Venture EVI-2

ESTO
Earth Science Technology Office

RADIOMETER FOR THE TEMPORAL EXPERIMENT FOR STORMS AND TROPICAL SYSTEMS TECHNOLOGY DEMONSTRATION (TEMPEST-D) MISSION

Sharmila Padmanabhan, Todd Gaier, Boon Lim, Robert Stachnik, Alan Tanner, Shannon Brown, Steven Reising, Wesley Berg, Christian Kummerow and V Chandrasekar

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Mission Manager: Shannon Brown, Jet Propulsion Laboratory, California Institute of Technology (started June 1, 2018)
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Instrument Systems Engineer: Boon Lim, Jet Propulsion Laboratory, California Institute of Technology
Instrument Manager: Sharmila Padmanabhan, Jet Propulsion Laboratory, California Institute of Technology
Instrument Mission Assurance Manager: Ella Seal, Jet Propulsion Laboratory, California Institute of Technology
Spacecraft Leads: John Carvo and Matt Pallas, Blue Canyon Technologies
Validation Lead: Christian Kummerow, Colorado State University, Fort Collins, CO
Validation / Engineering Interface: V. Chandrasekar, Colorado State University, Fort Collins, CO

Temporal Experiment for Storms and Tropical Systems (TEMPEST)

- TEMPEST proposed to NASA Earth Venture Instrument-2 in Nov. 2013
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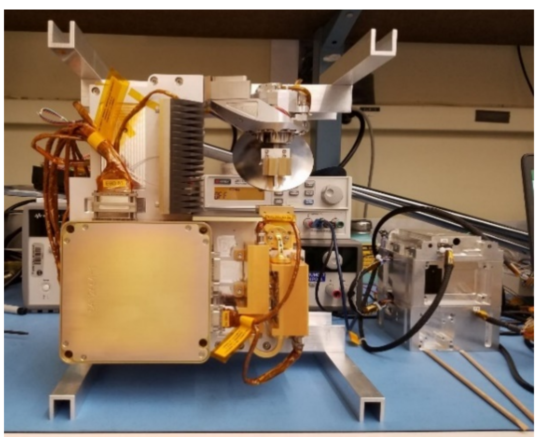
  to ISS on May 21, 2018.
  - Deployment into orbit by NanoRacks on July 13, 2018.

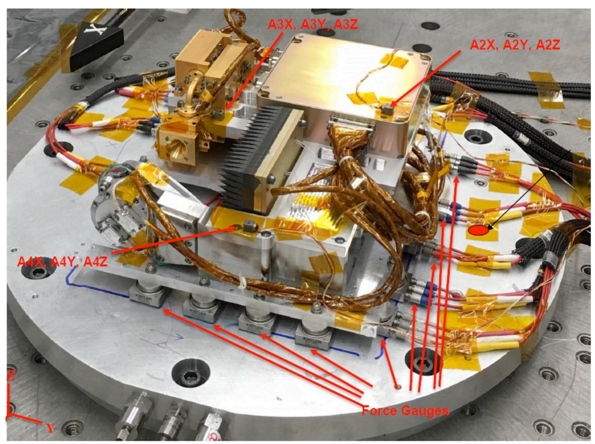
Attend talk on TEMPEST Mission given by Prof. Reising on Thursday at 8:50 am in the ***Instrument Technologies to Enable Small Satellite Remote Sensing Missions I*** ***in Room 4D***

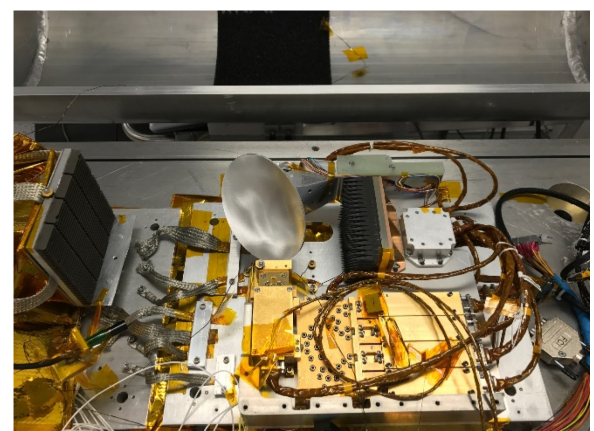
5 identical 6U small sats, each with an identical 5-channel radiometer, flying 5 minutes apart

Instrument Status

- Instrument Shipped to BCT July 19,2017
- Flight TEMPEST-D instrument successfully integrated in flight spacecraft bus in Sept. 2017.
- Spacecraft vibration, thermal balance and thermal vacuum testing completed (including instrument calibration) in Jan. 2018.
- Workmanship vibration penalty testing performed on Feb 22, 2018.
- Thermal balance penalty testing performed again from Feb. 27 to Mar. 2, 2018.
- Total Payload operating hours (including at JPL and BCT) is ~550 hours
  - ~250 hours at JPL and ~300 hours at BCT.
- Instrument has been tested, calibrated and ready to fly







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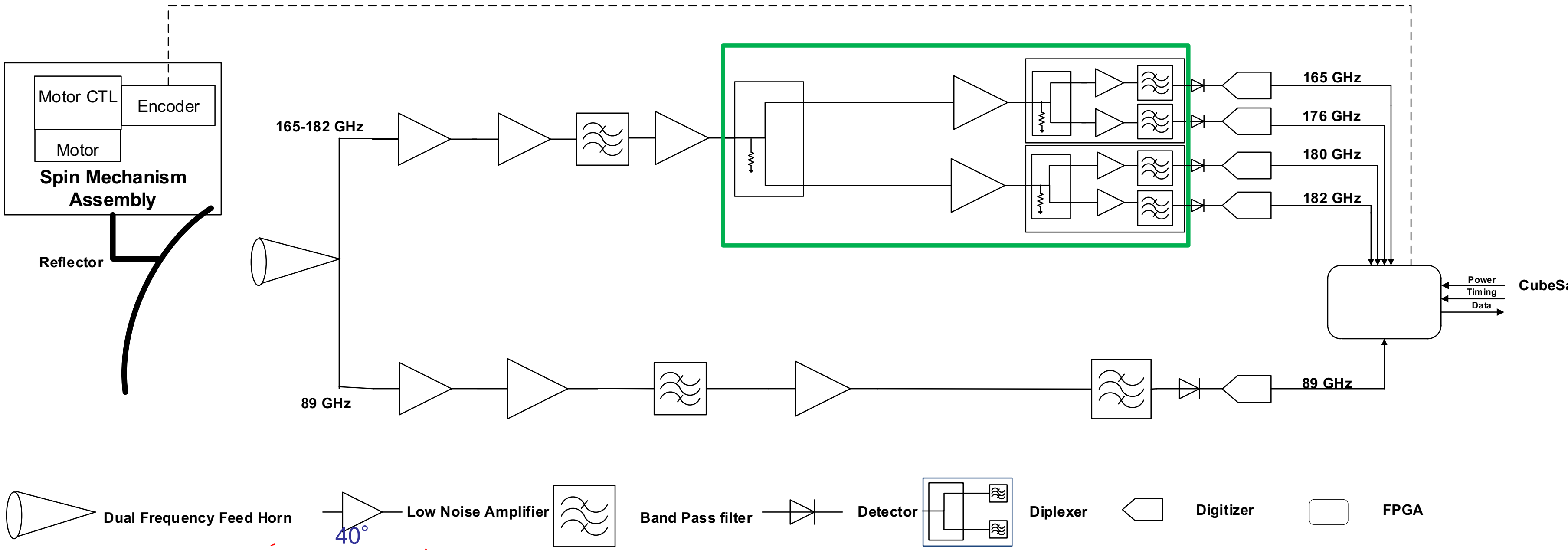
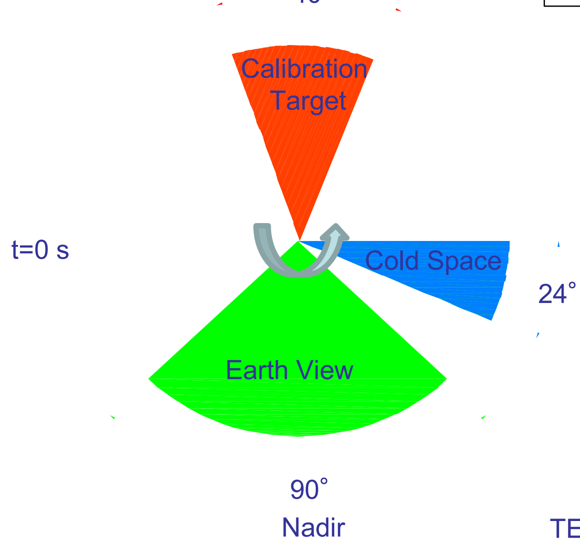
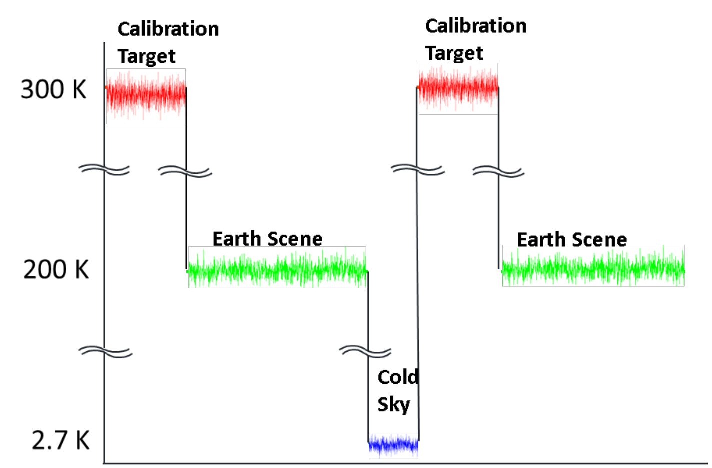
Block Diagram: Direct-Detection Approach

