Overview of the NASA TROPICS CubeSat Constellation Mission

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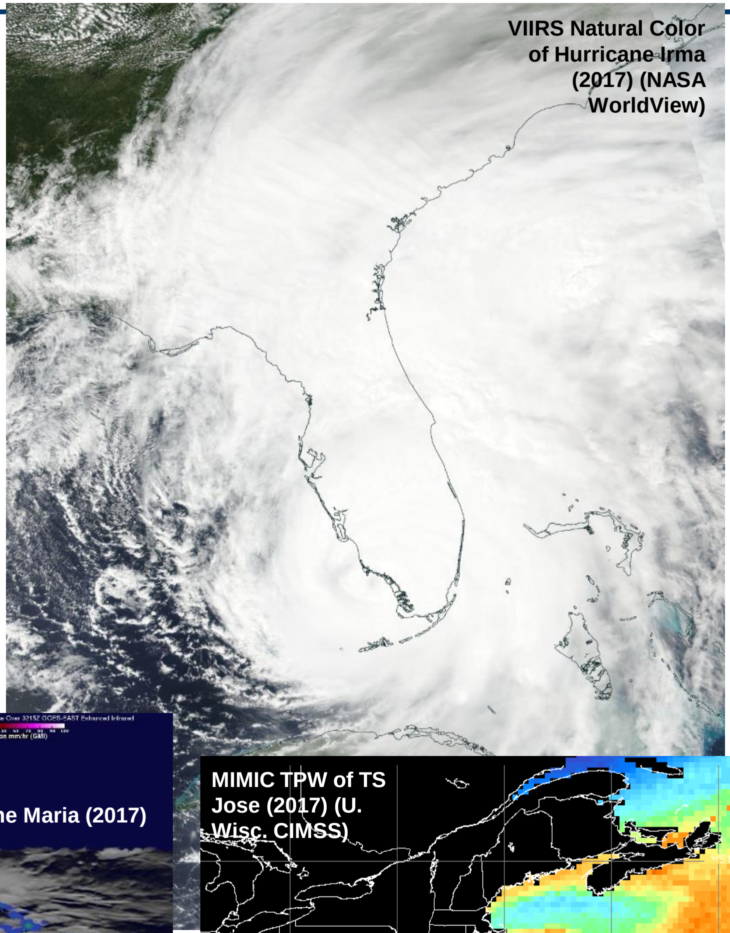
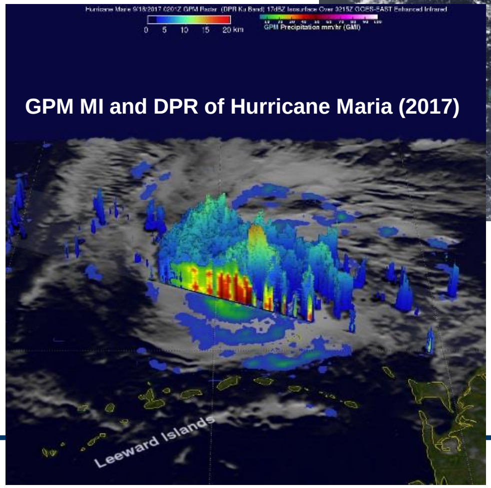
SPIE Optics + Photonics Conference

San Diego, CA

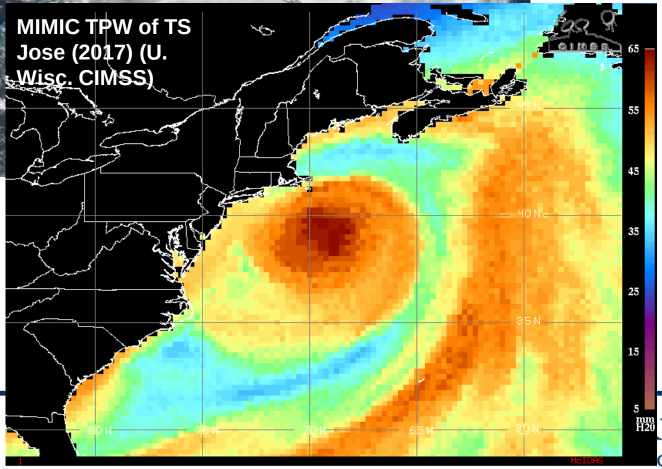
Why does NASA Study Hurricanes

- **Hurricanes result in large impacts to human population and infrastructure**
  - **Hundreds of deaths in 2017**
  - **\$369.6B (\$206.6B U.S.) damage in 2017†**
- **Lots of unanswered questions related to hurricane development being presented at this meeting:**
  - **Rapid intensification**
  - **Eyewall replacement cycles**
  - **Diurnal pulsing**
- **Mounting evidence that climate change is resulting in conditions that are more favorable for major hurricanes**


VIIRS Natural Color of Hurricane Irma (2017) (NASA WorldView)



GPM MI and DPR of Hurricane Maria (2017)

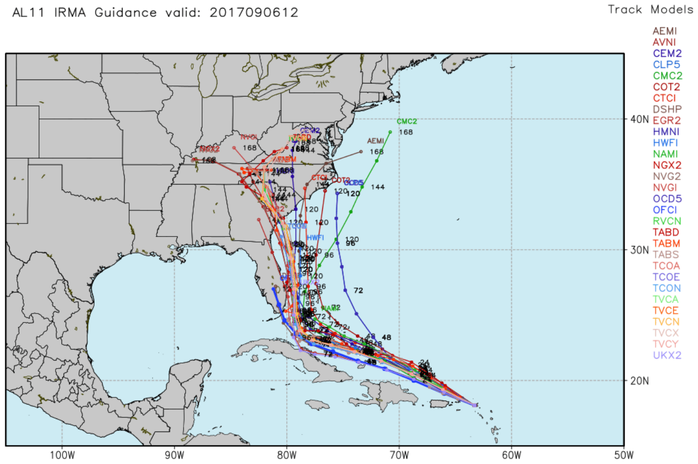


MIMIC TPW of TS Jose (2017) (U. Wisc. CIMSS)

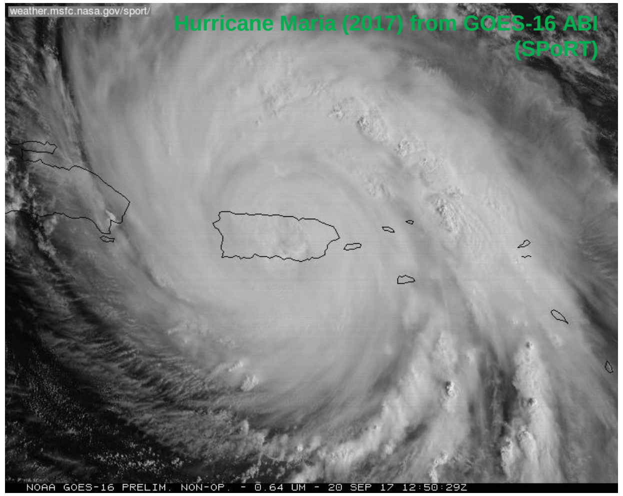
†Source: Charles Watson Jr. of Enki Holdings, LLC and Mark Johnson of JISC, Inc.

