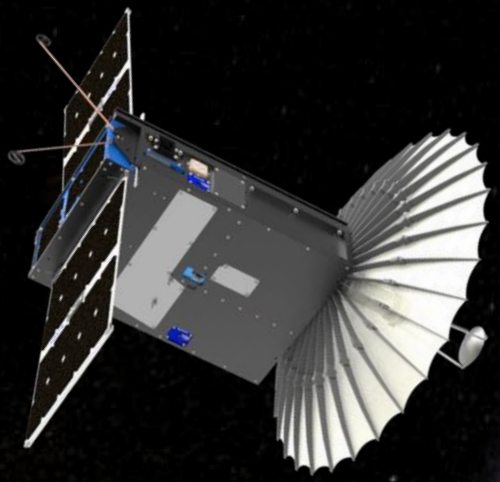
RainCube

Ka-Band Precipitation **Ra**dar **in** a 6U **Cube**Sat

ARSI'17 and KEO'17
September 2017 – Noordwijk, The Netherlands



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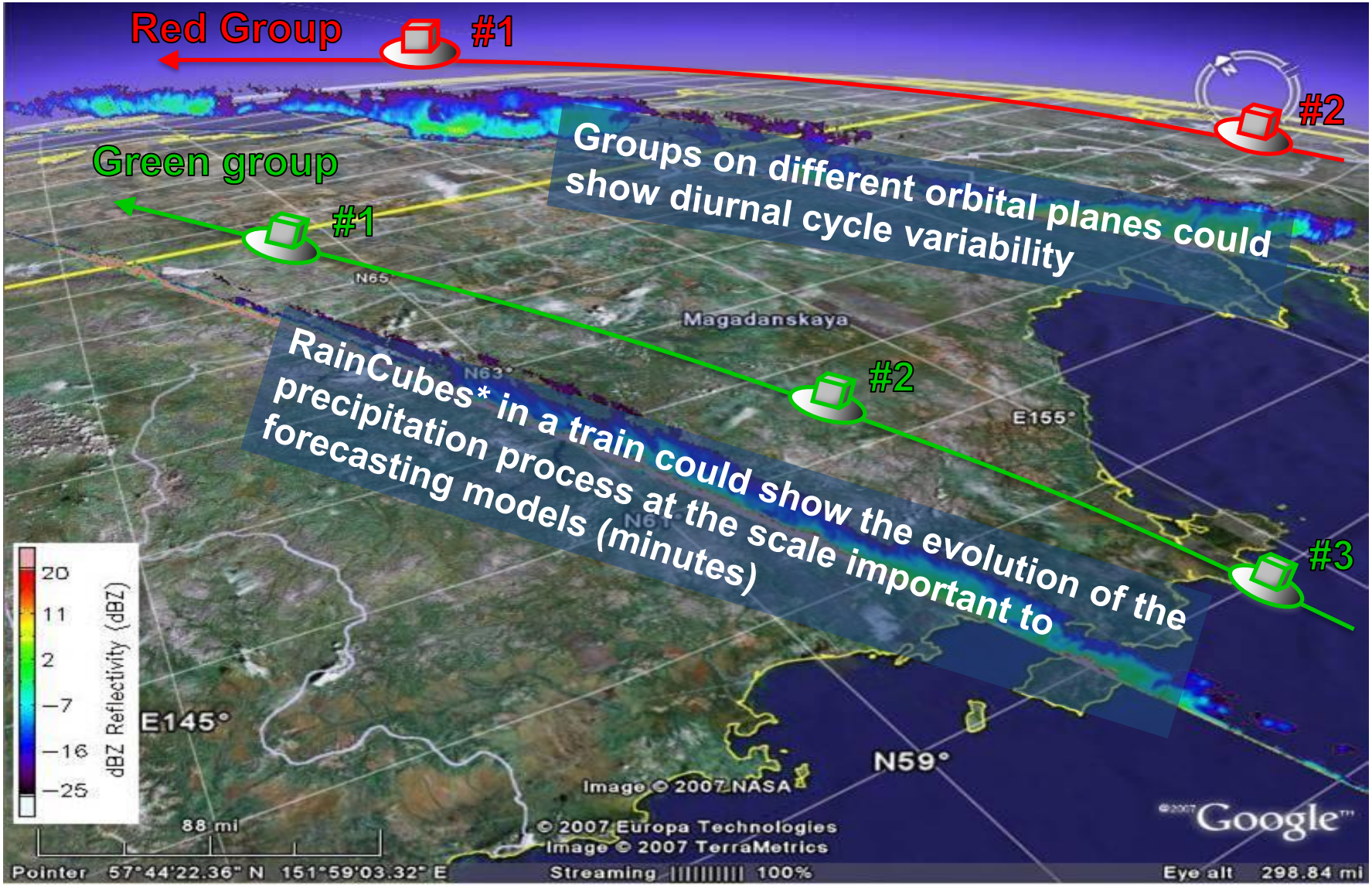
RainCube – **Ra**dar **in** a **Cube**Sat

RainCube is a ***technology demonstration*** mission to enable ***Ka-band*** precipitation radar technologies on a low-cost, quick-turnaround platform.

