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

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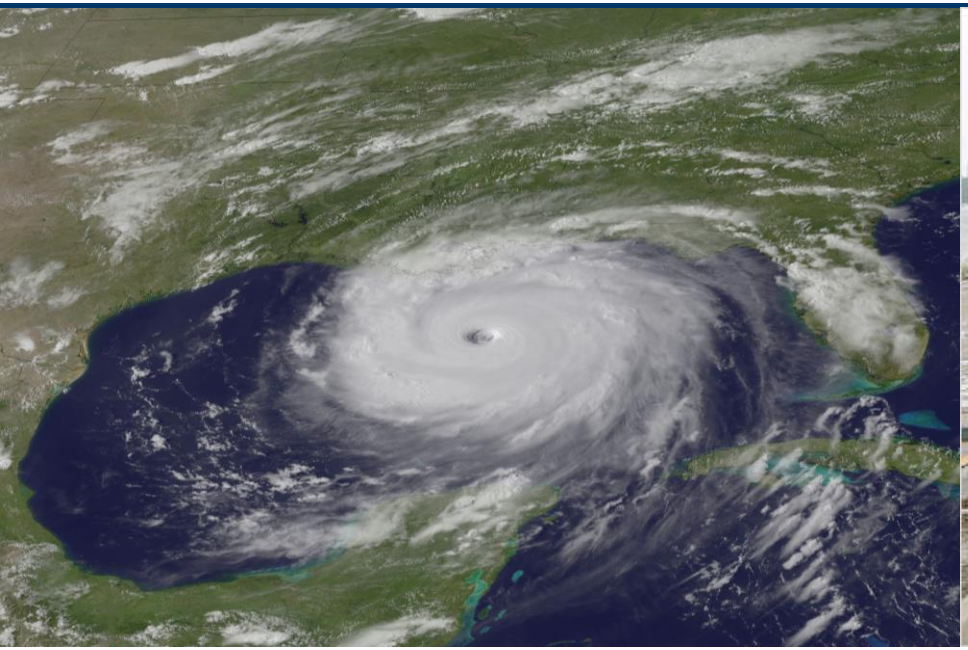
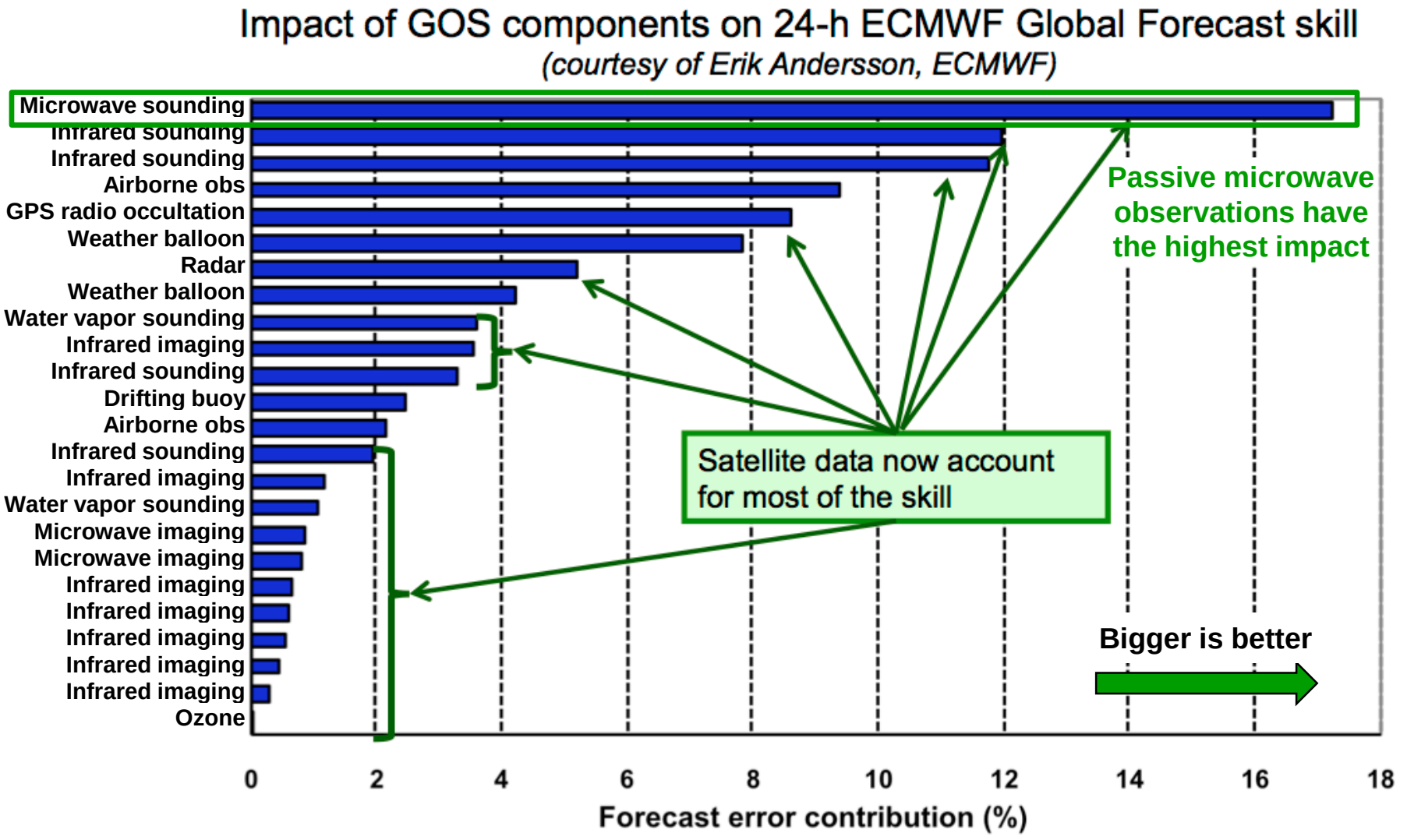
Our Ability to Predict the Weather Has Profound Societal and Economic Implications



- **The US derives $32 B of value from weather forecasts annually[1]**
- **Earth observing satellites drive the forecasts**
- **Eternal quest for resolution: Spatial (vertical and horizontal), temporal, and radiometric**

[1]University Center for Atmospheric Research

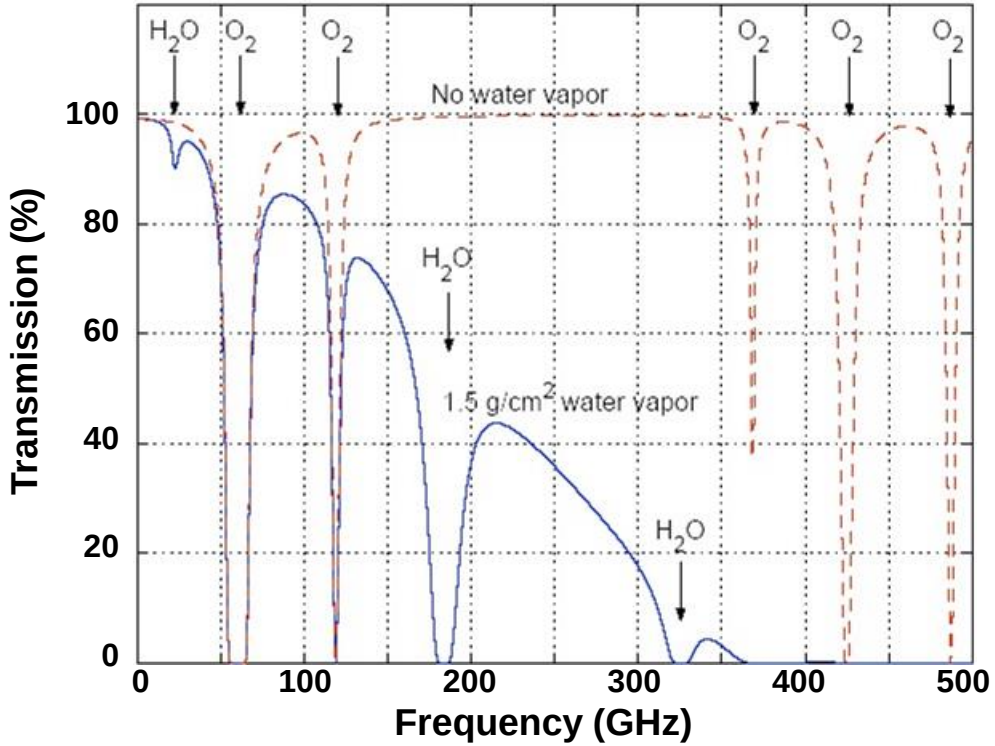
Satellites Provide the Most Forecast Skill



Microwave Atmospheric Sensing

Wavelength (meters)	Radio	Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma Ray
	10^{3}	10^{-2}	10^{-5}	$.5 \times 10^{-6}$	10^{-8}	10^{-10}	10^{-12}

Cloud Penetration; Highest Forecast Impact



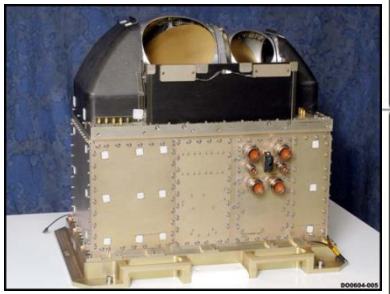
The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines

New Approach for Microwave Sounding

Suomi NPP Satellite (Launched Oct. 2011)

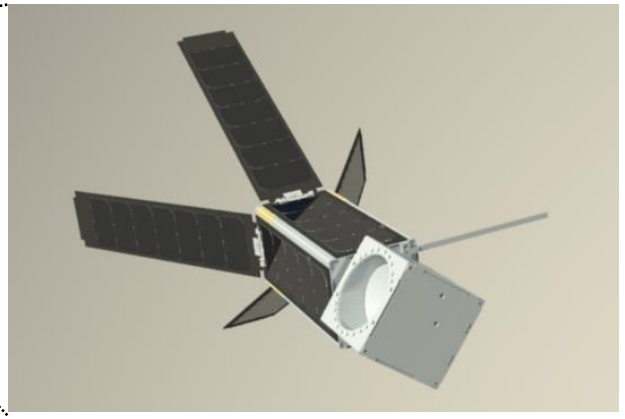
2100 kg **NASA/GSFC**

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**

NPP: National Polar-orbiting Partnership

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

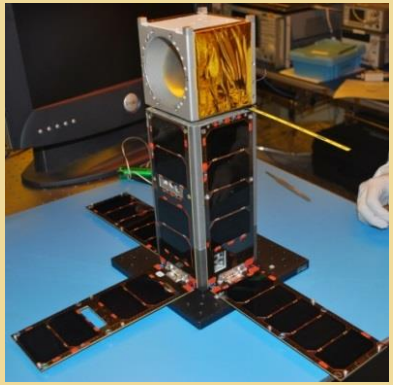
MicroMAS = Microsized Microwave Atmospheric Satellite
MiRaTA = Microwave Radiometer Technology Acceleration

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

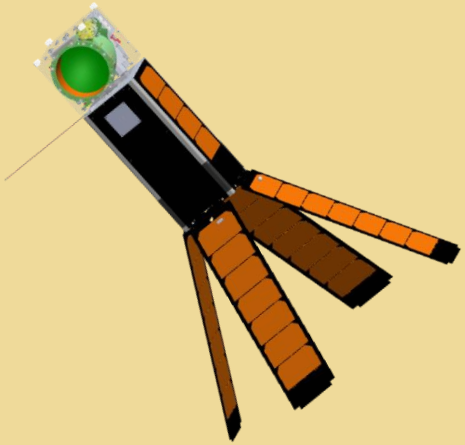


MicroMAS-2

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

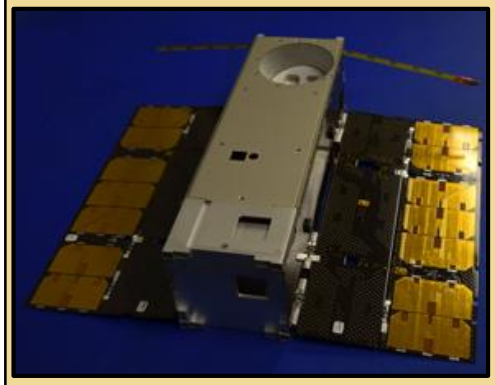


MiRaTA

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



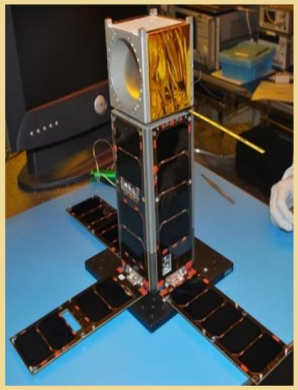
Next Generation: Constellations

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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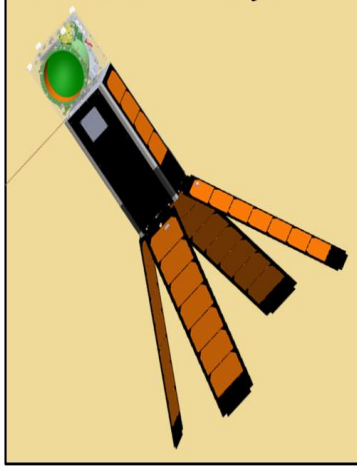

