Carbon Nanotube Flat Plate Blackbody Calibrator

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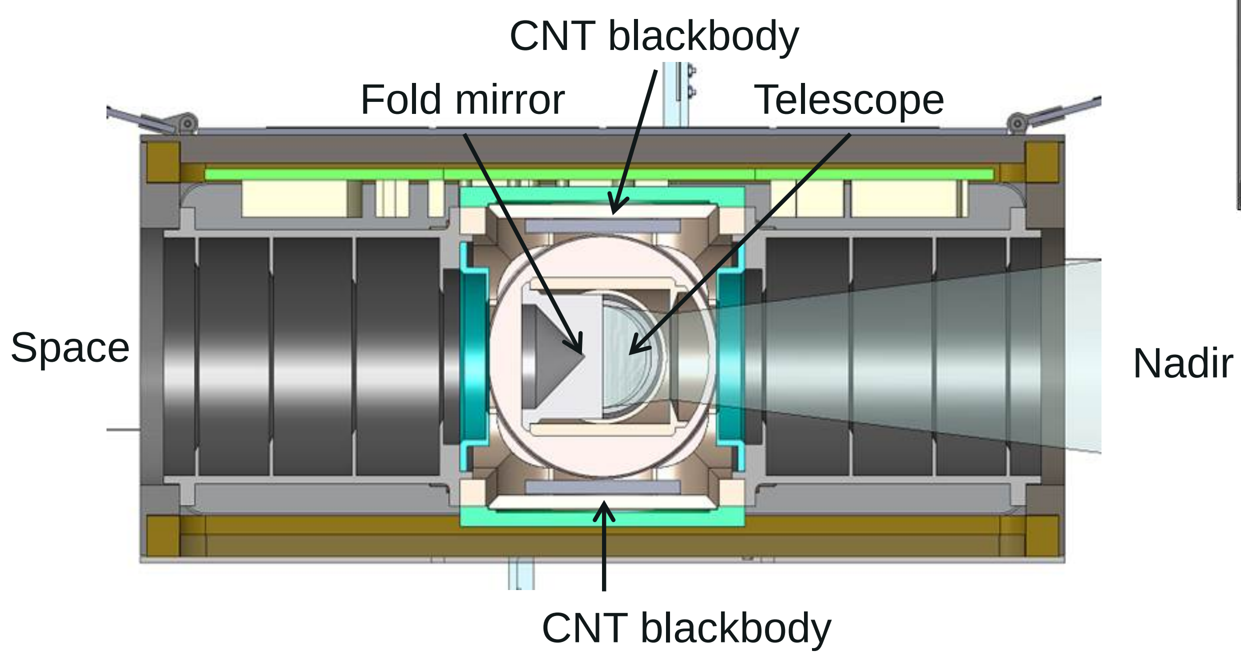
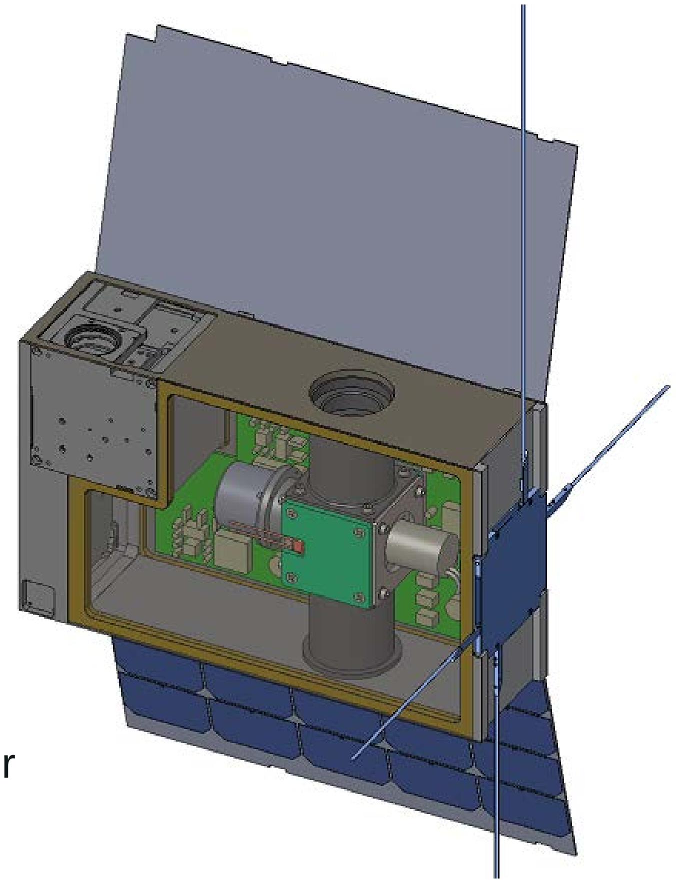
Outline