- **InVEST-15 Selection, ESTO**
  - Validate new Earth science technologies in space (TRL 4 to TRL 7)
  - 6U CubeSat, deploy to LEO from ISS
  - Three month primary mission (1 month payload demo phase)
  - Launch date is March 14, 2018 (T-7 months!)
- **Two Key Mission Objectives**
  - Demonstrate new technologies in Ka-band on a CubeSat platform
    - Miniaturized Ka-band Atmospheric Radar for CubeSats (miniKaAR-C)
    - Ka-band Radar Parabolic Deployable Antenna (KaRPDA)
  - Enable precipitation profiling radar missions for Earth Science
- **Roles & Responsibilities**
  - NASA ESTO: Sponsor
  - JPL: Project Management, Mission Assurance, Radar Delivery
  - Tyvak: Spacecraft Delivery, System I&T, Mission Operations

Science Drivers for RainCube

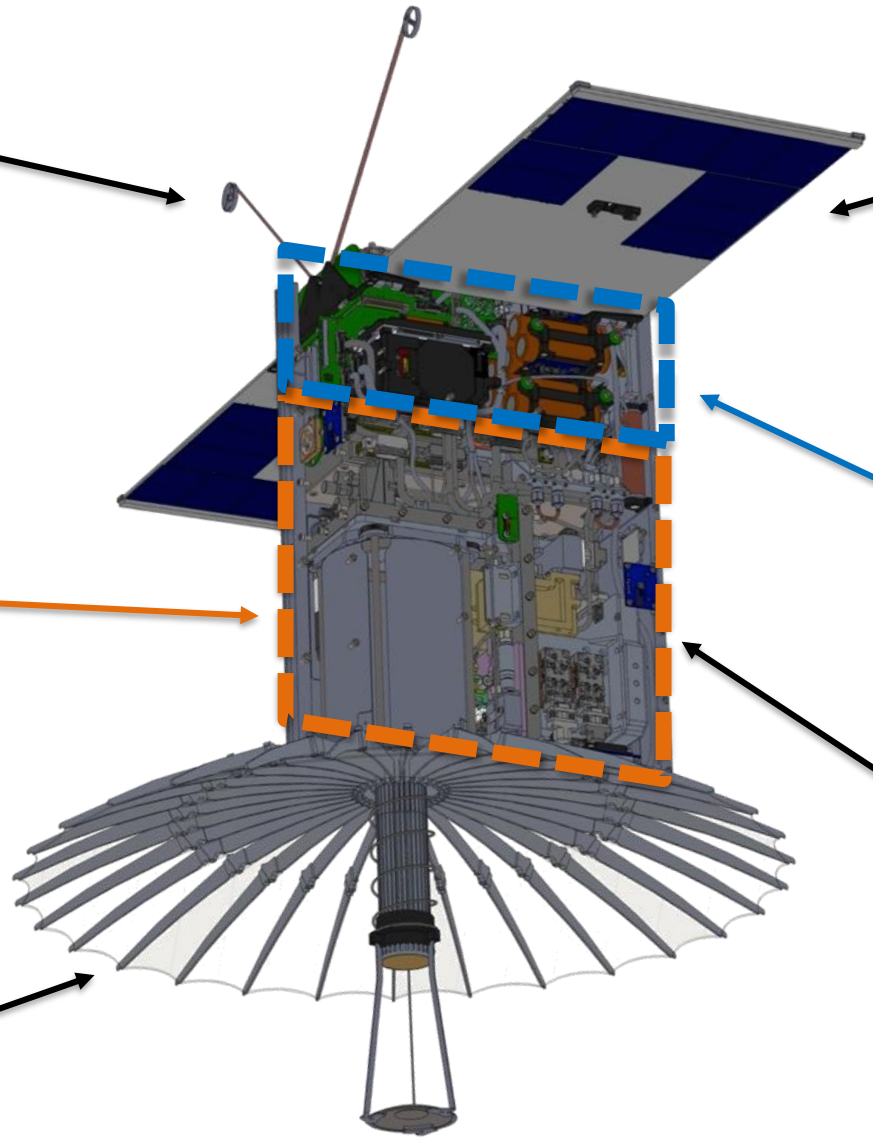


***Mission Concept – Pre-decisional – Planning and Discussion Purposes Only**

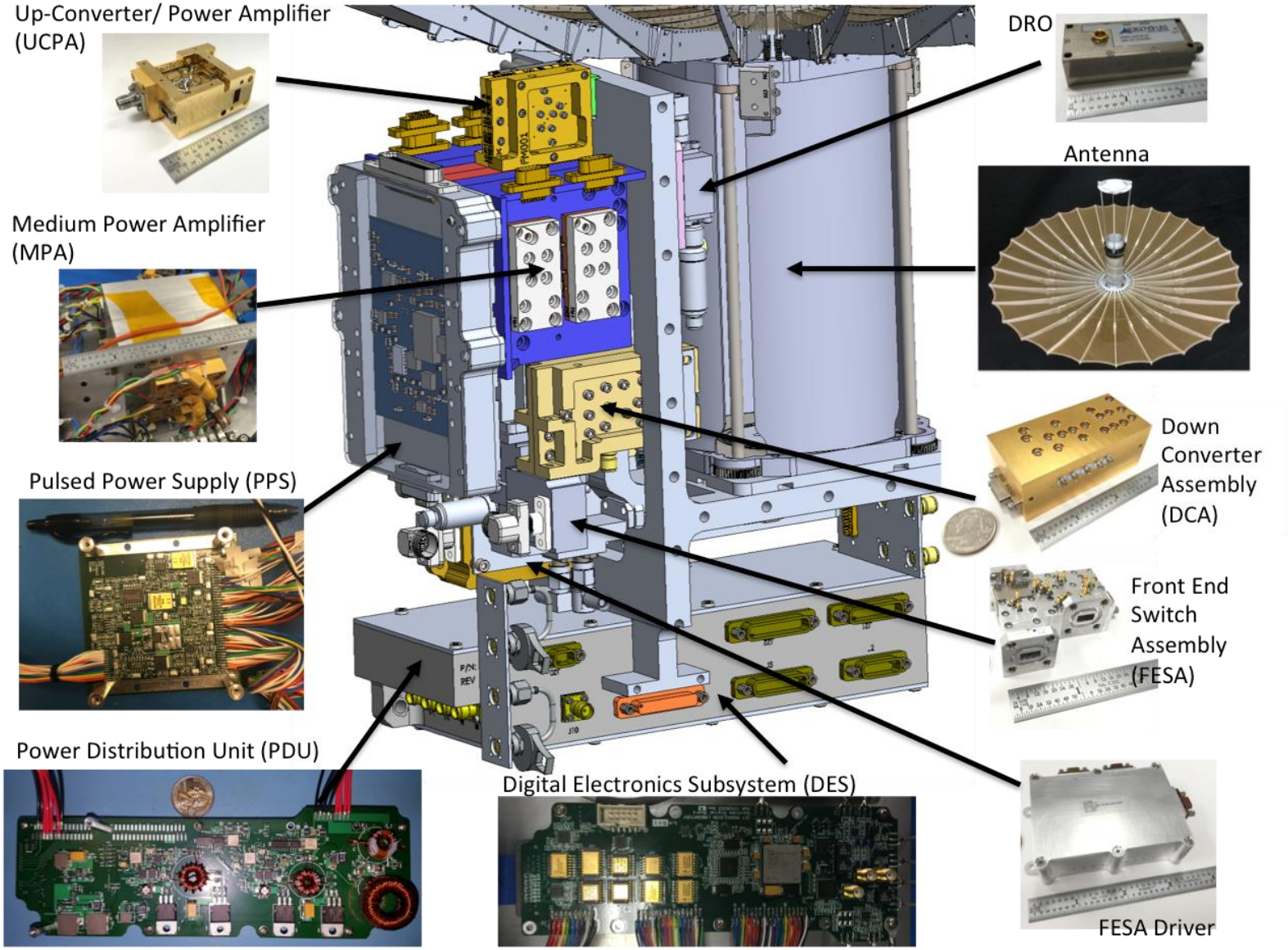
Key & Driving Requirements

- Radar
  - Vertically profile precipitation between **0 and 18 km** altitudes
  - **250 m** vertical resolution
  - **10 km** horizontal resolution (≥ 0.5 m antenna aperture)
  - Sensitivity ≥ **20 dBZ**
- Spacecraft
  - Provide **35 W** for payload power (transmit mode)
  - Maintain **25%** payload duty cycle in transmit mode
  - Operate payload through **continuous orbits** (1 orbit in transmit)
  - Store and downlink **12.1 Gb** payload data per week
  - Maintain payload temperatures (**-5C to +50C** operational)

