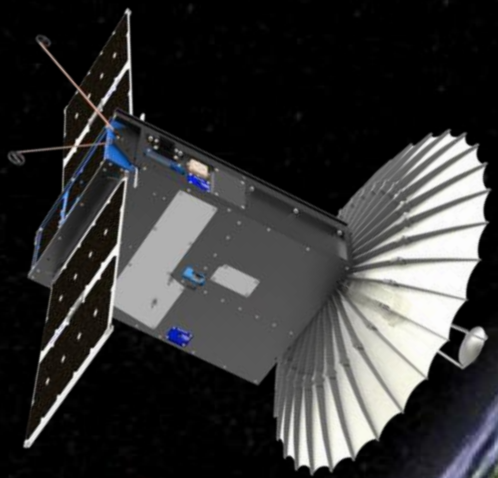
RainCube

# RainCube - First Ka-Band Precipitation Radar in CubeSat: From Concept To Mission



**Presenter - Shivani Joshi (Mission Operations Manager)**

**Principle Investigator - Eva Peral**
**Project Scientist - Simone Tanelli**
**Project Manager - Shannon Statham**
Jet Propulsion Laboratory,
California Institute of Technology, CA, USA

**Mission Operations Lead – Chris Shaffer**
Tyvak Nano-Satellite Systems, Inc., Irvine, CA, USA

CubeSat Developers Workshop – April 2019
Cal-Poly San Luis Obispo, CA

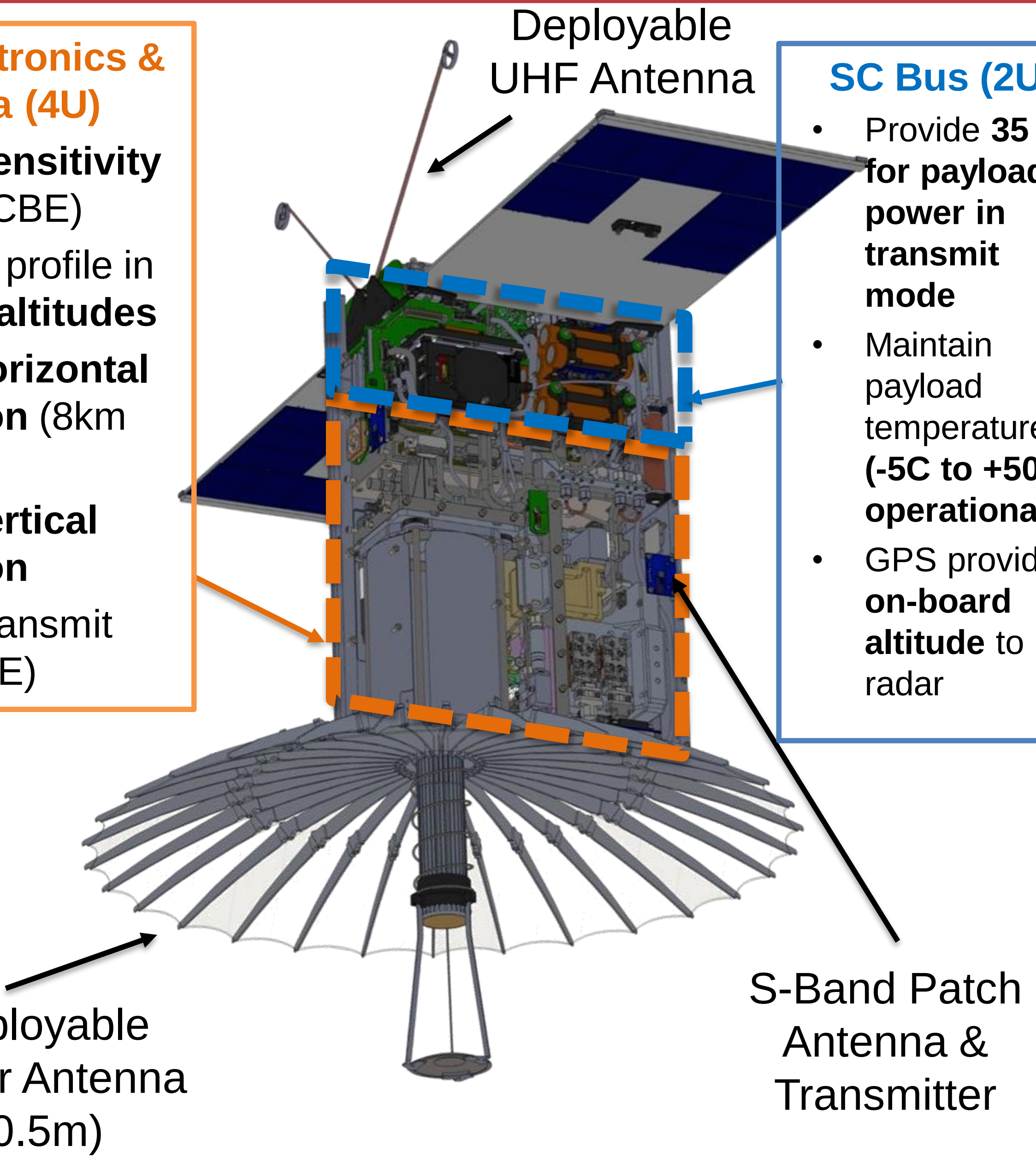
# Mission Overview and System Architecture

- RainCube (Radar in a CubeSat) is the first active radar instrument in a CubeSat platform to operate in Low Earth Orbit.

- RainCube is funded through the NASA Science Mission Directorate's (SMD) Research Opportunities in Space and Earth Science (ROSES) 2015 In-Space Validation of Earth Science Technologies (InVEST) solicitation with the goal of raising the instrument TRL from entry 4-5 to exit 7.

**Radar Electronics & Antenna (4U)**

- **20dBZ sensitivity** (10 dBZ CBE)
- Vertically profile in **0-18 km altitudes**
- **10 km horizontal resolution** (8km CBE)
- **250 m vertical resolution**
- 35W in transmit (22W CBE)




**SC Bus (2U)**

- Provide **35 W for payload power in transmit mode**
- Maintain payload temperatures **(-5C to +50C operational)**
- GPS provides **on-board altitude** to radar

# Organization Chart

**RainCube Program Manager**
Eastwood Im / Gary Lau

**Principal Investigator**
Eva Peral

**Principal Scientist**
Simone Tanelli

**Project Manager**
Shannon Statham

**Spacecraft Manager**
Macon Vining

***JPL***
**Mechanical:** J. Sauder
**Thermal:** J. Kanis, S. Carlson
**ACS:** K. Lo
**Comms:** A. Babuscia
**MOS/GDS:** S. Gibson

***Tyvak, Inc.***
**Manager:** A Williams
**Systems:** R Prasad
**Mechanical:** J Brown
**Thermal:** S Yamamoto
**ACS:** J Bowen
**Electrical:** J Abel
**Software:** S Fitzsimmons
**AIT:** N Fite

