The CubeSat Radiometer RFI Technology Validation (CubeRRT) Mission: Instrument Pre-Launch Testing and Project Status

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Silver Spring, MD

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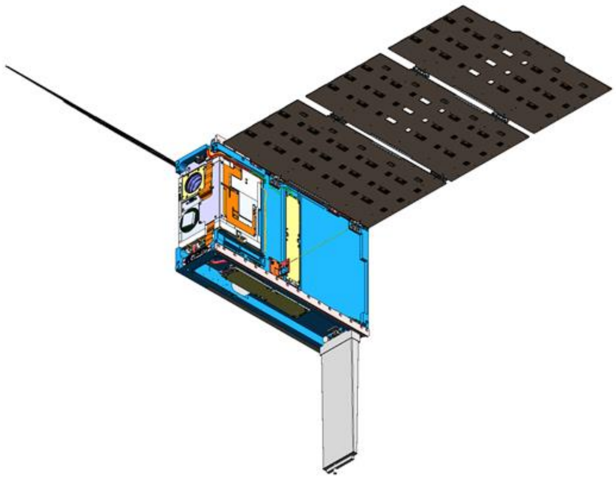
Overview

- CubeRRT overview and objectives
- Satellite bus and instrument overview
  - RF antennas
  - Radiometer front-end
  - Radiometer digital back-end
- Integration and test activities
- Launch
- Operations and data processing
- Conclusions and next steps

CubeRRT Overview

- CubeRRT: CubeSat Radiometer Radio Frequency Interference (RFI) Technology Validation mission
  - Funded by NASA's In-space Validation of Earth Science Technologies (InVEST) program
- 6U CubeSat to demonstrate spaceborne RFI detection and mitigation technology
  - Address data processing needs of future satellite-based microwave radiometer systems
- Spacecraft delivered to Nanoracks for launch preparation
- Launched on May 21, 2018 (OA-9 / ELaNa 23 ISS resupply)
- Deployment from ISS: late July, early August

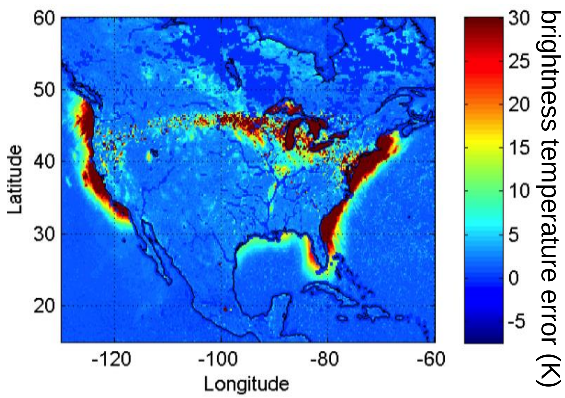


RFI Problem for Microwave Radiometry

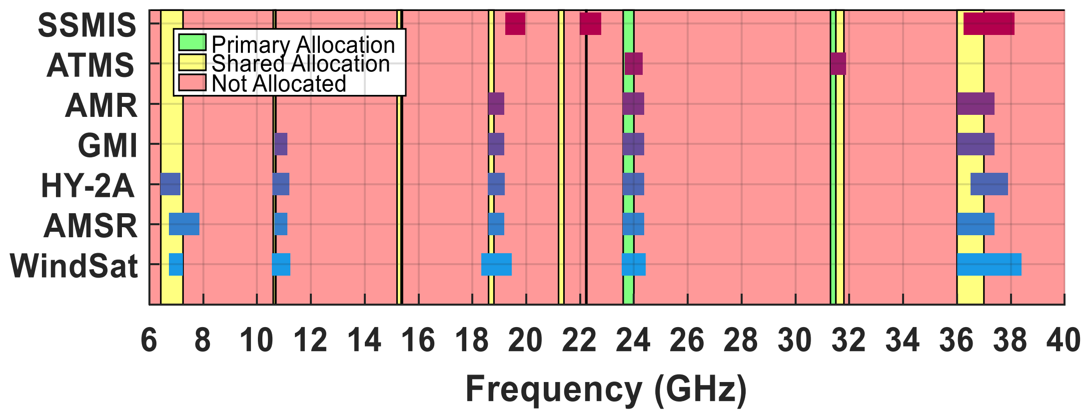
ESTO Earth Science Technology Office

- Microwave radiometers observe the naturally generated microwave thermal emission from Earth for use in a variety of science applications
  - Man-made transmissions cause radio-frequency interference (RFI)
- Radiometers attempt to avoid RFI by operating in frequency bands where transmission is prohibited, but this is not always possible or effective

GMI Image at 18.7 GHz with RFI 'hot spots'



Spectrum Allocation and Usage



- RFI problem is even more challenging for future radiometer systems

	SMAP	Future
Number of bands	1	6 or more
Bandwidth	20 MHz	100's of MHz in each channel
RFI Processing on ground?	Yes (small downlink volume)	Not possible (downlink volume too large)
RFI Processing on-board spacecraft?	No; not necessary	Yes; only way to address RFI for future systems

CubeRRT Mission

- Technology validation mission
  - Designed for 1 year of operation
- Mature RFI mitigation technology from TRL 5 to TRL 7
- Demonstrate digital processor to detect and filter RFI
  - Mitigate pulsed and continuous sinusoidal RFI
  - Downlink raw and RFI-mitigated data
  - Compare reported RFI flags with reconstruction on ground
- Meet baseline mission requirement
  - Provide radiometry data from at least 100 hours of spaceborne operation
  - 10 hours in each of 10 pre-defined frequency bands

Center Frequencies (MHz)

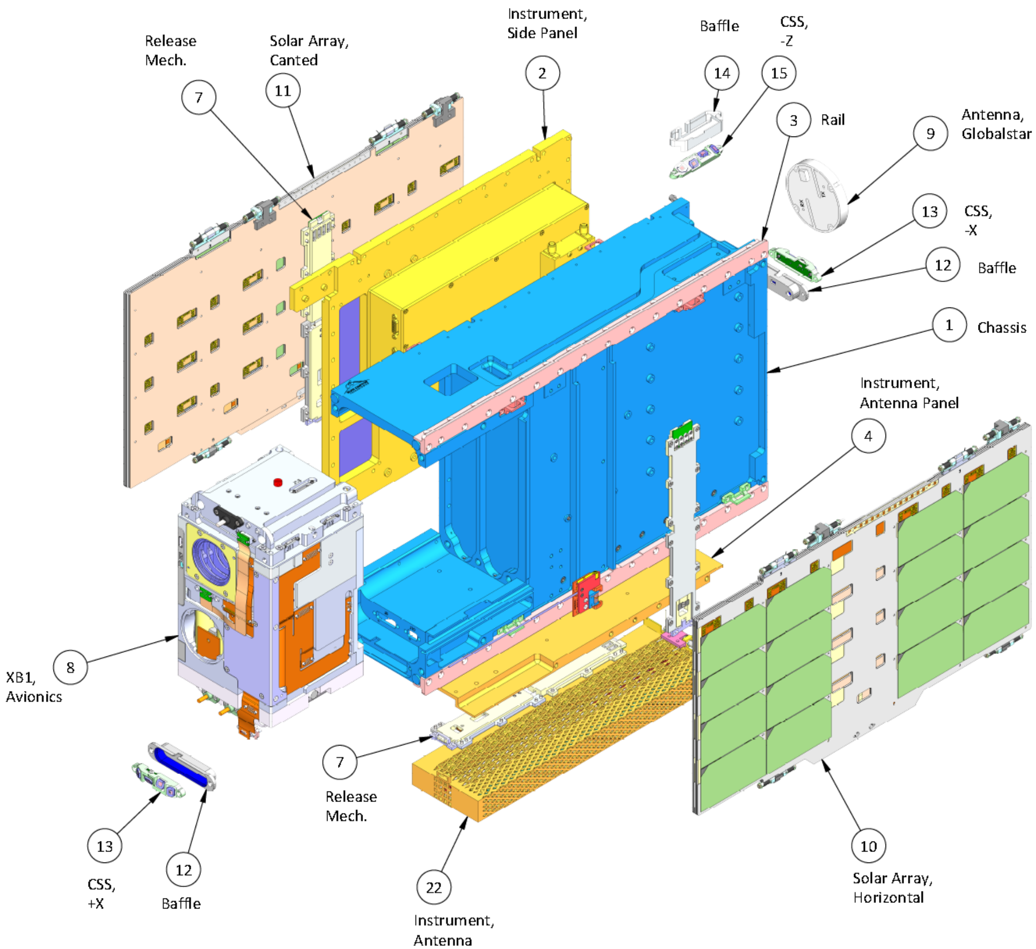
6800	23800
10400	31400
18700	34000
19400	36500
22200	37500

