Current Research in High-Accuracy Radiometers for Solar and Earth Observations

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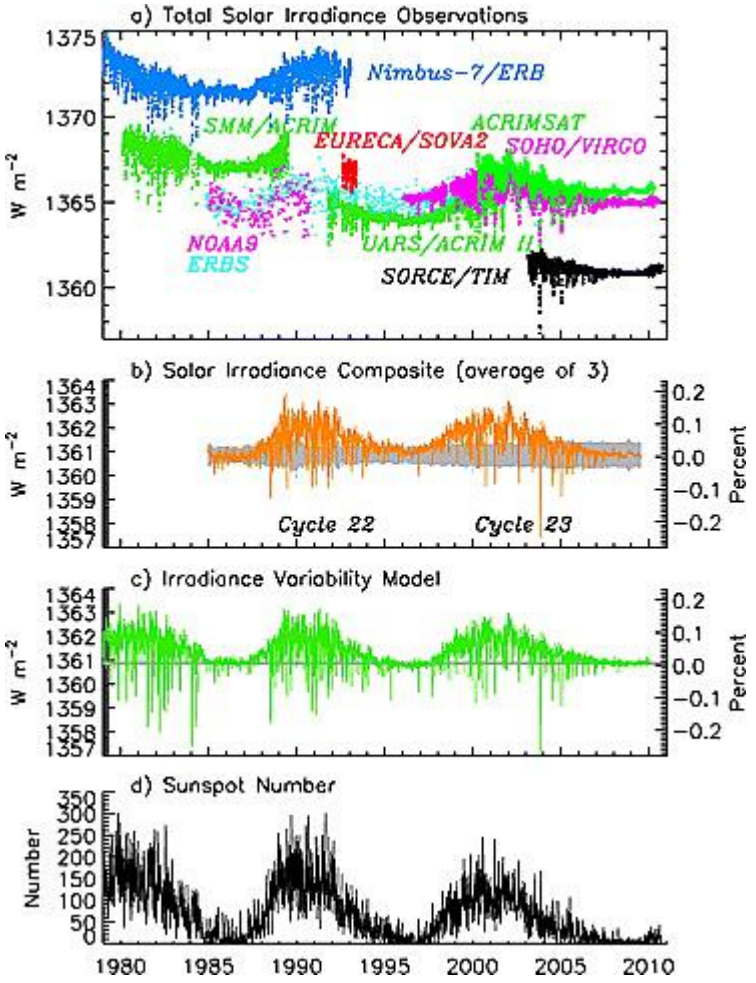
NIST National Institute of Standards and Technology U.S. Department of Commerce

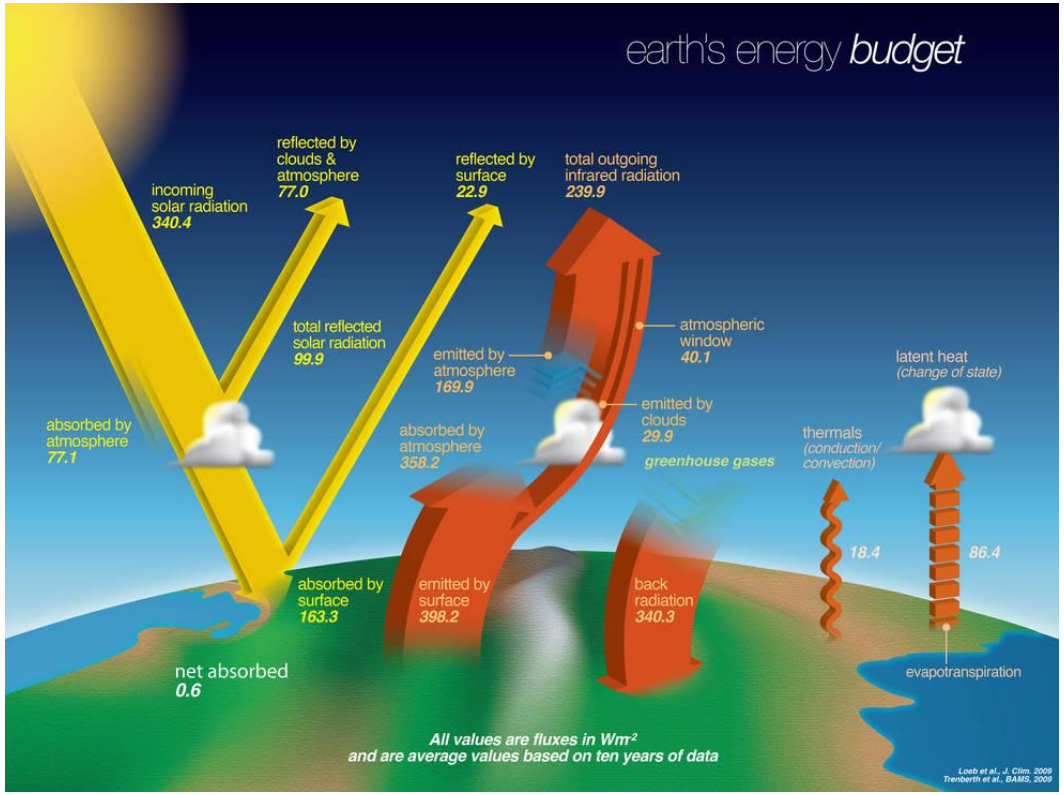
LASP Laboratory for Atmospheric and Space Physics

