The RAVAN ~~CubeSat~~ U-Class Mission: Developing Technologies for Measuring Earth's Climate

William H. Swartz (*JHU/Applied Physics Laboratory*)

Steven R. Lorentz,[2] Philip M. Huang,[1]
Allan W. Smith,[2] David M. Deglau,[1] Shawn X. Liang,[1]
Kathryn M. Marcotte,[1] Edward L. Reynolds,[1]
John Carvo,[3] Lars P. Dyrud,[4] Stergios J. Papadakis,[1]
Dong L. Wu,[5] and Warren J. Wiscombe[5]

[1]*JHU/Applied Physics Laboratory,*
[2]*L-1 Standards and Technology,* [3]Blue Canyon Technologies,
[4]*OmniEarth,* [5]*NASA/Goddard Space Flight Center*

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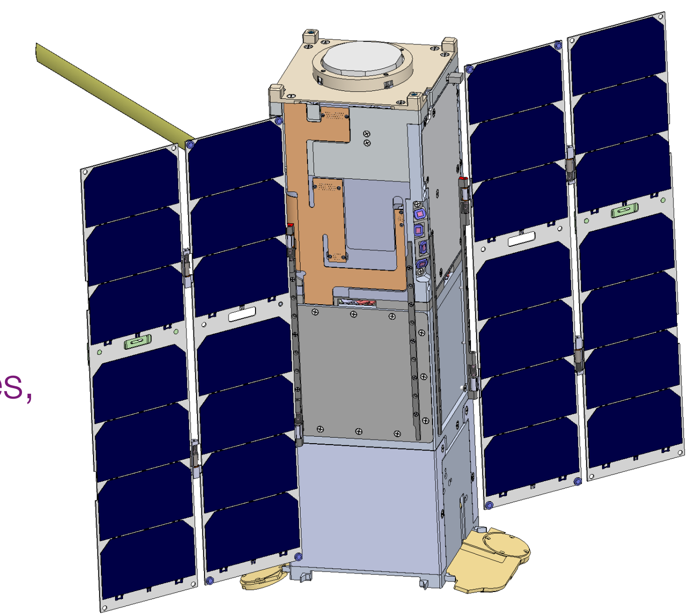
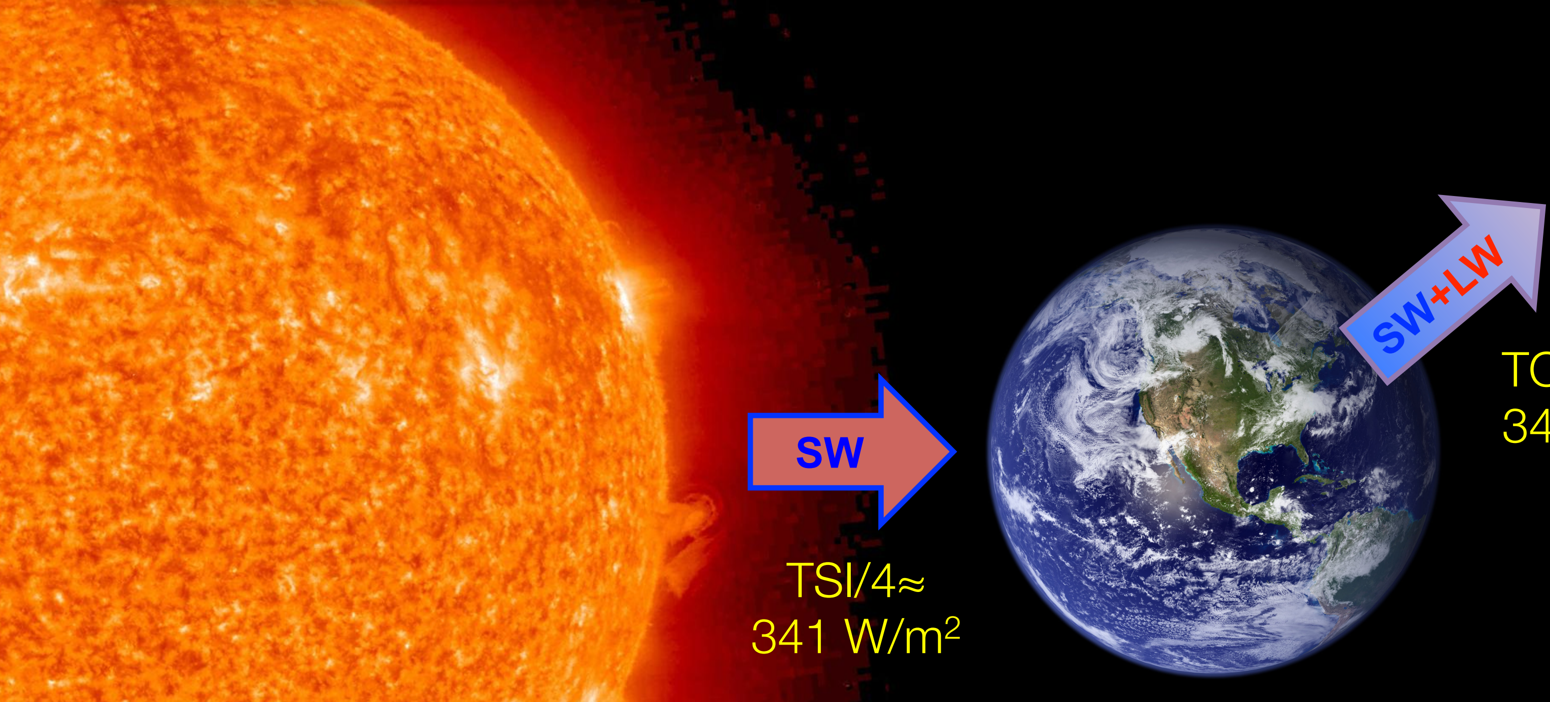


RAVAN payload

BCT XB1

RAVAN
as of June 14, 2016

ERI is most important quantity for climate change

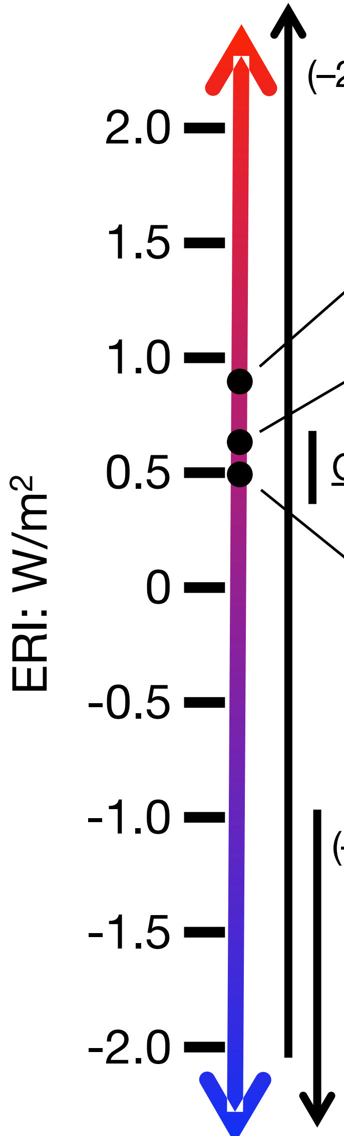


$$\boxed{\text{TSI/4} - \text{TOR} = \textbf{ERI} \approx +1\ \text{W/m}^2}$$

ERI (Earth Radiation Imbalance)

(ERI = Earth Radiation Imbalance)

The problem is the absolute value of ERI



(–2 → +7): Satellite [Loeb et al., 2009]

Climate models [Hansen et al., 2005]; Combination of models and observations [Trenberth et al., 2011]

Climate models [Hansen et al., 2011]

Oceanographers [Trenberth, 2009; Lyman et al., 2010; von Schuckmann et al., 2009]

Satellite [Loeb et al., 2012]