**Radar Instrument Manager**
Eva Peral

**Instrument Engineer:** D Price
**Antenna RF**: N Chahat
**Antenna Mechanical:** J Sauder, T Bailey
**Power Electronics:** G Cardell, B Wang, D Chi
**Electronics RF:** D Price, C Parashare
**Digital Assembly:** M Cruz, S Joshi, B Ortloff, D Wang
**Electronics Packaging:** G Gaughen, J Cardone

**Mission Operations Manager**
Shivani Joshi

**SC Mission Operations Lead**
Chris Shaffer (Tyvak Inc.)

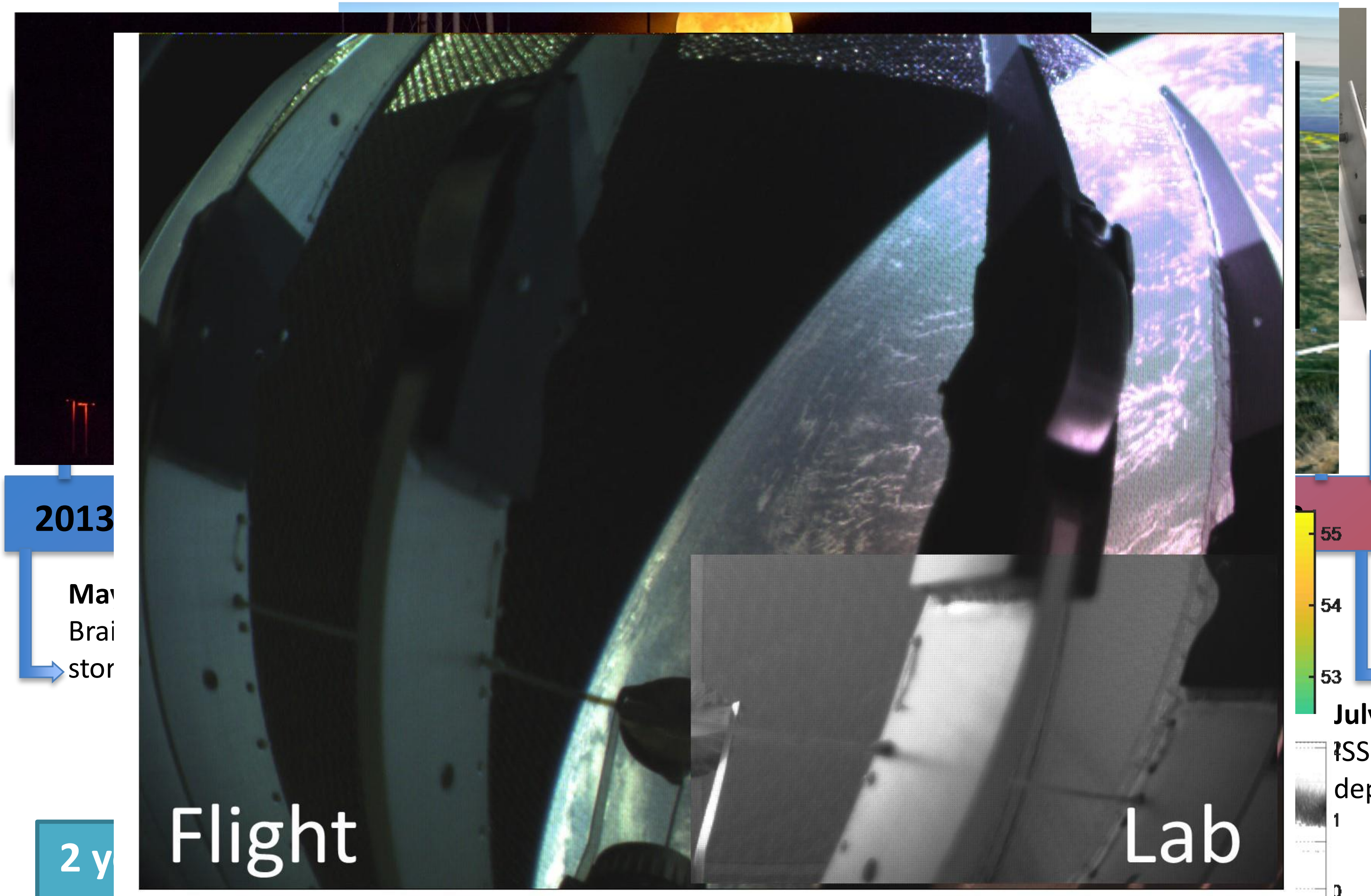
**JPL**
**Science Data Processing:** E Peral, S Tanelli, G F Sacco, O Sy
**JPL Anomaly Response Team:** E Peral, S Tanelli, S Statham, T Imken, N Rouse, J Sauder (Antenna)
**Additional Anomaly Resolution support:** B Ortloff, D Price, M Cruz

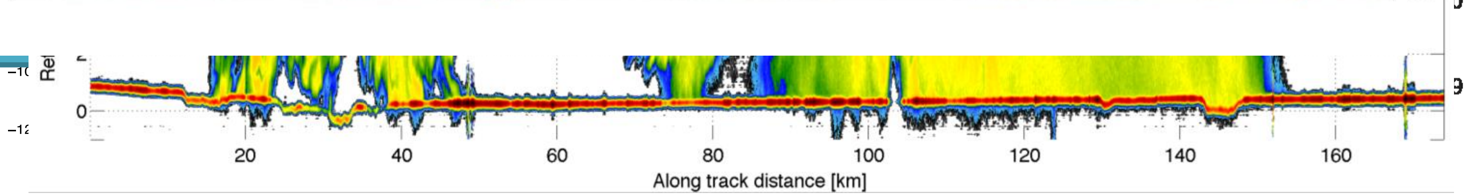
***Tyvak, Inc.***
**Manager:** A Williams, T Mosher
**Operations Manager:** M Villa
**SC Operators:** K Kawashima, J Price, S Sundin
**SC Commissioning support:** S Fitzsimmons