System Architecture

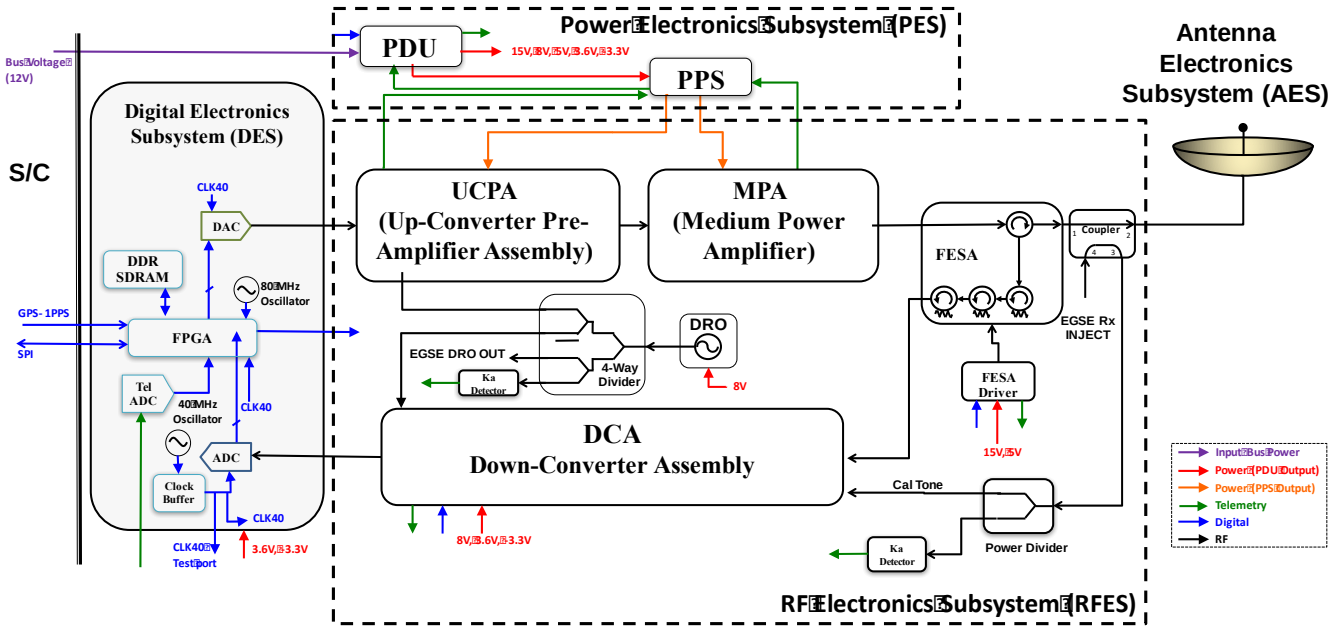


Radar Payload



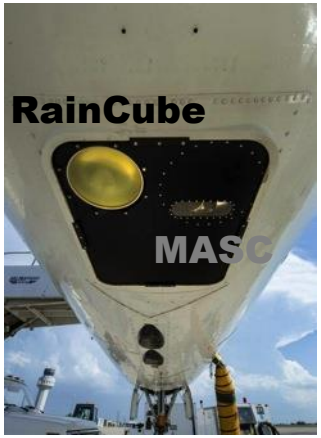
Radar Electronics - miniKaAR-C

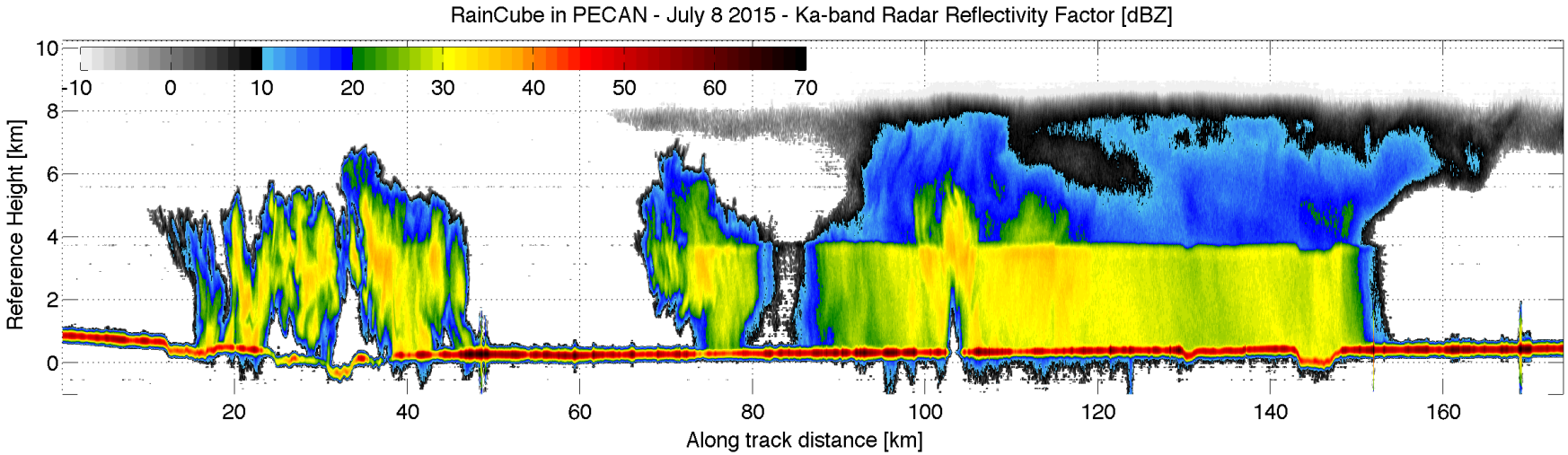
- Novel radar architecture that greatly reduces size, mass, and power
  - Only 5 unique RF active components
  - One Ka-band and one 40 MHz oscillator
  - One digital board for control, timing, on-board processing, SC digital interface, etc.
- Radar has three operational modes:
  - Standby, Receive Only, and Transmit



Radar Airborne Demo

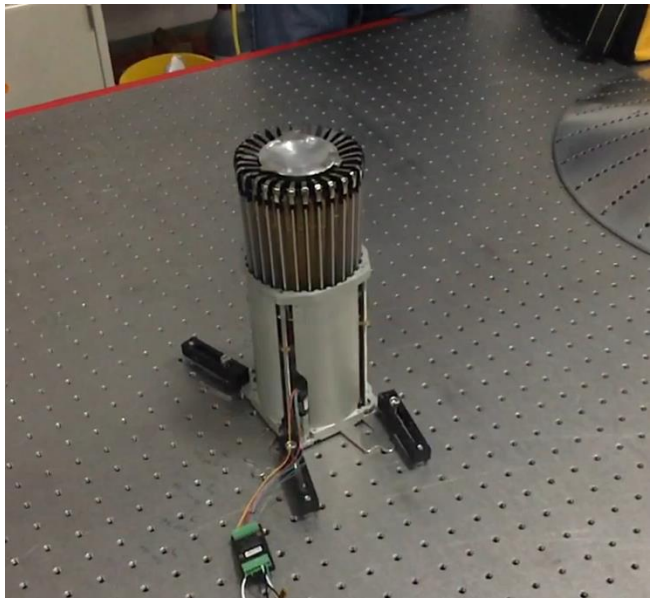
- Airborne demo of critical RF components completed in July 2015
  - Validated miniKaAR-C architecture beyond ground testing