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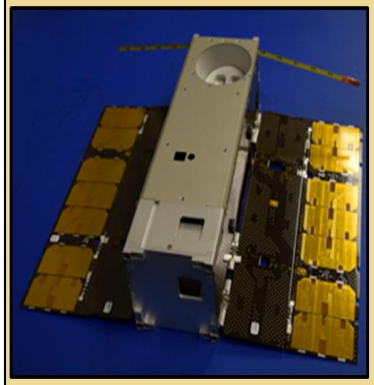


TROPICS

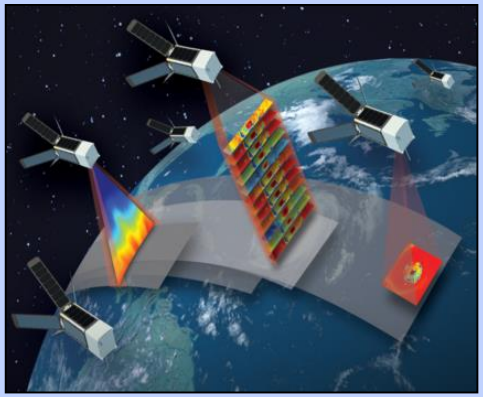
Selected for EVI-3

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

Temperature and moisture profiling and cloud ice measurements

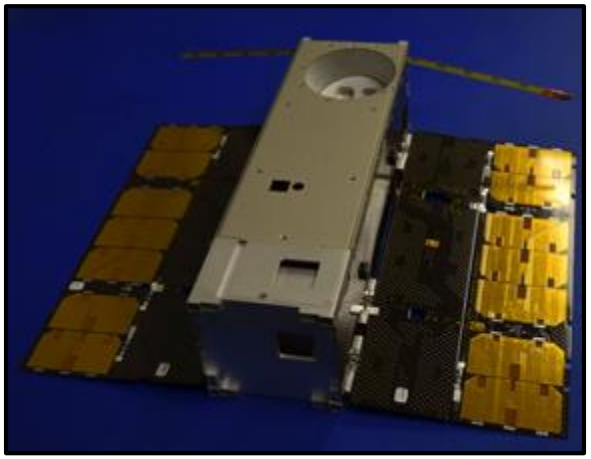
30-minute revisit

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)

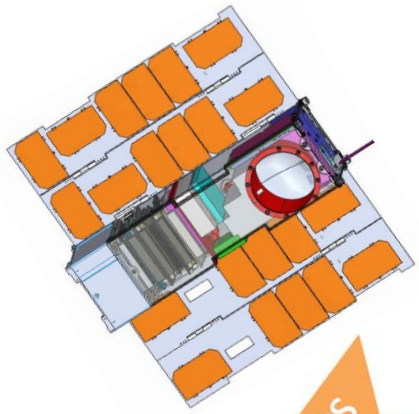
- **(1) IF spectrometer**
  - Verify that the V-band radiometric accuracy is within 1.5 K of the truth predictions
  - V-band end-to-end receiver temperature sufficient to yield 0.1K NEdT.
  - *Blackwell ACT10 "Hyperspectral Microwave Receiver" IFP module leveraged here*
- **(2) G-band mixer**
  - 2.0 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

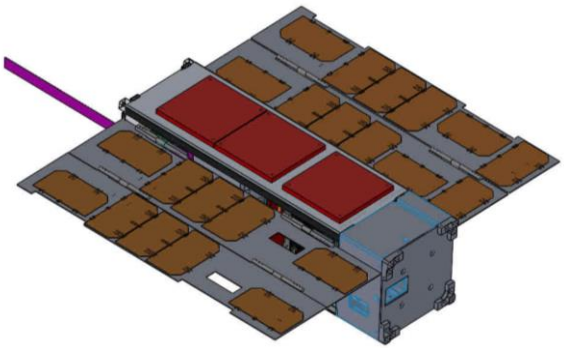
    Direct radiance comparisons with operational passive microwave sounders will also be utilized for verification

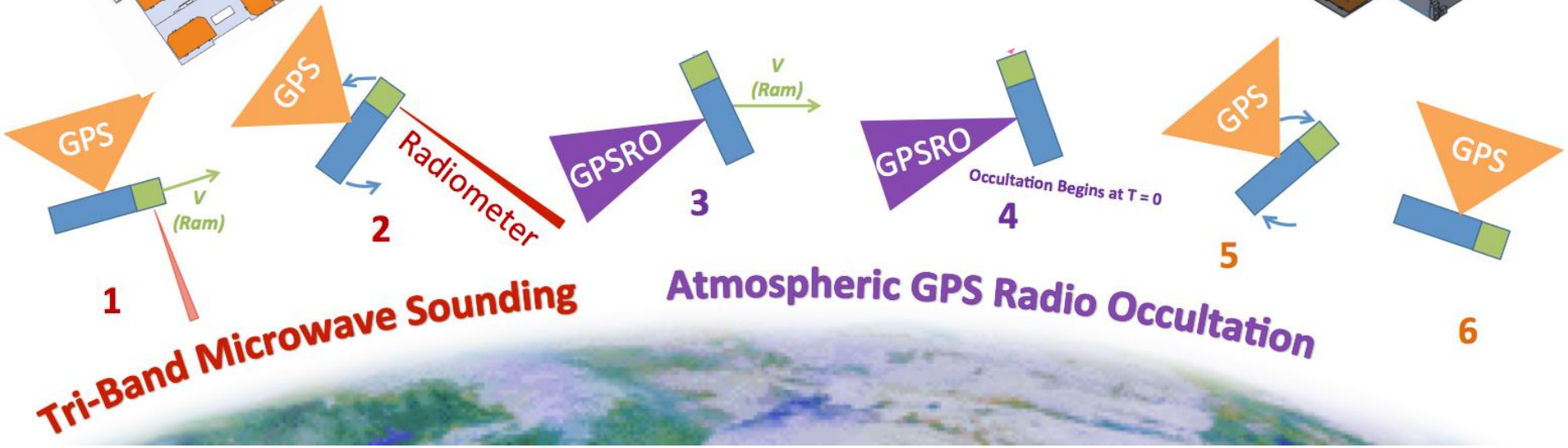
MiRaTA Calibration Maneuver

Nominal Sci Ops for Coupled Atmospheric GPSRO & Microwave Radiometry



~ 10 minute maneuver
0.5° / sec rate

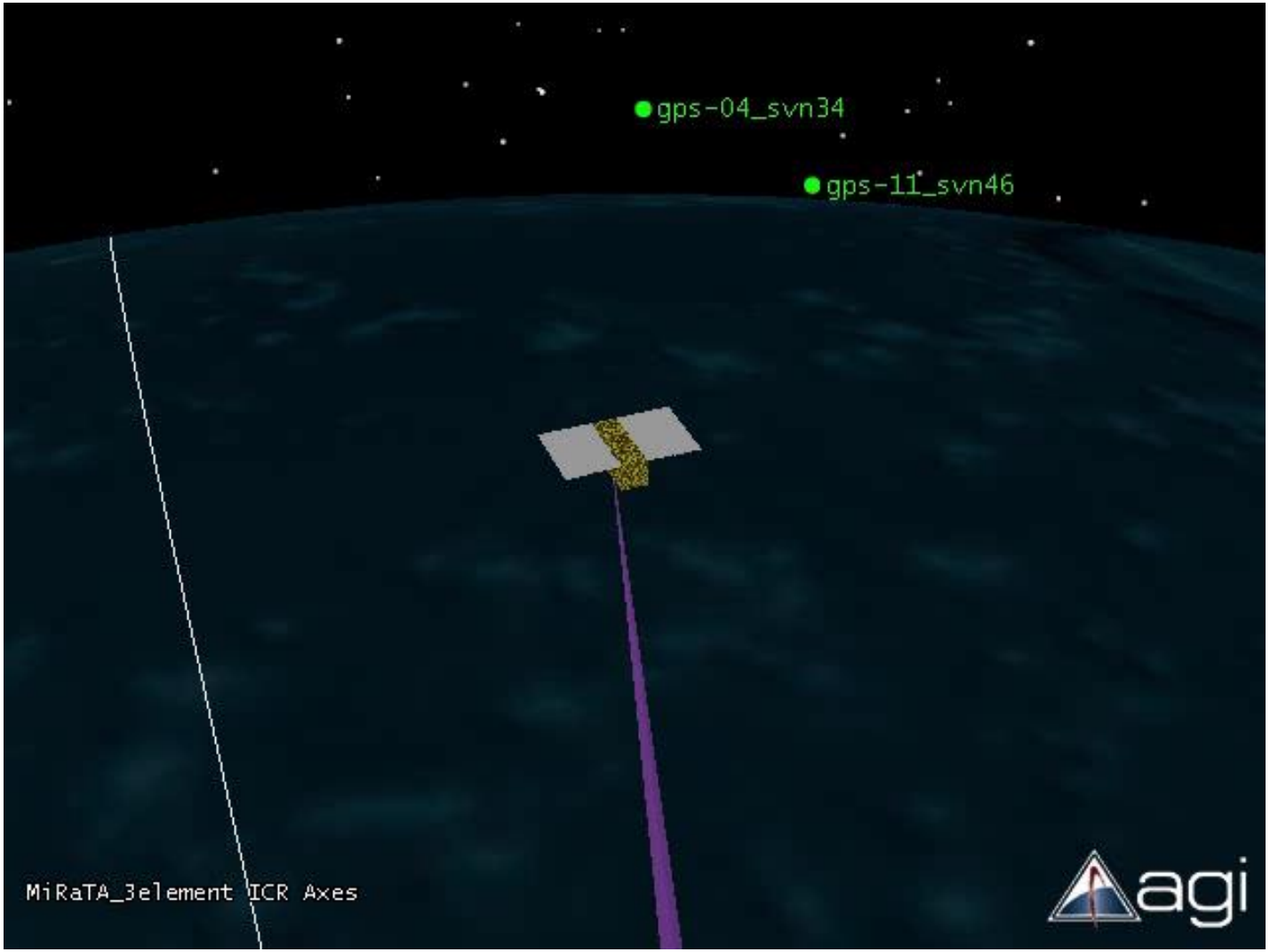




MiRaTA Pitch-Up Maneuver

Objective:

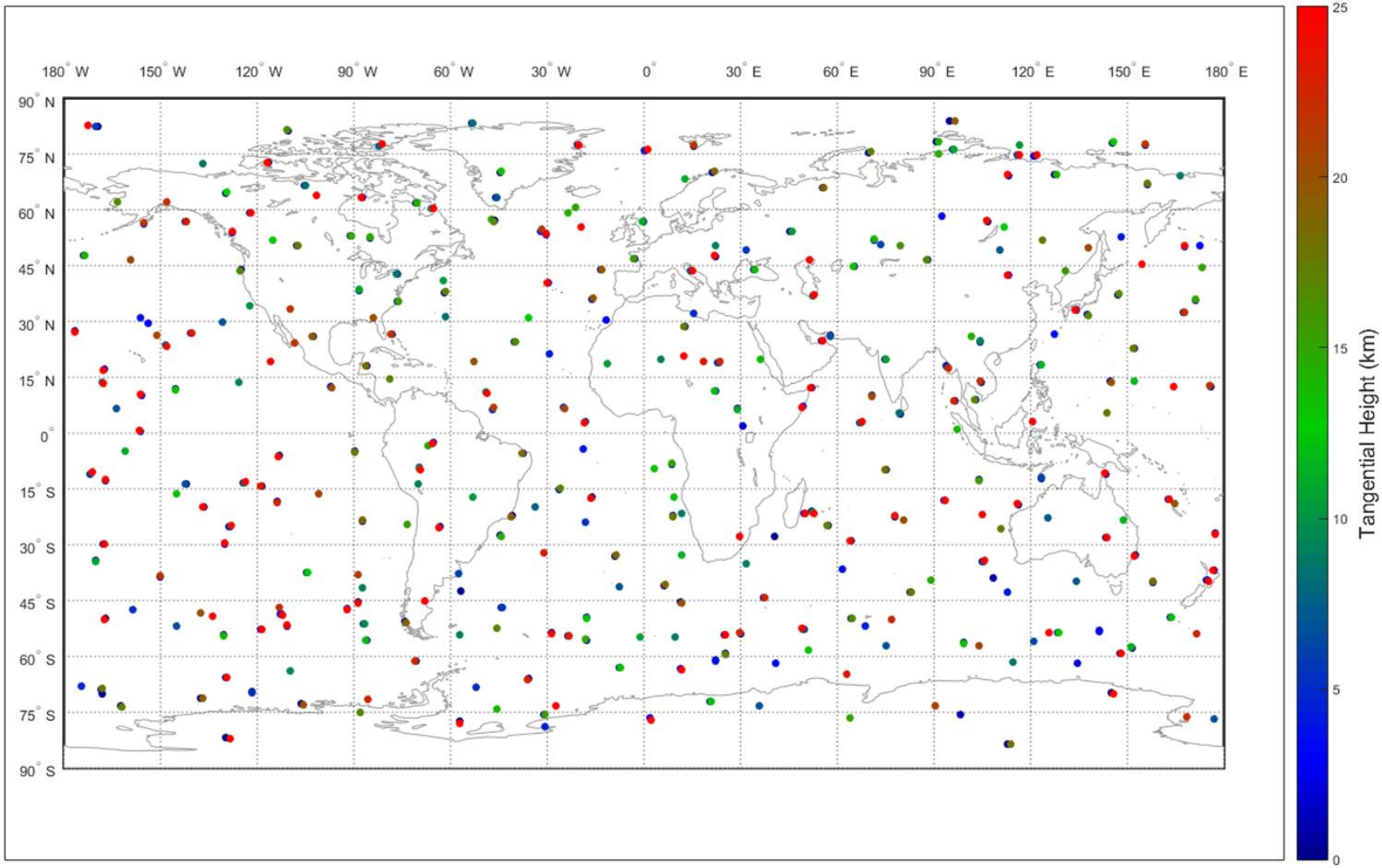
Collocate radiometric data and GPS RO temperature profile