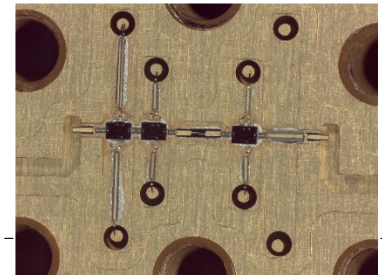
Colorado State University Knowledge to Go Places
Jet Propulsion Laboratory California Institute of Technology
BCT

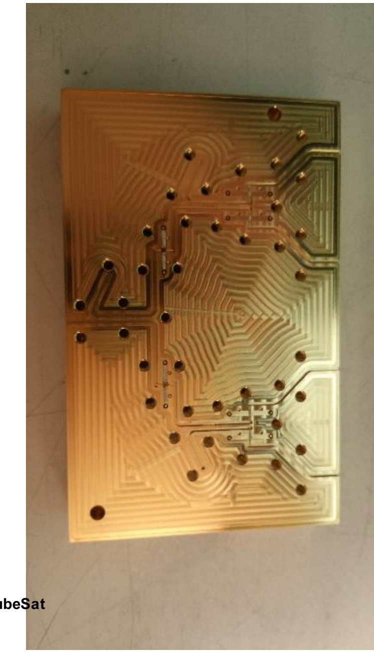


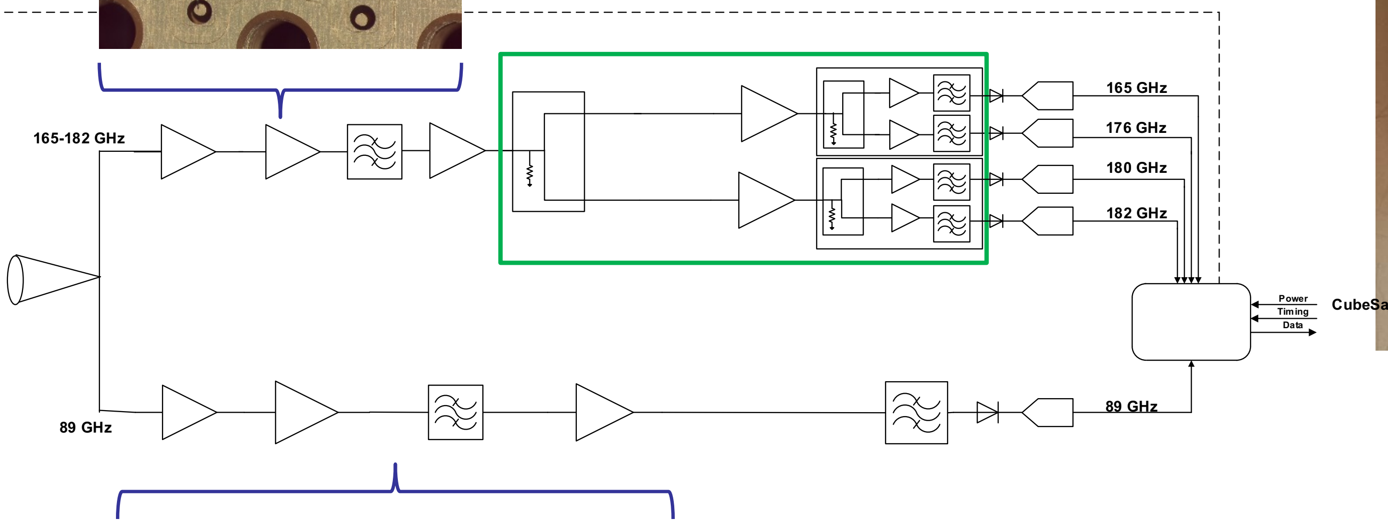


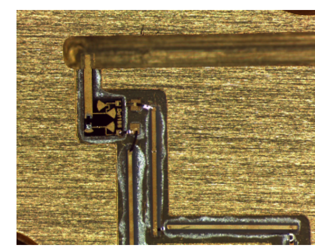


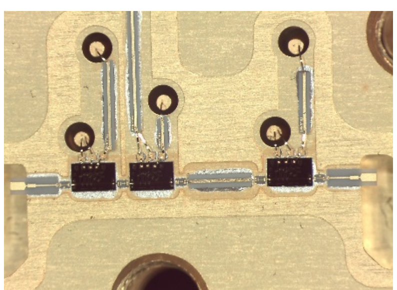
RF Front-End
Direct-Detection Approach

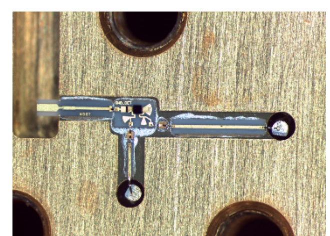




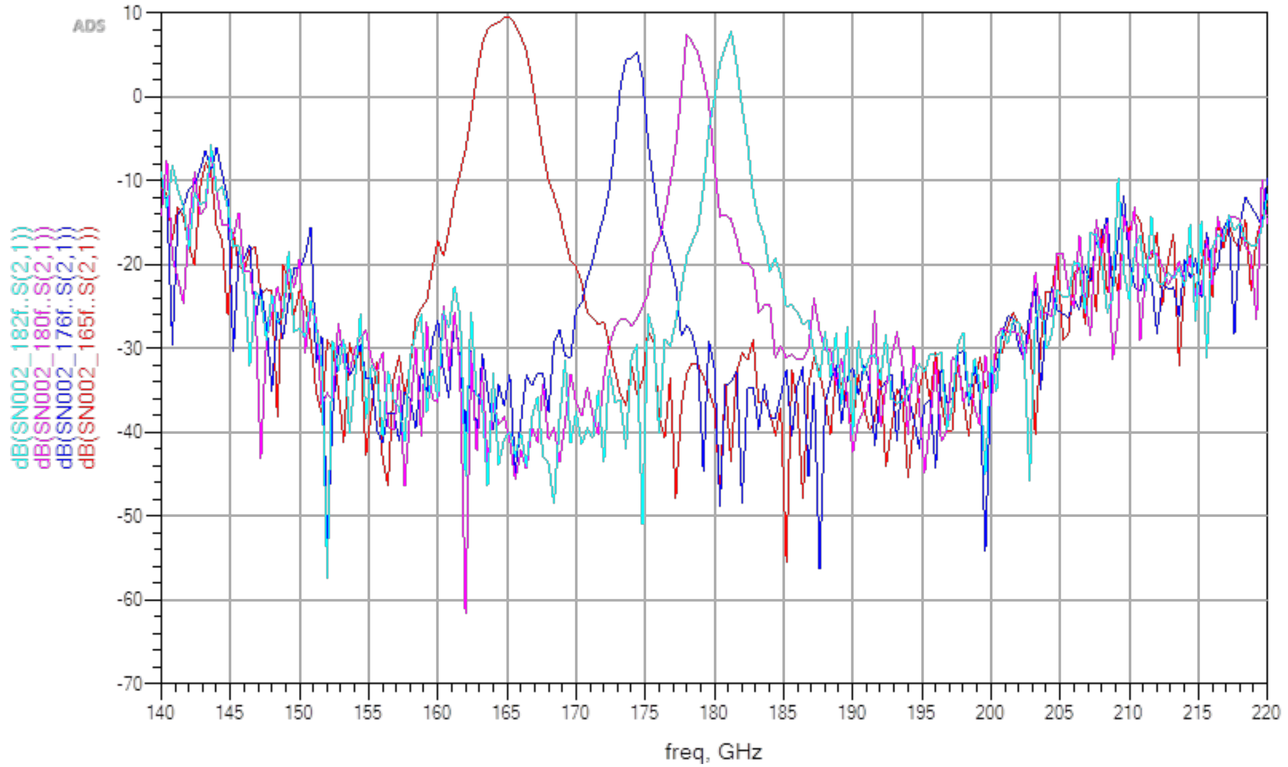






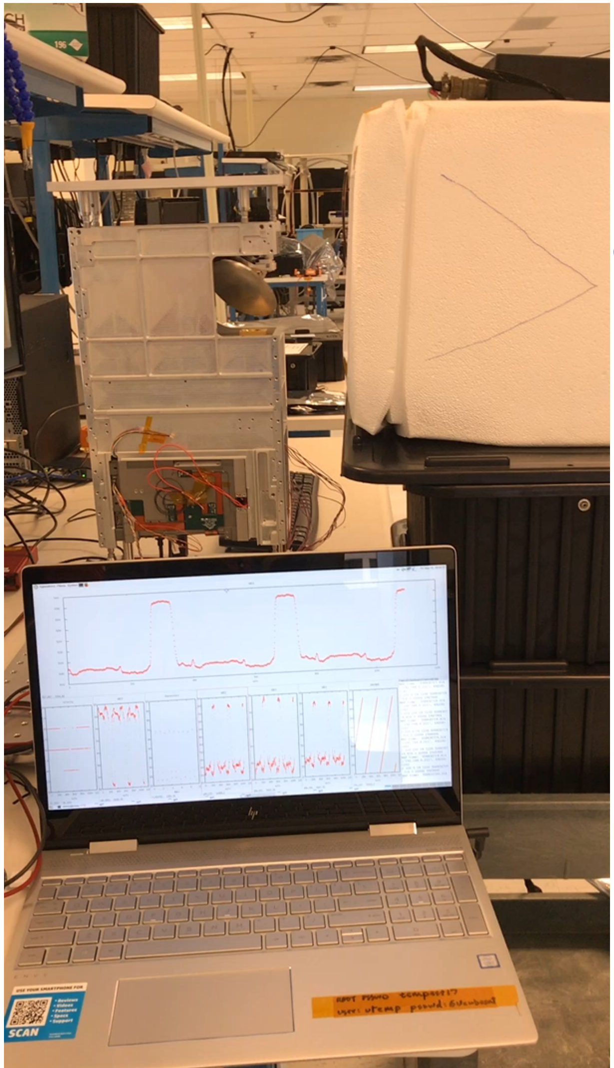


FM Filterbank Data

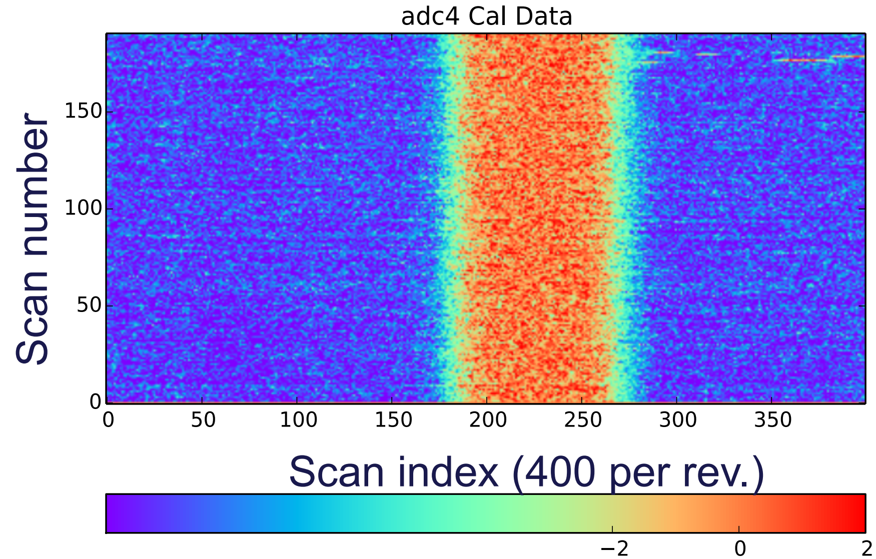


Center Frequency (GHz	Noise Bandwidth (GHz)
163.9	4.071
175.2	1.901
178.3	1.986
181.1	1.908

