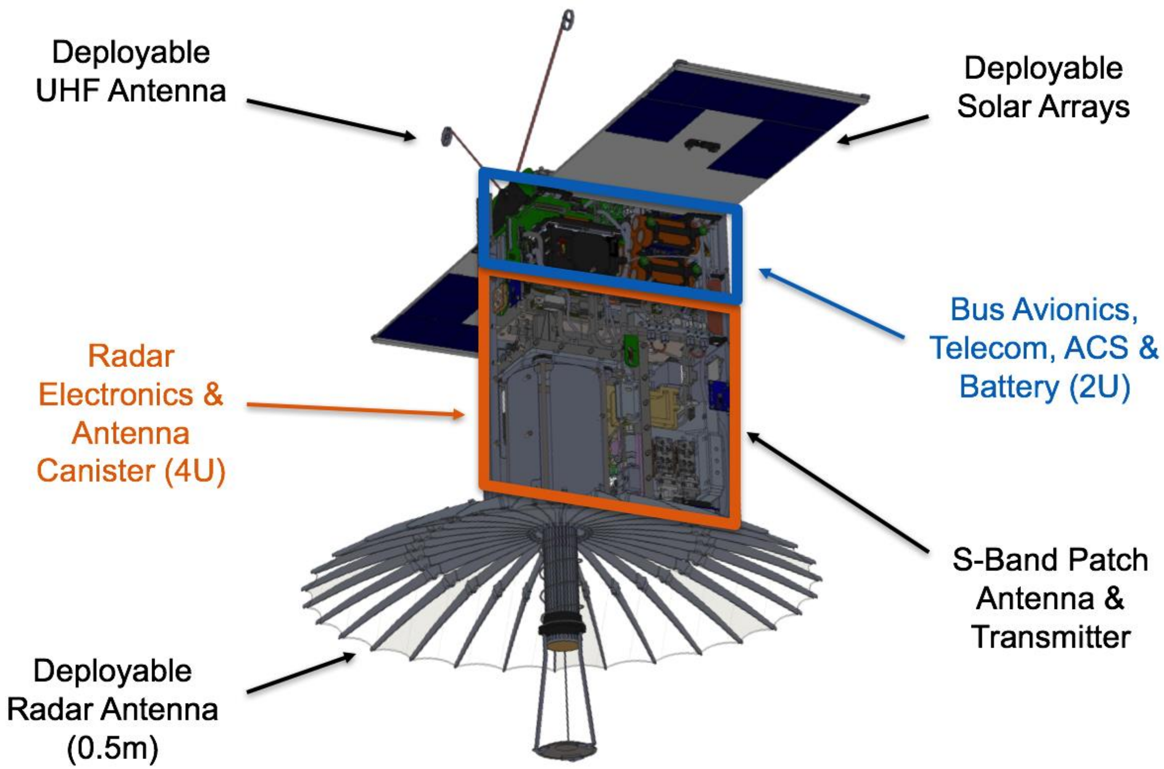
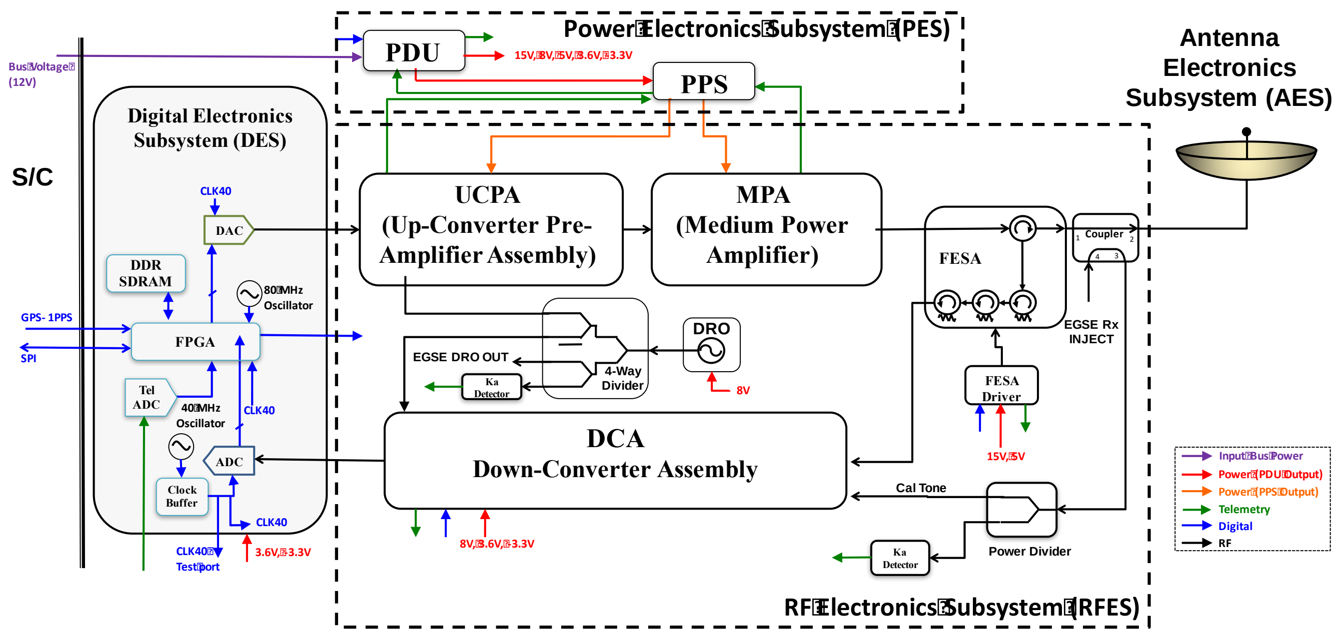
RainCube: System Architecture