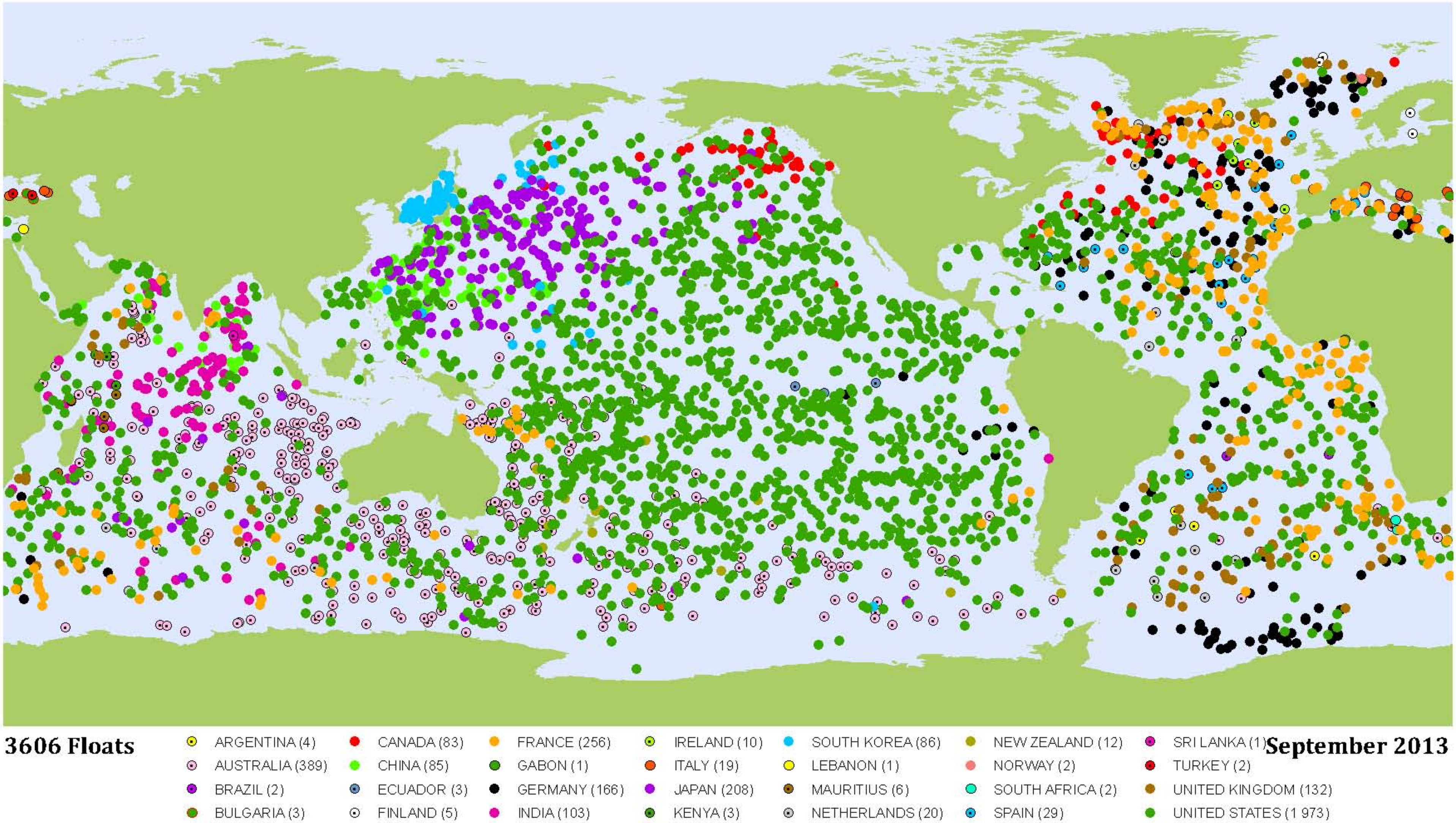
This is a very challenging measurement to make from space.

(–1 → –8): Reanalysis [Trenberth et al., 2011]

Note: Not comprehensive, and not all the same time periods considered.

(OHC = Ocean Heat Content)

Argo network informs our view of OHC

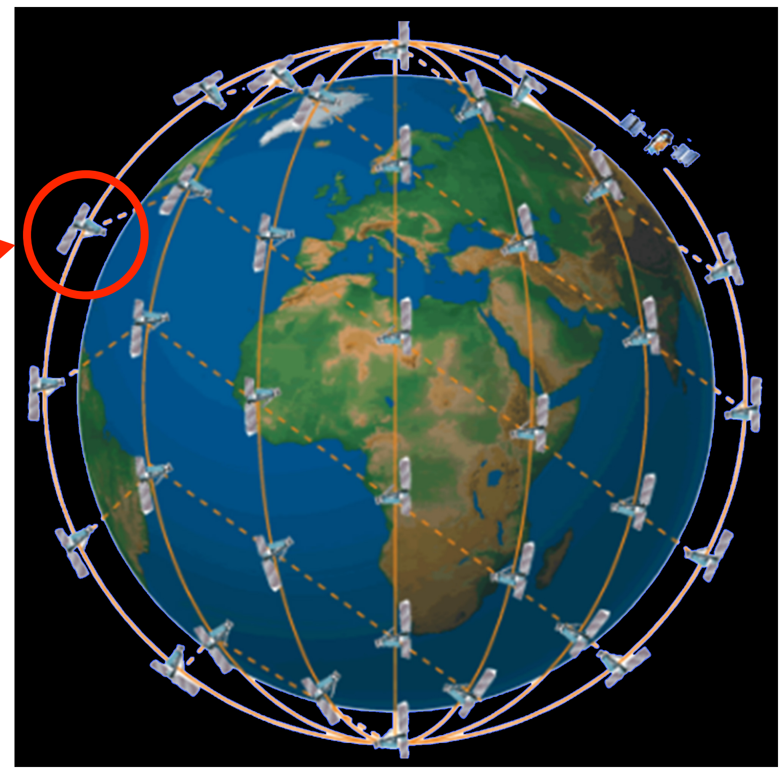


(TOR = Total Outgoing Radiation)

What we need is an "Argo" in space for TOR

- Accurate, un-tuned measurements of TOR
- Global, simultaneous, 24/7 coverage
- Diurnal sampling of rapidly varying phenomena
  - Clouds
  - Plants
  - Ozone/photochemistry
  - Aerosols

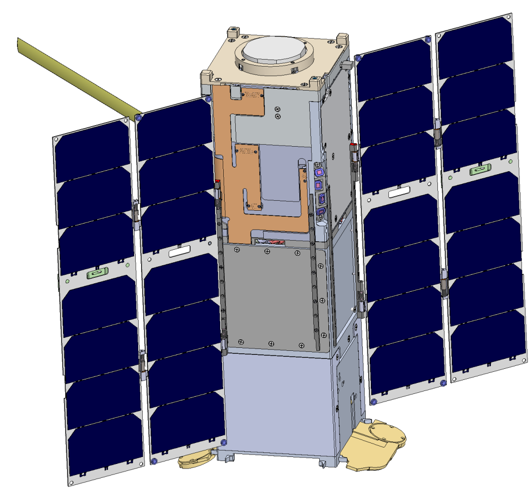
RAVAN



The maturation of smallsat/hosted payload and constellation technology provides an opportunity for taking a big step forward in Earth radiation budget science. **RAVAN is a pathfinder for a future ERB constellation.**

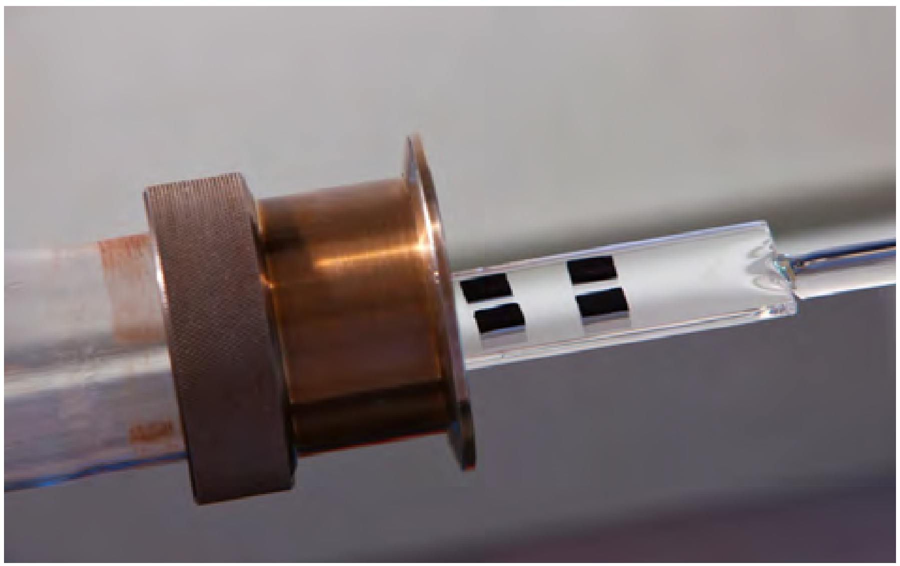
RAVAN is a pathfinder for an ERB constellation

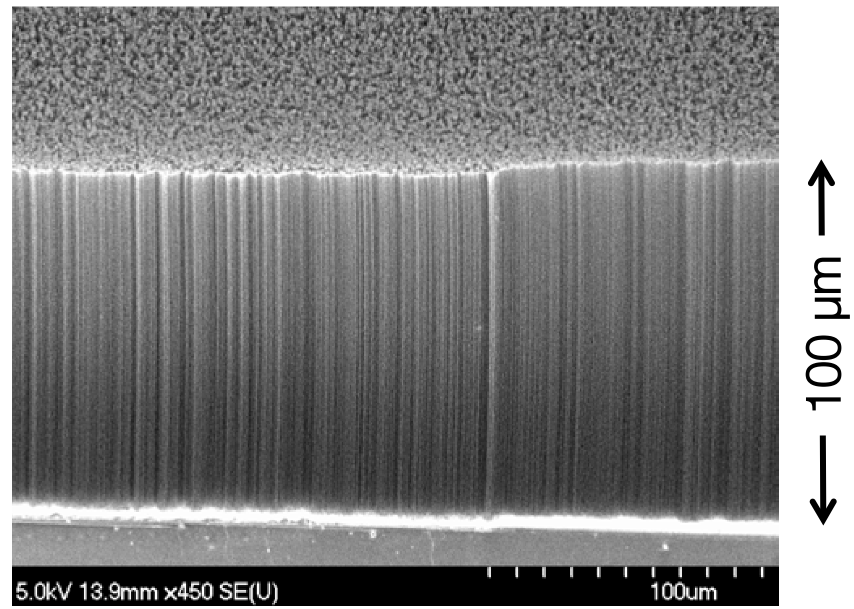
- RAVAN: Radiometer Assessment using Vertically Aligned Nanotubes
- CubeSat (a single CubeSat) mission funded through NASA ESTO's InVEST program
- Combines
  - Compact, low-cost radiometer that is absolutely accurate to NIST-traceable standards (L-1/APL)
  - VACNT radiometer absorber (APL)
  - 3U CubeSat bus (Blue Canyon)
- Launch expected in 2016
- Is a technology demonstration



