
Development of the Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat for All-Weather Atmospheric Sounding

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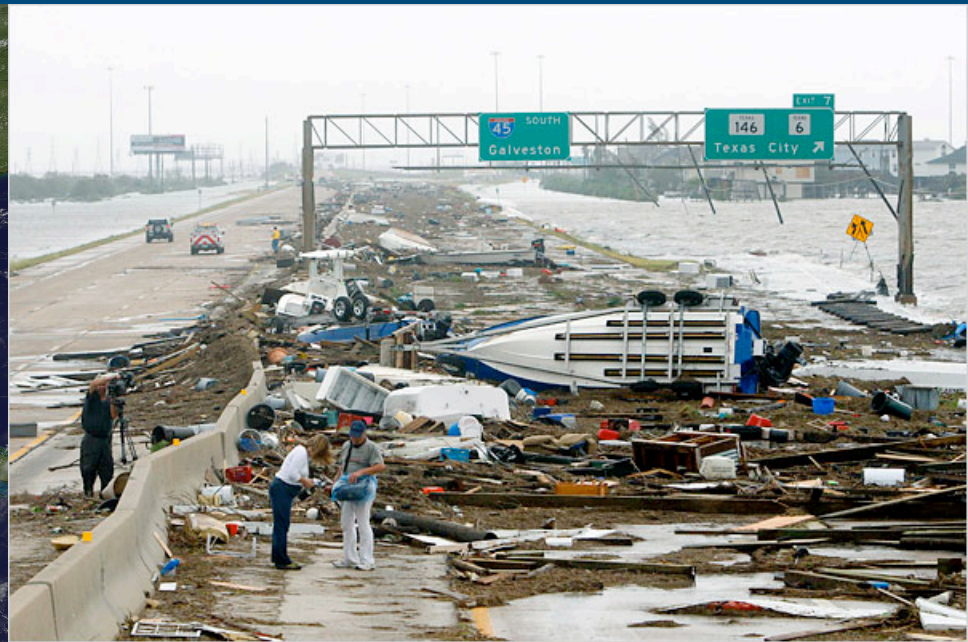
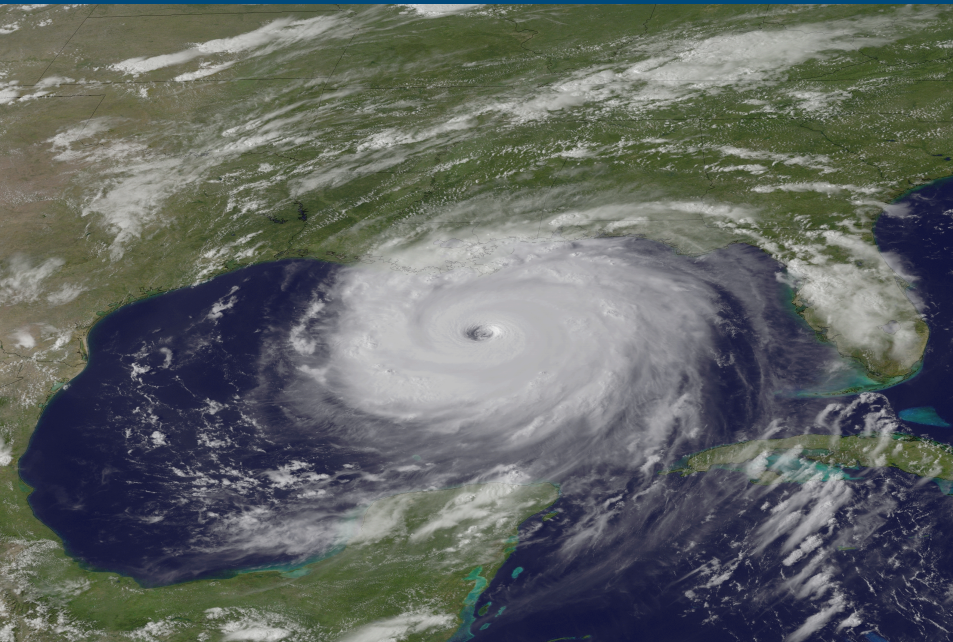
June 15, 2016



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.



Our Ability to Predict the Weather Has Profound Societal and Economic Implications



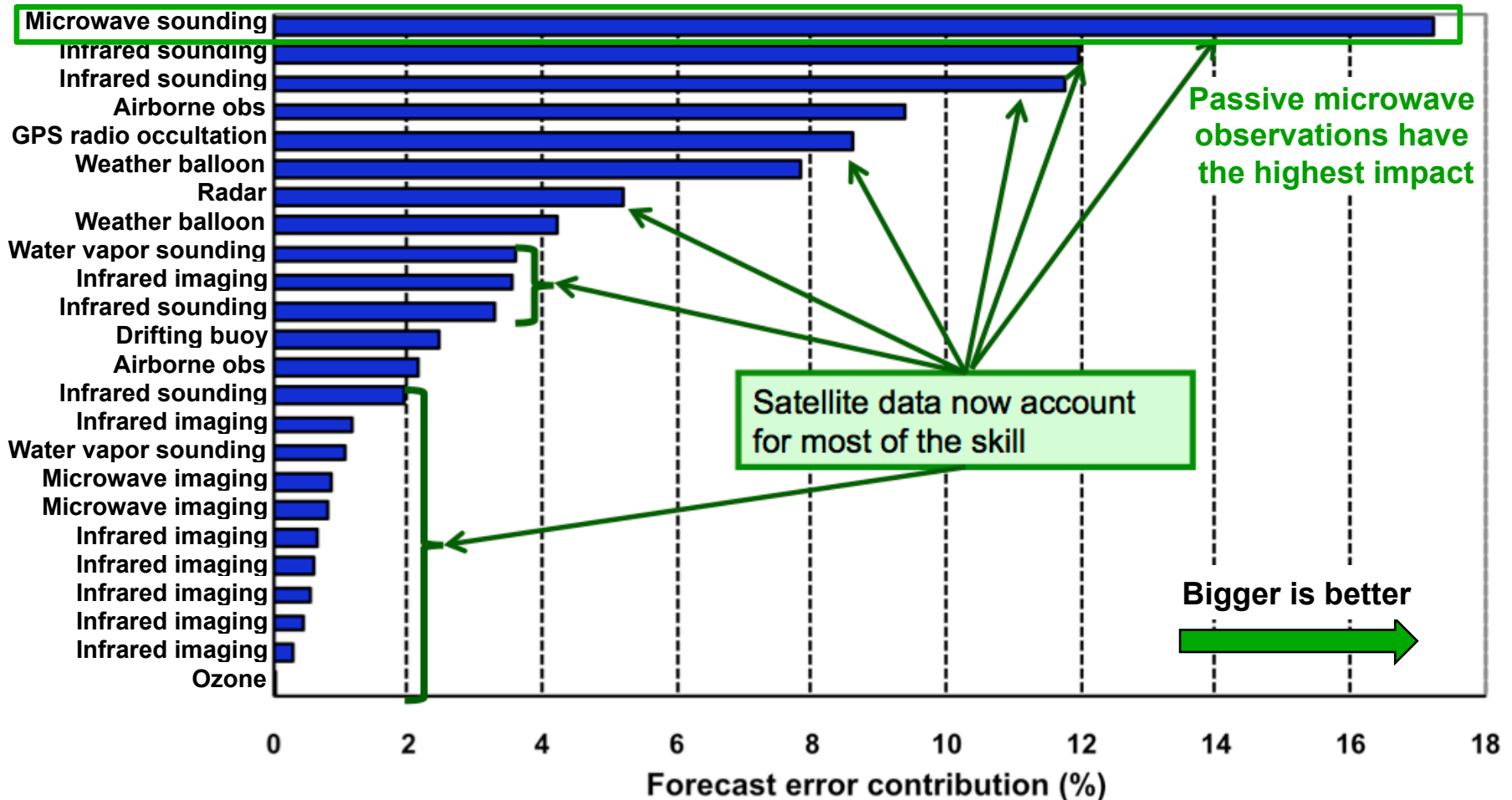
- **The US derives \$32 B of value from weather forecasts annually¹**
- **Earth observing satellites drive the forecasts**
- **Eternal quest for resolution: Spatial (vertical and horizontal), temporal, and radiometric**

¹University Center for Atmospheric Research



Satellites Provide the Most Forecast Skill

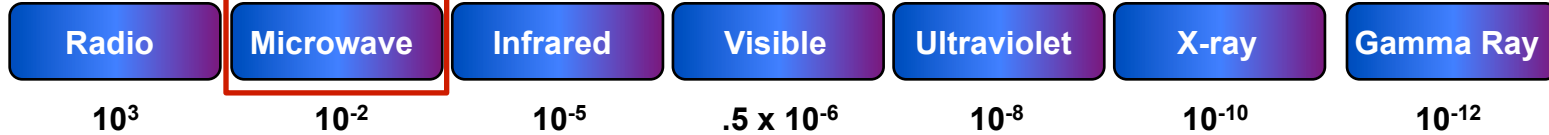
Impact of GOS components on 24-h ECMWF Global Forecast skill
(courtesy of Erik Andersson, ECMWF)



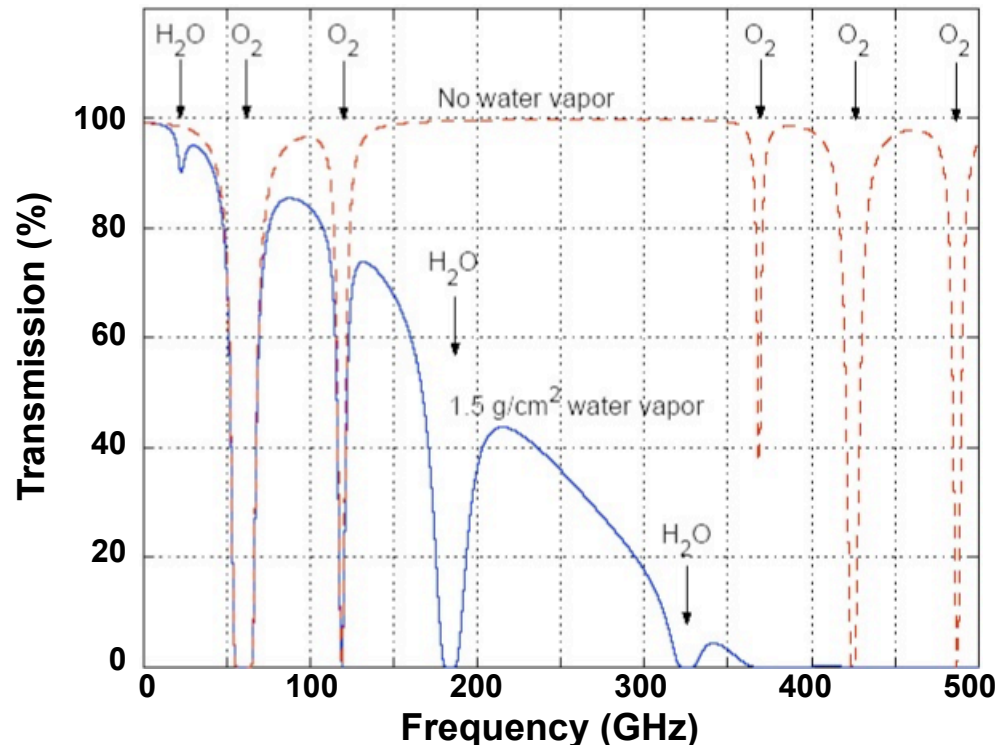


Microwave Atmospheric Sensing

Wavelength
(meters)



Cloud Penetration; Highest Forecast Impact

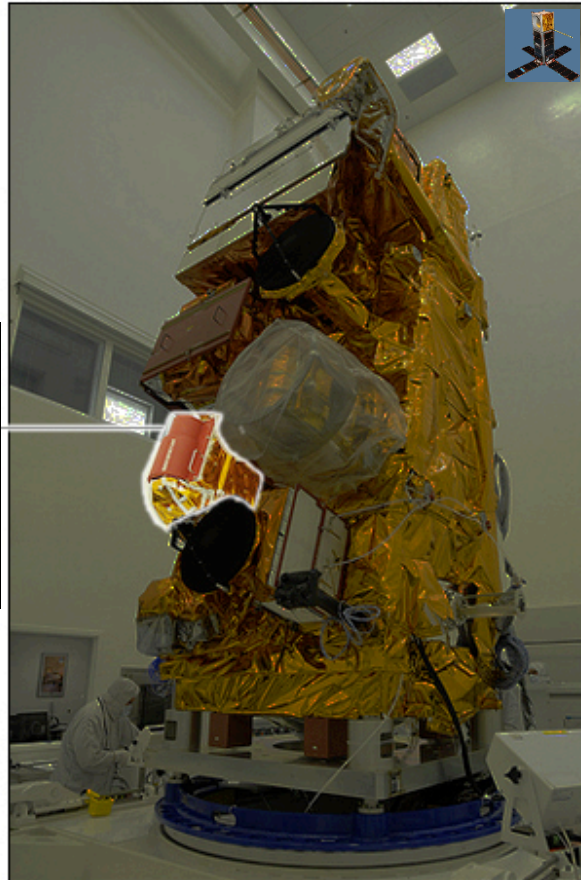


The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines



New Approach for Microwave Sounding

**Suomi NPP Satellite
(Launched Oct. 2011)**

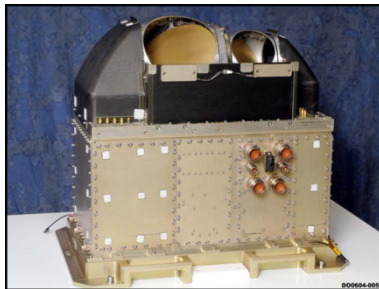


2100 kg

NASA/GSFC

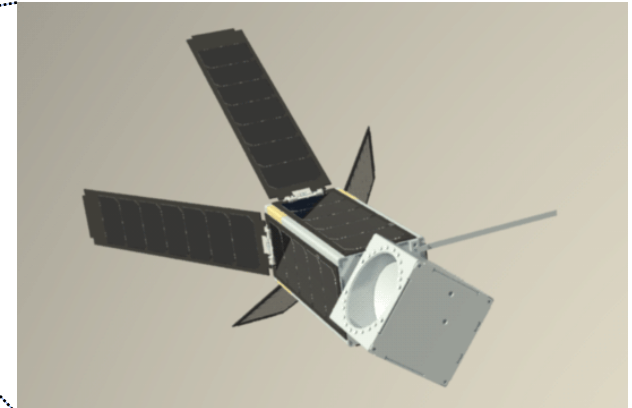
NPP: National Polar-orbiting Partnership