Current State of Observation and Forecasting

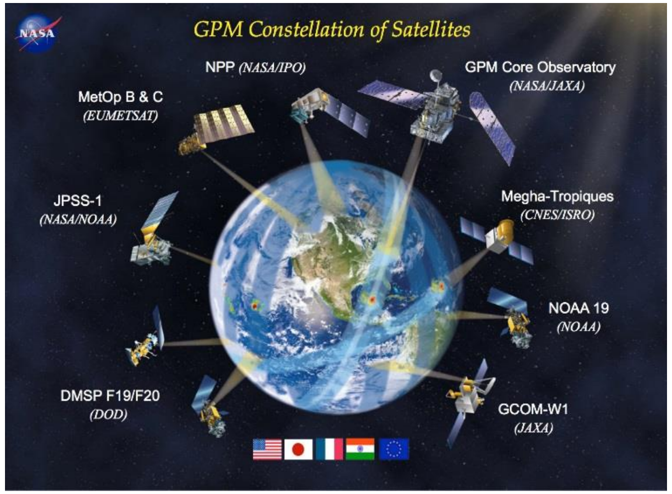
- **Numerical models provide information on storm track, capturing environment for steering and strengthening (or weakening)**
- **Intensity is measured using in situ observations, including dropsondes during aircraft missions**
- **Satellites help understand storm structure, which relates to intensity**
  - **Geostationary measurements rely on visible and infrared wavelengths that can see shape and motion but lack the ability to see through clouds**
  - **Passive microwave sensors can see through clouds but are limited to polar-orbiting or high-inclination orbits, reducing ability to study storm evolution**




Eye of Hurricane Irma (2017)



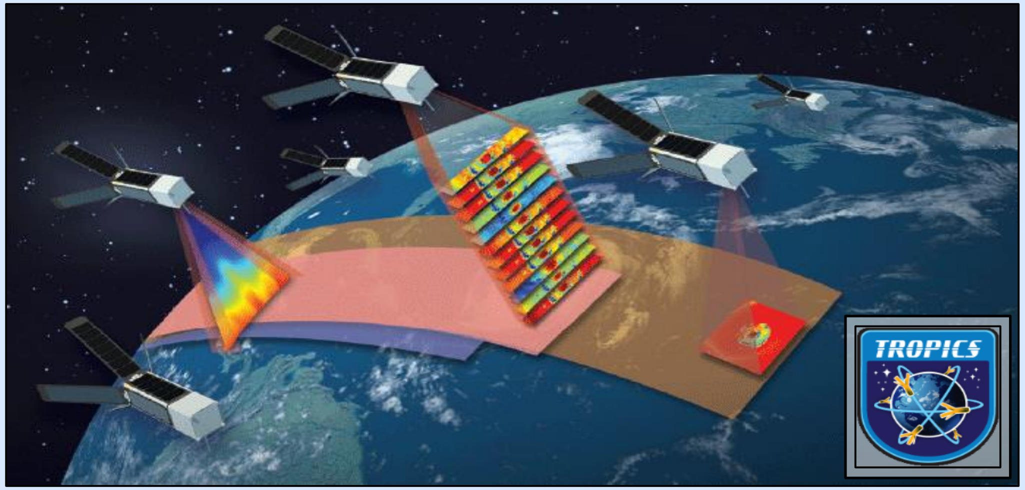
Hurricane Maria (2017) from GOES-16 ABI (SPoRT)



TROPICS

<u>T</u>ime-<u>R</u>esolved <u>O</u>bservations of <u>P</u>recipitation structure and storm <u>I</u>ntensity with a <u>C</u>onstellation of <u>S</u>mallsats

- Led by MIT Lincoln Laboratory
- TROPICS data will address critical science questions related to Tropical Cyclones
- First NASA science mission implemented with CubeSats
- First proliferated CubeSat constellation mission funded by the US government
- Flight hardware now under test
- NASA-provided launches NET 2020
- $31M PI-managed budget cap



Ultra-compact Processor
Univ/Industry Partnerships

High-Performance
BCT 3U CubeSat

TROPICS Science Objectives

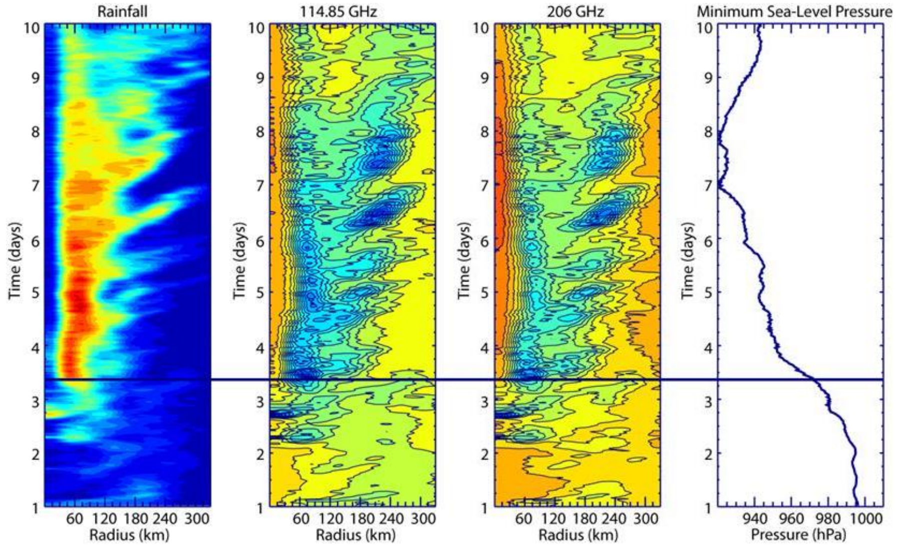
Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated intensity changes

Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution

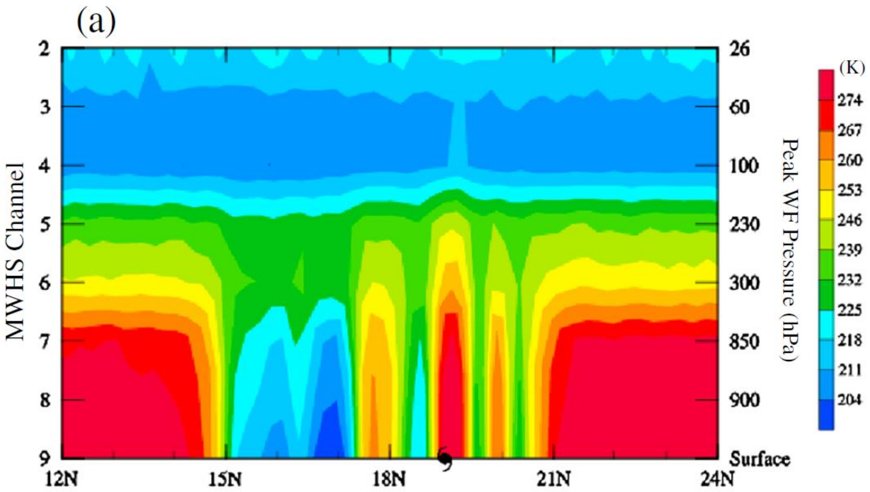
Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity

Assimilate microwave observations in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity