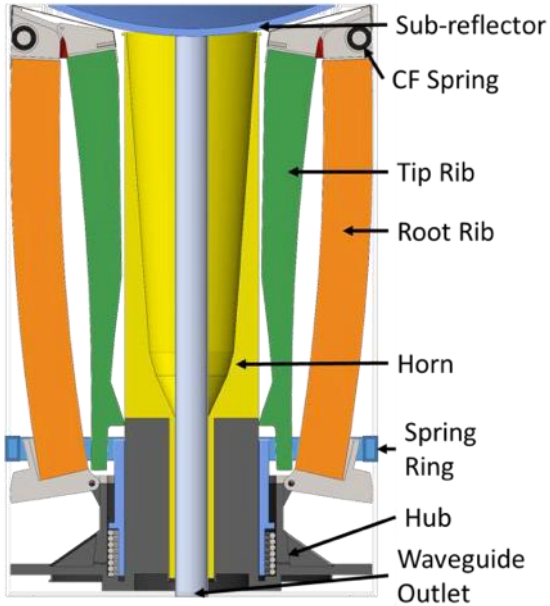


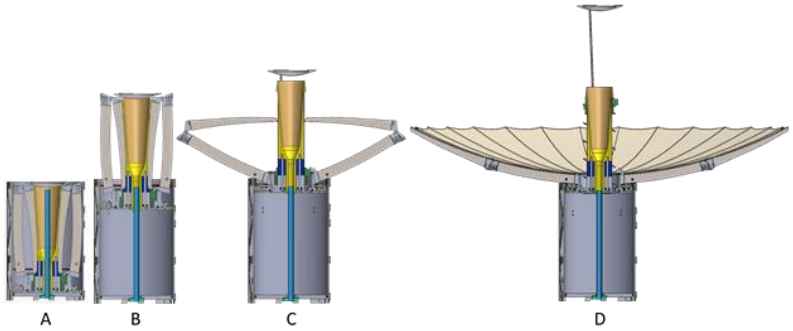


Radar Antenna - KaRPDA

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





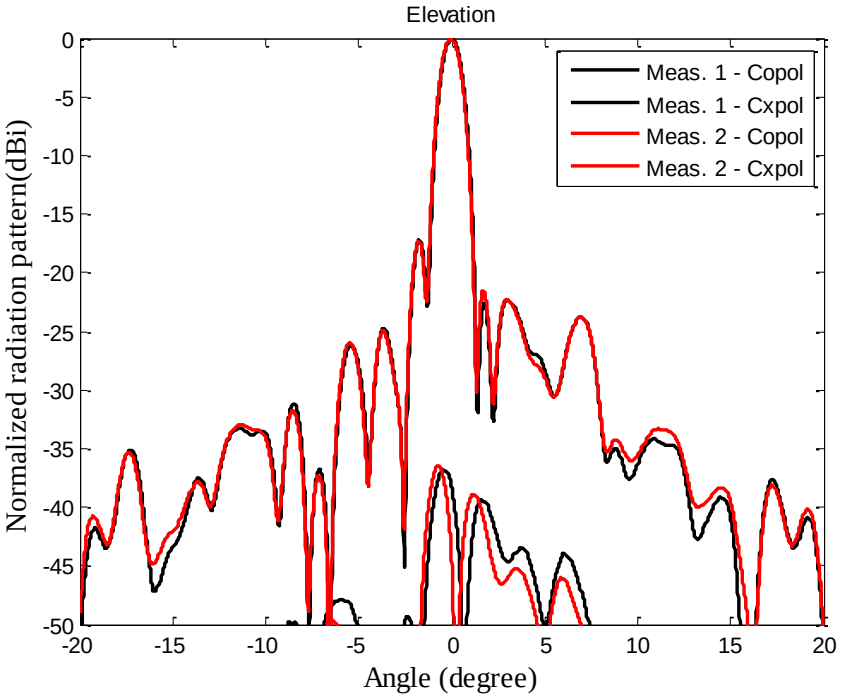


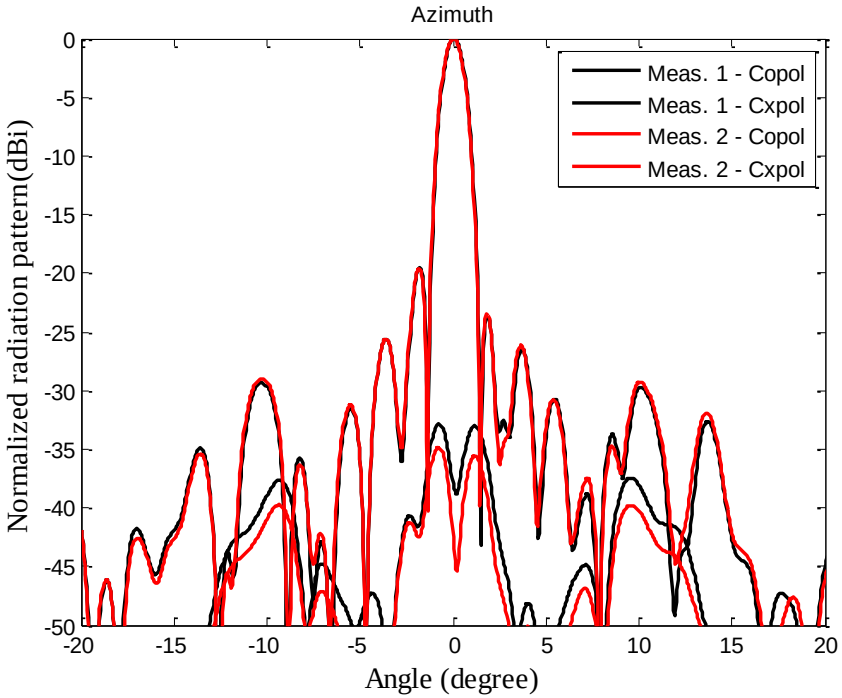
N. Chahat, J. Sauder, M. Thomson, R. Hodges, and Y. Rahmat-Samii, “CubeSat Deployable Ka-band reflector antenna development for Earth Science Mission,” IEEE Trans. Antennas and Propagation, vol. 64, no. 6, pp. 2083-2093, June 2016.

Radar Antenna Results

- Radiation pattern
  - Two RF tests completed (before [1] and after [2] antenna tvac)

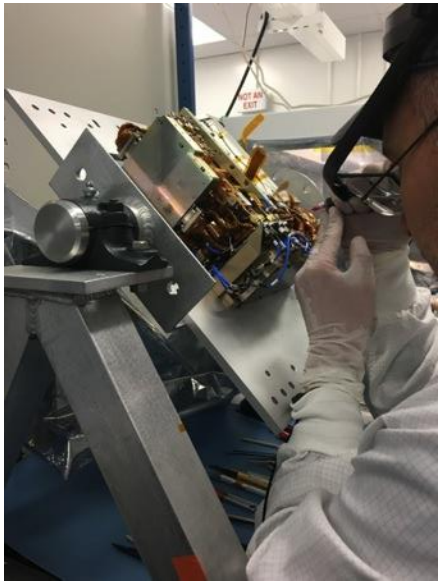
		Requirement	Measured result
L3-AES-1	Antenna gain	The AES antenna gain shall be greater than 42 dBi at 35.75GHz.	42.6dBi
L3-AES-2	Antenna beamwidth	The AES antenna 3dB beamwidth shall be less than 1.2 deg.	1.13 / degree
L3-AES-3	Antenna sidelobe level	The AES first main lobe to side lobe ratio shall be under than -17 dB.	-17.2dB