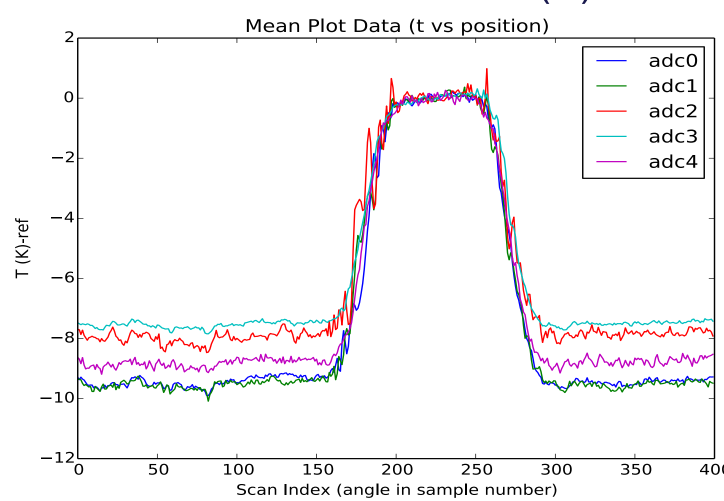
Testing Results: EMI Self-Compatibility Tests



Hot target enclosed in Styrofoam box



Tant – Tref (K)



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Testing Results: End-to-End Receiver Bandpass Responses

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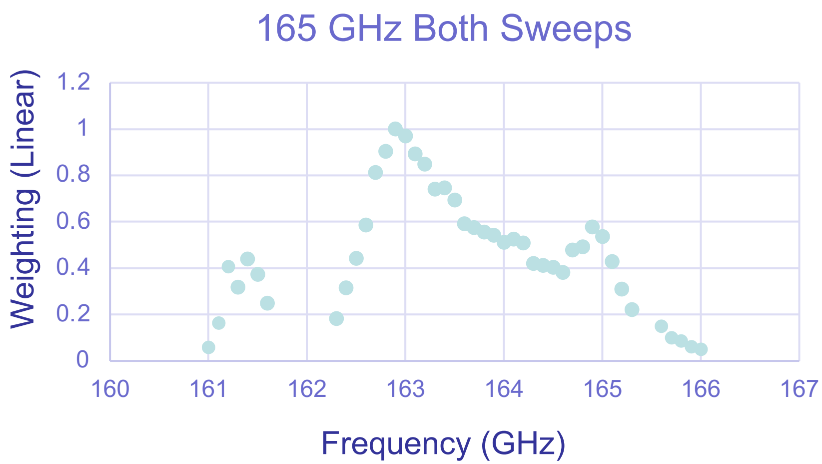

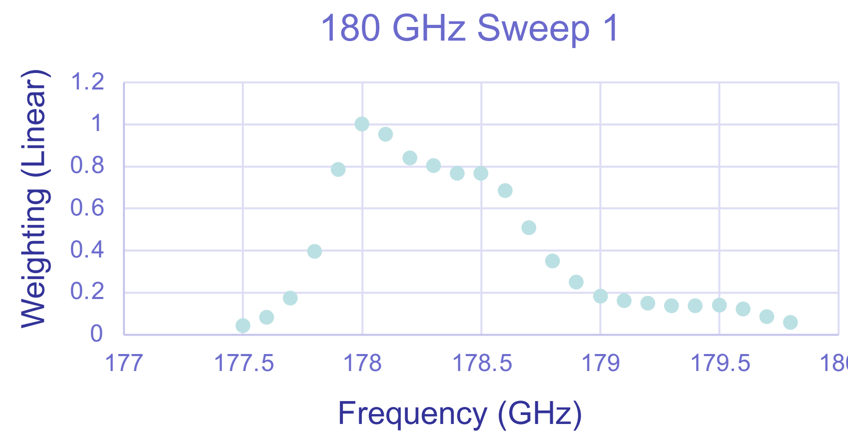

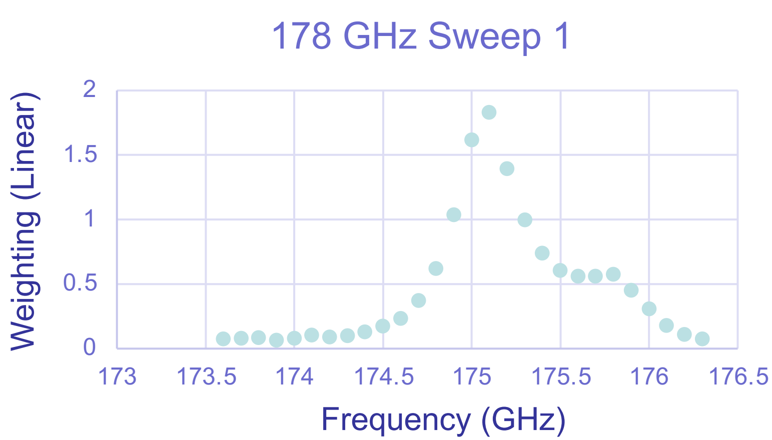

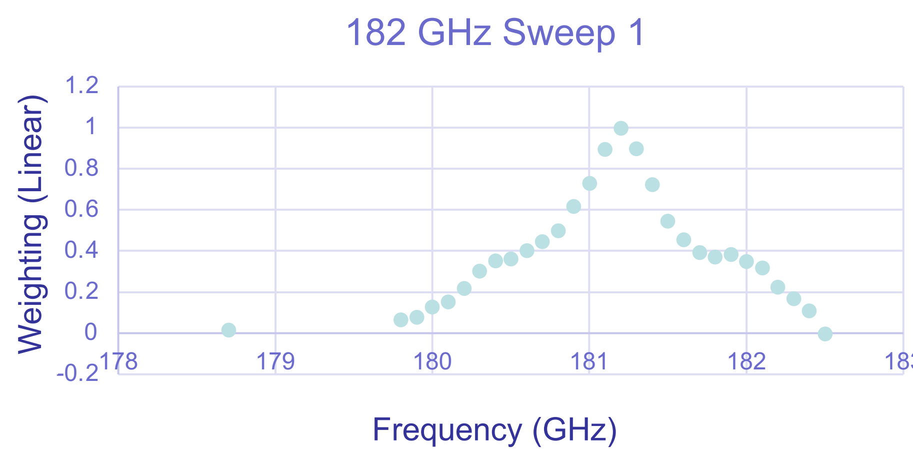

Measured end-to-end receiver bandpass responses will be used as input to validation algorithms.

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Roof Testing for Beam pattern Characterization