RAVAN Technology objective #1: VACNTs

- **Demonstrate the use of a vertically aligned carbon nanotube (VACNT) absorber** within a radiometer for high-accuracy on-orbit measurements

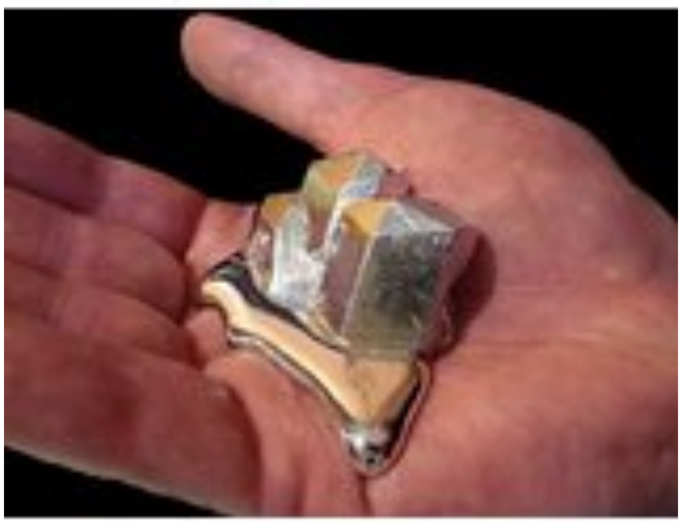


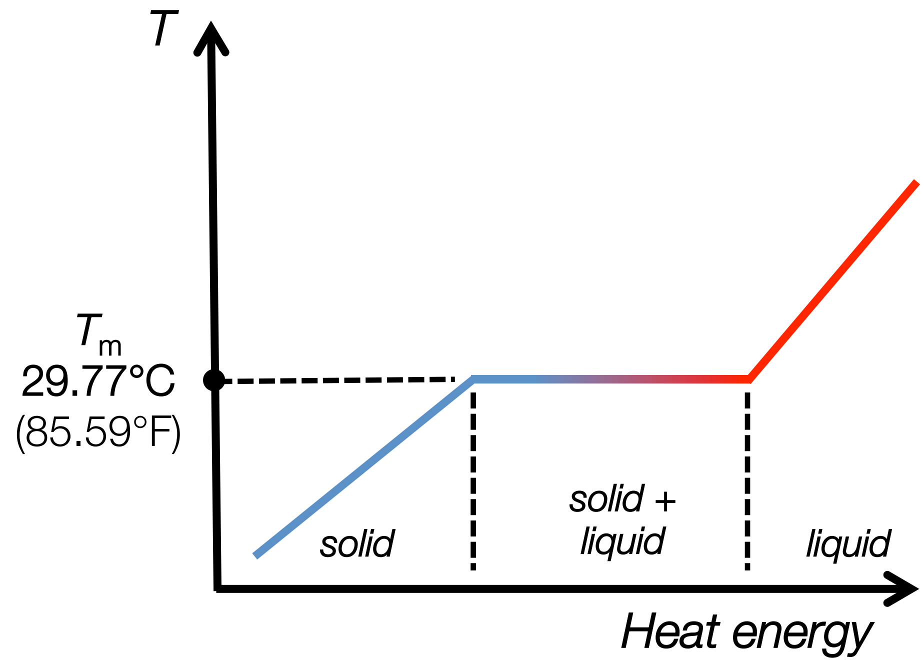


  - Very black, and spectrally flat from UV to far-IR
  - Fast response time
  - Very low mass

Technology objective #2: Gallium black body

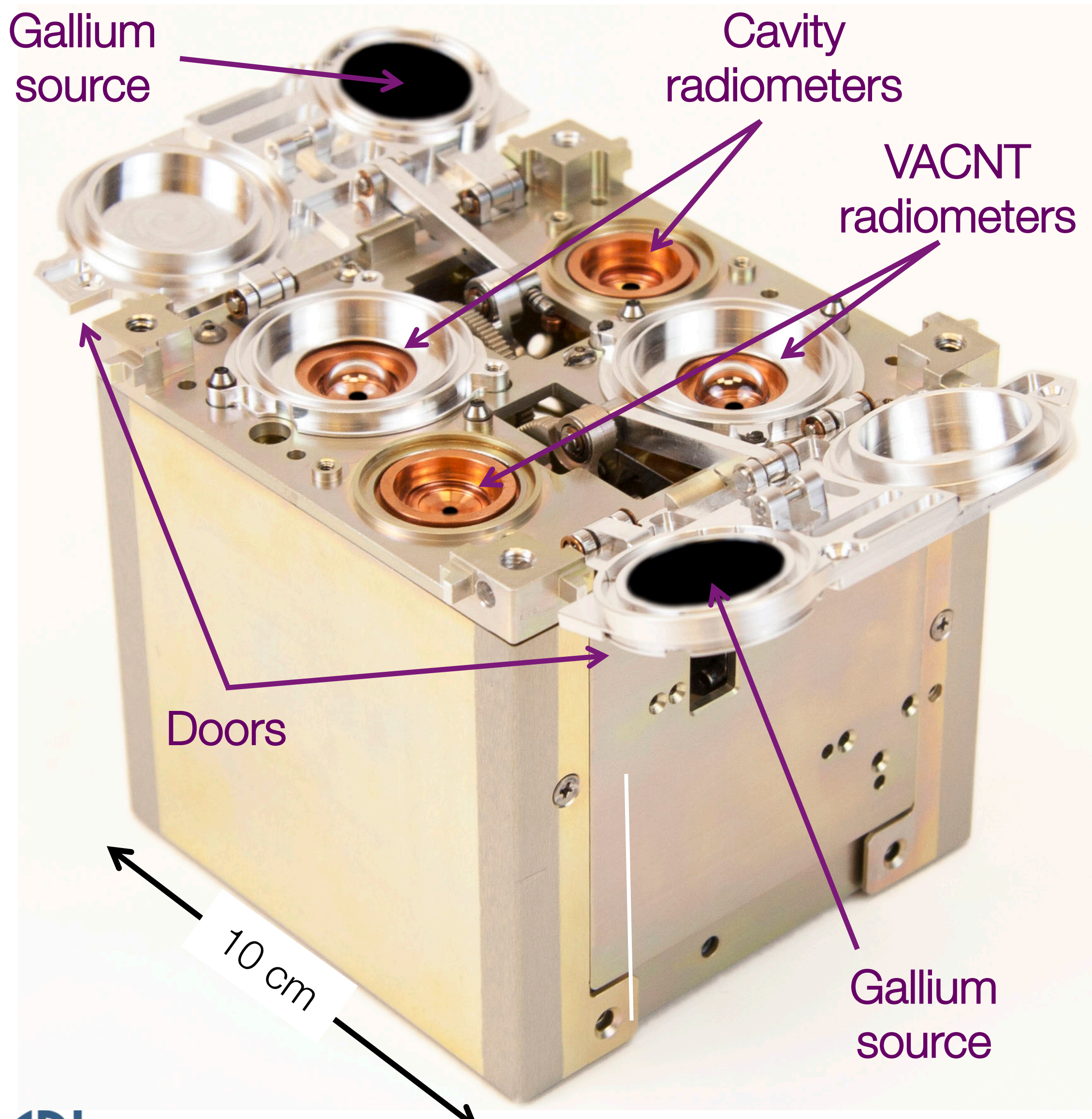
- **Demonstrate the use of a gallium closed-cell source** for calibration transfer