- 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



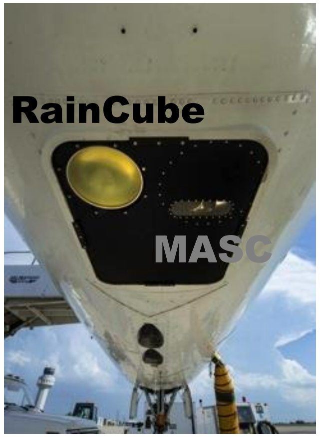
RainCube: Radar Electronics

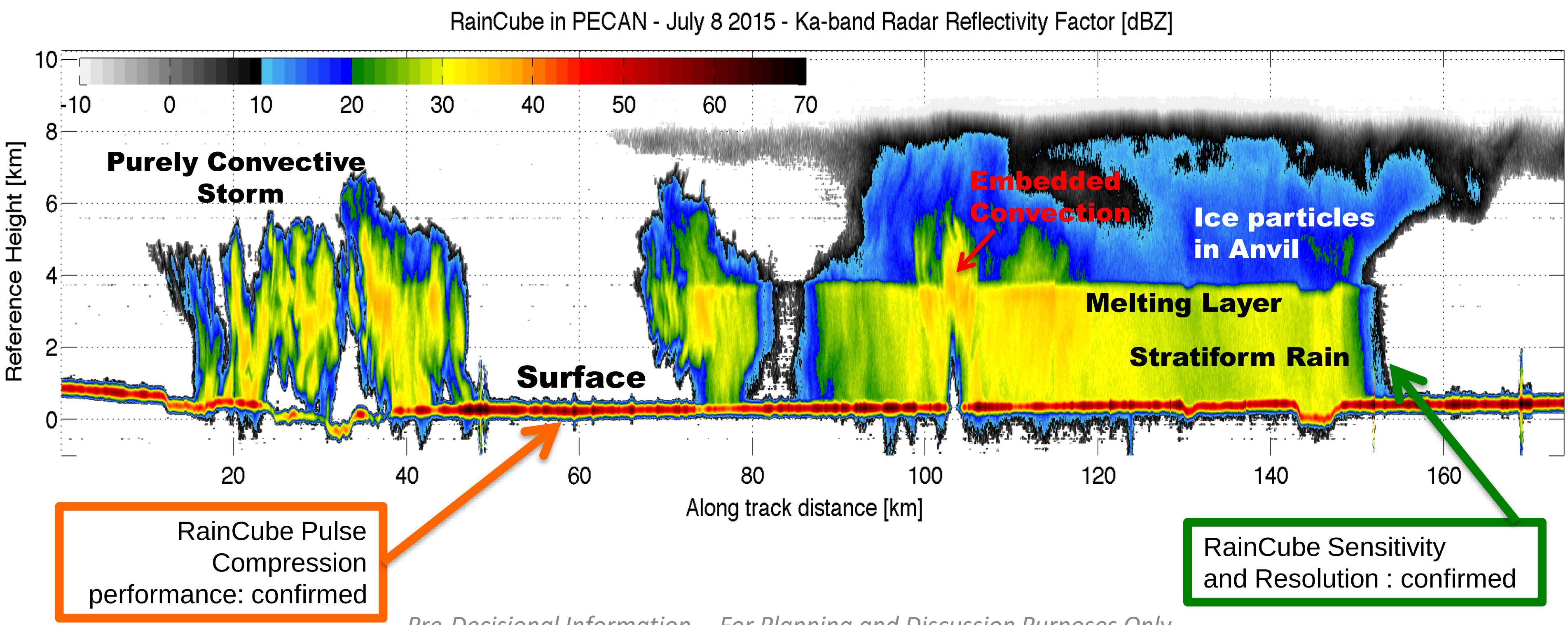
- Use several novel designs to greatly reduce size, mass, and power
  - Offset IQ architecture
  - Direct up- & down-conversion
  - Pulse compression
- Radar consists of:
  - Only 5 unique RF active components
  - One Ka-band and one 40 MHz oscillator
  - One digital board for control, timing, on-board processing, SC digital interface, etc.



RainCube: Airborne Demonstration of Radar Electronics

- Airborne demo of critical radar components and functions on NASA DC-8 aircraft in July 2015
  - Rain detection sensitivity
  - Range resolution for atmospheric profiling
  - Radar timing and control
  - Pulse compression and other signal processing functions





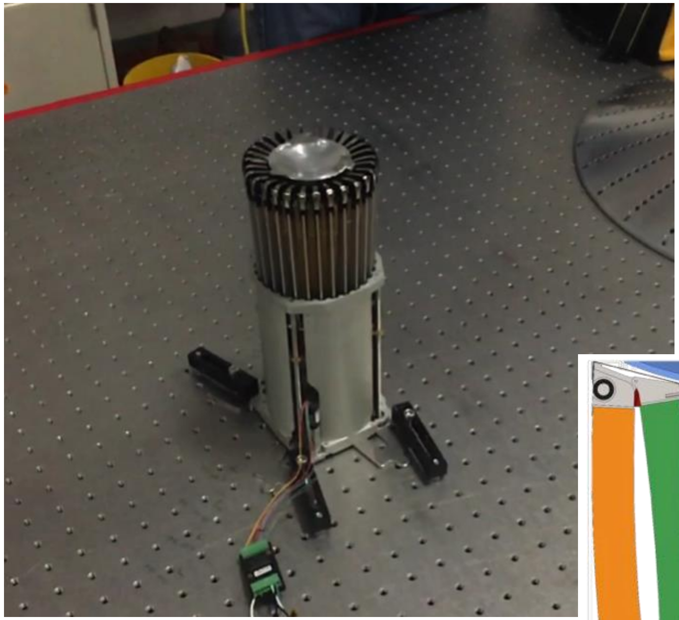
Pre-Decisional Information -- For Planning and Discussion Purposes Only.

