MicroMAS: A First Step Towards a Nanosatellite Constellation for Global Storm Observation

K. Cahoy, D. Miller, A. Marinan, R. Kingsbury, E. Wise, S. Paek, E. Peters, M. Prinkey, P. Davé, and B. Coffee (MIT Space Systems Laboratory)
N. Erickson (UMass-Amherst)
15 August 2013

This work is sponsored by the Assistant Secretary of Defense for Research & Engineering under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.
Outline

- Introduction and Motivation
- Microwave Radiometer Payload
- Spacecraft Bus Overview
- Recent and Upcoming Milestones
- Summary
Dual-Spinning MicroMAS CubeSat

- **MicroMAS Spacecraft**
  - Reaction wheel module
  - Electronics stack
  - UHF radio, antenna
  - Scanner assembly

- **MicroMAS Payload**
  - Payload Interface Module
  - Payload antenna assembly
  - Receiver Front End
  - Back end processor
  - Payload power conditioning
  - Thermal management
  - Payload C&DH

**Deployable Solar Panels**
(deploy to 120°)

- Attitude Control Module
- Electronics Stack
- Payload Scanner Assembly
- 1U Passive Microwave Spectrometer

High-resolution 118-GHz spectrometer provides all-weather measurements of atmospheric temperature and precipitation

10 x 10 x 34 cm, 4.0 kg, 10 W avg
MicroMAS Objectives

- Focus on hurricanes + severe weather
- 20-km pixel diameter at nadir (cross-track scan out to ± 50°)
- 1 K absolute accuracy, 0.3 K sensitivity
- Geolocation error 10% of pixel near nadir
- 20 kbps (avg) payload data rate
- 10 W (avg) power
- 12-month design life; 3-month mission
- December 2013 launch, Cygnus-2 ISS resupply (~400 km, 51.6°)

Made available by NanoRacks, LLC via its Space Act Agreement with NASA’s U.S. National Lab, in collaboration with Spaceflight Services.

MicroMAS 3U CubeSat will demonstrate the core element of a transformative sensing constellation architecture
Cloud Penetration with Microwaves

- Atmospheric absorption is frequency dependent
- We can probe different altitudes by placing channels around absorption features at different frequencies
Outline

• Introduction and Motivation
• Microwave Radiometer Payload
• Spacecraft Bus Overview
• Recent and Upcoming Milestones
• Summary
MicroMAS Radiometer Payload

- 8 channels near 118.75-GHz oxygen line
- 1 window channel
- Cross-track scan
- Spatial Nyquist sampling
- 2.4-degree FWHM antenna beam
- 95% beam efficiency
- 2 W (avg)
- 0.3 K noise equiv. delta T (NEdT)
- 1 K calibration accuracy
- Noise diode, earth limb, and cold sky calibration

Super Typhoon Pongsona (Dec 8, 2002) MODIS image (Terra)
MicroMAS Channels as Measured

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Center (GHz)</th>
<th>Bandwidth (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114.458</td>
<td>0.594</td>
</tr>
<tr>
<td>2</td>
<td>115.104</td>
<td>0.598</td>
</tr>
<tr>
<td>3</td>
<td>115.733</td>
<td>0.638</td>
</tr>
<tr>
<td>4</td>
<td>116.354</td>
<td>0.608</td>
</tr>
<tr>
<td>5</td>
<td>117.050</td>
<td>0.594</td>
</tr>
<tr>
<td>6</td>
<td>117.727</td>
<td>0.590</td>
</tr>
<tr>
<td>7</td>
<td>118.285</td>
<td>0.588</td>
</tr>
<tr>
<td>8</td>
<td>118.975</td>
<td>0.532</td>
</tr>
<tr>
<td>9</td>
<td>108.685</td>
<td>1.074</td>
</tr>
</tbody>
</table>

- Approximately 1 revolution/second
- 1 degree sample spacing (Nyquist)
- +/- 50 degree swath
Payload: 118-GHz Spectrometer

- IF Processor
- Dielectric Resonator
- Oscillator
- Frequency Tripler
- Mixer
- Preamplifier/Noise-diode Module
- Waveguide
- Feed-horn

10x10x10 cm, <1 kg, <2 W

Approximately a factor of 100 reduction in size, weight, and power relative to the current state of the art!
MicroMAS 118-GHz Spectrometer Technology

- Physical principles:
  - Thermal emission near O₂ absorption line at 118.75 GHz provides atmospheric temperature
  - “Hydrometeor” scattering provides precipitation intensity and type
Outline

• Introduction and Motivation

• Microwave Radiometer Payload

• Spacecraft Bus Overview

• Recent and Upcoming Milestones

• Summary
MicroMAS Bus Design

- Solar Panel Interface Plate
- MAI-400 ADCS Unit
- Avionics Stack
- Scanner Assembly Motor
Bus Subsystem Integration

- **Bottom Interface Plate**
- **MAI-400**
- **Bus Stack**
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- **Chassis**
- **Scanner Assembly**
- **Antenna Assembly**
- **Solar Panels**
Systems Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - **Bottom Interface Board**
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - **Radio**
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - **Motherboard**
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels

Motor housing also enclosed by chassis.
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- **Antenna Assembly**
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- Scanner Assembly
- Antenna Assembly
- Solar Panels
Bus Subsystem Integration

