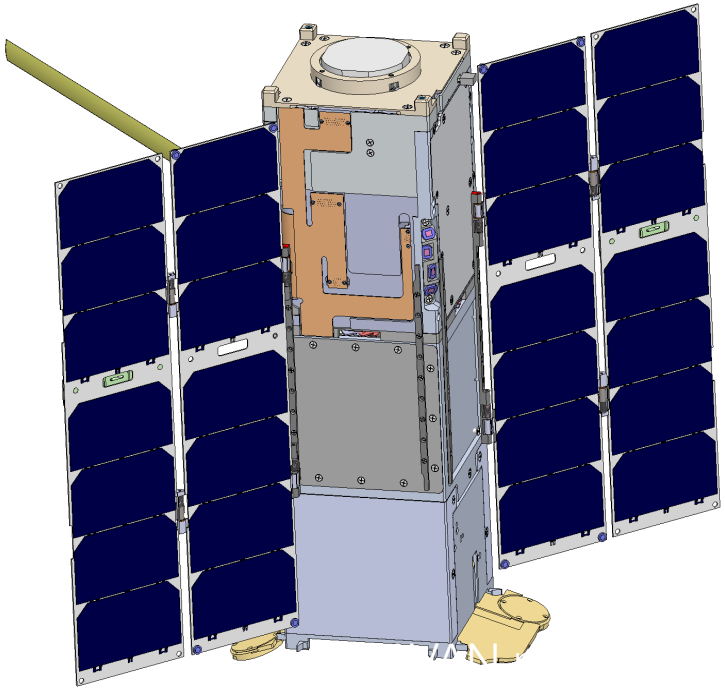
The RAVAN CubeSat Mission: Progress toward a new measurement of Earth outgoing radiation



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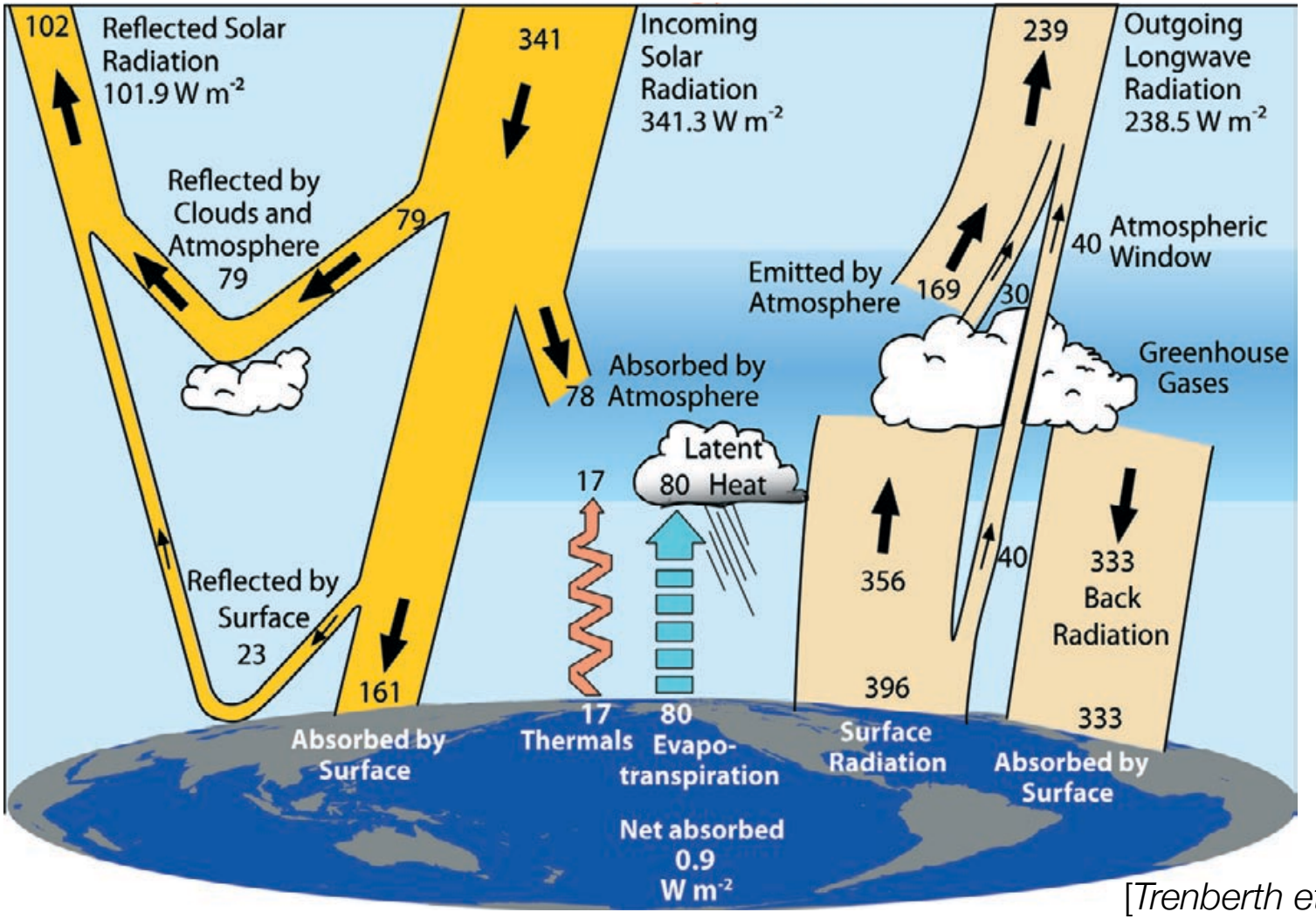
(ERI = Earth Radiation Imbalance)