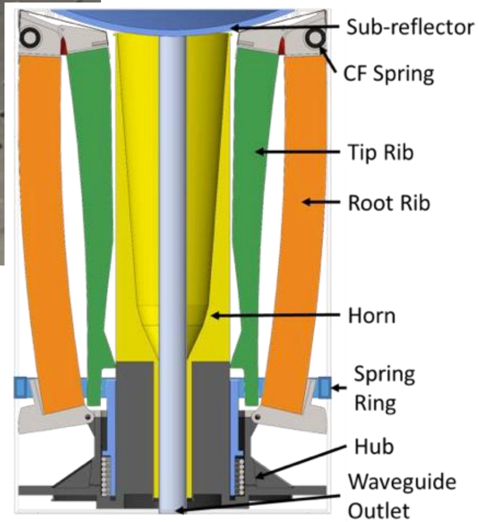
RainCube: Deployable Antenna Capability Demonstrated

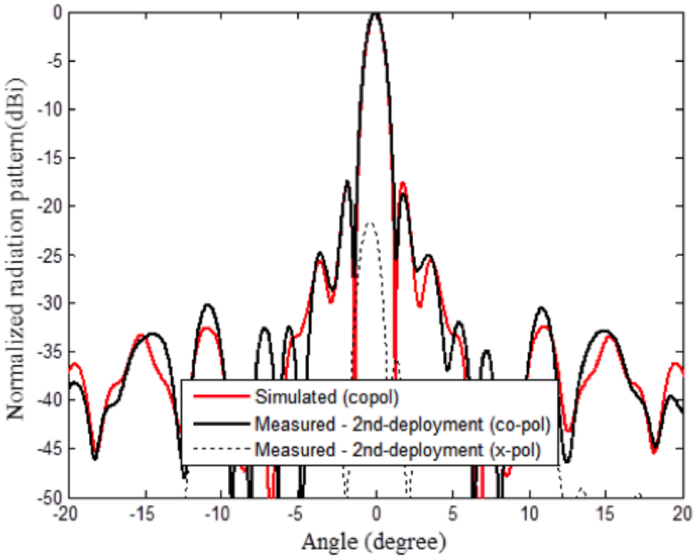
- Cassegrain architecture
- Motorized system with spring-loaded ribs and sub-reflector
- 0.5 meter dish that stows in ~1.5U

Deployment Testing

Quantity	Units	Goal	Simulated	Pre-Deploy	1st Deploy	2nd Deploy	5th Deploy
Stowed Size	U (10x10x10 cm^3)	1.5	1.54	1.54	1.54	1.62	1.62
Gain	dB	42	42.6	42.5	42.0	42.7	42.7
Surface Accuracy	mm	0.40	--	0.22	0.25	--	--
Mass	kg	3.0	1.9	1.4	1.4	1.4	1.4

