Nanosatellite Passive Microwave Radiometers: Microwave Radiometer Technology Acceleration (MiRaTA) and the Micro-sized Microwave Atmospheric Satellite (MicroMAS-2A)

Angie Crews, Cadence Payne, Andrew Kennedy, Bobby Holden, Gregory Allan, Pratik Dave, Thomas Murphy, Kerri Cahoy
MIT STAR Laboratory
William J. Blackwell, Vince Leslie, Daniel Cousins, Michael DiLiberto, Idahosa Osaretin, Adam Milstein, Michael Shields, Erin Main, Mike Diliberto
MIT Lincoln Laboratory
Michael Grant, *NASA Langley*
Rebecca Bishop, *The Aerospace Corp.*

May 2nd, 2018

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

This work is sponsored by the National Aeronautics and Space Administration. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

Overview

- **Motivation**
- MiRaTA Overview
- MiRaTA Status
- MicroMAS-2A Overview
- MicroMAS-2A Status

This work was supported by a NASA Space Technology Research Fellowship.

Motivation: Predicting the Weather

Hurricane Ike, 2008

Image: NASA MODIS

Hurricane Ike damage, Galveston, TX

Image: NY Times

- The US derives $32B of value from weather forecasts annually[1]
- Severe weather events cost the US $313.5B in 2017[2]
- Satellites that observe Earth drive the forecasts
- Need to observe the entire Earth, all the time, with quick availability, of temperature, water vapor, and cloud ice

This work was supported by a NASA Space Technology Research Fellowship.

Roadmap to a Microwave Radiometer Constellation

MicroMAS-1

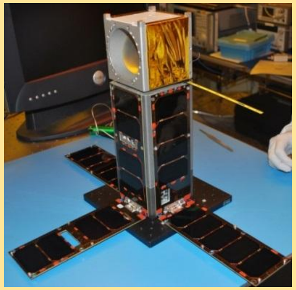
Scanning 3U CubeSat

Intended to measure 3D temperature

Launched in July 2014

ISS released it March 2015

Three successful contacts before radio failed



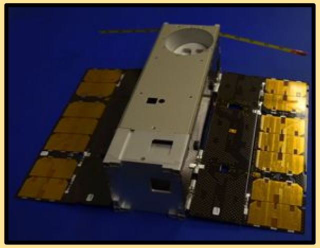
MiRaTA

Pitch-up 3U CubeSat

To measure temperature, water vapor, and cloud ice

GPS radio occultation to enable <1 K calibration

Launched November 2017 with JPSS-1

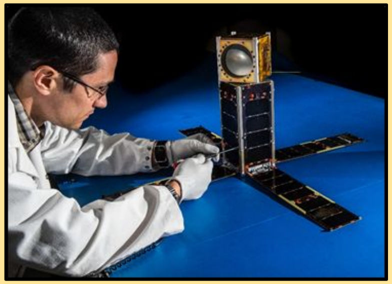


MicroMAS-2A & 2B

Scanning 3U CubeSat

To measure temperature, water vapor, and cloud ice

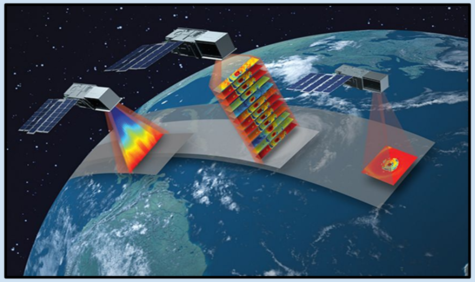
MM-2A: January 2018
MM-2B: Fall 2018



TROPICS

Selected for EVI-3
6 CubeSats (3U) in three orbital planes
To measure temperature, water vapor, and cloud ice

30-minute revisit
2020 launch



MiRaTA
~52-58 GHz (temperature, V-band)
~175-191 GHz (water vapor, G-band)
~206-208 GHz (cloud ice, G-band)

NASA ESTO

NASA EVI-3
Earth System Science Pathfinder
Science Mission Directorate

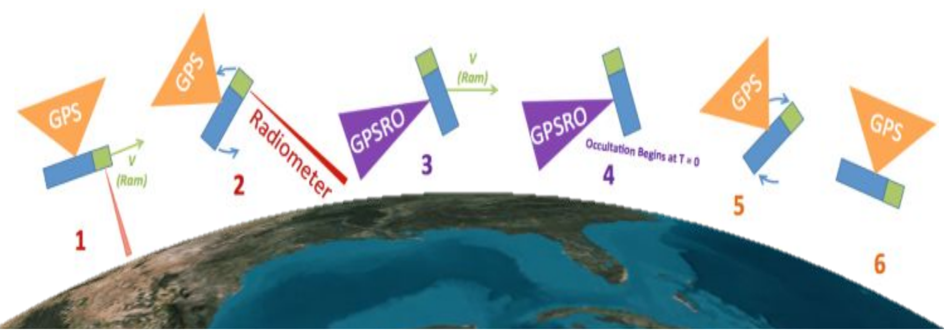
This work was supported by a NASA Space Technology Research Fellowship.

MiRaTA CubeSat

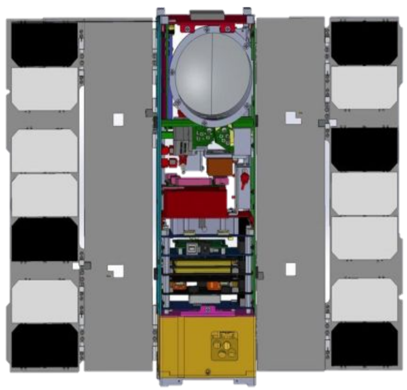
Microwave Radiometer Technology Acceleration CubeSat

Mission Goals

- Flight test new ultra-compact, low-power radiometer
- Flight test new GPS receiver and patch antenna array
- Demonstrate novel radiometer calibration using GPS Radio Occultation (GPSRO) measurements



MiRaTA Overview

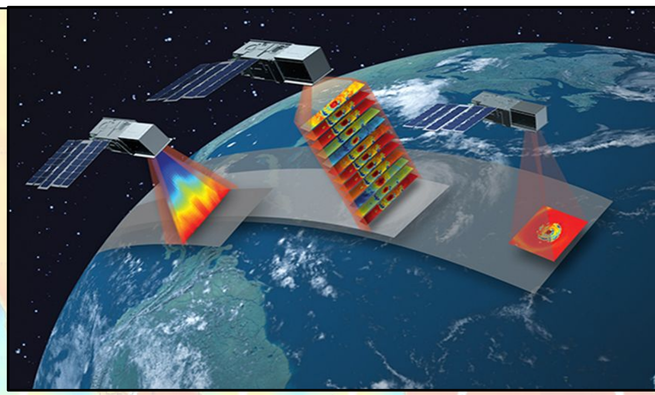


3U CubeSat bus:
- Custom avionics/comm
- 3-axis-stabilized ADCS
- 25 W solar power generation and 20 W-hr battery capacity
- Custom 3U chassis

3 band microwave radiometer:
- ~60 GHz V-band (temperature)
- ~183 GHz G-band (water vapor)
- ~207 GHz G-band (cloud ice)

Compact TEC and Atmosphere GPS Sensor:
- GPSRO of L1 and L2 frequencies
- Temp, pressure, water vapor

Mission Significance



MiRaTA's atmospheric sensing technology will enable low-cost constellation systems that could offer unprecedented temporal and spatial resolution for weather imaging. Future TROPICS mission shown above.