Spatio-Temporal Characteristics

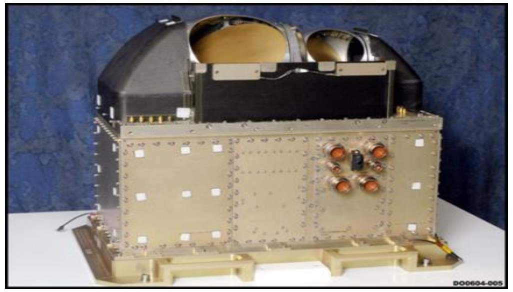


Spectral Characteristics



New Approach for Microwave Sounding

Advanced Technology
Microwave Sounder
(ATMS)



100 kg, 100 W

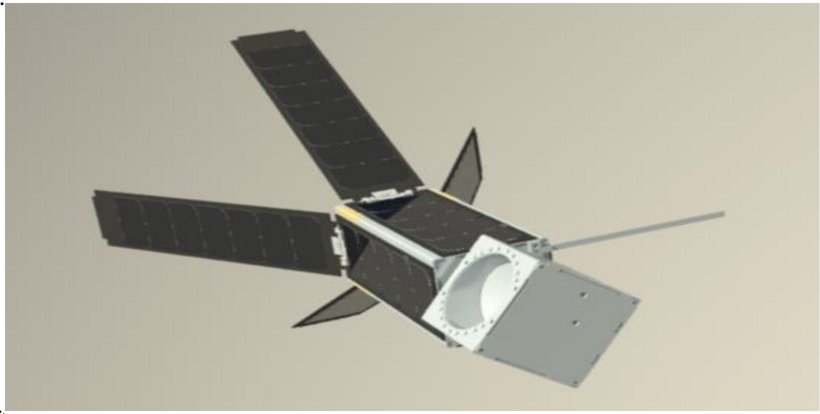
Suomi NPP Satellite
(Launched Oct. 2011)

2100 kg

NASA/GSFC

NPP: National Polar-orbiting Partnership

MicroMAS Satellite



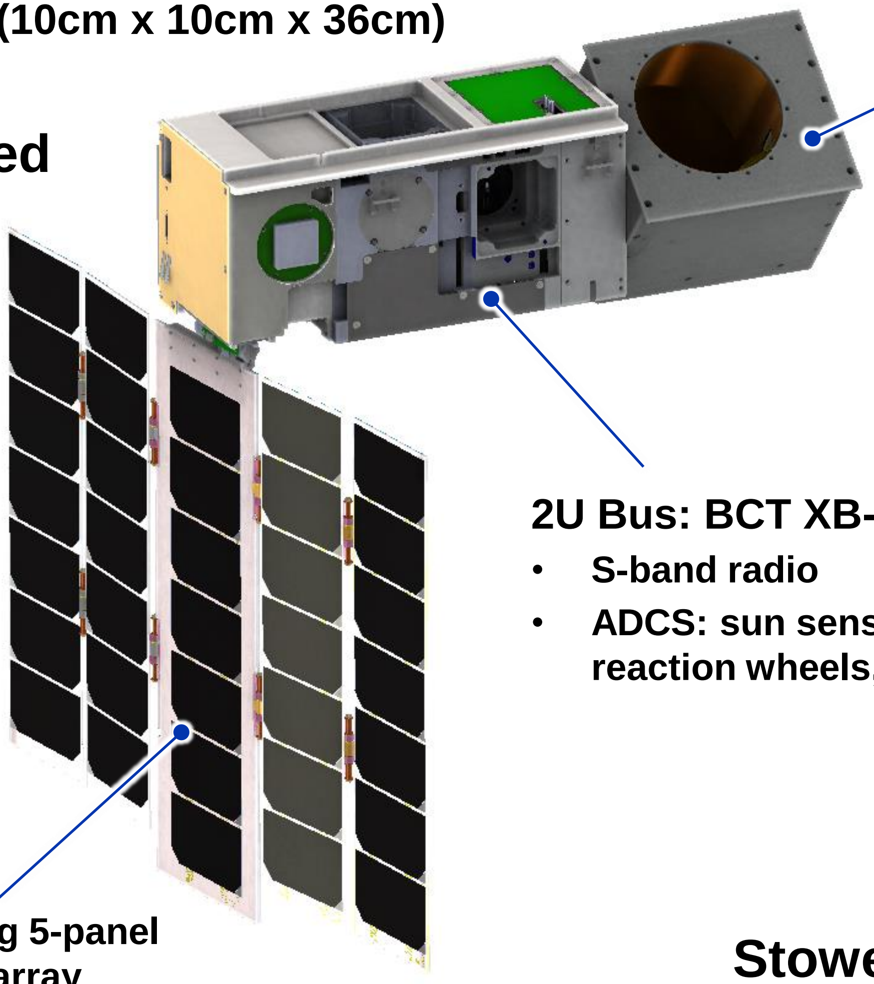
4.2 kg, 10W, 34 x 10 x 10 cm

- Microwave sensor amenable to miniaturization (10 cm aperture)
- Broad footprints (~50 km)
- Modest pointing requirements
- Relatively low data rate

TROPICS CubeSat Overview

3U CubeSat
(10cm x 10cm x 36cm)

Deployed



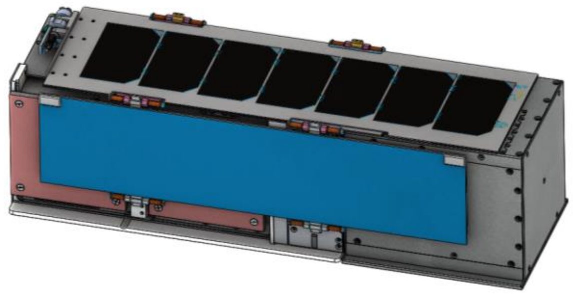
1U Payload
- Rotating microwave radiometer
- Scanner assembly
- 83 mm aperture
- Noise-diode / sky calibration

Ultra-compact W / F / G radiometer
- W band 92 GHz
- F band 7 ch (114-119 GHz)
- G band 4 ch (183±1, 3, 7), 204 GHz

