The RAVAN CubeSat Mission: On-Orbit Demonstration

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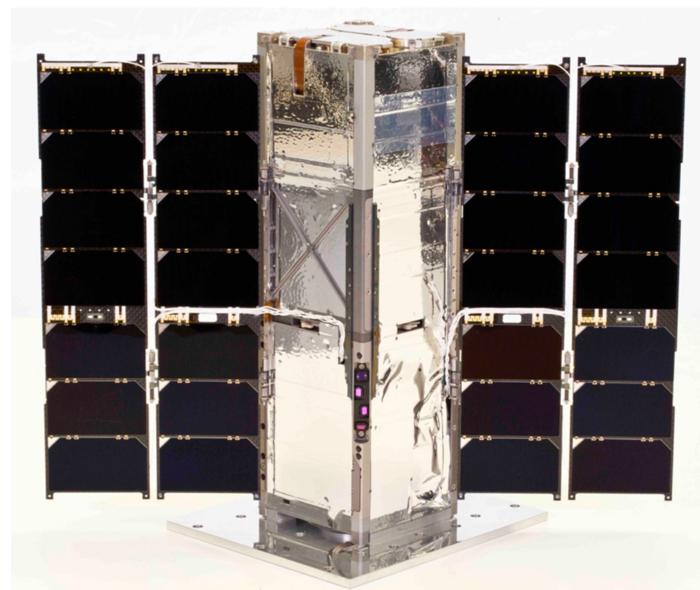


Funding: InVEST Program,

NASA Earth Science Technology Office

RAVAN, one year ago

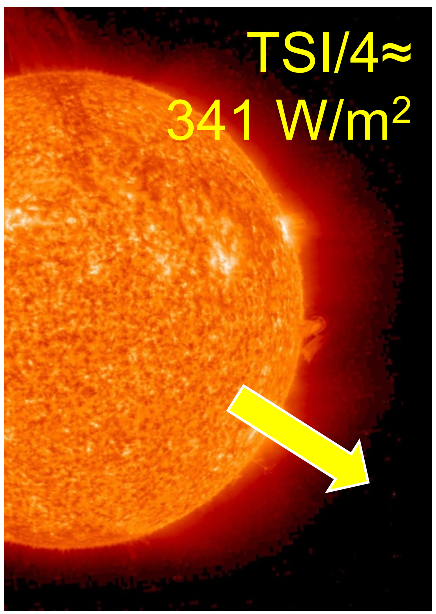
RAVAN
as of June 14, 2016

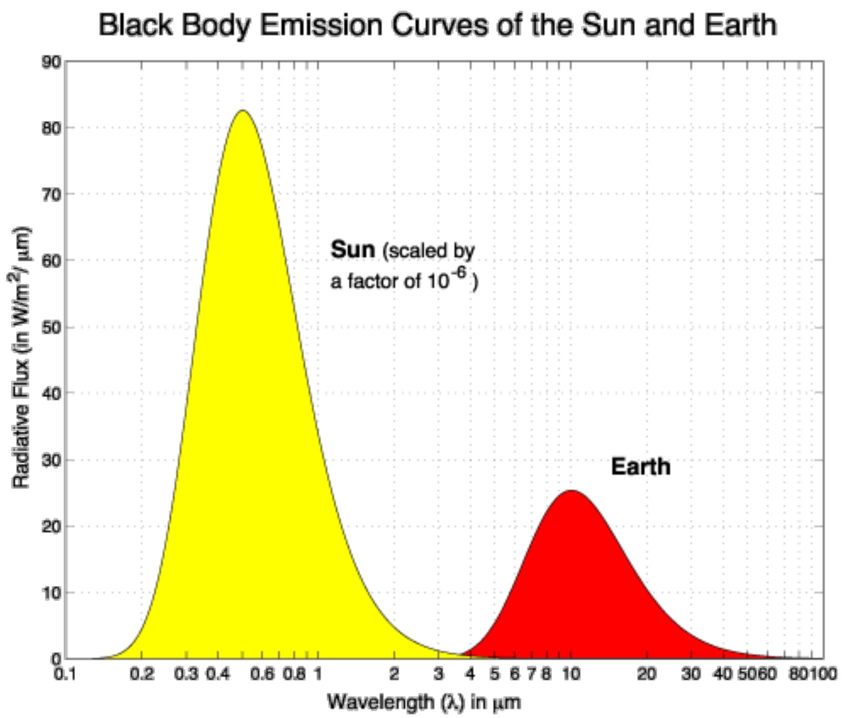
APL *RAVAN CubeSat Mission • bill.swartz@jhuapl.edu • Earth Science Technology Forum • 6/15/16* 26

(EEI = Earth Energy Imbalance)

EEI is most important quantity for climate change

- **The small imbalance (~1 W/m^2) between incoming solar irradiance and Earth outgoing energy (solar reflected + Earth's black body emission) drives climate change**
- **Current space-based assets cannot quantify Earth's outgoing radiation well enough to resolve EEI**





$$\text{TSI/4} - \text{TOE} = \textbf{EEI} \approx +1\ W/m^2$$

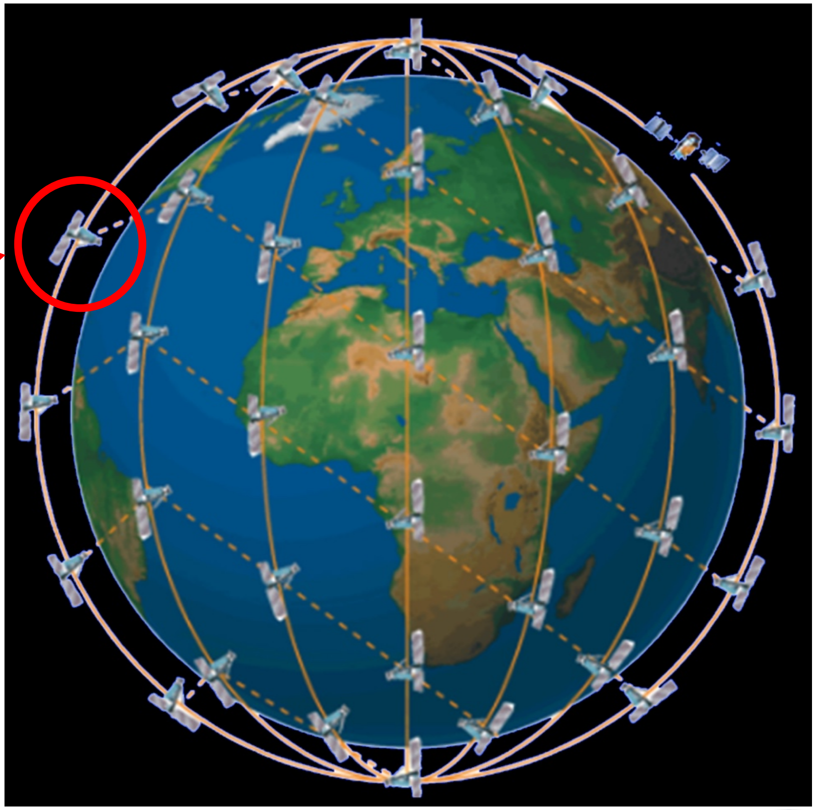
TSI = Total Solar Irradiance
TOE = Total Outgoing Energy
EEI = Earth Energy Imbalance