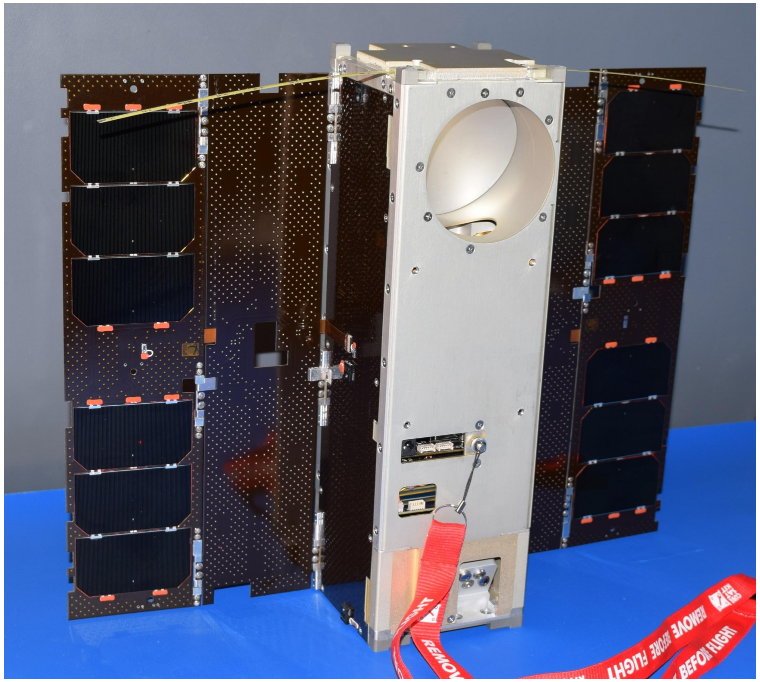
MiRaTA Team & Key Dates

Delivery – Q2 2017
Launched – Nov 18th 2017

The MiRaTA team of MIT/LL professionals & MIT grad students

MiRaTA Status

As Built



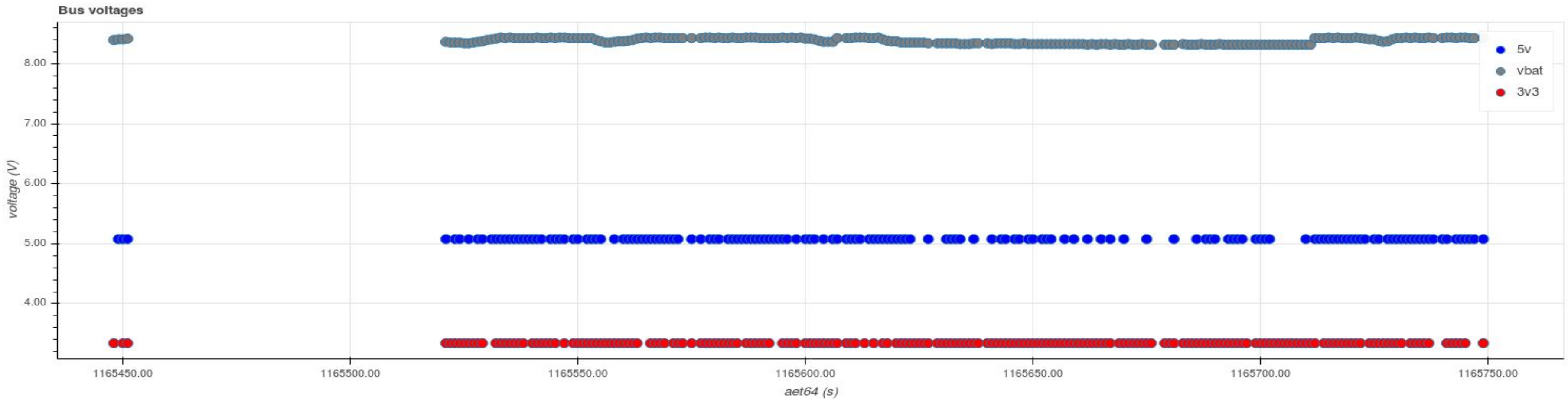
Launched with JPSS-1

Nov 18, 2017

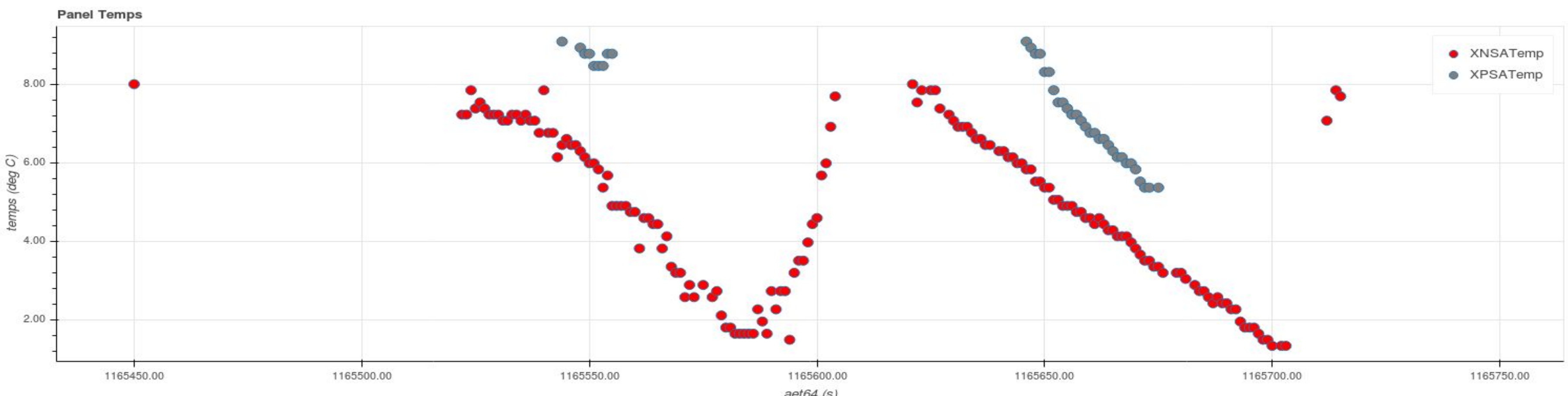
Image: NOAA

This work was supported by a NASA Space Technology Research Fellowship.

MiRaTA Telemetry



Bus Voltages



Panel Temperatures

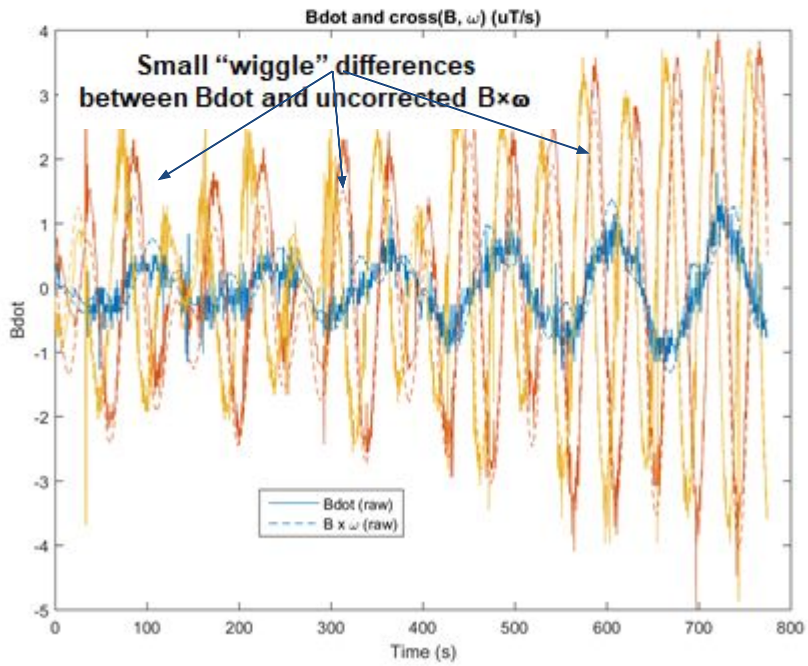
Image: E. Main

This work was supported by a NASA Space Technology Research Fellowship.