ERI is most important quantity for climate change

Total Outgoing Radiation
TOR: SW

Total Solar Irradiance
TSI/4

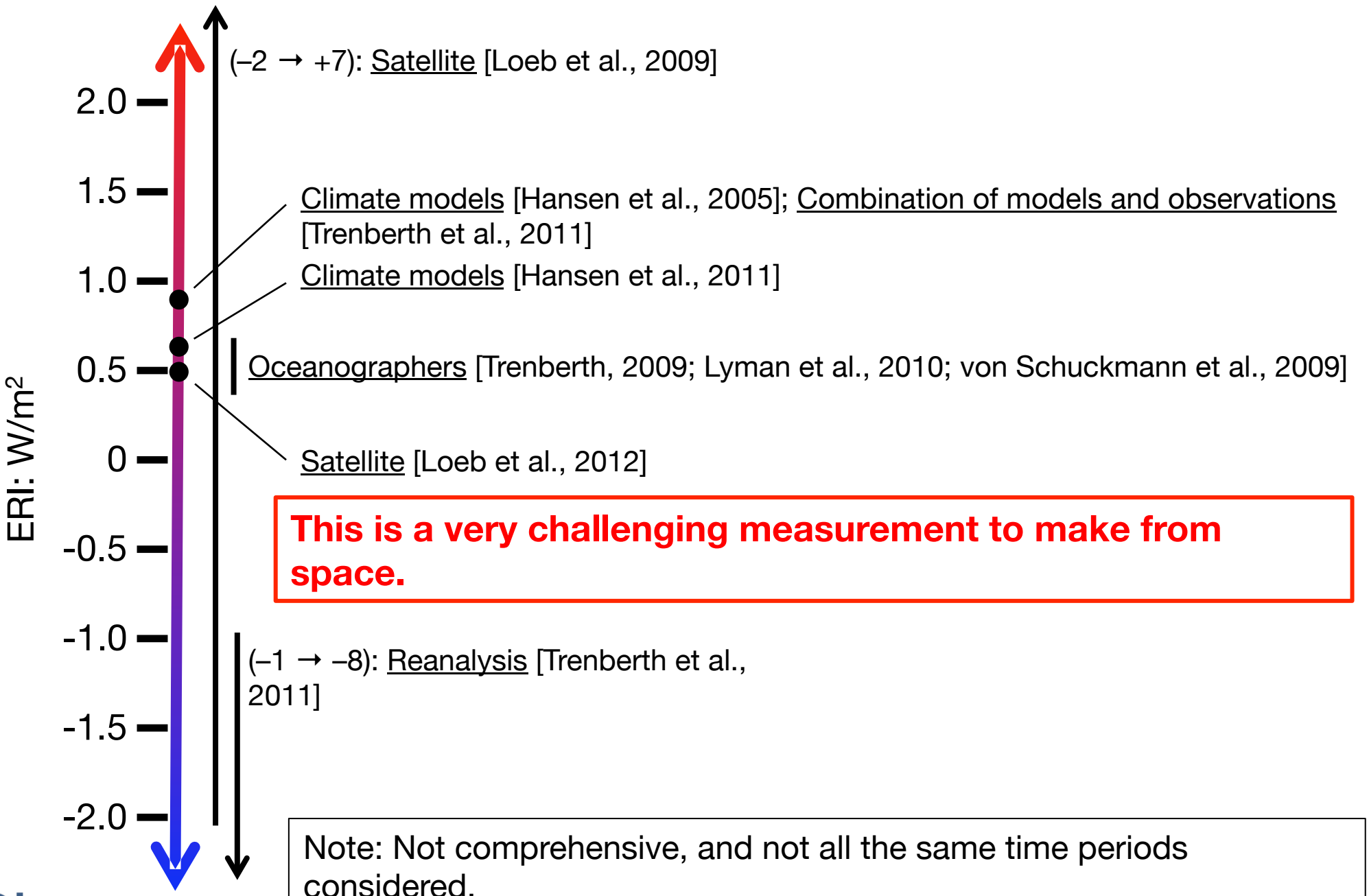
Total Outgoing Radiation
TOR: LW



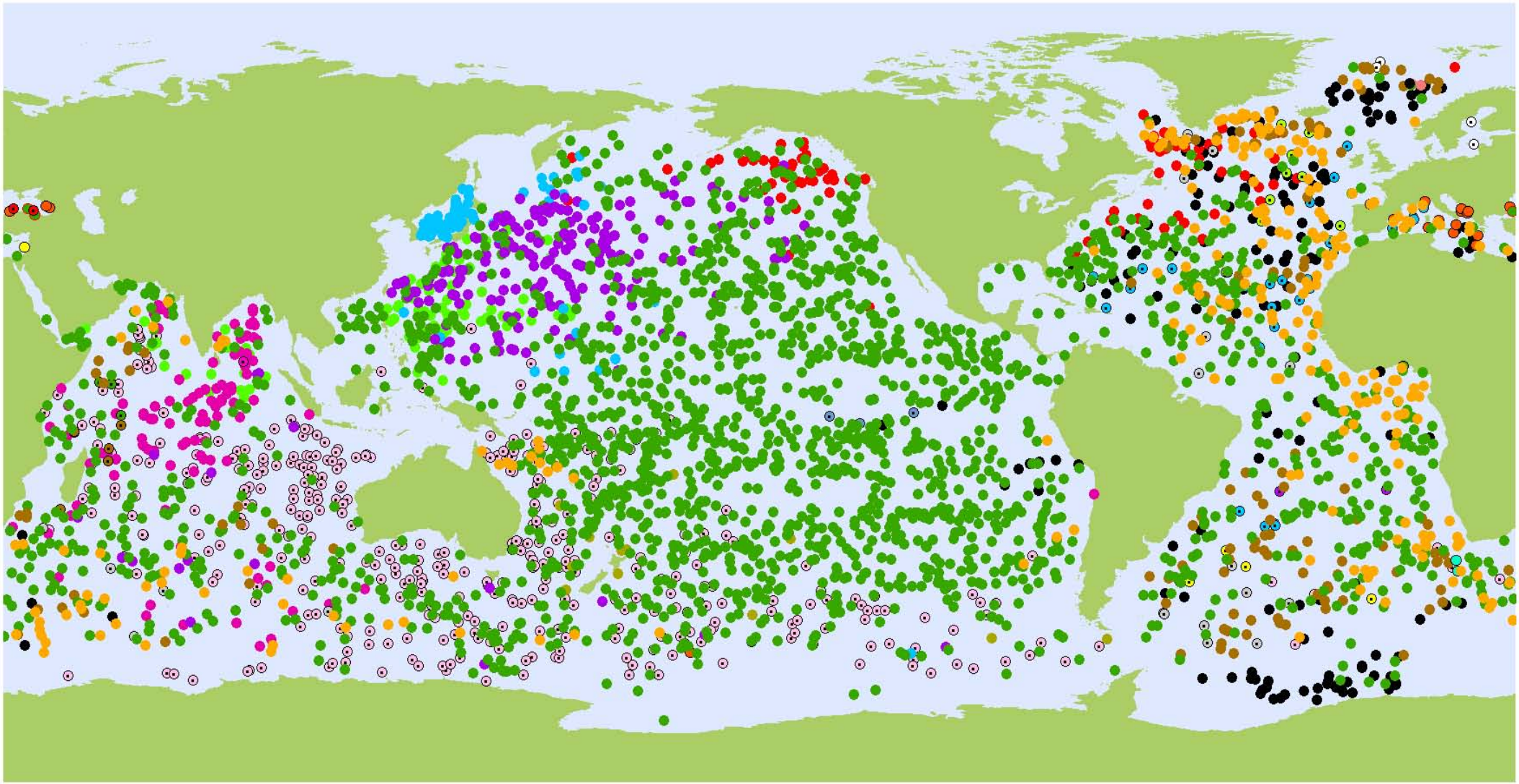
[*Trenberth et al.*, 2009]

$$\textbf{ERI} = \text{TSI}/4 - (\text{TOR}_{\text{SW}} + \text{TOR}_{\text{LW}}) \approx ?$$