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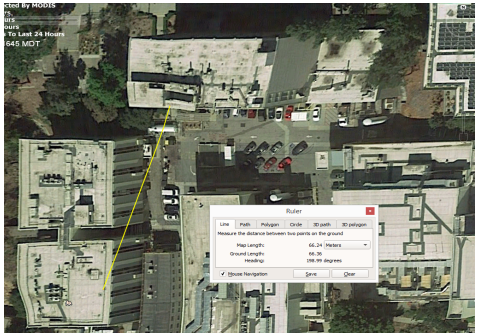
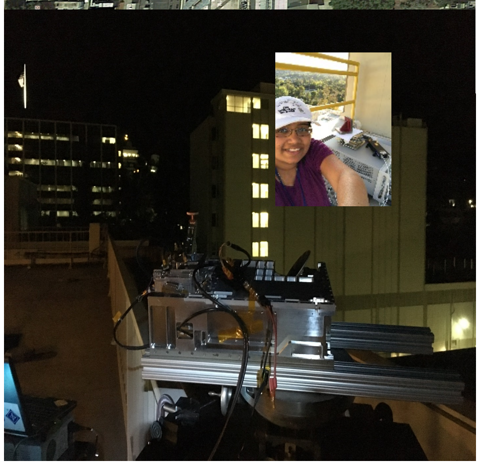
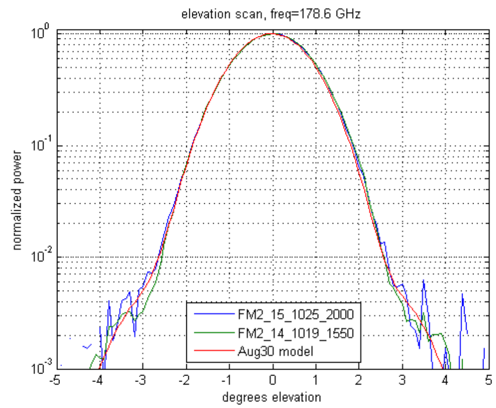
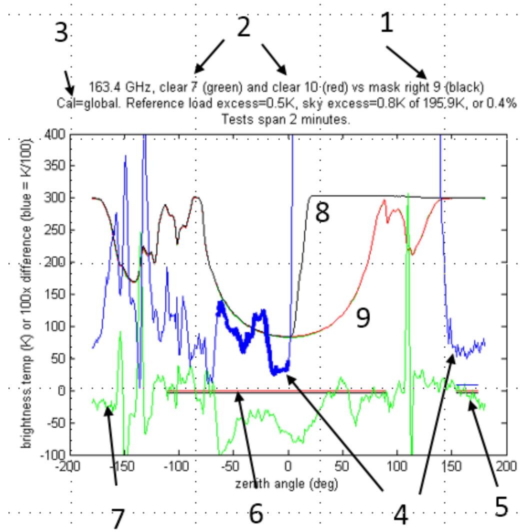
Knowledge to Go Places
Jet Propulsion Laboratory
California Institute of Technology
BCT



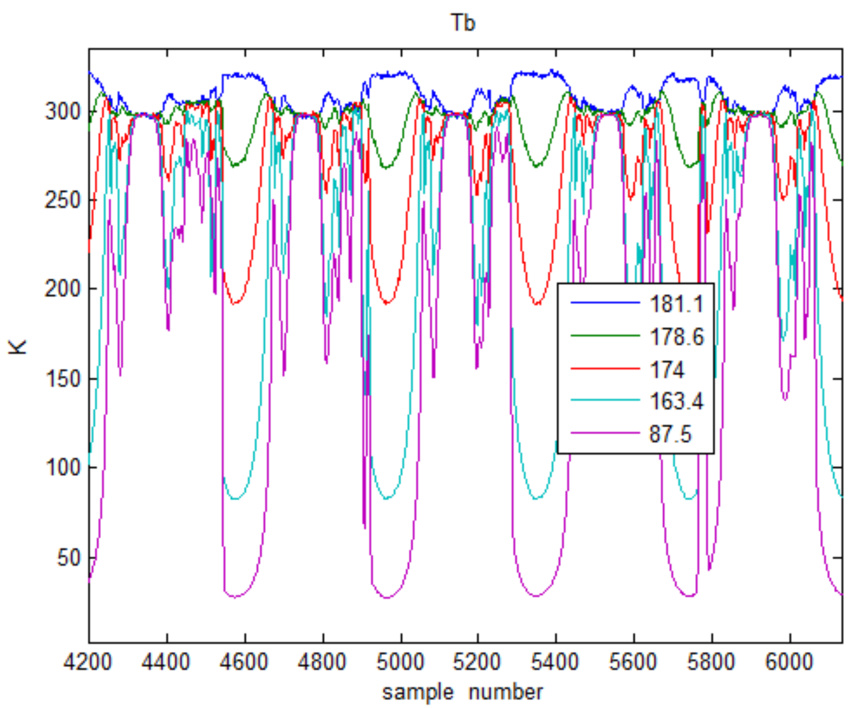


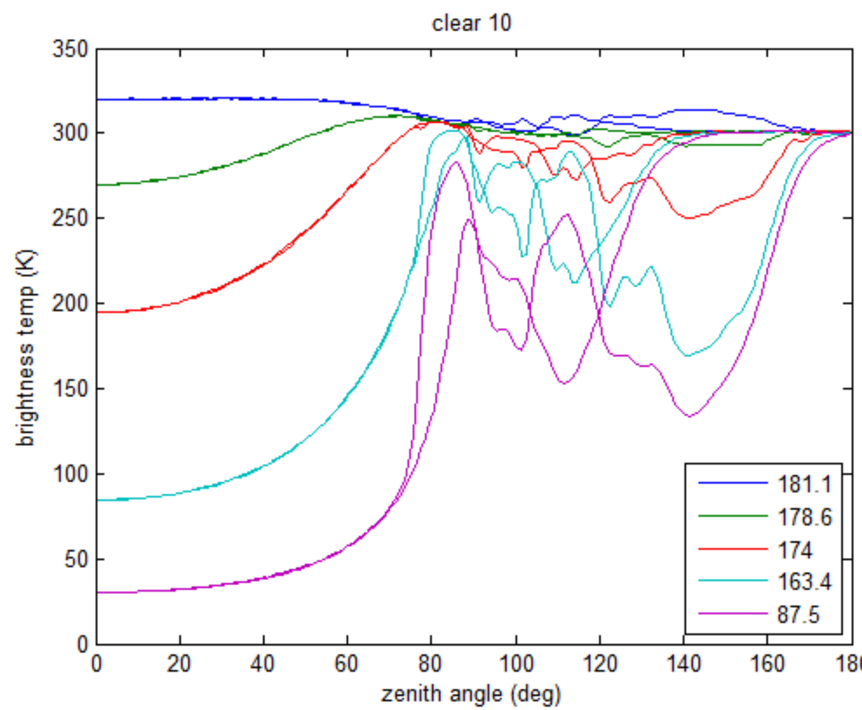




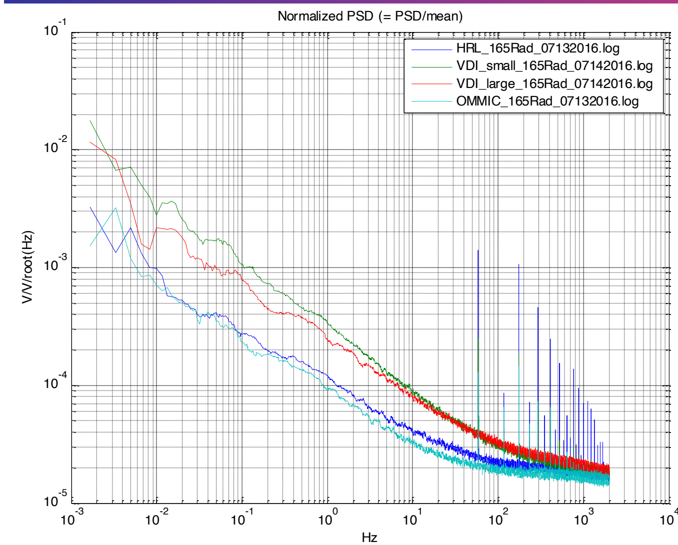
Explanation of composite plots: 1) main test name and sequence number; 2) reference test and number used for comparison (when two tests are listed the average of the two are used as the reference); 3) calibration method (either “global” or “scan/scan referenced”); 4) blue curve is 100 times the difference between test and reference (e.g. 100 K means 1 Kelvin difference), and the heavy blue curve highlights the region where the “sky excess” temperature is evaluated; 5) marks the region where the calibration target occurs; 6) marks the primary observation window (which is notably asymmetric, given the extra field of view to the left, as in Figure 1); 7) the green curve is 100x the difference between the two reference scans, and serves to show in this example that the reference sky background temperatures changed significantly during the tests, as compared with the primary result (blue curve).