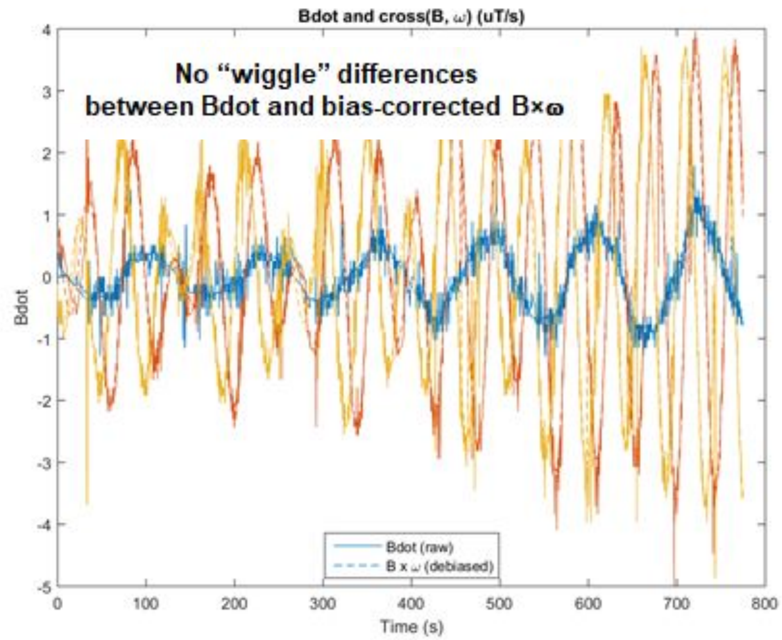
MiRaTA Telemetry

Magnetometer/ Bdot Checks

Bdot vs B×ω: Before Bias Corrections



Bdot vs B×ω: After Bias Corrections

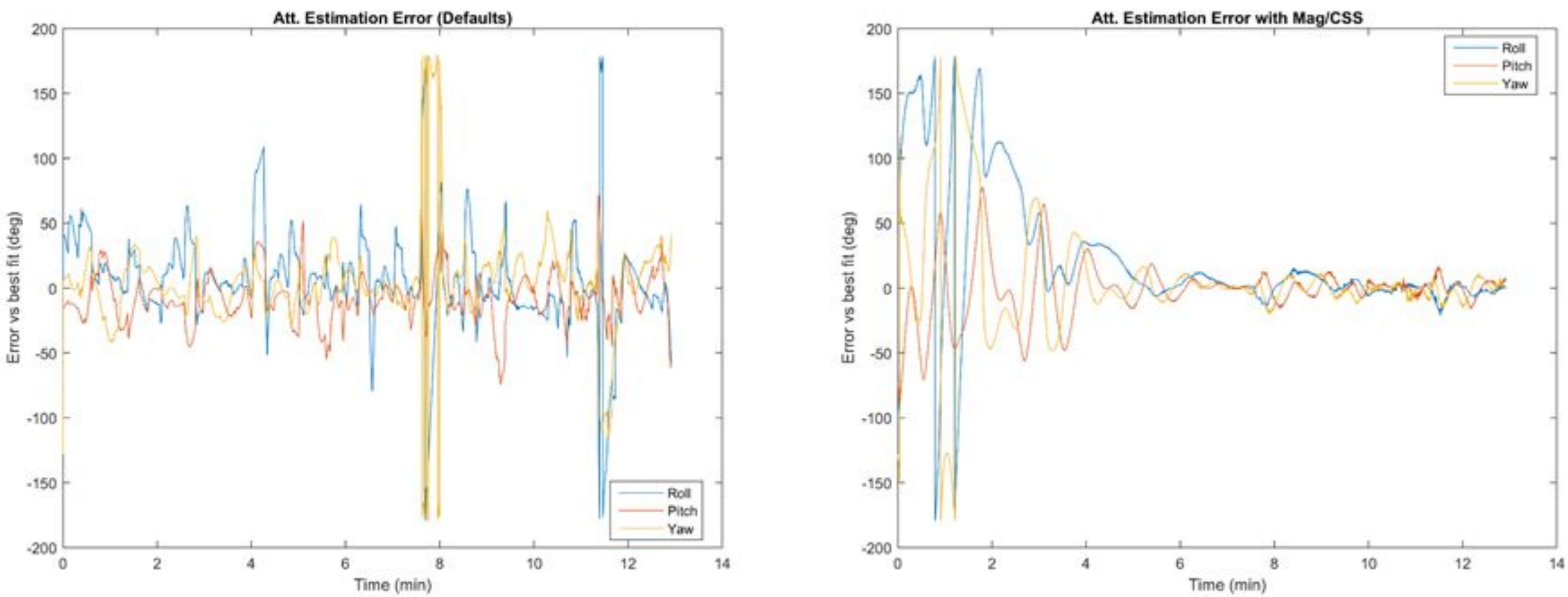


Sign/sanity check: Bdot should ~equal B×ω (confirmed)

Image:A. Millstein

This work was supported by a NASA Space Technology Research Fellowship.

Attitude Estimation Errors vs. "Truth": Before and After Tuning



After tuning, attitude estimation error improves to within ~15 degrees in this dataset, though with slower convergence

Image:A. Millstein

This work was supported by a NASA Space Technology Research Fellowship.

MiRaTA Status

- **Launch Nov. 18, 2017 from Vandenberg**
  - First contact Nov. 21 from Wallops to primary Cadet UHF radio
  - Then contact to low-rate backup UHF radio at MIT Campus
  - Solar panels deployed
  - Power system nominal
- **Early Orbit Operations**
  - Allowed to remain tumbling (goal of testing payload during tumble to sweep Earth/space)
    - Tumble rate < 2 minutes
  - Some IMU PDU faults (similar to ground test during Cadet radio Tx)
  - Some EPS faults (on ground, were sometimes due to timing jitter)
  - Cadet UHF Radio nominal
  - Turned on MAI, obtained sensor data, did not spin up wheels yet
  - Checked queued commanding (commanding components on/off with timer)
  - Turned on Payload PNT mode, tumbling too fast for GPS receiver to lock (did get GPS time)
  - Turned on Payload Science mode, after completing 20 minutes in Science mode S/C went to Safe and reset due to low battery voltage (stale EPS TLM I2C at microcontroller, OBC)
  - Lost contact with spacecraft primary radio on Dec 14th before downlink of Payload data
  - Was only able to re-establish contact with low-rate backup radio (on 3.3 V) from Campus
    - On-board Computer (OBC) not responsive to attempted resets
  - Reprogram of backup radio to sense voltage rails attempted on January 25th
  - Reprogram unsuccessful; was last contact with spacecraft
  - Regular contact attempts since last contact
  - Anomaly investigation ongoing, possible anomaly with OBC or EPS
  -

This work was supported by a NASA Space Technology Research Fellowship.

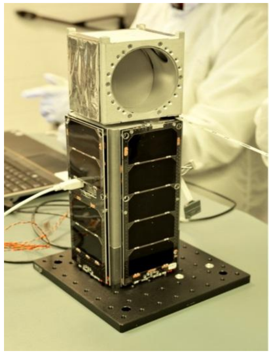
Overview

- Motivation
- MiRaTA Overview
- MiRaTA Status
- **MicroMAS-2A Overview**
- MicroMAS-2A Status

This work was supported by a NASA Space Technology Research Fellowship.

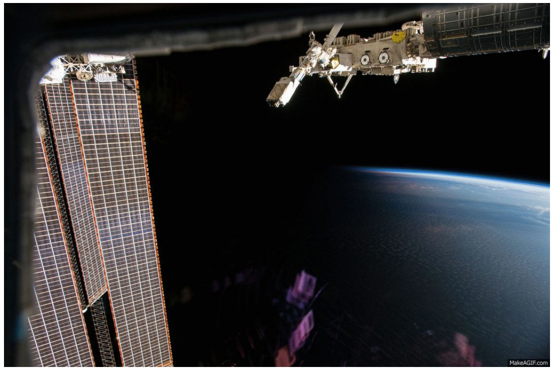
MicroMAS: Micro-sized Microwave Atmospheric Satellite

- **MicroMAS-1:**
  - 3U dual-spinner CubeSat
  - High resolution cross track spectrometer
  - 9 Channels in 118 GHz band