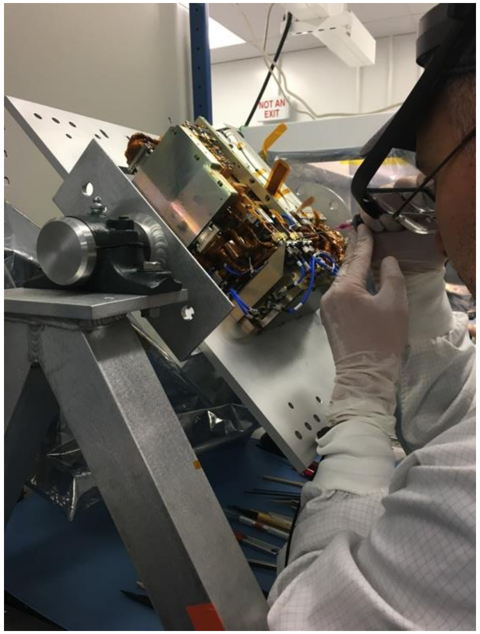


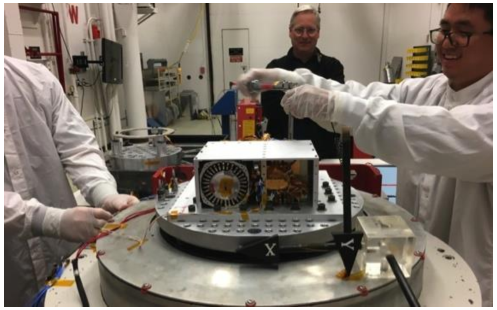


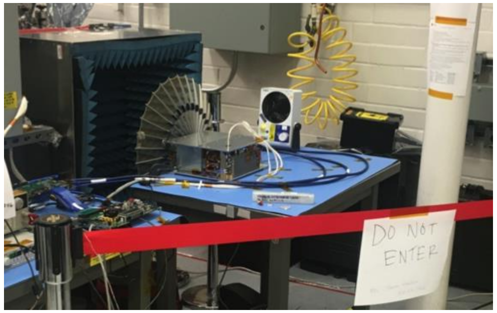


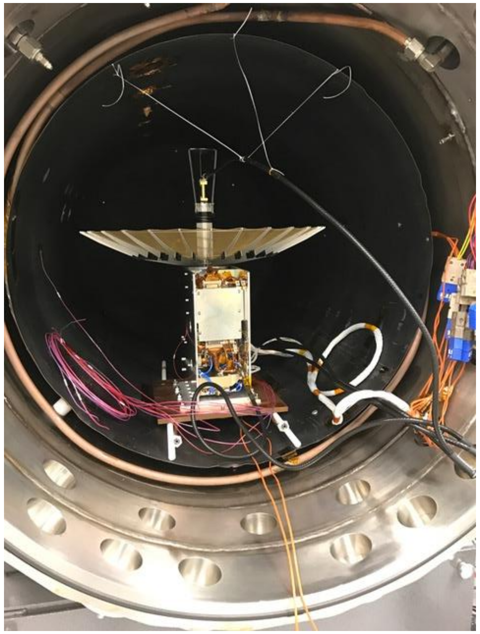
RainCube Radar Flight Instrument Testing Completed

- Completed radar assembly and test in March 2017
  - Functional and RF performance tests in ambient
  - Radar calibration over temperature (thermal-atmosphere)
  - Workmanship random vibe, protoflight thermal-vacuum (including antenna deployment)
- As-built measurements
  - 22 W power draw in transmit mode (versus 35 W allocation)
  - 5.5 kg total mass (versus 6 kg allocation)



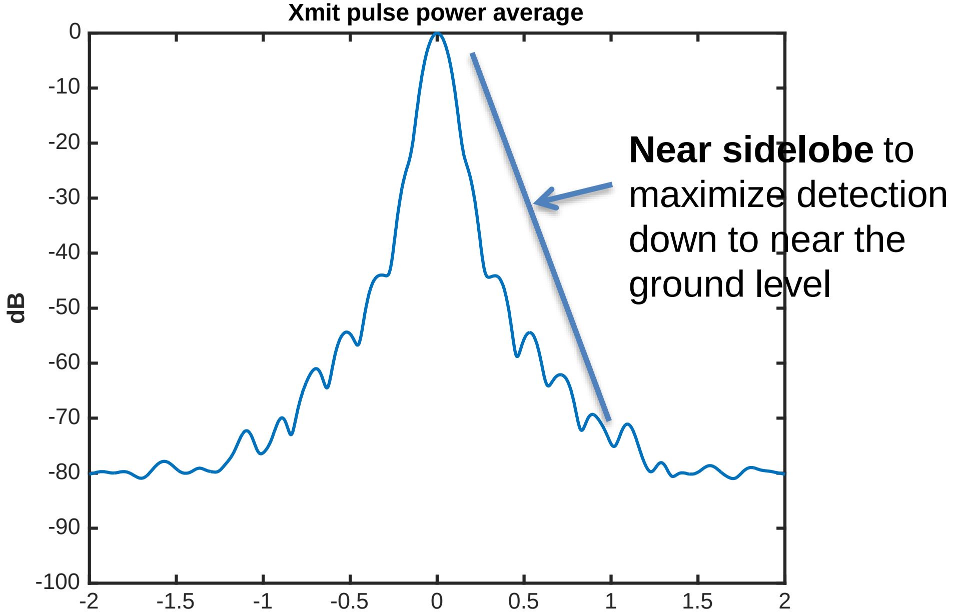


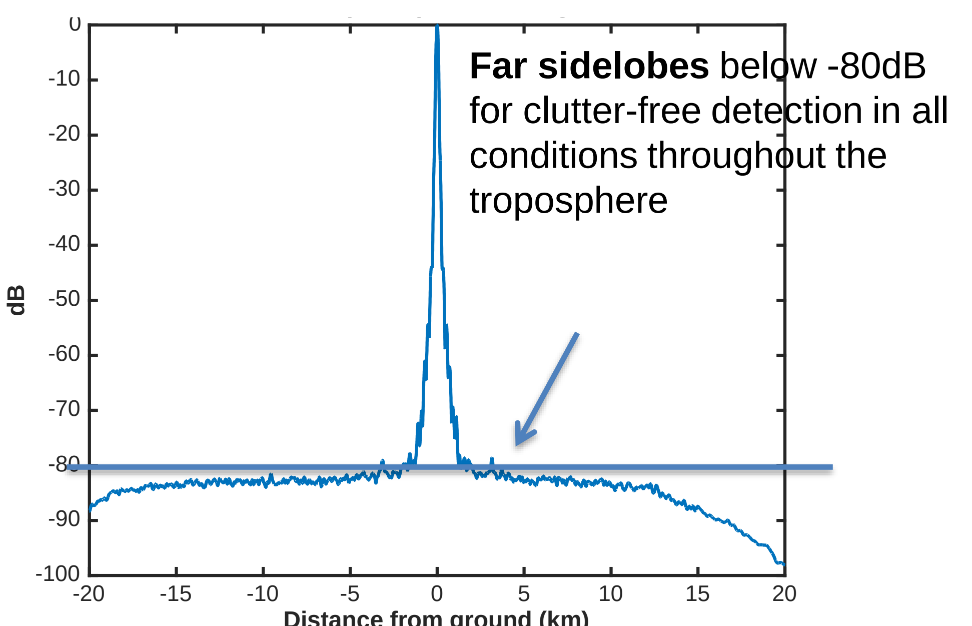




RainCube's As-Built Performance

Req't Name	Requirement	Measured
Sensitivity @400km	20dBZ	10.5dBZ
Horizontal resolution @400km	10km	7.9 km
Vertical resolution	250m	250m
Downlink data rate (in transmit)	50 kbps	49.57 kbps
Payload power consumption	8W: Standby 15W: Rx only 35W: Tx 10W: Antenna deployment	3W: Standby 10W: Rx only 22W: Tx 5W: Antenna deployment
Mass	6kg	5.5kg
Range sidelobe suppression	>60dB @ 5km	>65dB @ 1km
Transmit power Transmit loss	10W 1.1dB	>39dBm
Antenna gain	42 dB	42.6 dB
Antenna beamwidth	1.2 deg	1.13 deg