- Bottom Interface Plate
- MAI-400
- Bus Stack
  - Chassis Base Plate
  - Bottom Interface Board
  - EPS
  - Radio
  - Motherboard
  - Battery
  - Top Interface Board
- Chassis
- **Scanner Assembly**
- Antenna Assembly
- Solar Panels
MicroMAS Scanner Assembly

- Brushless dc zero cogging motor, controller
- Encoder

Encoder disk enclosed in motor housing.
Integration of flight scanner assembly

E. Peters, MIT
ADCS Test Rig

M. Prinkey, MIT

A. Marinan, MIT

M. Prinkey, D. Sklar, MIT
Board Stack Mockup Thermal Test

P. Davé, MIT
Thermal Modeling

High beta angle

Low beta angle

P. Davé, J. Emig, MIT

Temperature [°C], Time = 5457.01 sec

Temperature [°C], Time = 1392.09 sec
Clyde Space Panels and EPS
Radio Carrier Board

R. Kingsbury, MIT

R. Kingsbury, MIT
Bottom Interface Board

R. Kingsbury, MIT

R. Kingsbury, MIT
Top Interface Board

R. Kingsbury, MIT
Avionics Board Stack

R. Kingsbury, MIT
Communications Antenna

R. Kingsbury, MIT

R. Kingsbury, MIT
Outline

• Introduction and Motivation
• Microwave Radiometer Payload
• Spacecraft Bus Overview
• Recent and Upcoming Milestones
• Summary
### Recent/Upcoming Milestones

<table>
<thead>
<tr>
<th>Month</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2013</td>
<td>• EDU TVAC testing and calibration complete&lt;br&gt;• 3 blackbody targets (100-330 K) observed with payload (-40 to 40 °C)&lt;br&gt;• Flight hardware delivered</td>
</tr>
<tr>
<td>August 2013</td>
<td>• Payload FM TVAC testing, calibration, EMI/EMC, antenna pattern&lt;br&gt;• Bus integration and test, delivery</td>
</tr>
<tr>
<td>September 2013</td>
<td>• Space Vehicle integration &amp; TVAC / vibe</td>
</tr>
<tr>
<td>October 2013</td>
<td>• Delivery of SV to launch provider</td>
</tr>
<tr>
<td>December 2013</td>
<td>• Launch&lt;br&gt;• Check-out</td>
</tr>
<tr>
<td>January 2013</td>
<td>• Mission operations</td>
</tr>
</tbody>
</table>
Outline

• Introduction and Motivation

• Microwave Radiometer Payload

• Spacecraft Bus Overview

• Recent and Upcoming Milestones

• Summary
Summary and Path Forward

• MicroMAS will demonstrate core element of sounding constellation
  – Constellations provide unprecedented performance at relatively low cost and risk

• MicroMAS Dec 8, 2013 launch
  – Made available by NanoRacks, LLC via its Space Act Agreement with NASA’s U.S. National Lab and Spaceflight Services.

• Recent testing has indicated excellent performance
  – 60 RPM scanning
  – 95% antenna beam efficiency
  – 2 W payload power consumption

• MiRaTA, Microwave Radiometer Technology Acceleration mission selected by NASA ESTO

Marinan, Nicholas and Cahoy, “Ad hoc CubeSat Constellations.” IEEE Aerospace 2013
Thank you

• Utah State University Space Dynamics Lab and the DICE Team ground station, communication (Chad Fish, Erik Stromberg, et al.)

• NASA Wallops Flight Facility ground station (Scott Schaire and Team)

• NASA Goddard Space Flight Center (calibration targets)

• L-3 Communication Systems West

• NanoRacks and Spaceflight Services

• Clyde Space, Maryland Aerospace, Pumpkin Inc.

• Mr. Paul Bauer (MIT SSL staff)

• Undergraduate summer researchers: Devon Sklair, Kris Frey, Erin Main, Josh Emig, Derek Barnes, Ben Evans, Raichelle Aniceto, Krystal Arroyo-Flores, Hang Woon Lee

• Dr. Joel Villasenor (MIT Kavli)

• Mr. Todd Billings (MIT AeroAstro machine shop)
MicroMAS Related Publications


Backup slides
Radiation Testing

- *Kingsbury et al. IEEE NSREC 2013*
- Cobalt-60 TID testing of critical components.
- Estimated mission dose: 1.2 krad (SPENVIS)
- Test limitations: No SEL or SEU testing, low sample sizes
- All devices passed functional tests after 8 krad dose.

### Part Numbers and Test Results

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>8 krad</th>
<th>24 krad</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPF2700</td>
<td>Current limit switch</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>MAX3221-EP</td>
<td>RS232 transceiver</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>PIC24FJ256GA110</td>
<td>PIC24F Microcontroller 256 KB Program, 16KB SRAM</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>PIC24FJ256GB210</td>
<td>PIC24F Microcontroller 256KB Program, 96KB SRAM</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>PIC24EP512GU810</td>
<td>PIC24E Microcontroller 512+KB Prog. Flash, 52KB RAM</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
<tr>
<td>SE02SAMHL-C1000-D</td>
<td>Industrial SD card (Delkin)</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>LT6003 + photodiode</td>
<td>Op-amp (sun sensor circuit)</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>FOX924B</td>
<td>TCXO (oscillator)</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
</tbody>
</table>