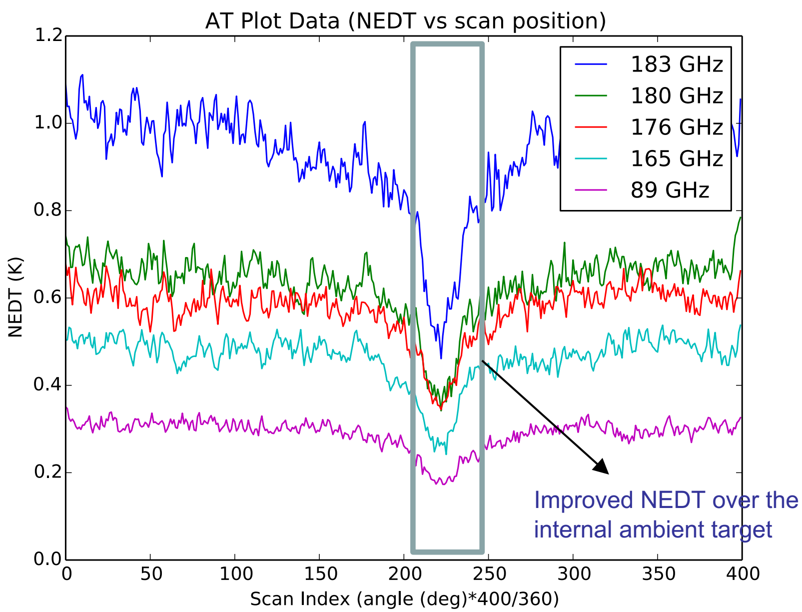
Santa Ana Zenith Scan





Testing Results: Post-EMI Self-Compatibility Tests



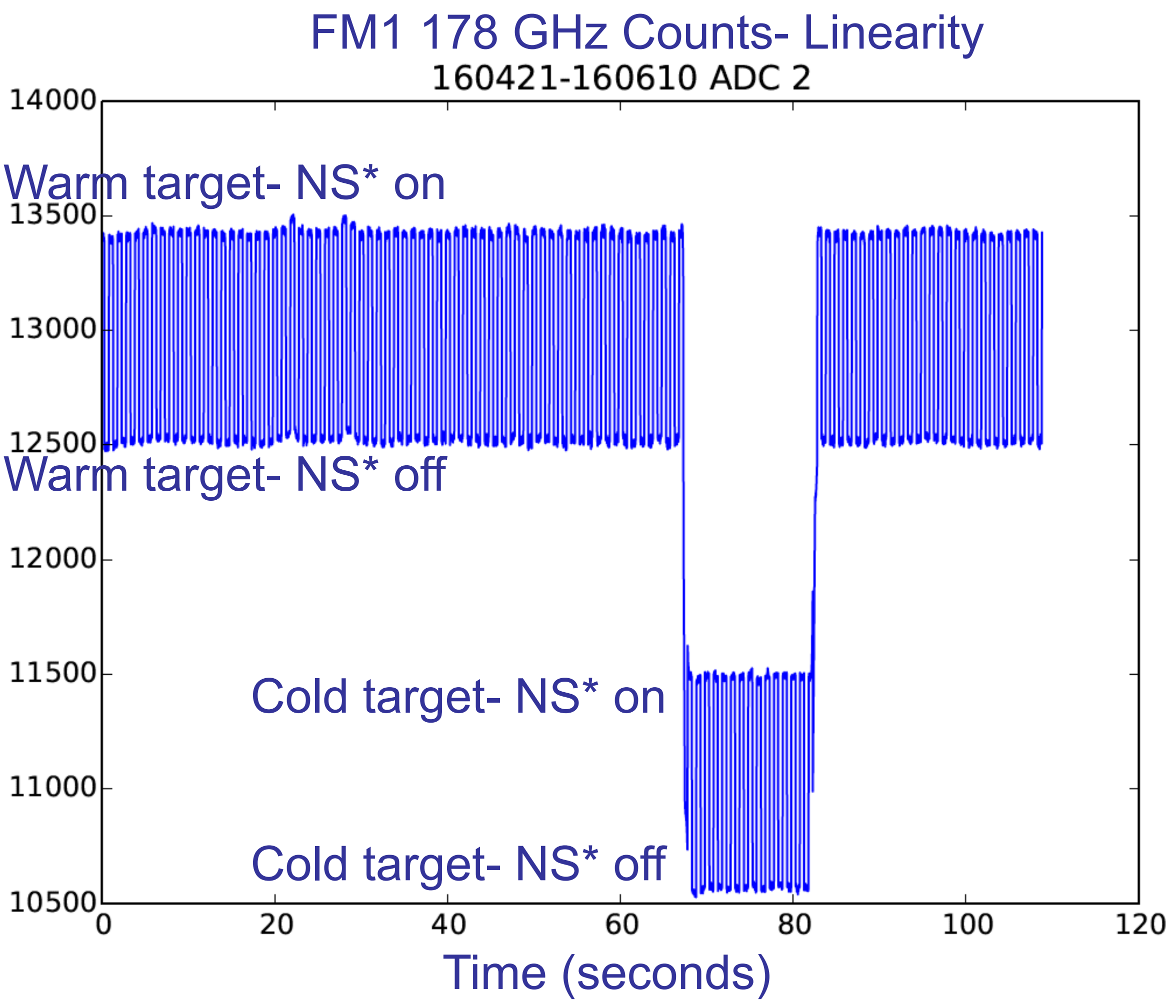


- **Design optimized for best possible 1/f noise by detector selection.**
- **Total noise for 165 GHz = √(0.23K^2 detector + 0.45 K ^2 LNA + 0.2 K ^2 white noise) =0.55 K**
- **For 175 to 181 GHz the LNA 1/f noise is worse, dominates and results in higher over all NEDT as shown in the table below.**

Frequency (GHz)	NEDT (K)	Total Noise Requirement (K)
89	0.3	1.4
164	0.5	1.4
175	0.6	1.4
178	0.7	1.4
181	0.9	1.4

Measured NEDT values meet total noise requirements for all five millimeter-wave radiometer channels.

Testing Results: Linearity of Flight Model and Flight Spare



Flight Model (FM1) QL Results:

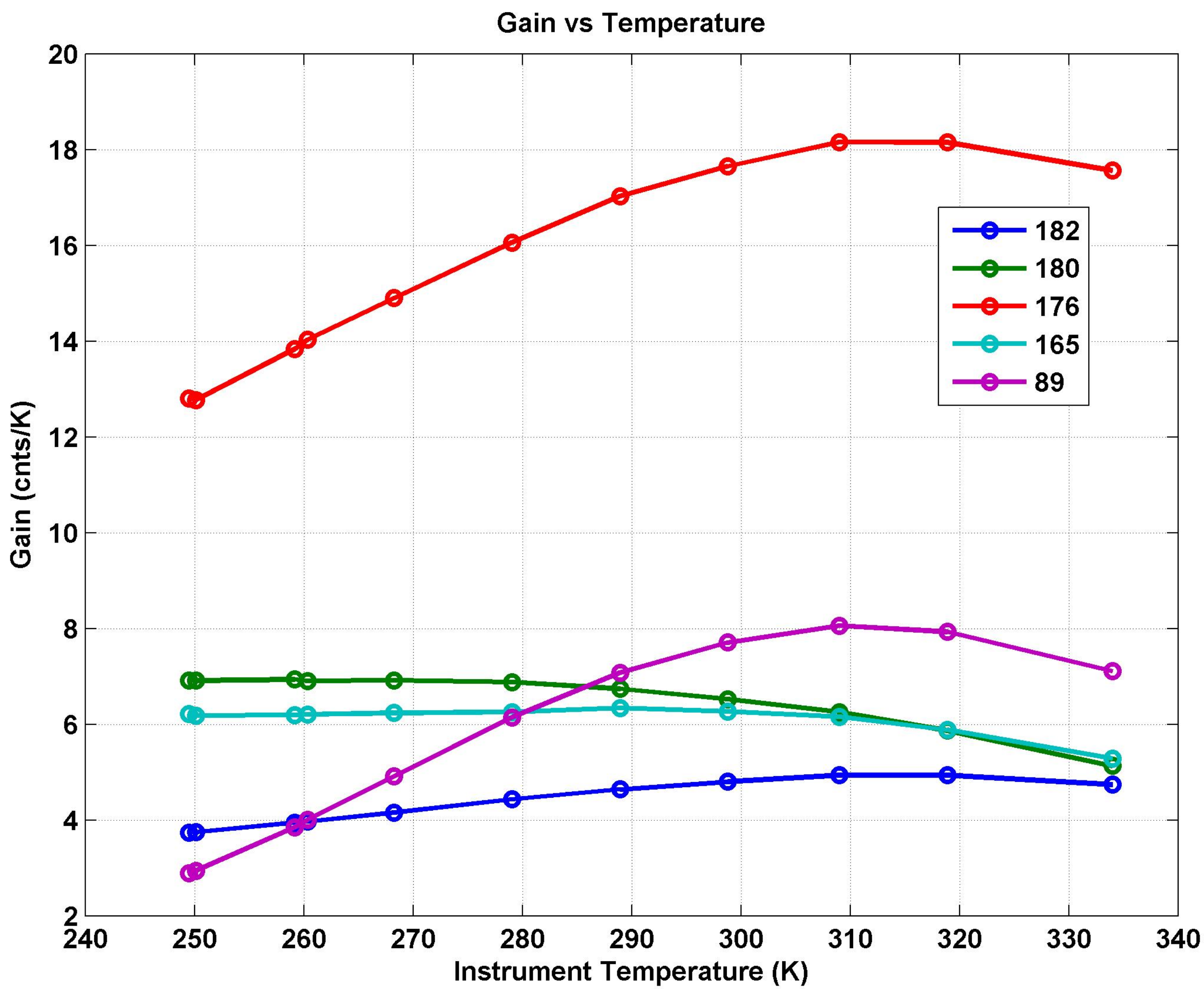
182 GHz max non-linearity = 2.67%
180 GHz max non-linearity = 2.93%
178 GHz max non-linearity = 2.04%
165 GHz max non-linearity = 2.90%

Flight Spare (FM2) QL Results:

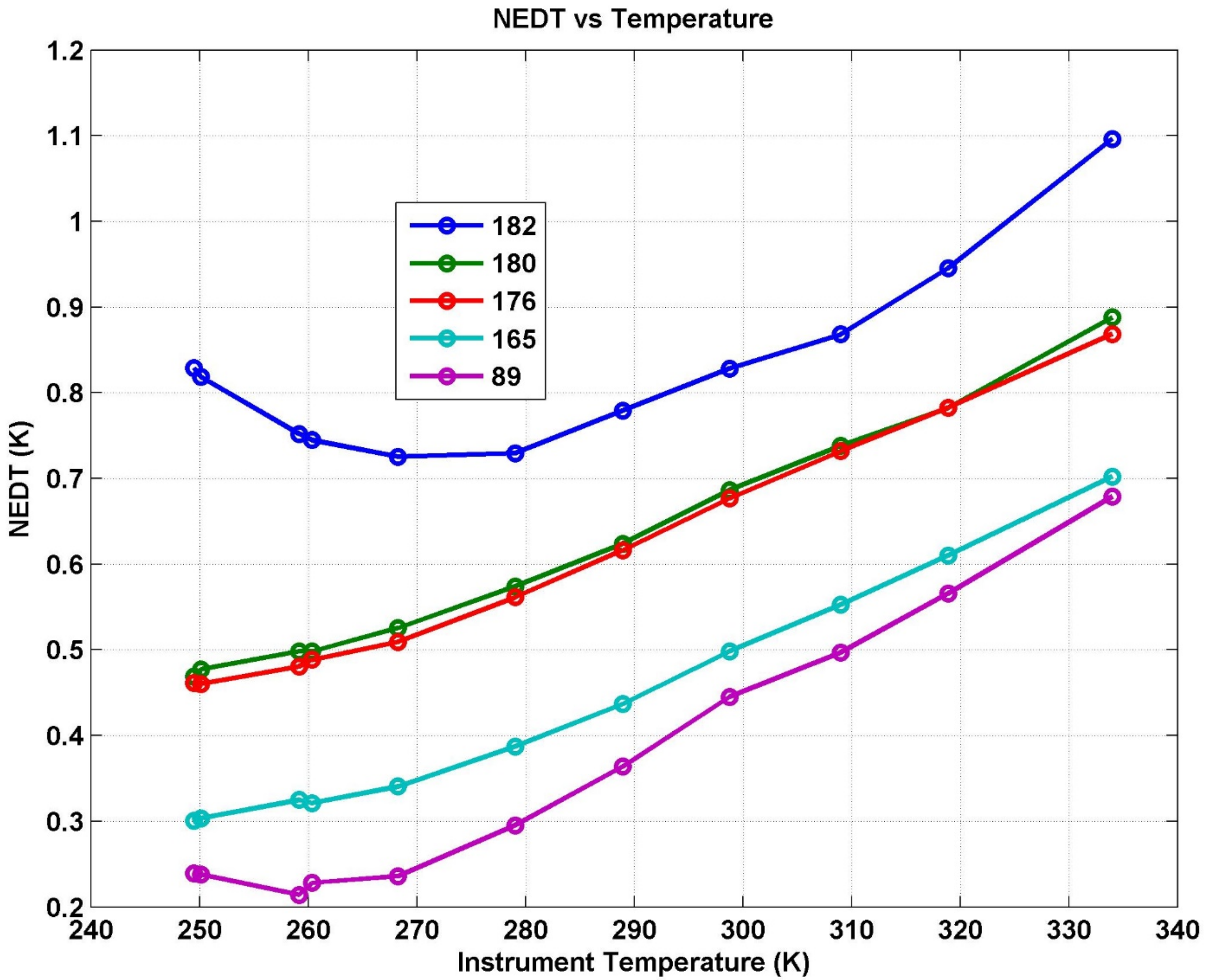
182 GHz max non-linearity = 2.81%
180 GHz max non-linearity = 2.69%
178 GHz max non-linearity = 2.73%
165 GHz max non-linearity = 4.88%