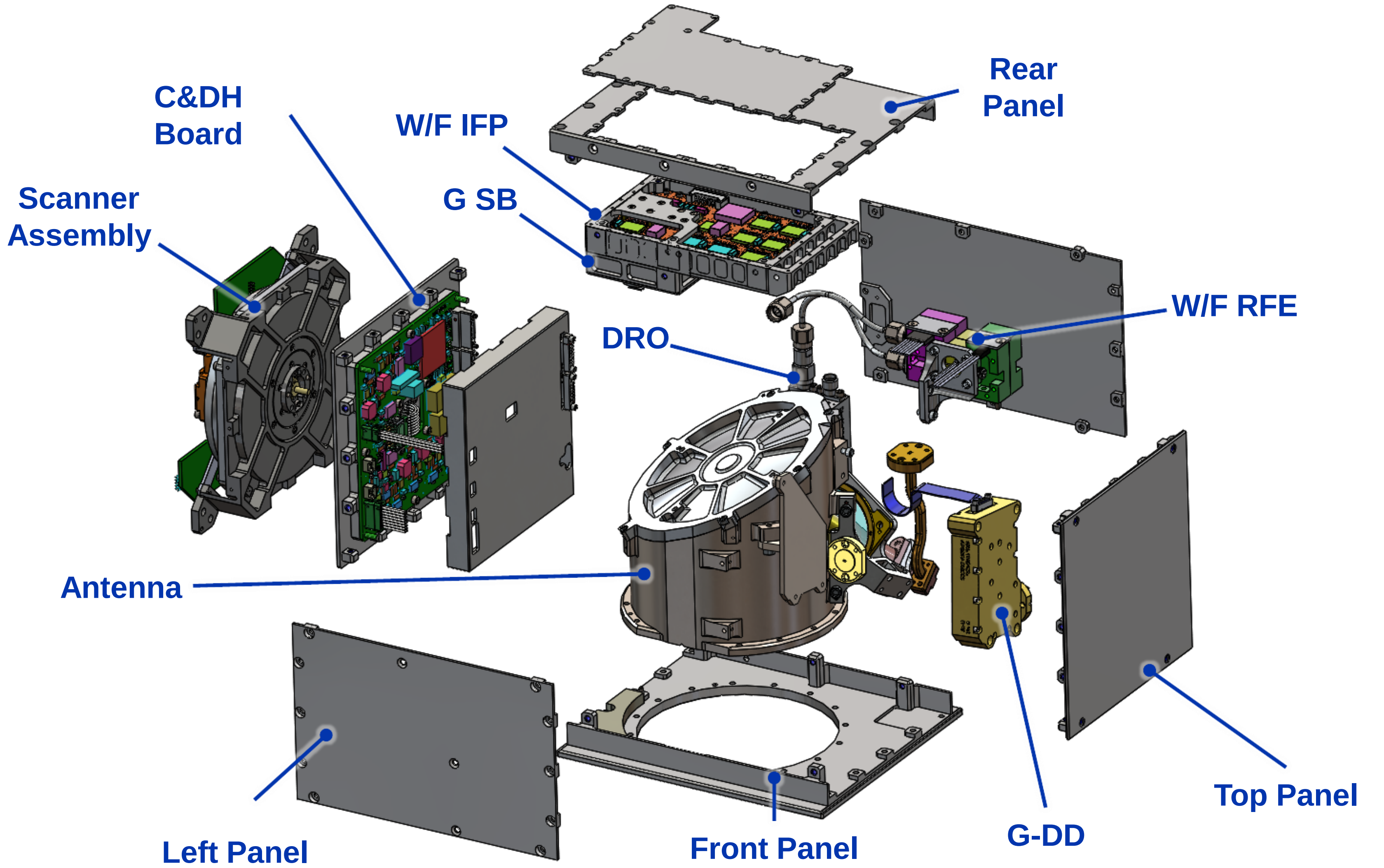
2U Bus: BCT XB-1
- S-band radio
- ADCS: sun sensor(s), star-camera, reaction wheels, torque rods

Articulating 5-panel solar array

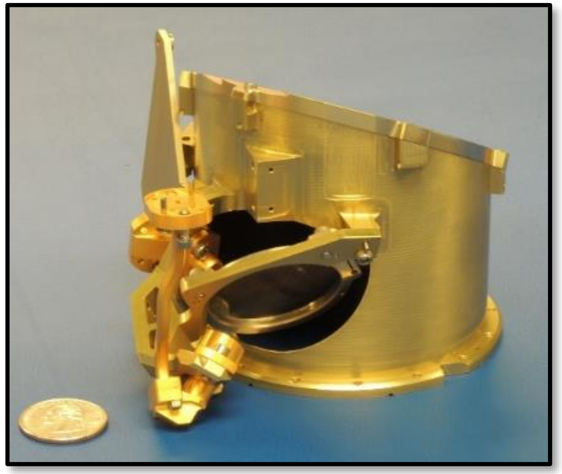
Stowed



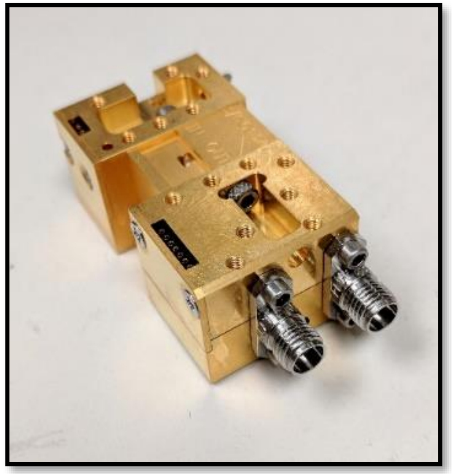
TROPICS Payload Details



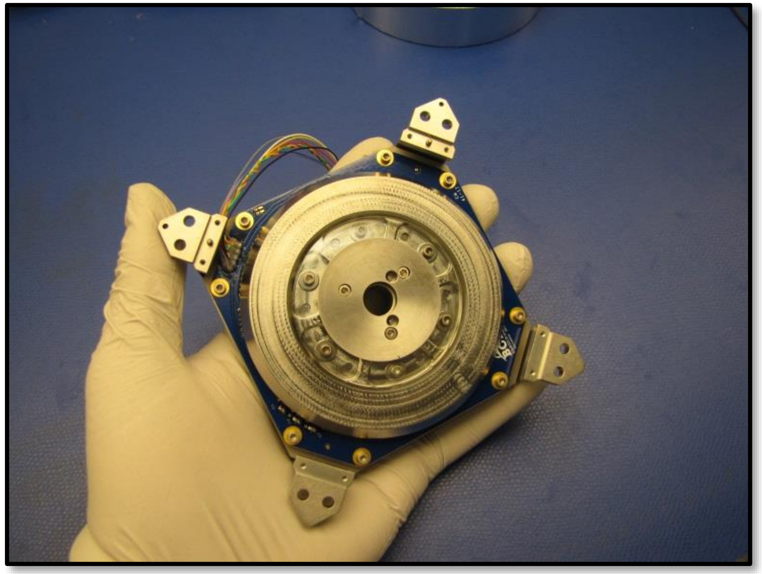
TROPICS Radiometer Flight Hardware



Dual-band antenna and
wire grid diplexer



90/120-GHz receiver
front end ("WF-RFE")