**Advanced Technology
Microwave Sounder
(ATMS)**



100 kg, 100 W

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**



Enabling the Next Generation: MicroMAS-1, MicroMAS-2, and MiRaTA

MicroMAS = Microsized Microwave Atmospheric Satellite

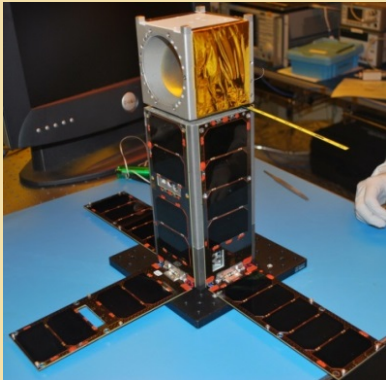
MiRaTA = Microwave Radiometer Technology Acceleration

MicroMAS-1

3U cubesat with 118-GHz radiometer

8 channels for temperature measurements

July 2014 launch, March 2015 release; validation of spacecraft systems; eventual transmitter failure

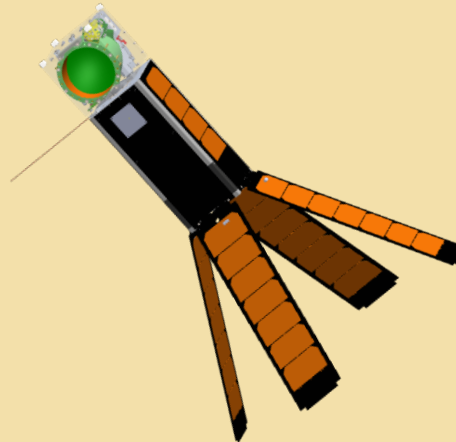


MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

12 channels for moisture and temperature profiling and precipitation imaging

Two launches in 2017

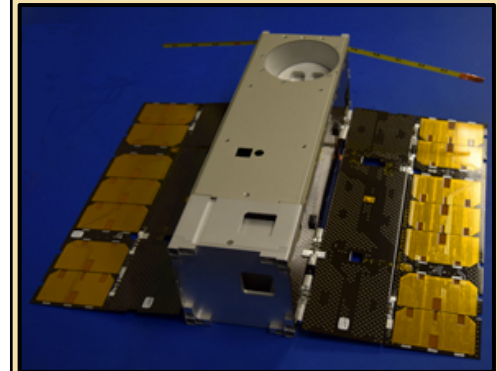


MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

10 channels for temperature, moisture, and cloud ice measurements

Early 2017 launch on JPSS-1





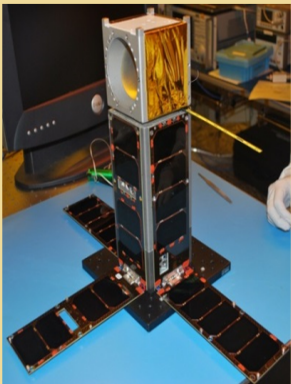
Next Generation: Constellations

MicroMAS-1

3U cubesat with 118-GHz radiometer

8 channels for temperature measurements

July 2014 launch, March 2015 release; validation of spacecraft systems; eventual transmitter failure

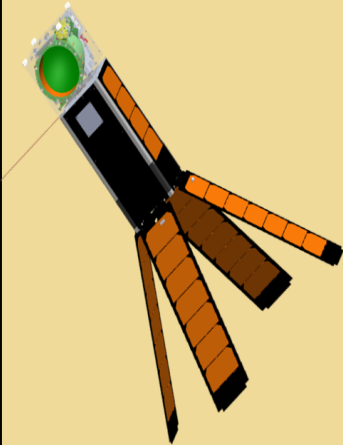


MicroMAS-2

3U cubesat scanning radiometer with channels near 90, 118, 183, and 206 GHz

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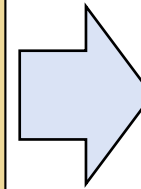
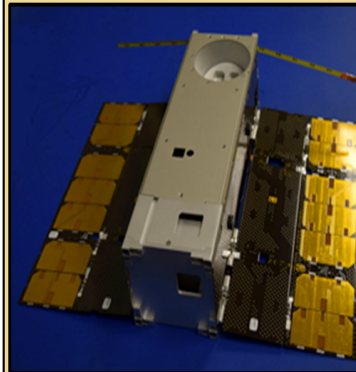


MiRaTA

3U cubesat with 60, 183, and 206 GHz radiometers and GPS radio occultation

10 channels for temperature, moisture, and cloud ice measurements

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TROPICS

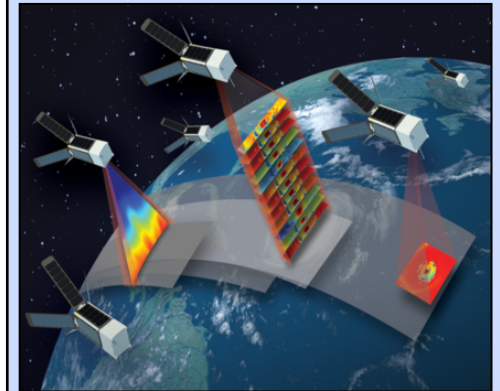
Selected for EVI-3

12 CubeSats (3U) in three orbital planes (600km/30°)

Temperature and moisture profiling and cloud ice measurements

30-minute revisit

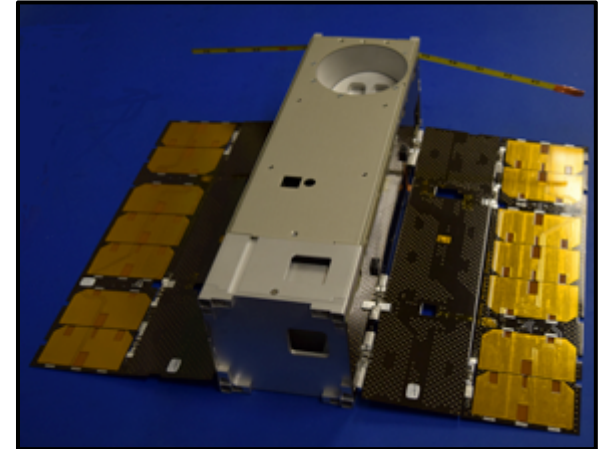
2019/2020 launch





Microwave Radiometer Technology Acceleration (MiRaTA)

- **3U (10 cm x 10 cm x 34 cm) tri-band radiometer**
 - Temperature, water vapor, and cloud ice
 - Absolute calibration better than 1 K
- **Calibration proof of concept using limb measurements and GPS-RO**
 - 60, 183, and 206 GHz; OEM628 GPS
- **Funded by NASA Earth Science Technology Office (ESTO) InVEST program**
- **~30-month build**
- **Launch in early 2017 (JPSS-1)**
 - Permits direct comparisons with ATMS



- **4.5 kg total mass**
- **10 W avg power**
- **10 kbps max data rate**
- **0.5° pointing accuracy**



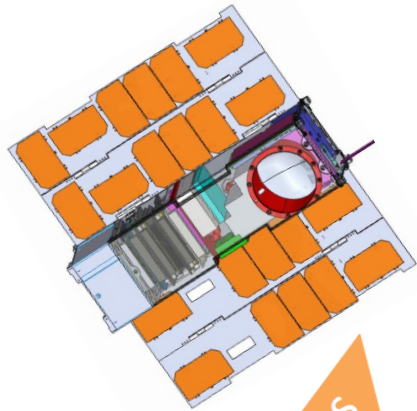
TRL Advancement Criteria (TRL 5 to 7)

- **(1) IF spectrometer**
 - Verify that the V-band radiometric accuracy is within 1.5 K of the truth predictions
 - V-band end-to-end receiver temperature sufficient to yield 0.1K NEdT.
 - *Blackwell ACT10 “Hyperspectral Microwave Receiver” IFP module leveraged here*
- **(2) G-band mixer**
 - 2.0 K radiometric accuracy against ground truth predictions
 - End-to-end receiver temperature sufficient to yield 0.25 K NEdT.
 - *Blackwell ACT10 “Hyperspectral Microwave Receiver” mixer module leveraged here*
- **(3) GPS-RO receiver**
 - Evaluate GPS-RO temperature retrievals are within 1.5 K of the truth predictions
 - Truth measurements consist of combination of radiosondes and NWP measurements coupled with radiative transfer model
 - Direct radiance comparisons with operational passive microwave sounders will also be utilized for verification

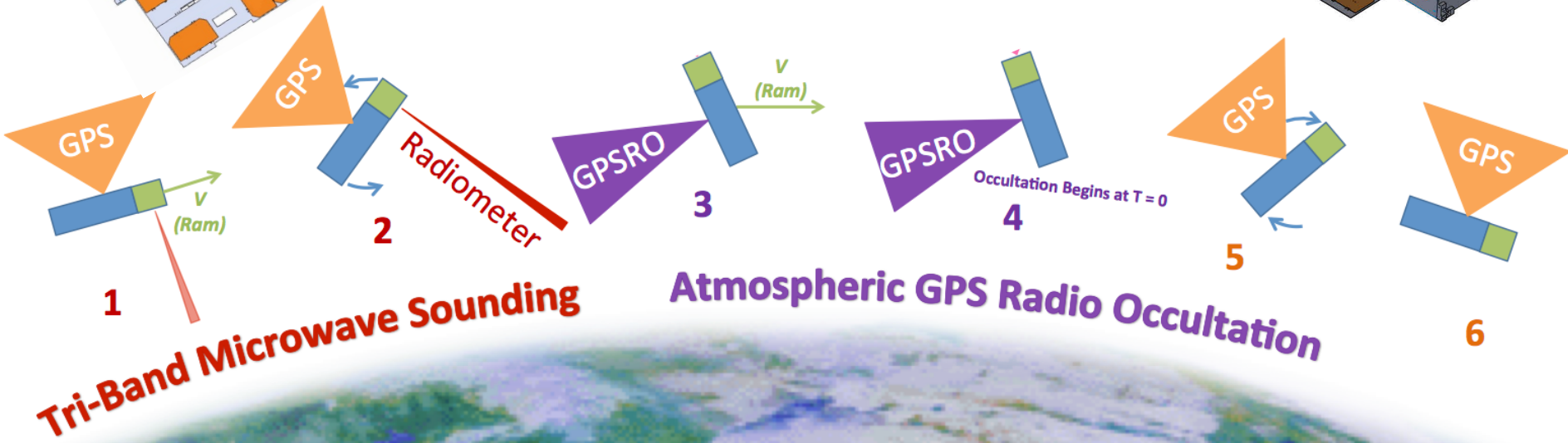
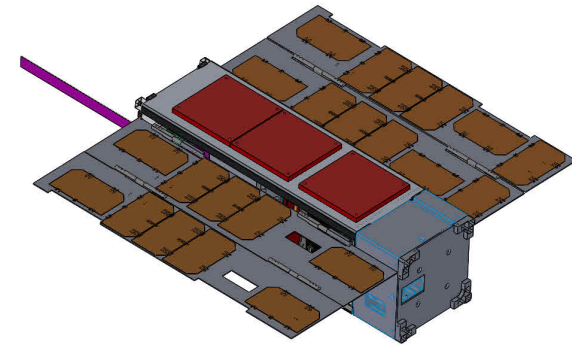