Credit:

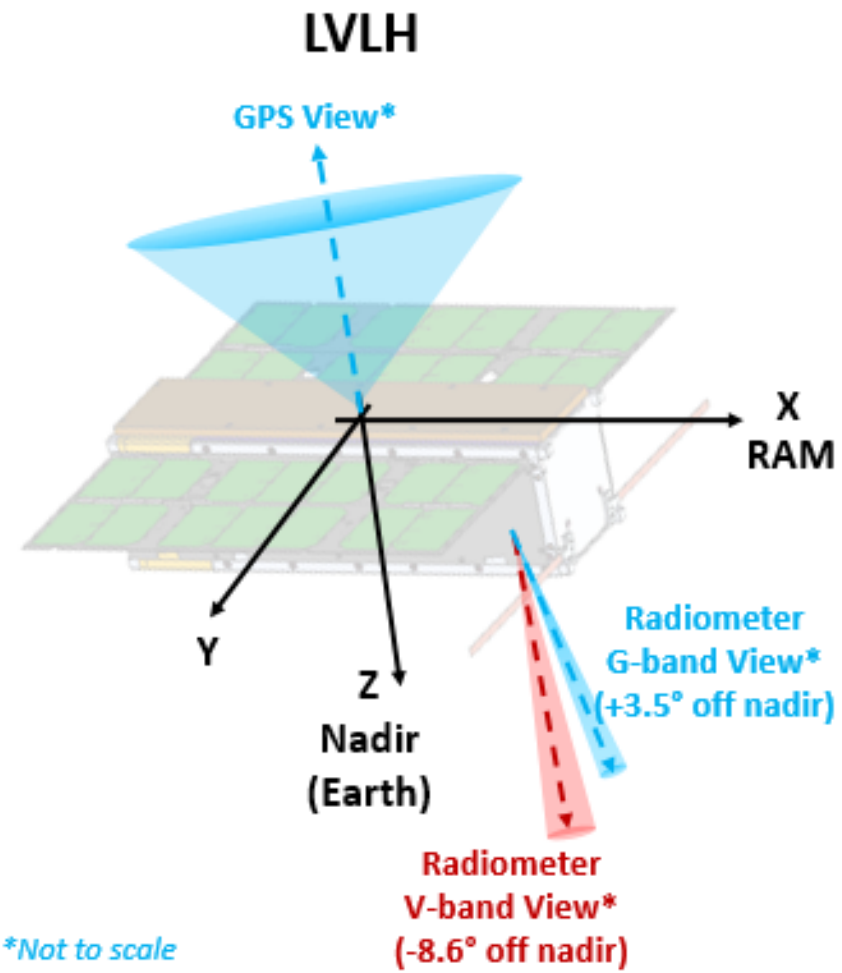
Annie Marinan (MIT SSL) & Weston Marlow (G95 & SSL)

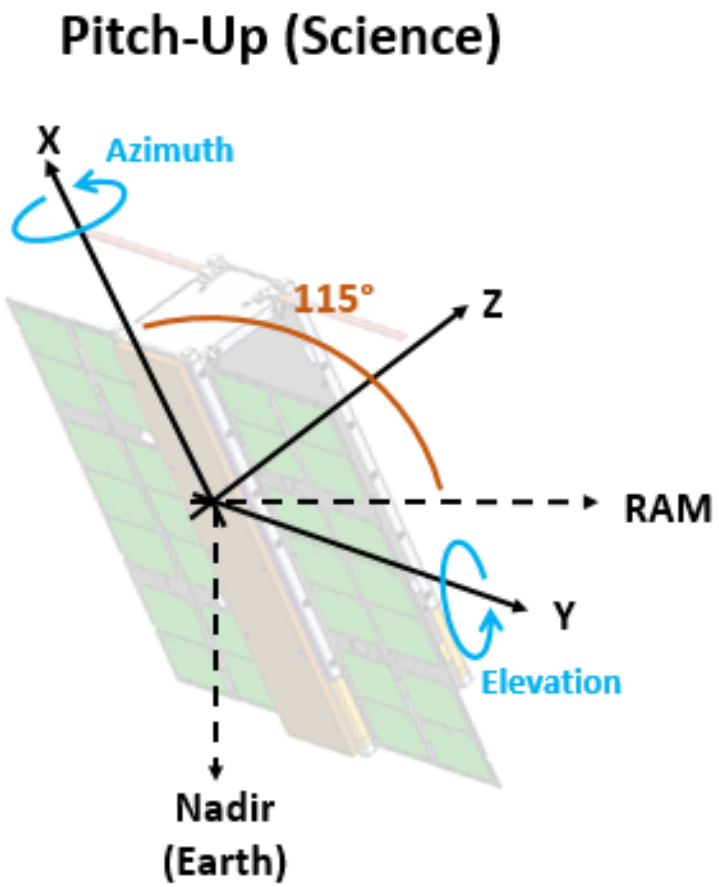
GPS-RO Opportunities for One Day



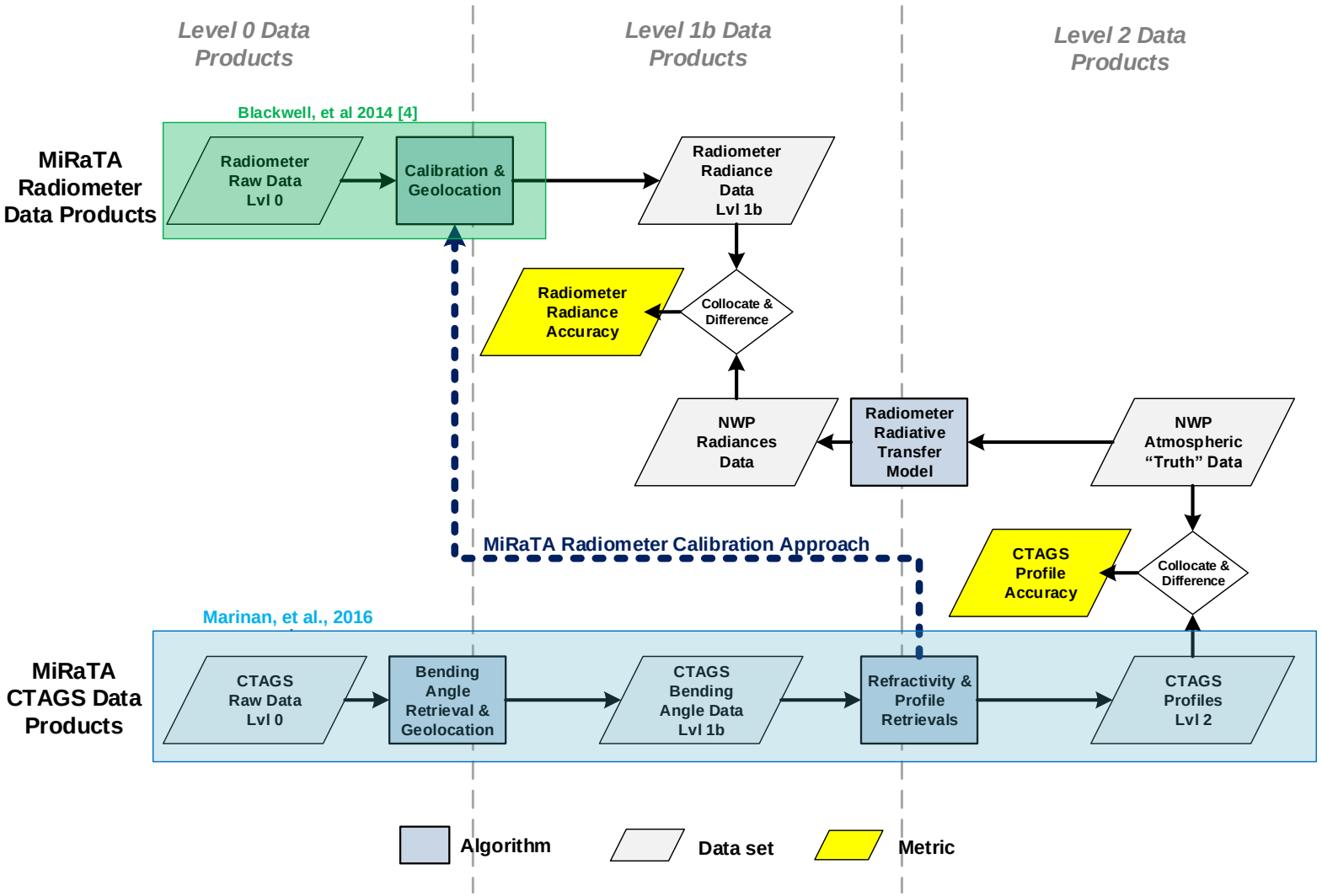
Setting GPS satellite, < 25 km tangent height