NASA

Why Solar and Earth Radiometers?



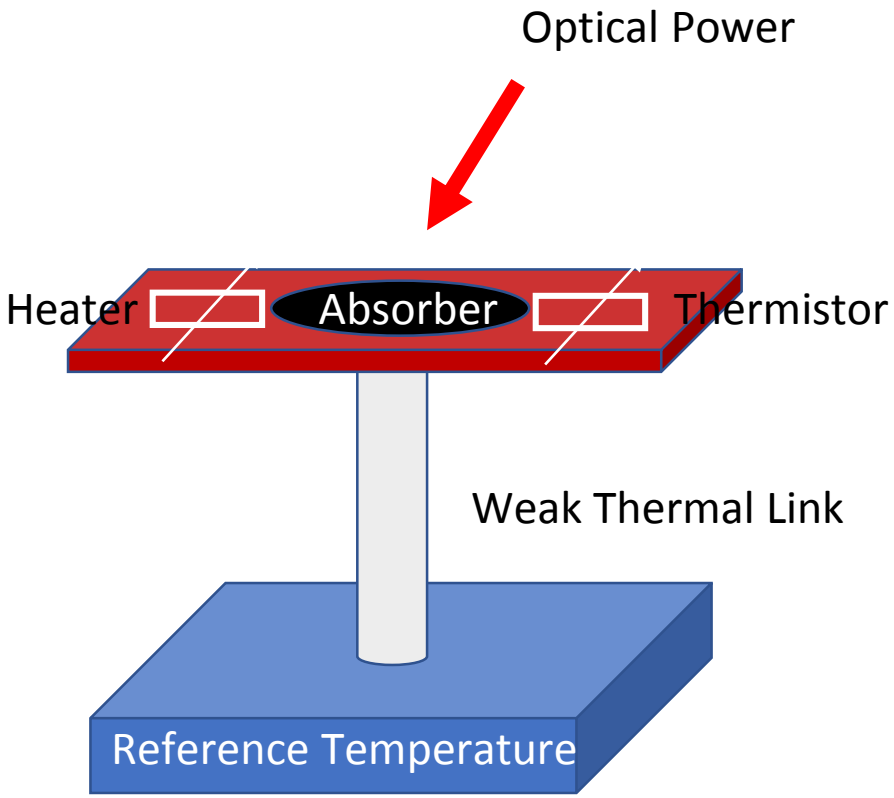
Greg Kopp and Judith L. Lean, Geophysical Research Letters 38 (2011),



Credit: NASA

- The Earth's climate responds globally to even small variations in the solar irradiance
- Accurate, long-term measurements establish energy balance records