The problem is the absolute value of ERI

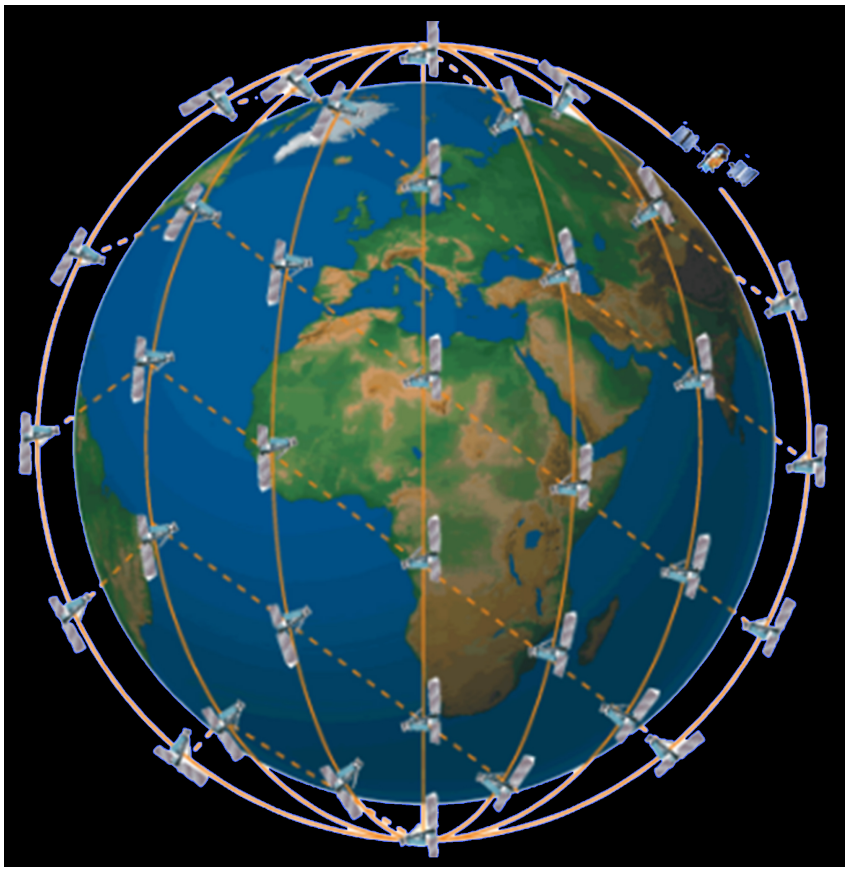


Argo network informs our view of OHC



What we need is an “Argo” in space for TOR

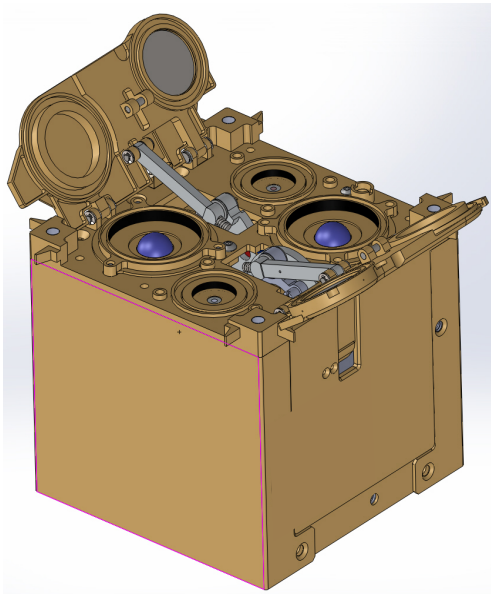
- Accurate, un-tuned measurements of TOR
- Global, simultaneous, 24/7 coverage
- Diurnal sampling of rapidly varying phenomena
  - Clouds
  - Plants
  - Ozone/photochemistry
  - Aerosols



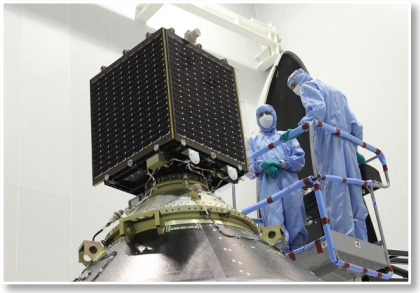
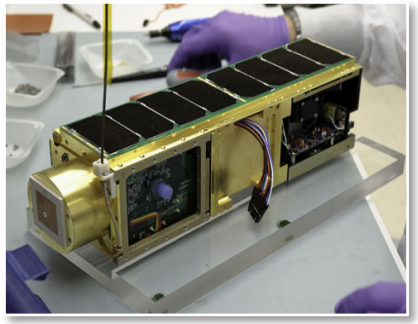
The maturation of smallsat/hosted payload and constellation technology provides an opportunity for taking a big step forward in Earth radiation budget science.

RAVAN is a pathfinder for 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)
  - Process engineering analysis (Draper)
- Launch in 2016(?)
- Is a **technology demonstration**

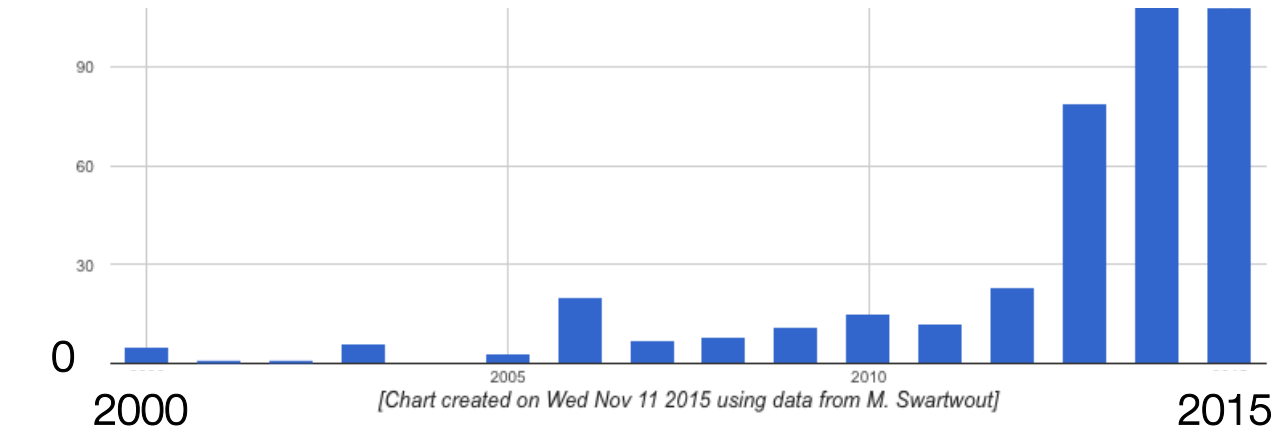


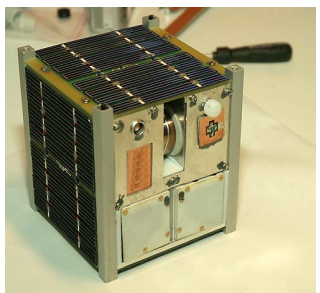
CubeSats are apparently impossible to define

Examples				
	 LANDSAT-8	 TACSAT-2	 PROBA-V	 O/OREOS
	Large	**Small (Mini)**	**Micro**	**Nano**
	> 500 kg	**<500 kg**	**<100 kg**	**<10 kg**

"CubeSats"

CubeSats launched each year, by mission type [*M. Swartwout database*]