MicroMAS-1 in stowed configuration

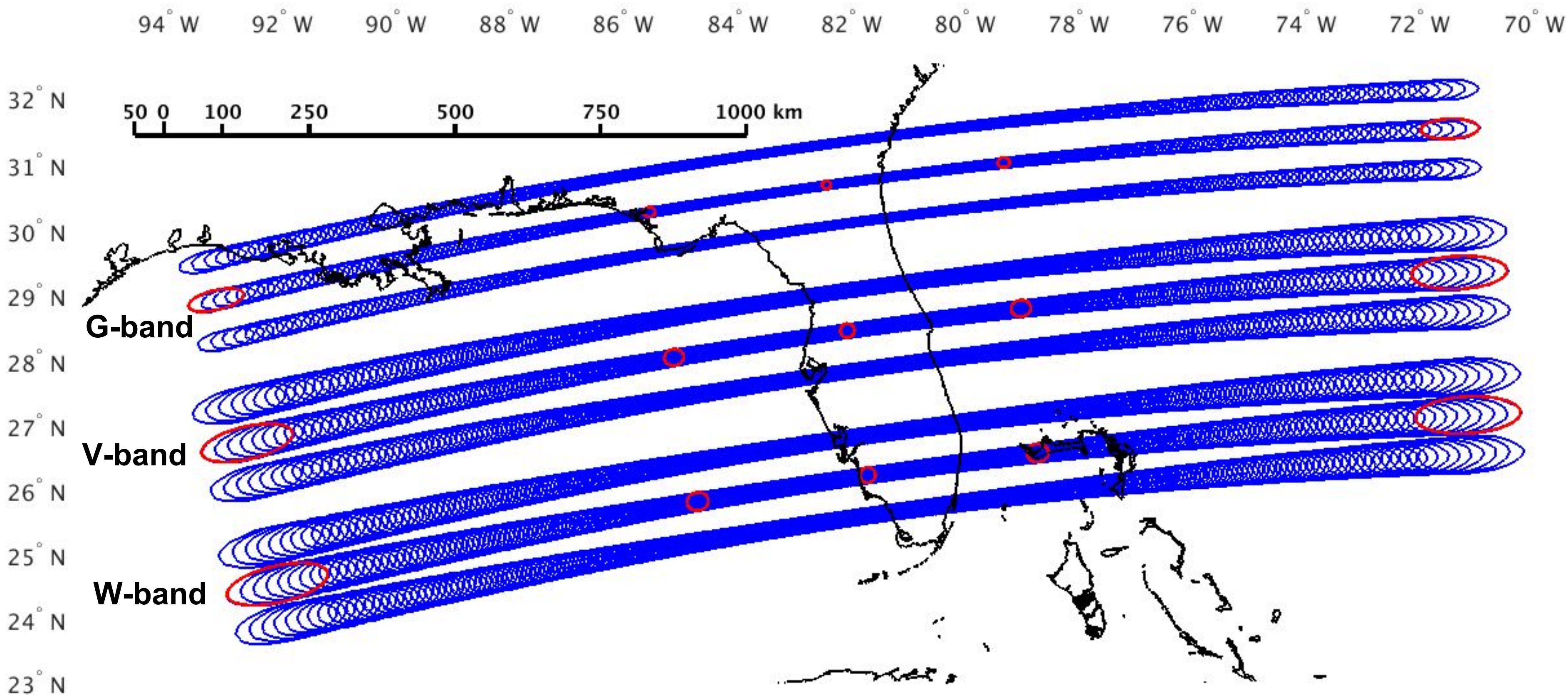
- **MicroMAS-2 is a follow-up mission to MicroMAS-1**
  - 3U dual-spinner CubeSat
  - High resolution cross track spectrometer
  - 10 Channels, 4 bands
    - 89 GHz – water vapor
    - 207 GHz – water vapor
    - 118 GHz – temperature, pressure, precipitation
    - 183 GHz – humidity and precipitation
  - Beam width of 3°
  - Swath of 2500 km; nadir resolution of 20 km
  - MM-2A launched Jan 11th 2018
  - MM-2B launch fall 2018



MicroMAS-1 being deployed from the ISS

This work was supported by a NASA Space Technology Research Fellowship.

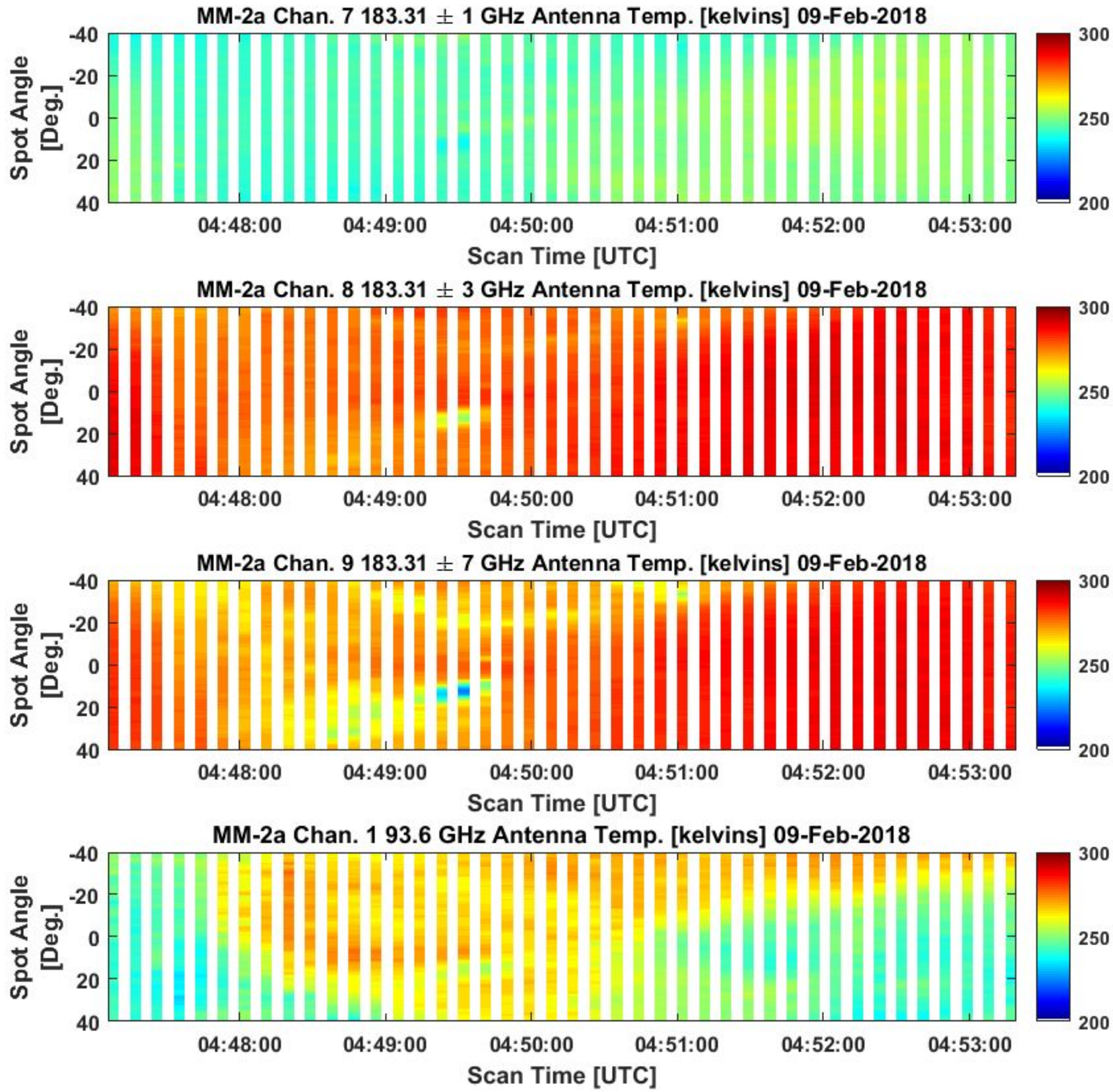
First-Light Tumble Data
6-RPM Scan Rate



This work was supported by a NASA Space Technology Research Fellowship.