(TOE = Total Outgoing Energy)

What we need is a space-based constellation for TOE

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

RAVAN

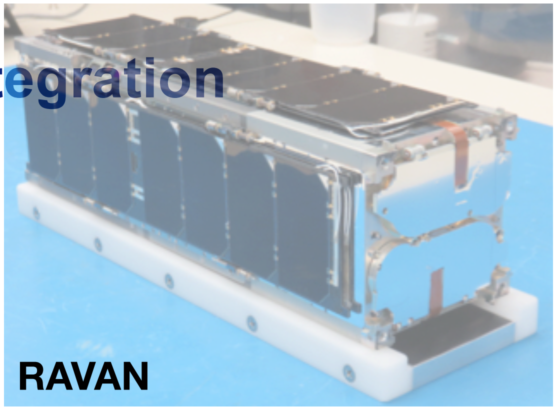


The maturation of smallsat/hosted payload and constellation technology provides an opportunity for taking a big step forward in Earth energy budget science. **RAVAN is a pathfinder for a future EEB constellation.**

RAVAN timeline

- Nov-12 RAVAN proposal submitted
- Apr-13 RAVAN selected
- Nov-13 CubeSat Launch Initiative (CSLI) proposal submitted
- Feb-14 RAVAN selected for CSLI launch (TBD)
- Apr-14 Payload CDR
- Dec-14 Decision on bus (BCT selected)
- Jul-15 Bus CDR
- Feb-16 RAVAN becomes "back-up" on commercial launch
- May-16 RAVAN is officially manifested for launch
- Jun-16 Payload delivered to BCT for I&T
- Aug-16 RAVAN delivered to Cal Poly for LV integration
- Nov-16 Launch

RAVAN waited for launch opportunity for two years.

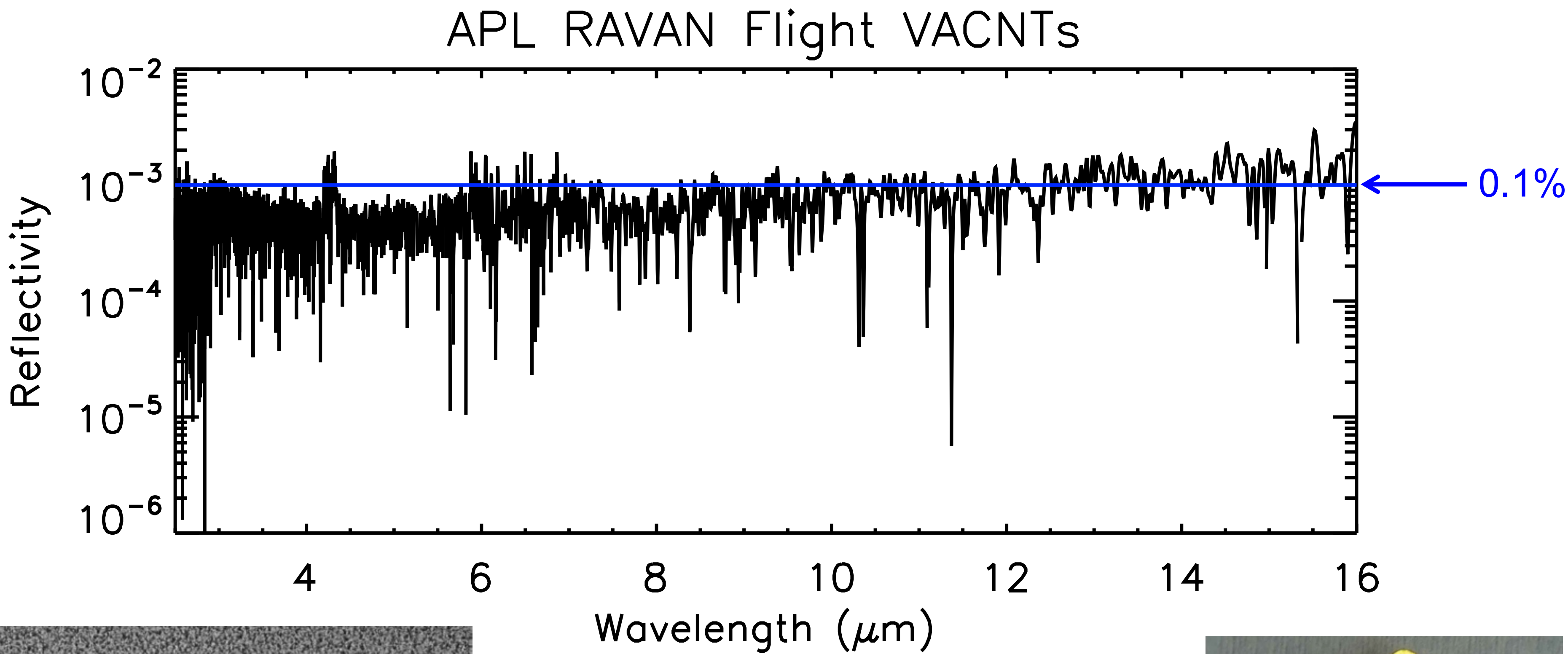


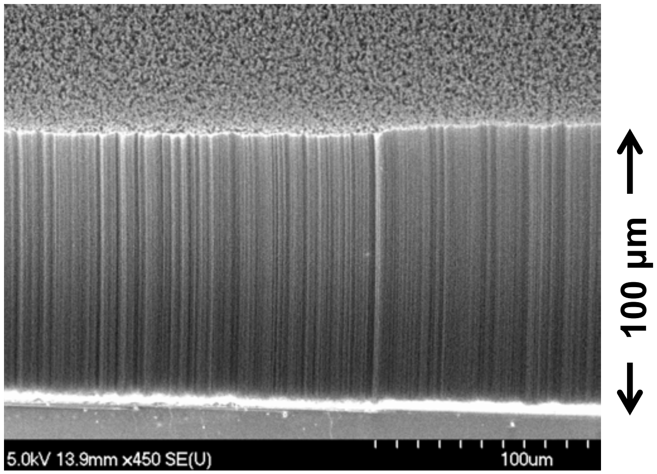
Basic design concept

- Treat as simple irradiance measurement
  - Thermal detectors with spectrally flat black absorbers and precision apertures
- Redundant Total (2x) and SW (2x) channels
  - Sapphire dome used as shortwave filter
- *Primary radiometers: vertically aligned carbon nanotubes (VACNTs) on Si*
  - Compact radiometer with better sensitivity for a given time constant
  - Good but not perfect absorber
  - Potential degradation due to contamination
- Secondary radiometers: Black painted conical Cu cavity
  - "Old" tech
  - Less subject to contamination
  - Degradation monitor for primary radiometers
  - Proves performance of primary
  - Provides redundancy (risk mitigation)
- *Gallium black body emitter*
  - Transfer standard for Total channels
  - Degradation monitor of both primary and secondary Total channels
  - Ga BB coupled with solar and space looks gives offset and degradation monitoring