1U CubeSat

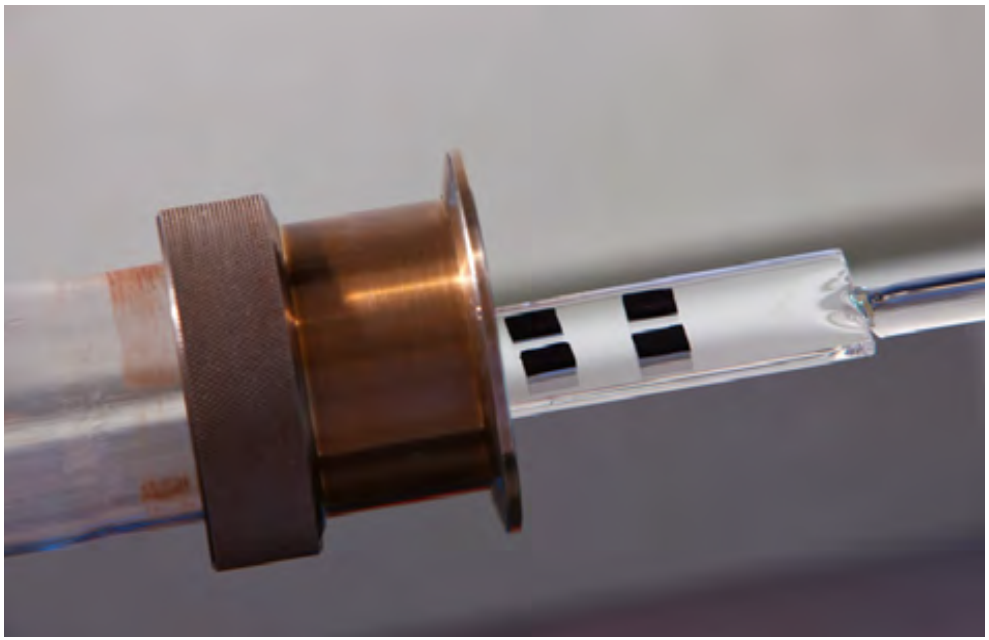
Classically based on
10 cm x 10 cm x 10 cm "Unit" (U)

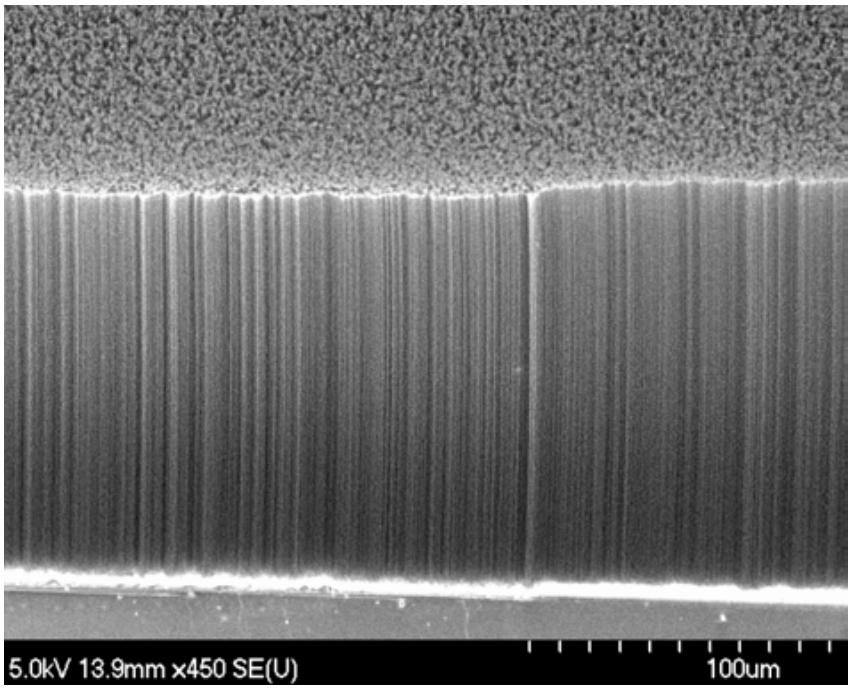
Why a CubeSat experiment?

- CubeSats provide a reasonably fast, inexpensive means to test new hardware and techniques on orbit.
- Increasingly used as a platform for science observations.

RAVAN Technology objective #1: VACNT

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

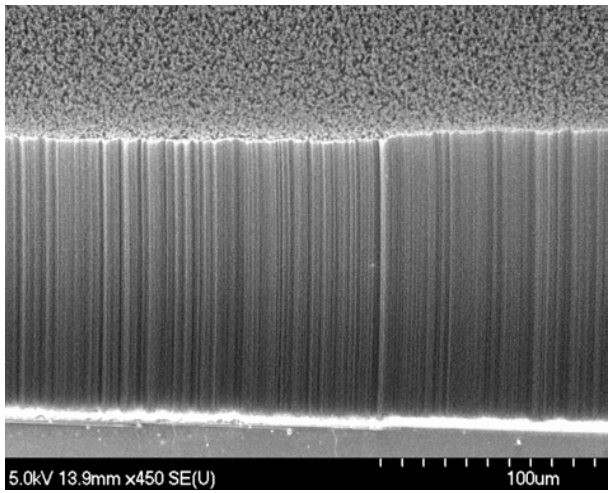


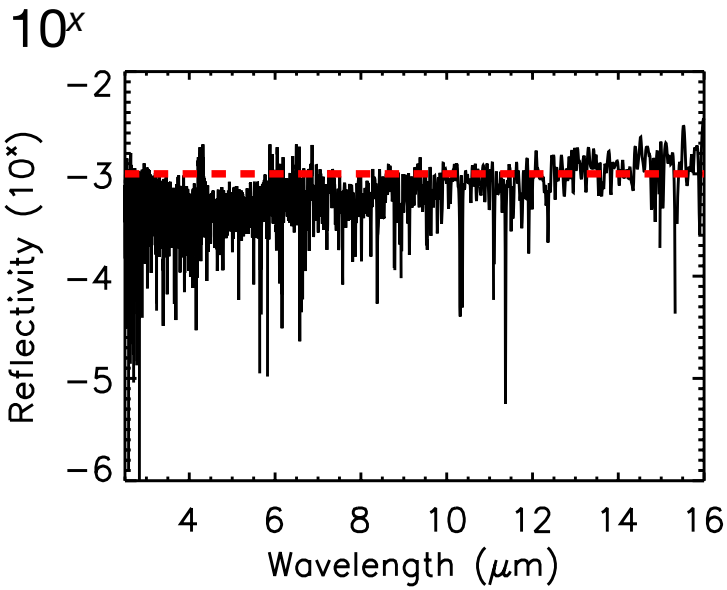


  - Very black, and spectrally flat from UV to far-IR
  - Fast(er) response time
  - Very low mass

VACNTs grown at APL

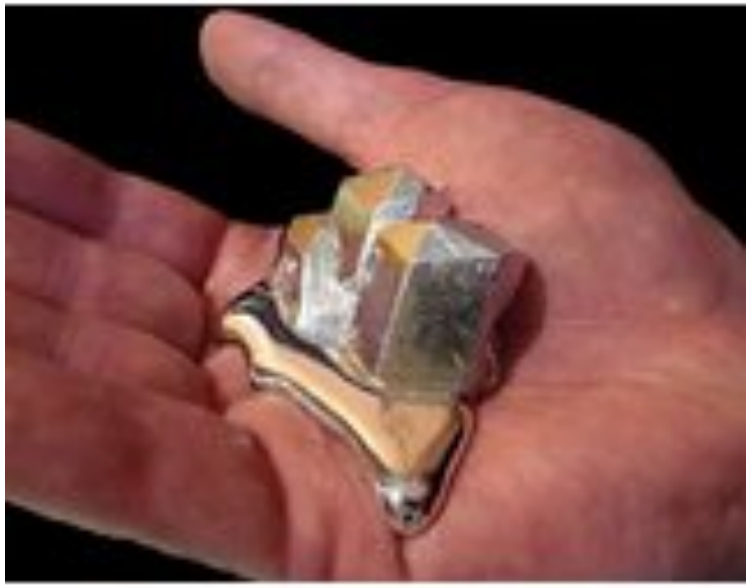
- Silicon wafer is covered with catalyst layer
- Chemical vapor deposition using ethylene as the carbon source is used to produce the VACNT growth
- Post-growth modification (vapor modifications, plasma etching)
- IR reflectivity measured to ~16 μm at APL
- Characterization (likely at NIST) to 100 μm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