MiRaTA Calibration Maneuver

Nominal Sci Ops for Coupled Atmospheric GPSRO & Microwave Radiometry



~ 10 minute maneuver
 $0.5^\circ / \text{sec}$ rate





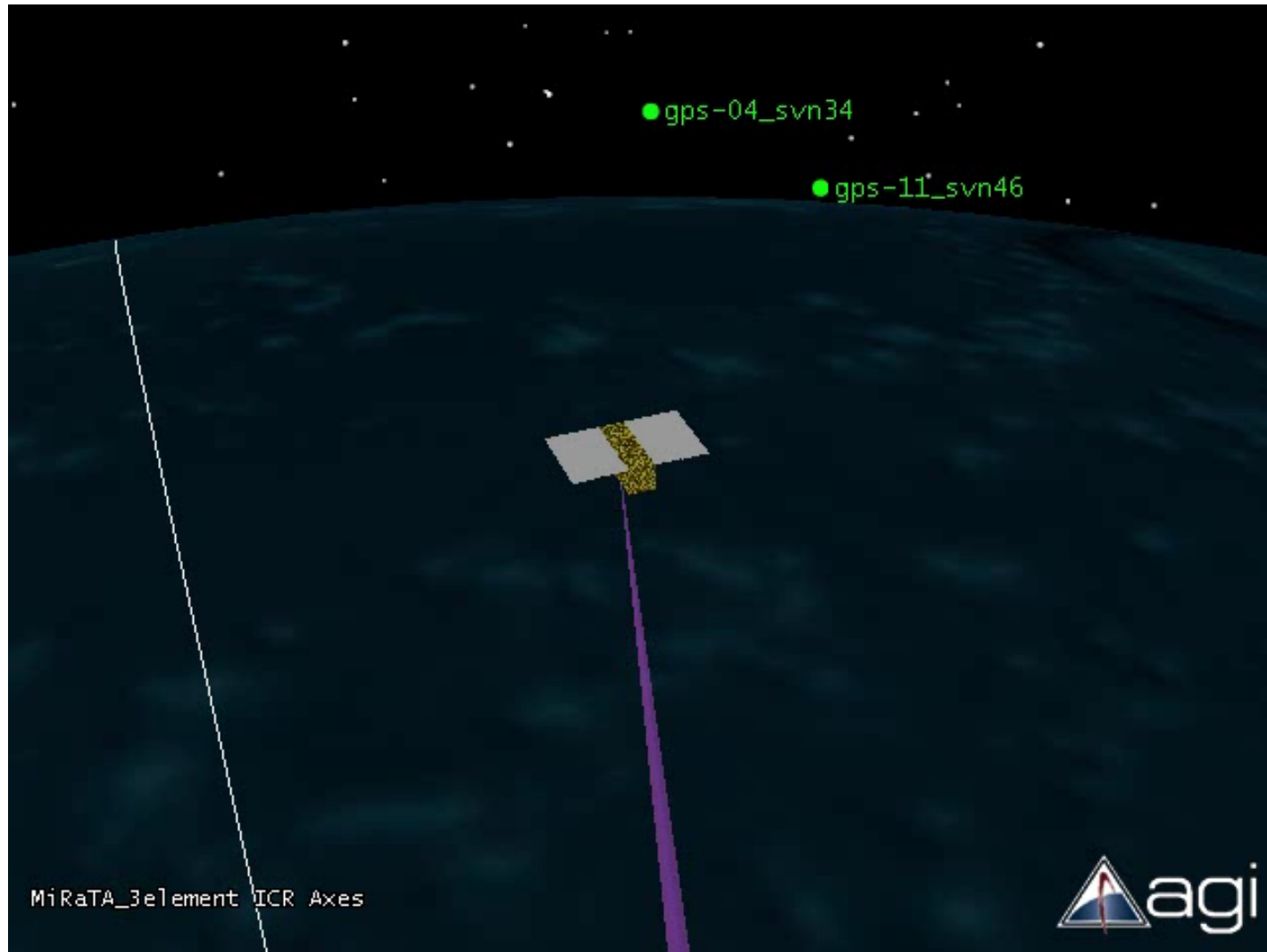
MiRaTA Pitch-Up Maneuver

Objective:

Collocate radiometric data and GPS RO temperature profile

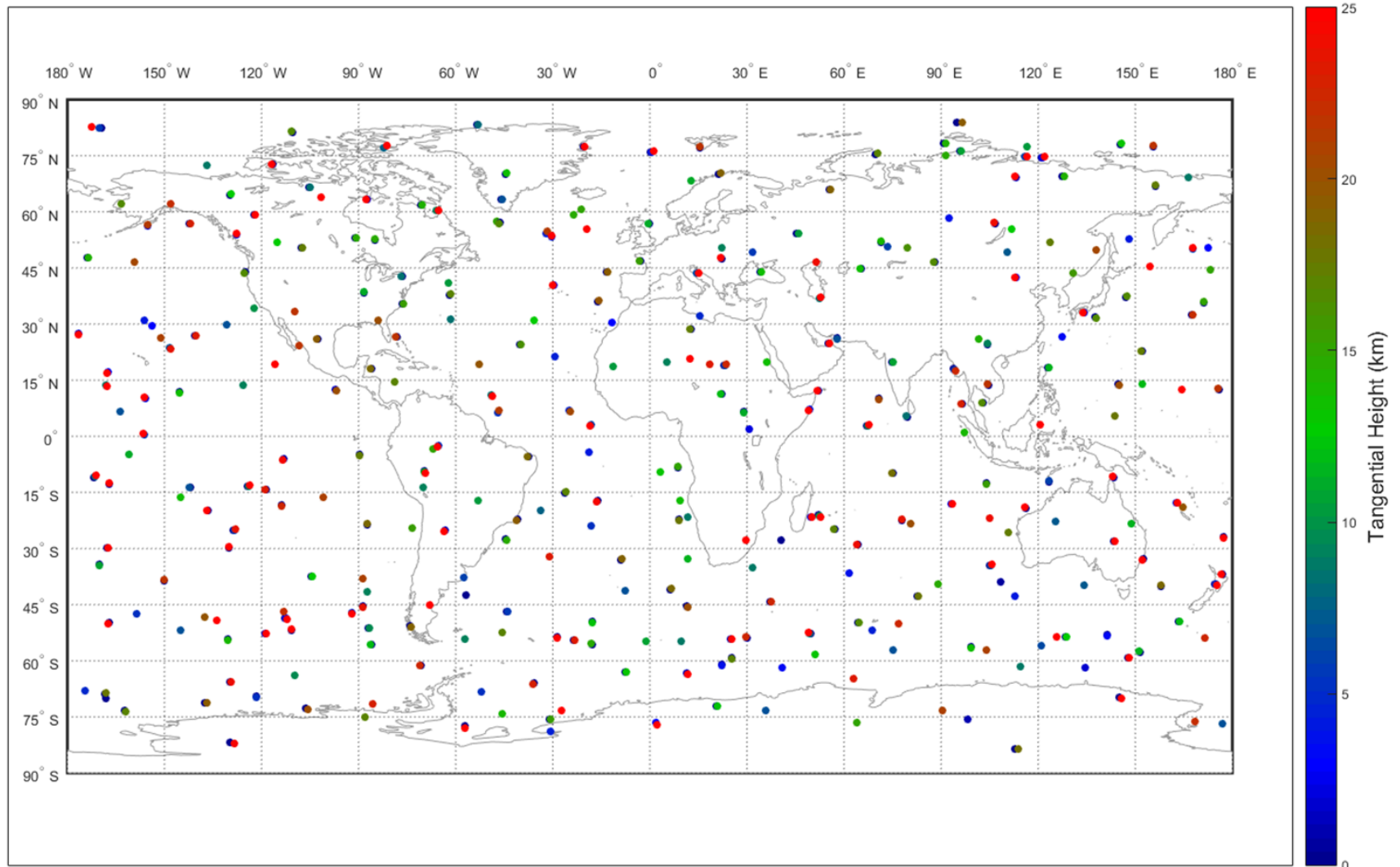
Credit:

Annie Marinan
(MIT SSL) &
Weston Marlow
(G95 & SSL)



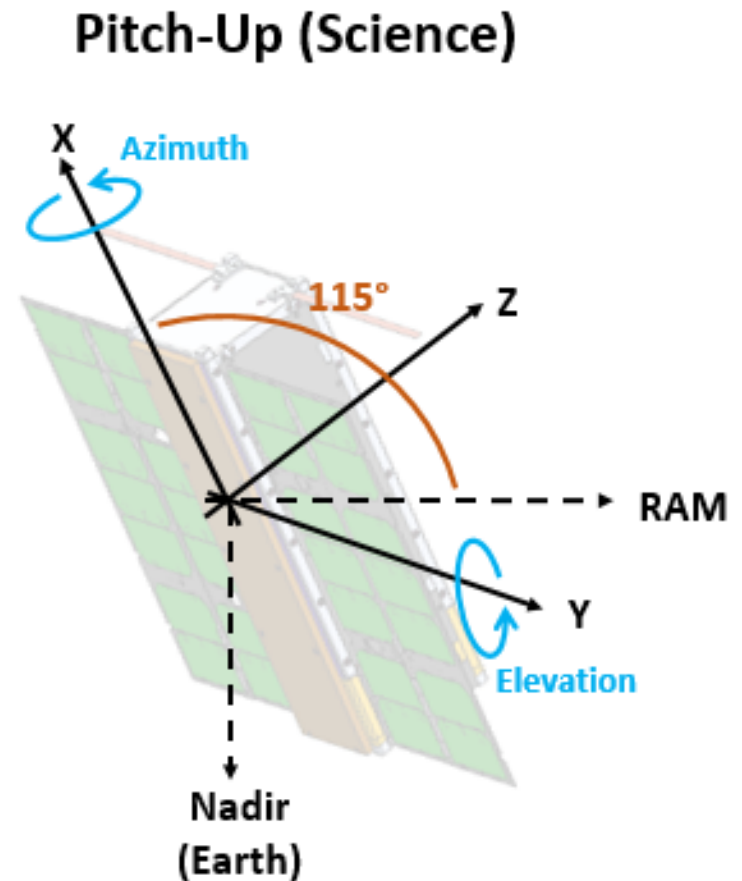
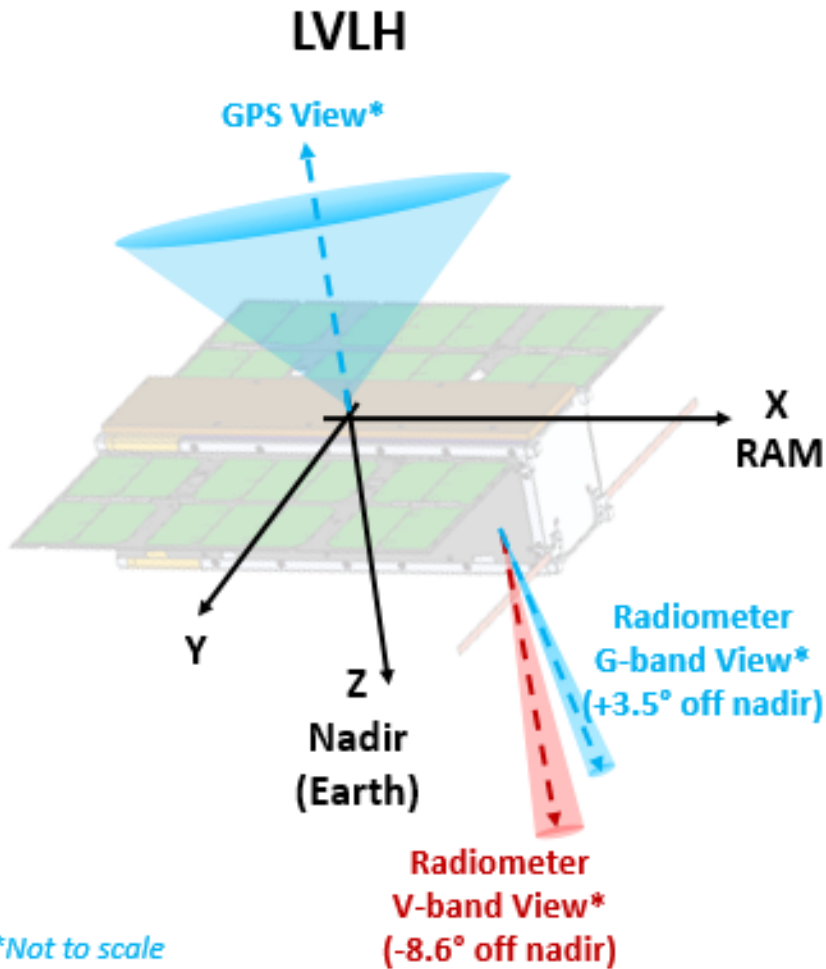


GPS-RO Opportunities for One Day



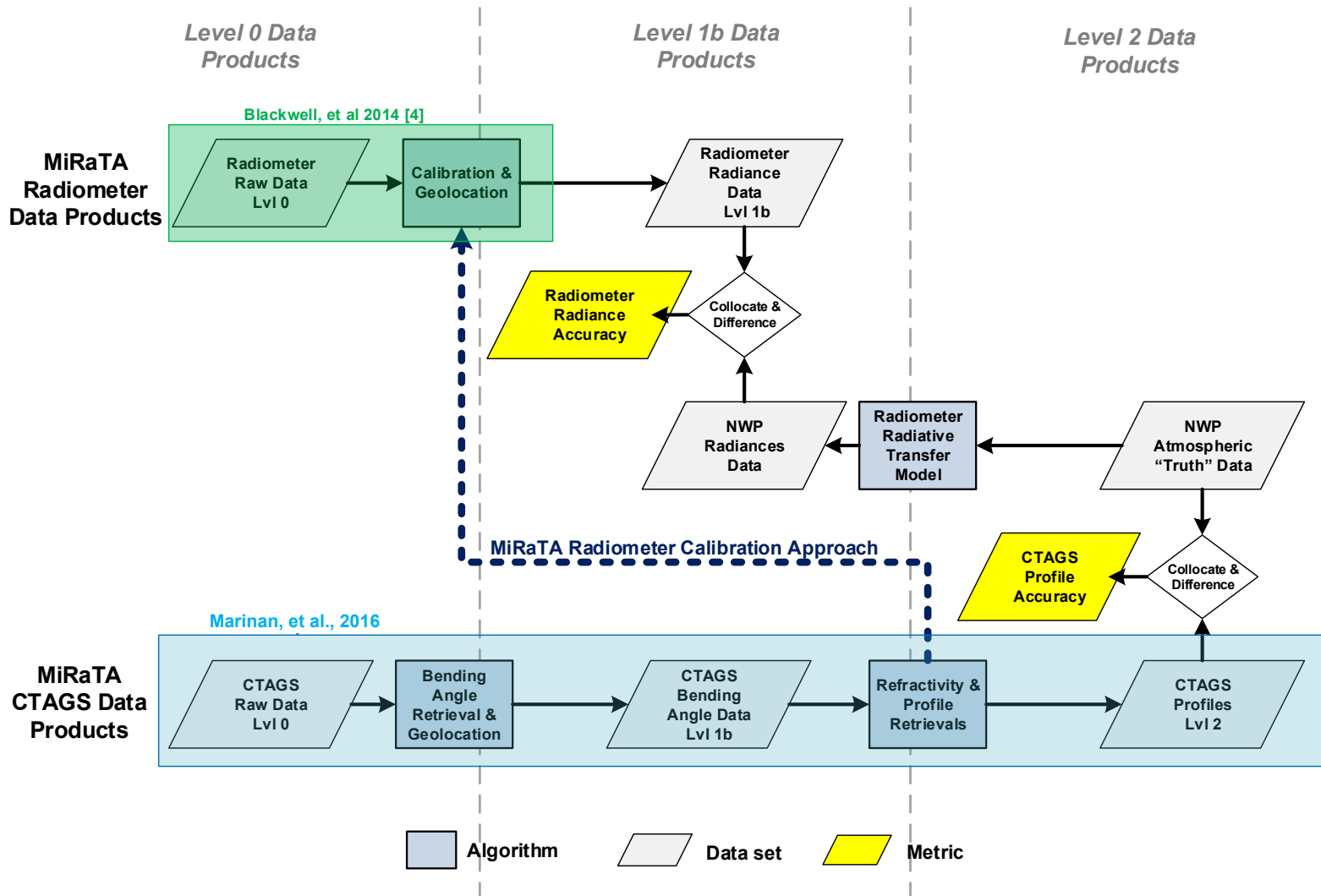


MiRaTA Sensor Viewing Geometries





MiRaTA Product Validation Approach





MiRaTA Manifested on ELaNa 14

- Launch on a Delta II with JPSS-1
- Inclination – 97.73 degrees
- Orbit – ~811km x ~440km
- LTAN - 13:20:35
- JPSS-1 launch in Jan. 2017