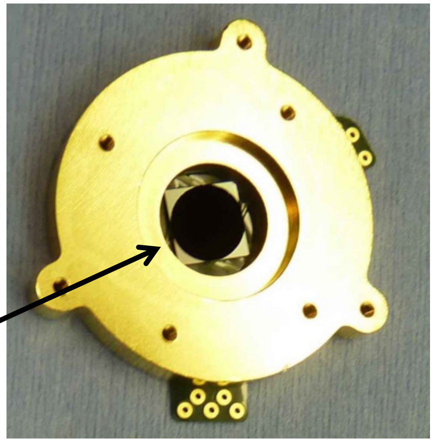
*Technology demonstrations

Technology objective #1: Carbon nanotubes

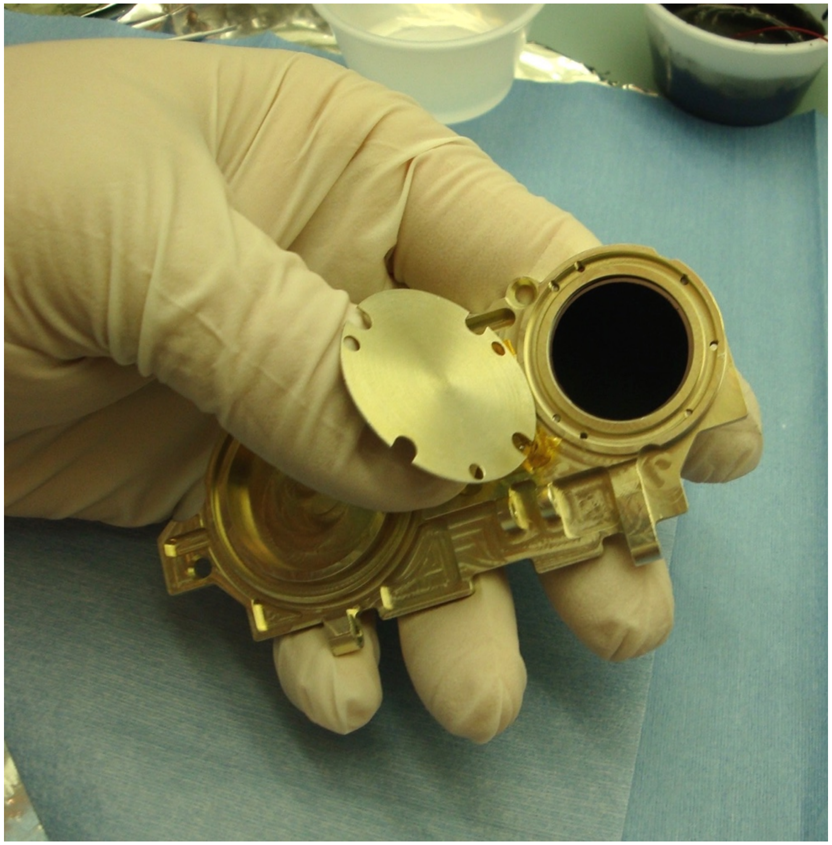


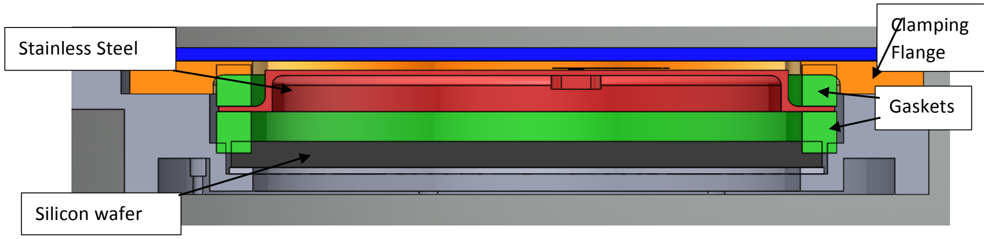


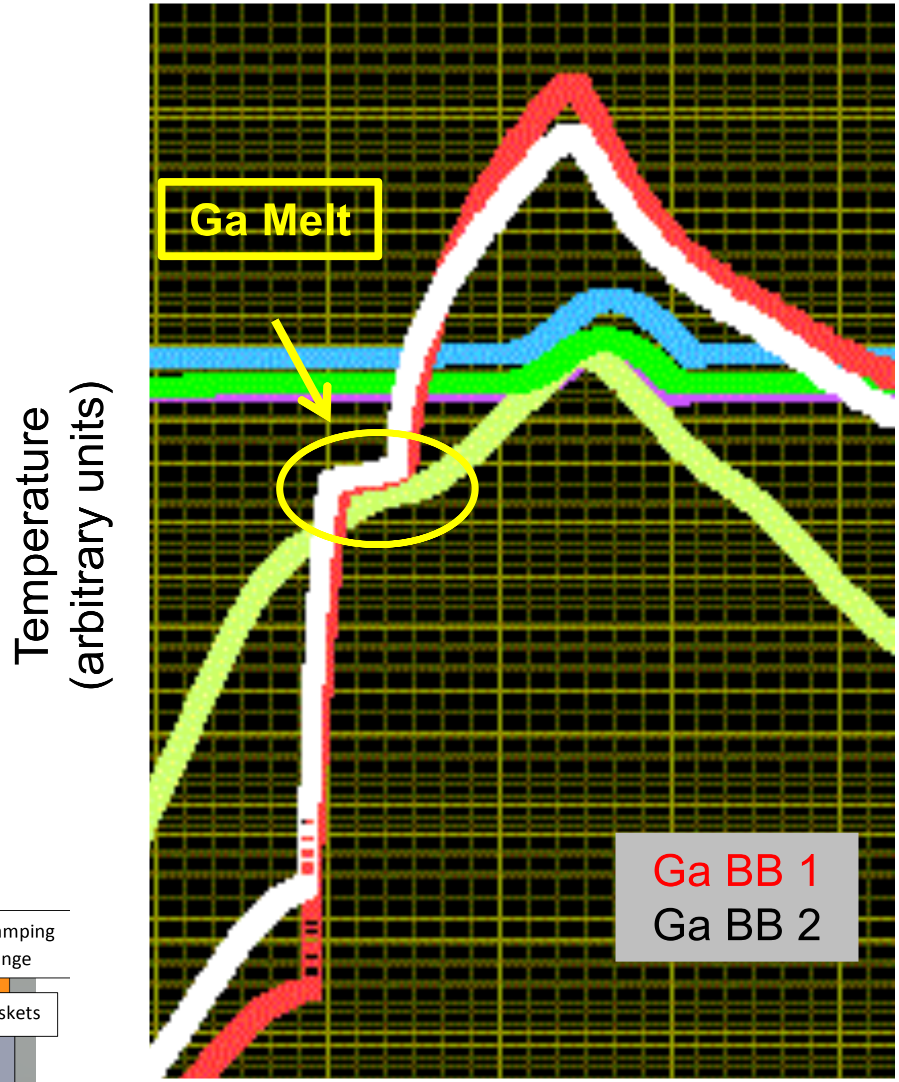
Radiometer assembly:
VACNT absorber 7 mm in diameter