- InVEST CIRiS project
- Overview of the CNT flat plate blackbody calibrator
- Results
  - Environmental
  - Ambient breadboard tests

Compact Infrared Radiometer in Space (CIRiS) to Validate CNT Blackbody

- ESTO InVEST-15 (In-space Validation of Earth Science Technologies) program to validate microbolometer detector arrays and CNT blackbodies
- BESST (Ball Experimental Sea Surface Temperature) airborne LWIR three channel radiometer modified for a CubeSat
- Program began in January, 2016





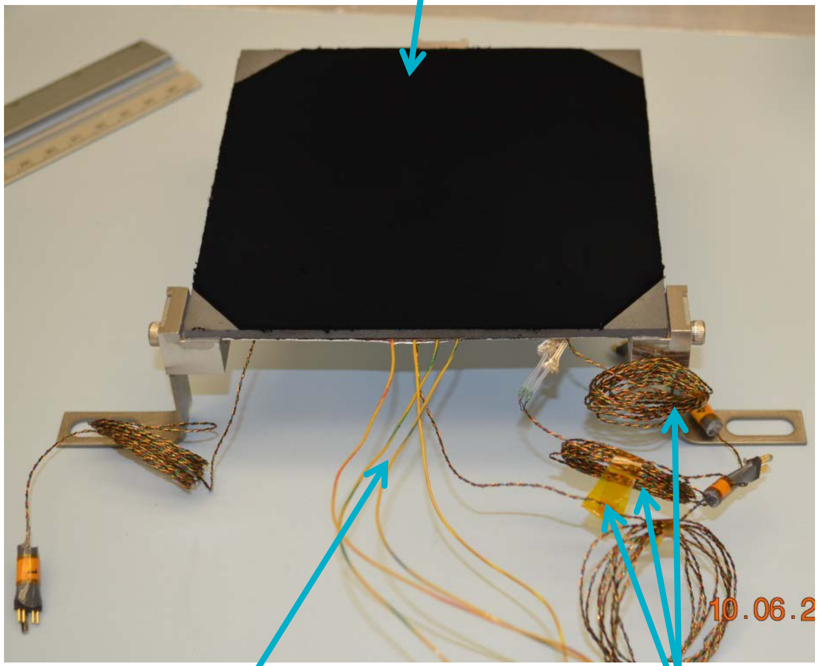
CIRiS Blackbody Based on Laboratory Breadboard

General Requirements for the CIRiS calibrator

Performance Metric	Flat Plate CNT BB Requirements
Spectral Range	9 – 14 µm
Temperature Range	270 – 330 K
Emissivity	>0.995
Weight (kg)	< 1
Time to change temperature	2 K/min (heating)
Time to stabilize	Seconds
Uniformity at 350K	230 mK
Temperature accuracy	200 mK