**Mission Assurance Manager**
Carlo Abesamis, Nazilla Rouse

**Lead Systems Engineer**
Travis Imken

# Timeline from TRL0 to TRL 7




**2013**

**May**
Brai
stor

**2 y**

**July 13**
ISS
deployment

**July 28**
Antenna
deployment

**Aug 5**
First echo

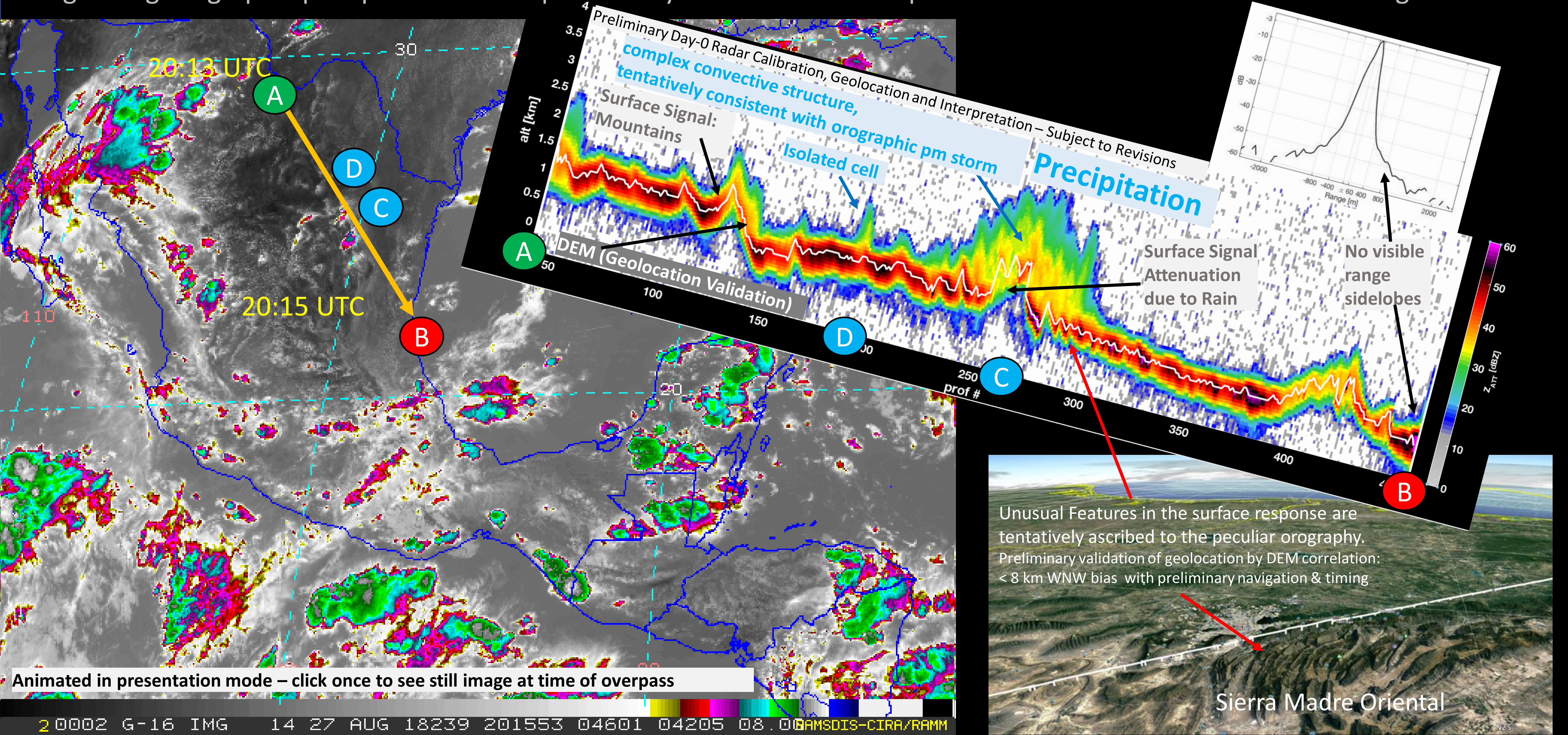
**Aug 27**
**First rain!**

**Sept '18**
1st Extended
Mission

**Feb '19**
2nd Extended
Mission

# RainCube Tx Operation #23 - August 27 , 2018 – 20:14 UTC

First successful operation in Nadir Pointing & first detection of rain over the Sierra Madre Oriental, near Monterrey, Mexico. Fast growing orographic precipitation developed shortly before RainCube's pass which overflew its north-eastern edge



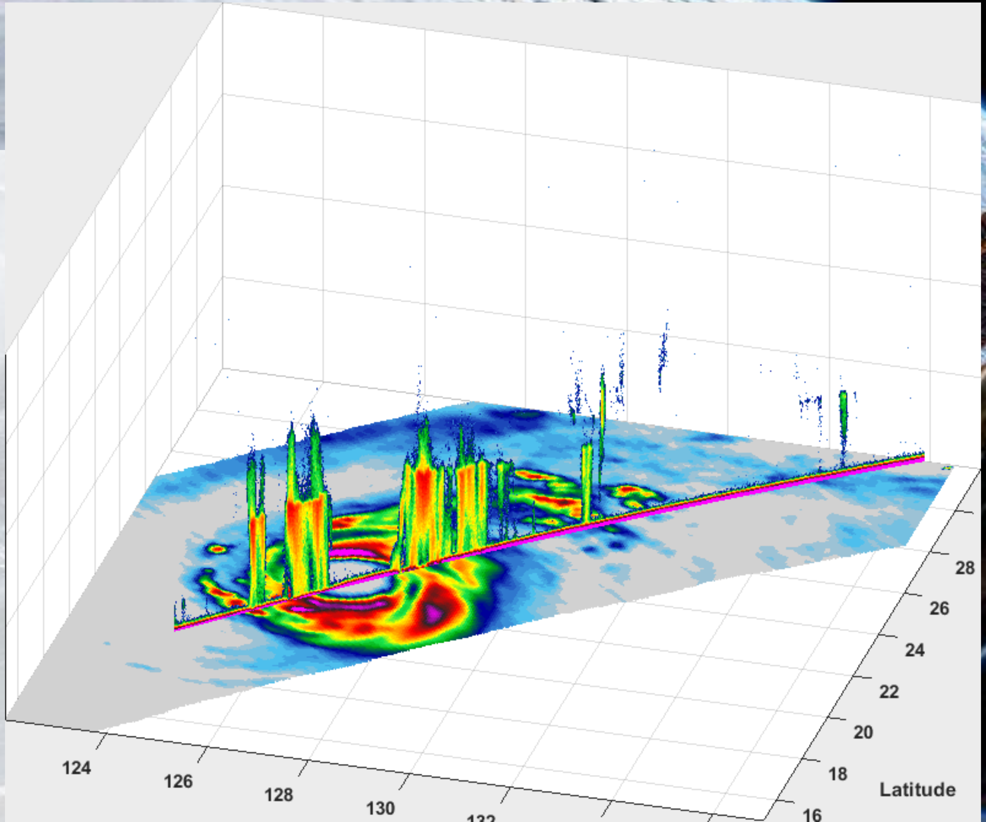
# RainCube and TEMPEST-D coincidental measurement of Typhoon TRAMI

• September 28, 2018, TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart

• RainCube nadir Ka-band reflectivity shown overlaid on TEMPEST-D 165 GHz brightness temperature illustrating complementary nature of these sensors in constellation for observing precipitation