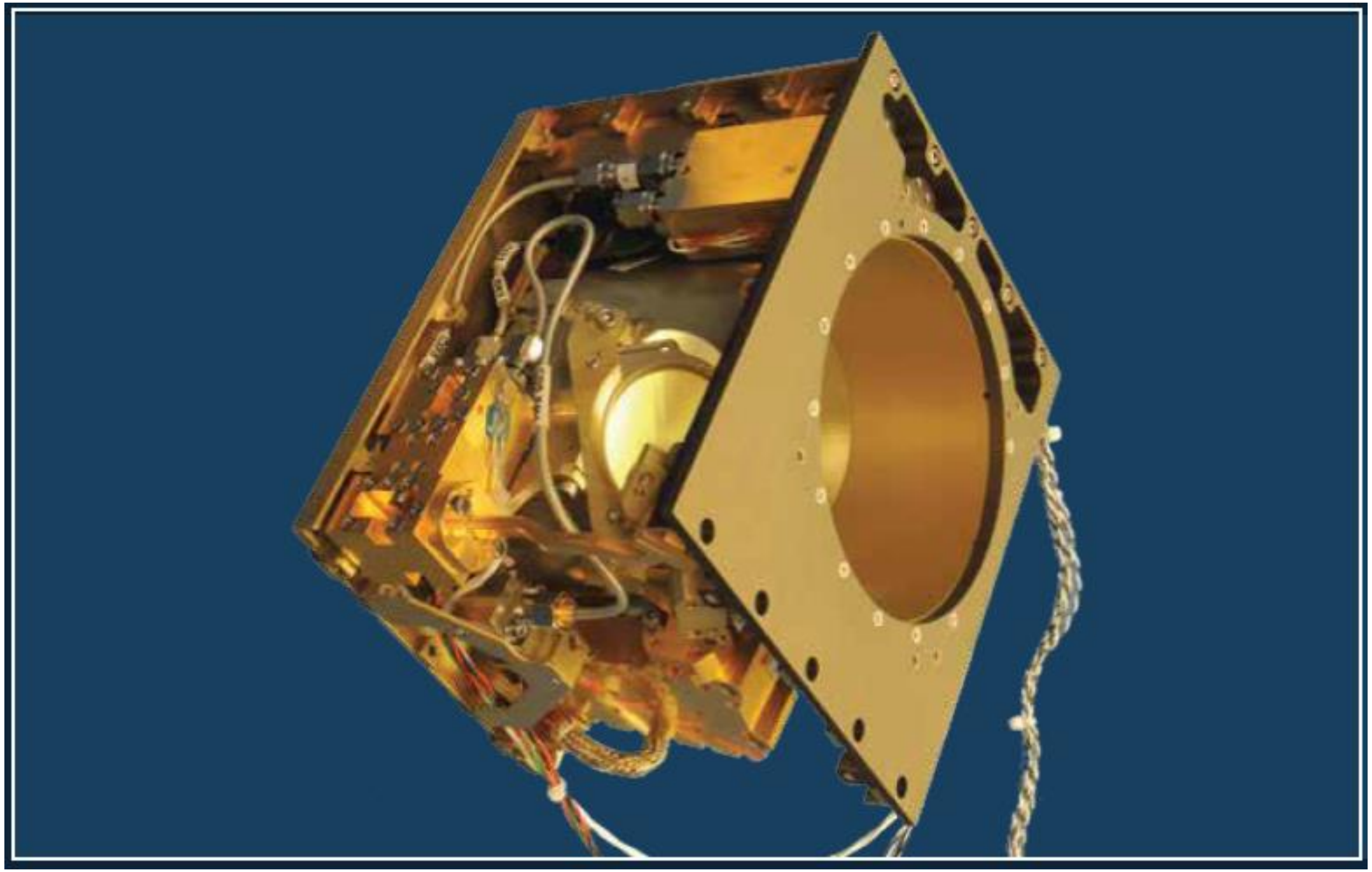


Precision Scanning Assembly

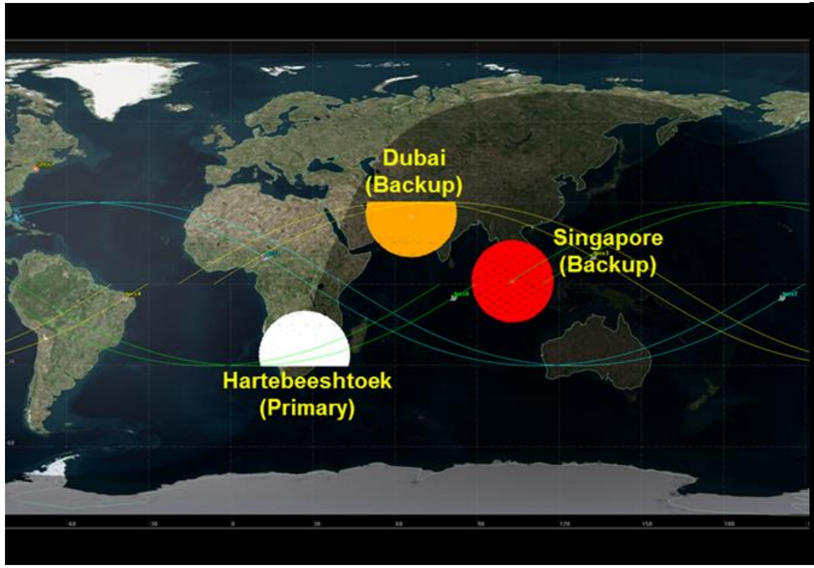
Radiometer back-end
processor ("WF-IFP")