Mission Properties

Frequency	6 to 40 GHz Tunable, 1 GHz instantaneous
Polarization	Circular polarization
Observation angle/Orbit (ISS launch)	0° Earth Incidence Angle 400 km altitude, 51.6° orbit inclination
Spatial Resolution	80 km (40 GHz) to 240 km (6 GHz)
Integration time	100 msec
Ant Gain/ Beamwidth	12dBi/30° (6 GHz), 21 dBi/10° (40 GHz)
Interference Mitigation	On-board Nyquist sampling of 1 GHz spectrum; On-board real-time Kurtosis and Cross-Frequency Detection Downlink of frequency resolved power and kurtosis in 128 channels to verify on-board performance
Calibration	Internal: Reference load and Noise diode sources External: Cold sky and Ocean measurements
Noise equiv dT	0.8 K in 100 msec (each of 128 channels in 1 GHz)
Average Payload Data Rate	9.375 kpbs (including 25% duty cycle) ~102 MB per day,~ 37 GB over 1 year mission life
Downlink	135 MB per daily ground contact [6 minute contact with 3 Mbps UHF cadet Radio] 32% margin over payload data

CubeSat System Overview

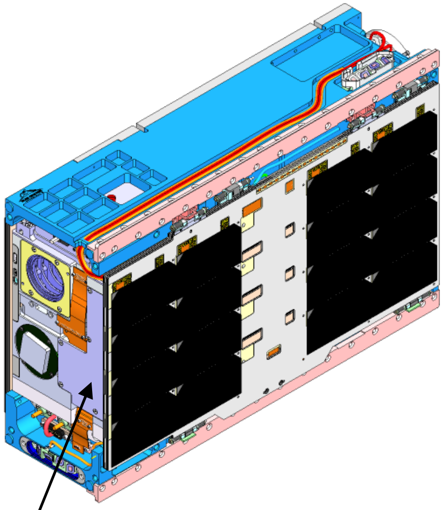
- Blue Canyon Technologies delivered 6U spacecraft bus
- BCT's XB1 unit provides flight computer, attitude control, navigation information, and communications
- Bus provides isolated power to payload radiometer to prevent ground loops
- Two contacts per weekday planned using WFF ground station
  - Primary: UHF Cadet radio
  - Backup: Globalstar satellite network



Spacecraft Deployment

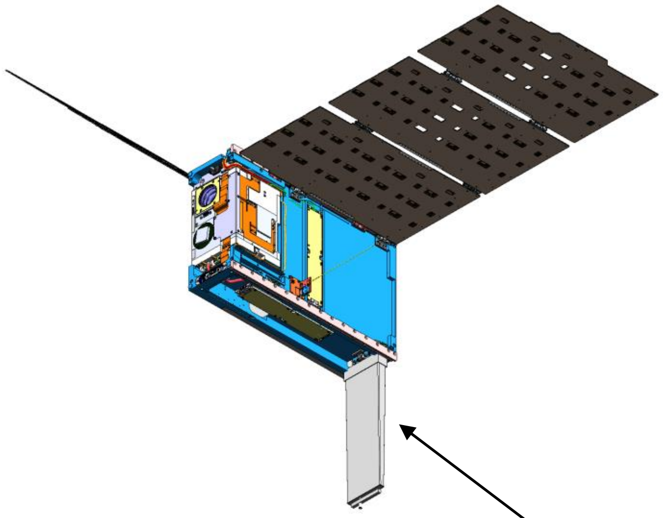
- Antennas and solar panels deploy from stowed position post-deployment
- Operates in a nadir viewing configuration
- Designed for yaw steering, which maximizes solar panel view of sun while taking radiometry measurements