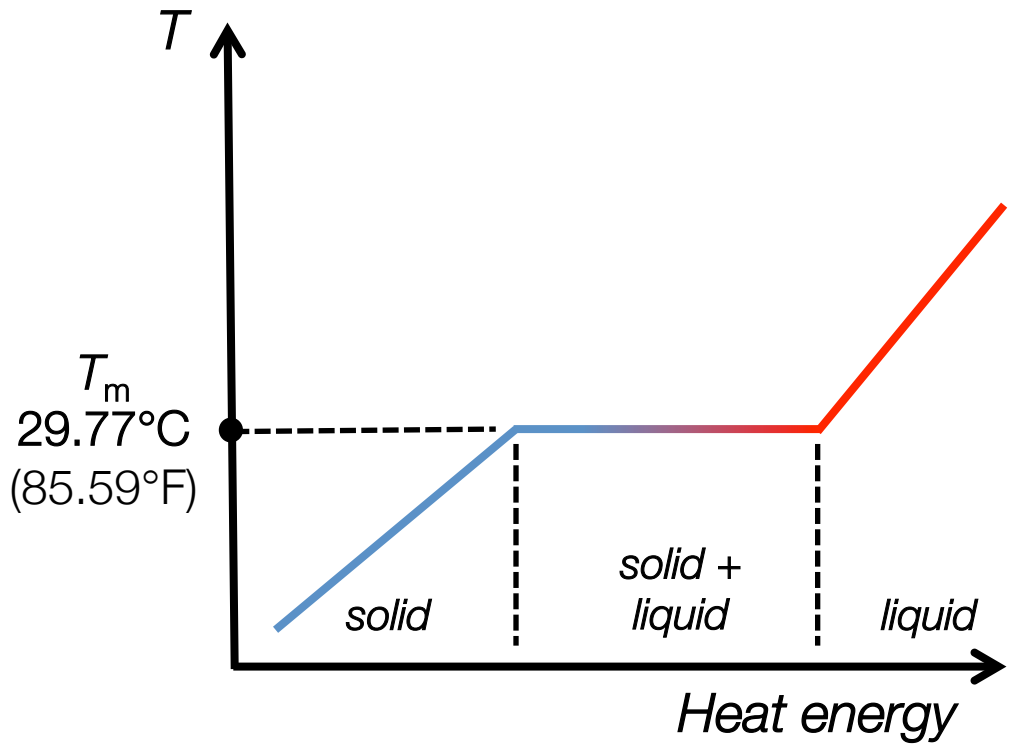




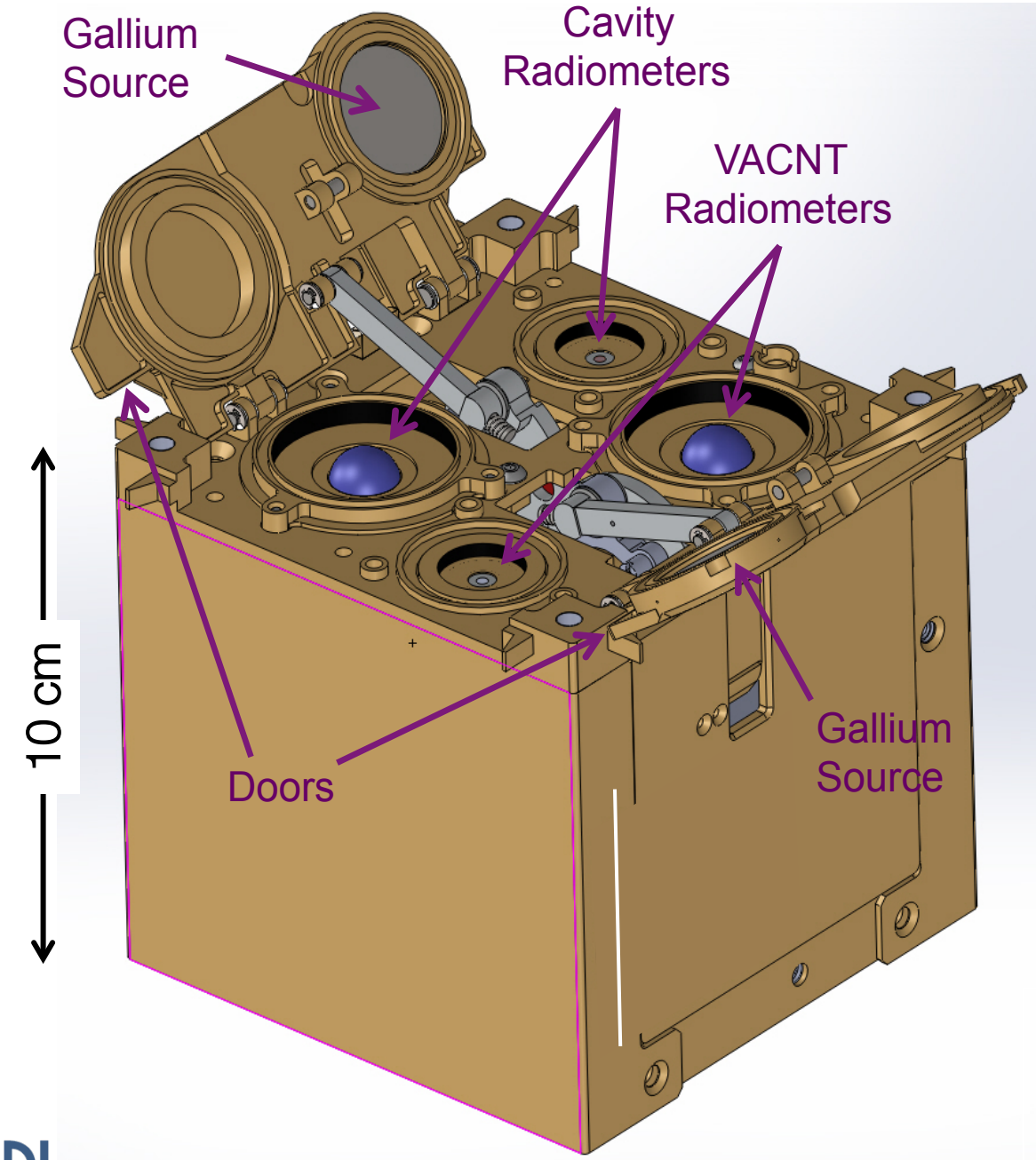
Technology objective #2: Gallium blackbody