MicroMAS-2A 90 GHz & 183 GHz

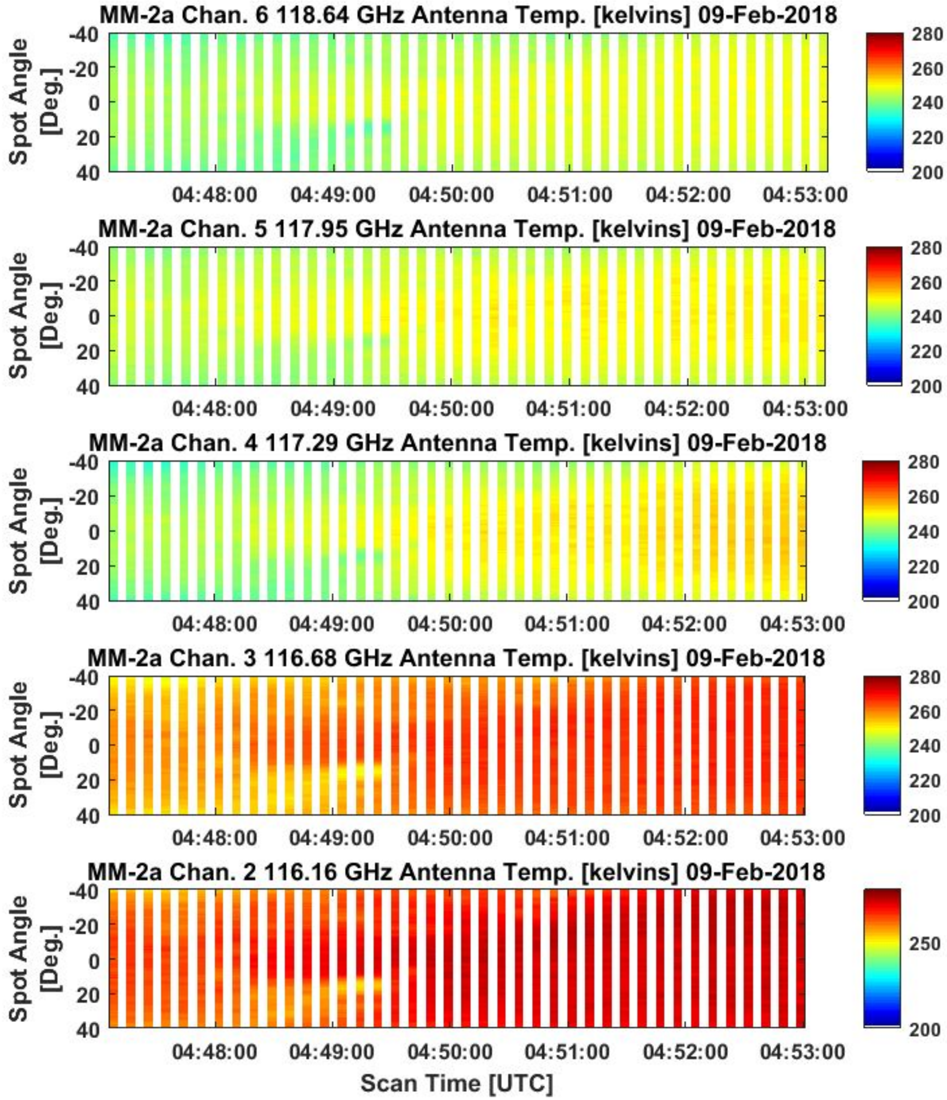
- **6 RPM Scan Rate**
  (non-contiguous scans)
- 90 GHz water vapor
- 183 GHz precipitation and humidity



This work was supported by a NASA Space Technology Research Fellowship.

MicroMAS-2A 118 GHz

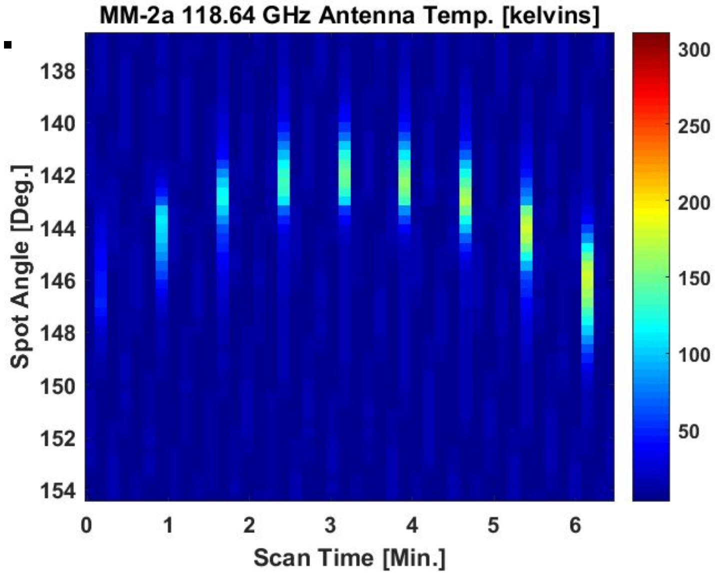
- **6 RPM Scan Rate**
  (non-contiguous scans)
- 118 GHz temperature, pressure, precipitation



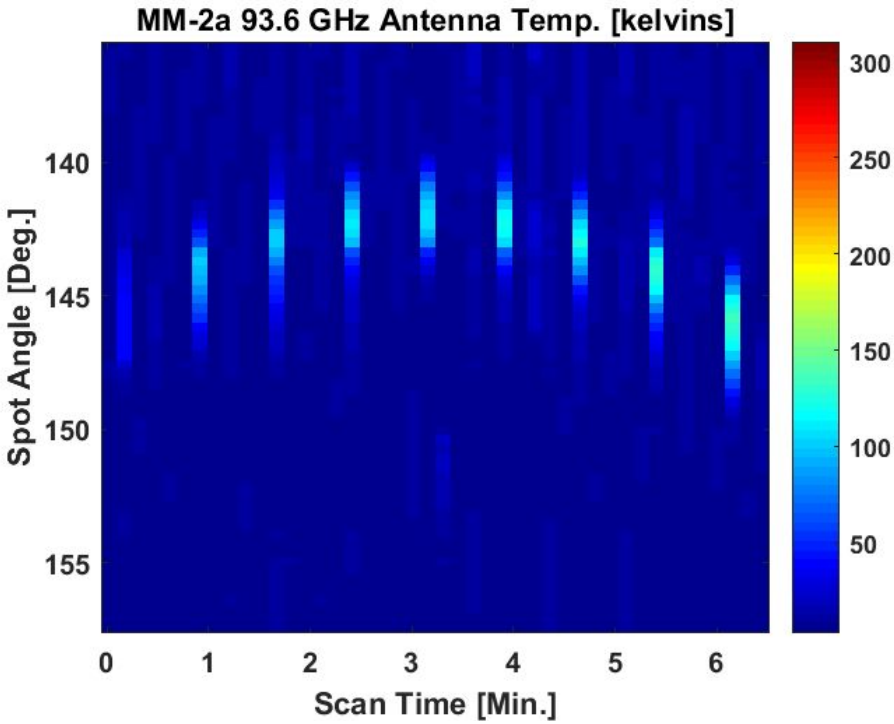
This work was supported by a NASA Space Technology Research Fellowship.

MicroMAS-2A Sun Measurements

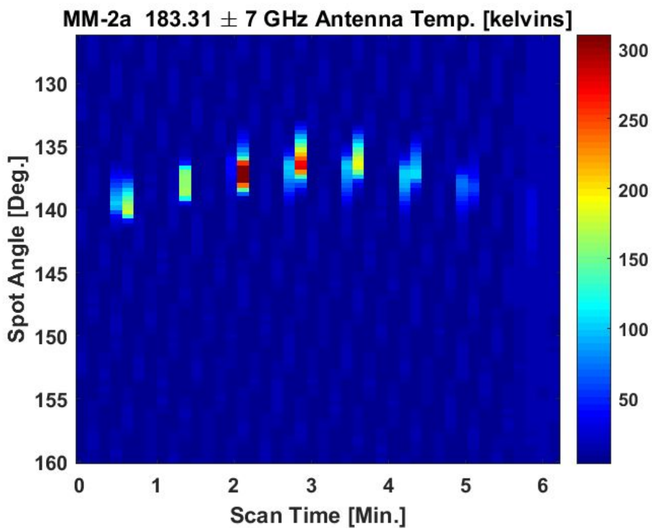
2.4 Deg.