• Trami observed shortly after it had weakened from Cat 5 to Cat 2

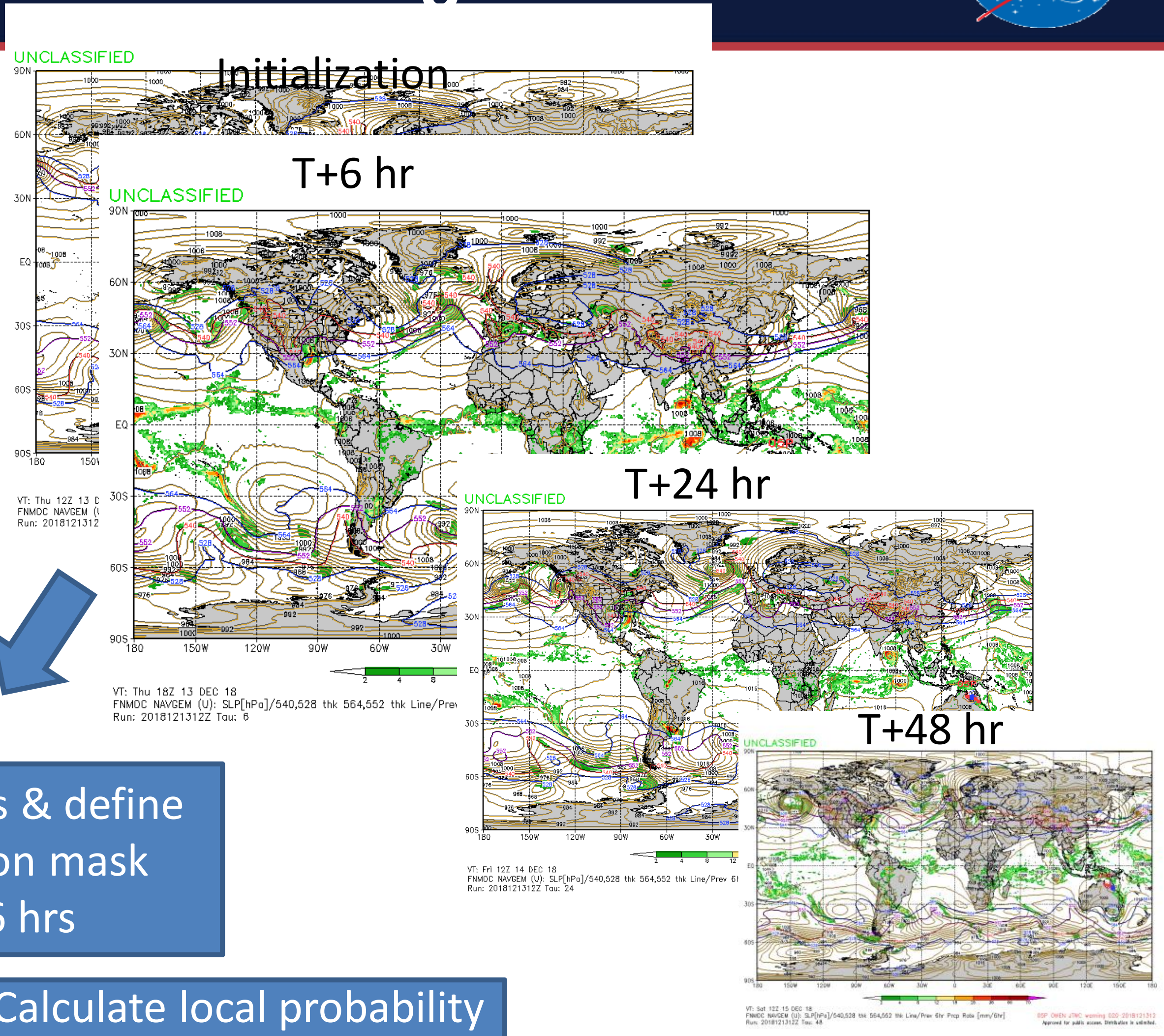
*Slide Credit – Shannon Brown (TEMPEST-D), Simone Tanelli (RainCube)*



# Science Operations Planning

In order to improve efficiency of mission operations, we increased automation starting with automating the planning of events in a prioritized way

- **Constraints**
  - Maximum of 6 20 minute Radar Acquisitions per day
    - Imposed by spacecraft power system
  - No operations on consecutive orbits
    - Imposed by spacecraft power system
  - No operations in umbra
    - Preferred because of higher occurrence of reboots in umbra
- **Target Priorities**
  - Forecasted presence of precipitation
  - CONUS – for NEXRAD
  - GPM – for DPR
  - Storms of interest



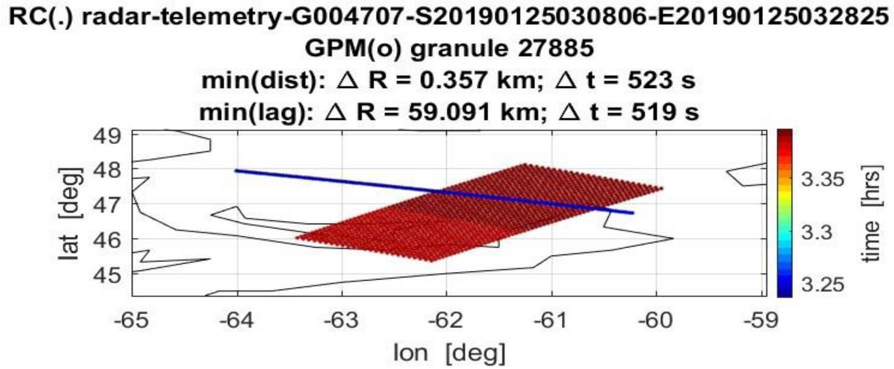

Parse images & define precipitation mask every 6 hrs

Calculate local probability of precipitation along the predicted orbit of RainCube

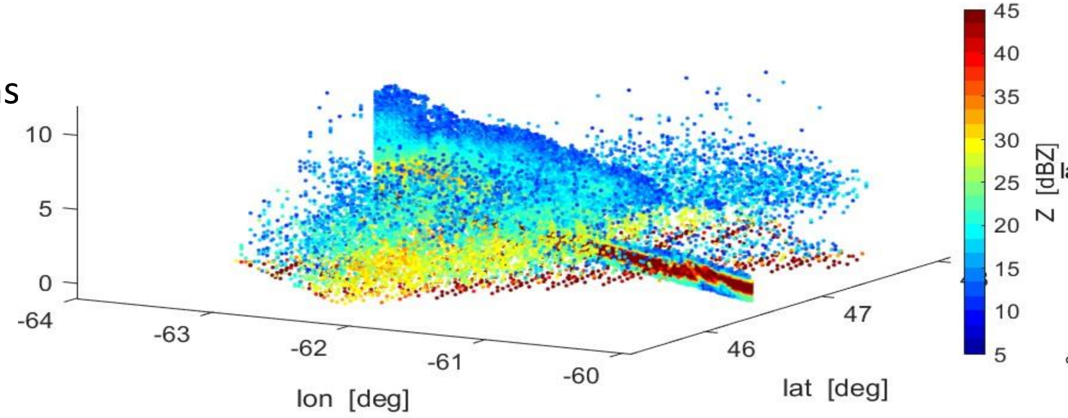
Prioritize close approaches with GPM and passes over GPM GV sites (CONUS, Japan, Australia)