MiRaTA Key Dates

Milestone	Date
Award “Start”	<i>Dec. 20, 2013</i>
NSSC Approval	<i>Feb. 12, 2014</i>
Funds distributed	<i>Mar. 14, 2014</i>
Project Kickoff with Subs	<i>Apr. 2014</i>
System Requirements Review	<i>June 2, 2014</i>
System PDR	<i>Oct. 2014</i>
System CDR	<i>June 1-3, 2015</i>
Flight-ready Spacecraft	<i>Aug. 2016</i>
Deadline to complete testing reports	<i>Sept. 1st, 2016</i>
Mission Readiness Review	<i>Oct. 4th, 2016</i>
CubeSat Delivery	<i>Nov. 7th, 2016</i>
Launch	<i>Jan. 20th, 2017*</i>

*** ELaNa-XIV launch with JPSS-1**



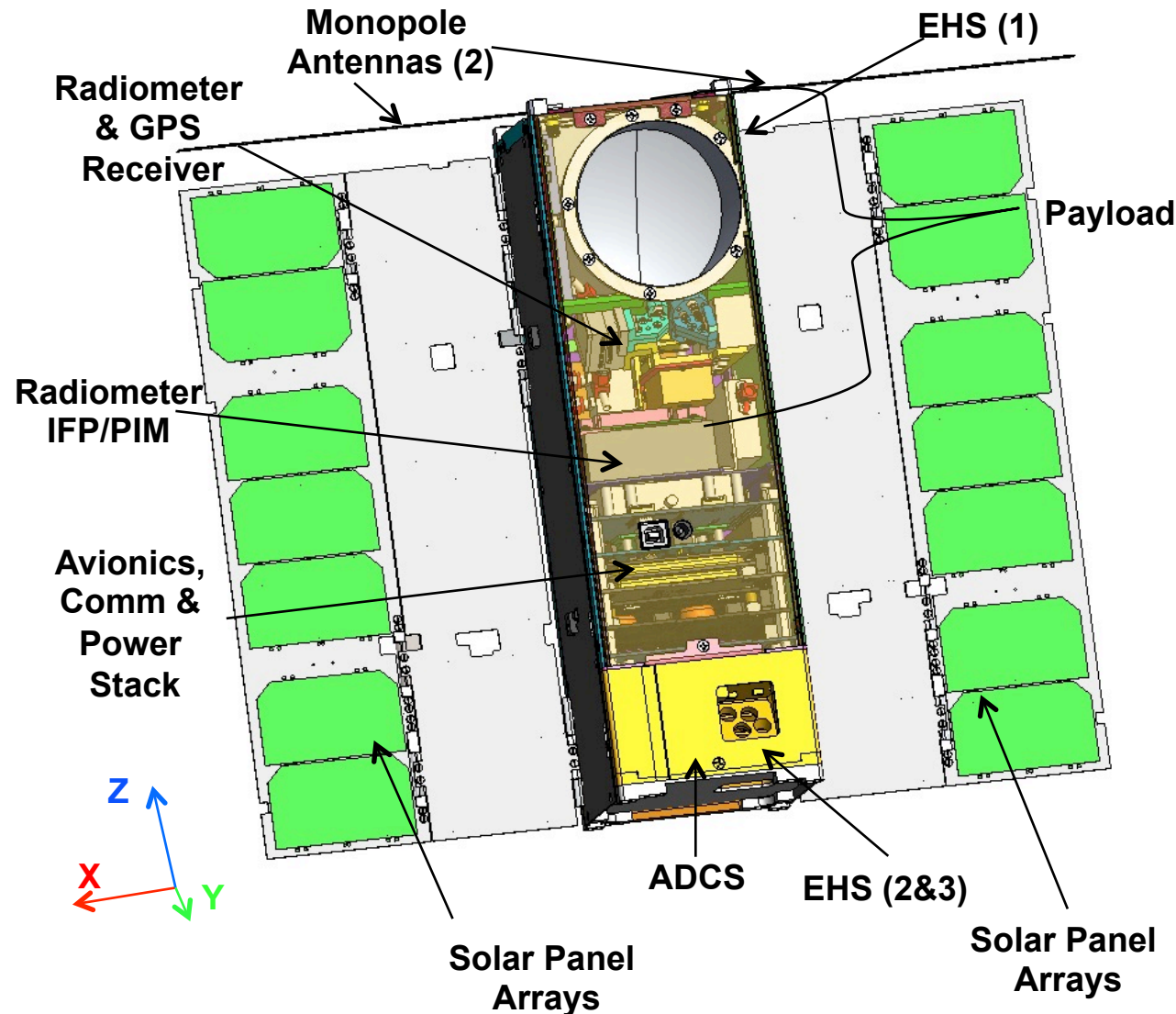
MiRaTA Spacecraft Overview

- **Payload**

- Microwave Radiometer
- GPS Radio Occultation receiver and Patch Antenna array (GPSRO or CTAGS)

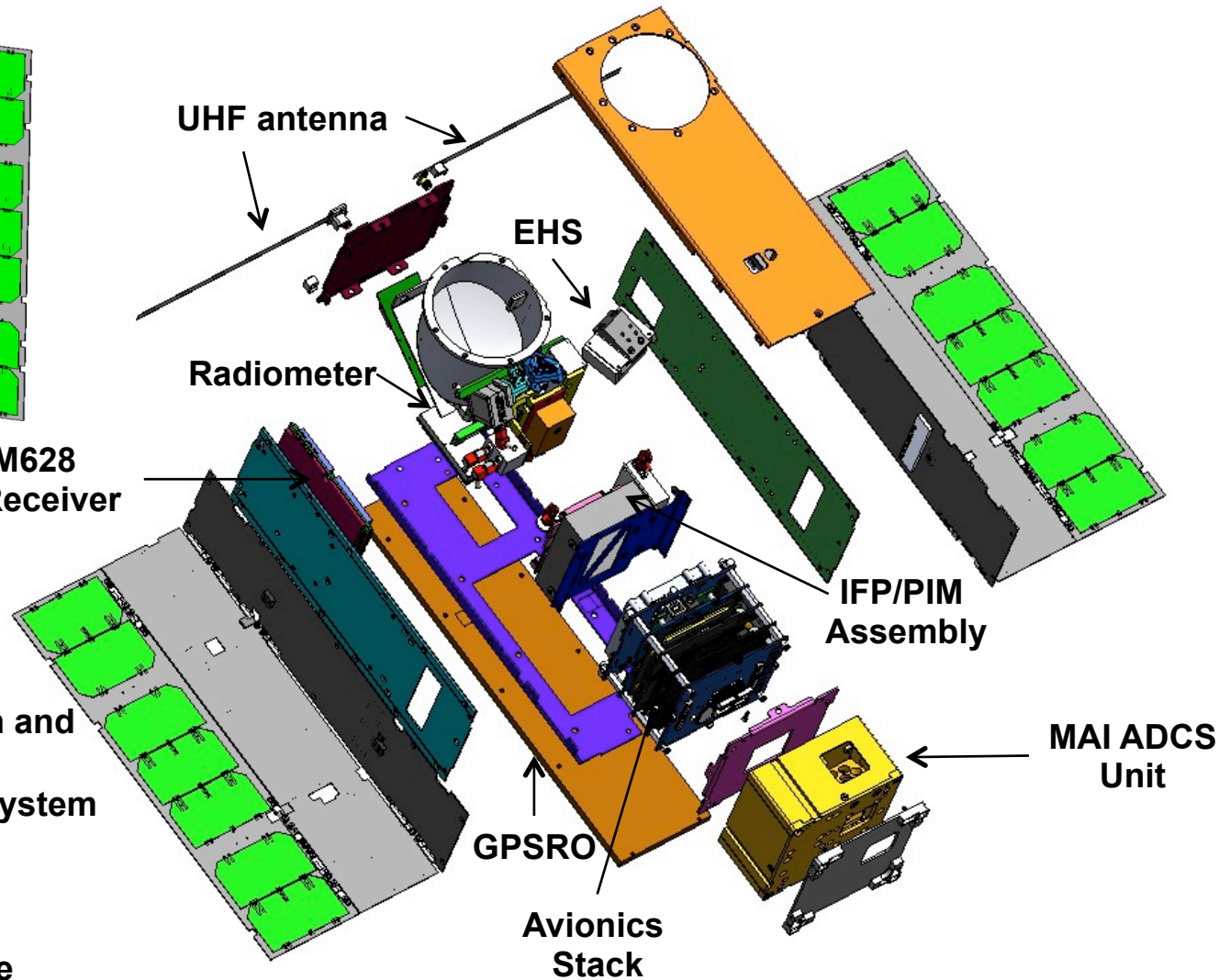
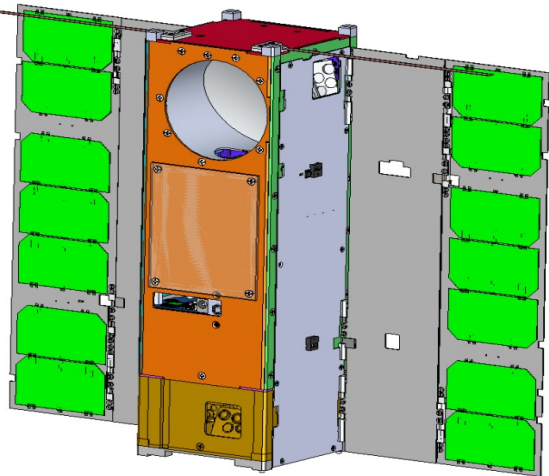
- **Bus**

- Cadet UHF Radio with Monopole UHF Antenna
- Avionics Stack
 - With low data-rate UHF radio and antenna
- Attitude Determination and Control System
- Power system, batteries





MiRaTA Space Vehicle Overview



EHS = Earth Horizon Sensor
ADCS = Attitude Determination and
Control System
GPSRO = Global Positioning System
Radio Occultation
IFP = Intermediate Frequency
Processor
PIM = Payload Interface Module

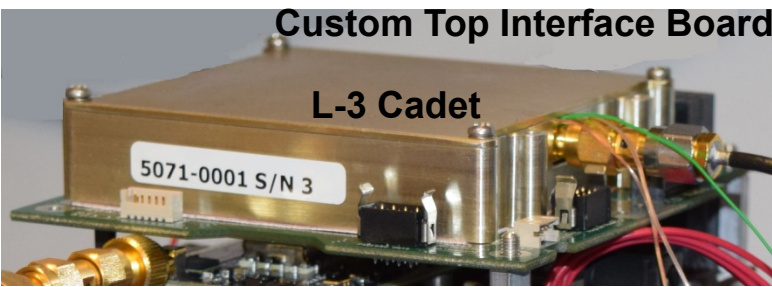


Bus Flight Hardware

Custom Top Interface Board

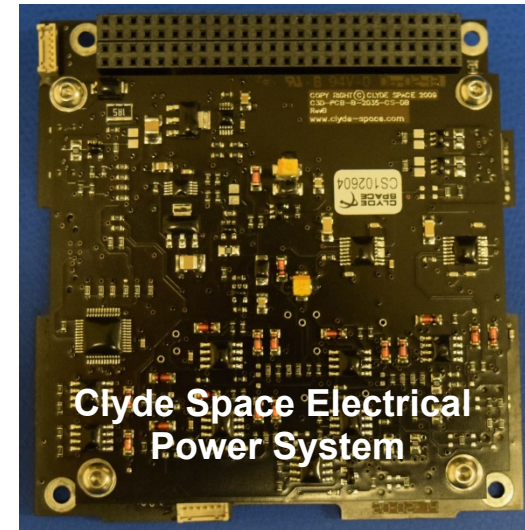
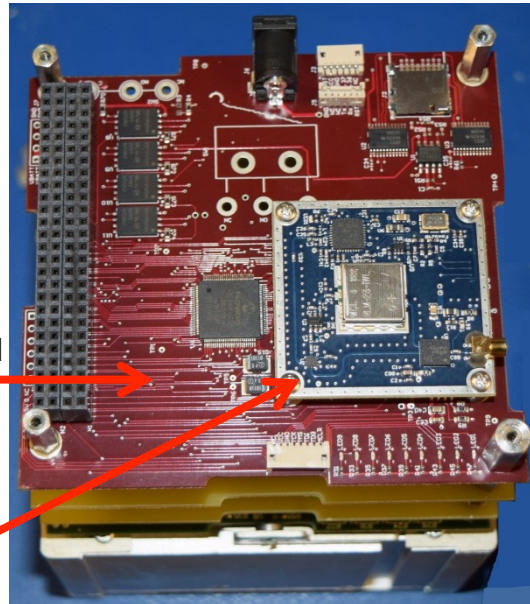
L-3 Cadet