3.0 Deg. FWHM



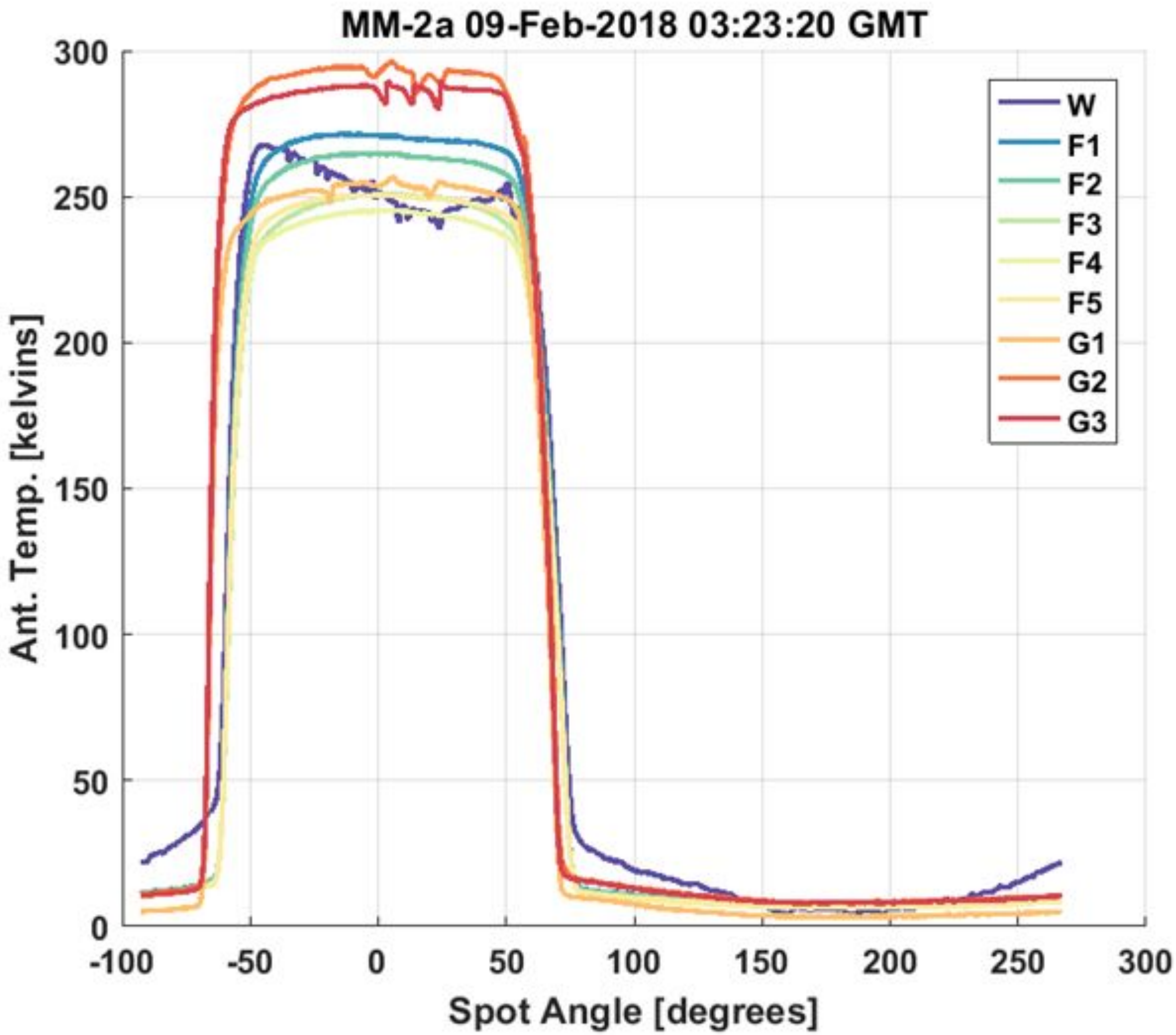
1.6 Deg.



Sun is ~0.5 deg. disc

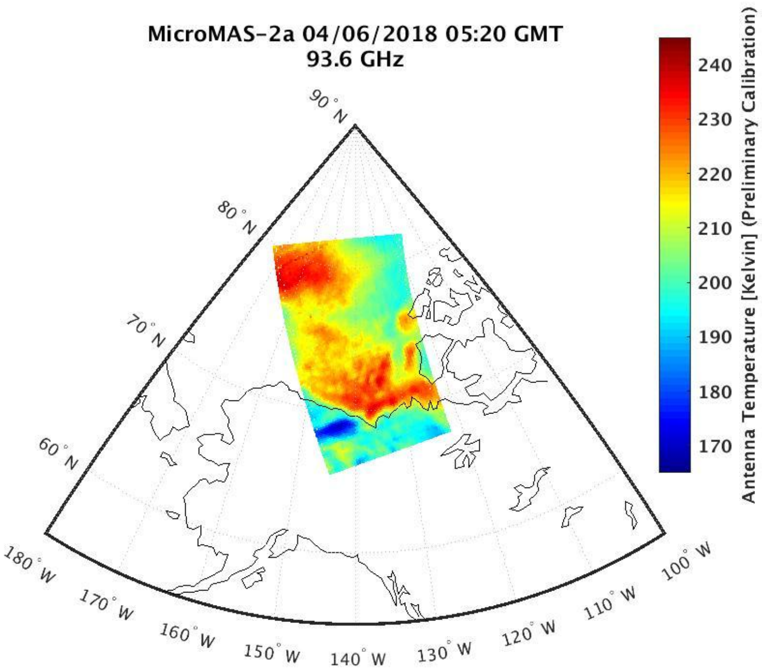
This work was supported by a NASA Space Technology Research Fellowship.

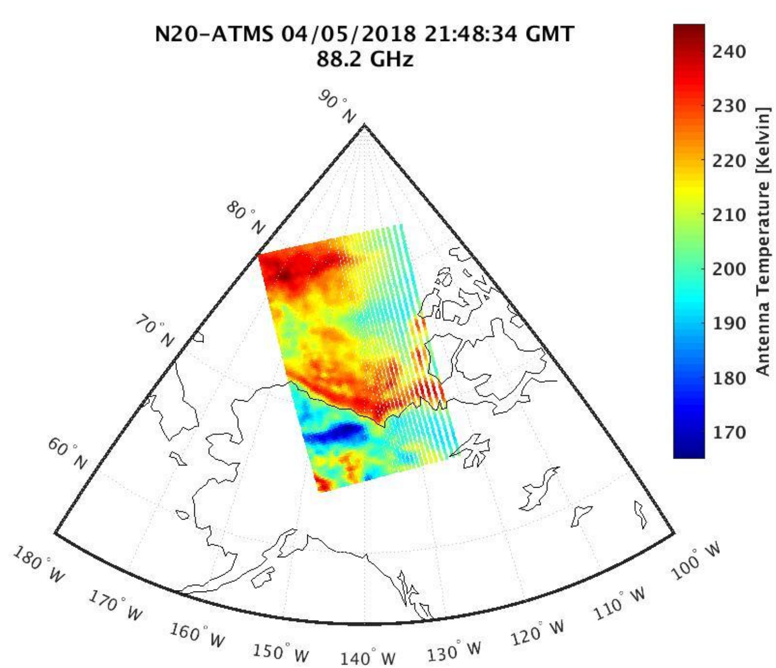
MicroMAS-2A Scan-Angle Average Radiances



This work was supported by a NASA Space Technology Research Fellowship.

MicroMAS-2A and ATMS Comparison

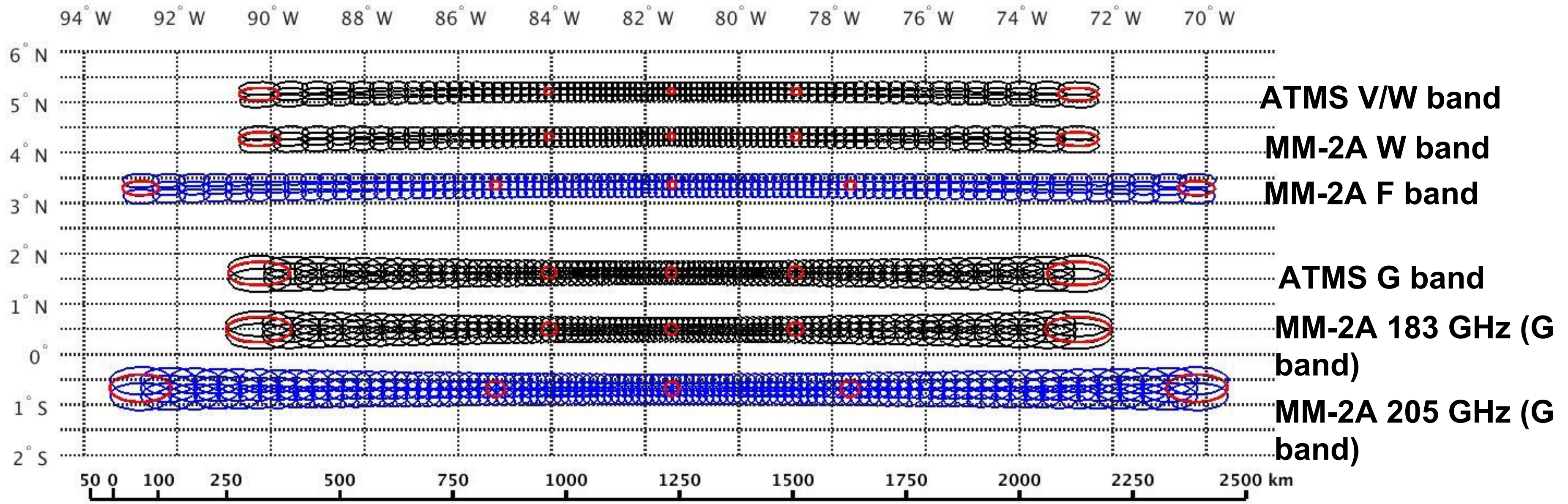




M. DiLiberto, R. V. Leslie, MIT LL

This work was supported by a NASA Space Technology Research Fellowship.