# RainCube Collocated Observations with GPM (Post Optimisation)

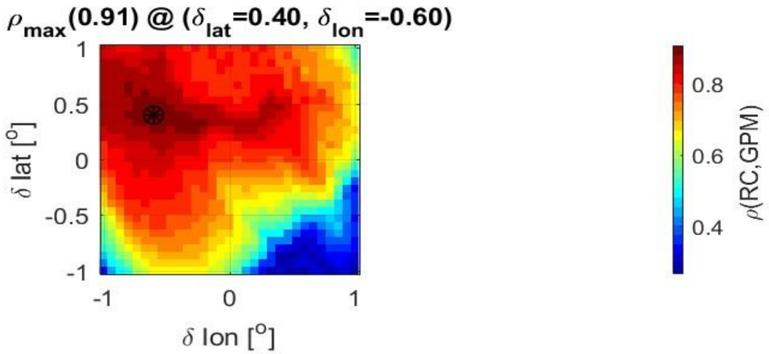
RainCube
GPM
tracks vs time

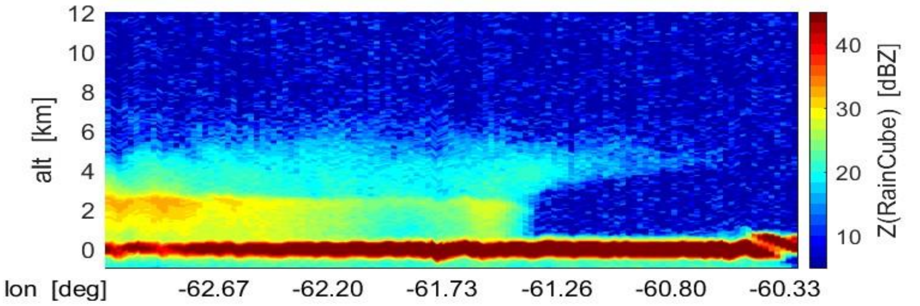



3D view of
Observations
close to
intersection

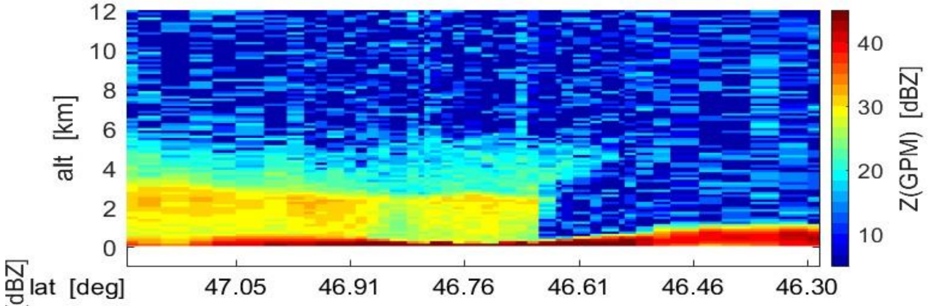



Pointing
assessment

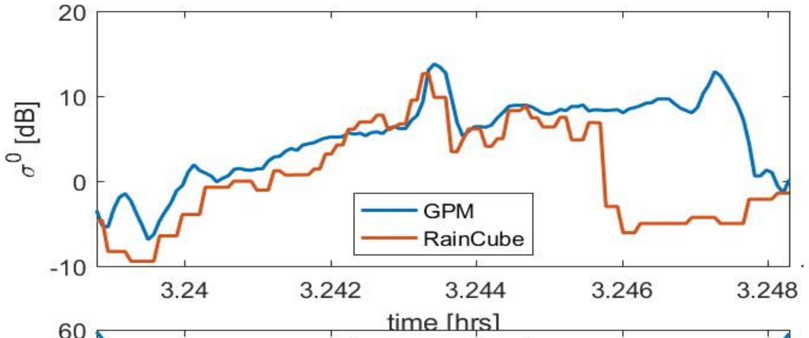


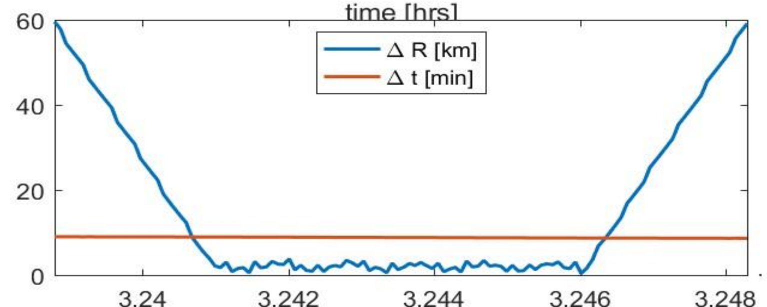

Z(RainCube)