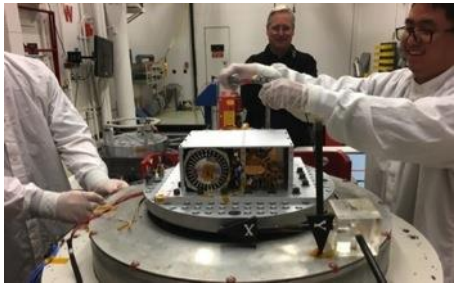


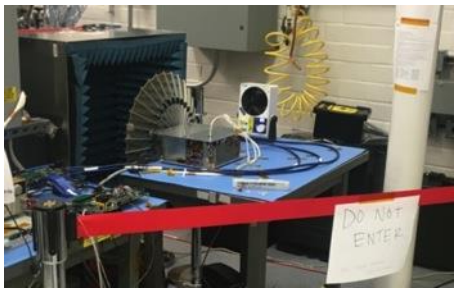


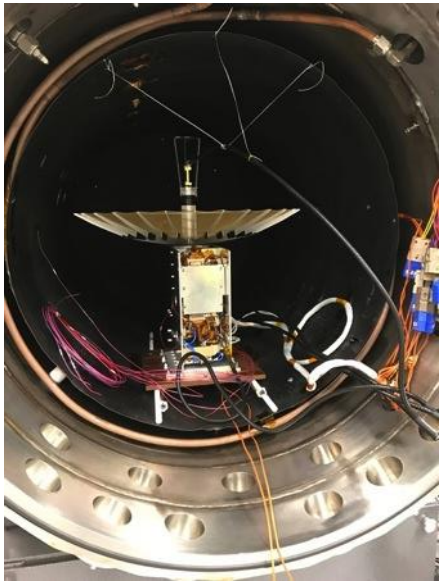
Radar Instrument I&T

- Completed radar assembly and test in March 2017
  - Functional and RF performance tests
  - Radar calibration over temperature (thermal-atmosphere)
  - Workmanship random vibe, protoflight thermal-vacuum (including antenna deployment)