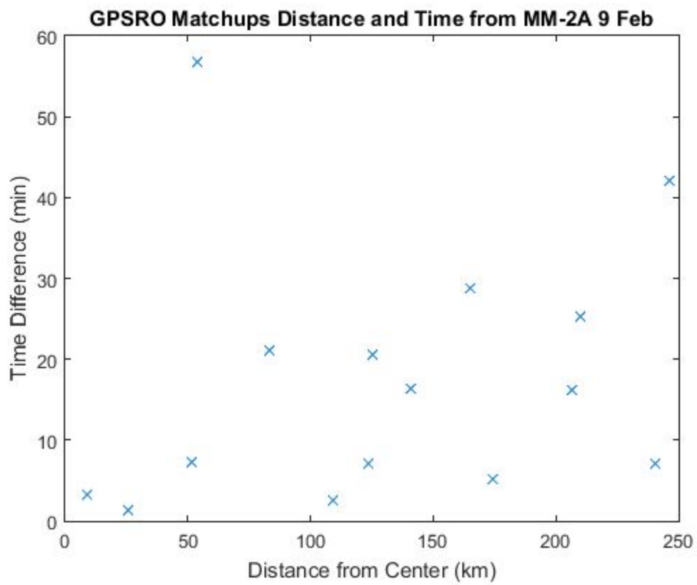
MicroMAS-2A and ATMS Footprint Comparison

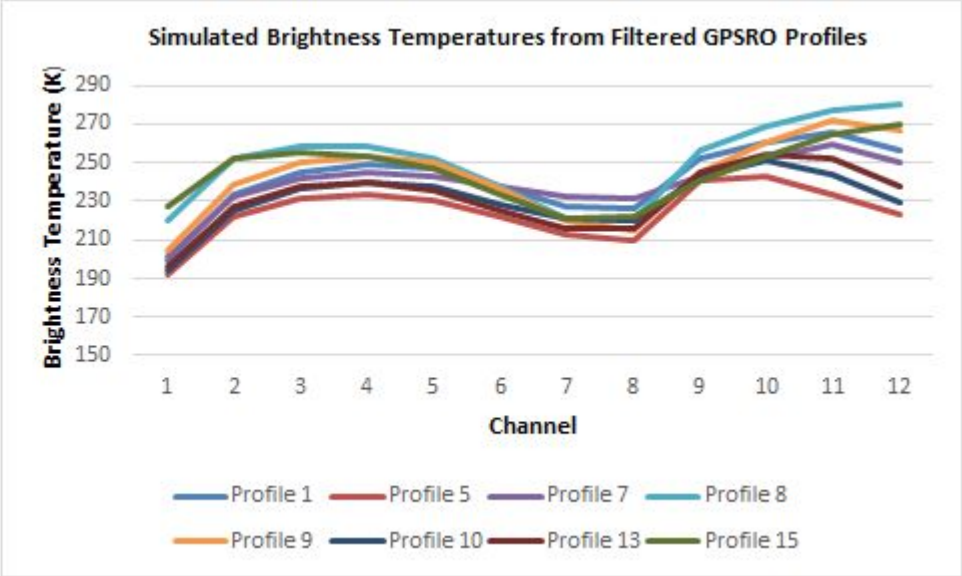


This work was supported by a NASA Space Technology Research Fellowship.

Radiometric Bias Validation

- Community Radiative Transfer Model (CRTM) is used with GPS Radio Occultation (GPSRO) atmospheric profiles to provide simulated brightness temperatures
- Of the 15 possible GPSRO matchups with the MM-2A data, 8 were acceptable for radiometric bias validation





This work was supported by a NASA Space Technology Research Fellowship.

Summary

MiRaTA built, tested and flown and initial engineering data was acquired.

MiRaTA payload science data was not acquired due to an anomaly; investigation is nearing conclusion.

MM-2A built, tested and flown with ongoing checkout.

Initial data from MM-2A looks promising.

Future work will provide radiometric bias validation for MM-2A data using GPSRO, radiosondes, and NWP models.

This work was supported by a NASA Space Technology Research Fellowship.

Backup Slides

This work was supported by a NASA Space Technology Research Fellowship.

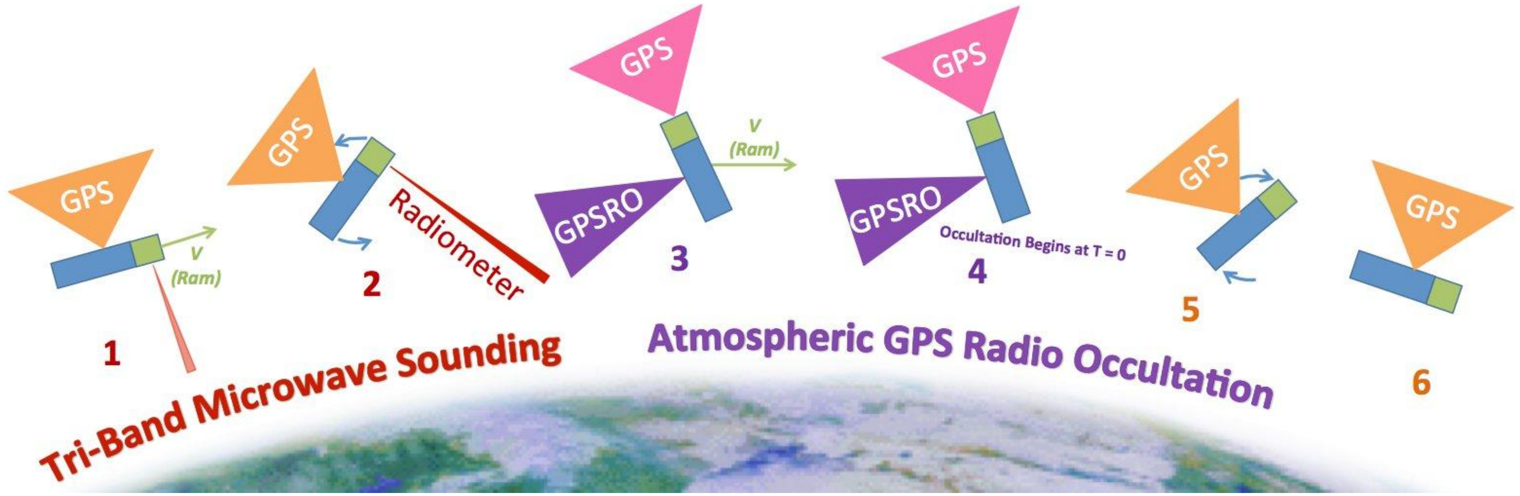
MiRaTA Mission

MiRaTA: Microwave Radiometer Technology Acceleration

- **Two Payloads:**
  1) **Microwave Radiometer**
     - 10 Channels
     - 52-58 GHz – Temperature
     - 175-191 GHz – Humidity
     - ~206-208 GHz – Cloud Ice
  2) **CTAGS: Compact Total Electron Content Atmospheric GPSRO System**
     - The Aerospace Corporation (R. Bishop)

- **Advance TRL from 5 to 7 for:**
  - IF Spectrometer (Radiometer Payload)
  - G-band Mixer (Radiometer Payload)
  - GPSRO Receiver (CTAGS Payload)
- **Calibrate microwave radiometer using GPS radio occultation**