Z(GPM)
collocated

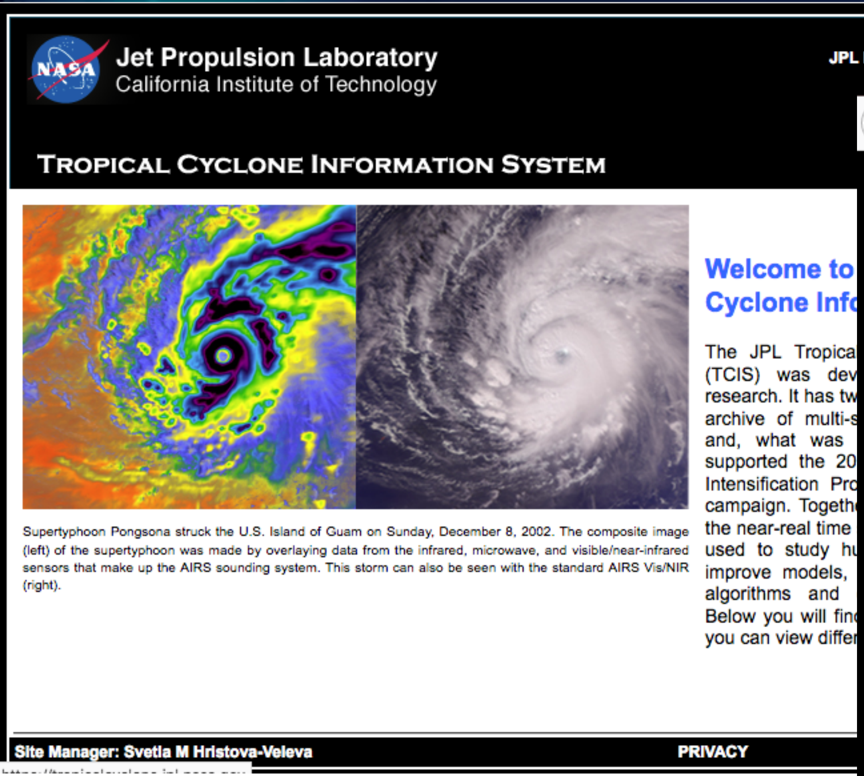


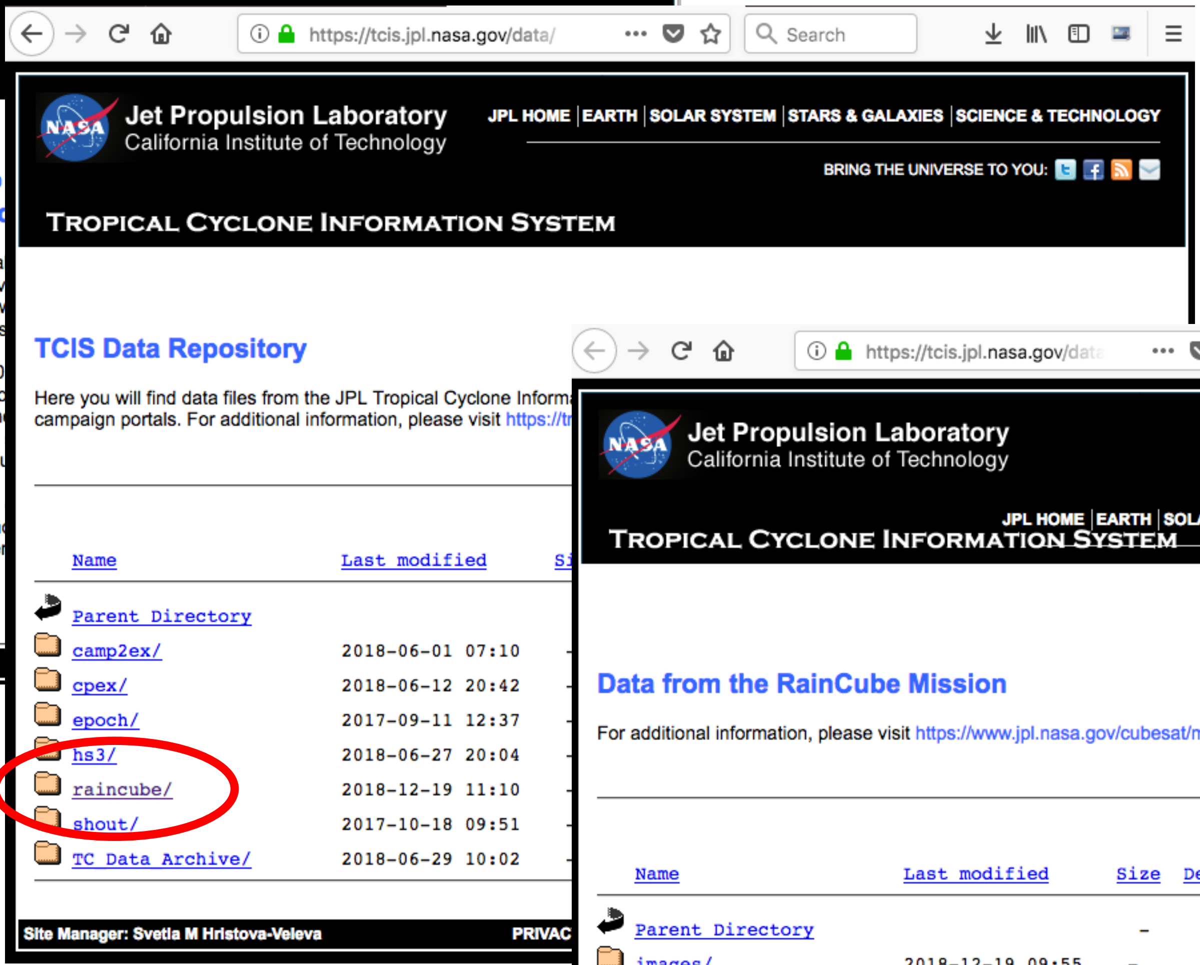

NRCS $\sigma^0$

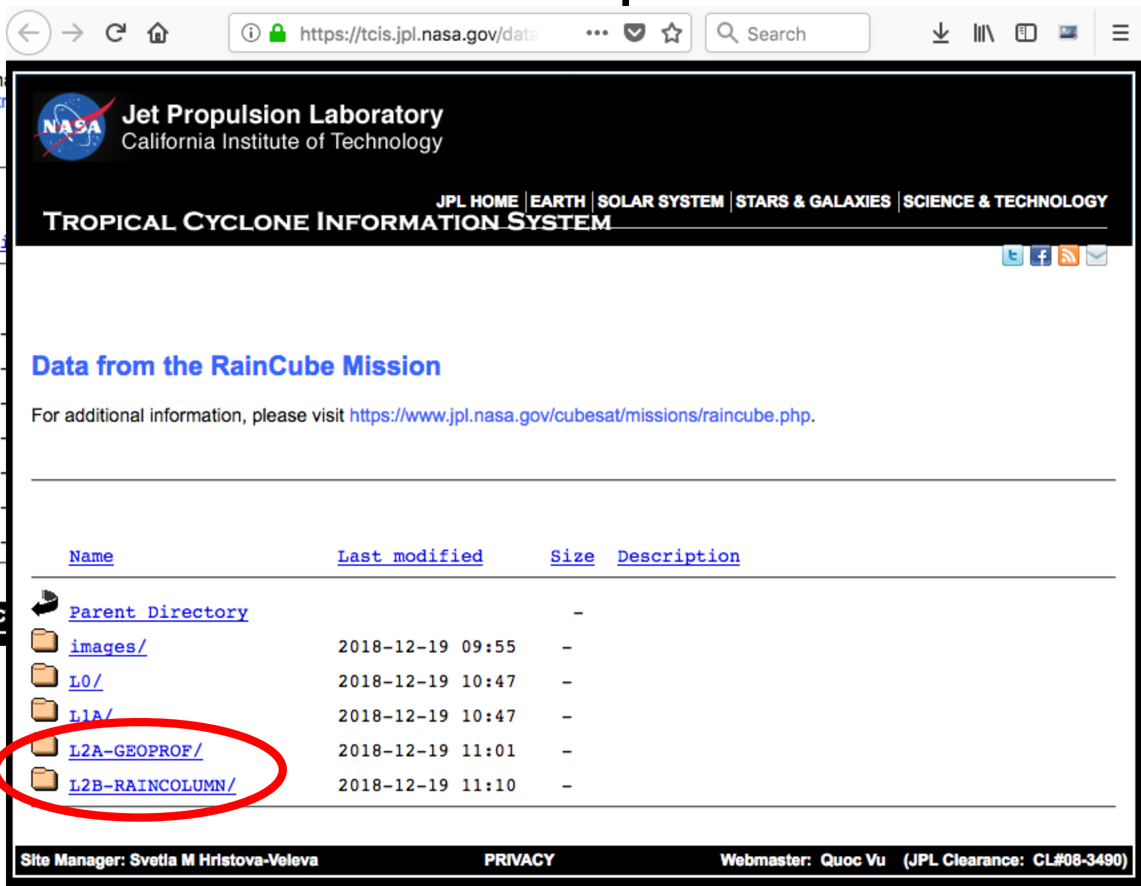



Separation
between
RainCube and
closest GPM
profile

# RainCube Data is Available on TCIS Portal




The Tropical Cyclone Information System will host RainCube data.