Payload control and
data handling board

TROPICS Qualification Payload Now Undergoing TVAC Testing



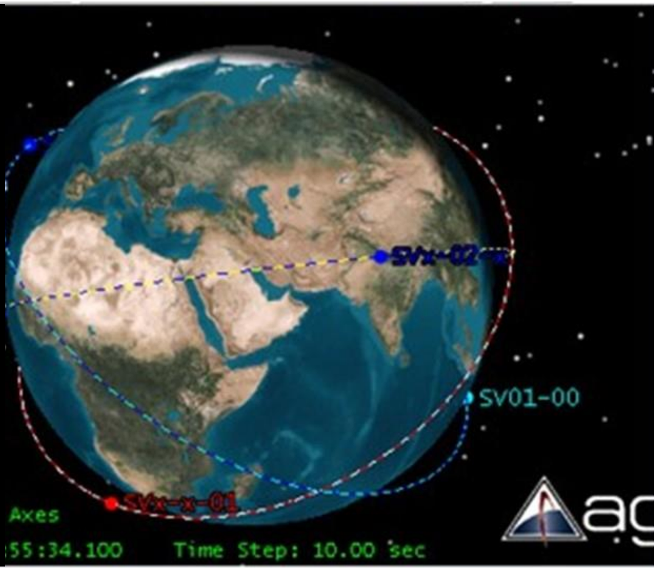
TROPICS Mission Overview



Six CubeSats
Three orbital planes
15-month lifetime

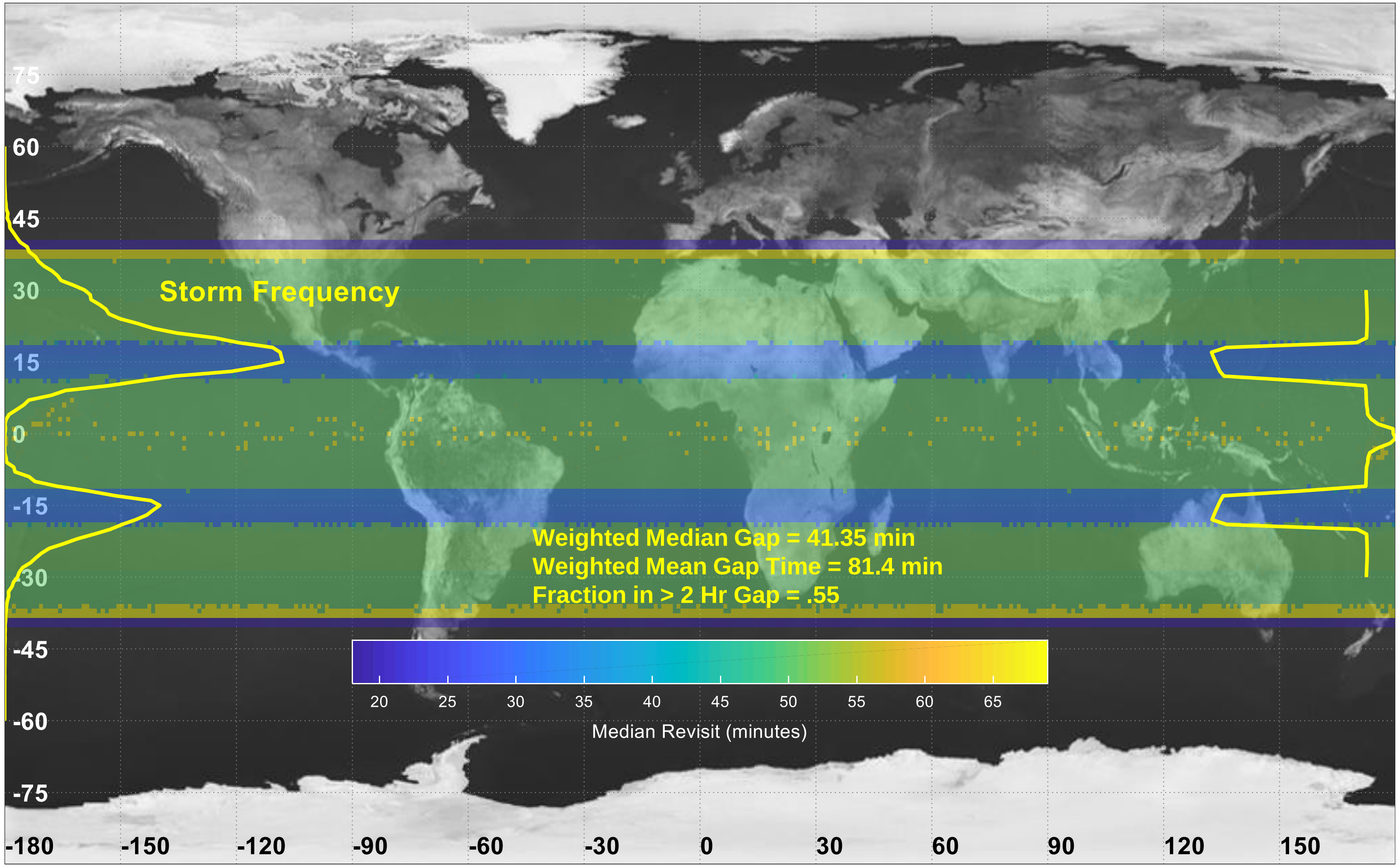
Better than 60-min median revisit rate over most of globe

State-of-the-art temperature and moisture sounding



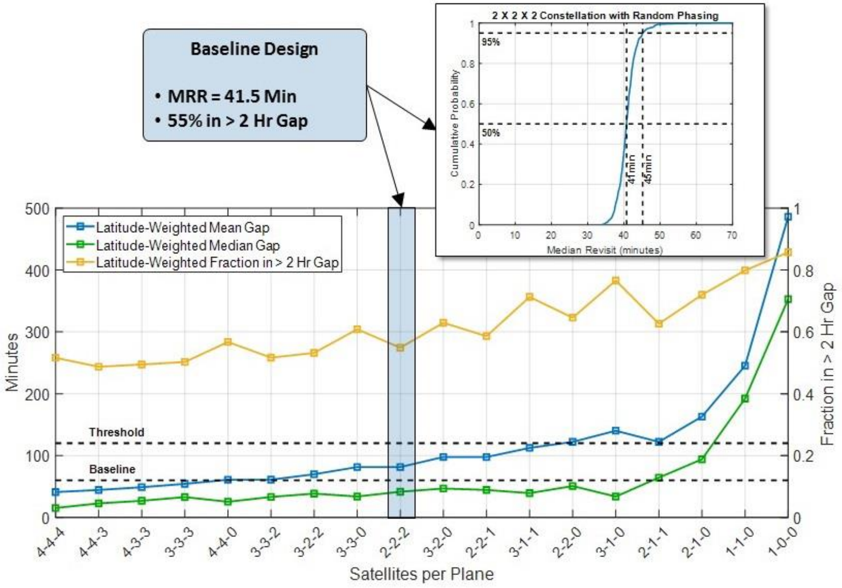
KSAT	BCT	MIT LL	UW-SSEC
			
Ground Station Network	Mission Operations Center	Science Operations Center	Data Processing Center

TROPICS Revisit



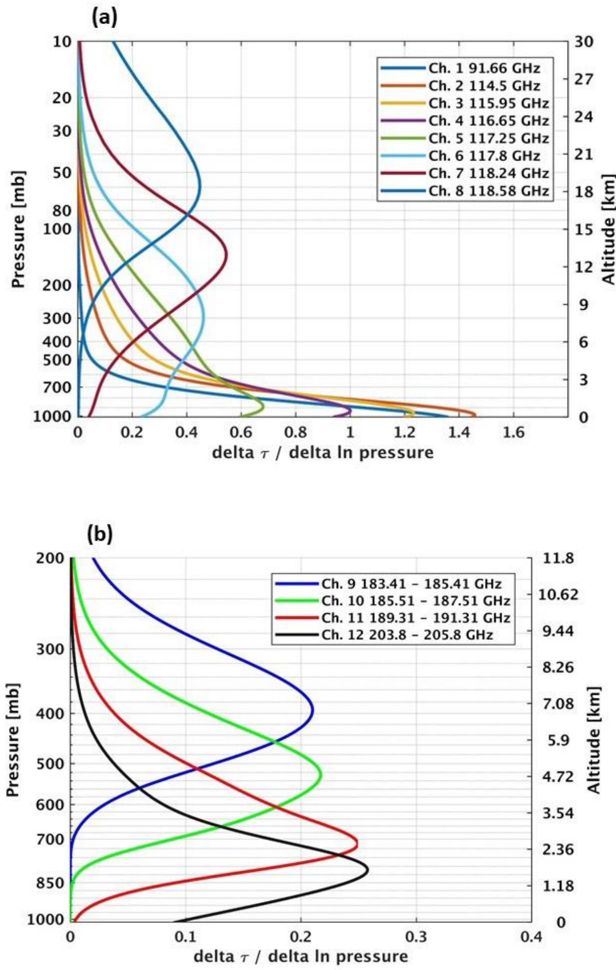
Current constellation configuration:

- **six satellites**
- **three orbital planes**
- **30° inc., 550 km alt.**



TROPICS Frequencies and Weighting Functions

TROPICS Chan.	Center Freq. (GHz)	Bandwidth (GHz)	RF Span (GHz)	Beamwidth (degrees) Down/Cross	Nadir Footprint Geometric Mean (km)*	Expected NEdT (K)
1	91.656 ± 1.4	1.000	89.756-90.756, 92.556-93.556	3.0/3.17	29.6	0.6
2	114.50	1.000	114.00-115.00	2.4/2.62	24.1	0.55
3	115.95	0.800	115.55-116.35	2.4/2.62	24.1	0.60
4	116.65	0.600	116.35-116.95	2.4/2.62	24.1	0.70
5	117.25	0.600	116.95-117.55	2.4/2.62	24.1	0.70
6	117.80	0.500	117.55-118.05	2.4/2.62	24.1	0.75
7	118.24	0.380	118.05-118.43	2.4/2.62	24.1	0.85
8	118.58	0.300	118.43-118.73	2.4/2.62	24.1	1.00
9	184.41	2.000	183.41-185.41	1.5/1.87	16.9	0.50
10	186.51	2.000	185.51-187.51	1.5/1.87	16.9	0.50
11	190.31	2.000	189.31-191.31	1.5/1.87	16.9	0.50
12	204.8	2.000	203.8-205.8	1.35/1.76	15.2	0.50