Post-deploy stowed



XB1 Control Unit

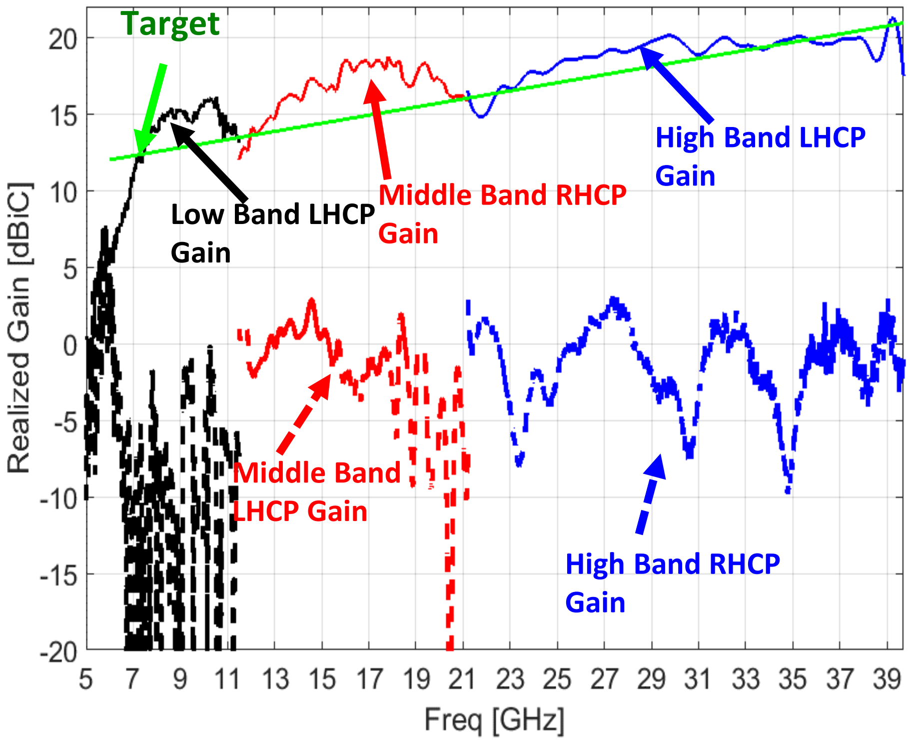
Payload antennas deploy toward nadir

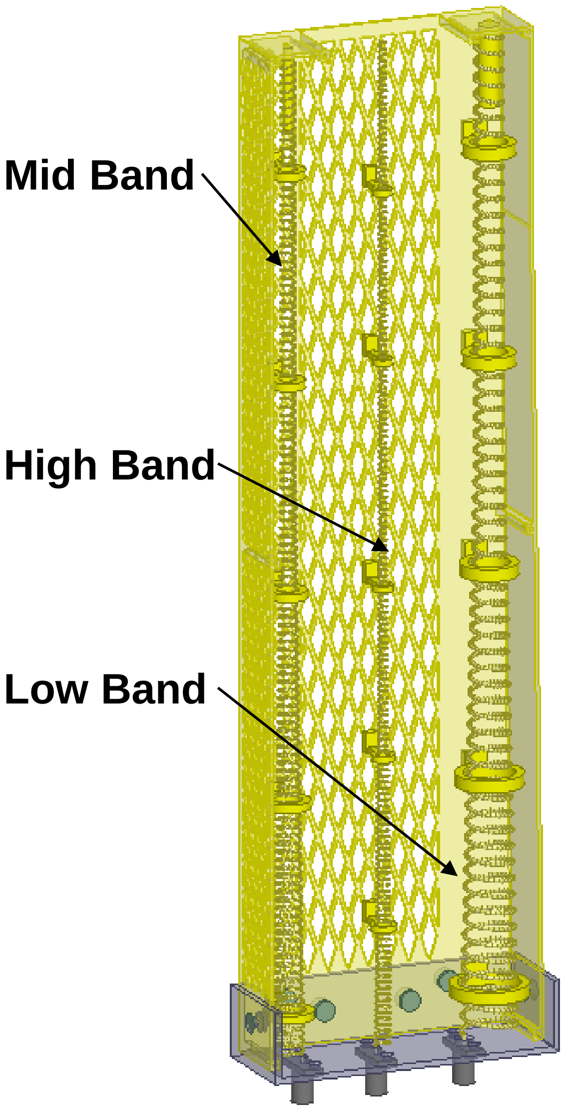


Antenna
Deployed position

Payload Instrument – RF Antennas

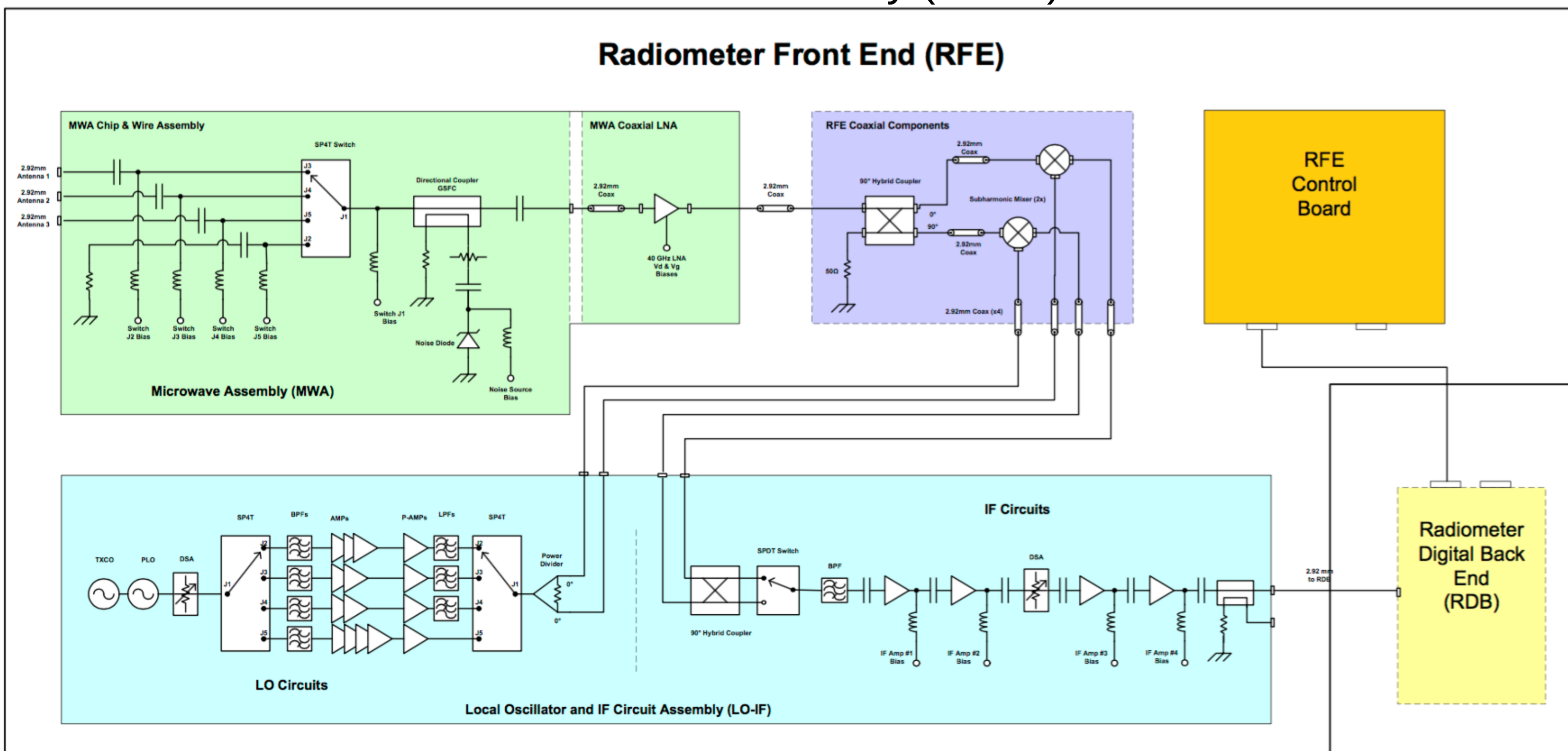
- Developed by Ohio State University
- Three tapered helical antenna elements to allow coverage of 6-40 GHz
- Radome included for mechanical support and to improve tuning; optimized for each antenna element





Payload Instrument – Radiometer Front-End

- Developed by NASA Goddard Space Flight Center
- Major subsystems
  - Microwave Assembly (MWA)
  - Local Oscillator and IF Circuit Assembly (LO-IF)