Technology objective #2: Gallium black bodies

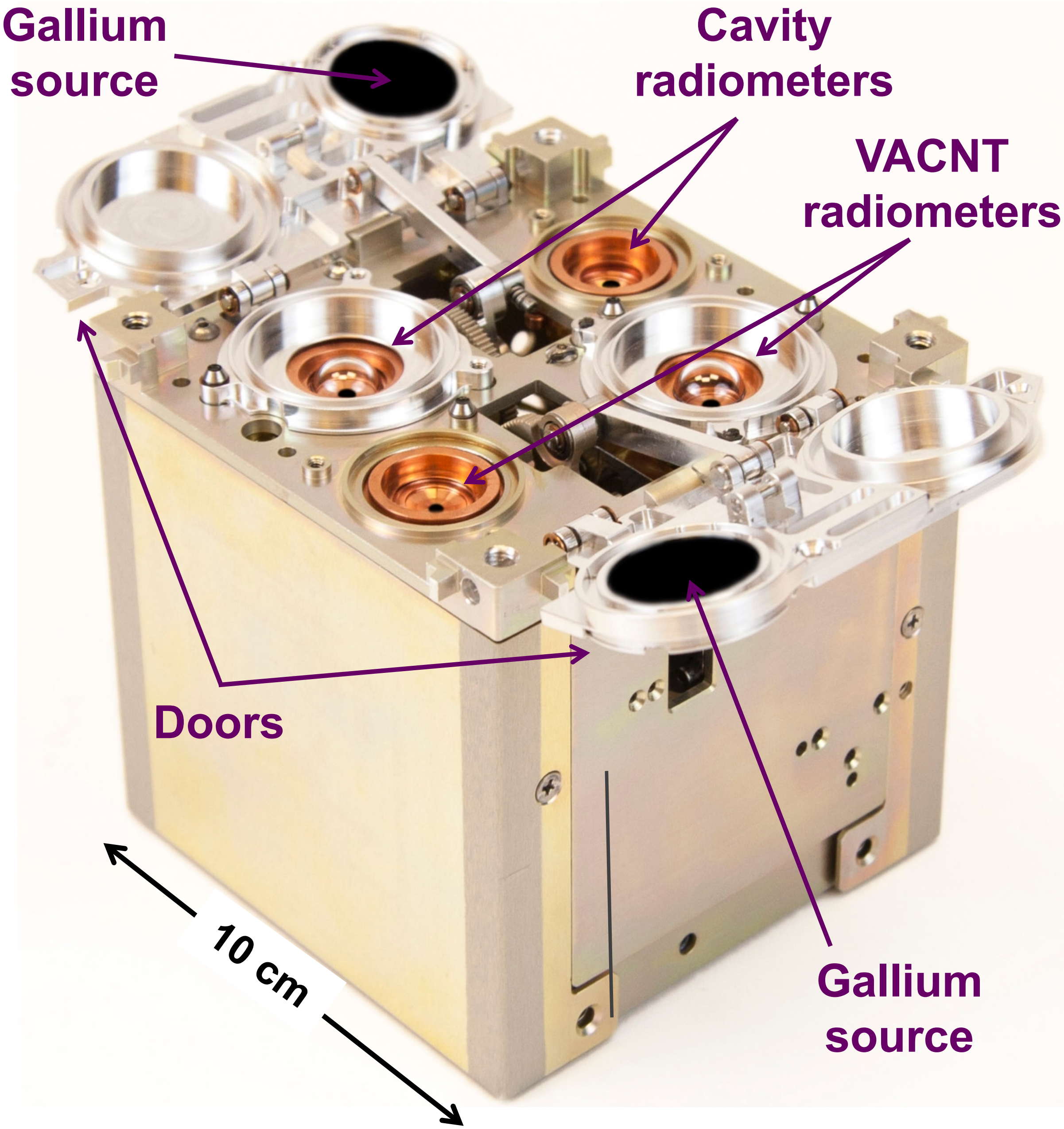






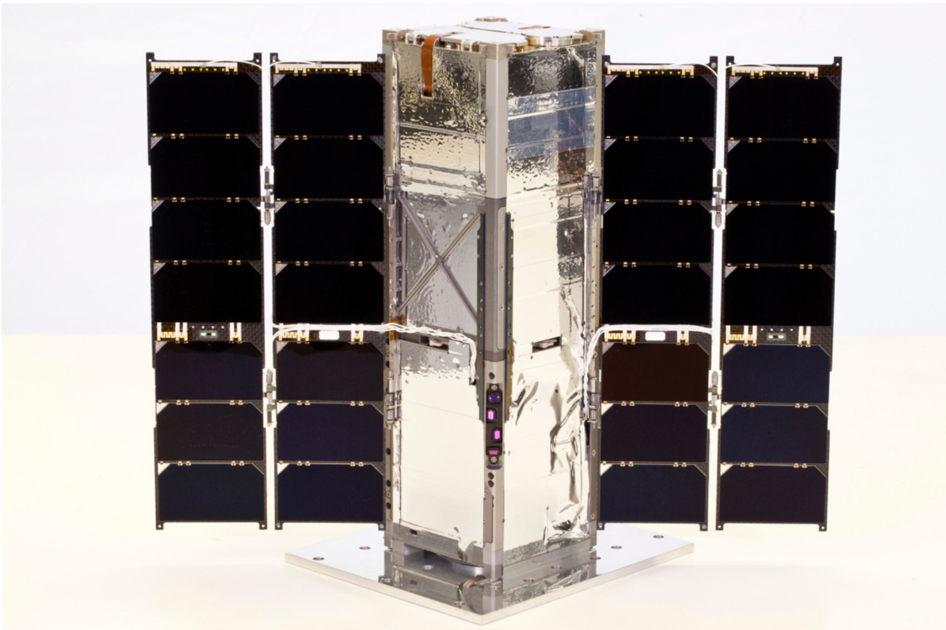
Measured in the lab

Payload very compact (<1U)