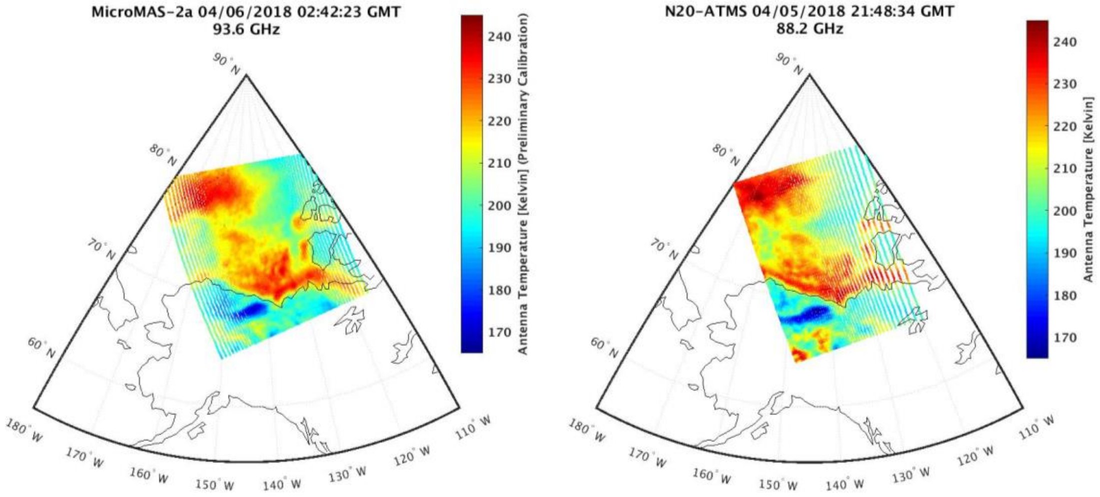


LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

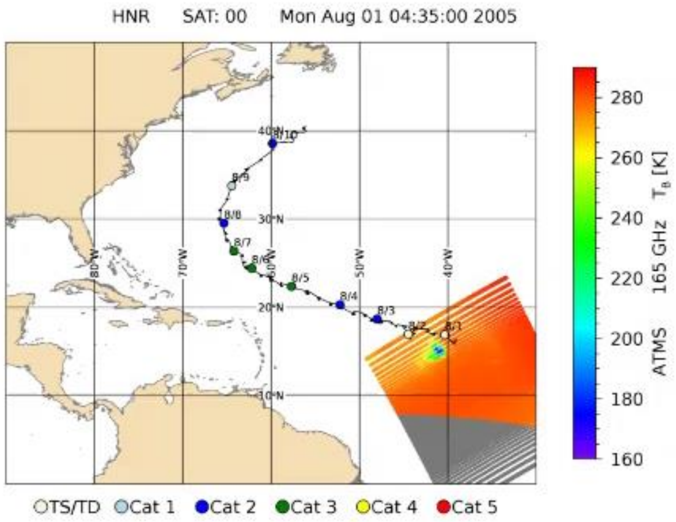
TROPICS Data Products

Designation	Description	Requirement
Level 0	Raw CCSDS payload and telemetry from SVs	N/A
Level 1a	Timestamped, geolocated, calibrated antenna temperature	See Table 2
Level 1b	Timestamped, geolocated, calibrated antenna temperature with bias removed	See Table 2
Level 2a	Spatially resampled G-band brightness temperature to F-band resolution	N/A
Level 2b	Atmospheric Vertical Temperature Profile (K)	2K RMS at 50-km scan-averaged spatial resolution
Level 2b	Atmospheric Vertical Moisture Profile (g/g)	25% at 25-km scan-averaged spatial resolution
Level 2b	Instantaneous Surface Rain Rate (mm/hr)	25% at resolution of 2.5ox2.5o on weekly basis
Level 2b	TC Intensity: Minimum Sea Level Pressure (hPa)	10 hPa RMS
Level 2b	TC Intensity: Maximum Sustained Wind (m/s)	6 m/s RMS

MicroMAS-2a Data and Proxy Datasets



MicroMAS-2a on-orbit data (left) compared to NOAA-20 ATMS data (right) observed approximately seven hours earlier.

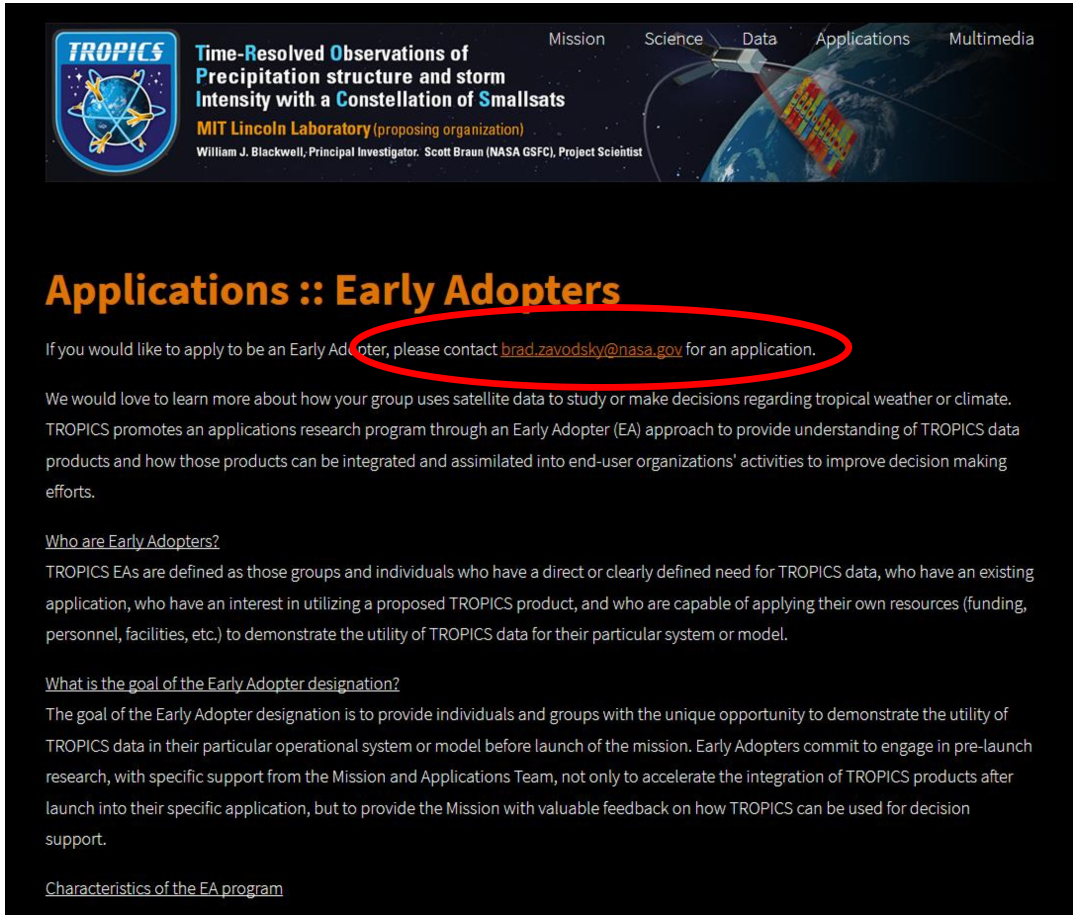


Early-look simulated TROPICS data derived from the Hurricane Nature Run showing temporal resolution of data