Breadboard calibrator

Carbon Nanotube surface

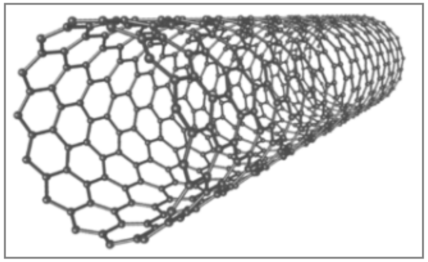


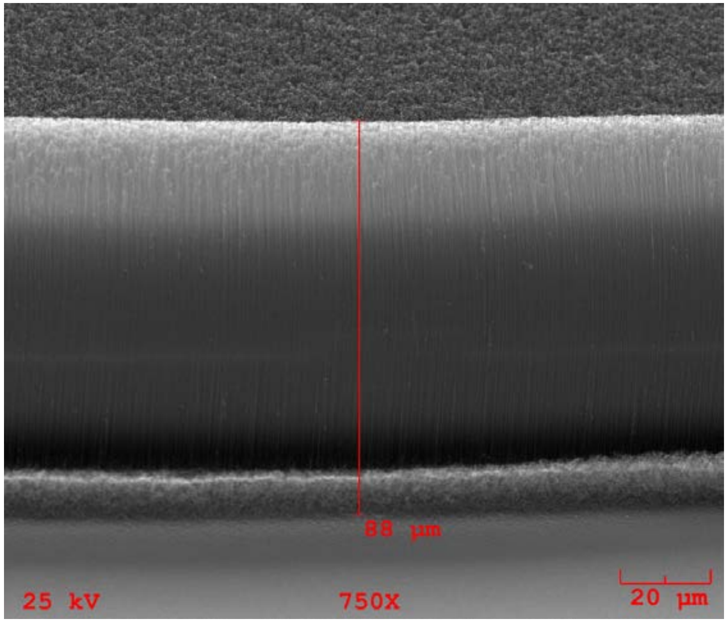
Heater cables

PRT cables

Carbon Nanotubes are Unique from all other Forms of Carbon

- Vertically Aligned Carbon Nanotubes (VACNTs) are hollow cylinders of sp2 bonded carbon
- 10s of nm diameter, 100s of µm length, >10^{10} CNTs/cm2 density