  - Repeatable, stable IR source
  - Degradation monitoring

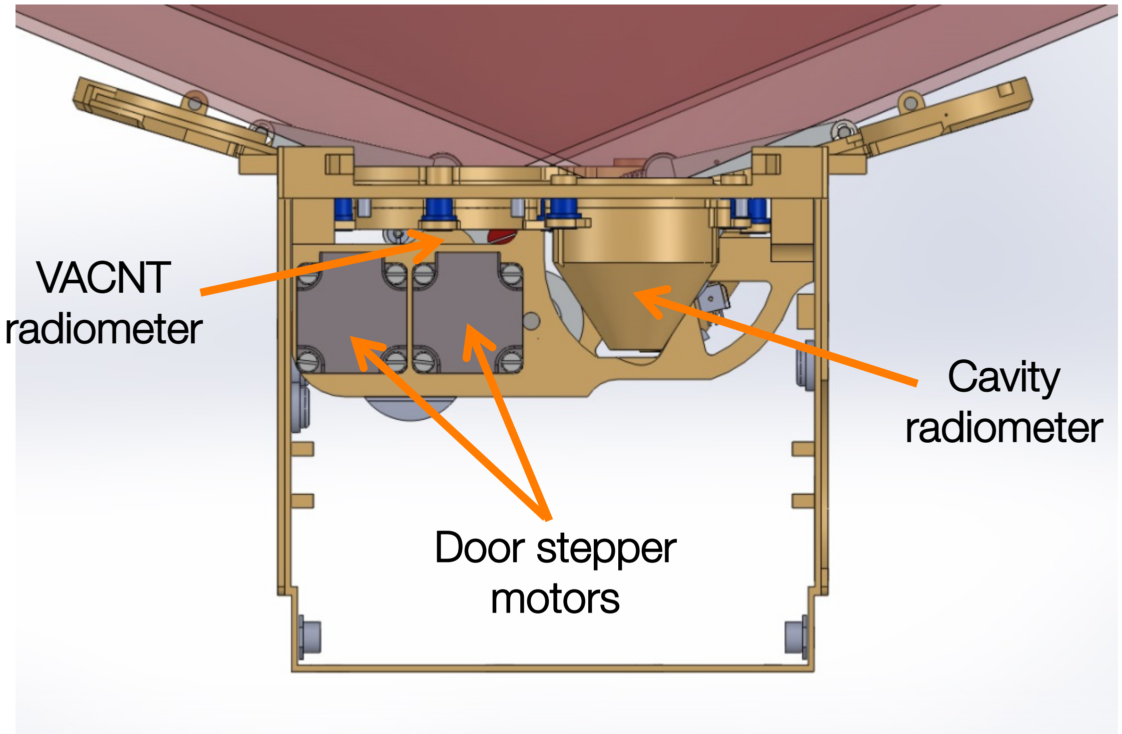
Payload includes four radiometer heads



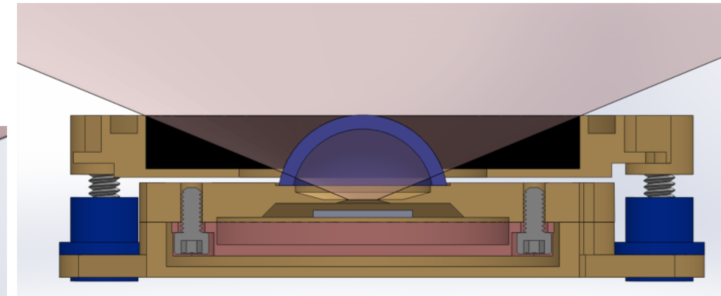
- Pair of two-channel differential bolometric sensors
  - Pair #1: VACNT absorber
  - Pair #2: Cavity absorber
- Total channels (2)
  - UV to 200 μm
- Shortwave channels (2)
  - Sapphire domes (2)
  - UV to ~5.5 μm
- Fixed-point gallium BBs in covers (2)
- Reusable doors must open to clear radiometer 130° fields of view (FOVs) and lock tightly for launch
- Radiometers thermally isolated from spacecraft and actively temperature controlled
- SMaP (payload only)
  - Size (volume): <1 U
  - Mass: <1 kg
  - Power: ~1.9 W (average)

VACNT radiometers smaller and faster

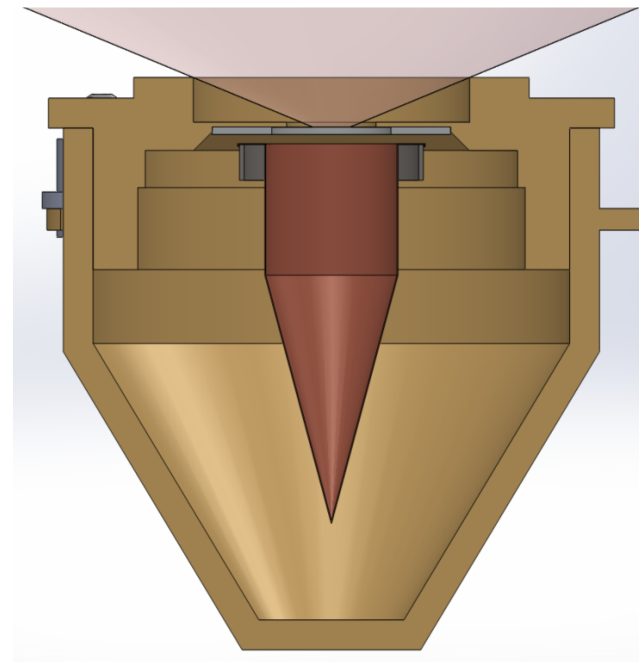
Radiometer FoVs (130°)



(payload electronics not shown)



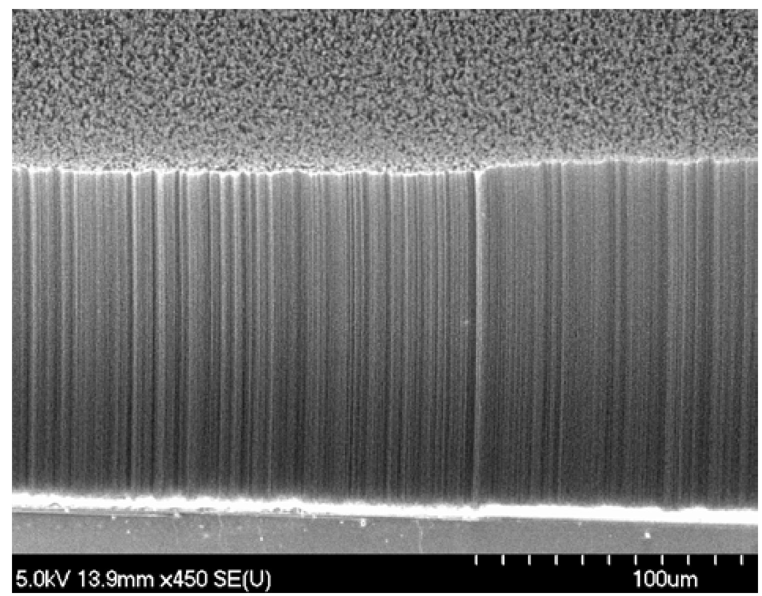
VACNT radiometer



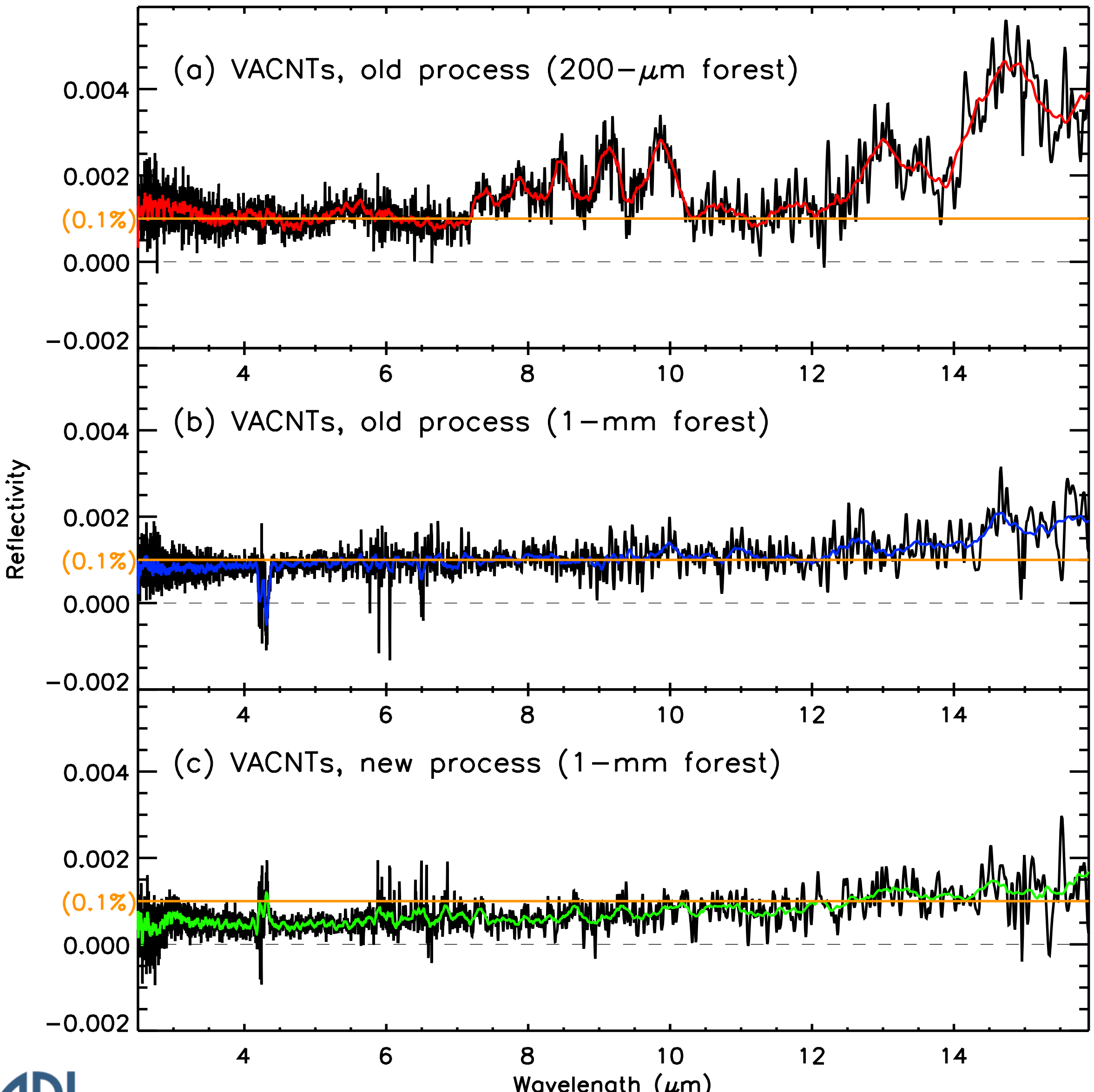
Cavity radiometer

VACNTs grown at APL

- Silicon wafer is covered with iron catalyst layer
- Chemical vapor deposition using ethylene as the carbon source is used to produce the VACNT growth
- Post-growth modification (vapor modifications, plasma etching)
- IR reflectivity measured to ~16 μm at APL
- Characterization (likely at NIST) to 100 μm