Huge thank you to PI : Svetla Hristova-Veleva, Site Administrator Quoc Vu, and Data Manager Brian Knosp)

Tested posting data and accessing through url.

L2 Data will be made public when QC is satisfactory.

No plan to open L0 and L1 data to the public.

# Lessons Learned

## 1. Extended Formulation Phase

- Resulted in simplification of the architecture and **early execution of de-scopes** which focused the team on the core challenges needed for a successful technology demonstration.

- The many table top reviews with internal team of subsystem experts ensured that project and radar-system requirements captured mission's goals **without placing implementation burden on TBD bus vendor.**

## 2. Tailored versions of NASA and Institutional Flight Practices

- RainCube's project philosophy was to meet with all of the groups that are normally involved in flight projects and work with them to determine what benefits could be provided within the cost and schedule limits.

- For these items in which RainCube could not directly comply, the DTAB worked with the team to identify alternatives or mitigations. **The DTAB experts also provided guidance on the development of risk likelihoods, consequences, and mitigations that were specific to the mission.**

# Lessons Learned

## 3. Pros and Cons of 6U form factor

### Pros

- easy access to space through a standardized dispenser
- Most CubeSat bus vendors support this form factor
- More support and lessons learned available in CubeSat community

### Cons

- Routing of cables can be challenging
- Thermal control can be challenging
- Limits size of deployable antenna for radar applications

## 4. Revise mass growth contingency

- The project was too conservative on mass through formulation and implementation due to the application of traditional 'large spacecraft' contingencies for mass growth.
- This overestimation is problematic on CubeSats since delivering significantly under mass could impact Earth orbit lifetime or require ballast to be installed into the spacecraft.
- The traditional 5-30% contingency applied to mass growth on large spacecraft should be reduced in CubeSat implementations, since the volume limits inhibit mass growth.

# Lessons Learned

## 5. Value of pre-Operations ORT

- RainCube's pre-operations readiness reviews with operations team at Tyvak gave the team chance to rehearse operations procedures for nominal and off-nominal situations.

## 6. Value of Anomaly Response Team

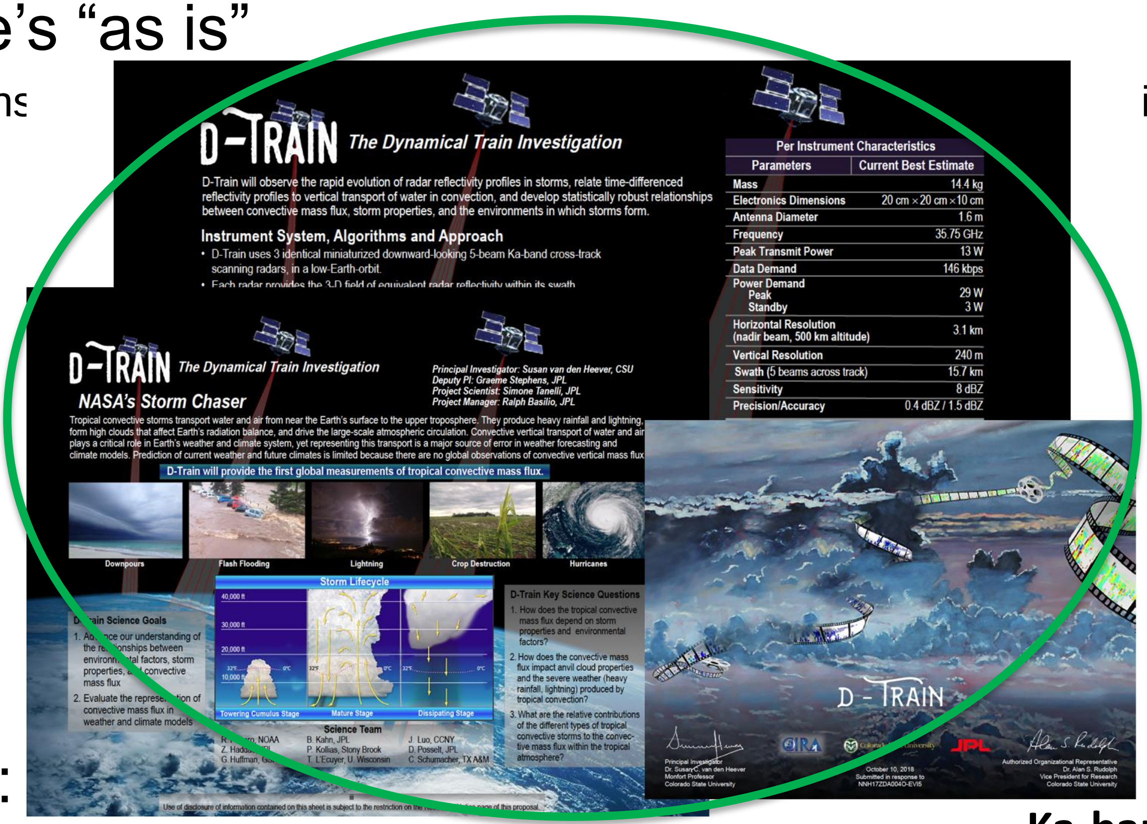
- Members of RainCube's ART provided valuable 24x7 anomaly response support to the operations team. They were instrumental in ensuring successful commissioning phase and prime mission success.