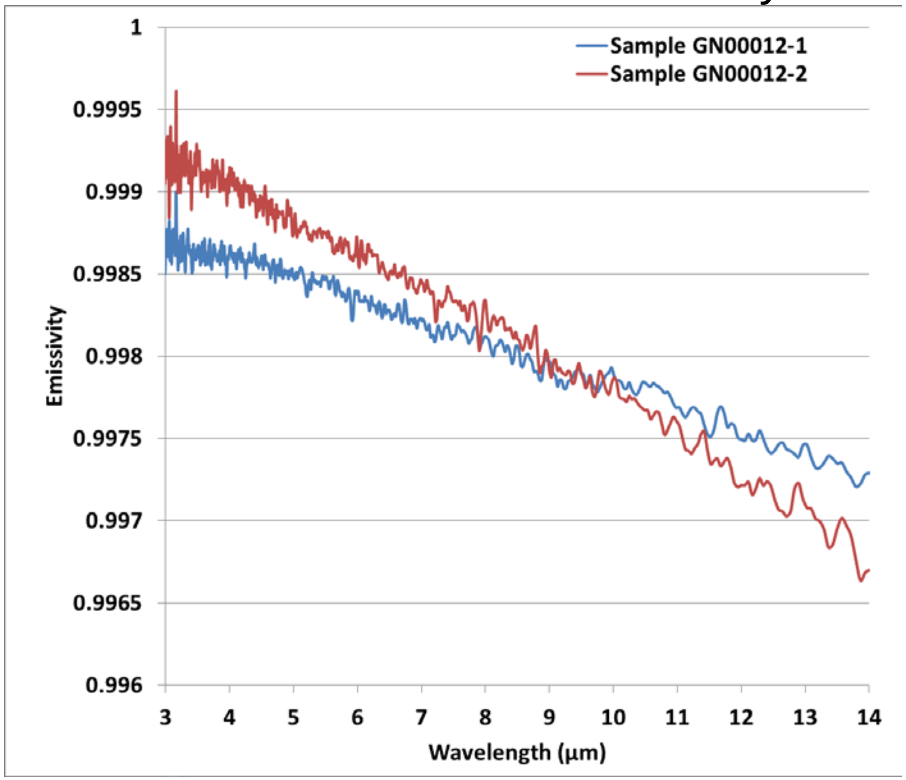


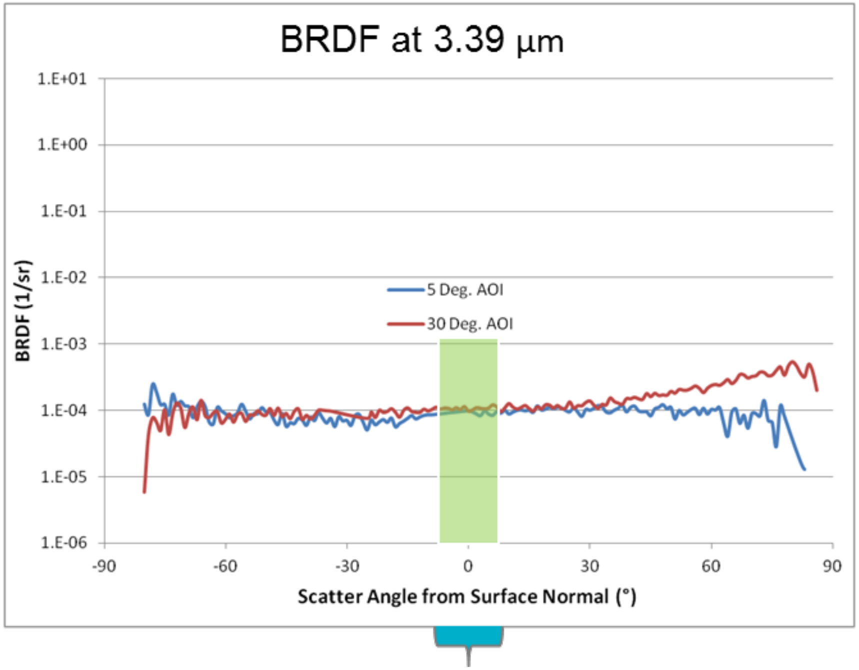
Vertically aligned CNTs (VACNTs)

Optimal Substrate and Growth Parameters Determined

Emissivity of CNT Samples Verified by NIST

- Highly emissive and Lambertian surface in the IR
- NIST measurement uncertainty ±10^{-4}

