RAVAN CubeSat Results: Technologies and Science Demonstrated On Orbit

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RAVAN measures the most important quantity for climate change

- The small imbalance (~1 W/m²) between incoming solar irradiance and Earth outgoing energy (solar reflected + Earth’s thermal emission) drives climate change
- Current space-based assets cannot quantify Earth’s outgoing radiation well enough to resolve the Earth energy imbalance (EEI)
- RAVAN is an Earth energy budget constellation pathfinder

TSI/4 = 341 W/m²

TSI/4 – TOE = EEI ≈ +1 W/m²

TSI = Total Solar Irradiance
TOE = Total Outgoing Energy
EEI = Earth Energy Imbalance
Technology objective #1: Carbon nanotubes

APL RAVAN Flight VACNTs

Reflectivity vs. Wavelength (μm)

Radiometer assembly: VACNT absorber 7 mm in diameter
Technology objective #2: Gallium black bodies

2. Is it pure gallium or a compound? I think it is pure. Please confirm.

3. Is the gallium enclosed in a container? As seen in the above cross section, the gallium cell consists of a silicon base (shown as black), a stainless steel top (red), and two silicone gaskets (green) which create seals against the silicon and stainless surfaces. There is an aluminum flange (shown as orange) which clamps down on the gaskets evenly using four screws. Stress analysis was performed to verify that the silicon wafer can withstand the internal pressure increase due to the expansion of the gallium as it freezes. Analysis also showed that the clamping pressure was significantly larger than the pressure inside of the cell (ensuring a reliable seal). This cell has already been filled and subjected to vibration testing with no indication of leaking.

4. Does the gallium emit hazardous radiation? It does not emit hazardous radiation. The gallium used for this assembly consists of its stable isotopes and not the isotopes used in medical imaging.

Measured in the lab
Payload very compact (<1U), including 4 radiometers

- 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)
Payload flies on a 3U CubeSat

- Using Blue Canyon Technologies XB-3 3U bus (their first spacecraft)
  - BCT hardware also flew/flying on MinXSS-1, IceCube, SHARC, CYGNSS, STP-H5
- Need attitude control for nadir/solar/deep space observations
- BCT: Payload I&T, LV integration, mission operations
Launch: November 11, 2016
“First light”: The VACNT and cavity radiometers track very well

Radiometer Total Channels

Radiometer SW Channels

Credit: United Launch Alliance, Lockheed Martin

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Payload data not continuous but providing what we need

Lessons learned from RAVAN on-orbit operations have been implemented in future BCT bus builds.
**Gallium transitioning “on its own” due to orbital temperature variation**

**Temperature measurement near Ga cell**
Controlled Ga transitions, as viewed by radiometer

[Graph showing controlled Ga transitions and radiometer readings over time]

Approximate Temperature (°C)
Filtered nadir data; preliminary, time-independent calibration

RAVAN radiometer dataset (preliminary calibration)
Direct VACNT-vs-cavity intercomparisons

Preliminary, time-independent calibration
Good correlation between VACNT and cavity Total and SW channels

**Total channels**

- $n = 21409$
- $r^2 = 0.988$

**SW channels**

- $n = 26023$
- $r^2 = 0.965$

Preliminary, time-independent calibration
Spatial information reconstructed from RAVAN-like sampling of TOA flux

Model reanalysis upwelling long-wave flux (instantaneous field)

RAVAN orbit

Long-wave flux reconstructed using spherical harmonics (daily mean)
More satellites provide greater spatial (and temporal) resolution and less error
Some top-level lessons learned from RAVAN

- Perform a site survey to at least understand the RF environment in the ground station location / If possible, be flexible in moving the ground station to a more favorable location
  - Being forced to be outside the amateur frequency band has introduced interference from other users
- Using multiple ground stations allows for more consistent data reception
  - Weather and ground antenna hardware issues at one station can be overcome if a second (or third) station is available
- Design in the capability to allow bus and/or payload flight software to be loaded on-orbit
  - Solutions can be implemented if there are options to load software from the ground
Summary: RAVAN as pathfinder

- **RAVAN has met its technology validation objectives**
  - Collected enough data for basic technology demonstration
  - More data desired for refinement and longer-term stability
  - Extended BCT contract one year for mission operations
- Looking forward to more analysis and measurements!

Carbon nanotube forest

RAVAN payload

RAVAN 3U CubeSat

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