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

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May 2nd, 2018
Overview

• Motivation
• MiRaTA Overview
• MiRaTA Status
• MicroMAS-2A Overview
• MicroMAS-2A Status
Motivation: Predicting the Weather

- 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
Roadmap to a Microwave Radiometer Constellation

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<td>Pitch-up 3U CubeSat</td>
<td>Scanning 3U CubeSat</td>
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<td>To measure temperature,</td>
<td>To measure temperature,</td>
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<td>water vapor, and cloud ice</td>
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MiRaTA

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

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

MiRaTA

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NASA ESTO

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

NASA EVI-3

- Earth System Science Pathfinder
- Science Mission Directorate

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

MiRaTA Team & Key Dates

Delivery – Q2 2017
Launched – Nov 18th 2017

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

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 Status

As Built

Launched with JPSS-1

Nov 18, 2017

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

Bus Voltages

Panel Temperatures

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

Magnetometer/ Bdot Checks

Sign/sanity check: Bdot should \(\approx\) equal \(B \times \omega\) (confirmed)

Image: A. Millstein

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

- Motivation
- MiRaTA Overview
- MiRaTA Status
- **MicroMAS-2A Overview**
- MicroMAS-2A Status
MicroMAS: Micro-sized Microwave Atmospheric Satellite

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

- **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

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
MicroMAS-2A 118 GHz

- 6 RPM Scan Rate (non-contiguous scans)
- 118 GHz temperature, pressure, precipitation
MicroMAS-2A Sun Measurements

3.0 Deg. FWHM

MM-2a 93.6 GHz Antenna Temp. [kelvins]

2.4 Deg.

MM-2a 118.64 GHz Antenna Temp. [kelvins]

1.6 Deg.

MM-2a 183.31 ± 7 GHz Antenna Temp. [kelvins]

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

ATMS V/W band
MM-2A W band
MM-2A F band
ATMS G band
MM-2A 183 GHz (G band)
MM-2A 205 GHz (G band)
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.
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.
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)
MicroMAS-2A Diagnostic Image

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