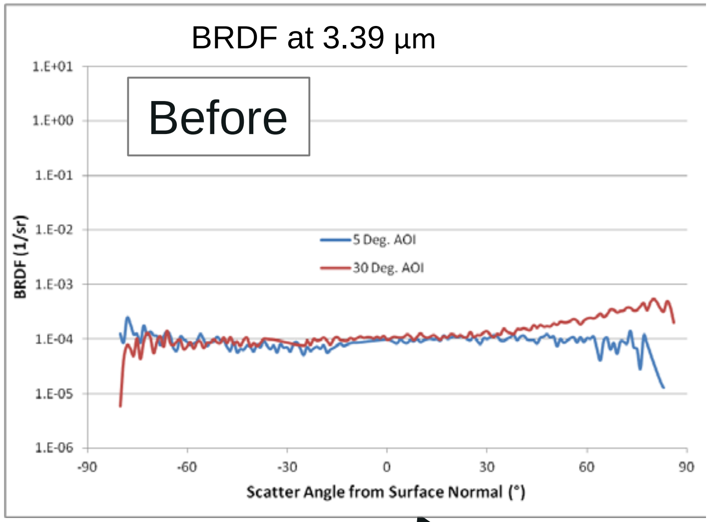


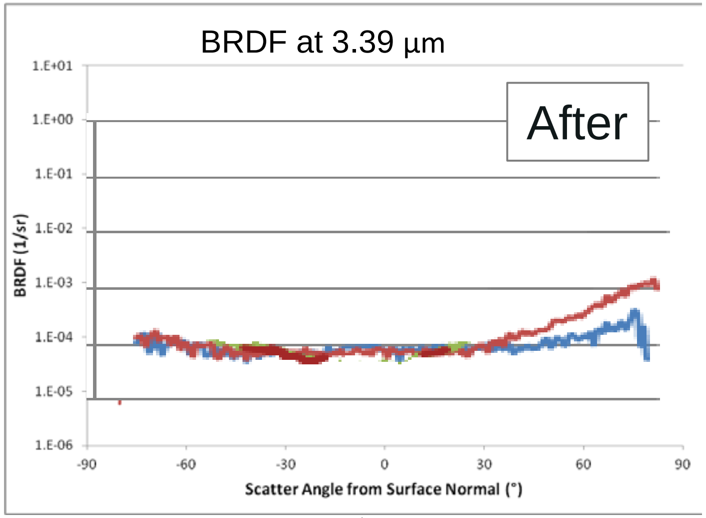


Typical instrument field of view

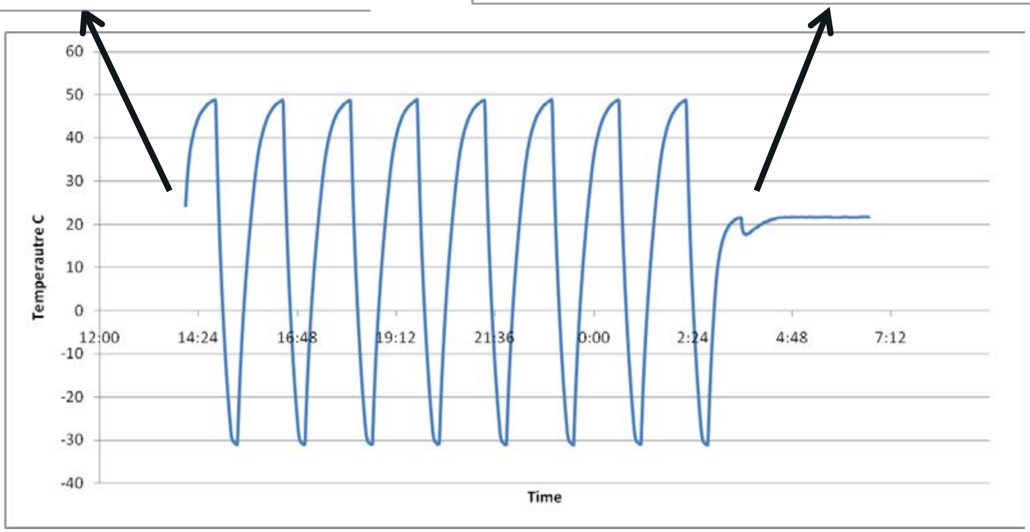
Emissivity and BRDF comparable to cavity blackbodies

No Visual Change or Measurable BRDF change after Thermal Cycling Demonstrates Survivability





BRDF (Bidirectional Reflectance Distribution Function) remained unchanged after thermal cycling (-30 °C to 50 °C)