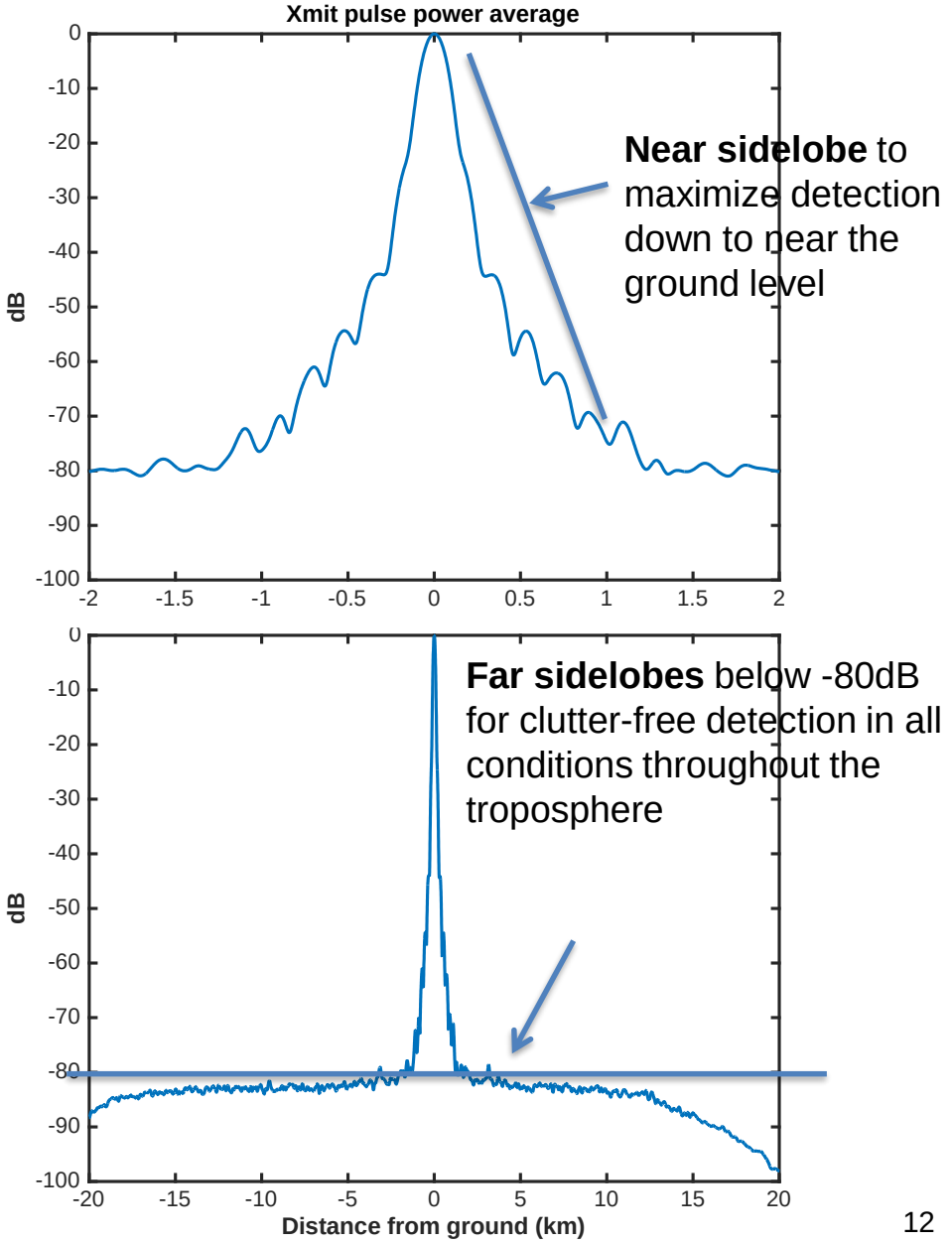






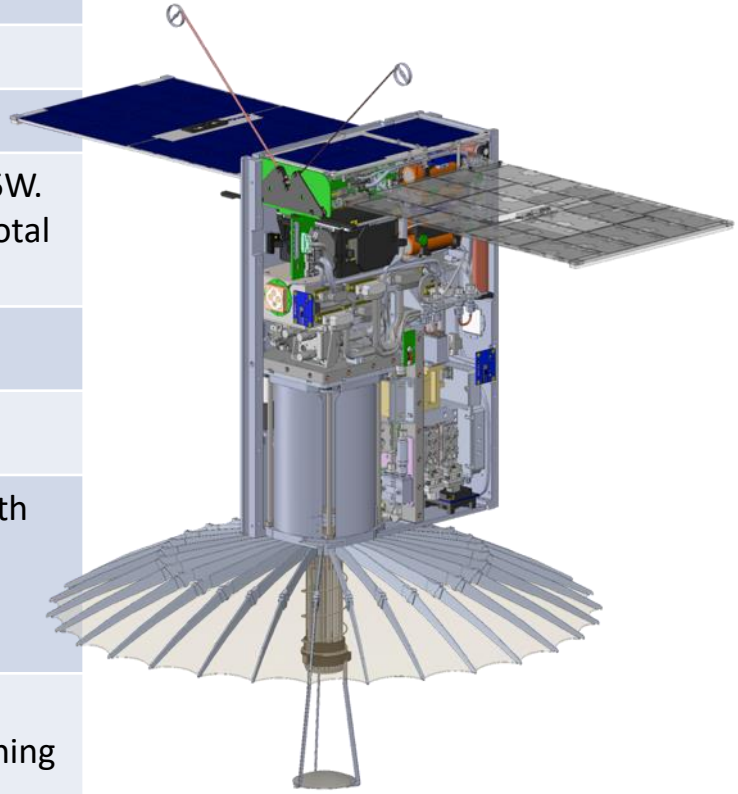
As-Built Radar Performance

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



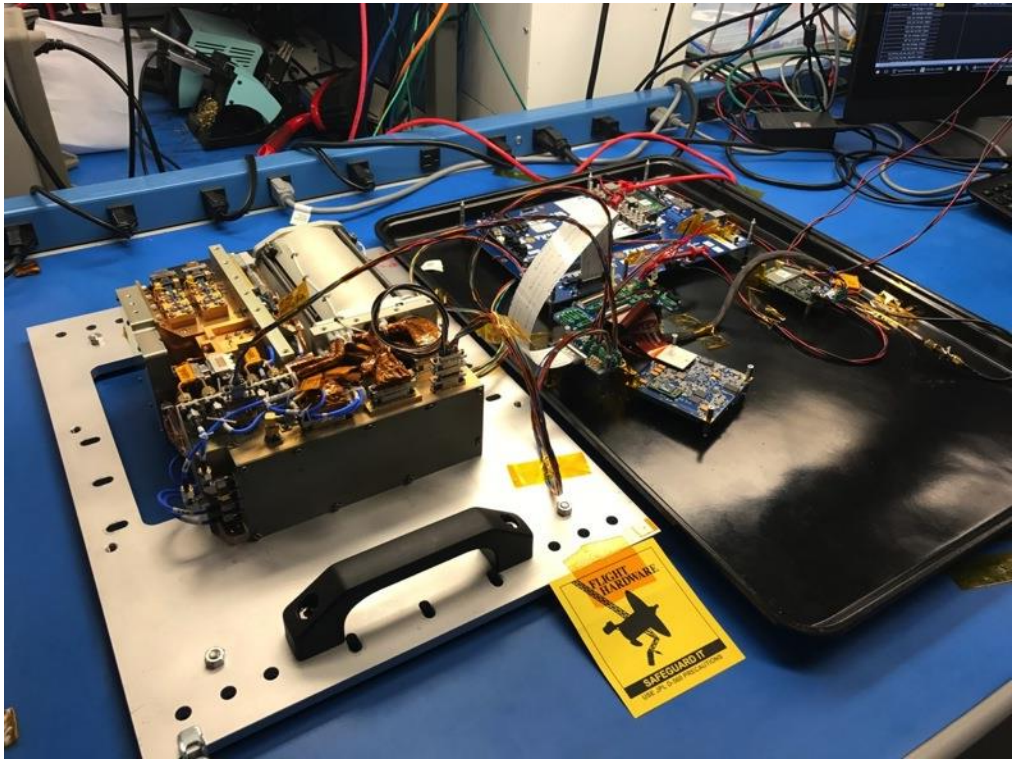
Spacecraft

Subsystem	Value
C&DH Processors	ARM9, Tyvak Linux Build
ADCS Processors (x2)	ARM Cortex A8
Battery Modules	~70Whr batteries @ 11.1V Nominal
Solar Panels	Deployable Fixed Angle Arrays. Peak Power ~ 45W. Contingency cells on opposing face. Sixty-Five total XTJ Cells.
UHF Radio	Tyvak UHF Radio operating @ 19.2kbps
S-Band Radio	Quasonix NanoTX transmitter at 4Mpbs
ADCS Control	0.029 degree control error (99.7th percentile) with redundant star trackers, three reactions wheels, three torque rods, IMU, sun sensors, and magnetometers.
Thermal Control	Active battery and payload warmers. Passive conduction and radiating surfaces for the remaining avionics and payload.
Antennas	Phased GPS Patches, and deployable UHF, S-Band Patch, and Ka-Band Dish
GPS	Novatel OEM-615