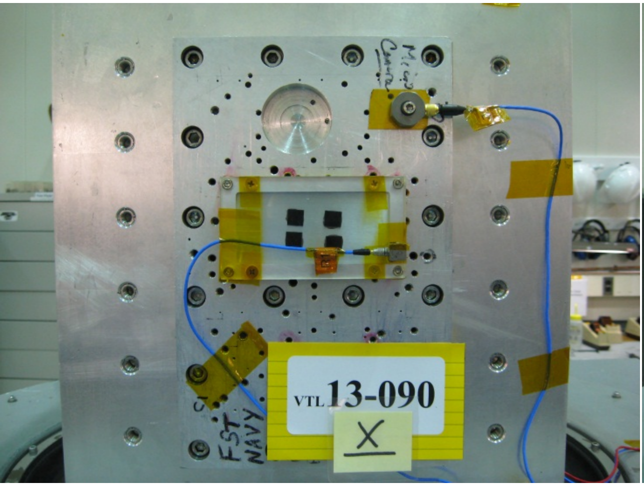
Process changes make VACNTs significantly blacker

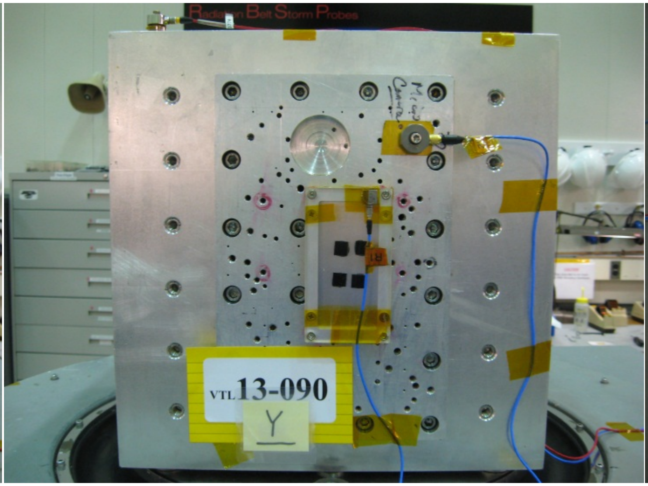


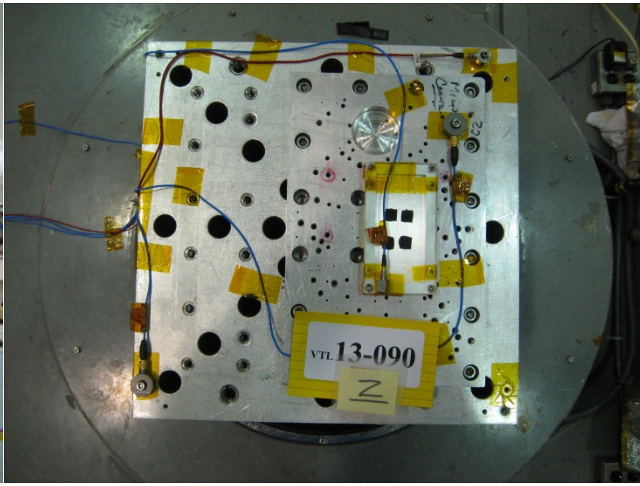
- First VACNTs largely above 0.1% target (bad)
  - 200-μm forest
  - first-generation post-treatment
- Increasing height of forest improves performance
  - 1-mm forest
- More-aggressive oxygen plasma etch meets 0.1% target out to ~13 μm (good)
  - similar etching less effective with shorter forests

VACNTs passed vibration test

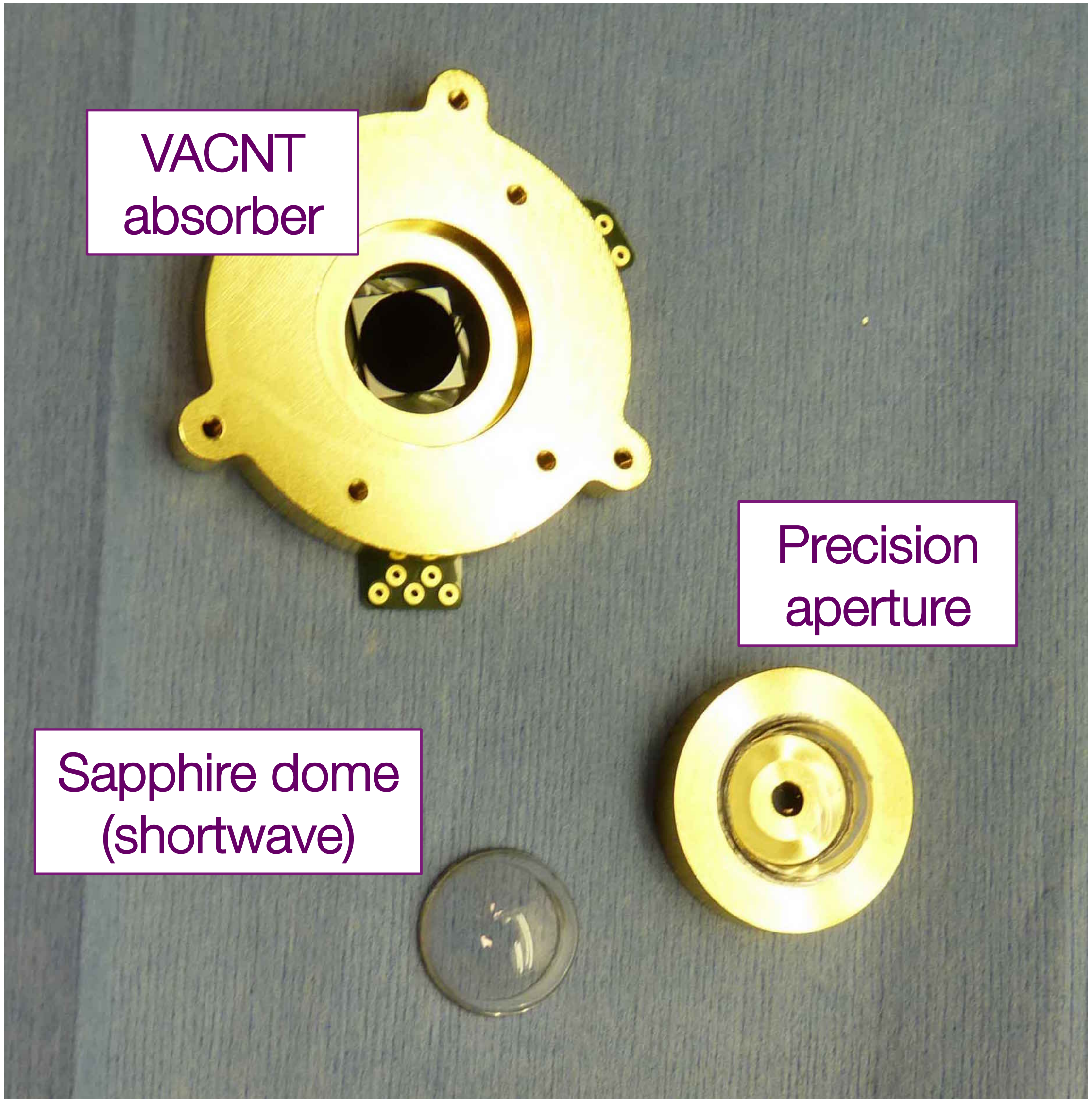
- Potential risk: VACNT release from substrate and/or loss of structural integrity during launch
- 3-axis vibe testing to be performed on flight-like samples to GEVS levels
- No apparent change during vibration