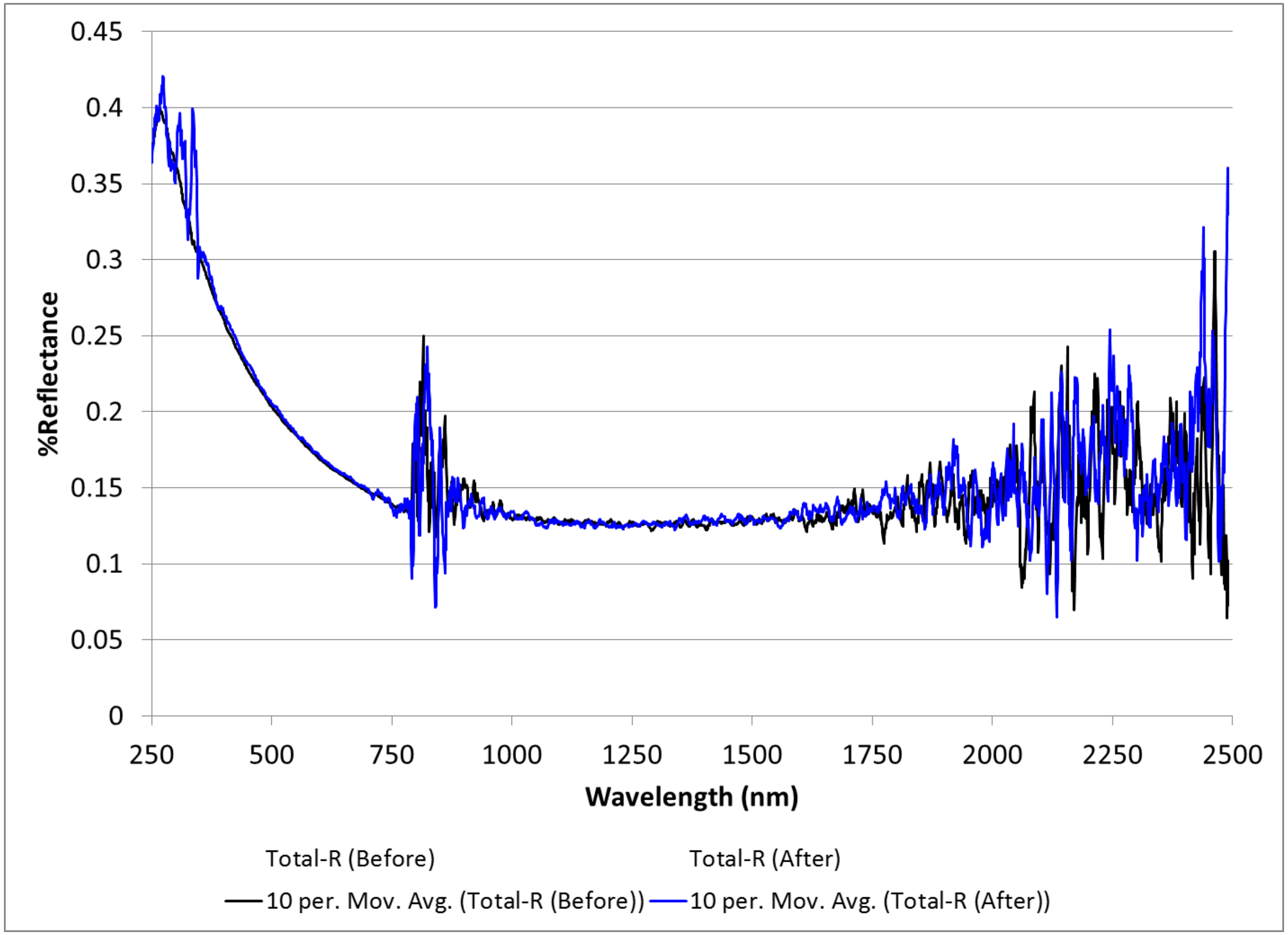


Vibration Testing Shows Almost No Particulates

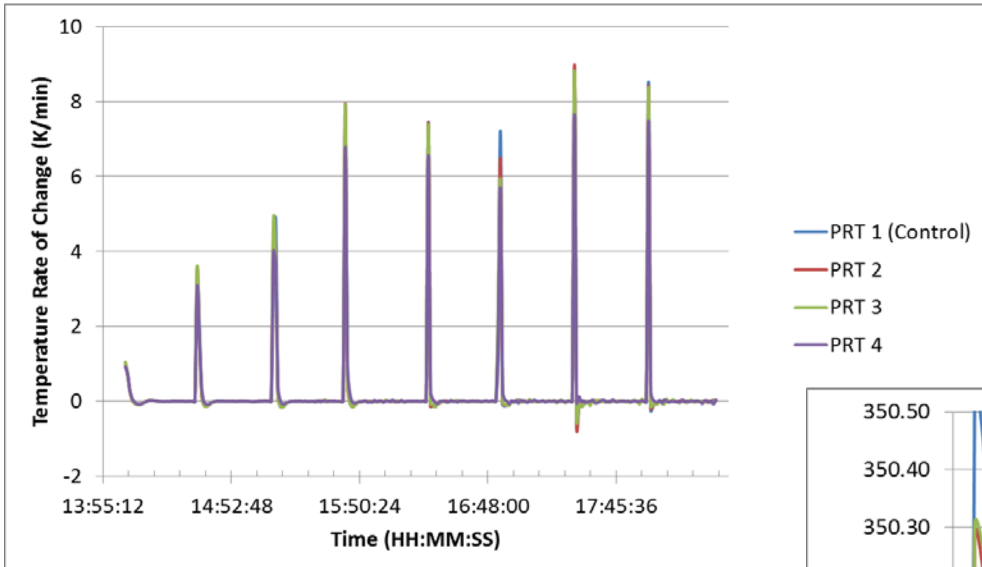
- Results from all CNT vibration tests < Level 300
  - Tested CNTs from multiple vendors
- All particulates found are counted even though they are not all CNTs
- Vibration in 2 axes at 14.1 Grms (GEVS) and 43.8 Grms
- Typical particle counts for Martin Black > Level 300
- Typical particle counts for Ball IR Black (JWST) = Level 300