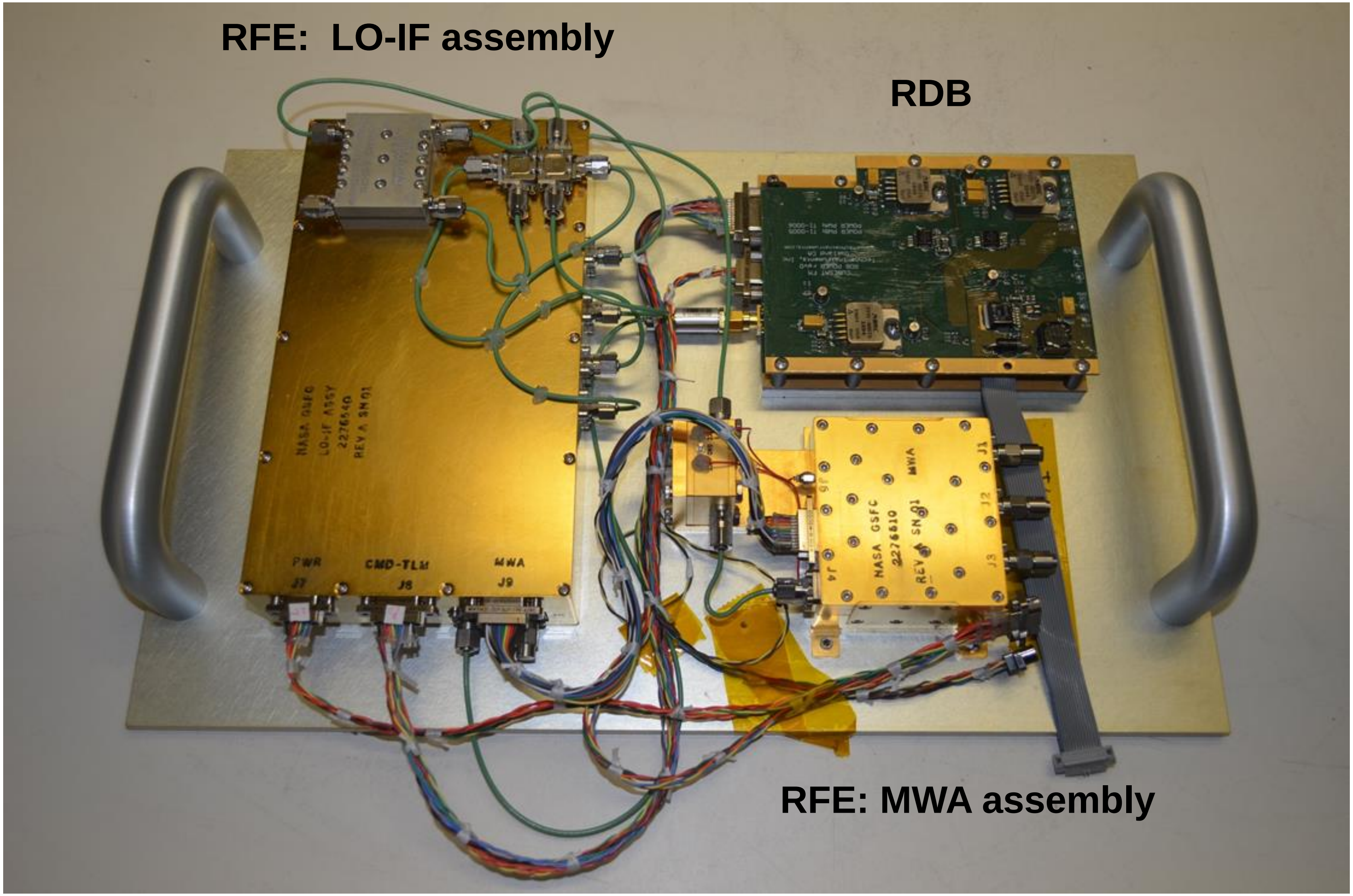
Payload Instrument – Digital Back-End

- Developed by NASA JPL
- ADC samples RFE's IF output at 2 GSPS
- RFI detection and mitigation performed using a combination of firmware (Zynq FPGA fabric) and software (Zynq embedded ARM processor)
  - Provides options in trading off power consumption versus flexibility and processor speed
- Multiple algorithms offer better performance for differing RFI types

Cross Frequency (128ch/100ms)	CW, narrowband signals
Kurtosis (128ch/100ms)	Pulsed-type/low-level RFI

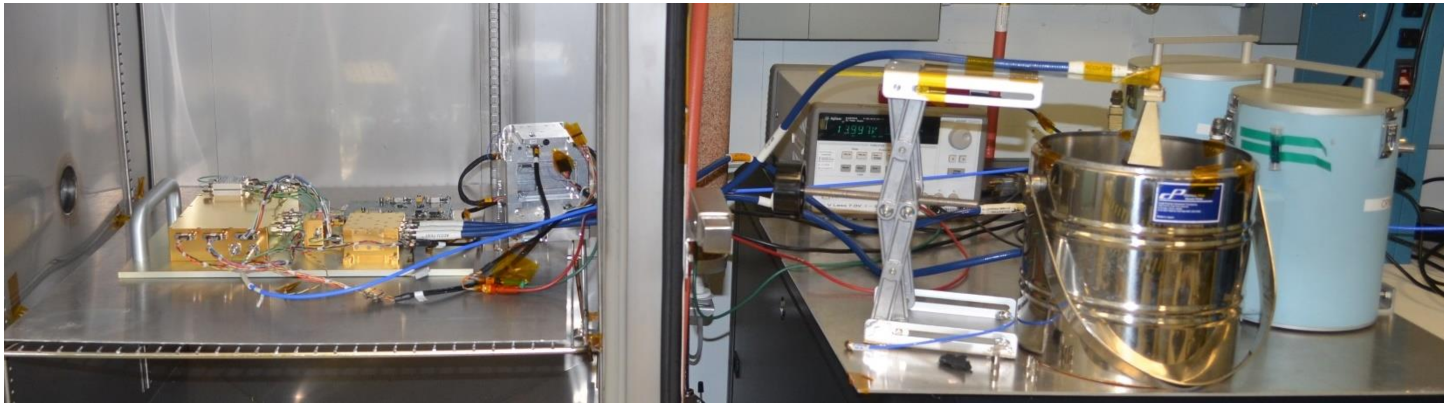
- Cross-frequency "flattens" data on board to improve sensitivity
  - Uses antenna/reference data to remove majority of passband shape prior to detection
  - Also includes additional on board frequency dependent table to "flatten" even further

Payload Integration



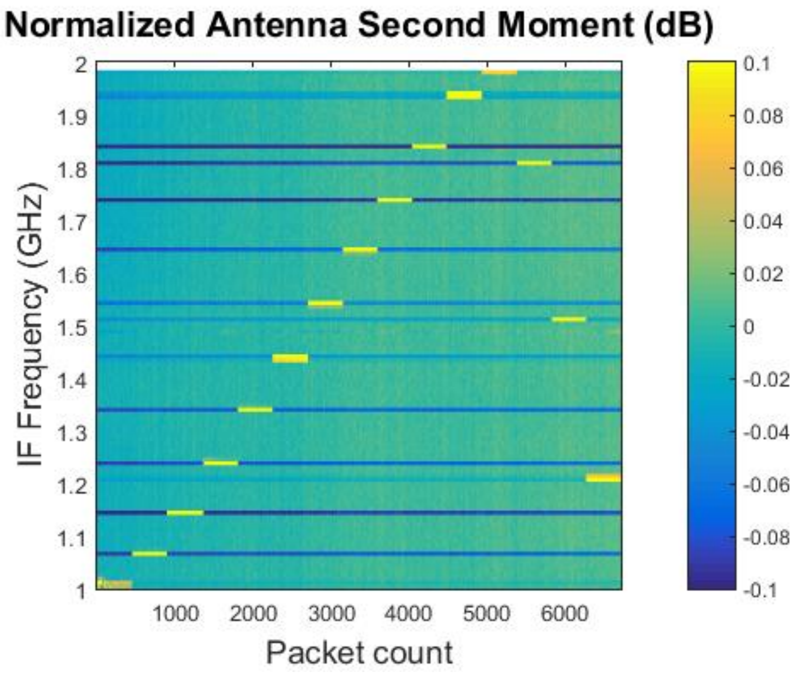
Payload Testing

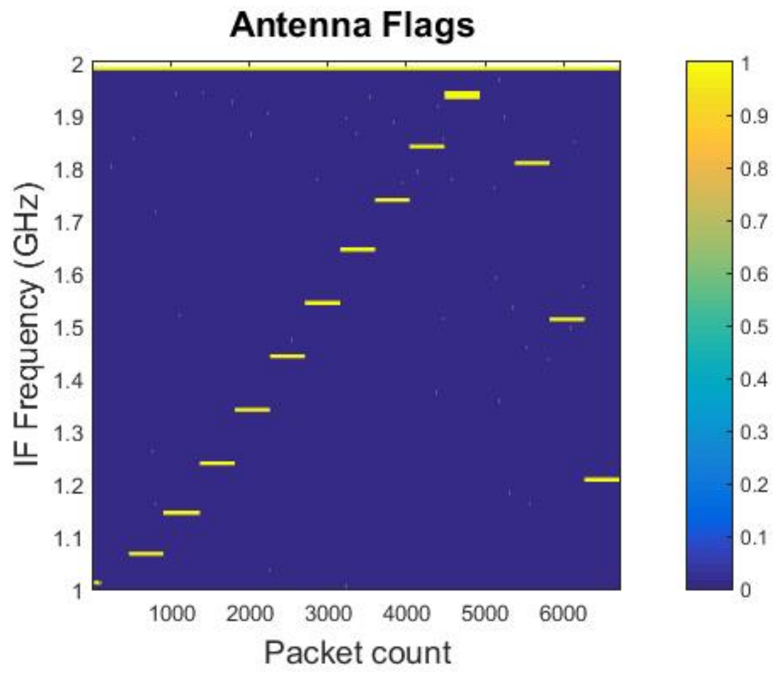
- Flight model testing for the integrated CubeRRT payload occurred in October 2017 at GSFC
- Testing highlights include:
  - End-to-end radiometry measurements through integrated payload
  - Passband flattening implementation and optimization
  - Successful RFI detection and mitigation using injected and radiated signals
  - Thermal cycle testing



Payload FM Testing: RFI Detection

- Tested the ability to detect injected RFI
- Radiometer was tuned to a fixed frequency, with RFI injected and stepped across passband
- RFI was correctly flagged for the antenna measurements