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



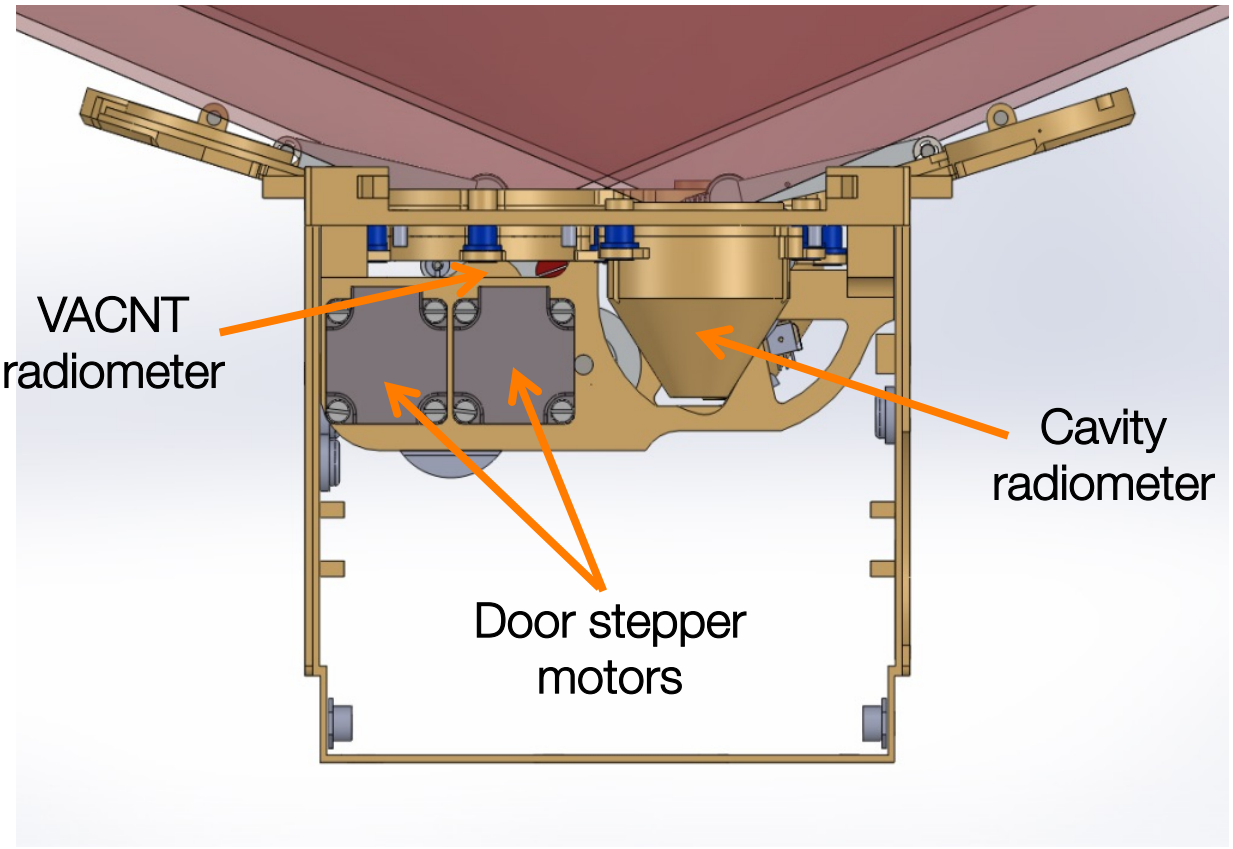


Payload includes four radiometer heads

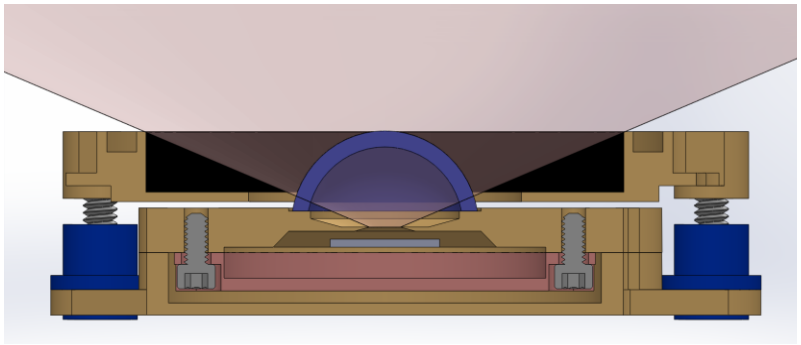


- Pair of two-channel differential bolometric sensors
  - Pair #1: VACNT absorber
  - Pair #2: Cavity absorber
- Total channel(s)
  - UV to 200 μm
- Shortwave channel(s)
  - Sapphire dome(s)
  - UV to ~5.5 μm
- Fixed-point gallium BB in cover (2)
- WFOV: ~130° (whole Earth disk)
- SMaP (payload only)
  - Size (volume): <1 U (10×10×10 cm^3)
  - Mass: <1 kg
  - Power: ~1.9 W (average)

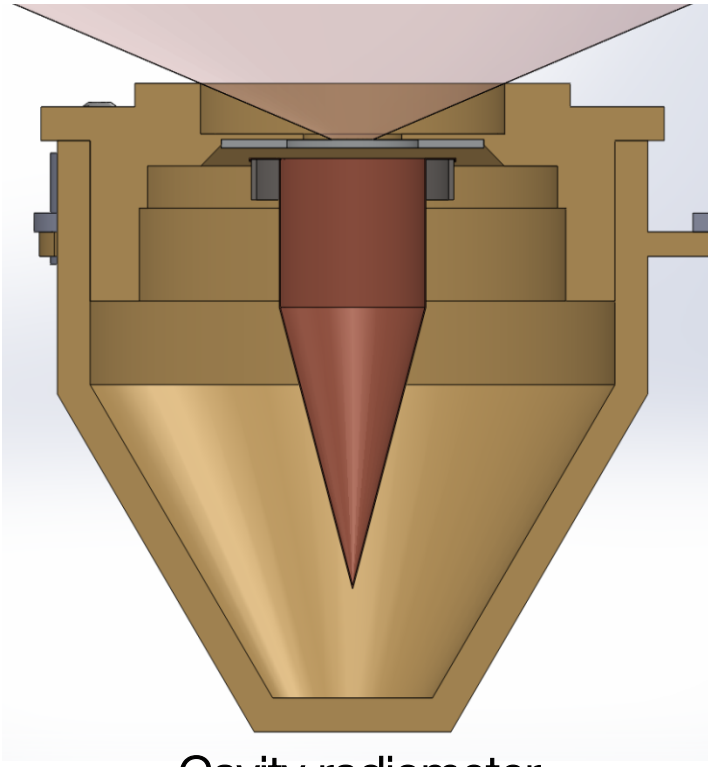
VACNT radiometers smaller and faster



(payload electronics not shown)