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

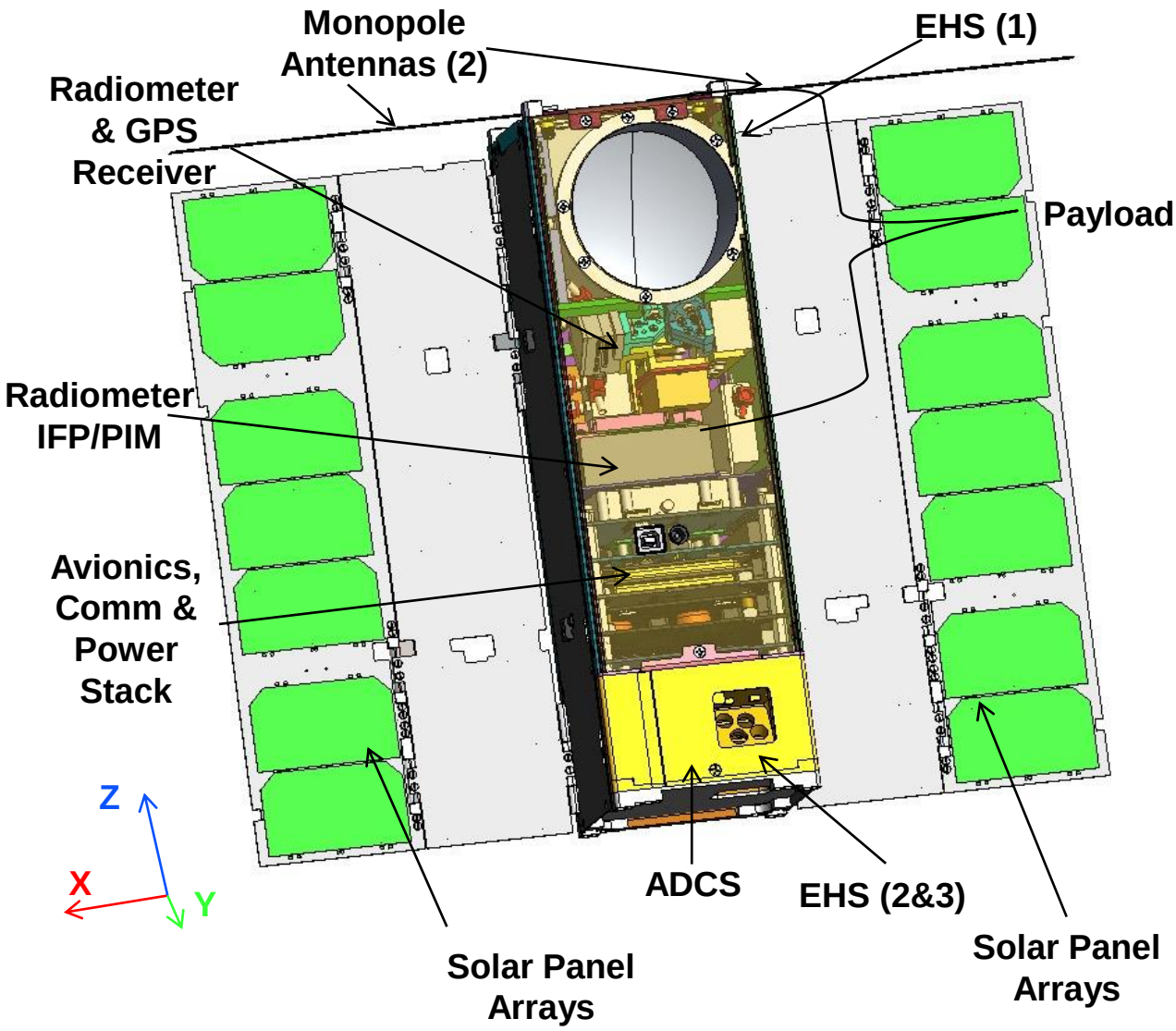
MiRaTA Key Dates

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

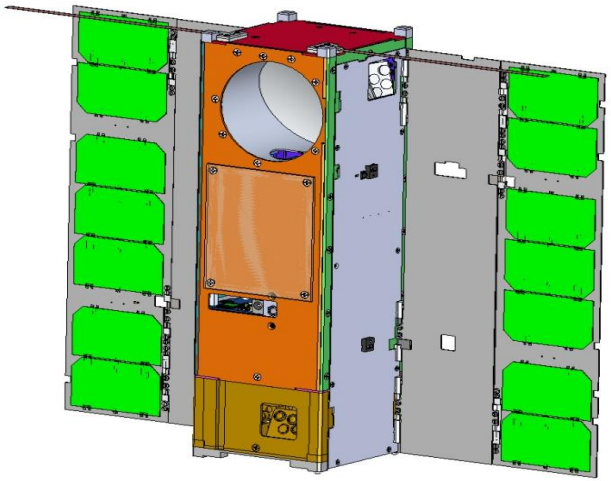
*** ELaNa-XIV launch with JPSS-1**

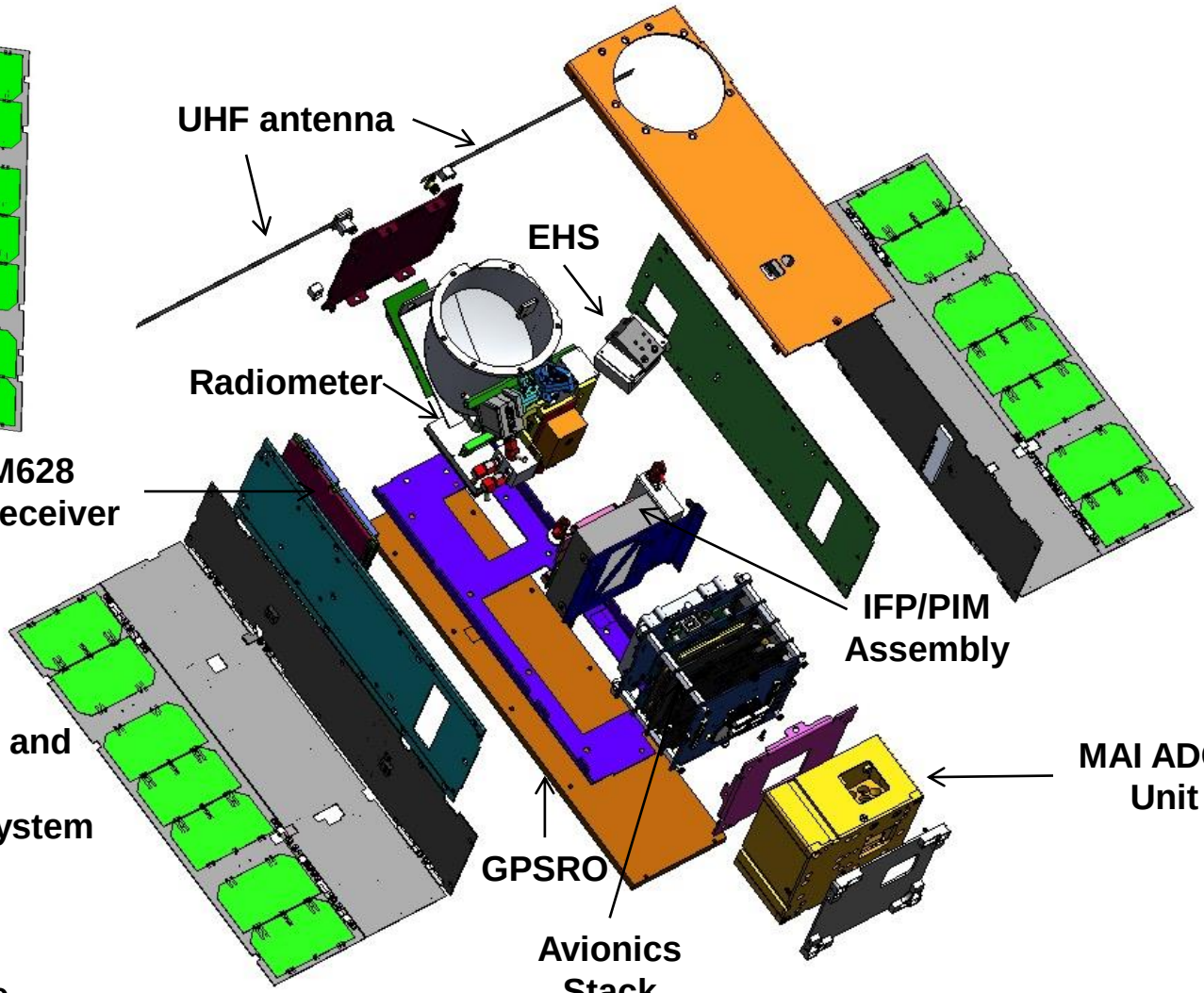
MiRaTA Spacecraft Overview

- **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



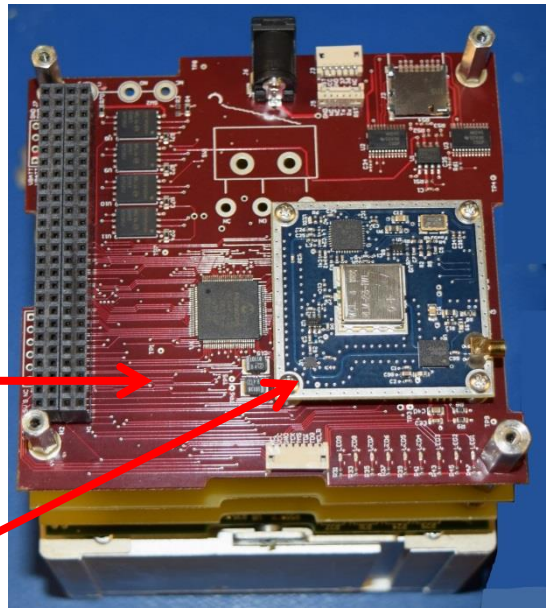
MiRaTA Space Vehicle Overview

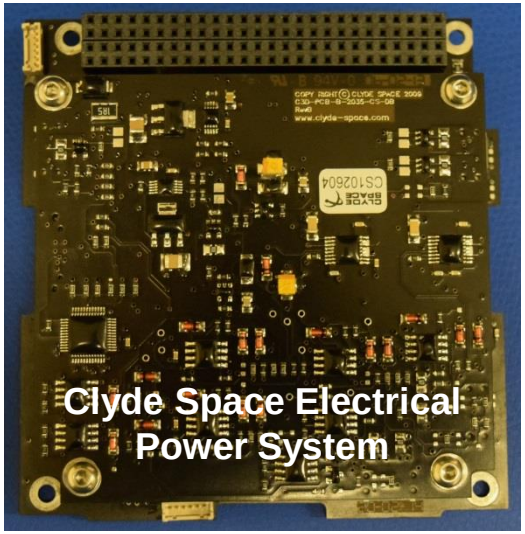


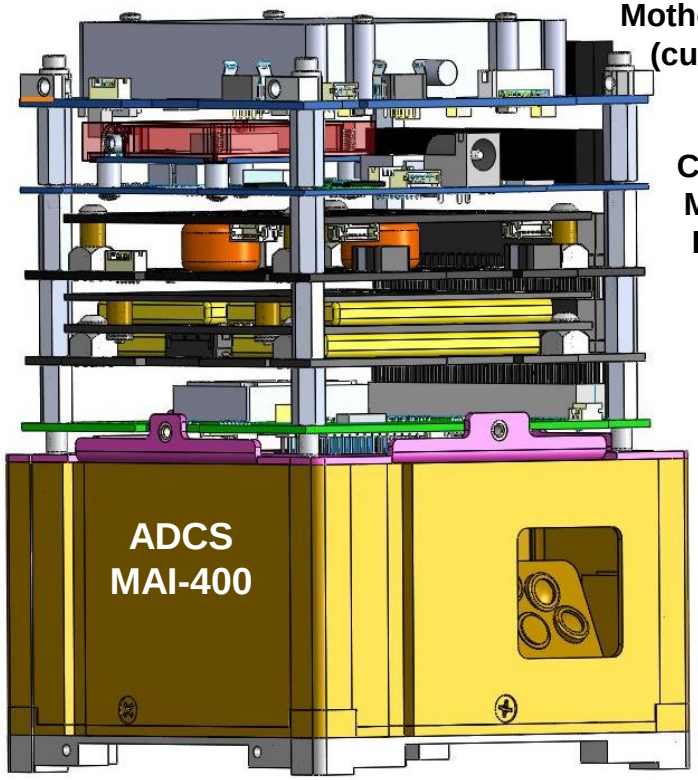


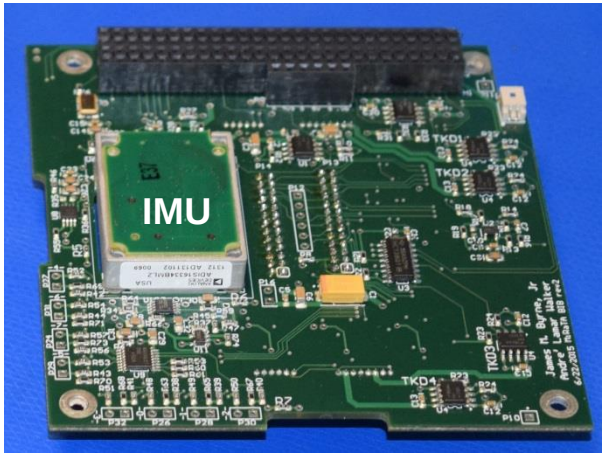
EHS = Earth Horizon Sensor
ADCS = Attitude Determination and Control System
GPSRO = Global Positioning System Radio Occultation
IFP = Intermediate Frequency Processor
PIM = Payload Interface Module

Bus Flight Hardware









Custom Bottom Interface Board

Measurement Requirements and Enabling Technologies

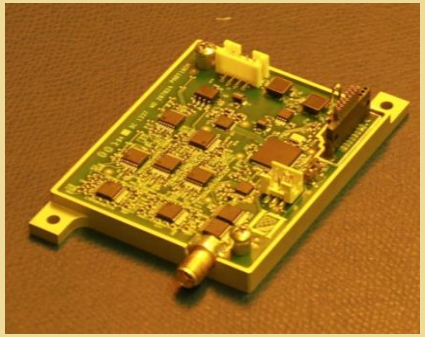
Temperature profile uncertainty of 2 K (RMS) in 50 km footprint needed to improve forecast accuracy

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)

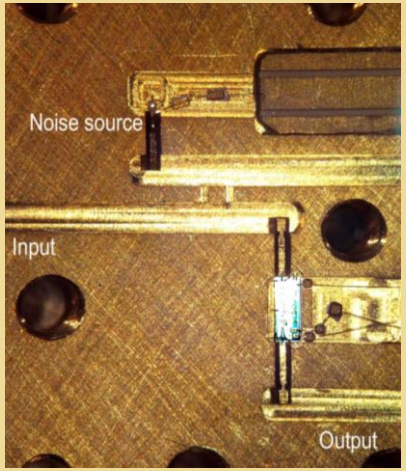
Receiver front-end electronics developed by UMass-Amherst