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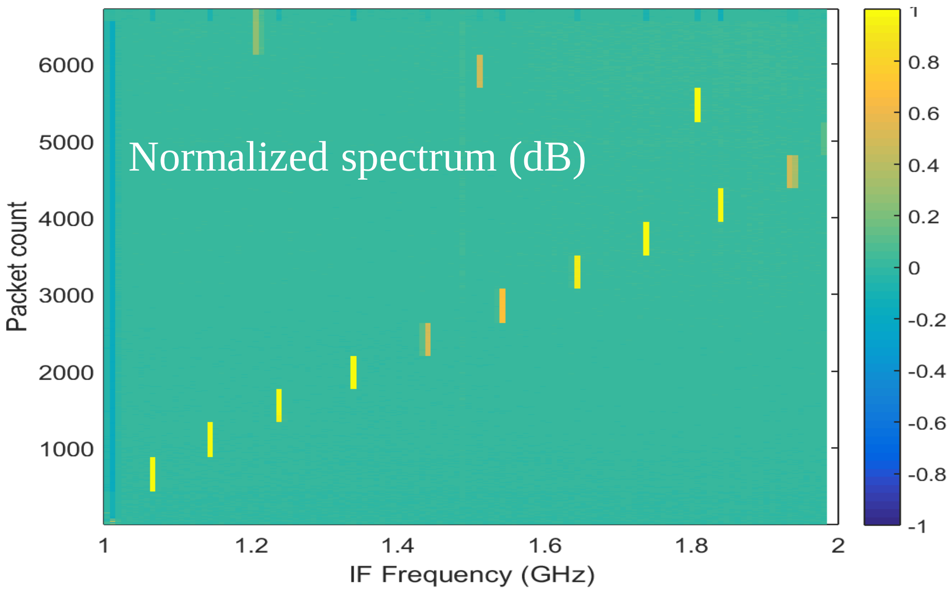
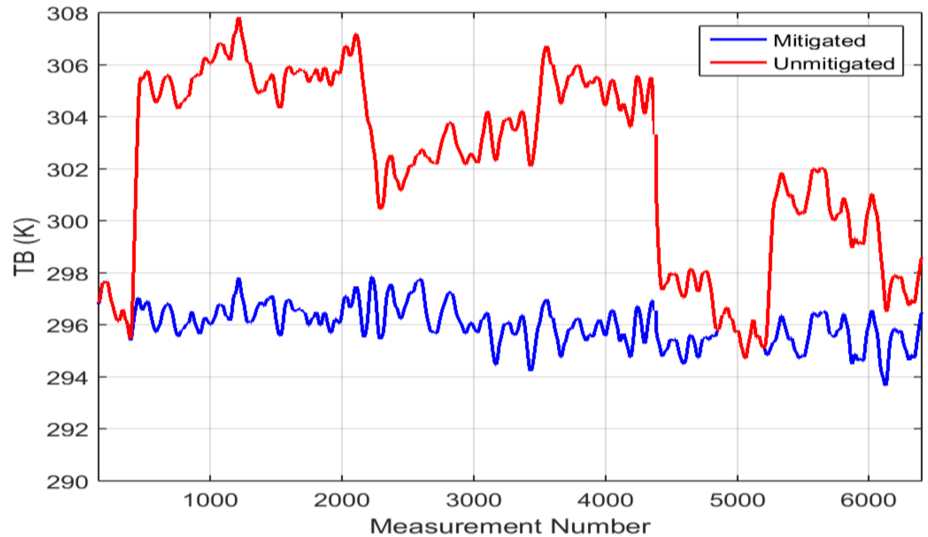
RFI Detection Performance Tests

- Example injecting sinusoidal RFI at differing frequencies into 9.9-10.9 GHz measurements
- RFI source power kept constant, but contribution modulated by passband shape of radiometer
- CubeRRT reports 128 point spectra versus time, but also removes corrupted RFI and reports mitigated and unmitigated total power

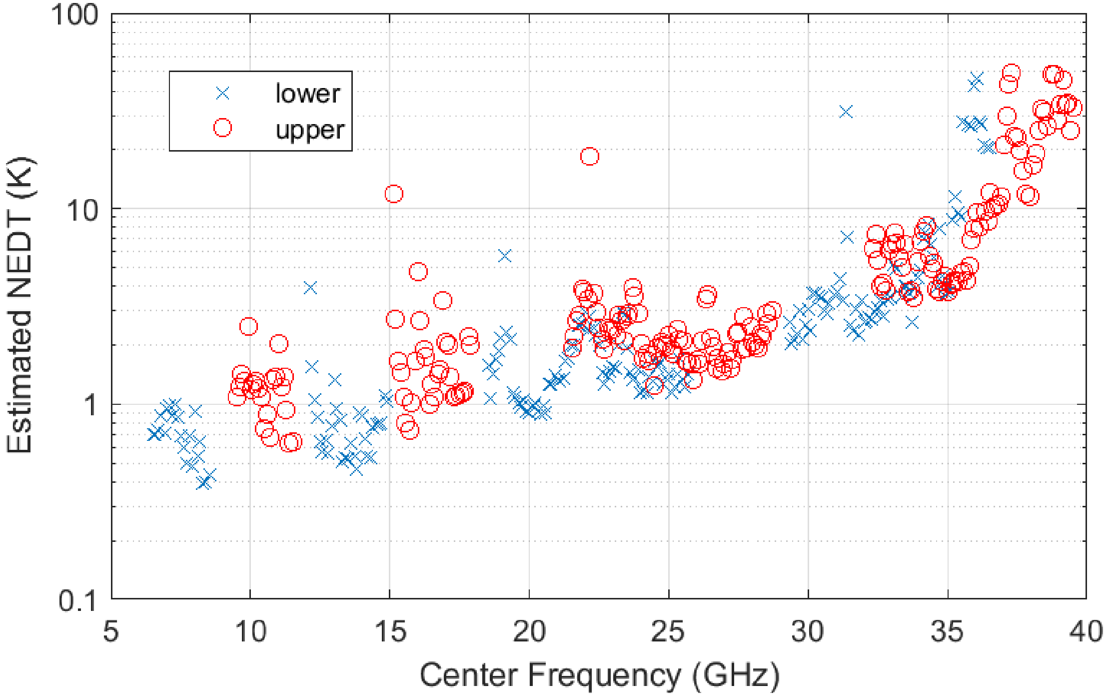


- Injected RFI contribution in this example varies from ~ 2K to ~ 10K depending on location in passband
- CubeRRT mitigates RFI down to ~ 2 NEDT level
    - Plot to right is averaged over multiple measurements to make RFI contributions clearer



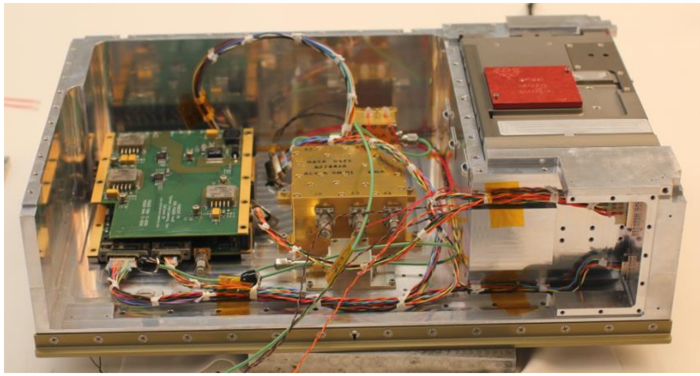
Sample Instrument Performance Data

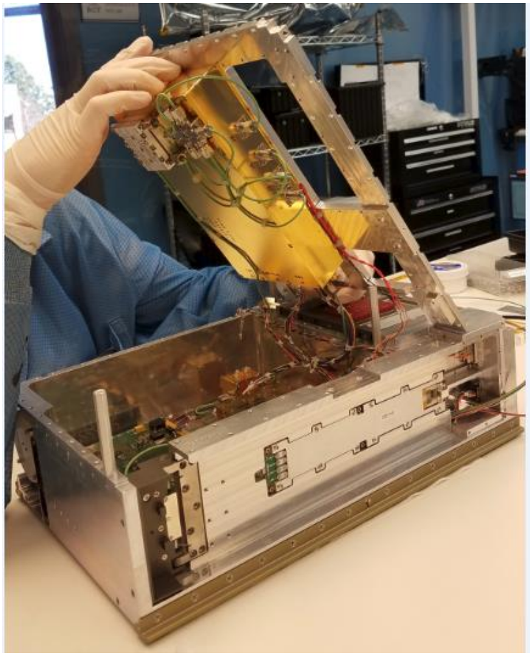
- Radiometric Sensitivity (NEDT):
  - < 1K for f< 10 GHz
  - ~ 1-3K for 10<f<35GHz
  - ~ 3-30K for f> 35 GHz
- Coarse sensitivity for f> 35 GHz will allow only large RFI sources O(~20-100K) to be observed
- Real-time RFI detection and removal can still be shown