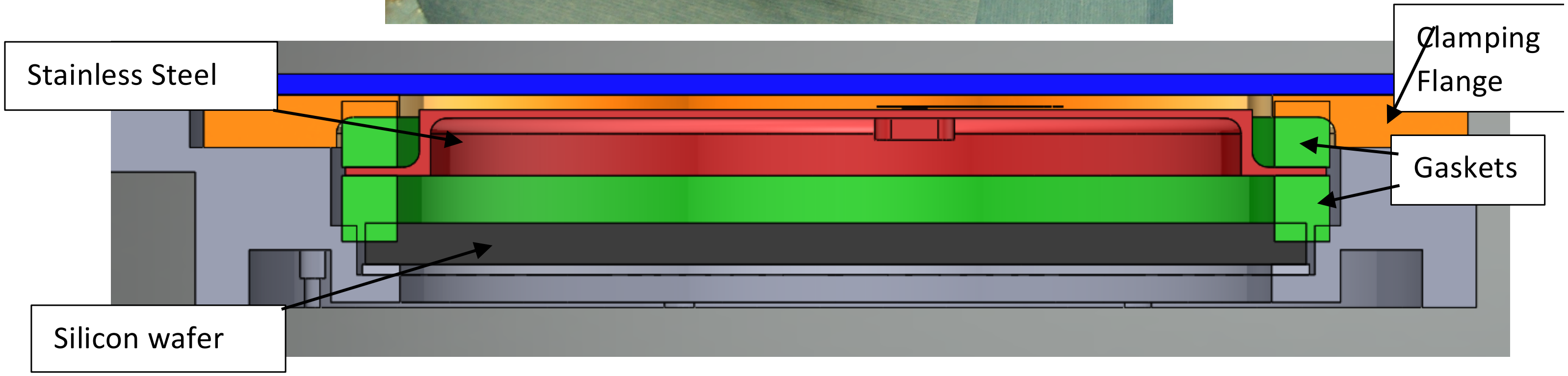


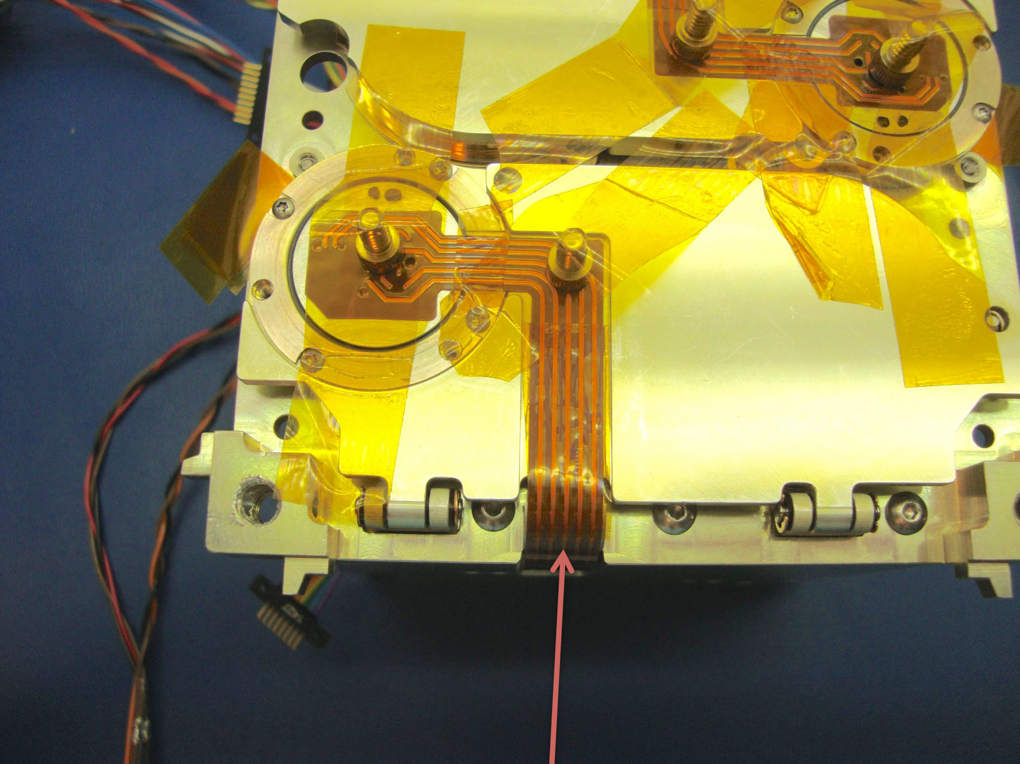
VACNT radiometer absorber



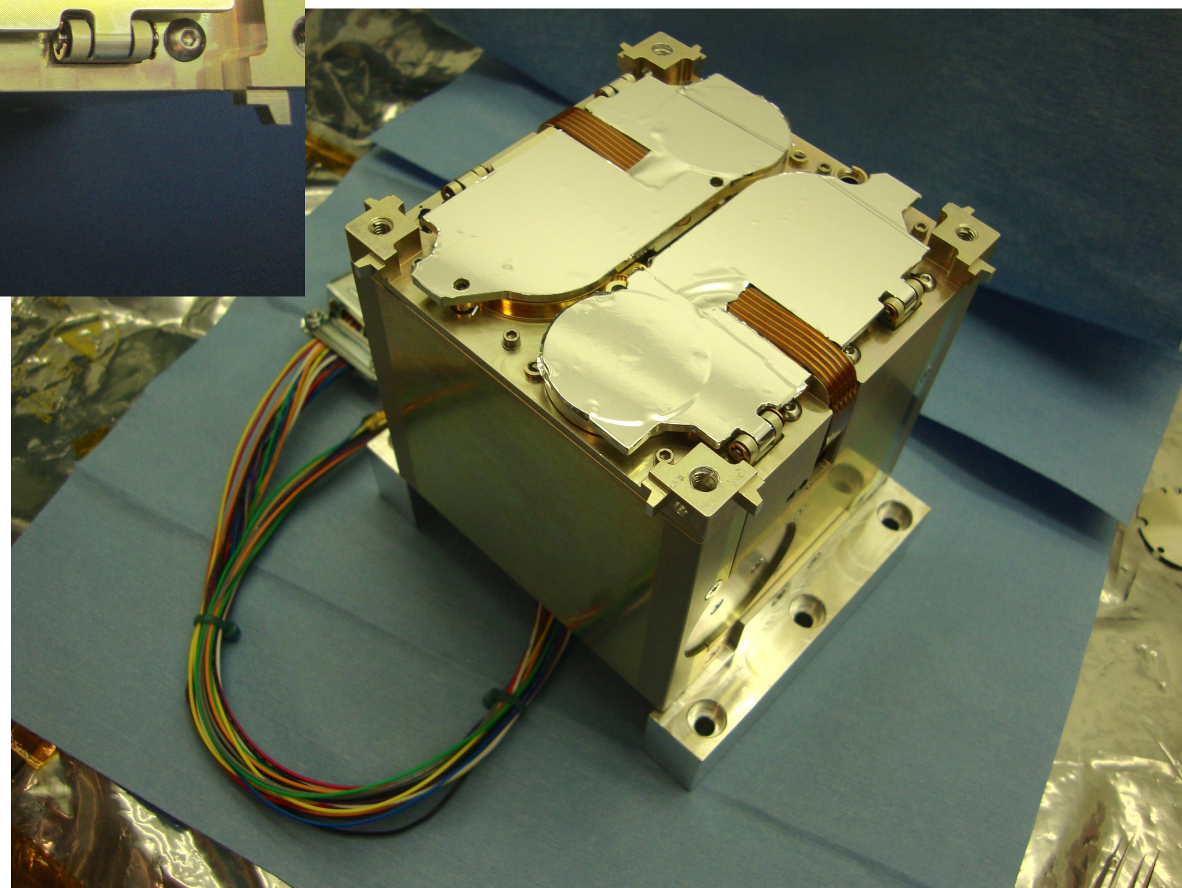
Gallium black body + VACNT emitter!