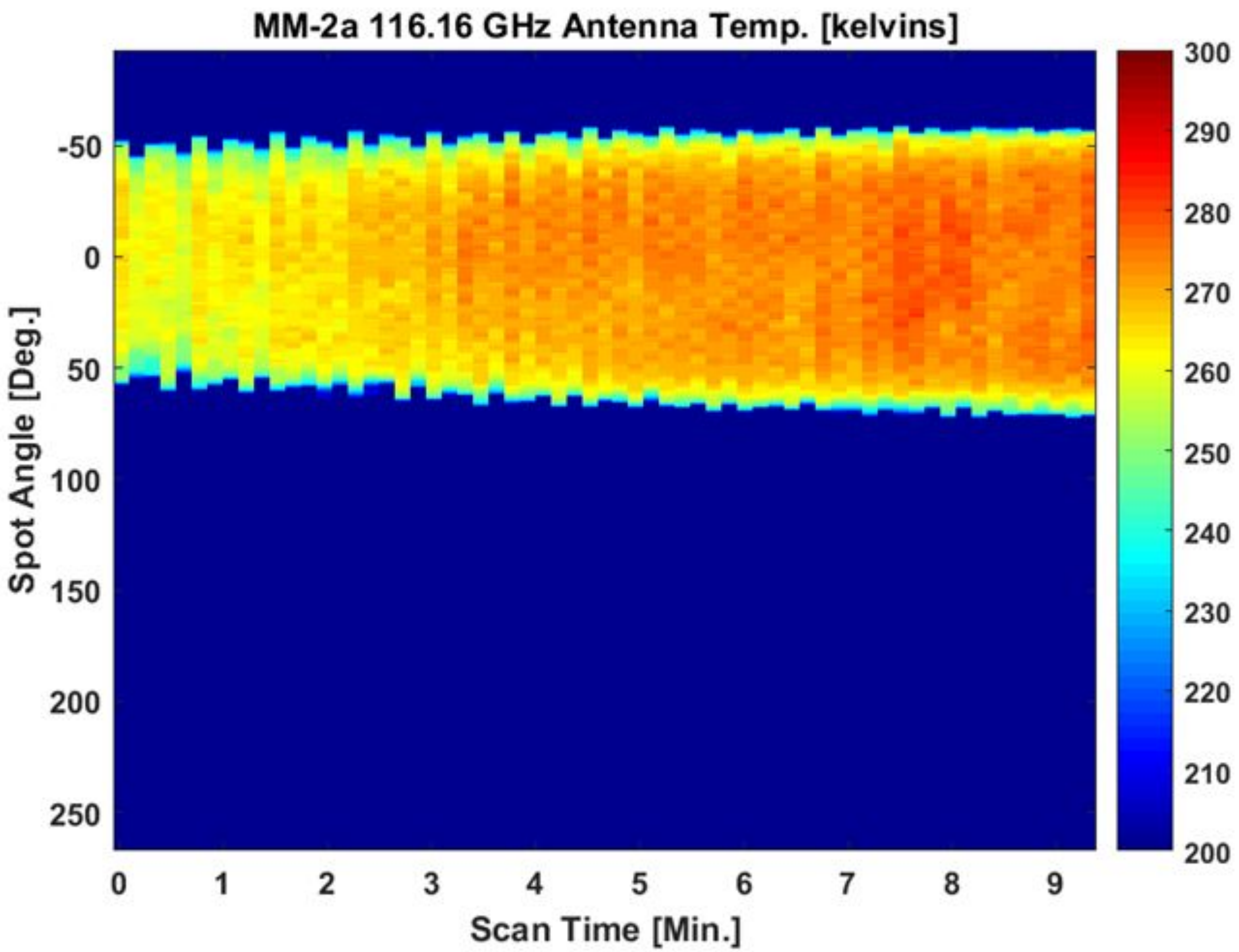
~ 10 minute maneuver
0.5° / sec rate



This work was supported by a NASA Space Technology Research Fellowship.

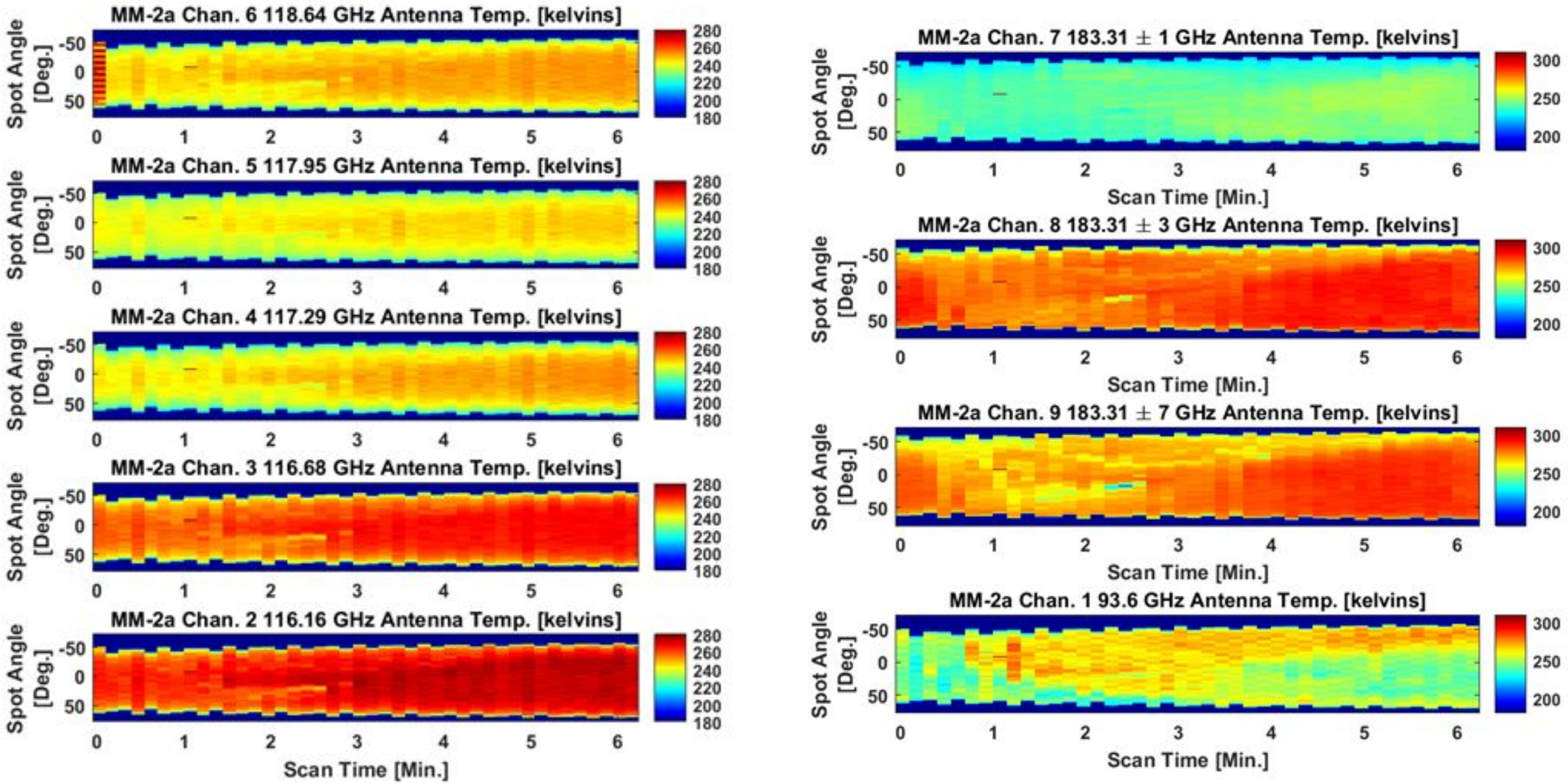
MicroMAS-2A Diagnostic Image

- Tumble period: 9 sec. (normal scanning is 2 sec)
- Safe mode is asynchronous sampling
- Outliners removed in W & G-band channels
- Interpolated to 2/236 sampling rate
- Calibrated using ND (fixed pre-launch room temp. radiance)



This work was supported by a NASA Space Technology Research Fellowship.

MicroMAS-2A Diagnostic Image



This work was supported by a NASA Space Technology Research Fellowship.