A more complete linearity test was performed, but the results have not yet been analyzed.
*NS = noise source

TVAC Results for FM1: Gain vs. Temperature



TVAC Results for FM1: NEDT vs. Temperature



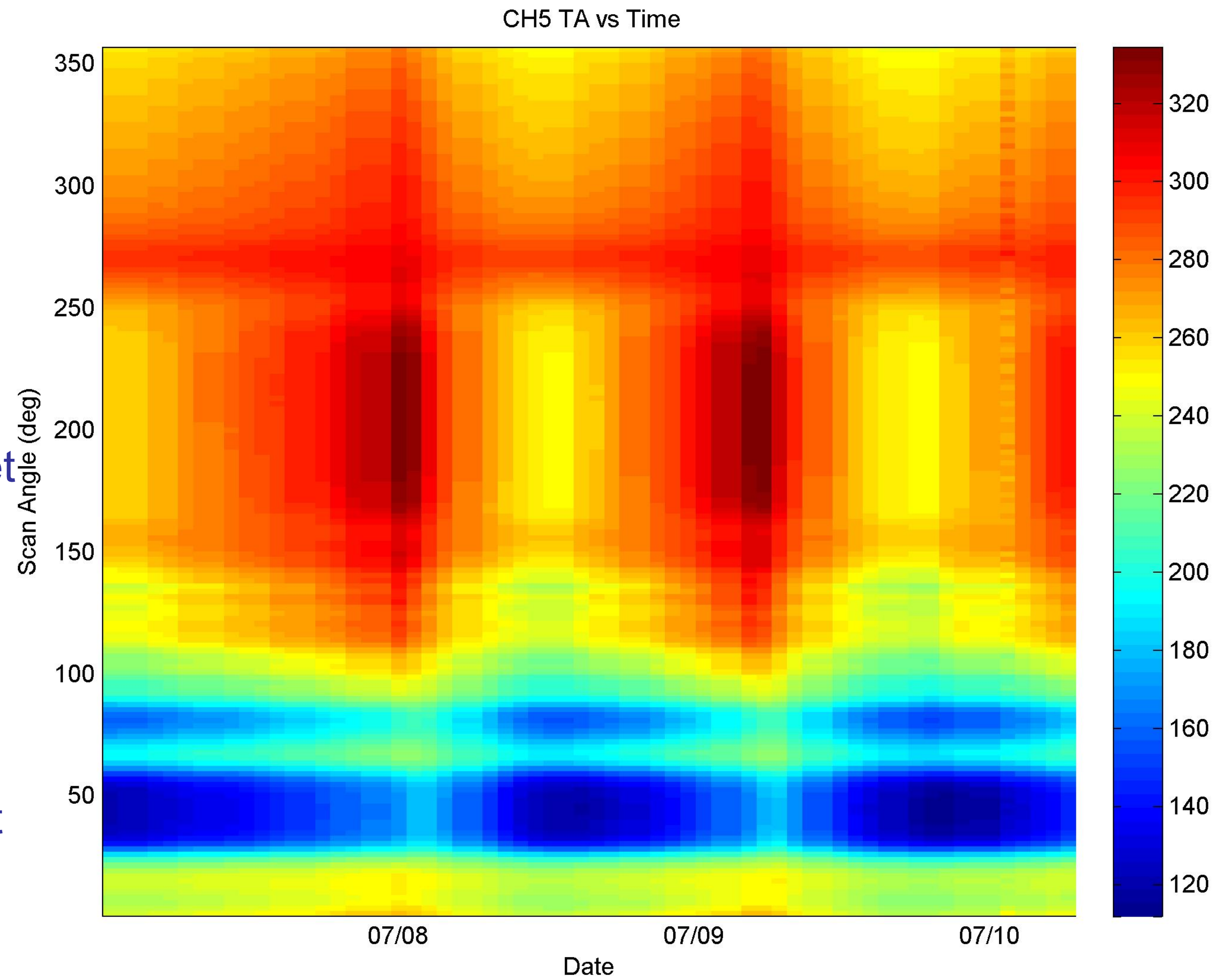
NEDT Measured on cold target, which varies with temperature