5071-0001 S/N 3



Micron
Motherboard
(custom)

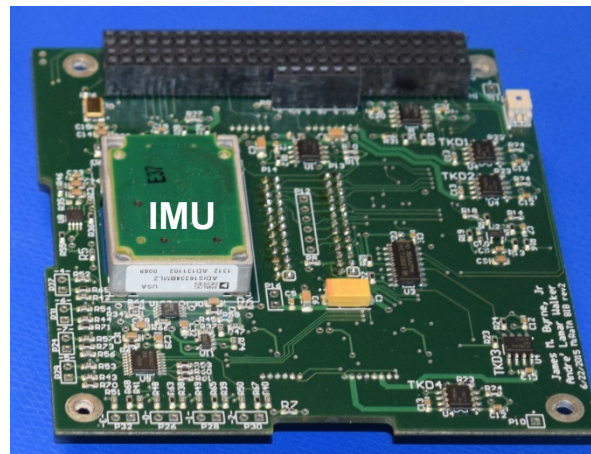
Custom
Micron
Radio



Clyde Space Electrical
Power System



ADCS
MAI-400



Custom Bottom Interface Board



Clyde Space Battery



Measurement Requirements and Enabling Technologies

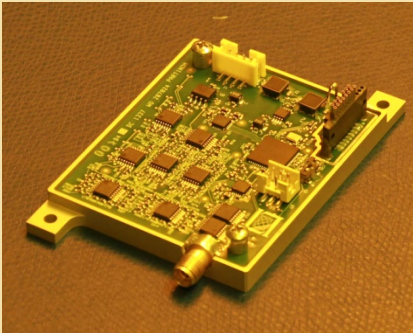
Temperature profile uncertainty of 2 K (RMS) in 50 km footprint needed to improve forecast accuracy

Six or more channels

Ultracompact spectrometer funded by NASA ESTO (ACT-10)

Low-temperature co-fired ceramic filters

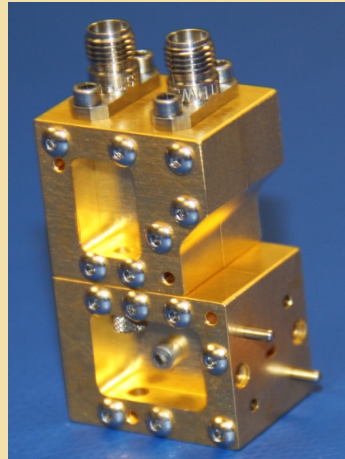
Operation from 18-29 GHz



Sensitivity better than 0.3 K (RMS)

Receiver front-end electronics developed by UMass-Amherst

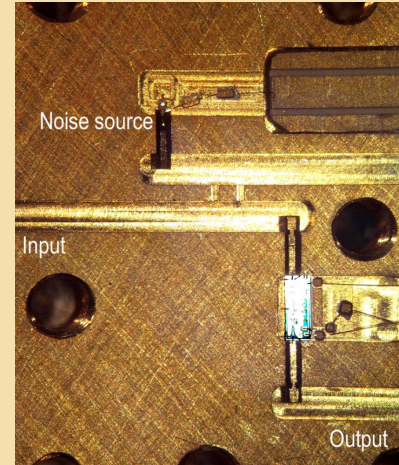
MMIC low-noise amplifiers and electronic calibration



Calibration accuracy better than 1 K (RMS)

Noise diode source provides periodic absolute calibration of radiometer

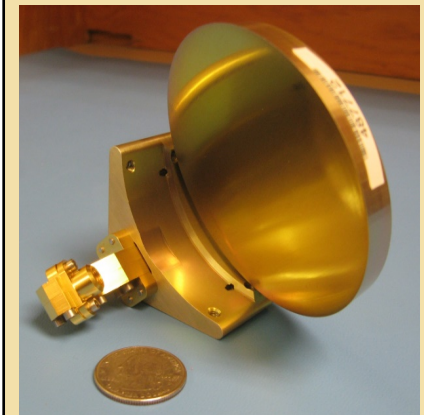
Highly stable; compact



**Aperture ~9 cm
Beam efficiency > 95%**

Offset parabolic reflector system with scalar feed

Lightweight, with 0.001" RMS surface tolerance



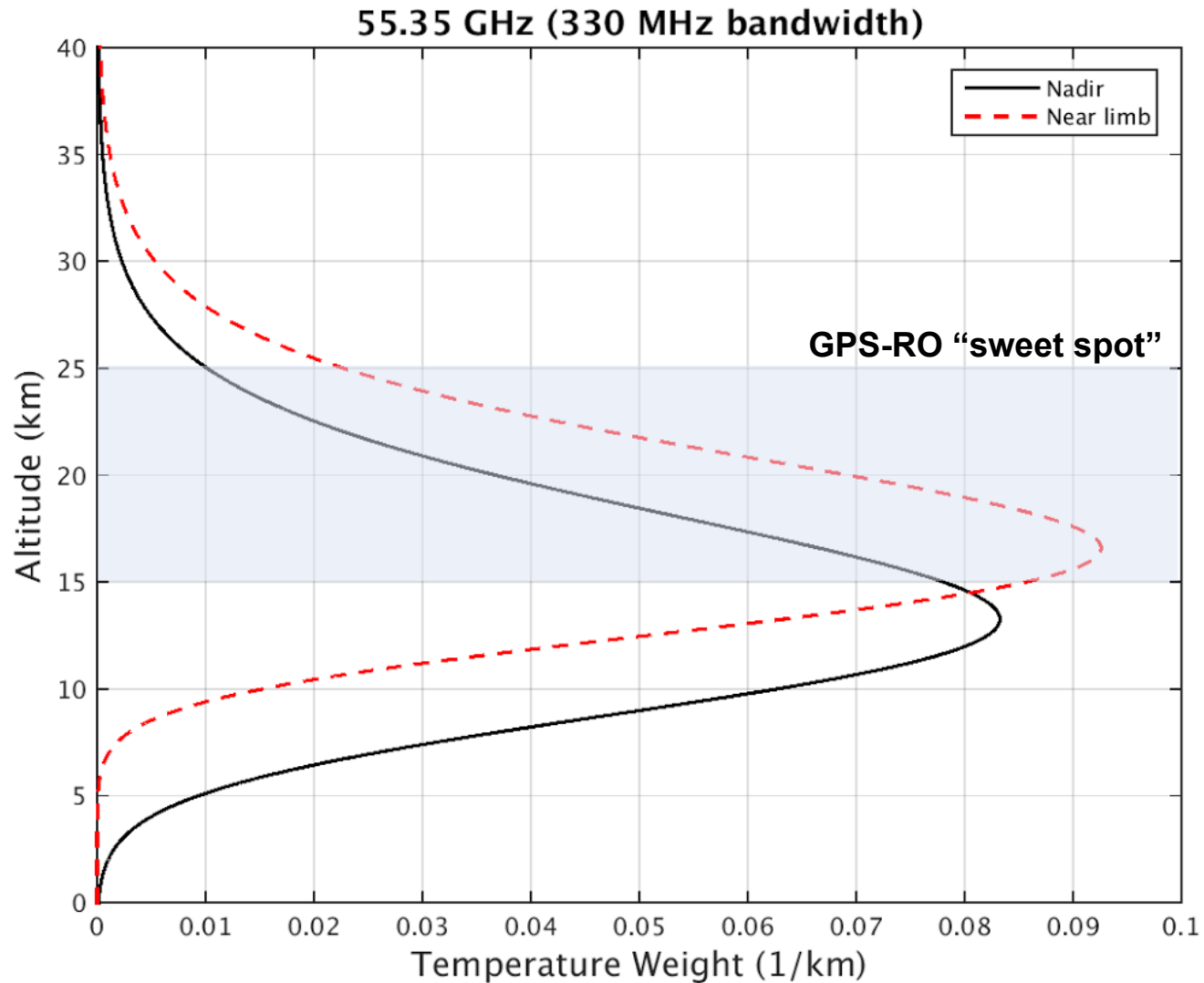


Channel Properties for MiRaTA Radiometers

Channel ID	Type	Center Frequency (GHz)	Bandwidth (MHz)	Weighting Function Peak Height (km)
V1	Single Side Band	50.30	180	0
V2		51.76	400	0
V3		52.80	400	2
V4		53.50	600	5
V5		54.40	400	8
V6		54.94	400	11
V7		55.50	330	13
V8		56.65	600	18
G1	Double Side Band	183.31 ± 1	500	7
G2		183.31 ± 3	1000	4
G3		183.31 ± 5	2000	2
G4		204.8	2000	1