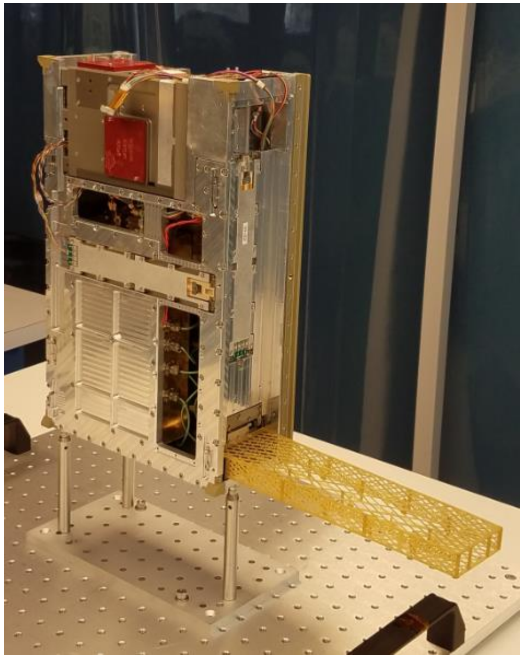


Payload-Spacecraft Integration

- RFE/RDB delivered to Blue Canyon Technologies and integrated into spacecraft November 2017

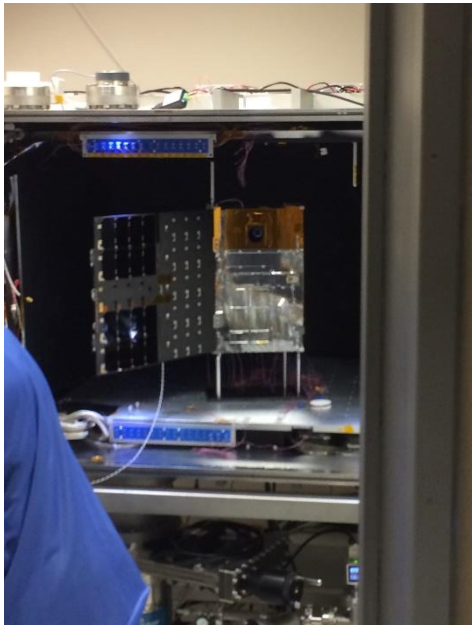


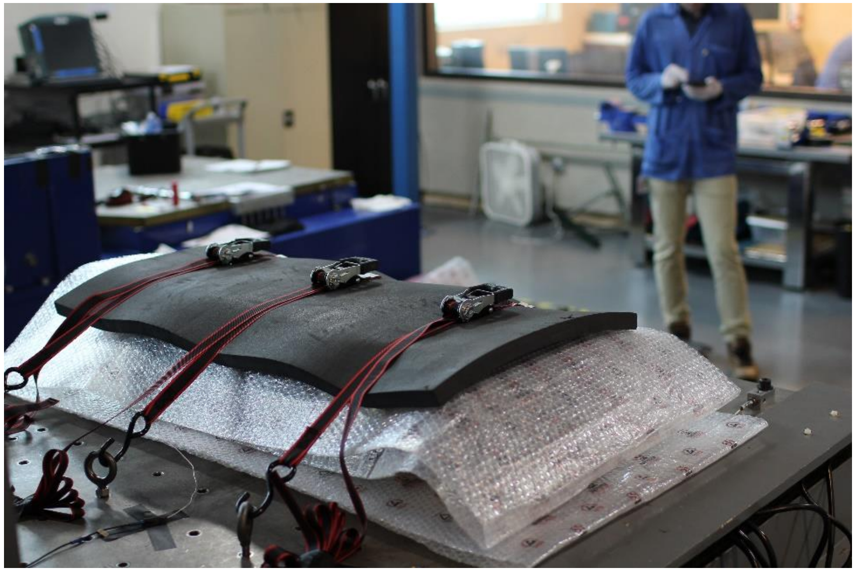




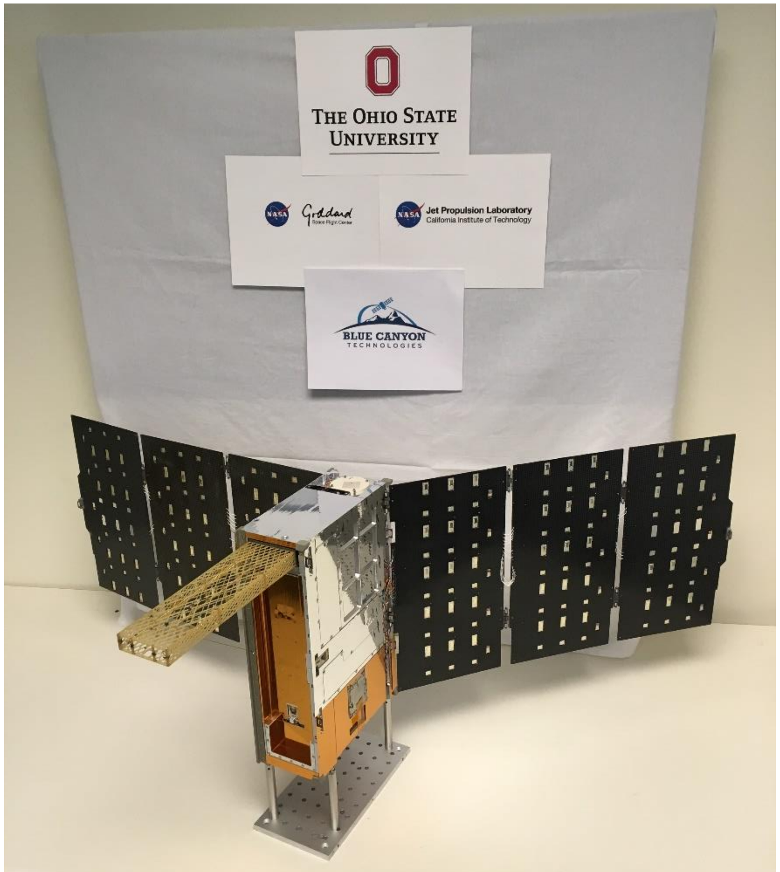
Integrated Spacecraft Testing

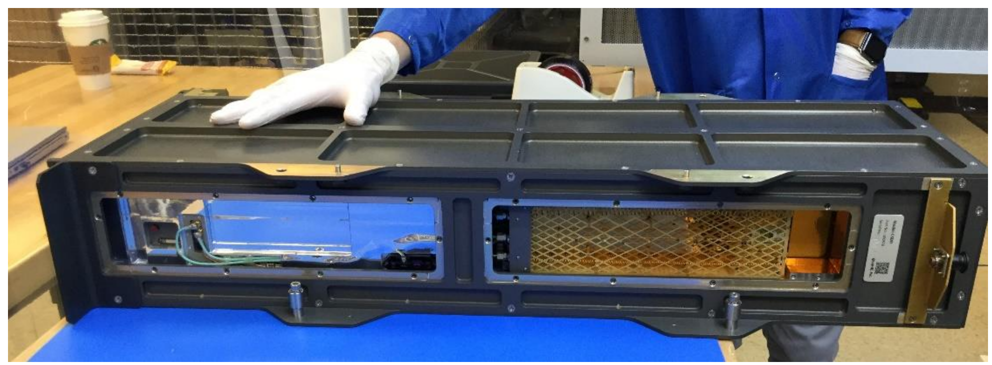
- Testing Jan-Feb 2018 included:
  - Self-compatibility
  - Environmental
    - Random vibration
    - Thermal vacuum
  - Day-in-the-Life