MMIC low-noise amplifiers and electronic calibration

Calibration accuracy better than 1 K (RMS)

Noise diode source provides periodic absolute calibration of radiometer

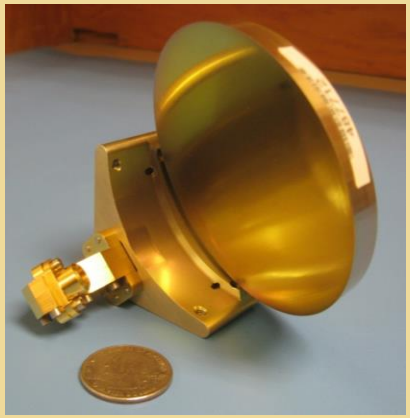
Highly stable; compact



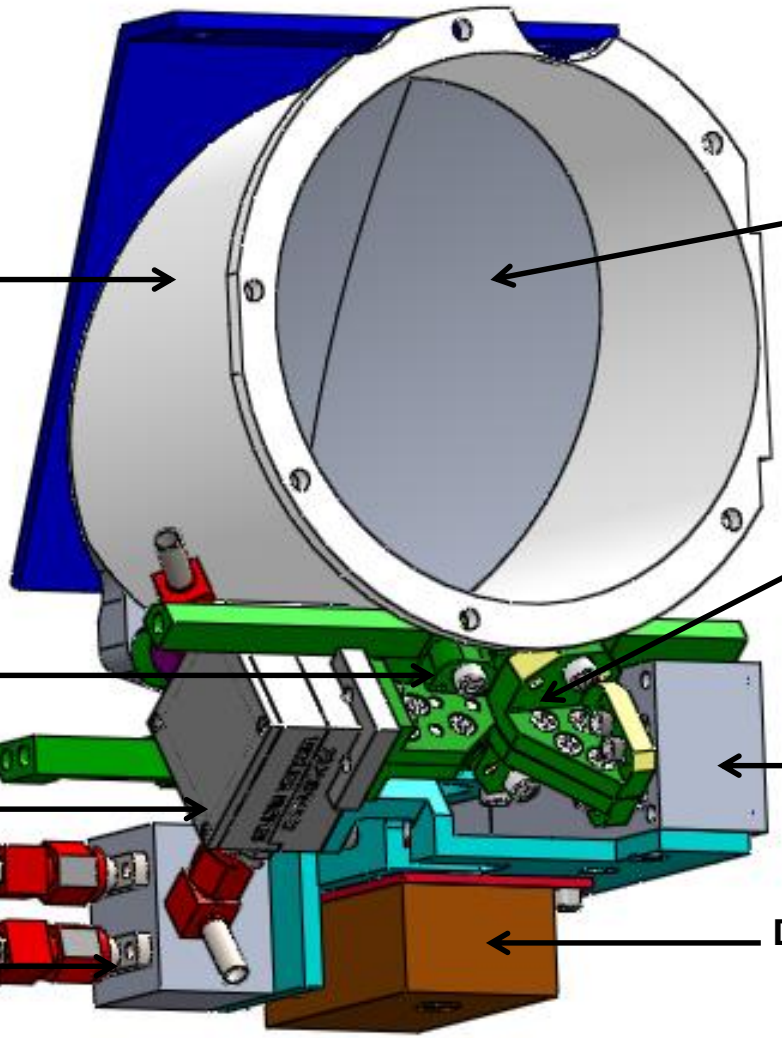
Aperture ~9 cm Beam efficiency > 95%

Offset parabolic reflector system with scalar feed

Lightweight, with 0.001” RMS surface tolerance

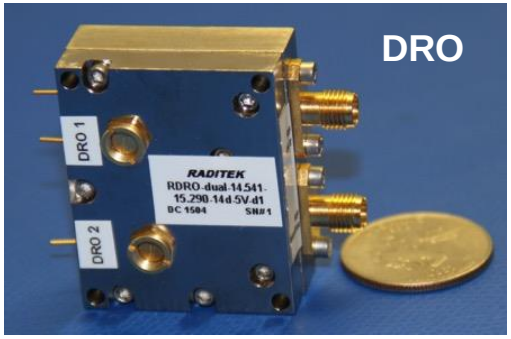


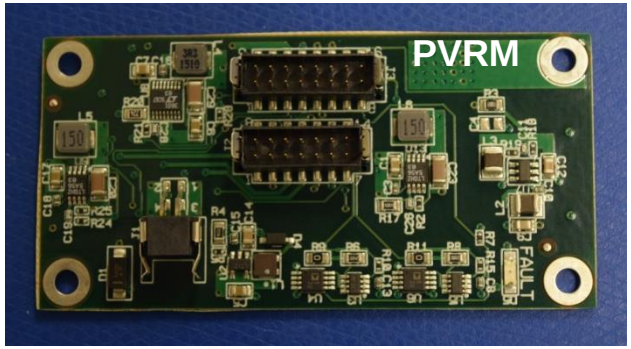
MiRaTA Radiometer System

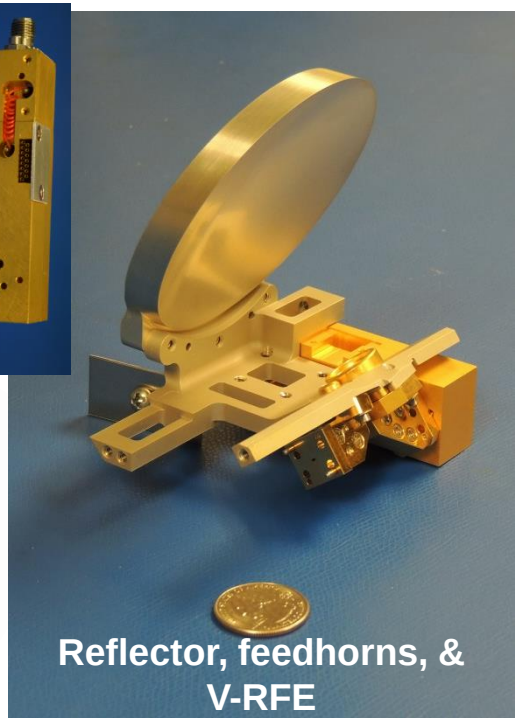


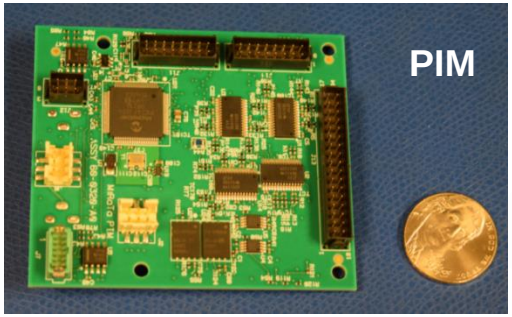
All flight radiometer hardware delivered