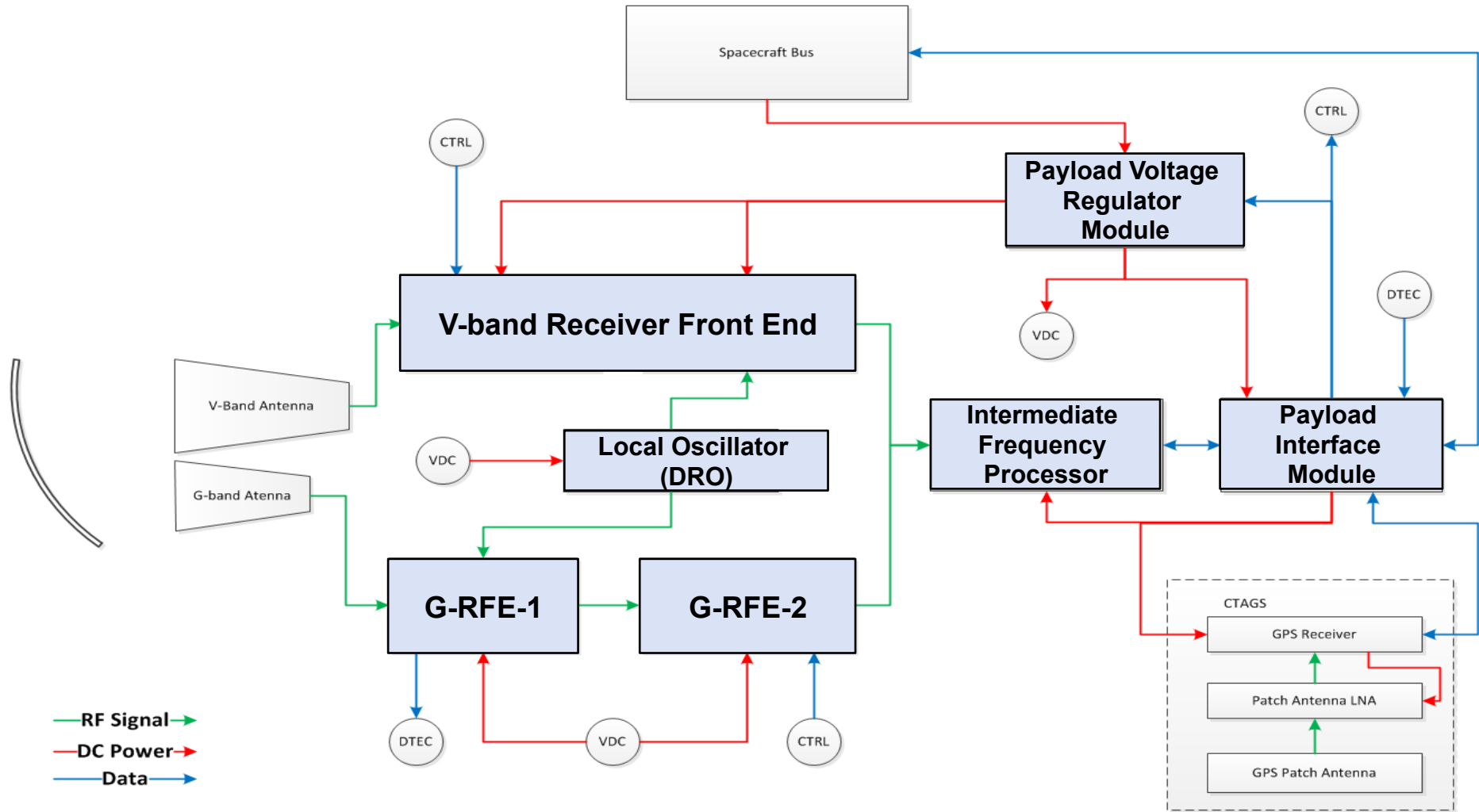


Advantage of Limb Comparisons



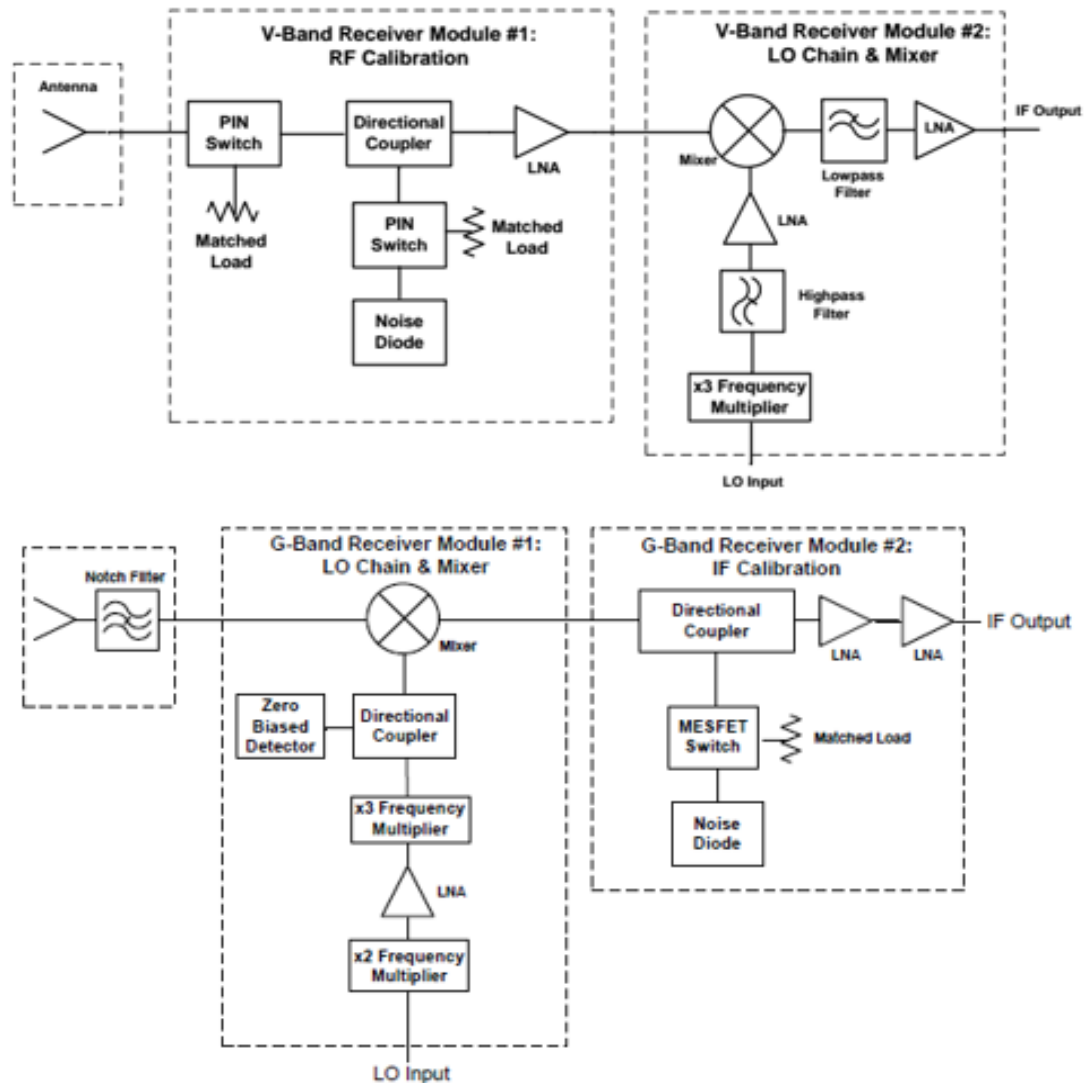


Radiometer Payload: Block Diagram



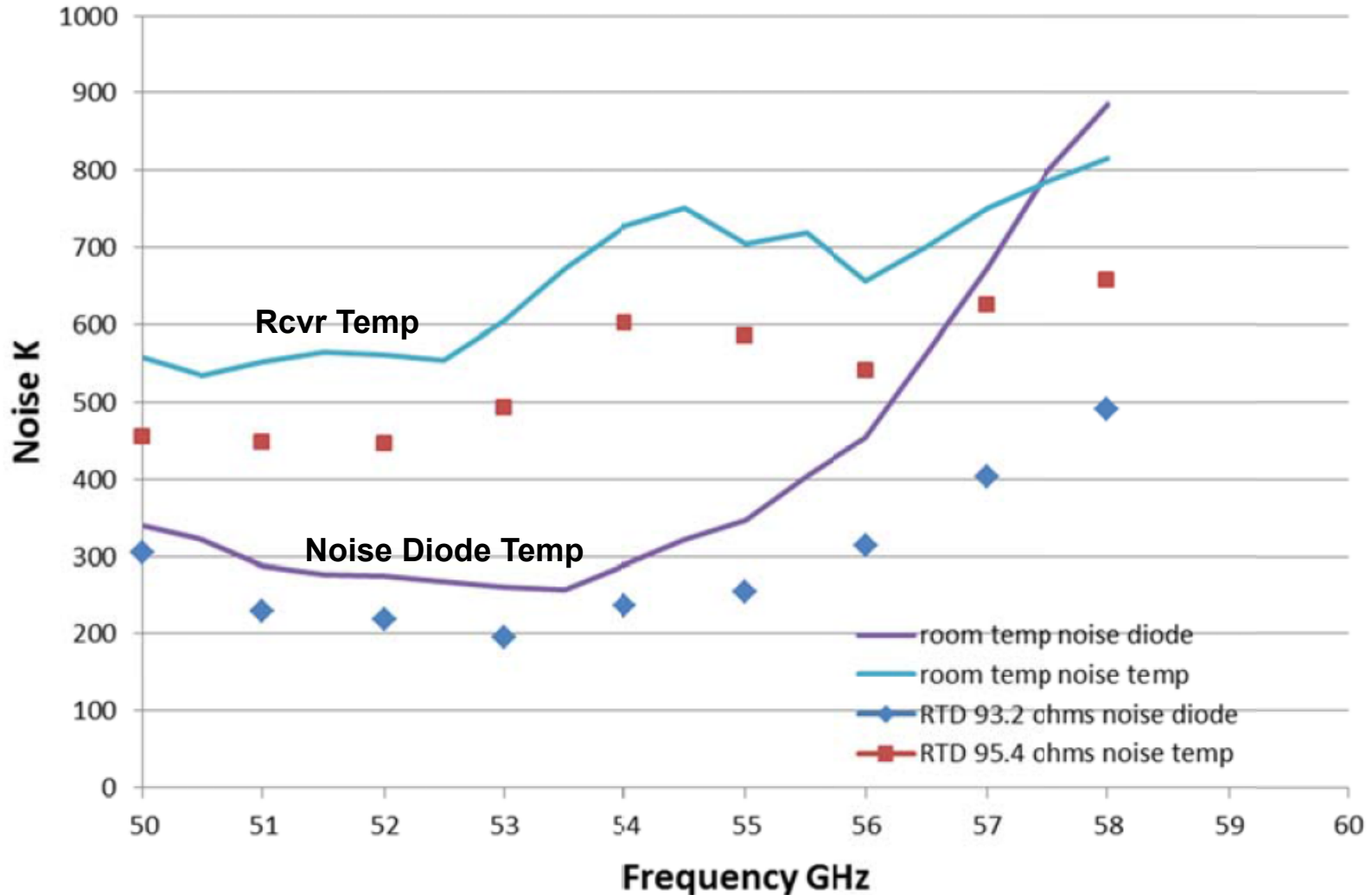


Payload: Radiometer Receiver Front End





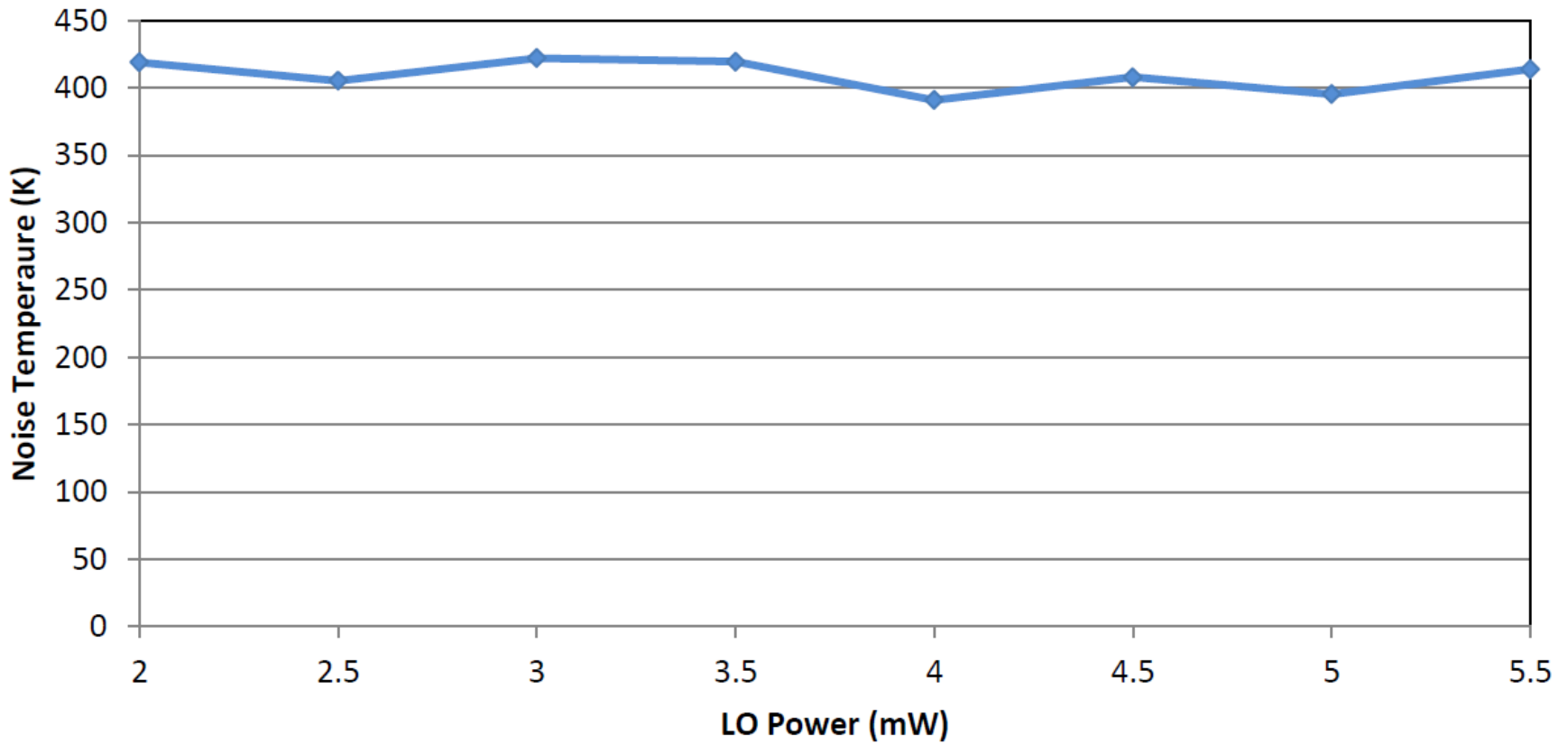
MiRaTA V-band Front-End Performance (Includes PIN Switch and Noise Injection)