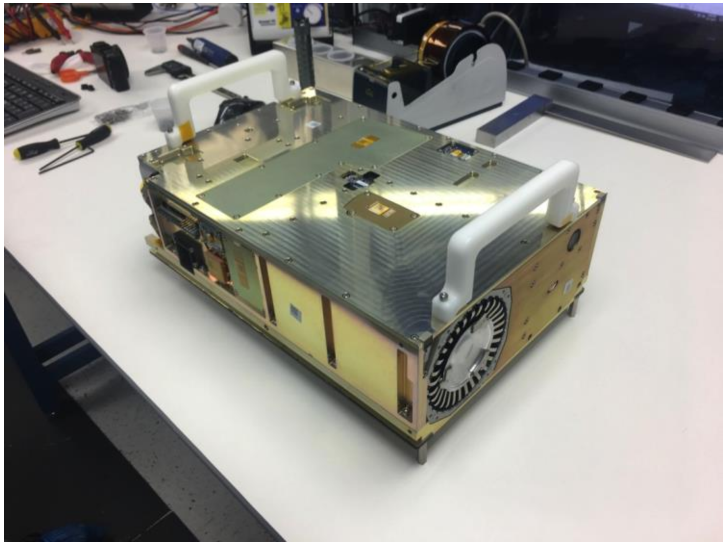




Key Milestones on RainCube Space Flight Demonstration

Project Event	ECD
Complete System Assembly & Functional Testing	Dec ‘17
Complete Environmental Testing	Jan ‘18
Mission Readiness Review & COFR	Jan ‘18
Deliver Flight System to NanoRacks	Feb ‘18
Launch	May ‘18
ISS Deployment	June ‘18
Complete 6-month Operations	Dec ‘18

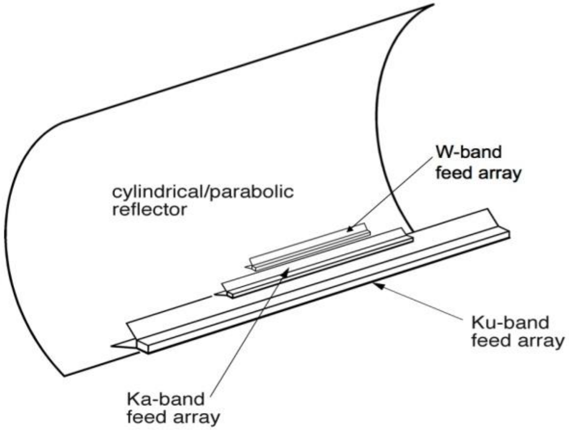
Mechanical fit check of the flight spacecraft and flight radar



MASTR Overview

- Since early 2017, JPL has begun the development of an airborne prototype of a SmallSat-class, tri-frequency, scanning radar called **MASTR** (**M**ulti-**A**pplication **S**mallsat **T**ri-band **R**adar)
  - Ku/Ka/W-band scanning radar
  - Cross-track scanning
  - Enable simultaneous clouds and precipitation measurements at 3 frequencies for studying
    - Cloud microphysics and drop size distribution
    - Cloud transition to precipitation

- Technical approach:
  - RF and Digital electronics adopt the RainCube design
    - RF electronics will be specific for each frequency
    - Digital electronics subsystem will be common to all frequencies
  - Single scanning antenna for all three frequencies
    - One singly-curved parabolic reflector
    - Three sets of active linear phase array feeds (Ku, Ka, and W) for off-set feeding the reflector



Evolution of Spaceborne 3-Frequency Scanning Cloud/Precipitation Radar Antenna Concept

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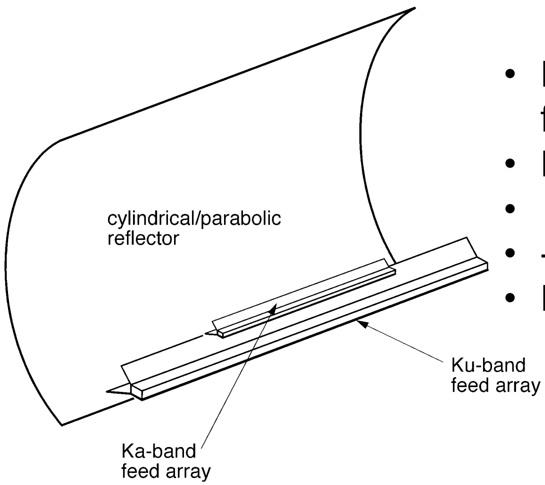
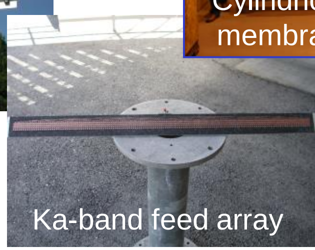
IIP-01: Ku/Ka-band cross-track scanning antenna