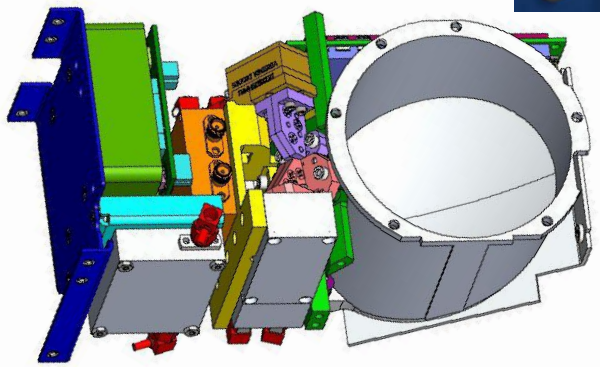
Radiometer Flight Hardware

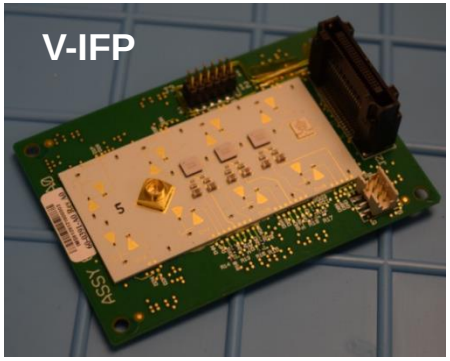


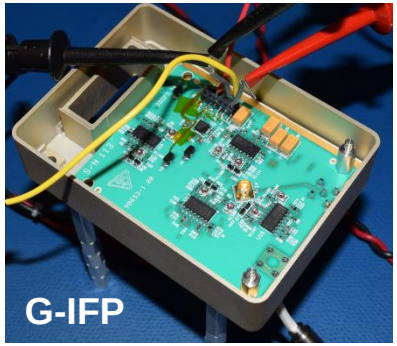


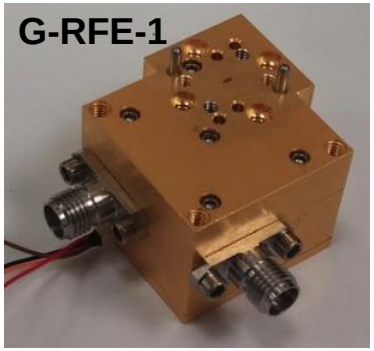


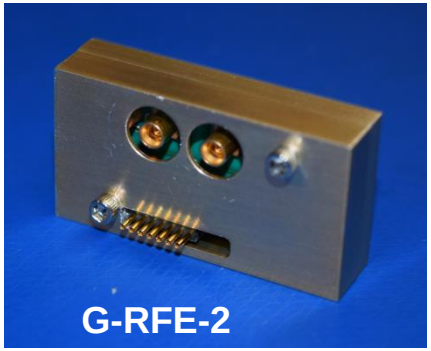






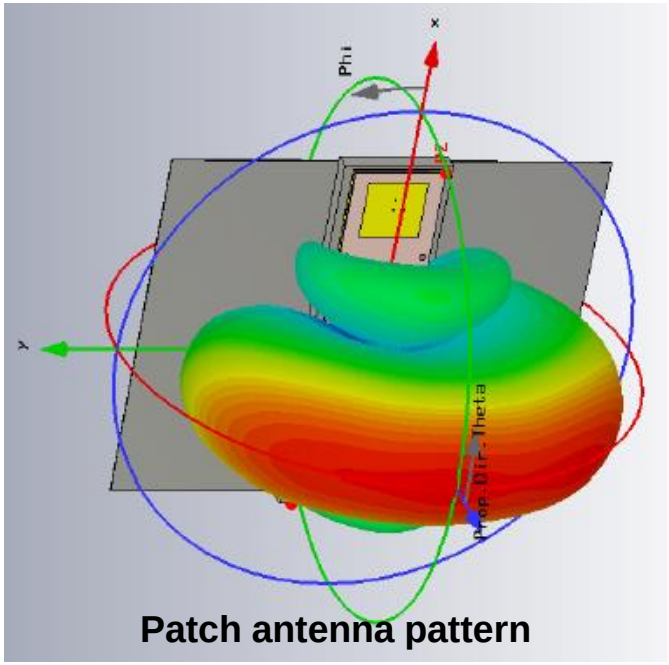




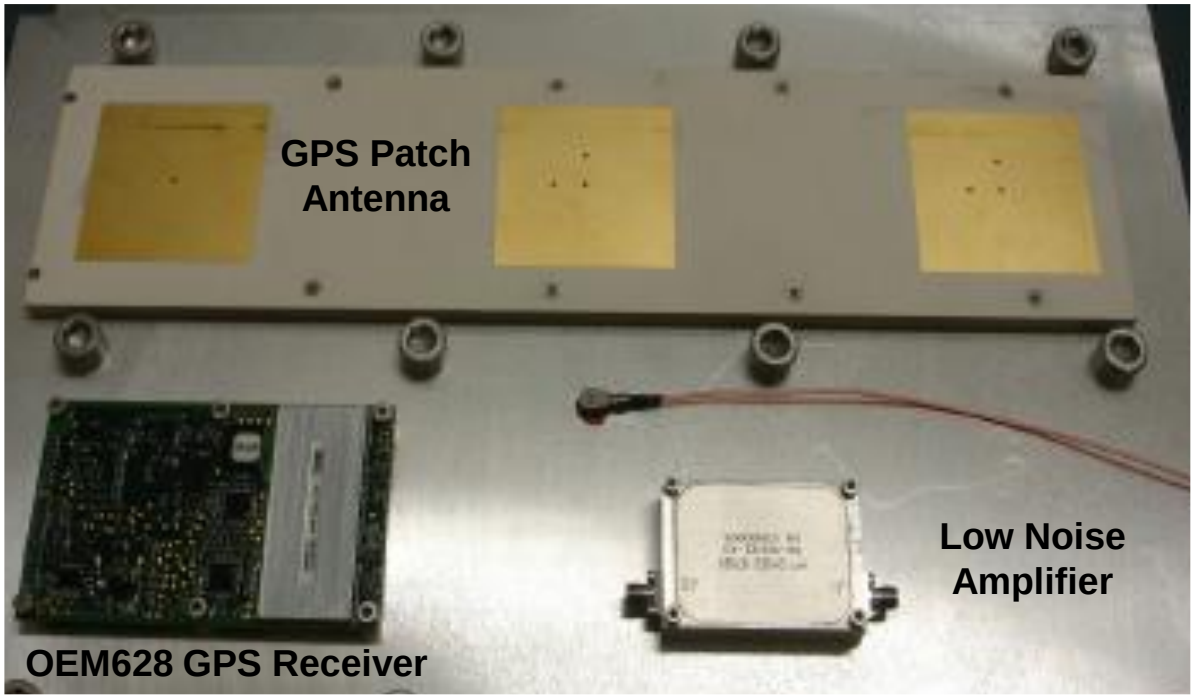


CTAGS Overview

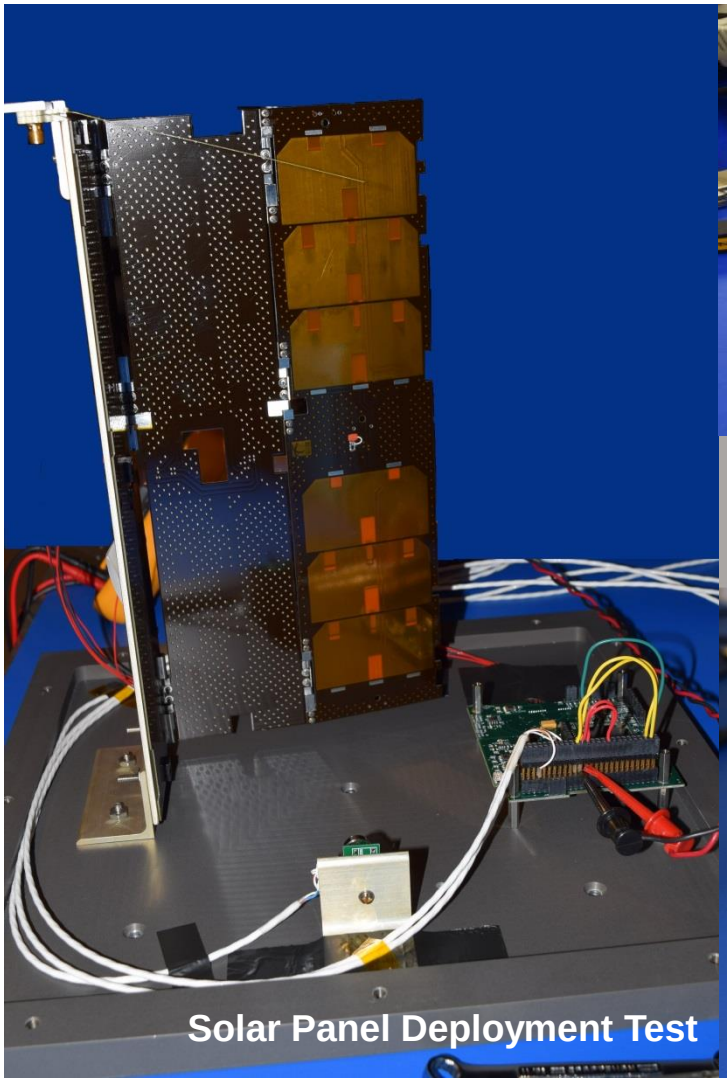
- Provided by Aerospace Corp. to retrieve temperature profiles using GPS radio occultation (Dr. Rebecca Bishop)
- Aerospace performed TVac testing, vibration testing, & on-orbit simulations
- Delivered flight and flight spare in Mar. 2016