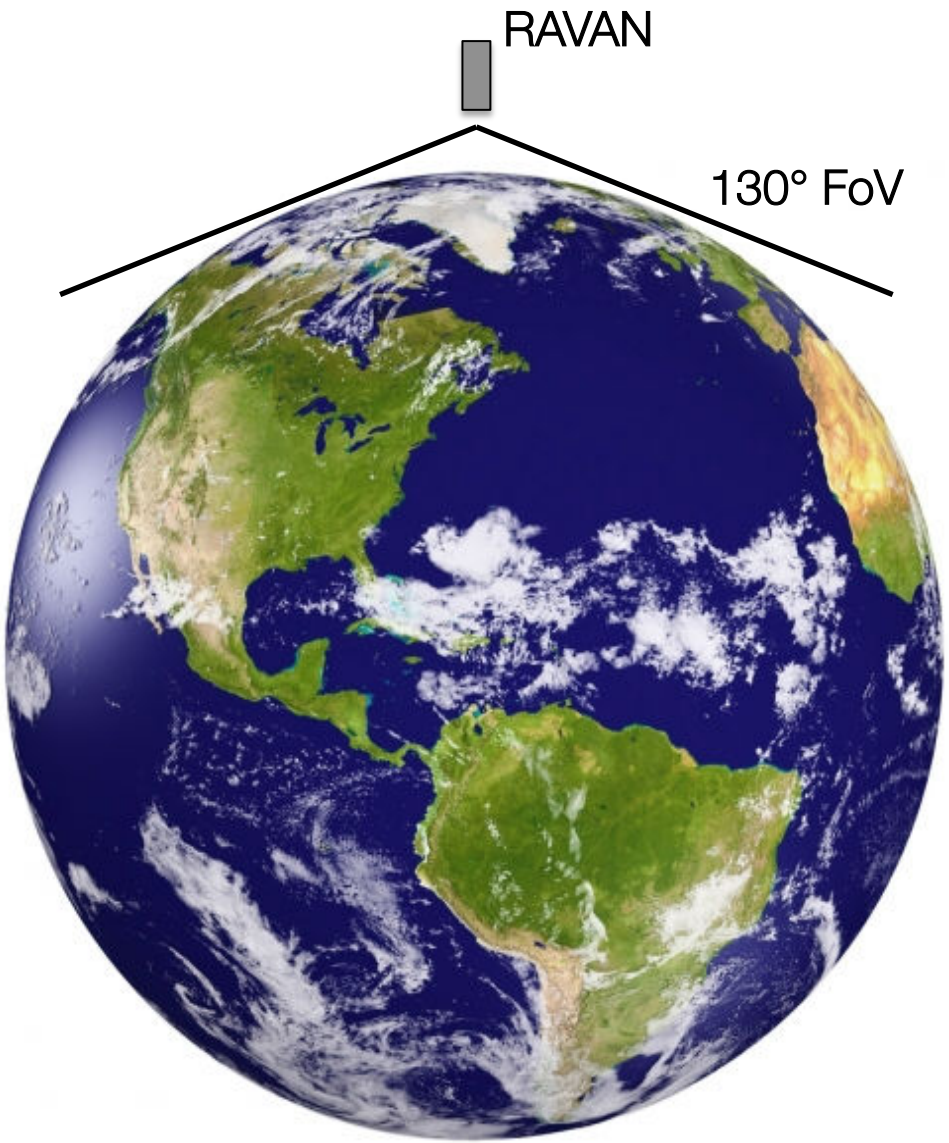


VACNT radiometer



Cavity radiometer

Earth disk subtends RAVAN FoV



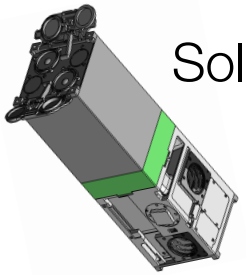
RAVAN capability objectives

- **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

Getting to climate accuracy

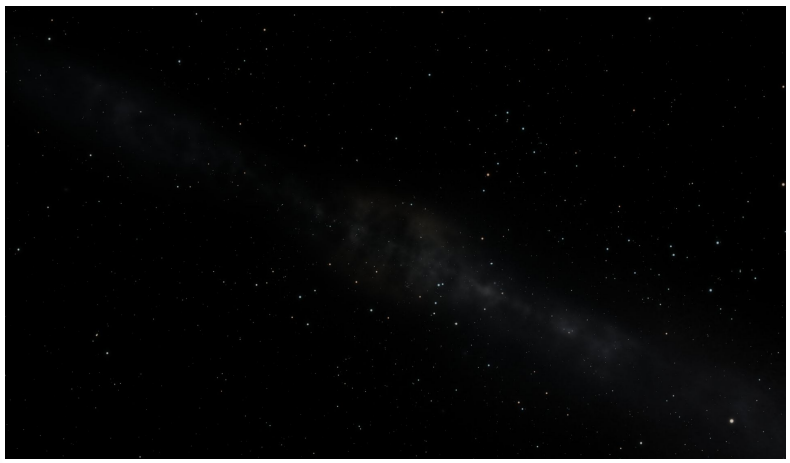
- **Ground calibration (at L-1)**
  - Component-level and end-to-end calibrations
    - Tied directly to NIST
    - Operational level cal in TVAC chamber
    - Laser-based measurements (SW channel)
  - Fixed-point gallium BB (Total channel)
    - 1σ 0.005K (0.03 W/m^2)
- **On-orbit calibration: Ga blackbody 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
- **Modes of operation/calibration (next slide)**

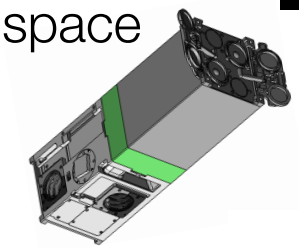
Multiple modes calibrate instrument on-orbit



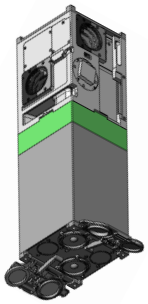
Solar

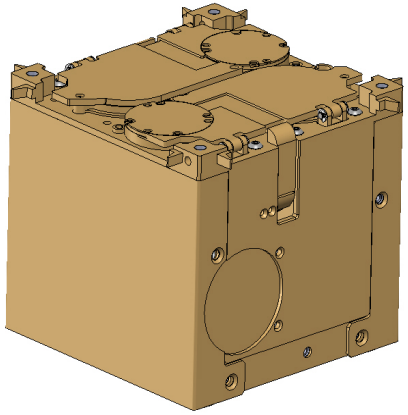
Deep space



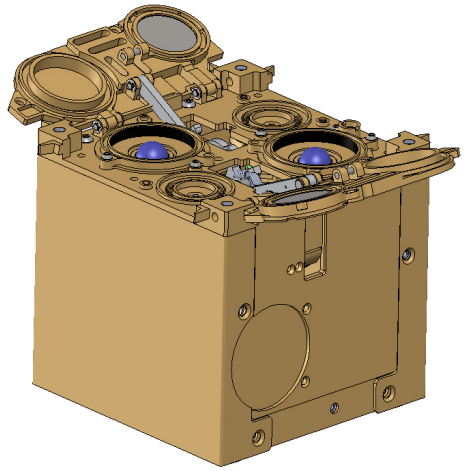


Nadir

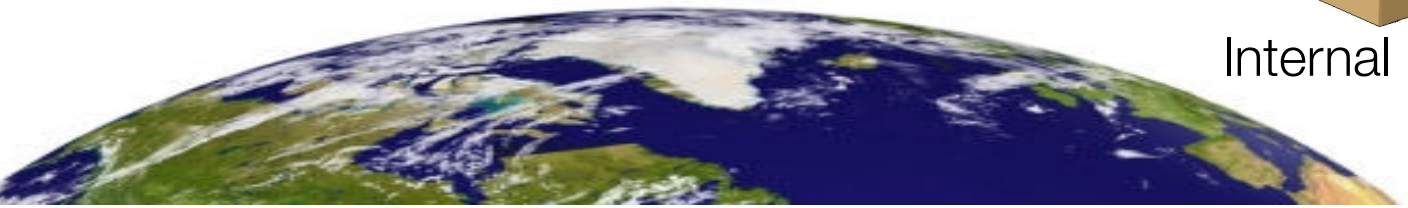




Internal (Ga BB)