No Change in Visible Reflectance Due to Radiation Exposure

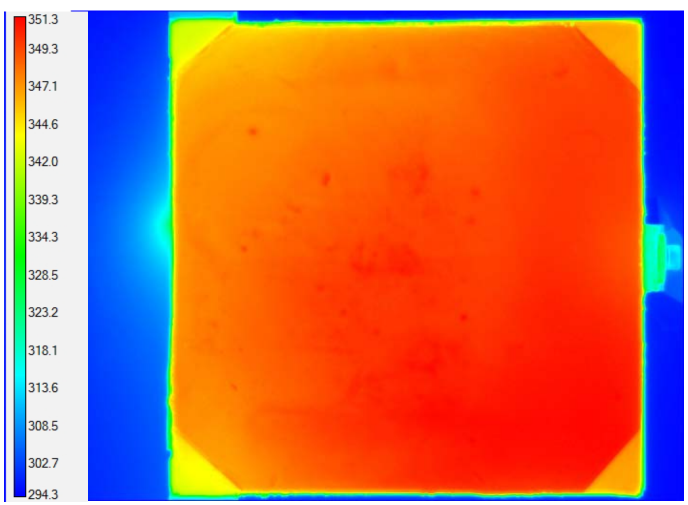
- Exposure equivalent to 5 years in a 700 km sun-synchronous orbit with 5 mils aluminum equivalent shielding

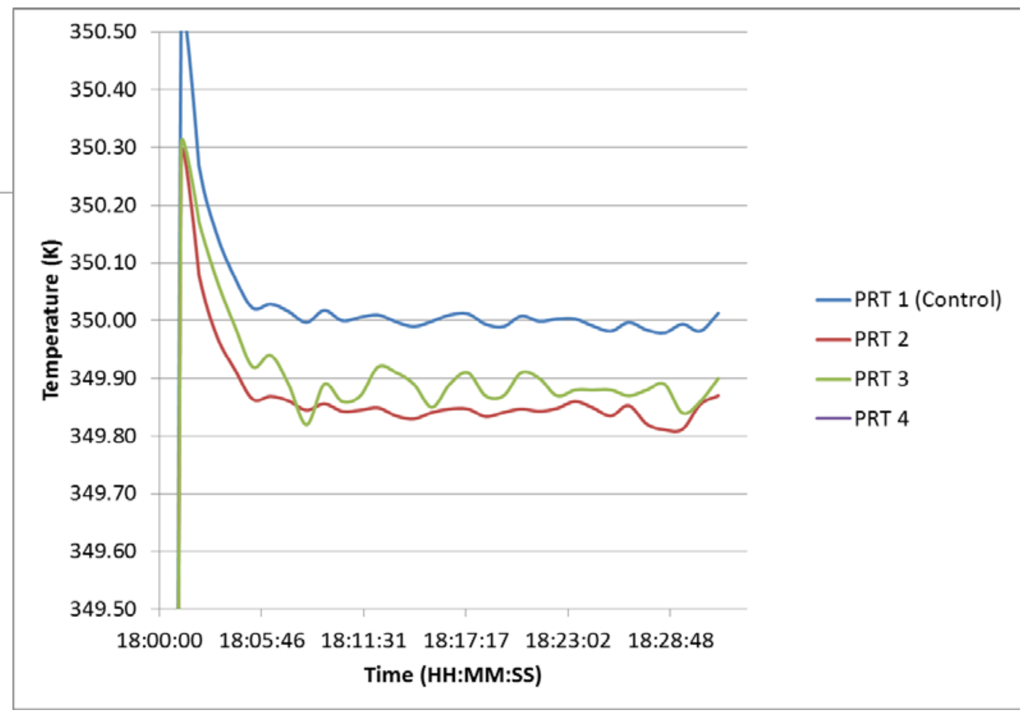


Breadboard CNT Blackbody Tested From 297 K to 350 K in Ambient Laboratory Environment



- Temperature Rate of Change for Heating is > 2 K/min
- 4 minutes to reach stability of 5 mK
- Temperature Uniformity between 3 PRTs is < 200 mK





CNTs Are an Enabling Technology

- CNT blackbodies are highly emissive and Lambertian
- Survive relevant environments (thermal, vibration and radiation)
- Breadboard calibrator performance demonstrated
- Thermal vacuum tests are ongoing
- CNT blackbodies are an integral part of the INVEST CIRiS project

Thanks to a LARGE Cast of Characters

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