- **Goal of proxy data for applications is to accelerate the use of mission data in operational/decision-making environments**
- **Proxy data are being developed using modeled data from a hurricane Nature run and from recently-launched MicroMAS-2a (see left)**
  - **Simulated datasets that match the spatial, temporal, and spectral frequency of planned satellite architecture**
  - **Plan to make data available in multiple data formats for easier, earlier integration**
- **Proxy datasets will first be available to the TROPICS Science Team for evaluation and—once mature—will be made available to the Early Adopter community**

TROPICS Early Adopters

- **Establishment of an Early Adopter (EA) community for TROPICS is underway**
- **Allows formal, albeit *unfunded*, connection to science team for early access to data and ability to ask questions about the data and provide feedback on early products**
  - **The EA will receive access to developmental products and interaction with the Applications Team and a relevant member of the Science Team to enable an increased understanding and integration of the new products into their systems**
  - **The Science Team member will gain a partner who can evaluate products and offer feedback from a functionality perspective as well as potential calibration and validation information**
- **Contact Brad Zavodsky (brad.zavodsky@nasa.gov) for a copy of the application form**


TROPICS Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

MIT Lincoln Laboratory (proposing organization)

William J. Blackwell, Principal Investigator. Scott Braun (NASA GSFC), Project Scientist

Mission Science Data Applications Multimedia

Applications :: Early Adopters

If you would like to apply to be an Early Adopter, please contact brad.zavodsky@nasa.gov for an application.

We would love to learn more about how your group uses satellite data to study or make decisions regarding tropical weather or climate. TROPICS promotes an applications research program through an Early Adopter (EA) approach to provide understanding of TROPICS data products and how those products can be integrated and assimilated into end-user organizations' activities to improve decision making efforts.

Who are Early Adopters?

TROPICS EAs are defined as those groups and individuals who have a direct or clearly defined need for TROPICS data, who have an existing application, who have an interest in utilizing a proposed TROPICS product, and who are capable of applying their own resources (funding, personnel, facilities, etc.) to demonstrate the utility of TROPICS data for their particular system or model.

What is the goal of the Early Adopter designation?

The goal of the Early Adopter designation is to provide individuals and groups with the unique opportunity to demonstrate the utility of TROPICS data in their particular operational system or model before launch of the mission. Early Adopters commit to engage in pre-launch research, with specific support from the Mission and Applications Team, not only to accelerate the integration of TROPICS products after launch into their specific application, but to provide the Mission with valuable feedback on how TROPICS can be used for decision support.

Characteristics of the EA program

Summary

- TROPICS is a first-of-its-kind cubesat mission that will provide temperature and moisture soundings and precipitation estimates from passive microwave channels with unprecedented temporal resolution
  - Aims to solve science questions related to precipitation structure and temperature and moisture of the storm core and environment to better understand storm evolution
  - Established an Early Adopter program to accelerate data use with end users post launch using proxy data
- TROPICS is in fabrication and is on schedule to be delivered by the end of 2019; NASA will provide the launch which will take place NET 2020

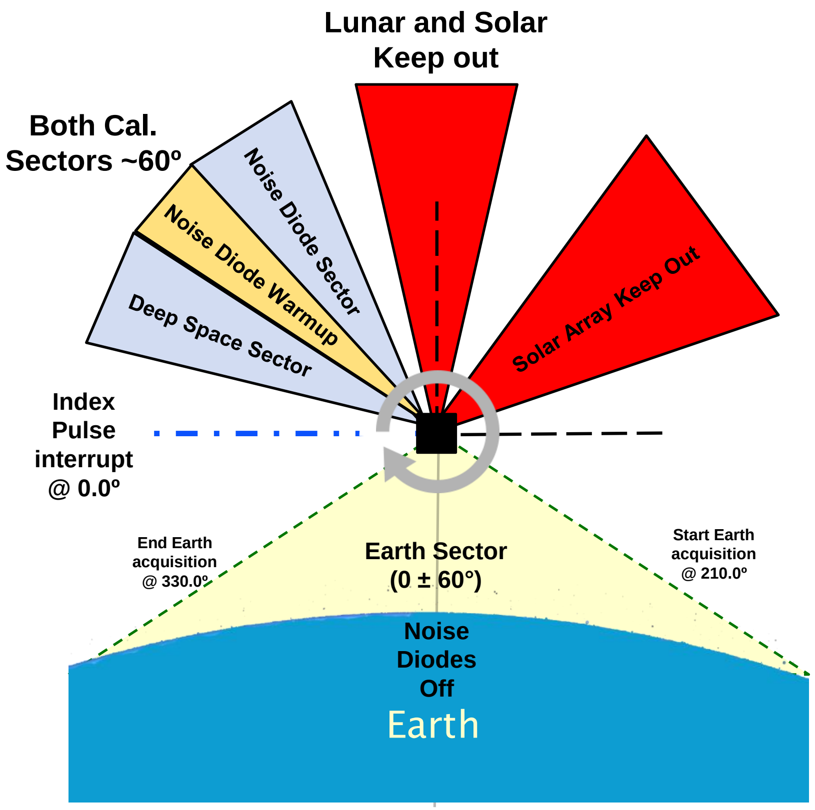
TROPICS Website: https://tropics.ll.mit.edu/CMS/tropics/

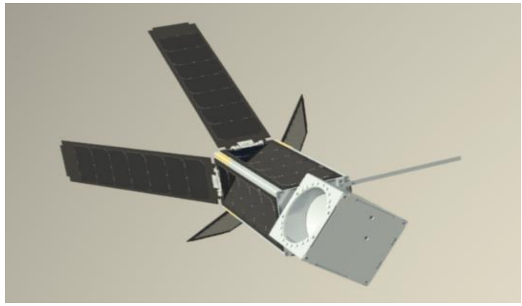
- Primary Author Contacts:
  - Bill Blackwell (mission PI; wjb@mit.ll.edu)
  - Scott Braun (mission project scientist; scott.braun@nasa.gov)
  - Brad Zavodsky (presenter; mission applications; brad.zavodsky@nasa.gov)

Back Up

BACKUP: Scan Profile for TROPICS

- **Rotation rate is 30 RPM (2 sec. period)**
- **81 Earth Sector samples per scan**
- **10 samples each in Space & ND Sectors**
- **Integration time: 8.333 msec (1/120 second)**
- **Spatial Information (at 550 km):**
  - **Beamwidth (FWHM):**
    - **W-band 3.0° DT (3.2° CT)**
    - **F-band 2.4° DT (2.62° CT)**
    - **G-band 1.5° DT (1.87° CT)**
    - **Sample spacing: 1.5°**
  - **Swath: ~2000 km**
  - **Nadir footprint diameter**
    - **W-band: 26-km DT, ~28-km CT**
    - **F-band : 22-km DT, ~24-km CT**
    - **G-band : 13.1-km DT, ~17.1-km CT**





DT = down track CT = cross track