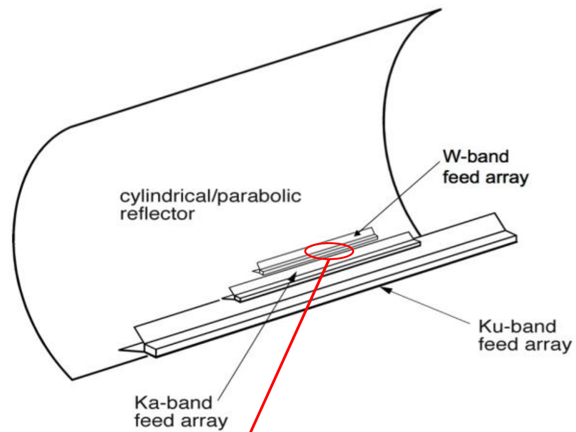
- Large aperture (e.g., 5m x 5m)
- Dual-frequency array feeds
- Matched beams
- ± 37 deg scanning
- -30 dB sidelobe level
- Est. mass: 120 kg



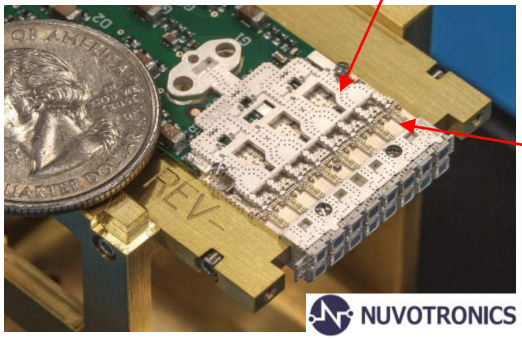
IIP-13: Ku/Ka/W-band cross-track scanning antenna

- Ku/Ka-band scanning concept well-developed
- Focus on W-band feed array technology
  - Scanning: up to 200 km swath
  - Sensitivity: -35 dBZ

JPL



Scanning Array Tile



NUVOTRONICS

3 mm

1 mm

GaN TR MMICs

Raytheon

Enabling W-Band Phase-Array Technology

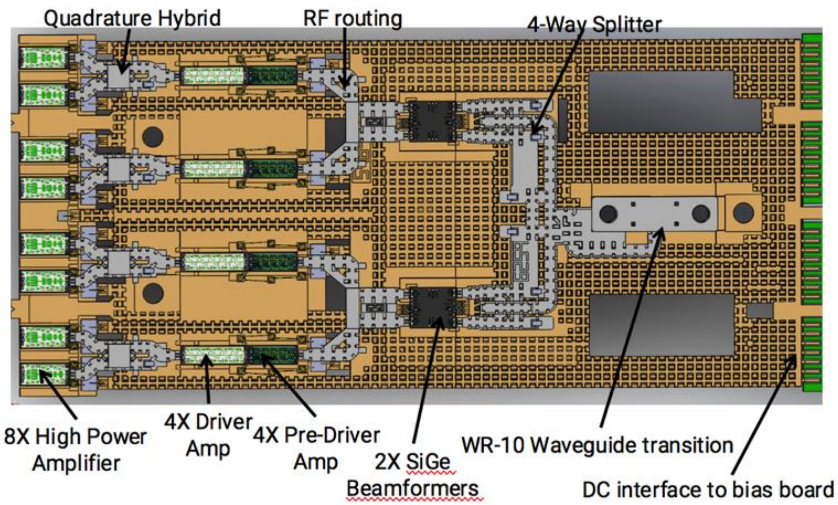
- W-band phase-array technology advances in the last 5 years enble the realization of the scanning W-band antenna concept
  - Gallium Nitride (GaN) power amplifiers and low noise amplifiers (LNA)
    - Provide >1W transmit power in a chip only 1 mm wide!
    - High input power tolerance LNAs – reduces isolation requirements
  - Silicon Germanium (SiGe) phase shifters with integrated serial digital control
    - Eliminates thousands of interconnects in W-band array
  - Micromachined all-metal (no dielectric) coax and radiators
    - Nuvotronics PolyStrata™ process provides high-density 3D RF signal routing with very low loss, excellent thermal conductivity, and very predictable design performance
  - Interlaced array architecture with high element-to-element isolation
    - Eliminate the need for front-end switching, greatly reducing losses

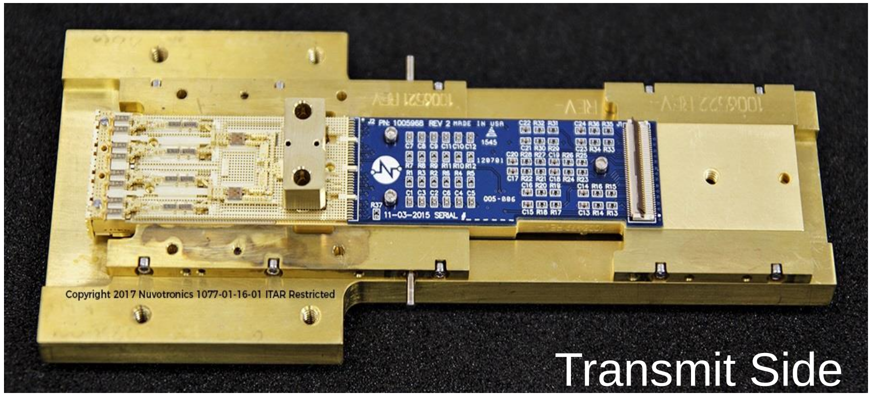
- Demonstrate the W-band scanning antenna technology by:
  - Developing 2x8 element Scanning Array Tile (SATs)
  - Combine 8 SATs to form a 64x2 element antenna subarray
  - Integrate the antenna subarray with a 30x50 cm cylindrical/parabolic reflector
  - Acquire antenna pattern measurements