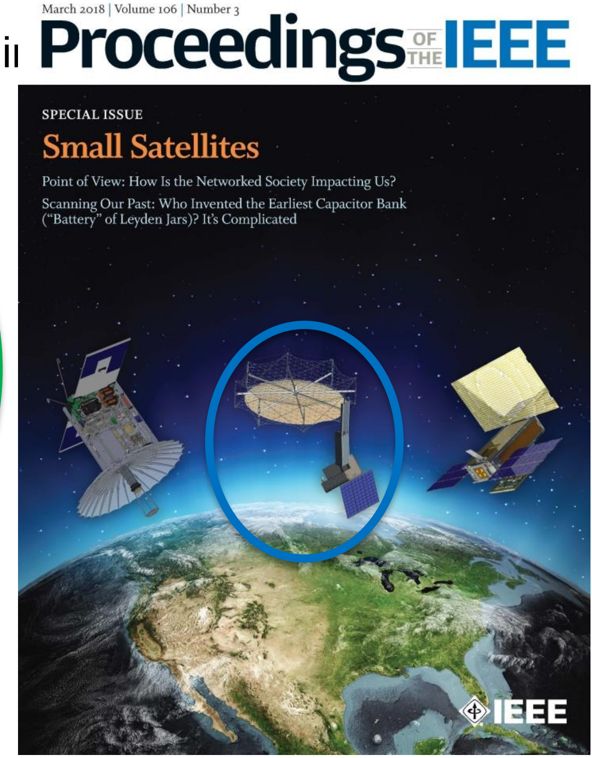
## 7. Prioritized mission objectives

- RainCube's PI and project scientist had clear objectives for operations team that went well beyond primary mission objectives.

# What’s Next?

- Constellation of RainCube’s “as is”
  - Analyze the current dataset to demons science questions.
- Constellation with a larger/scanning antenna
  - To address a larger set of science questions
  - Development of technologies and of mission concepts is ongoing
- Constellation with other Radars and Radiometers:
  - A study team in the Earth Science Decadal Survey 2017 will consider RainCube-like constellations for measurements of convection and precipitation
  - Higher frequency versions of RainCube for cloud and water vapor observations
- Planetary applications
  - An evolution of this instrument could support altimetry and cloud and precipitation on planetary targets




**Ka-band** ESTO InVEST and ACT programs

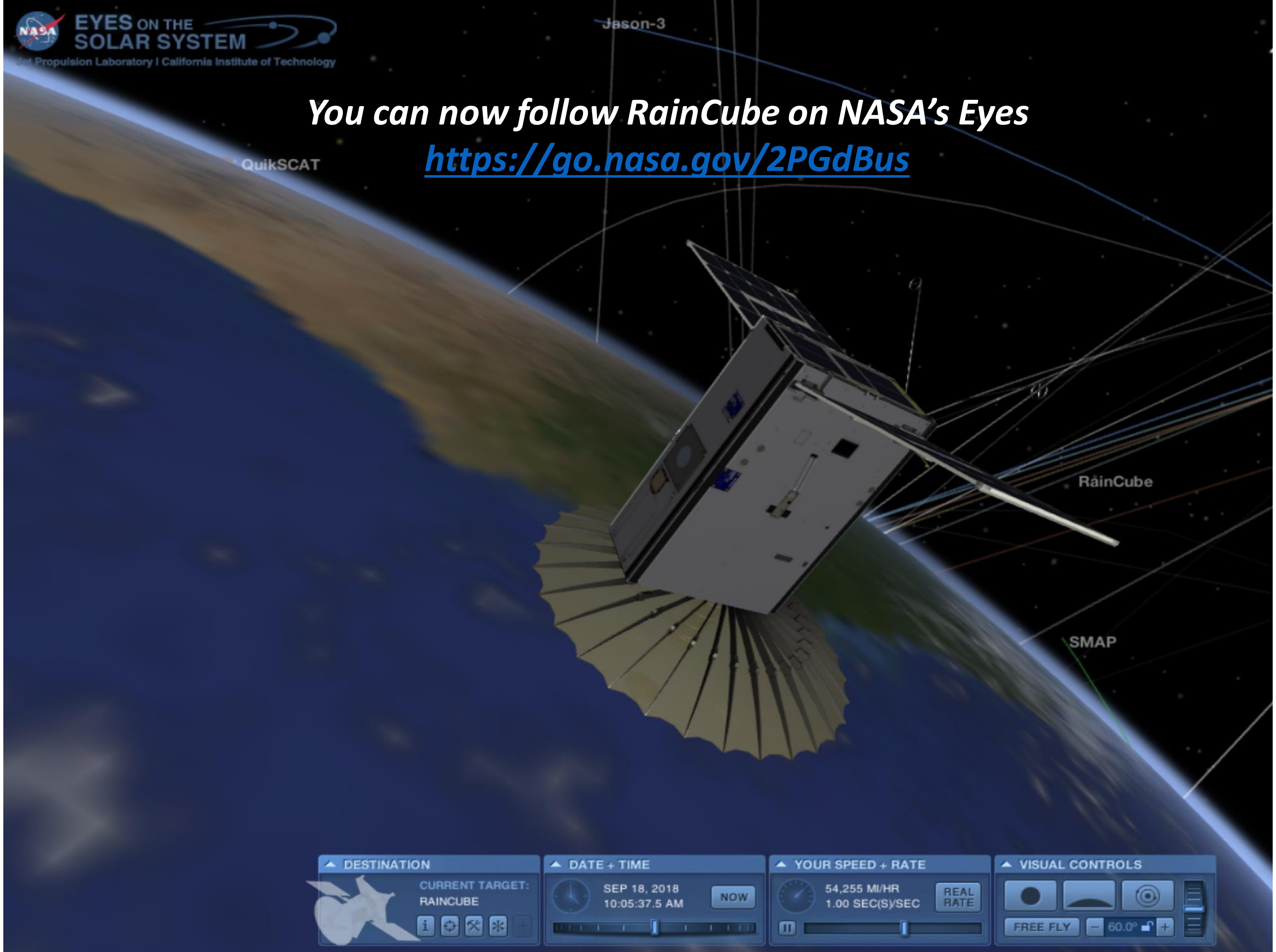
| | 6U | 12 U | 50 kg |
|---|---|---|---|
| Antenna size [m] | 0.5 | 1.0 | 2.0 |
| Sensitivity [dBZ] | 15 | 5-10 | 0-5 |
| Hor Resolution [km] | 8 | 4 | 2 |
| Range Res [m] | 250 | | |
| Beams | 1 | 1-3 | 1-5 |
| RF Power [W] | 10 | 10-20 | 10-40 |

# Concluding remarks

- RainCube is the first CubeSats to fly an active sensing radar payload, and the mission's success could pave the way for future constellations or convoy of many precipitation profiling radars.
- Since deployment in July 2018 with an originally planned three month demonstration mission, RainCube has been extended twice and has operated for nine months, three times its original mission length
- Different methods of operating the instrument and the spacecraft have been demonstrated based on lessons learned on-orbit
- JPL/Tyvak partnership and agility has enabled RainCube to exceed original mission expectations
- The project's lessons learned will be valuable as JPL and other institutions propose and develop enabling science and technology demonstrations on the small satellite platform.

*You can now follow RainCube on NASA's Eyes*

[*https://go.nasa.gov/2PGdBus*](https://go.nasa.gov/2PGdBus)




NASA
Jet Propulsion Laboratory
California Institute of Technology
RainCube Project Team
February, 2017
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RADAR FOR RAIN PROFILING
CubeSats
EXIT
RainCube
ASTERIA
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