Flight System I&T

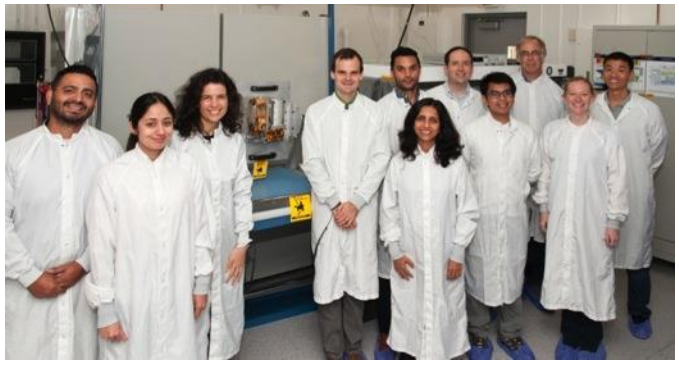
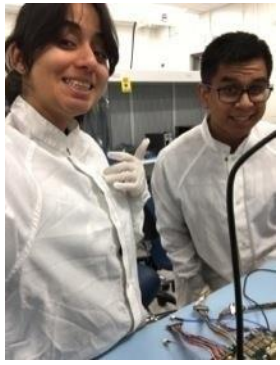
- Delivered flight radar July 2017
- Completed first interface test of radar and SC
- System I&T underway

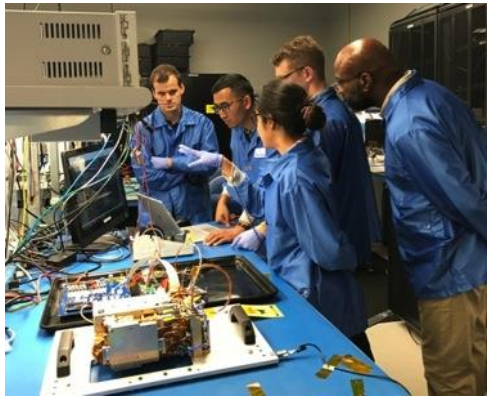
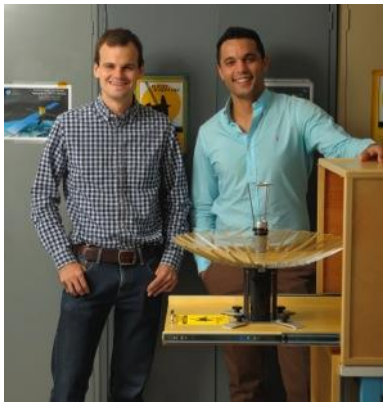
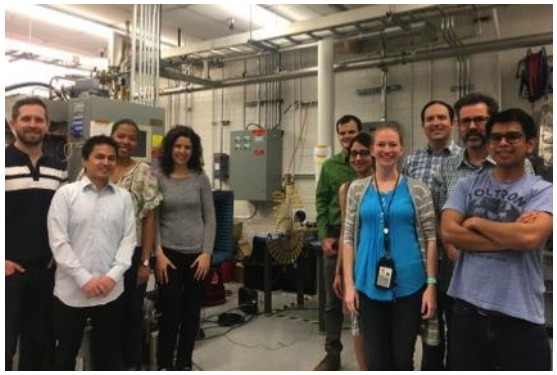


Work Ahead

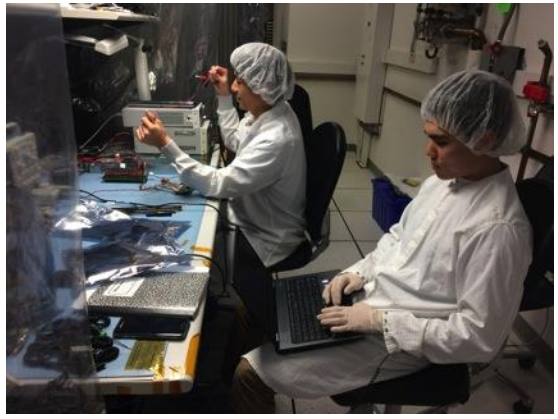
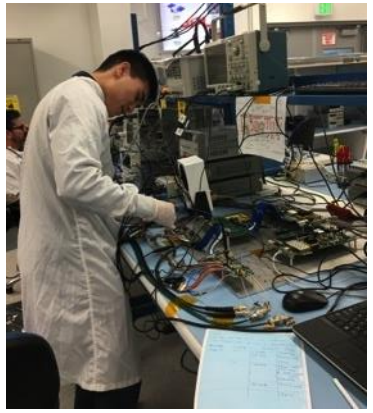
Activity	ECD
Flight system build and functional testing complete	Sept ‘17
Environmental testing complete - Hardware goes into storage and prep for mission ops	Nov ‘17
Mission Readiness Review	Jan ‘18
Deliver satellite to NanoRacks	Feb ‘18
Launch to ISS (OA-9 CRS Mission)	Mar ‘18
Deploy from ISS (est.)	May ‘18
Complete primary mission (est.)	Jul ‘18

RainCube Team Hard at Work



Special Thanks

- ESTO, Project Sponsor
  - Pam Millar
  - Charles Norton
- JPL Earth Science Program Office
  - Eastwood Im
- RainCube Team, JPL & Tyvak
  - Eva Peral
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  - Douglas Price
  - Nacer Chahat
  - Austin Williams
  - Many more…