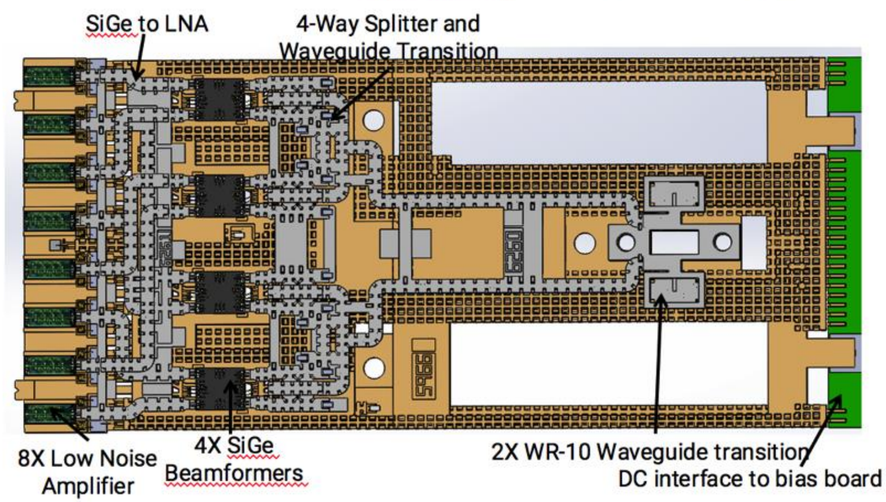
8x2 Scanning Array Tile (SAT) Circuit Board