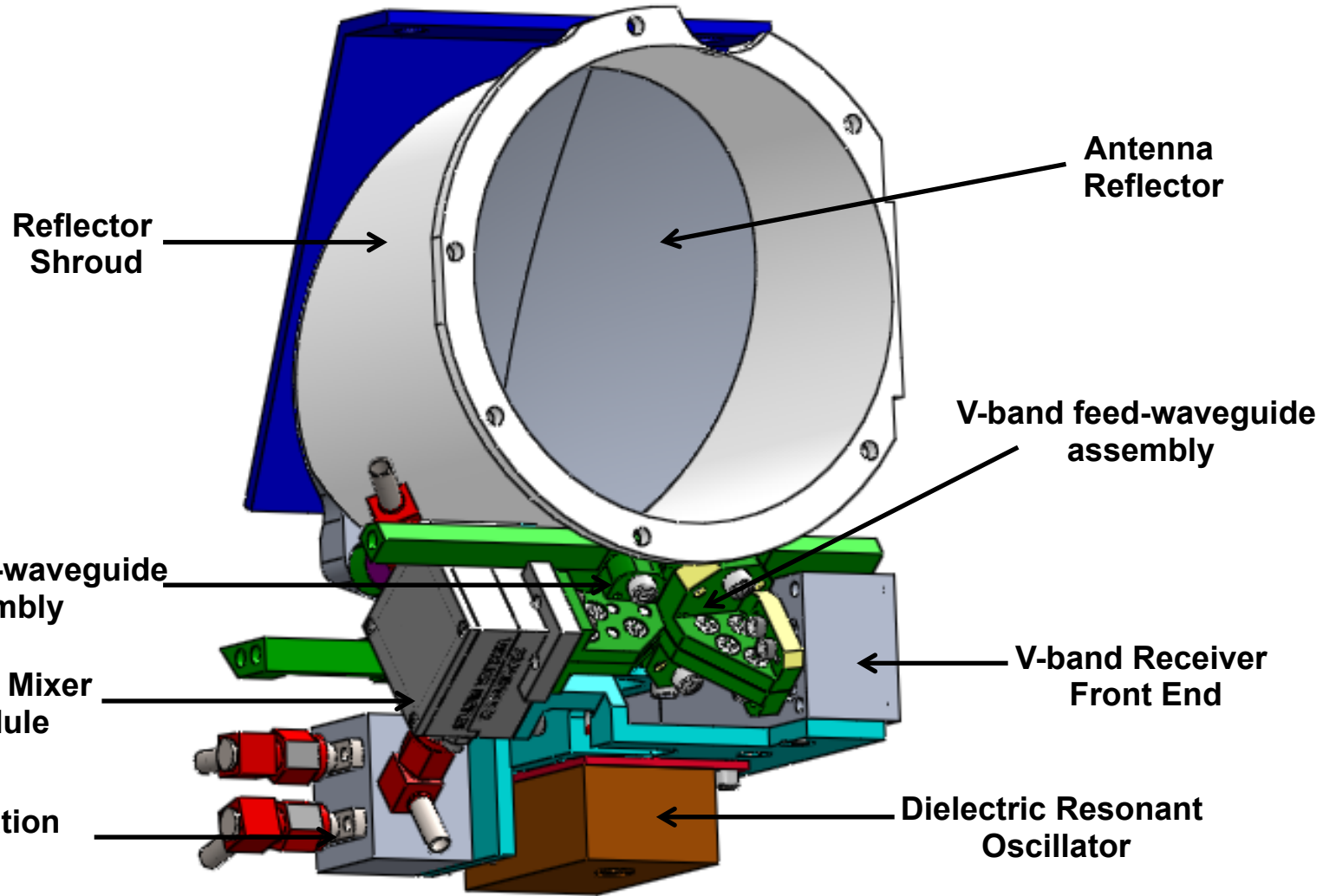
MiRaTA G-band Front-End Performance

VDI 183X6DSHMR1 1-04 Performance





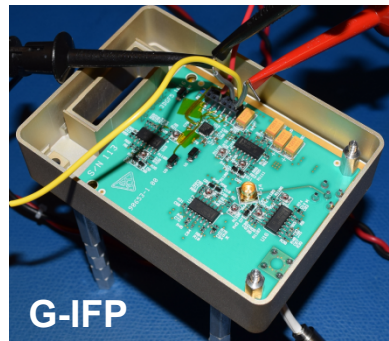
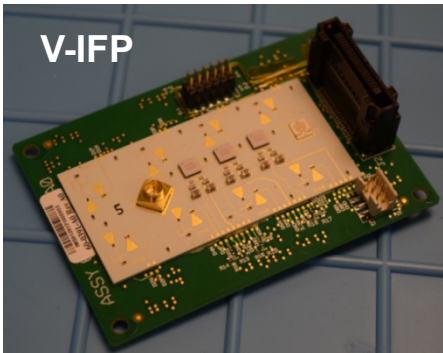
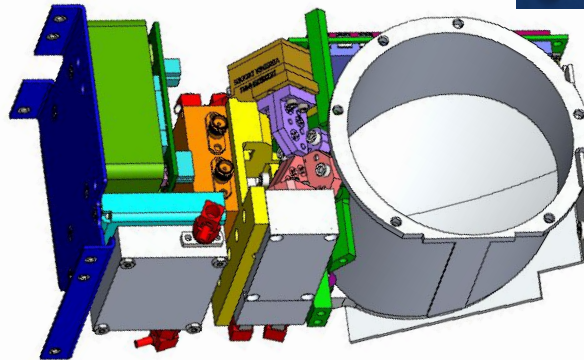
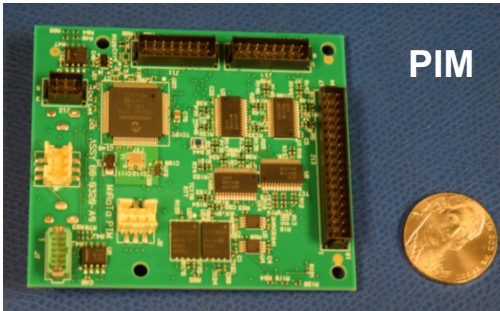
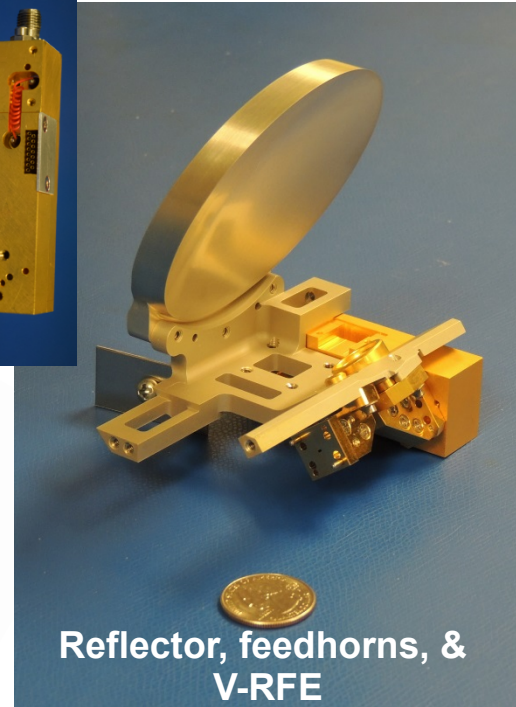
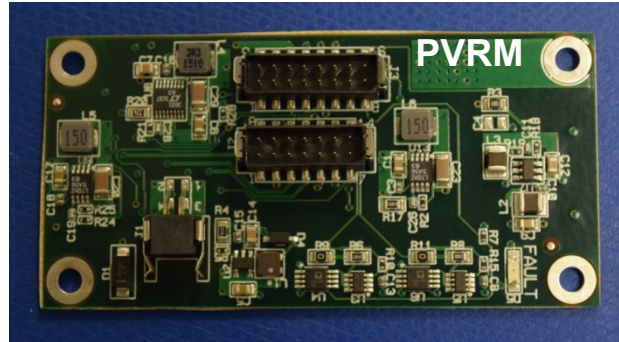
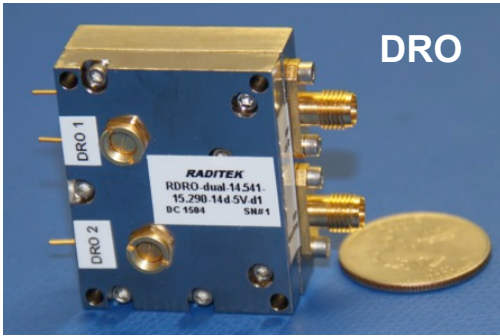
MiRaTA Radiometer System



All flight radiometer hardware delivered



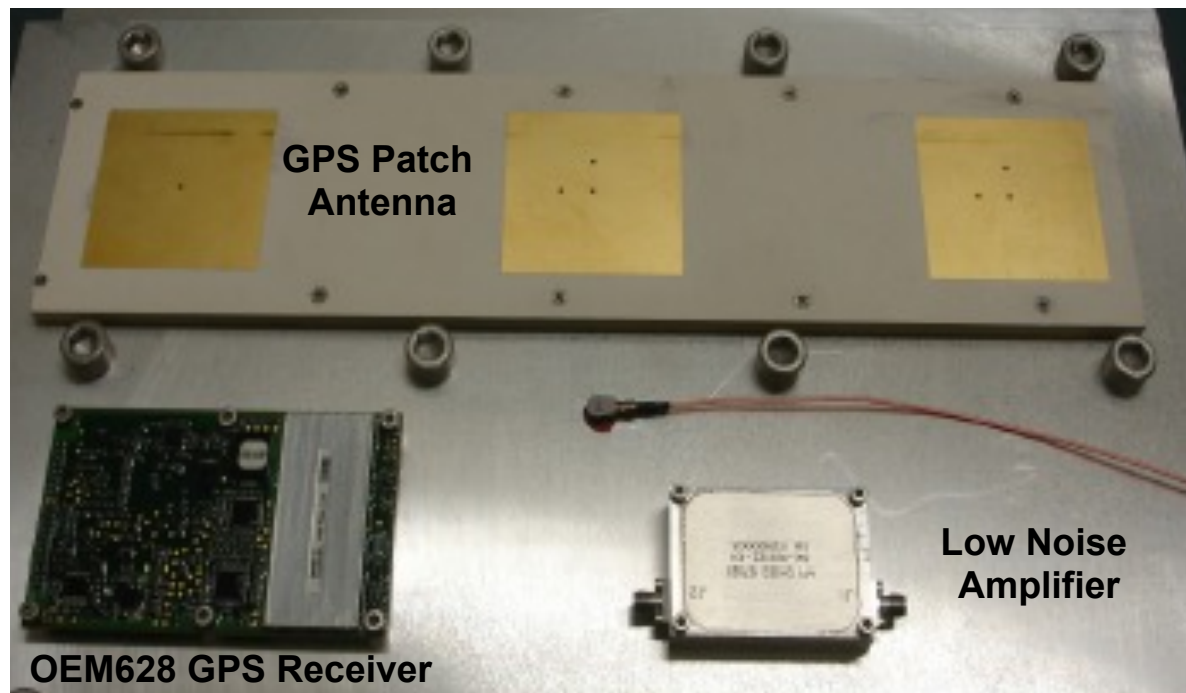
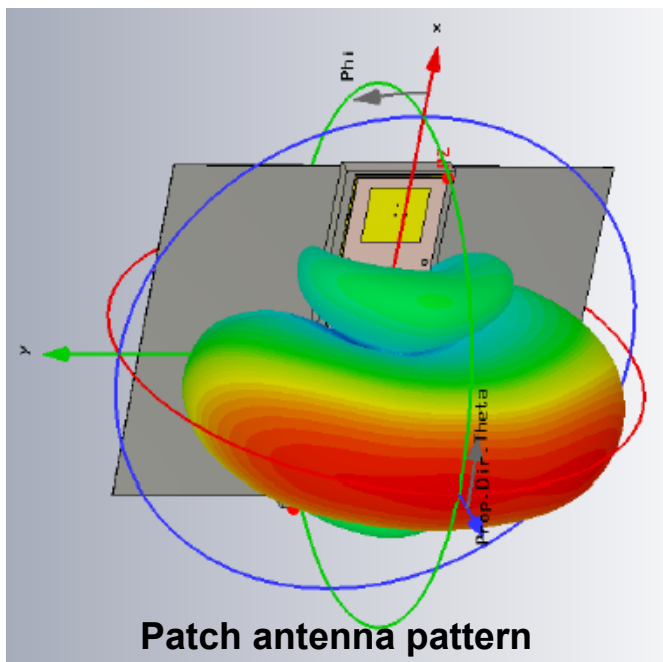
Radiometer Flight Hardware





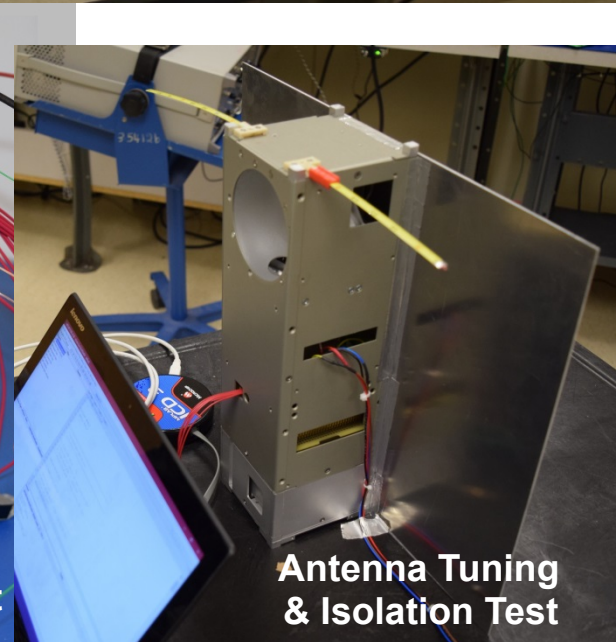
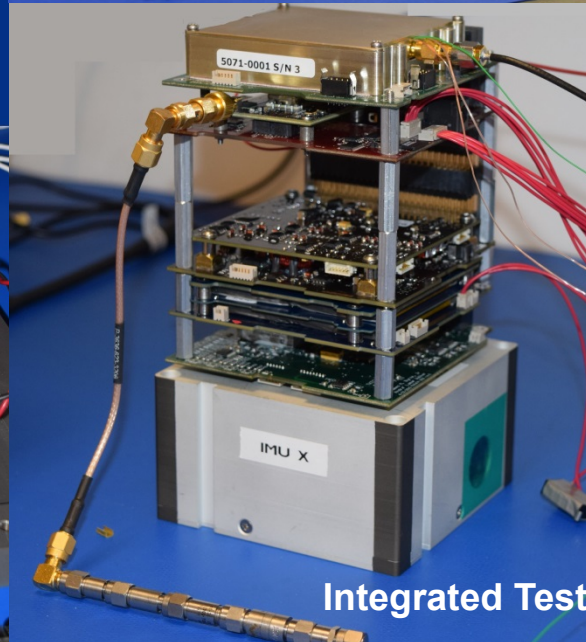
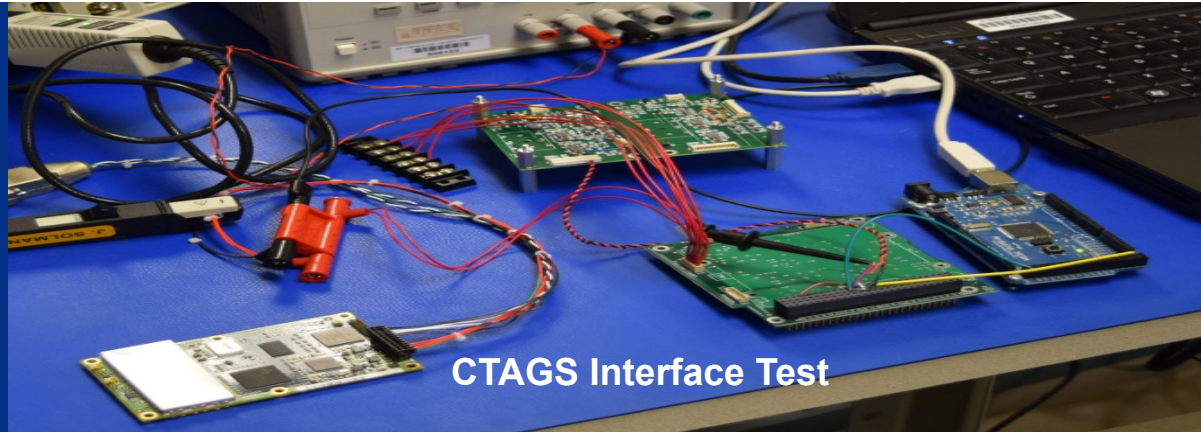
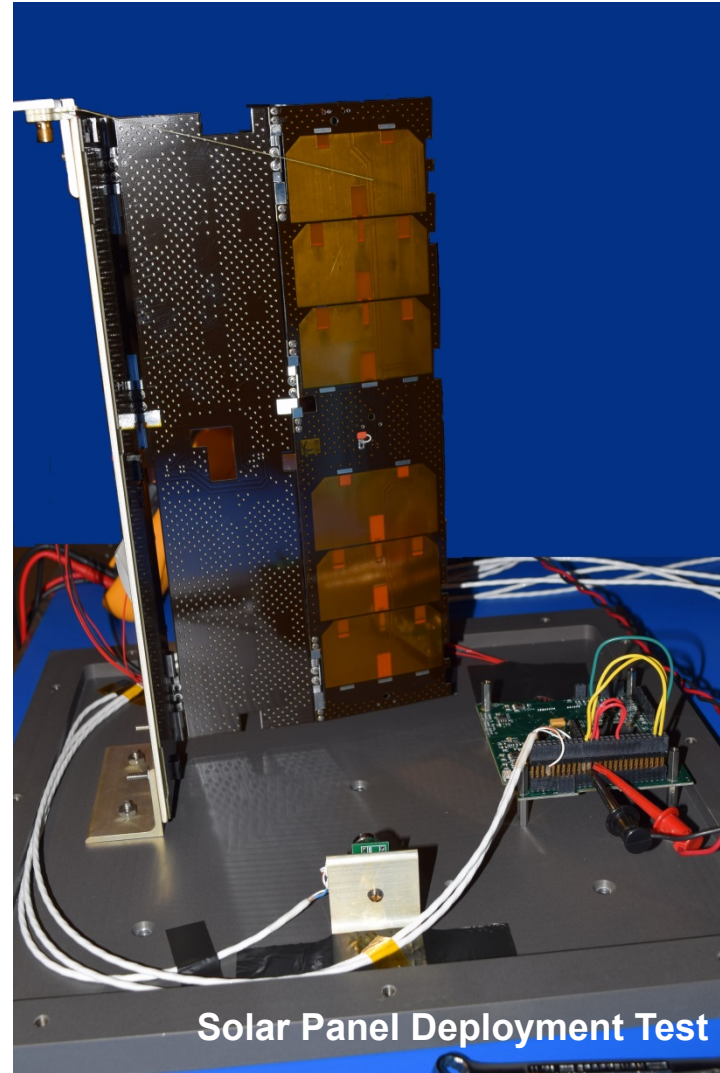
CTAGS Overview