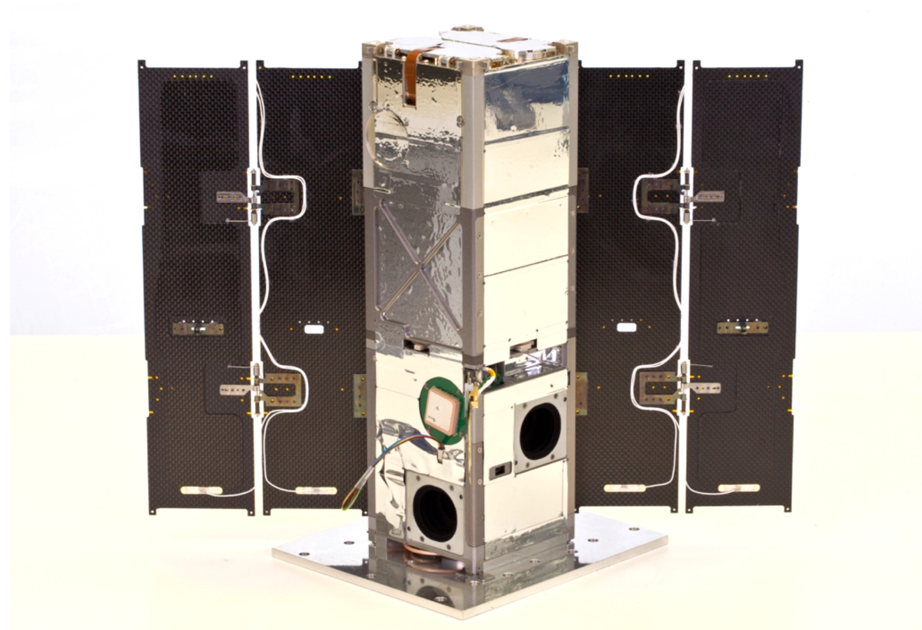


- Pair of two-channel differential bolometric sensors
  - Pair #1: VACNT absorber
  - Pair #2: Cavity absorber
- Total channels (2)
  - UV to 200 μm
- Shortwave channels (2)
  - Sapphire domes (2)
  - UV to ~5.5 μm
- Fixed-point gallium BBs in covers (2)
- Reusable doors must open to clear radiometer 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



Sunny side

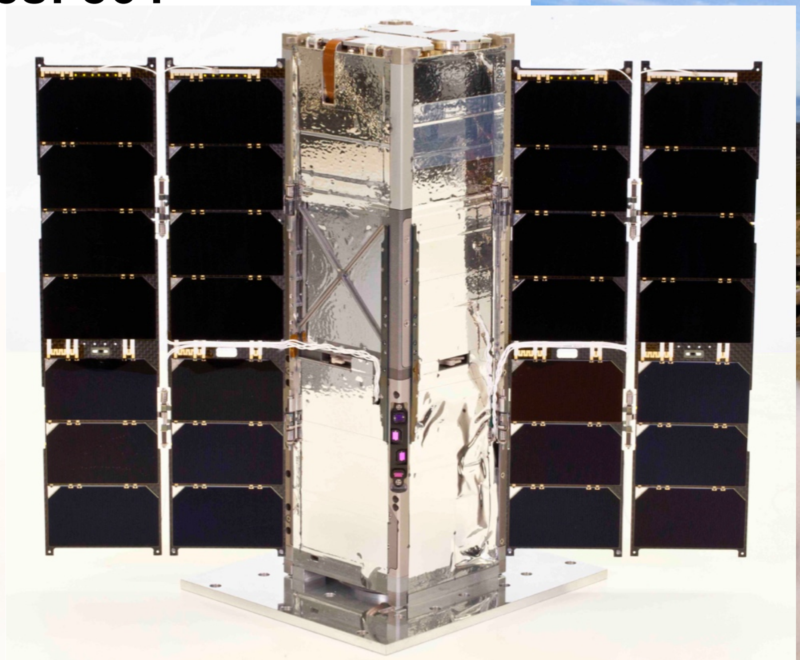


Shady side

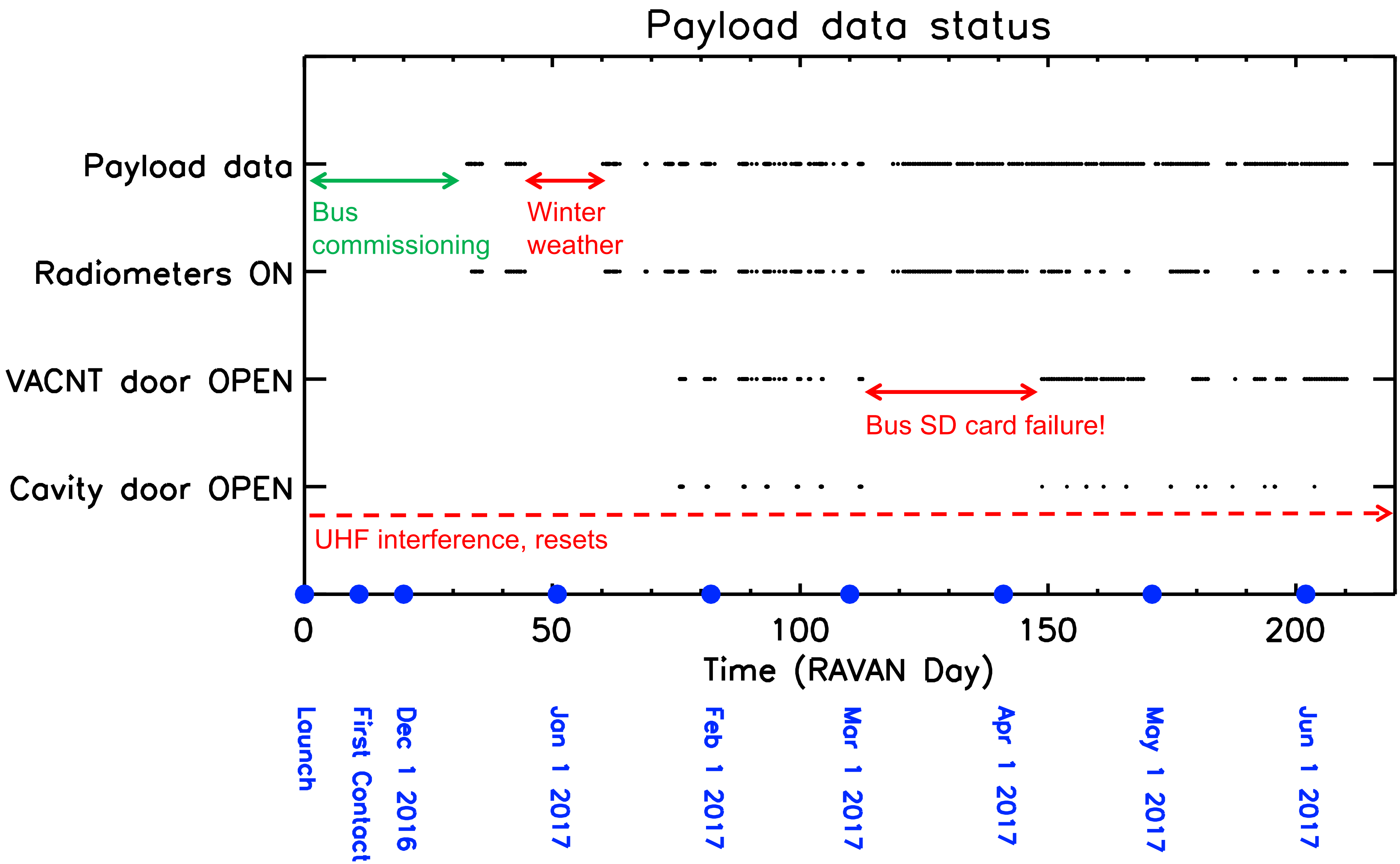
- Using Blue Canyon Technologies XB3 3U bus (their first spacecraft!)
  - Integrated XACT ADCS (also flew on MinXSS, deployed from the ISS in May 2016), GN&C for 3-axis control, GPS receiver
- Need attitude control for nadir/solar/deep space observations
- BCT: Payload I&T, LV integration, mission operations