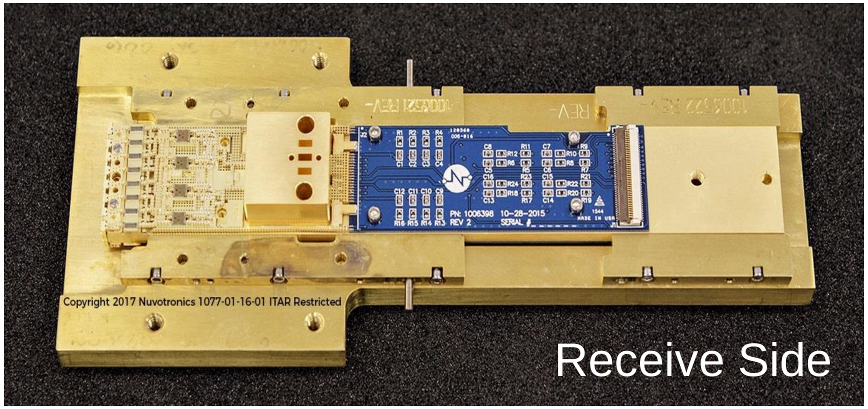
Transmit side

42mmx19.4mm







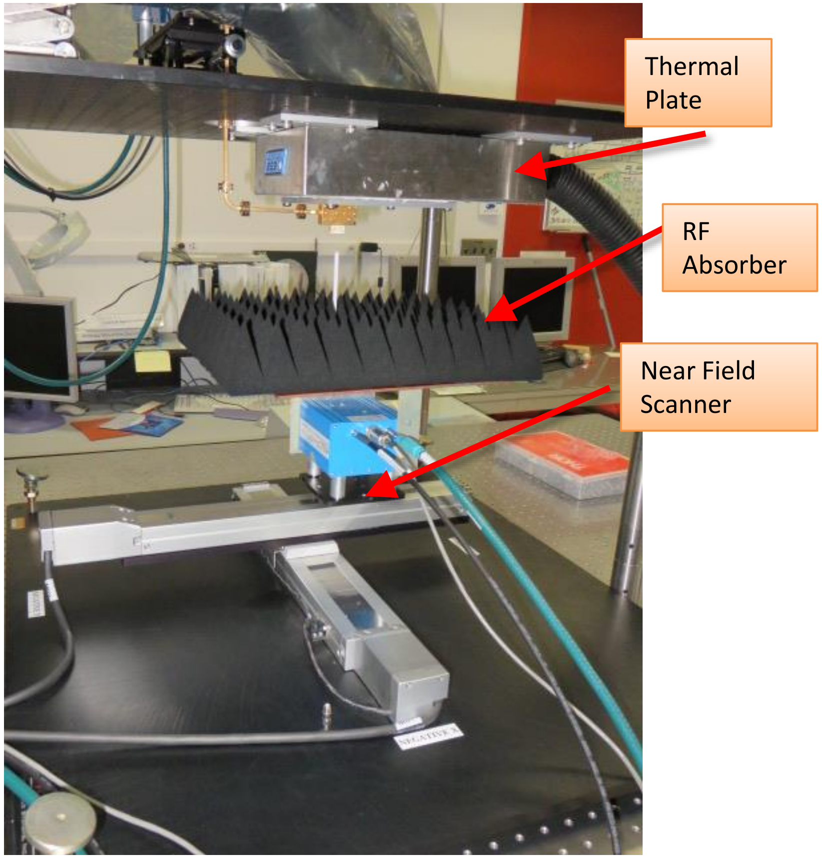


Receive side

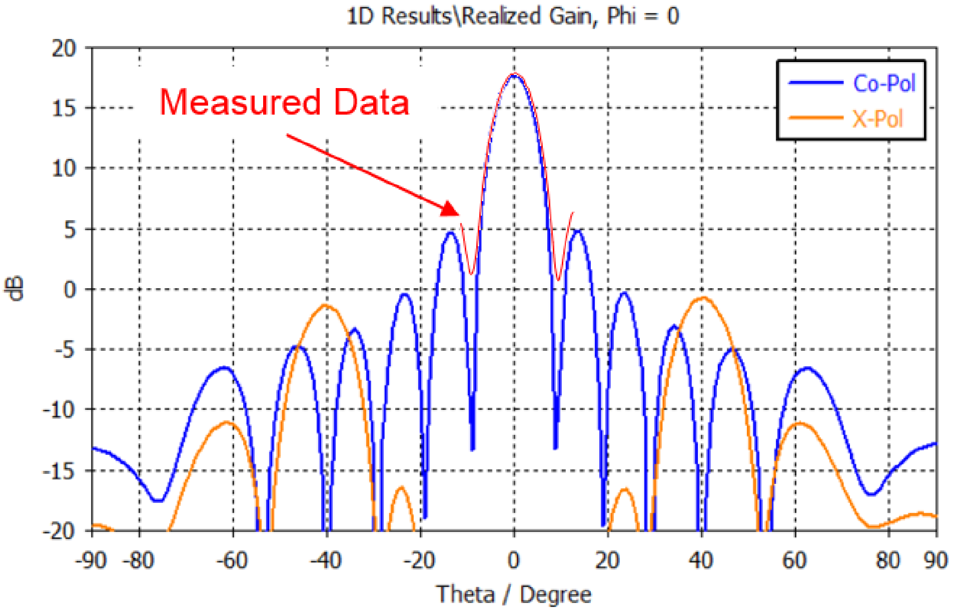
46mmx19.4mm

SAT Beamforming Antenna Pattern Measurements

- **Successfully demonstrated beamforming with 2x8 SAT**



Test setup



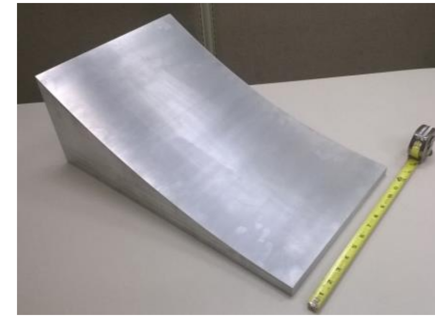
Measurement of 8x2 W-band array at 94GHz

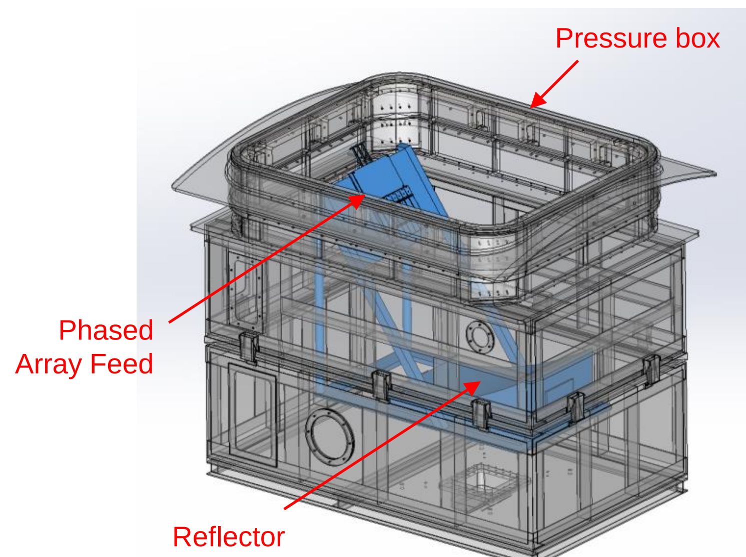
AirMASTR Instrument

- Airborne demonstration of MASTR.
- The modular architecture enables a demonstration with a scaled version of MASTR focused on raising the TRL of the subsystems.
- AirMASTR will be capable of Ku/Ka/W-band scanning, Doppler, and polarimetry.
- Reflector size 30cm x 50cm.
- Digital electronics based on RainCube.
- Direct frequency conversion.
- Platform: NASA DC-8.
- Expected completion in summer 2020

	Ku-band	Ka-Band	W-Band
Number of Tiles	4	8	8
Total Number of Transmit elements	16	32	64
Array Peak Transmit Power	320W	160W	96W
Array width [mm]	256mm	176mm	158.4mm

Tri-band Phased Array Feed

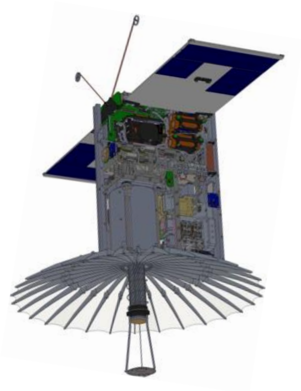

As-built reflector



Feed reflector model inside the DC-8 pressure box

Summary

- JPL is developing two innovative spaceborne radar instruments for studying weather and atmospheric processes
  - **RainCube (Radar in a CubeSat)**
    - Miniaturized and low cost Ka-band radars in 6U CubeSats
    - Enable constellations of CubeSats for fine-resolution temporal sampling of processes
      - Study time evolution, capture life cycle
      - Study diurnal cycle
    - Flight model built and tested. Expected launch in May 2018



  - **MASTR (Multi-Application Smallsat Tri-band Radar)**
    - Compact, SmallSat-class, Ku/Ka/W-band scanning radar
    - Enable simultaneous clouds and precipitation measurements at 3 frequencies for studying
      - Cloud microphysics and drop size distribution
      - Cloud transition to precipitation
    - Airborne prototype development started in early 2017. Expected completion in summer 2020