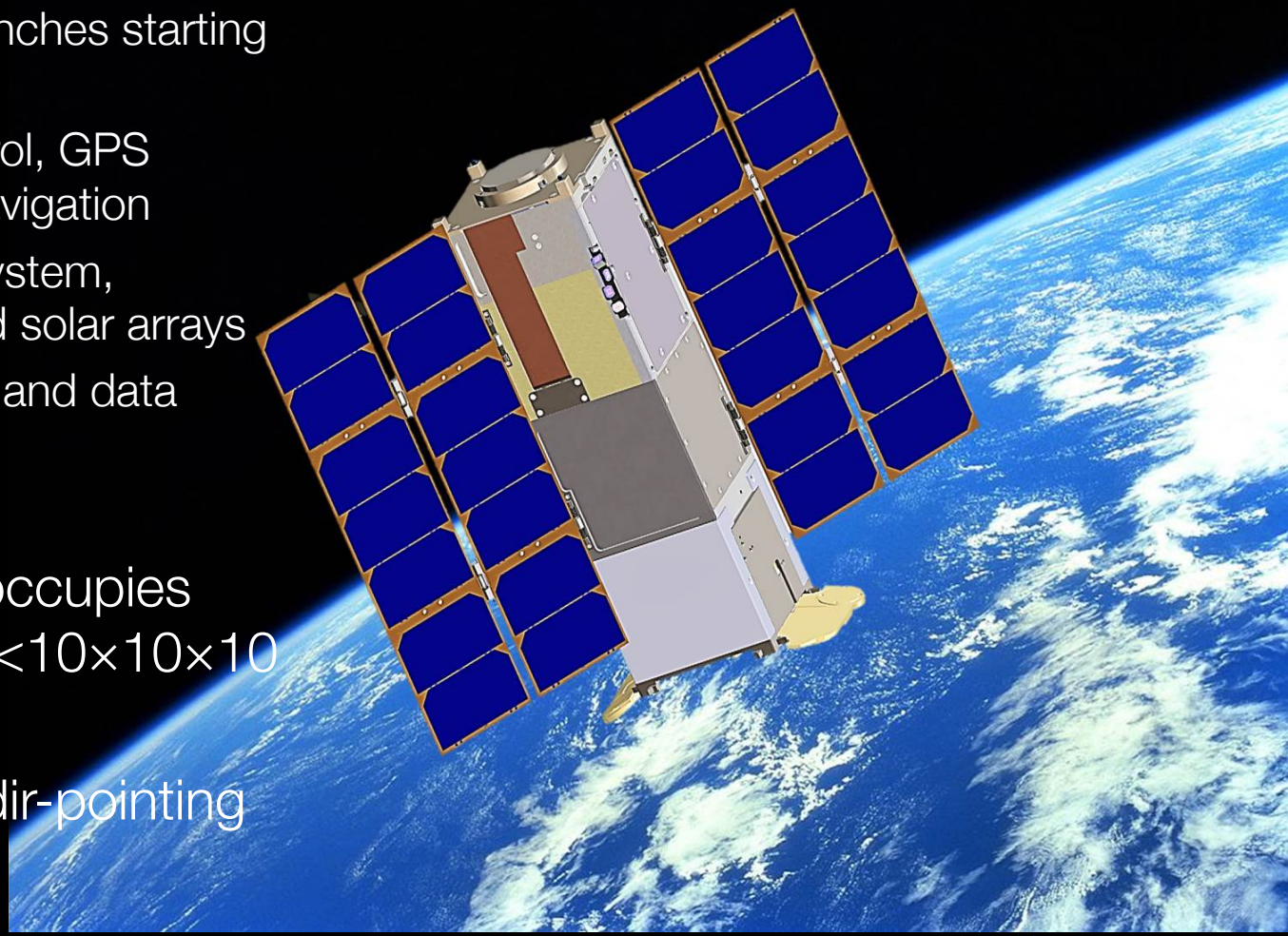


Cross-cal



RAVAN will fly on a 3U CubeSat

- Using Blue Canyon Technologies XB1 3U bus
  - Integrated XACT attitude determination and control system (several upcoming launches starting in fall 2015)
  - GN&C for 3-axis control, GPS receiver, and stellar navigation
  - Electrical power subsystem, including batteries and solar arrays
  - Spacecraft command and data handling
  - RF communications
- Radiometer payload occupies less than 1U volume (<10×10×10 cm^3)
- Sensor is typically nadir-pointing



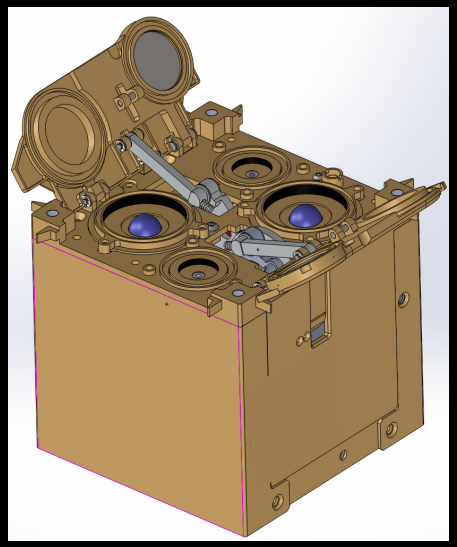
Mission parameters to achieve objectives

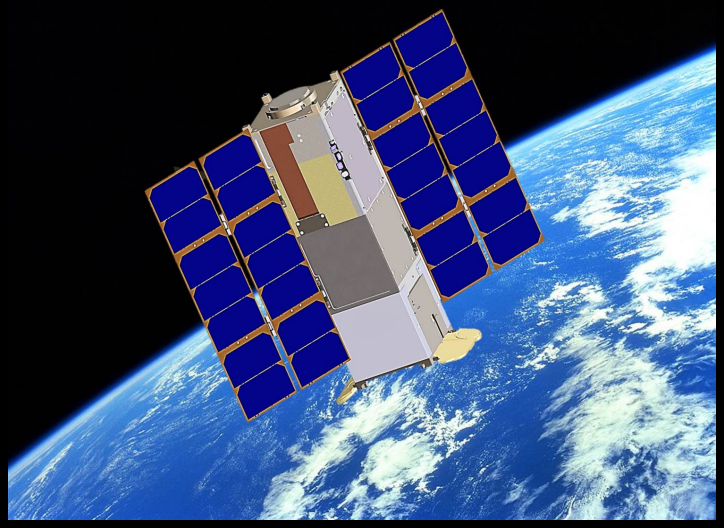
- Orbit
  - Provided by NASA's CubeSat Launch Initiative
  - Desire high (>550 km), high-inclination, not sun-sync orbit…or sun-sync similar to CERES
  - Waiting in queue; Possible launch date: 2016
- Mission operations
  - 1 month check-out
  - 4 months minimum operation for demonstration (achieves technology and science goals)
  - >1 year operation desired (allows for more TOR data for comparison with CERES)

RAVAN

Radiometer Assessment Using Vertically Aligned Nanotubes

- RAVAN demonstrates key technologies (VACNT absorber, Ga blackbody) for possible ERB mission
- Flying on a 3U CubeSat
- Launch 2016(?)





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