Payload-Spacecraft Integration





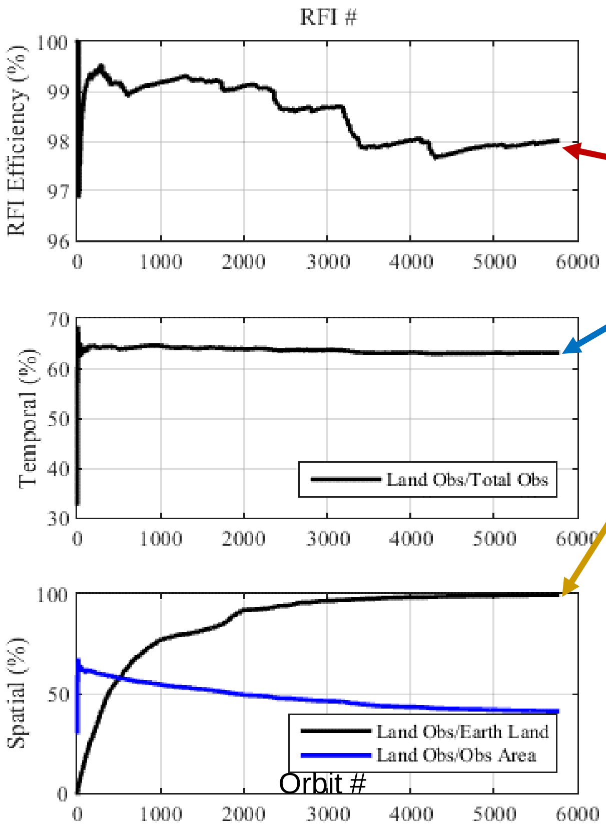
OA-9 Launch (May 21, 2018 4:44am)

Next Step: Operations

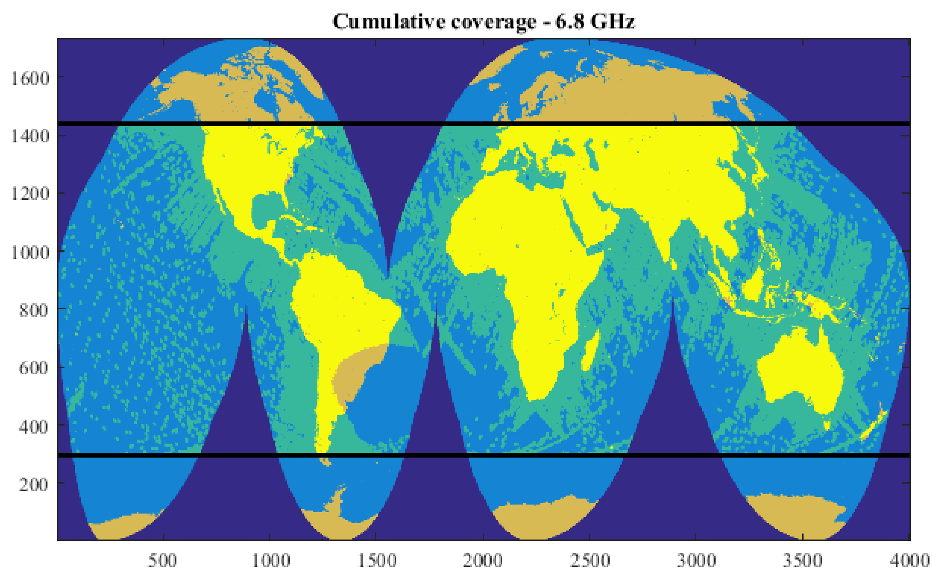
- Manage battery depth-of-discharge
  - Up to 33% duty cycle (~30 minutes out of a ~90 minute orbit)
- Power-on payload during passes over likely RFI locations
  - On-board timed command table
  - Highest incidence of RFI over land
- Plan weekly schedule of payload on/off times
  - Simulation tool used to predict satellite locations
  - Commands uploaded periodically to satellite
  - ICD between BCT and OSU to coordinate process
- Observe RFI ~14 seconds per location
  - Antenna has large spot size (~80 km at 40 GHz, ~240 km at 6 GHz)
- On-orbit commanding allows precise control of frequency list and calibration (load and noise diode) switching

CONOPS: 1 Year Results

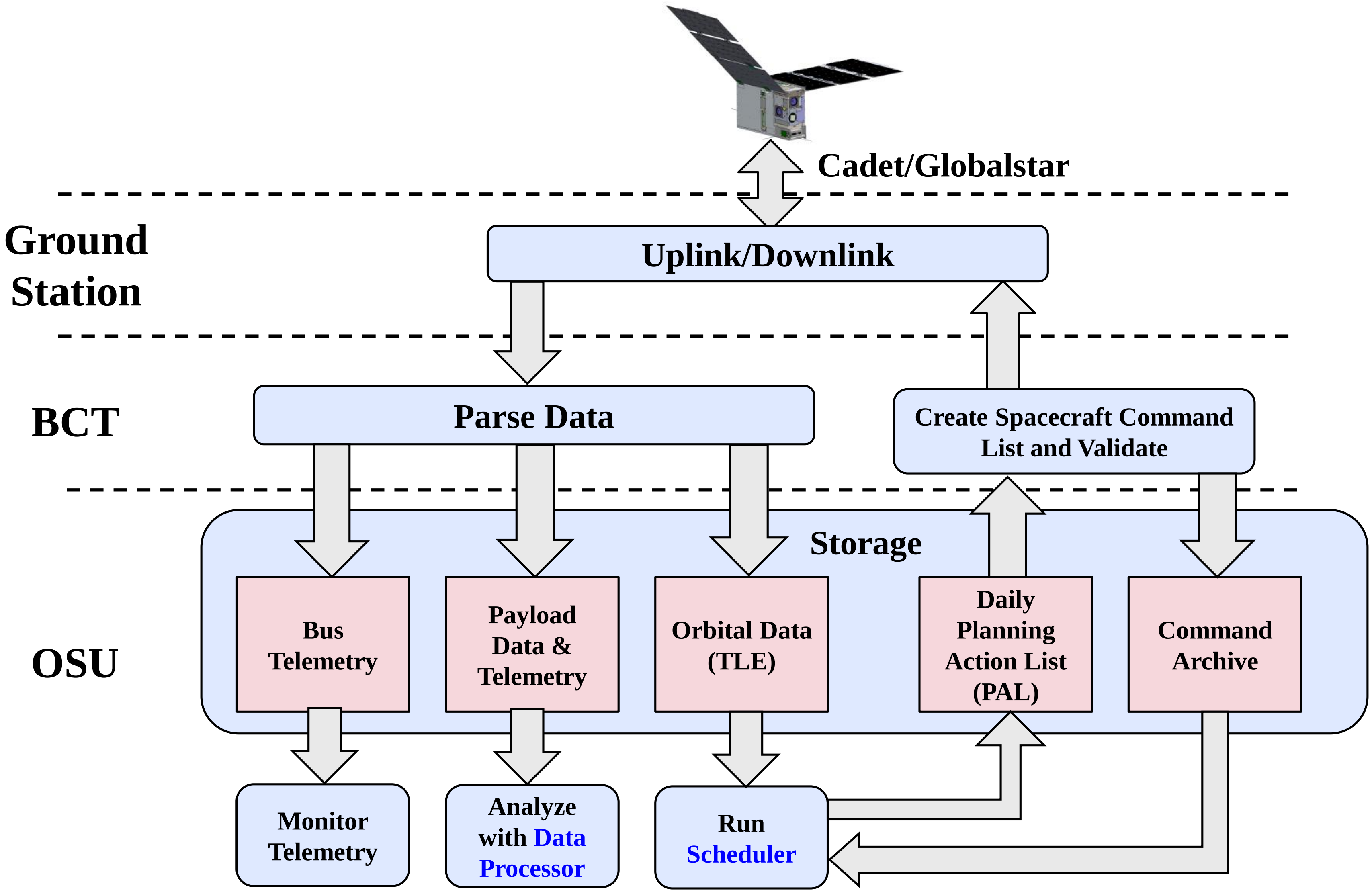
- 1 year of operation operating 30 min/orbit and frequency switching every 10s results in:



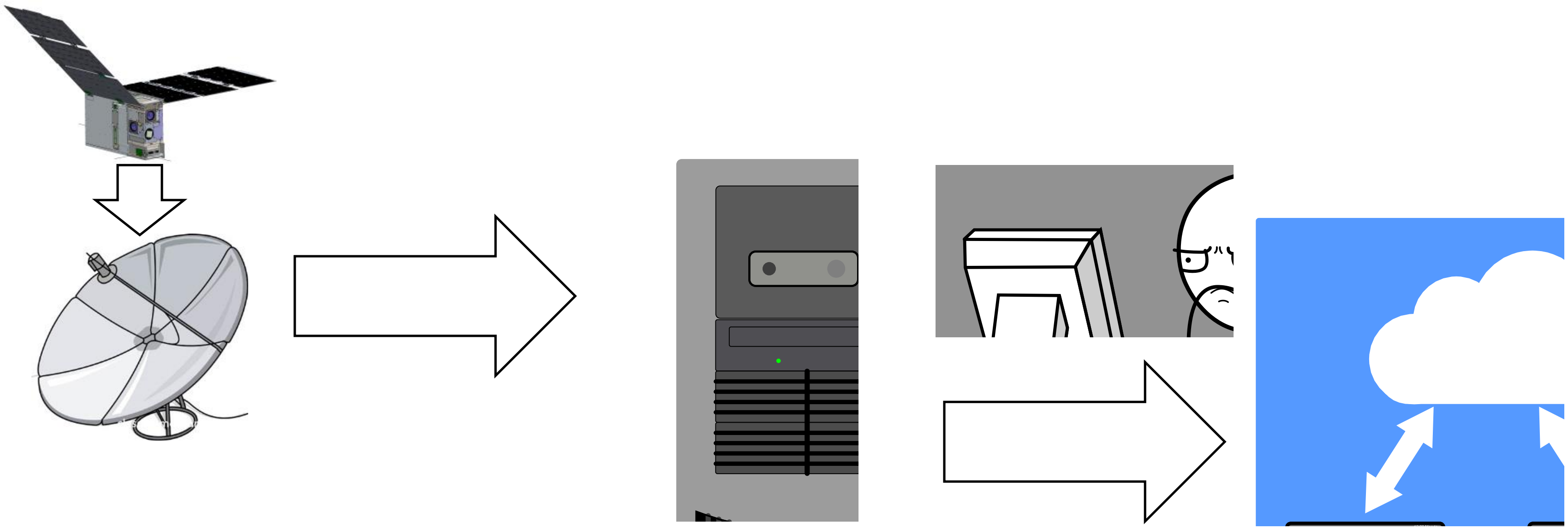
- Baseline mission objectives (10 hours of operation in all 10 frequency bands) achieved within first 14 days
- Average RFI efficiency of 98%
- 65% of total observation time over land
- Over 99% of land observed at each frequency



Standard Operations Flow



Data Processor Flow Diagram



Level 0	1A Processor	Level 1A	1B Processor	Level 1B
Raw downlinked data, pushed by BCT to SFTP server	Extract payload data and desired telemetry to Level 1A	Relevant CubeRRT data in HDF5 format	Calibrate brightness, geolocate data, analyze RFI	Final data product located at SFTP/web

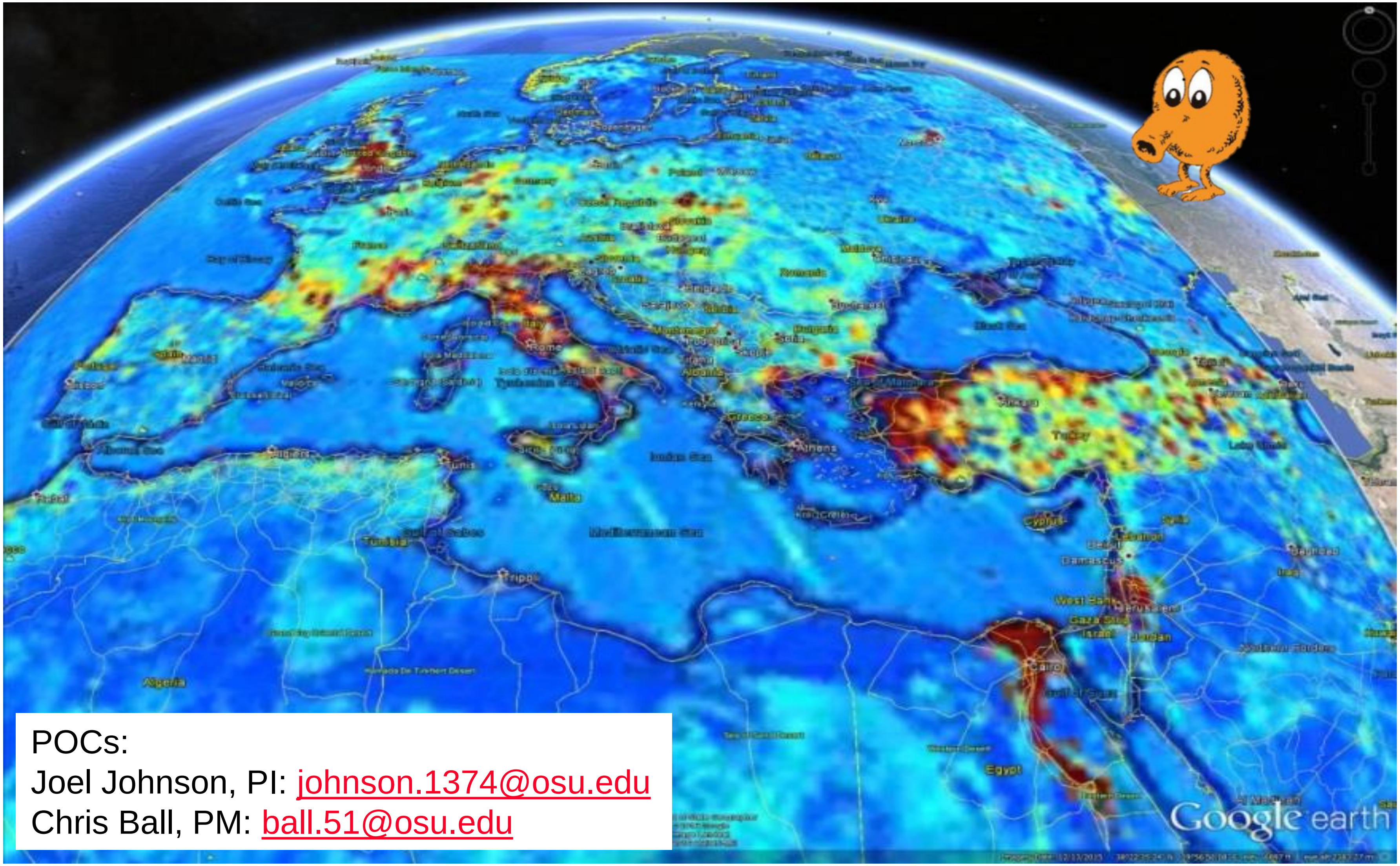
Data Products – Level 1B

- Frequency(ies)
- Unmitigated brightness temperature(s)
- Mitigated brightness temperature(s)
- Latitude
- Longitude
- Pixel Size
- Time
- RFI Flags

Conclusions and Next Steps

- CubeRRT will validate RFI detection and mitigation technologies for future Earth observing microwave radiometers operating 6-40 GHz
- Deployment from ISS into orbit expected late-July / early-August
- Commissioning phase (few weeks)
- Operations phase (up to 1 year)
- Level 1B data will be publicly available through OSU

Questions?



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