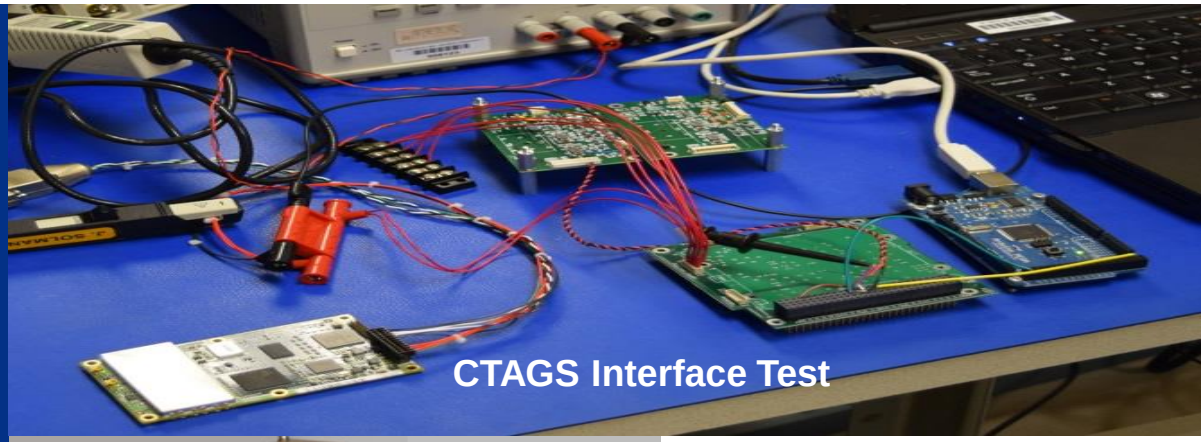


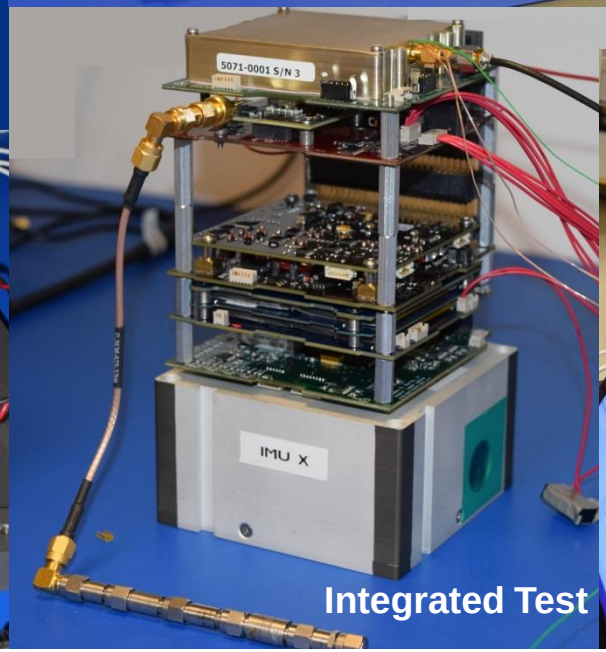
Patch antenna pattern

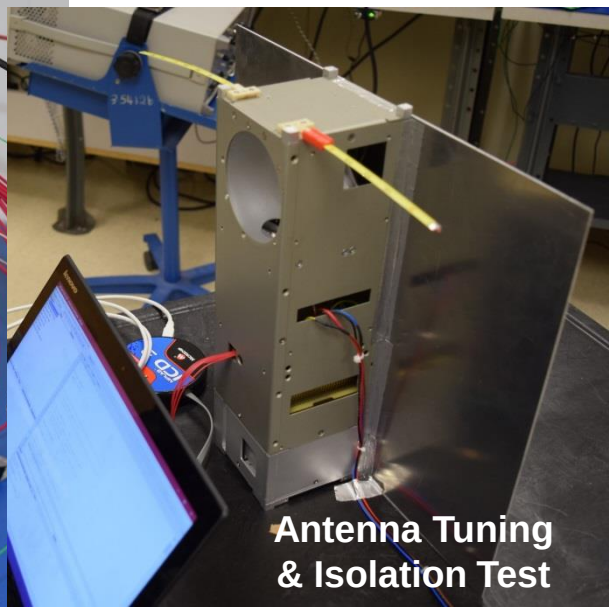


Testing Overview

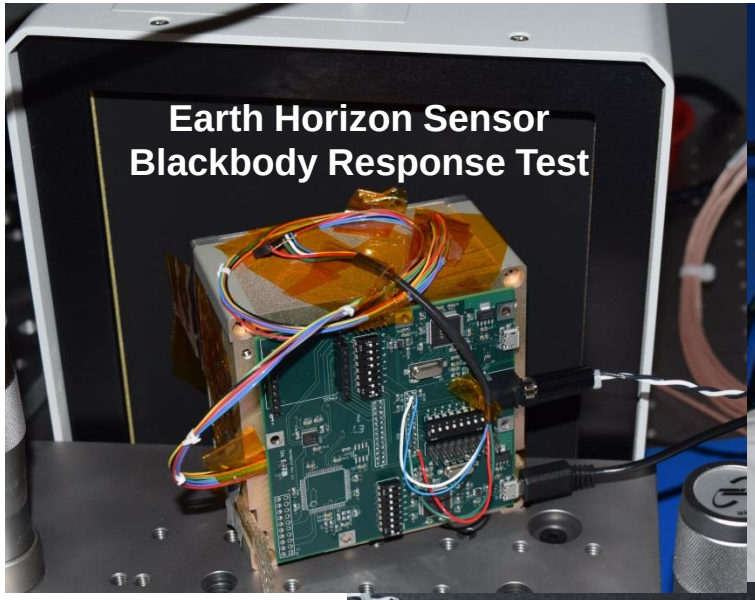


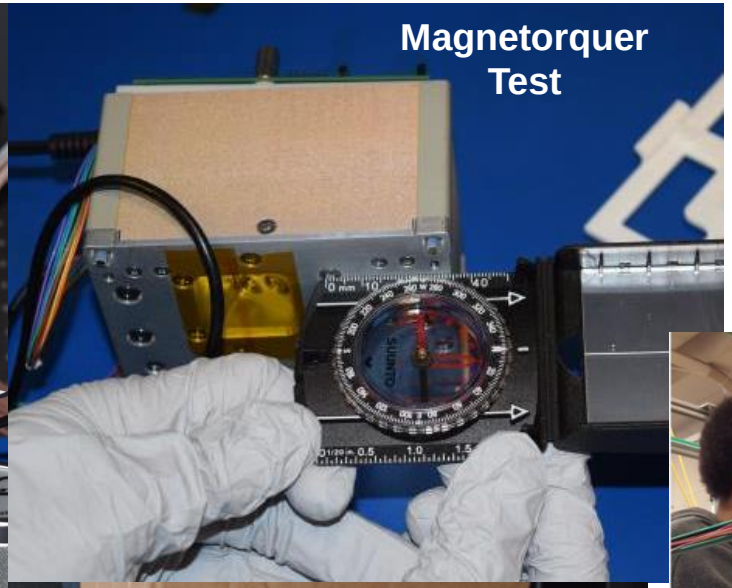






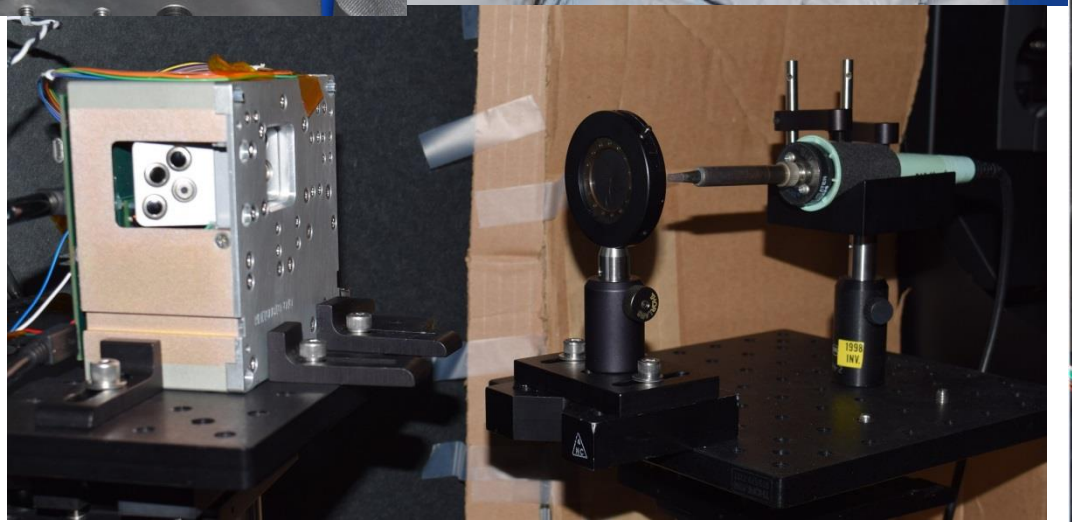
ADCS Testing Overview



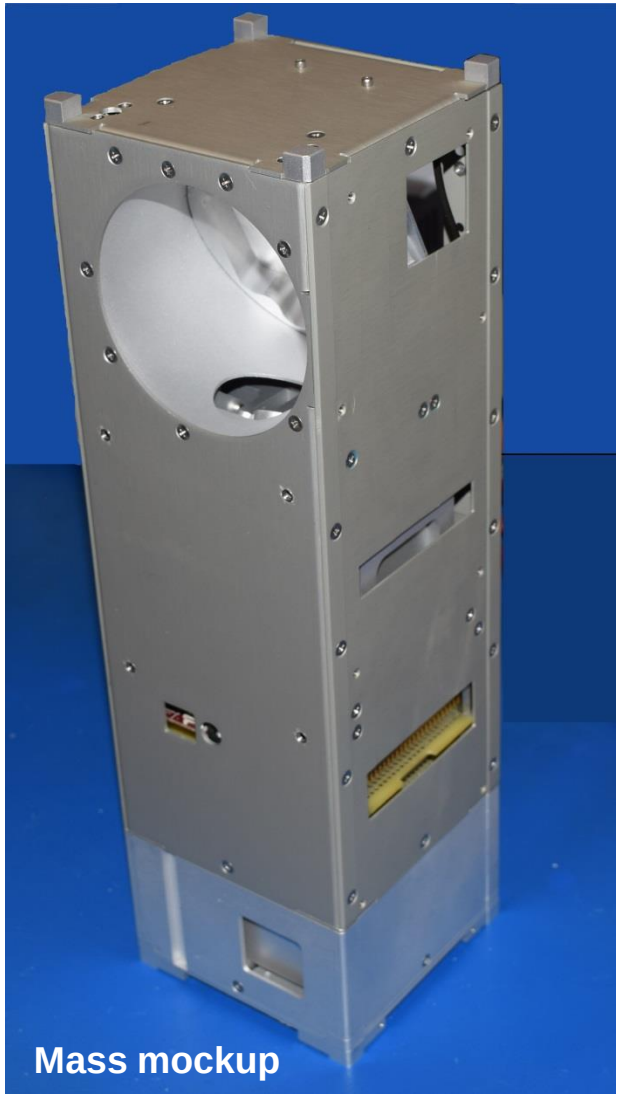


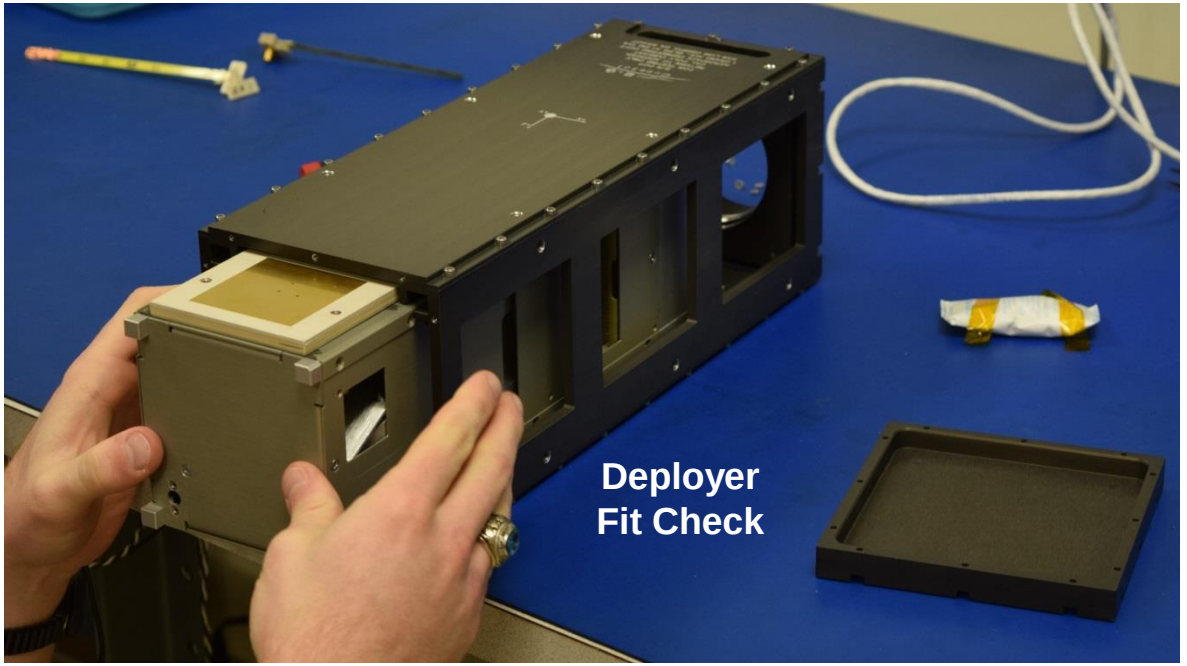
Magnetometer Testing in Helmholtz Cage

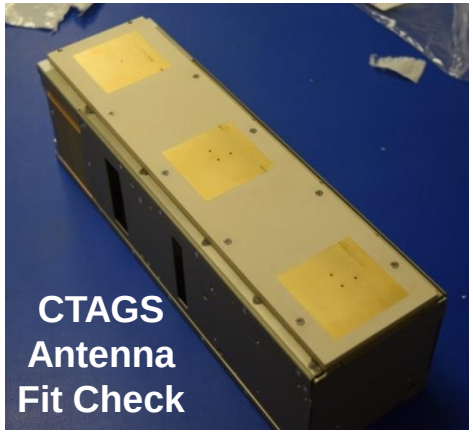
Earth Horizon Sensor Narrow & wide FOV Characterization

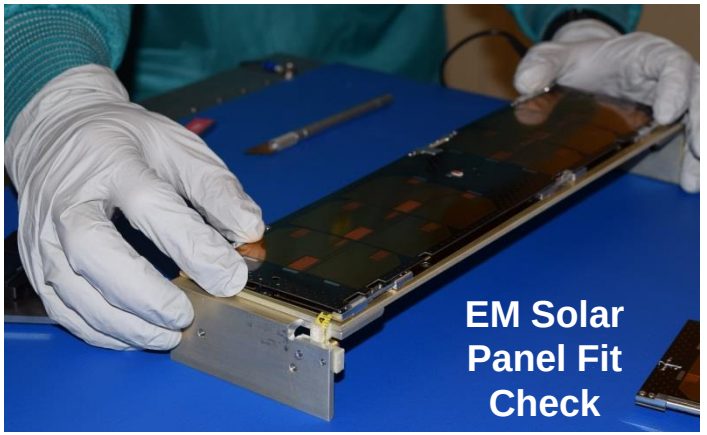


Space Vehicle Fit Checks









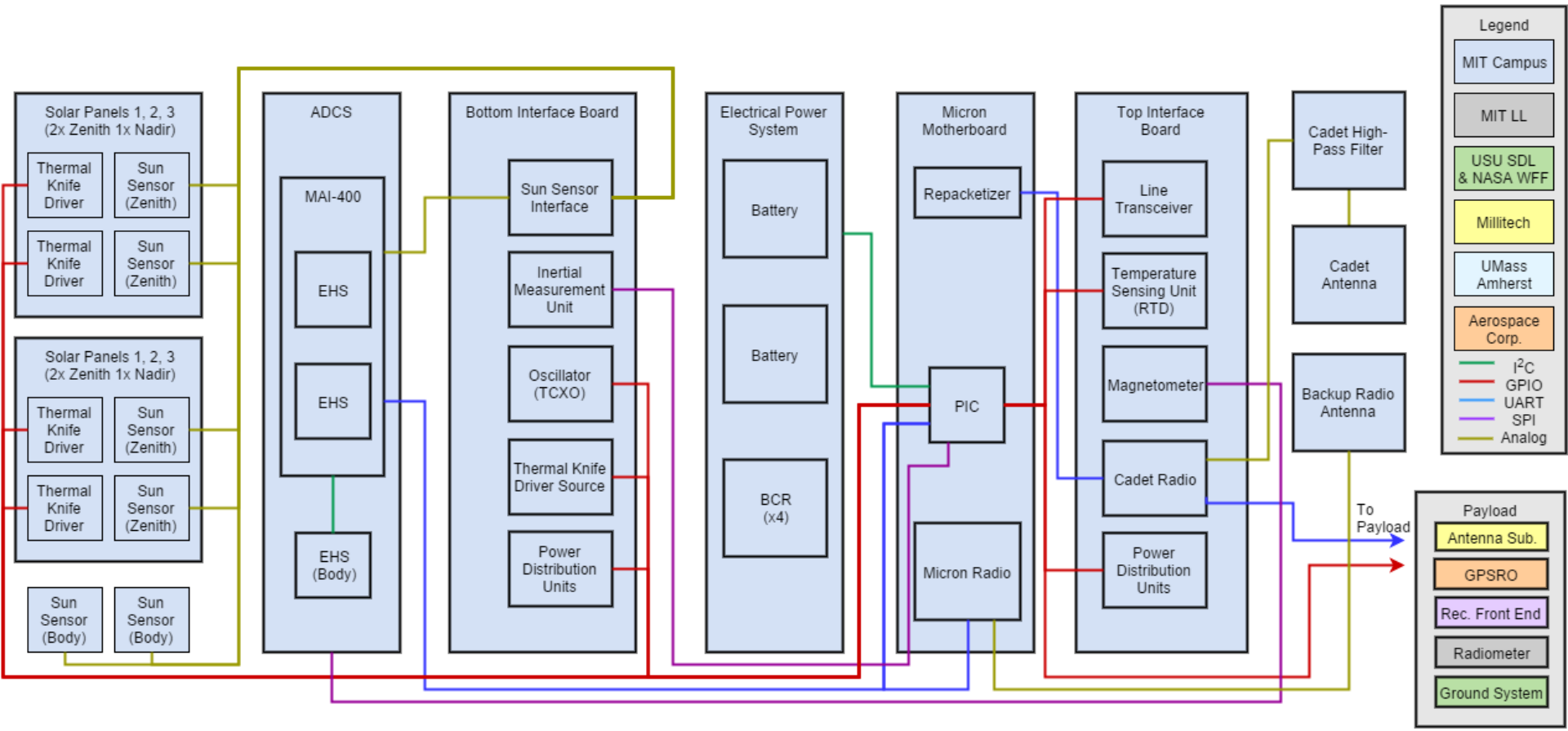
Volume & mass risks are low, but with slim margins