TVAC Results for FM1: 89 GHz Chamber Imagery

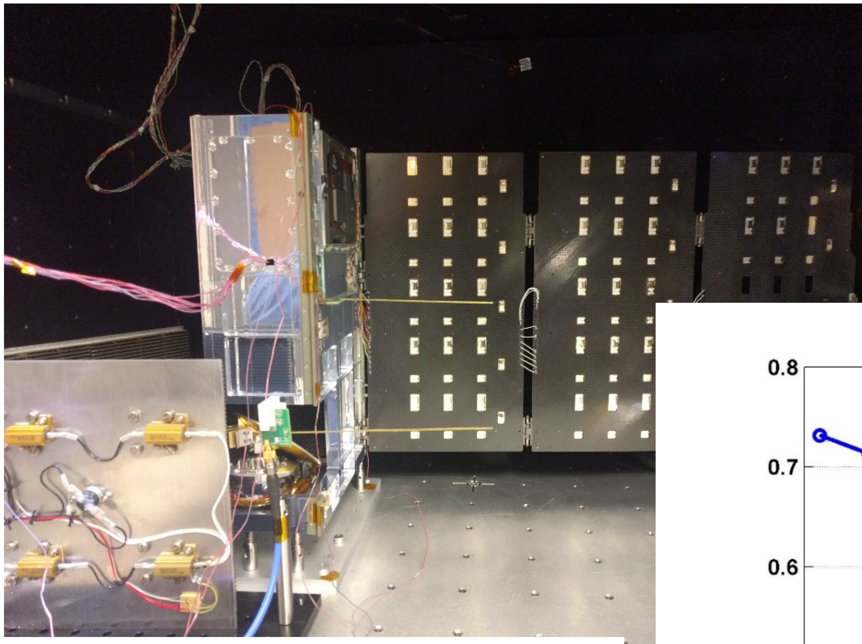
Lid Target

Warm Target

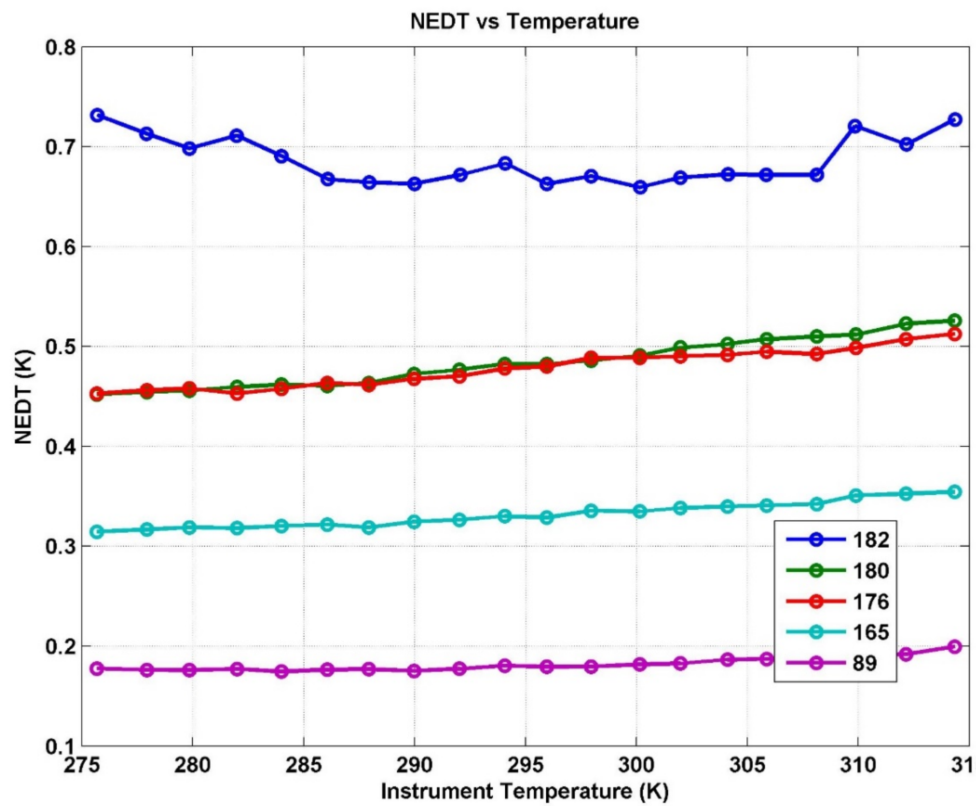
Cold Target

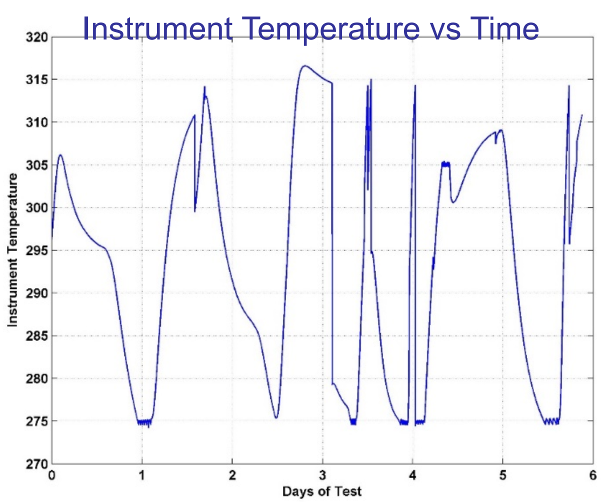


Instrument Performance during S/C Thermal Vacuum Testing (Jan. 2018)



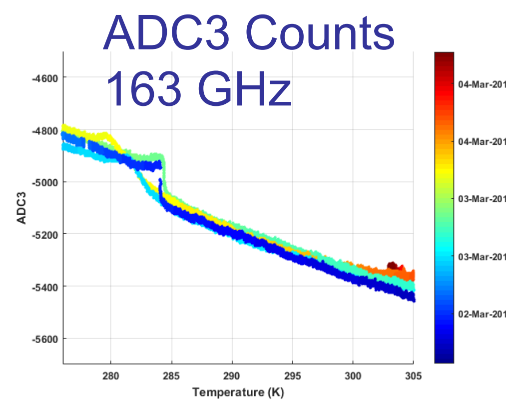
Instrument NeDT Requirement < 1.4 K

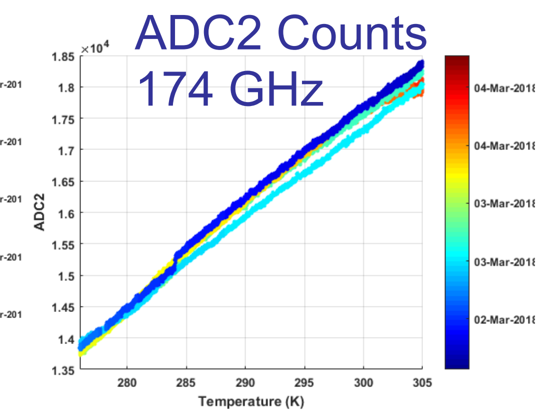




Instrument Anomaly March, 2018

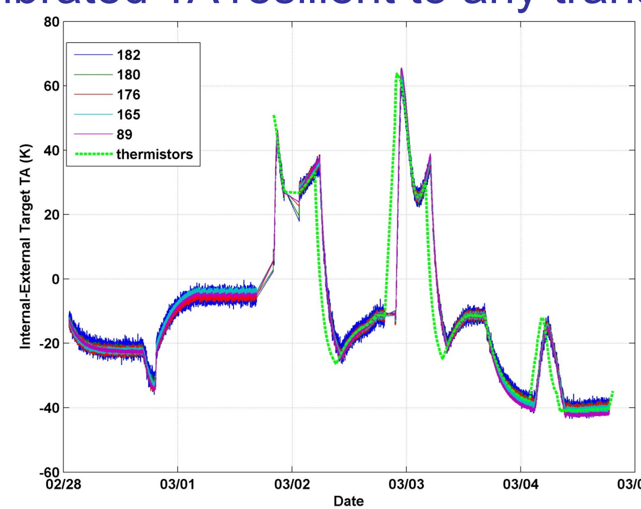
- Gain hysteresis observed in two out of five channels during penalty TVAC test at the S/C level after the Titanium standoff swap out with Aluminum.
- Gain computed during final BCT test when both external and internal targets at plateaus.





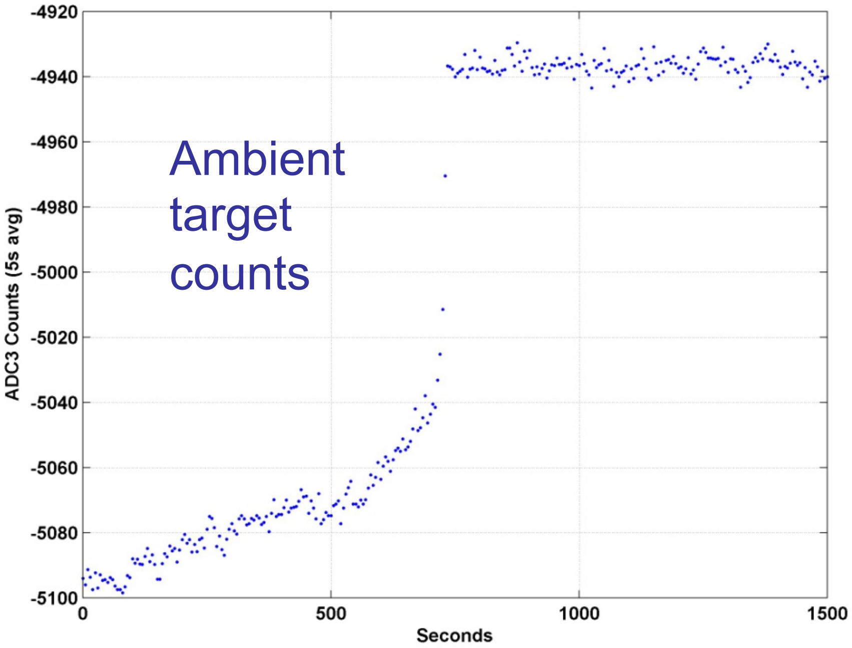
- No change to NEDT
- Gain changes by ~3% (0.1dB) before and after shift, tracked by calibration load for the affected channel.
- Calibrated antenna temperature (TA) computed over test shows that the radiometer external calibration allows us to calibrate out the transition and this has no impact on the calibrated TA.
- No root cause identified, but risk deemed acceptable by PI and PM – see attached package

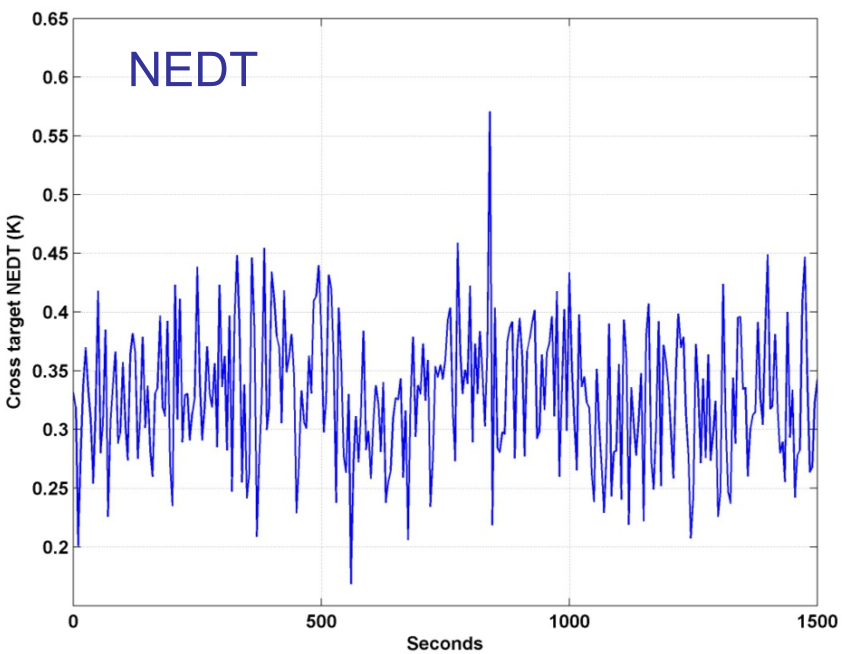
Calibrated TA resilient to any transitions

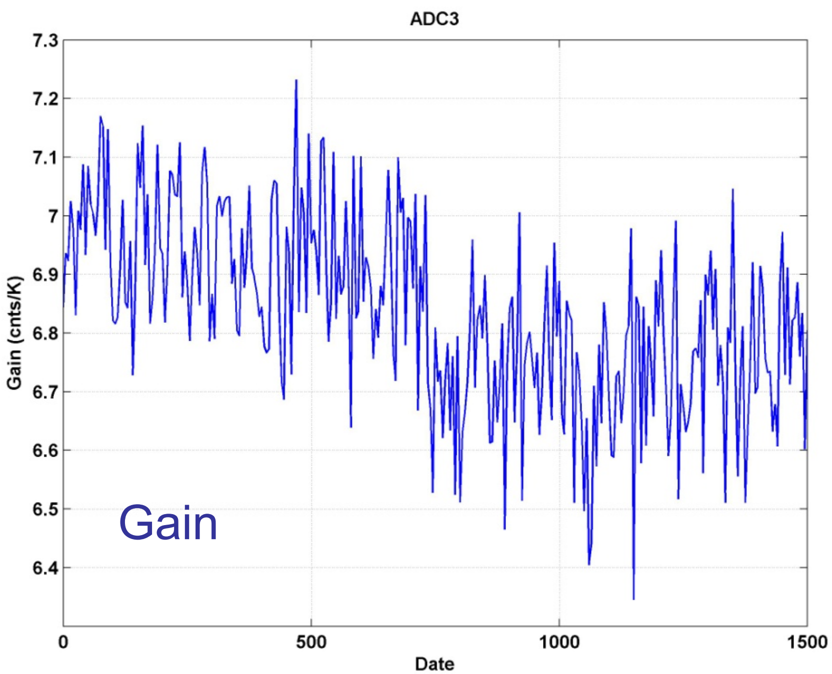


ADC3 Feature

- No change to NEDT
- Gain changes by ~3% (0.1dB) before and after shift, tracked by calibration load