- Provided by Aerospace Corp. to retrieve temperature profiles using GPS radio occultation (Dr. Rebecca Bishop)
- Aerospace performed TVac testing, vibration testing, & on-orbit simulations
- Delivered flight and flight spare in Mar. 2016





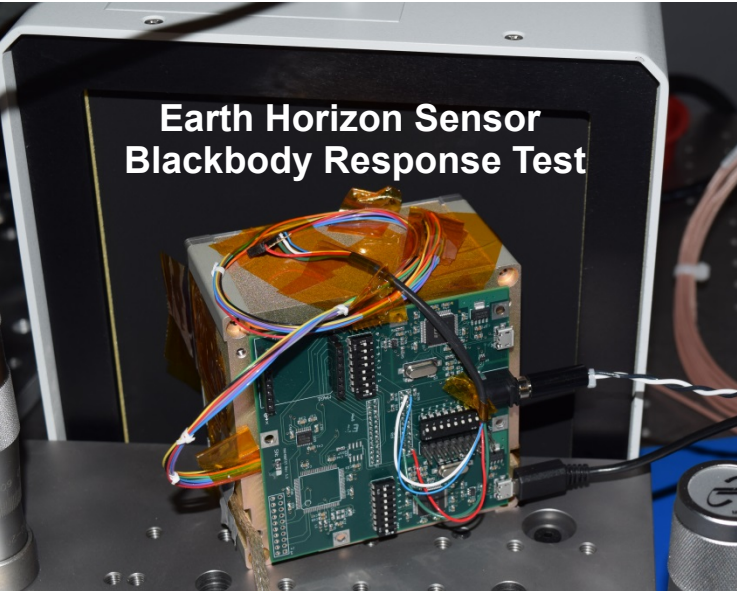
Testing Overview



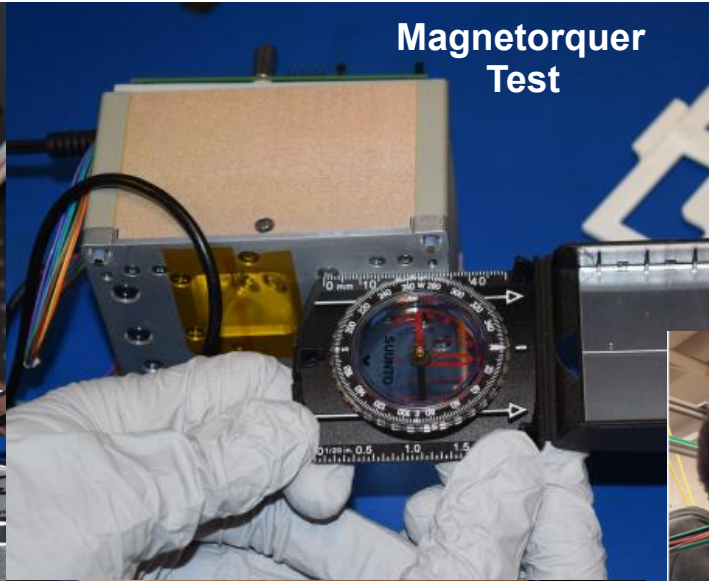


ADCS Testing Overview

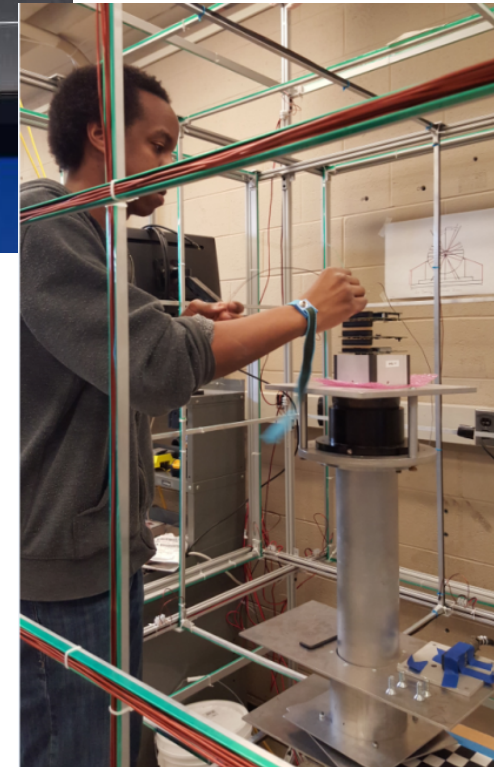
**Earth Horizon Sensor
Blackbody Response Test**



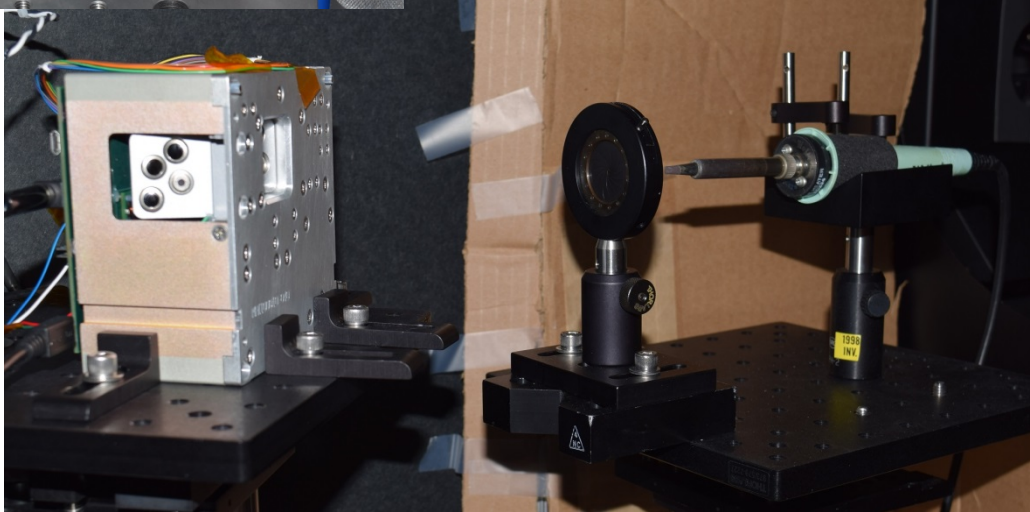
**Magnetorquer
Test**



**Magnetometer
Testing in
Helmholtz Cage**



**Earth Horizon
Sensor Narrow &
wide FOV
Characterization**

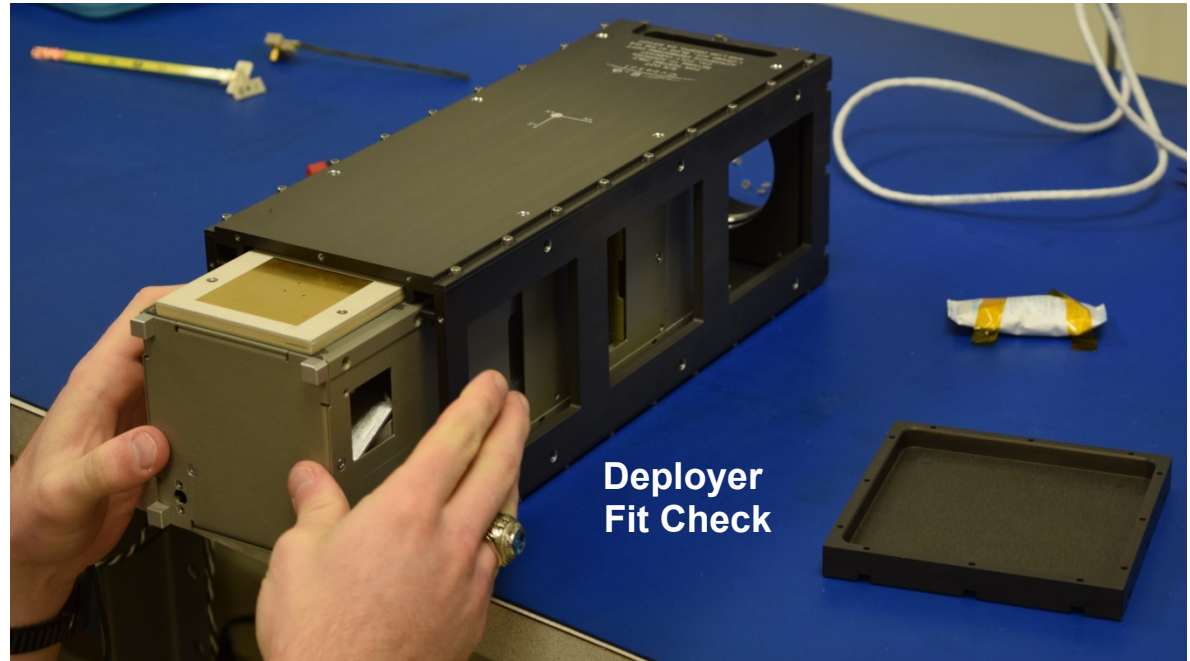




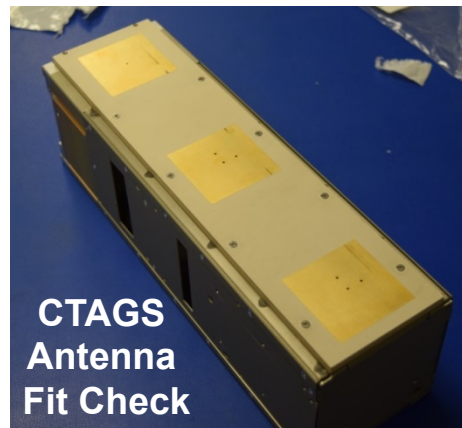
Space Vehicle Fit Checks



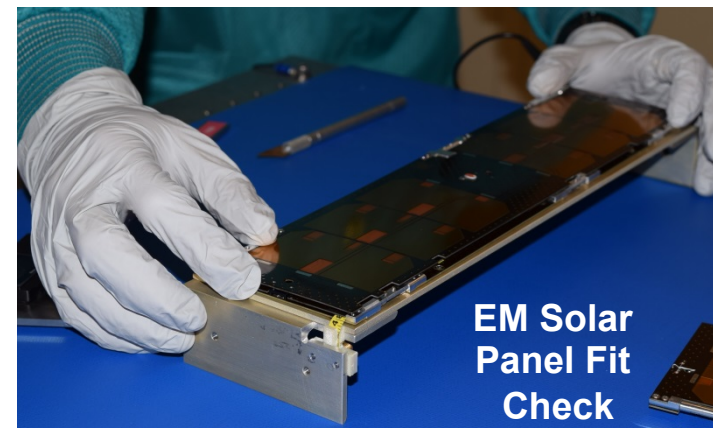
Mass mockup



Deployer
Fit Check



CTAGS
Antenna
Fit Check



EM Solar
Panel Fit
Check



Summary

- **MiRaTA will provide multi-band radiometry and GPS-RO in a single 3U cubesat**
 - **Temperature, moisture, and cloud ice with high absolute accuracy**
- **Flight hardware build is complete, system testing underway**
- **Payload TVAC later this month; Space vehicle TVAC in Jul/Aug**
- **Jan/Feb 2017 launch on JPSS-1**
- **MiRaTA is a critical pathfinder for the TROPICS constellation**
 - **Multi-band radiometry**
 - **Electronic calibration**
 - **Spacecraft maneuvers for mission capability**