Successfully launched and operating

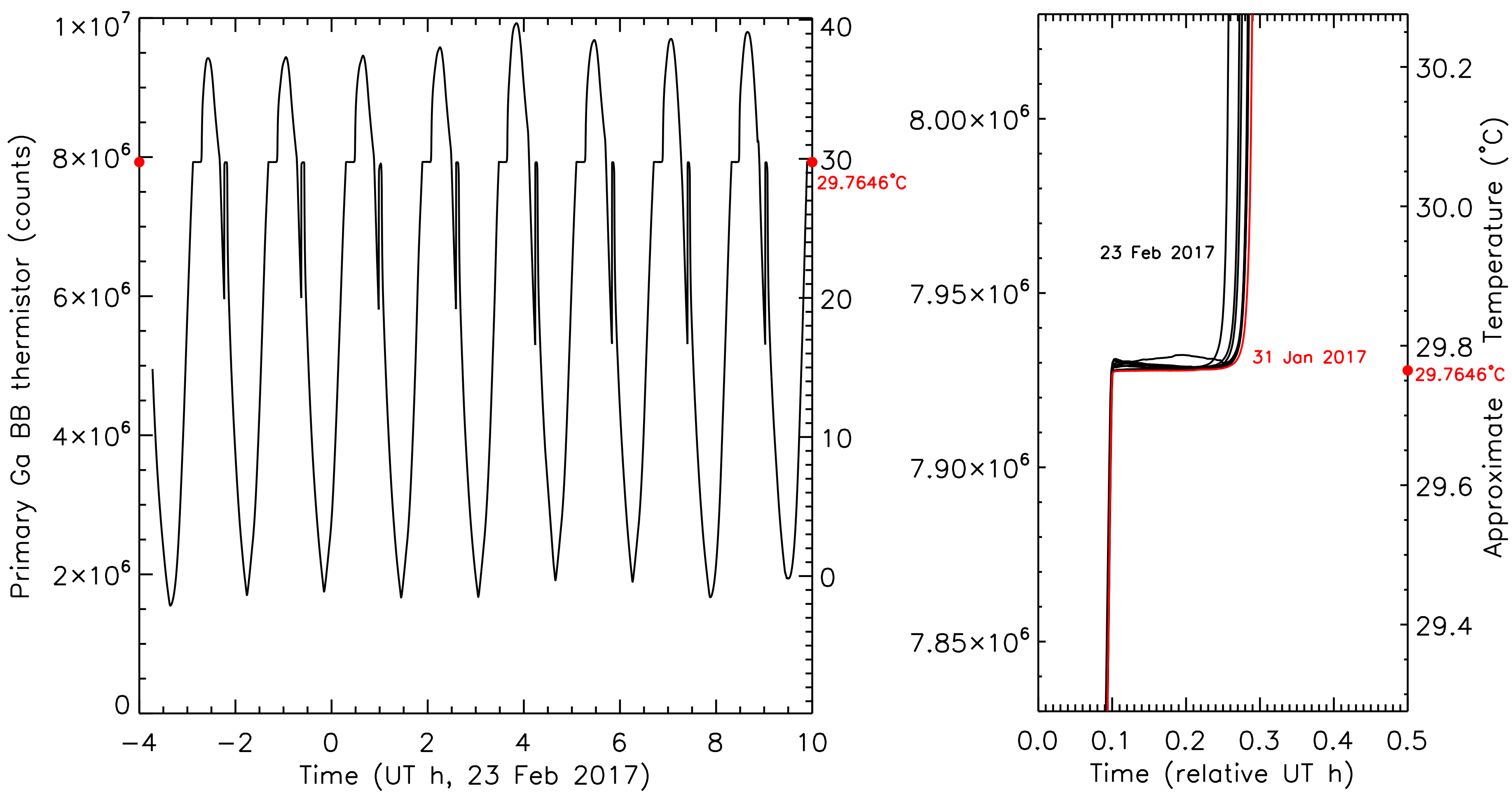
- **Launch: Nov 11, 2016**
  - **Atlas V, Vandenberg AFB**
  - **Orbit: ~600 km, sun-sync**
- **As of June 15, 2017:**
  - **# days on orbit: 216**
  - **# orbits: 3,231**
  - **# UHF overpasses: 864**