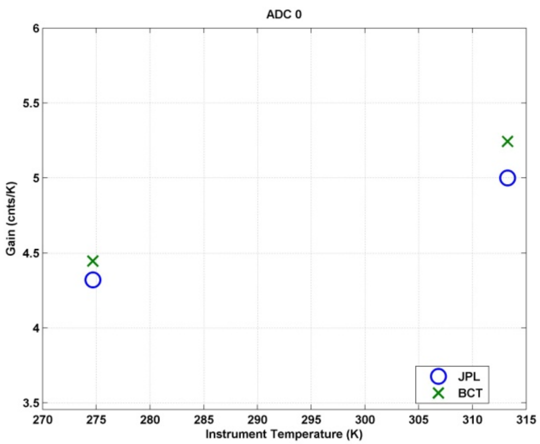


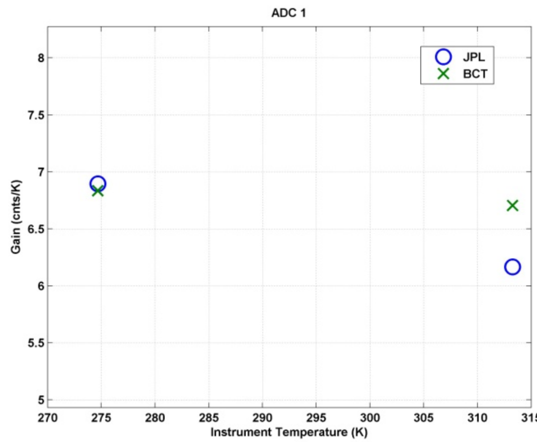


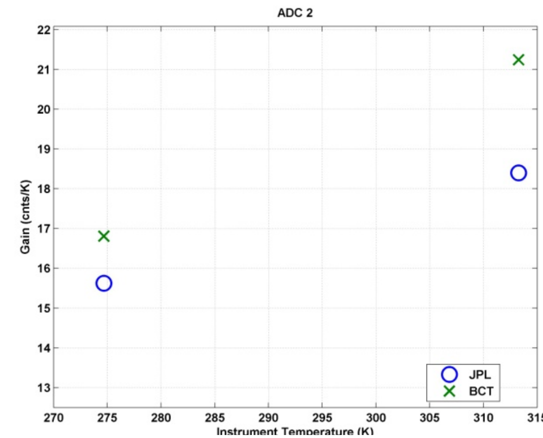


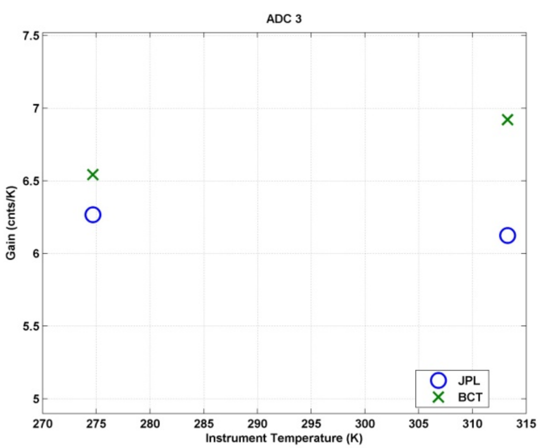
Gain Comparison

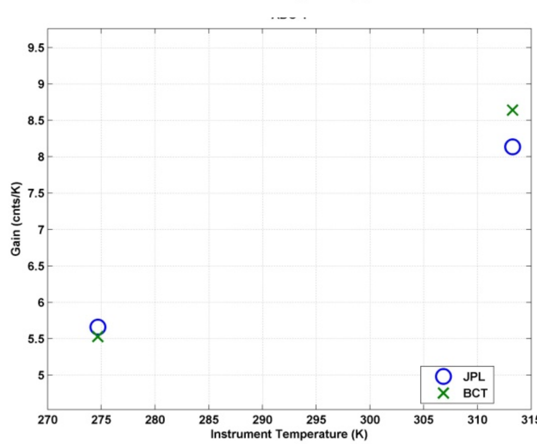
- Gain computed during final BCT test when both external and internal targets at plateaus
- No significant differences in end-to-end gain observed from JPL TVAC test
  - Absolute uncertainty in BCT gain likely at 5% level due to small target temperature difference (20-30K) and 1-2C target temperature knowledge

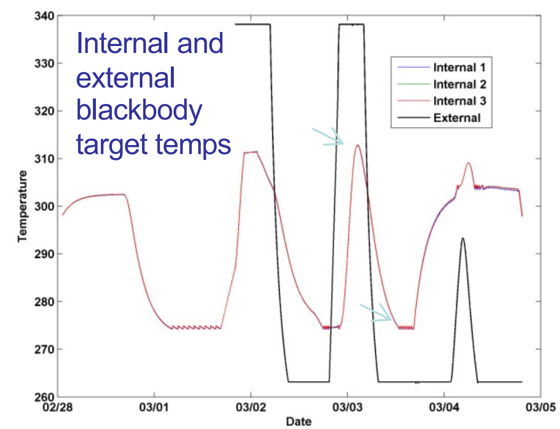




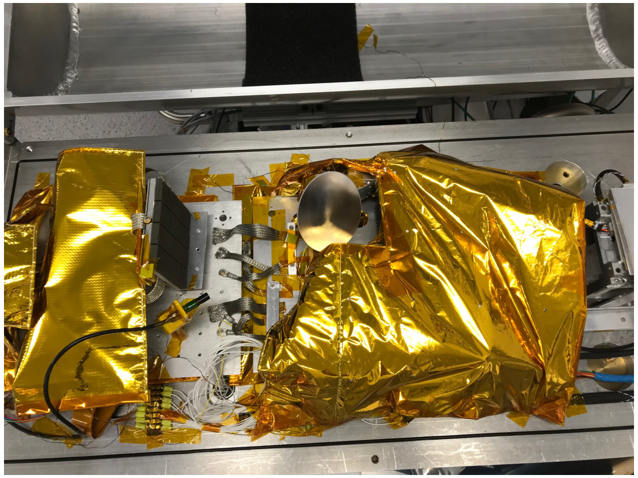






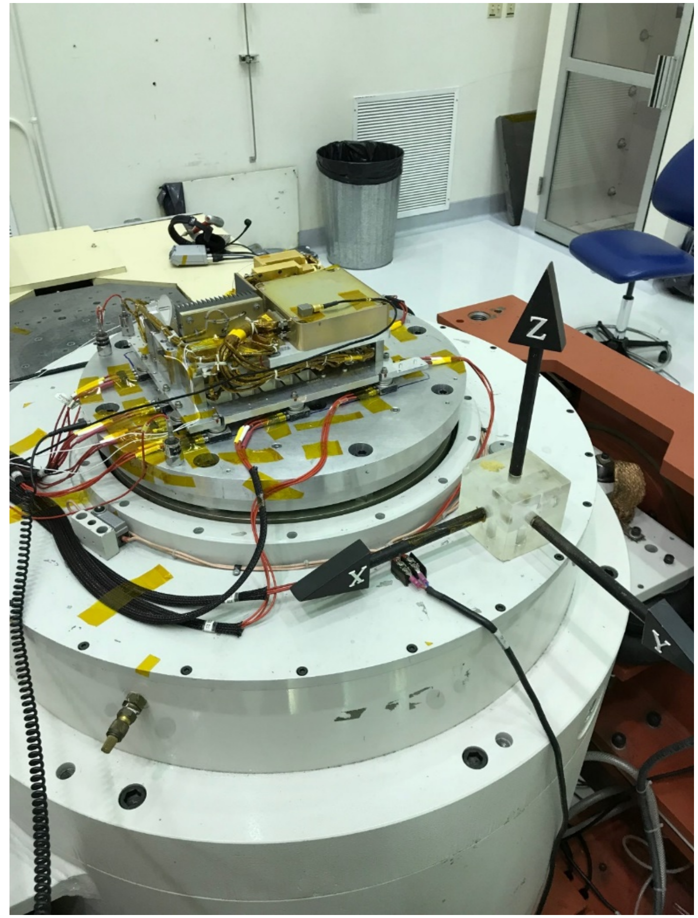


Spare TEMPEST-D Instrument



Spare TEMPEST-D instrument was tested in the thermal vacuum chamber at JPL from -25 ºC to +60 ºC (three ramps).

- **Spare currently at JPL and is undergoing swap out of Ti with Al standoffs.**



Spare TEMPEST-D instrument was vibration tested at JPL in all three axes to NASA GEVS protoflight levels of 10 g-rms for 1 minute each

Technical Resources Summary

Resource	CBE	Allocation	Margin (Actual)
Radiometer Mass (kg)*	3.8	4.0	6.25%
Radiometer Power (W)	6.0	6.5	8%
Radiometer Data Rate (Kbps)**	10.3	12.3	16%
Radiometer Precision (K)	0.4-0.95	1.4	71-32%
Radiometer Accuracy (K)	3.5	4	13%

$$MARGIN = 100 \times \frac{Allocation - CBE}{Allocation}$$

*Change due to titanium standoff replacement with aluminum
**Includes spacecraft state-of-health telemetry

All excess margin can now be released to the spacecraft.

Thank You

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Jet Propulsion Laboratory
California Institute of Technology
BCT