VACNT emitter

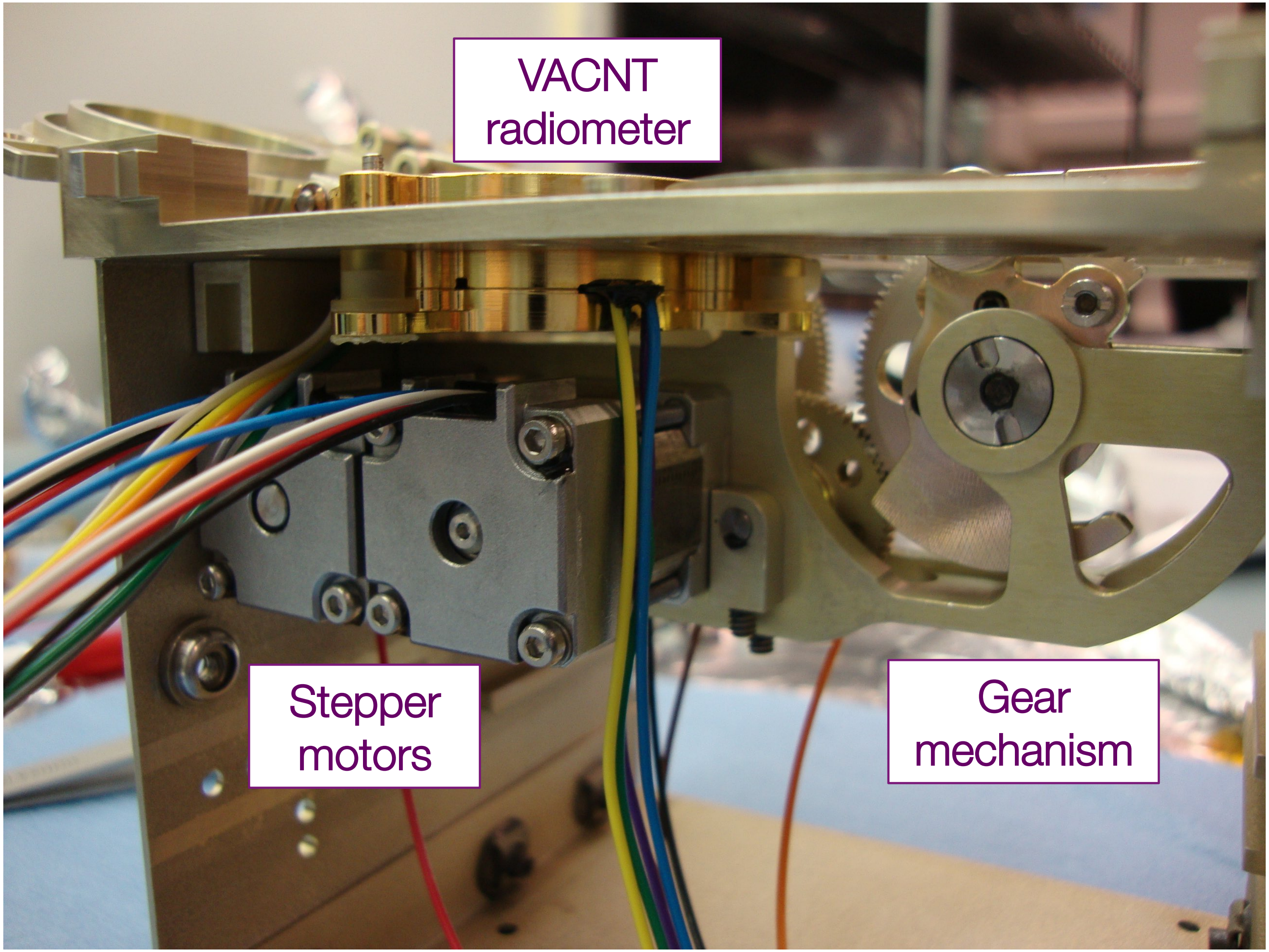




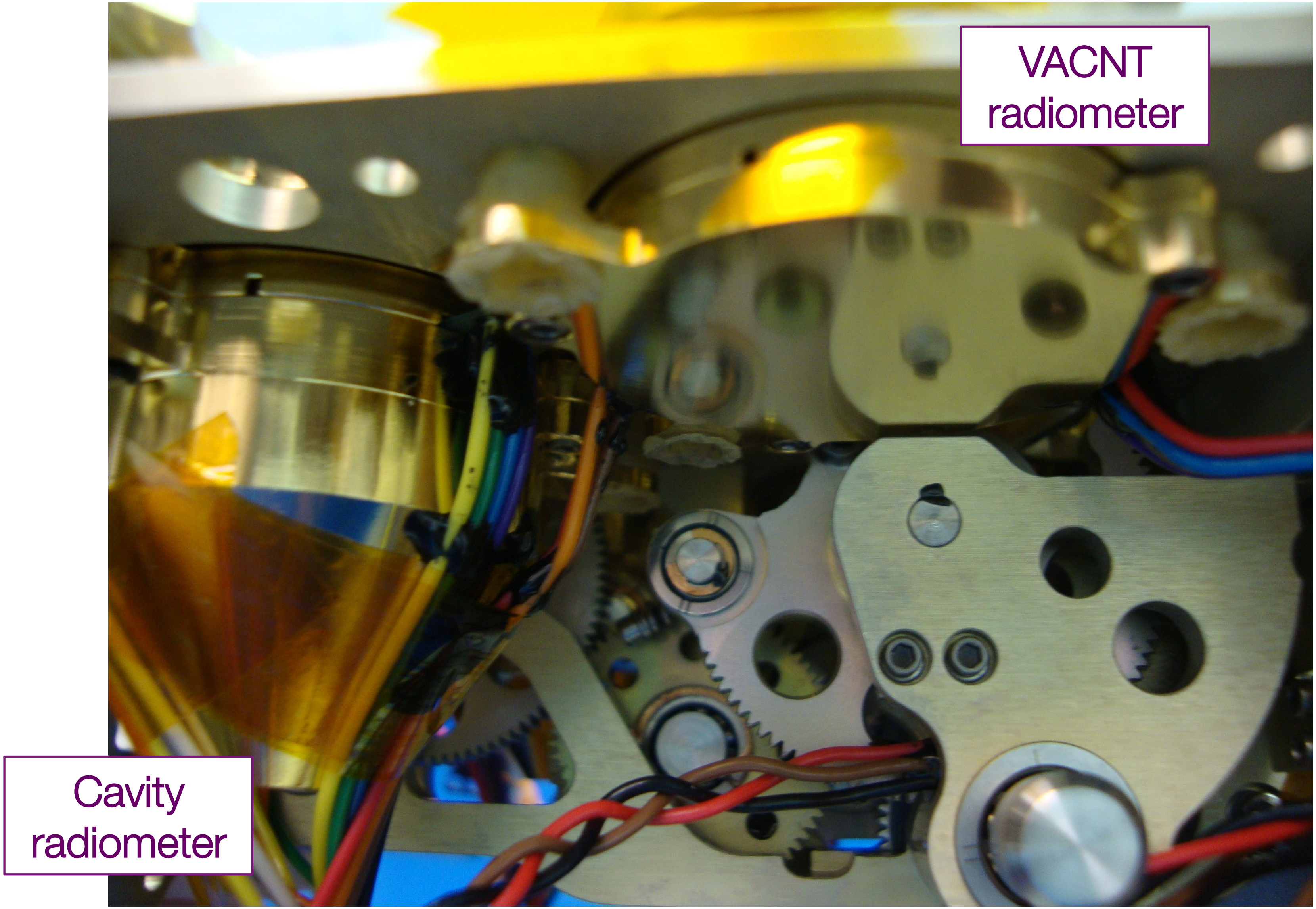
Heater + thermistor controls



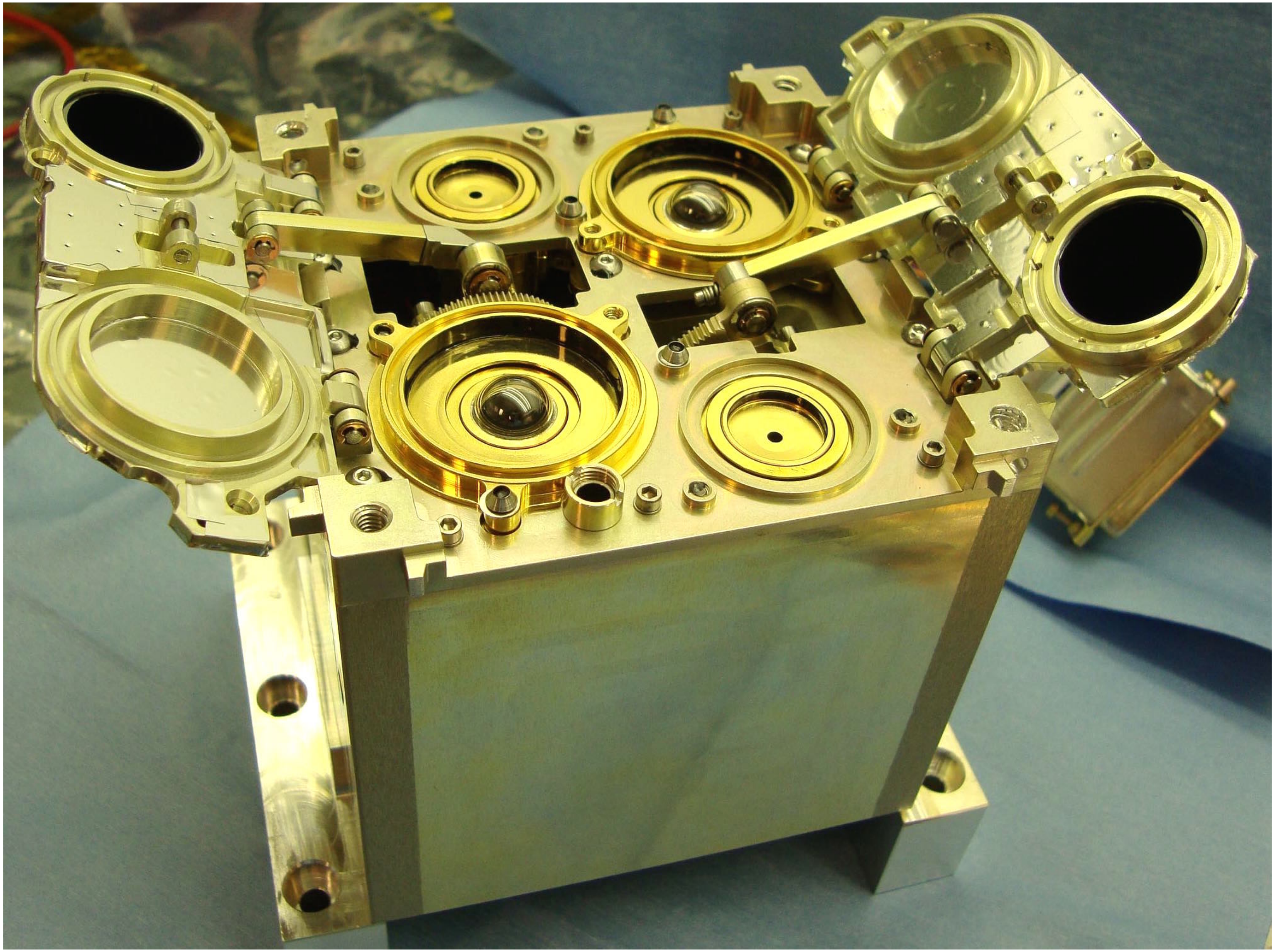
Stepper motors fit under VACNT radiometer