Payload data not continuous but providing what we need

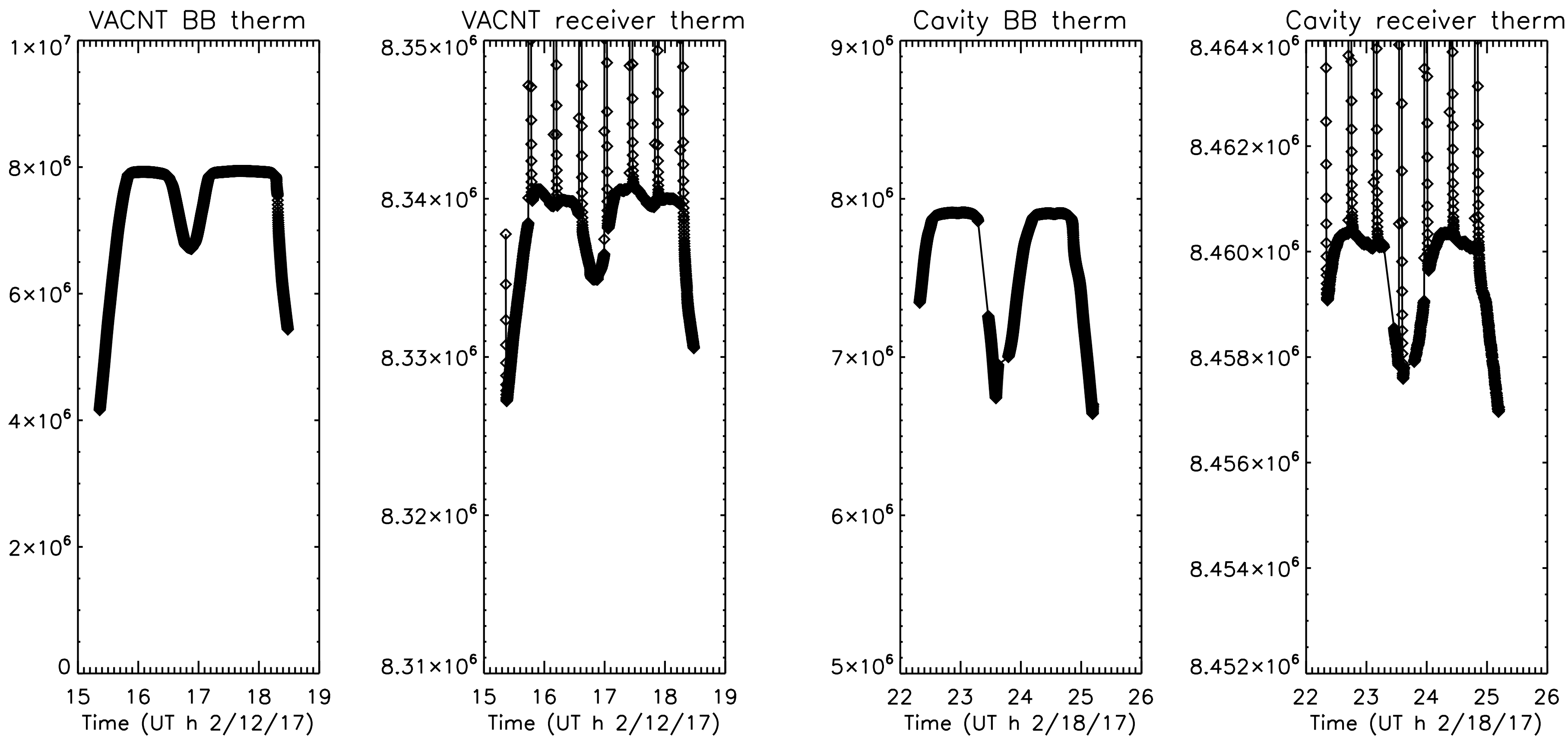


Ga transitioning "on its own" due to orbital temperature variation



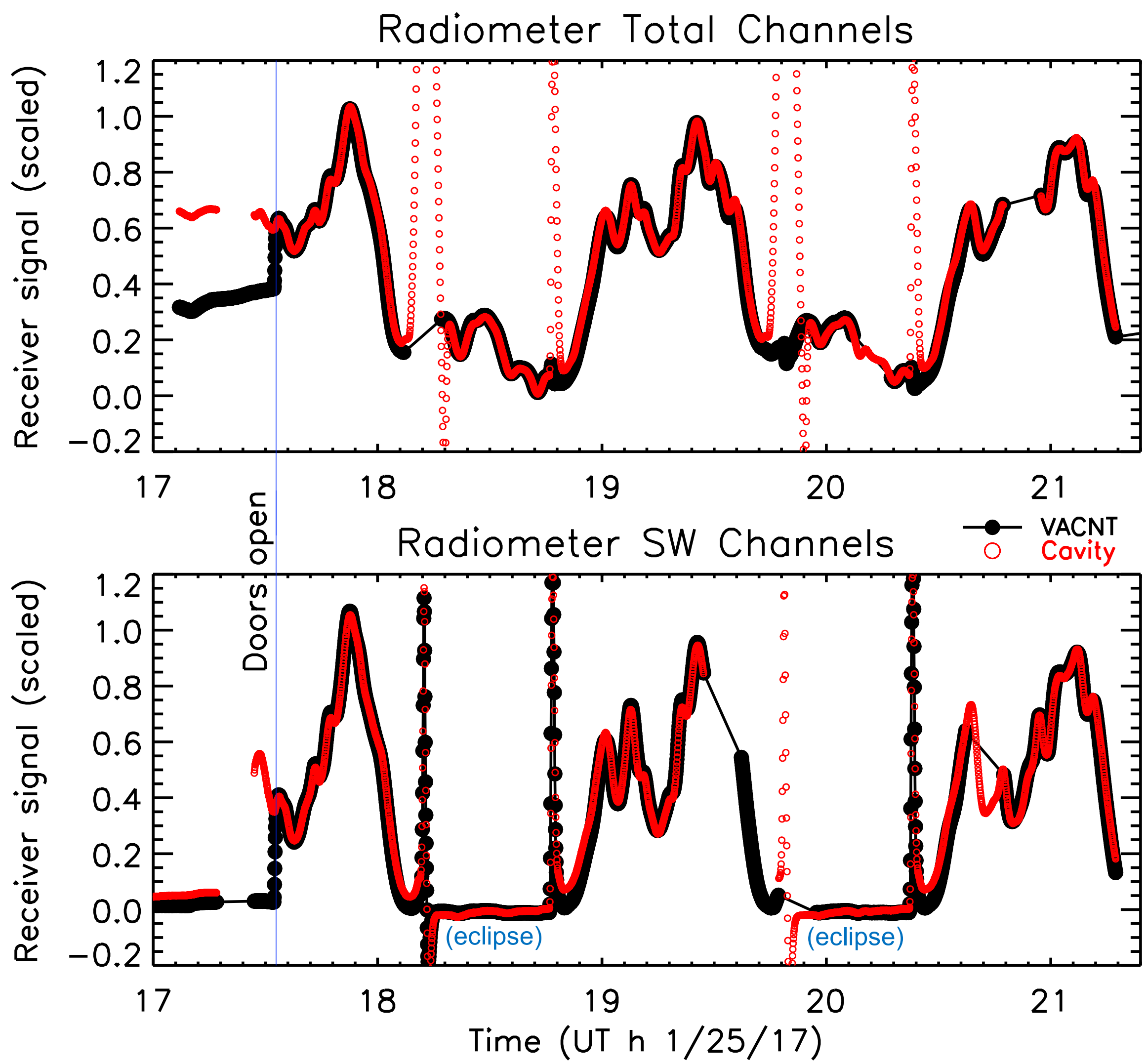
Temperature measurement near Ga cell

Controlled Ga transitions, as viewed by radiometers



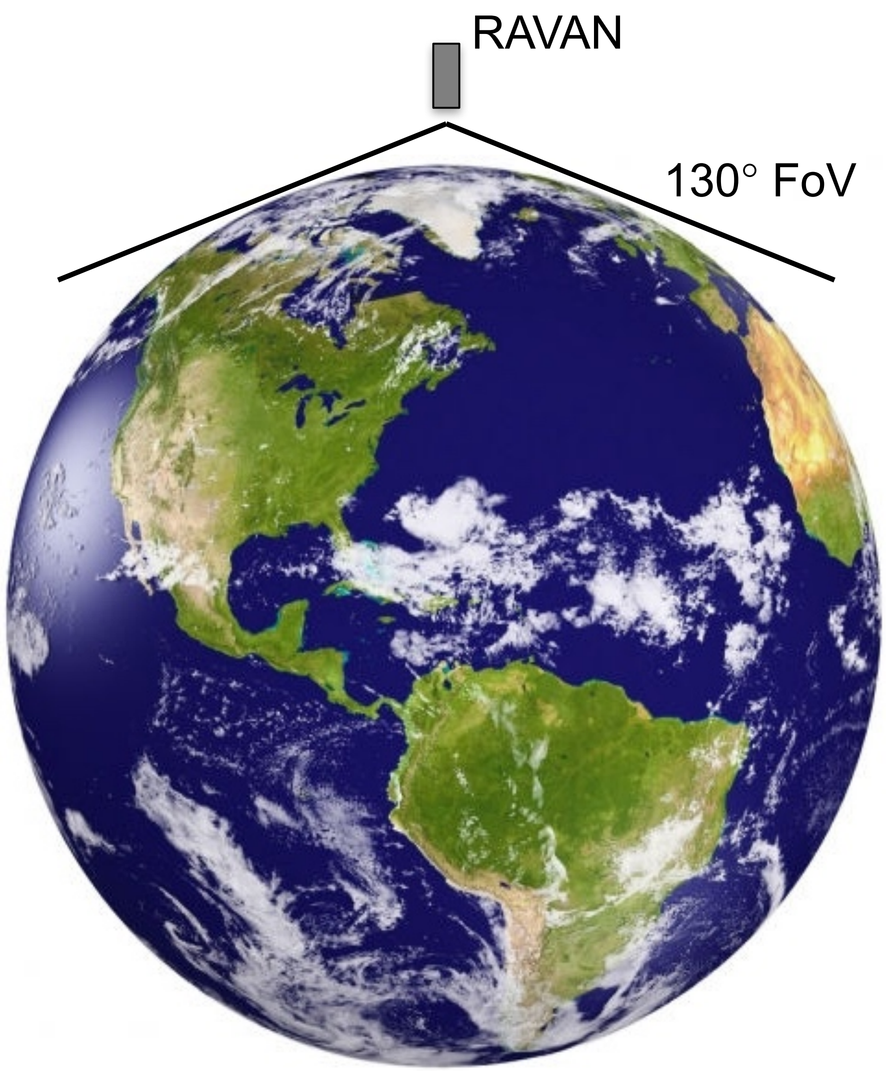
Data for the radiometer total channels

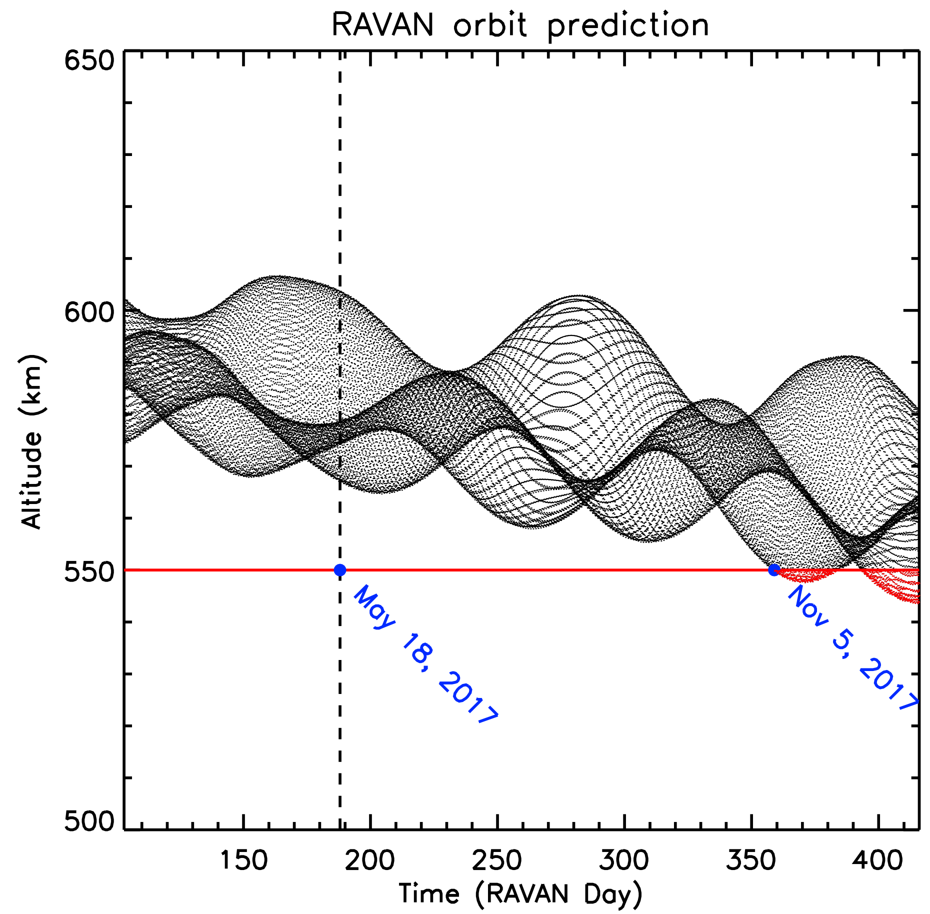
First light:
The VACNT and cavity radiometers track very well



Data spikes at terminator crossings likely due to glint

What's next?