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**

Backup

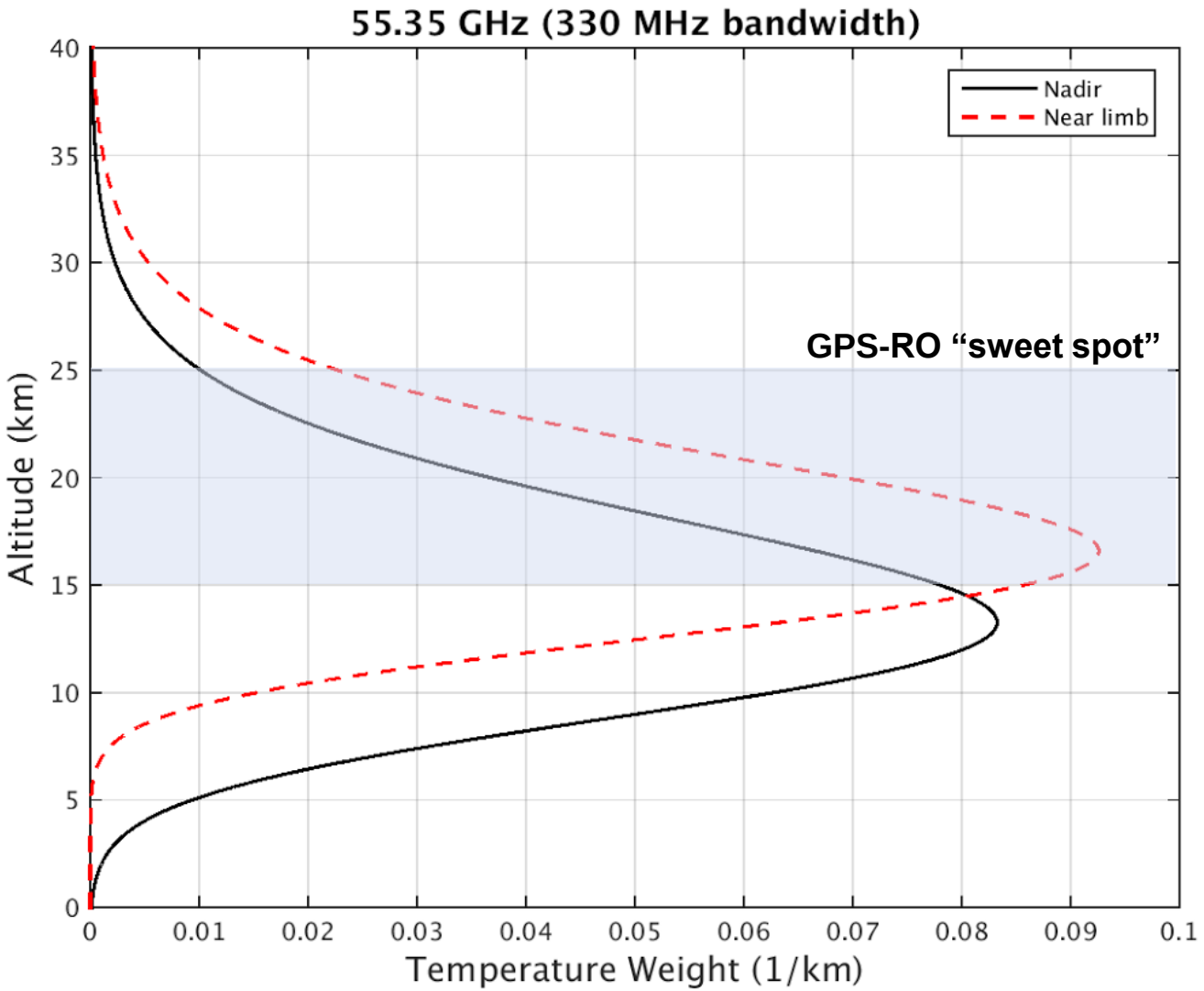
Systems: MiRaTA System Block Diagram



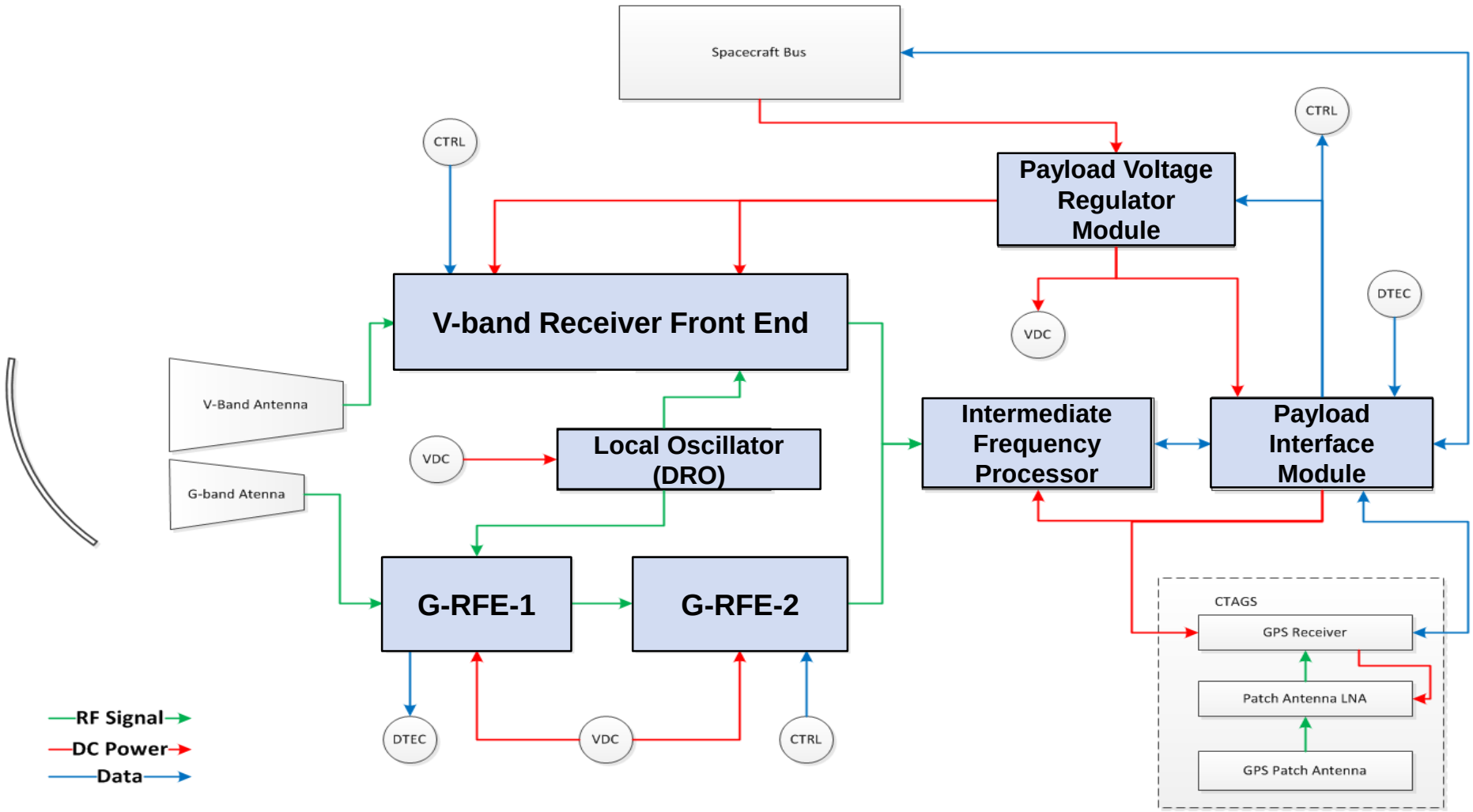
Channel Properties for MiRaTA Radiometers

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

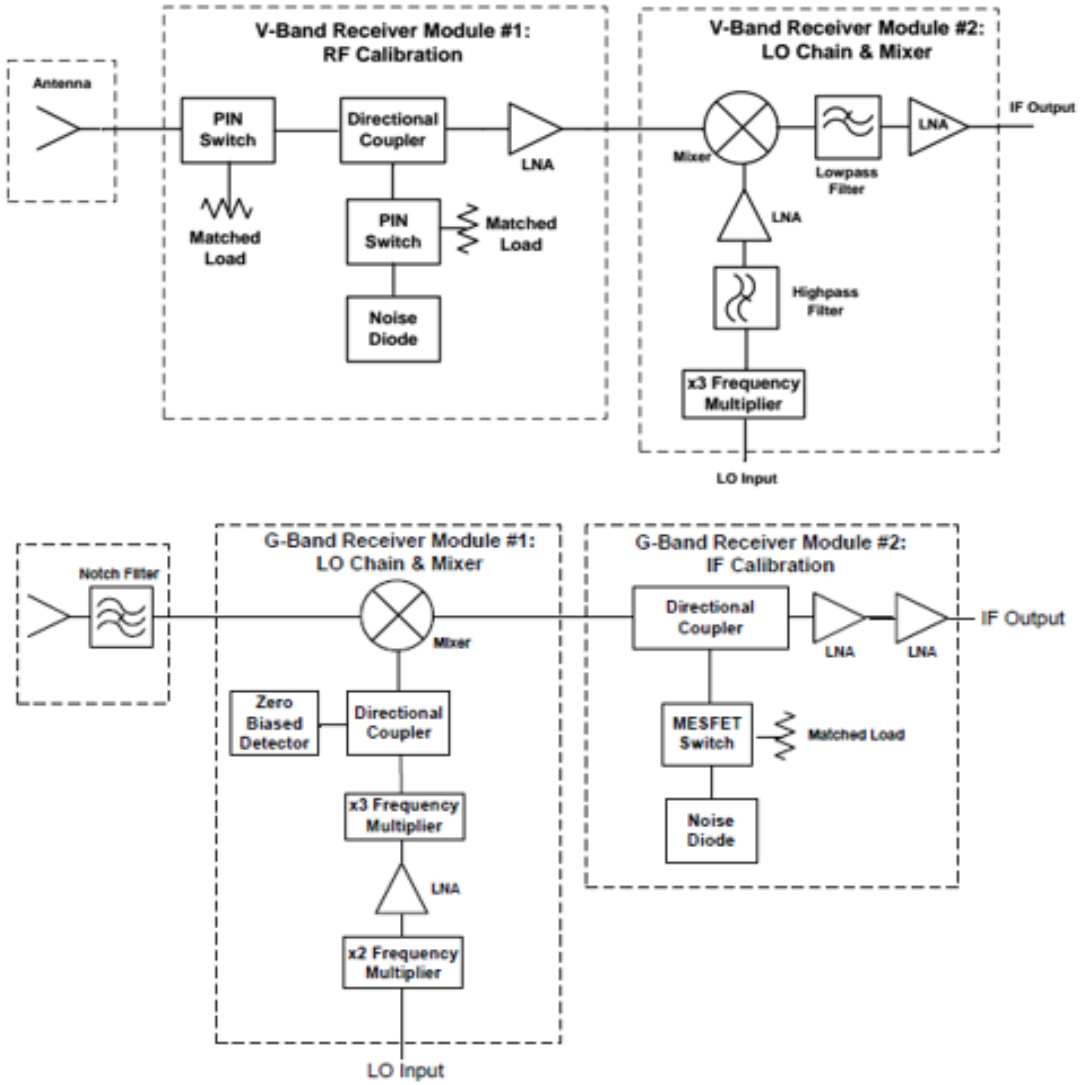
Advantage of Limb Comparisons



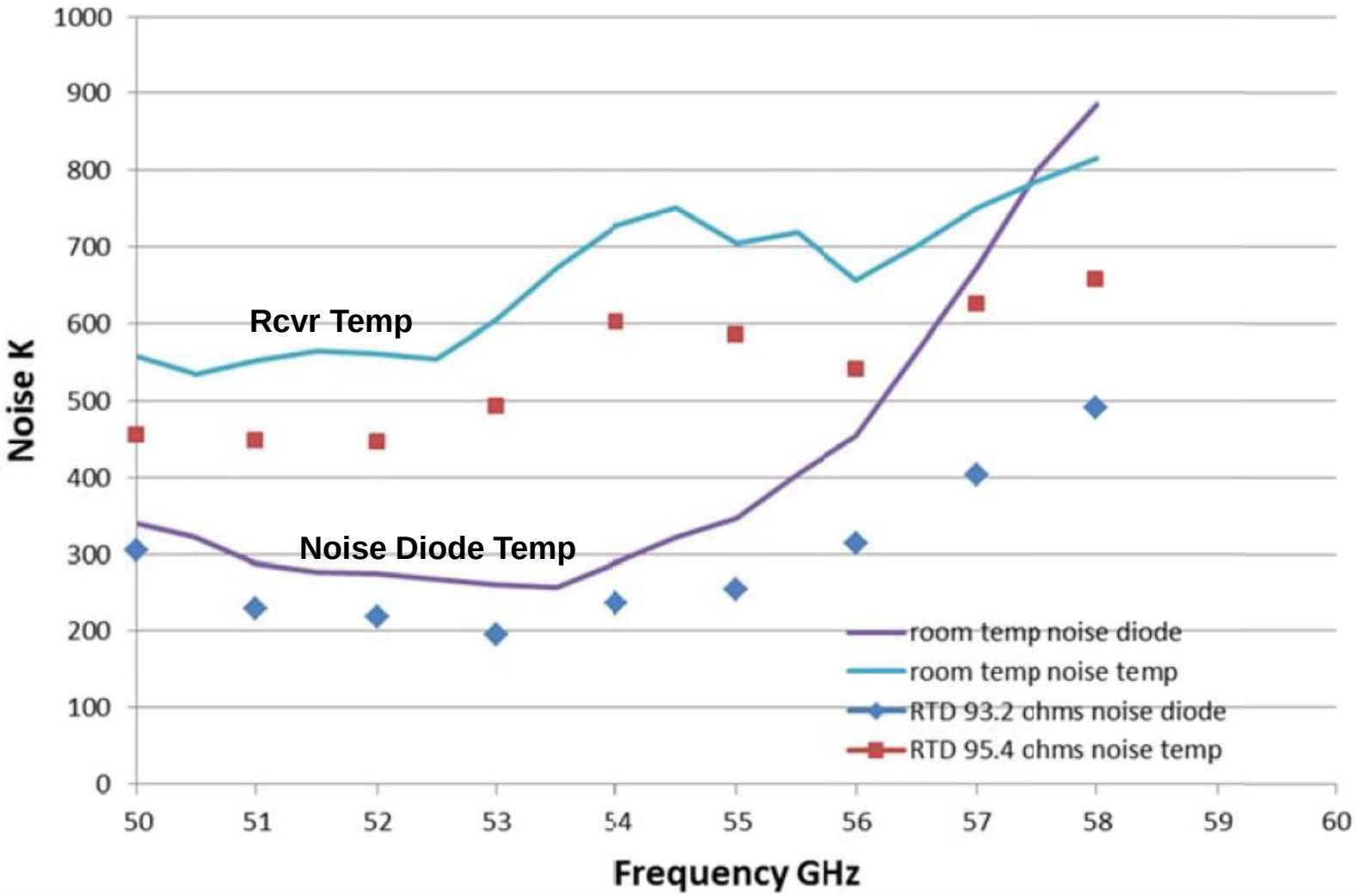
Radiometer Payload: Block Diagram



Payload: Radiometer Receiver Front End



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



MiRaTA G-band Front-End Performance