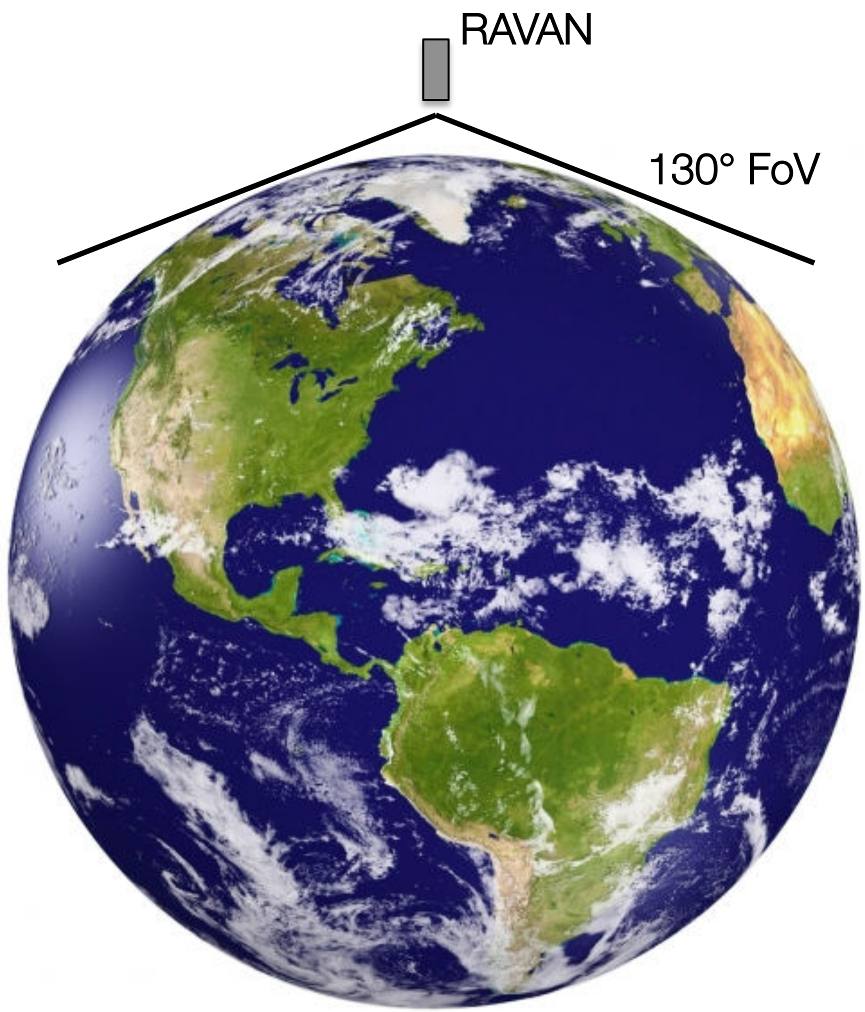
VACNT radiometers considerably smaller



Completed flight payload



RAVAN will be nadir-pointing most of the time



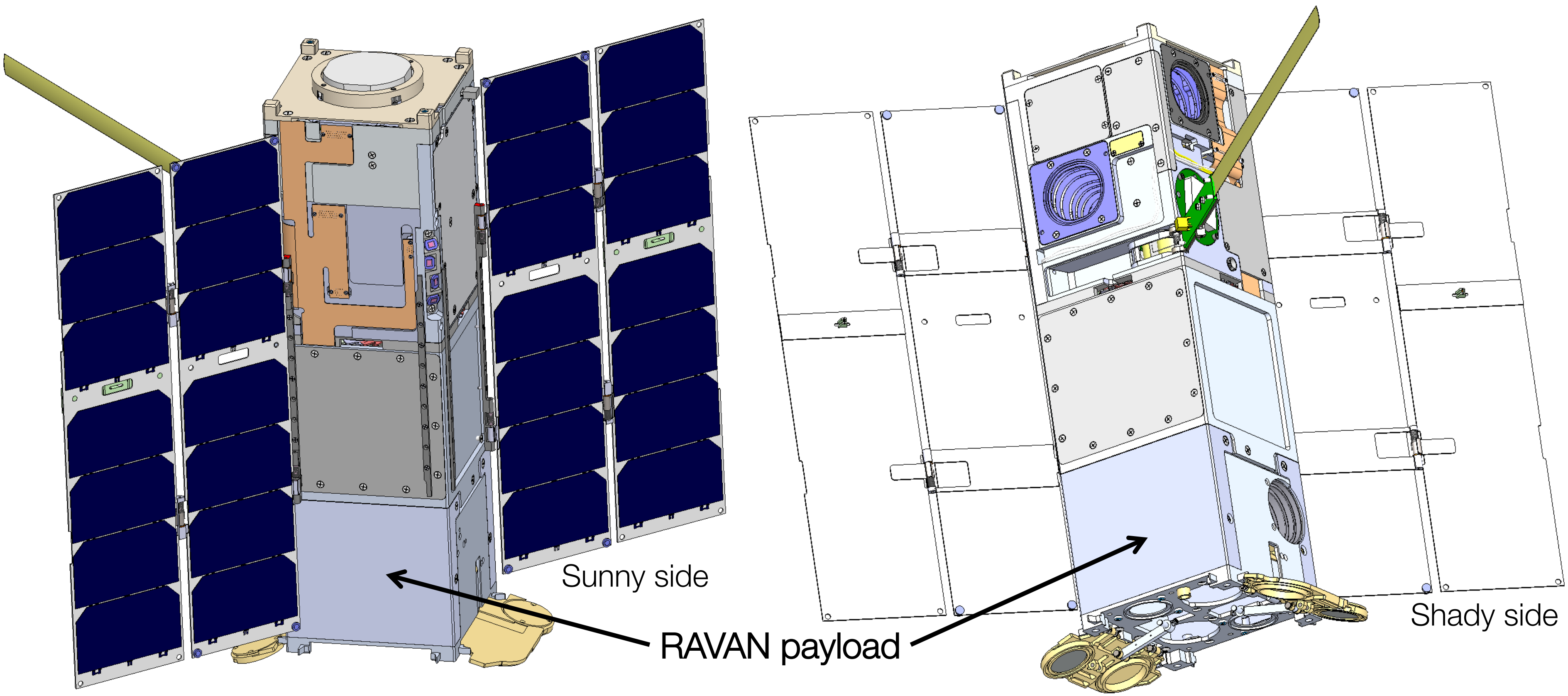
RAVAN capability objectives

- Provide better than 0.3 W/m^2 (climate accuracy) absolute Earth outgoing radiation measurements
- Establish an accuracy standard that remains stable over time on orbit
- Provide radiometer units that are manufacturable and calibratable at low cost so that the required constellations remain affordable

Primary calibration on orbit

Mode	Configuration	Purpose
Normal	Nadir, VACNT radiometer doors open	Normal Earth data collection
Solar	Point at Sun, doors open	Absolute calibration
Deep Space	Point at deep space, doors open	Offset calibration
Ga black body	Doors closed	Calibration with gallium black bodies
Inter-calibration	Both doors open	Intercompare VACNT and cavity radiometers

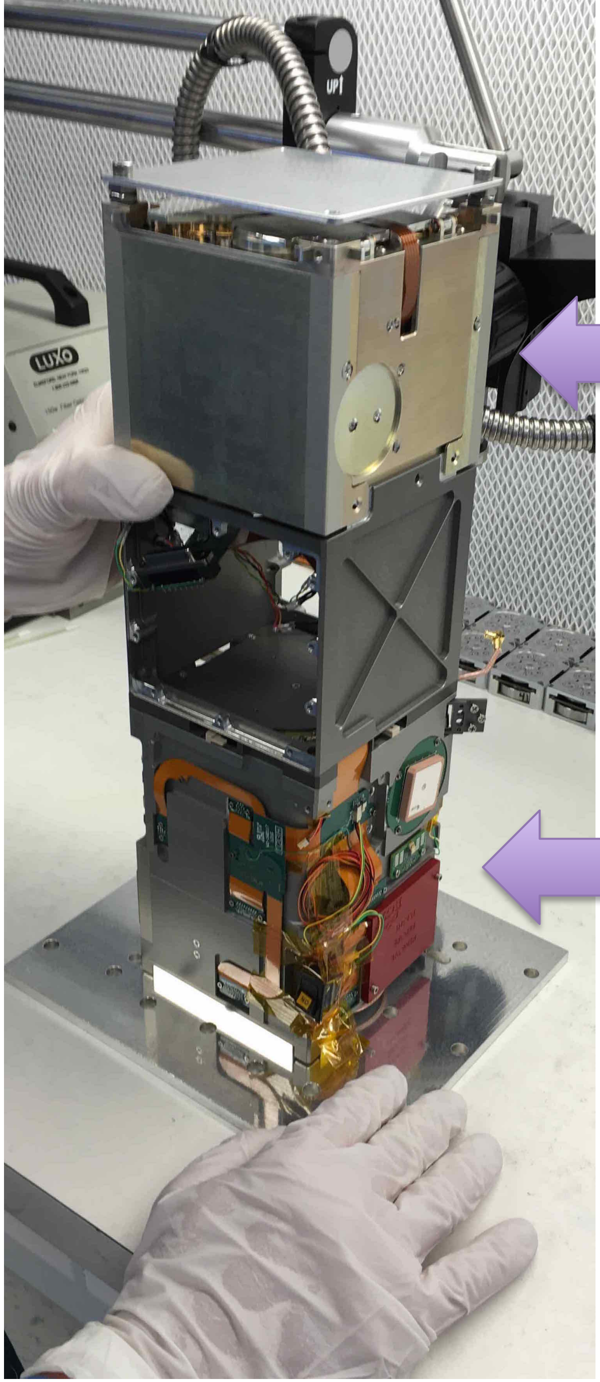
RAVAN will fly on a Blue Canyon 3U CubeSat



- Using Blue Canyon Technologies XB1 3U bus
  - Integrated XACT attitude determination and control system (working great on MinXXS, deployed from the ISS last month!)
  - GN&C for 3-axis control, GPS receiver, and stellar navigation
  - UHF and Globalstar communications

BCT is an active partner

- Blue Canyon Technologies has/will provide:
  - Design, manufacture, test, and integration of the RAVAN 3U CubeSat bus
  - Test (thermal vacuum and vibration) the integrated RAVAN spacecraft (bus and payload)
  - Support integration of the RAVAN spacecraft with the launch vehicle
  - Perform RAVAN spacecraft on-orbit checkout
  - Operate the RAVAN spacecraft for a minimum of 6 months
- Close working relationship with APL
  - APL has experience flying CubeSats
  - APL has extensive experience with radiation effects
  - APL working closely with BCT to
    - Increase likelihood of RAVAN success
    - Improve BCT products for future use in APL (and other) missions



RAVAN payload

BCT XB1

RAVAN
as of June 14, 2016

Mission parameters to achieve objectives

- Launch and mission operations
  - Desire high (>550 km), high-inclination, not sun-sync orbit…or sun-sync similar to CERES
  - 1 month check-out
  - 5 months minimum operation for demonstration (achieves technology and science goals)
  - >1 year operation desired (allows for more TOR data for comparison with CERES)
  - Launch anticipated in 2016

RAVAN

Radiometer Assessment Using Vertically Aligned Nanotubes

- RAVAN demonstrates key technologies (VACNT absorber, Ga black body) for possible ERB mission
- Flying on a 3U CubeSat
- Launching 2016

Funding: NASA
Earth Science Technology Office