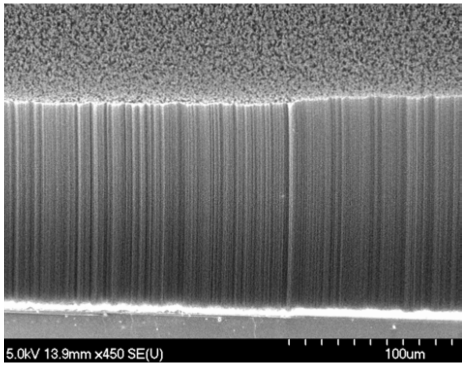


Next steps:

- Data analysis!
- Degradation monitoring
- LaRC visit

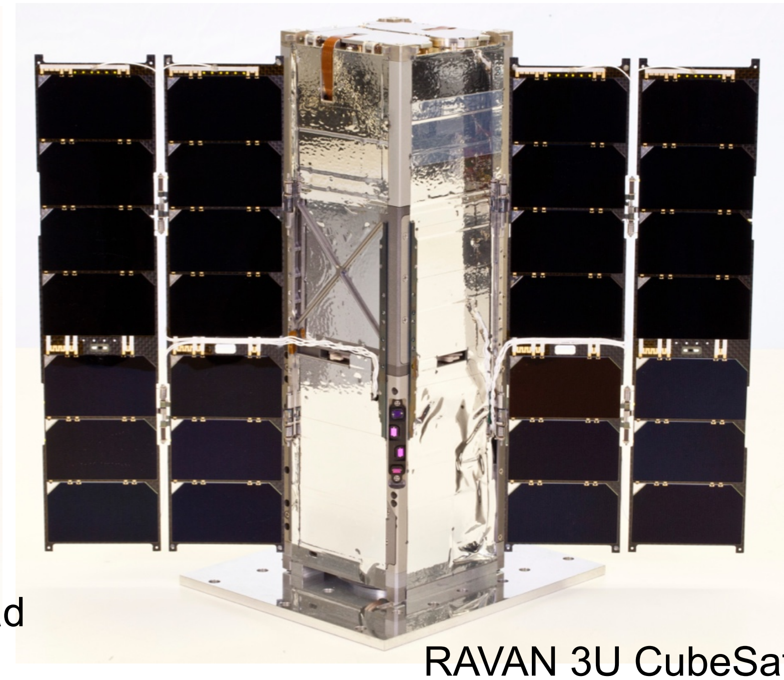
Summary: RAVAN as pathfinder

- RAVAN has met most mission objectives already
  - Collected enough data for basic technology demonstration
  - We have data for preliminary absolute calibration
  - More data needed for refinement and longer-term stability
- Looking forward to more analysis and measurements



Carbon nanotube forest

RAVAN payload



RAVAN 3U CubeSat

Funding: NASA
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