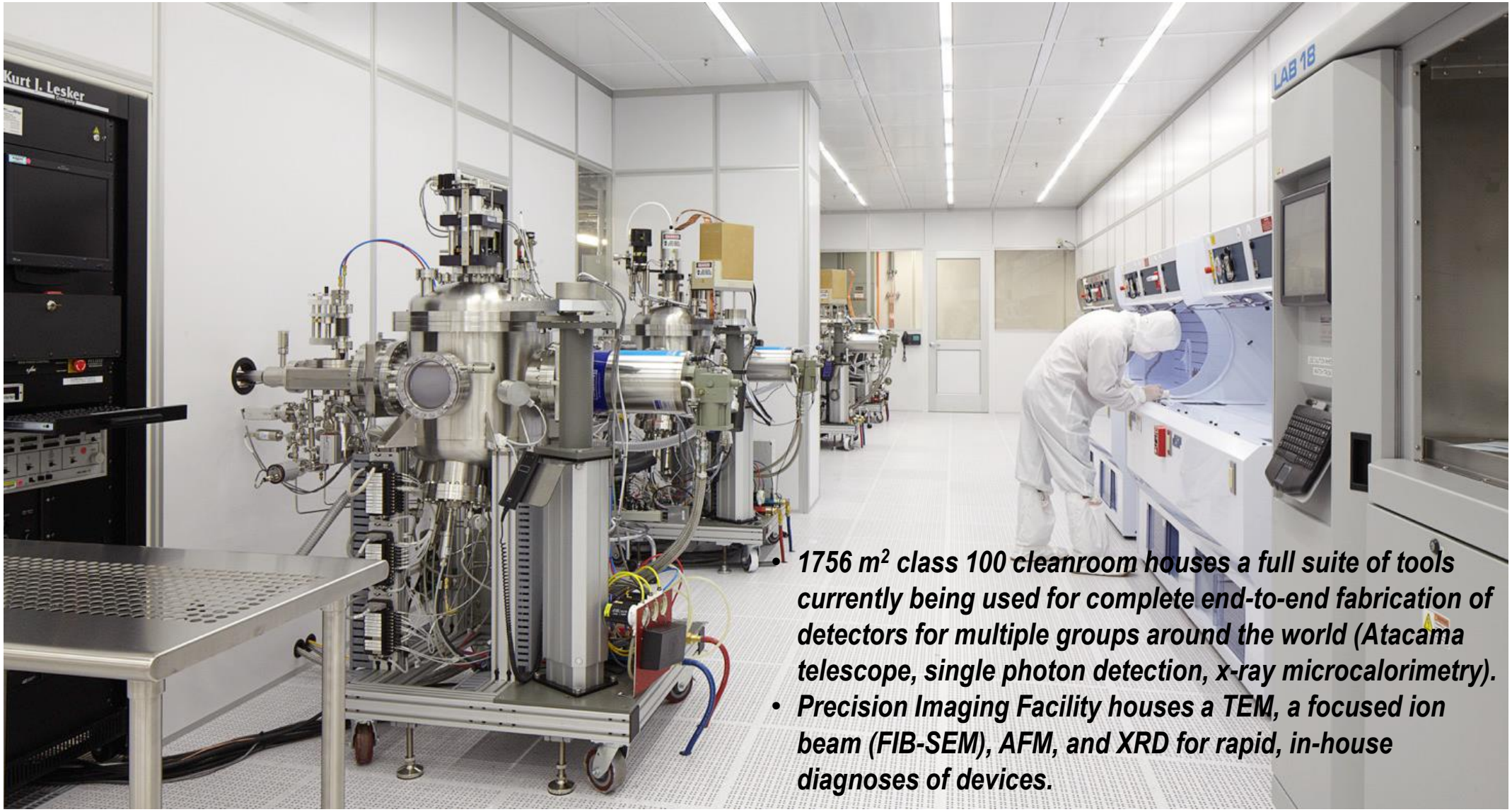
Why NIST?



Optical Power Traceable to the SI by Electrical Measurements
resistance, current, voltage

- Electrical substitution provides absolute measurement
- In-house fabrication of MEMs bolometers
- Vertically aligned carbon nanotubes (VACNTs) absorbers provide > 99.9% absorptivity in VIS-NIR, >99% absorptivity to > 100 μm wavelength

Boulder Micro-fabrication Facility and Precision Imaging Facility



- *1756 m^2 class 100 cleanroom houses a full suite of tools currently being used for complete end-to-end fabrication of detectors for multiple groups around the world (Atacama telescope, single photon detection, x-ray microcalorimetry).*
- *Precision Imaging Facility houses a TEM, a focused ion beam (FIB-SEM), AFM, and XRD for rapid, in-house diagnoses of devices.*

Vertically Aligned Carbon Nanotube Growth at NIST

- **Multiple depositions/growths are possible in one day.**
  - **Controllably grow *vertically aligned* CNTs (VACNTs) of desired height.**
  - **Reliably grow CNTs on various substrates – Si, SiO_2, SiN_x, diamond is under development**

Sputter tool – catalyst deposition

Bi-layer catalyst:

Aluminum oxide ~10 nm

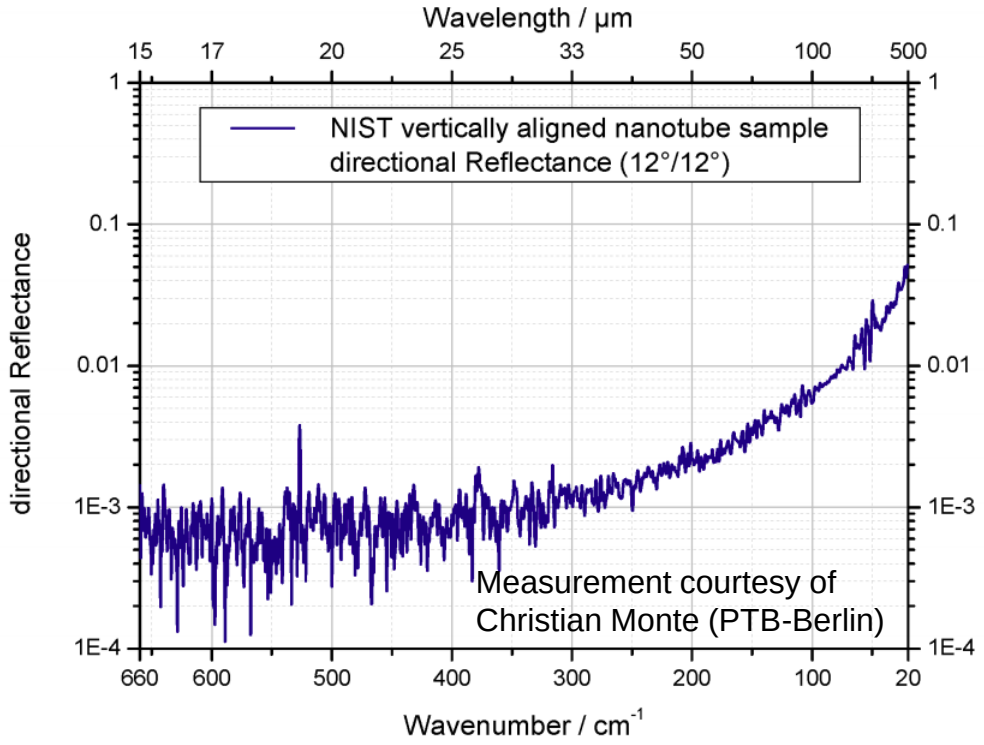
Iron ~2 nm

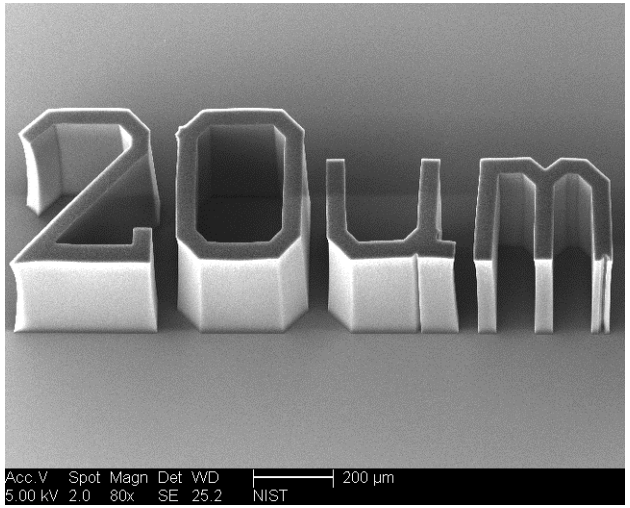
PECVD system – CNT growth

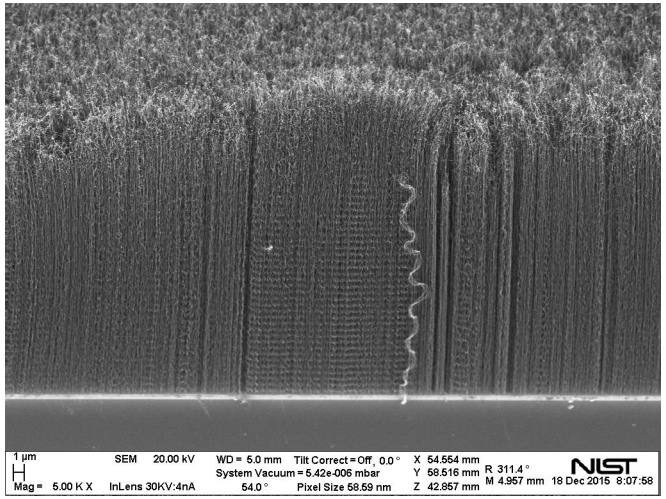
Temperature: 700 – 800 C
Pressure
Gas: CH_4 or C_2H_4
Ratios: Ar : H_2 : CH_4 : C_2H_4

Flow rates
Plasma power
DC bias

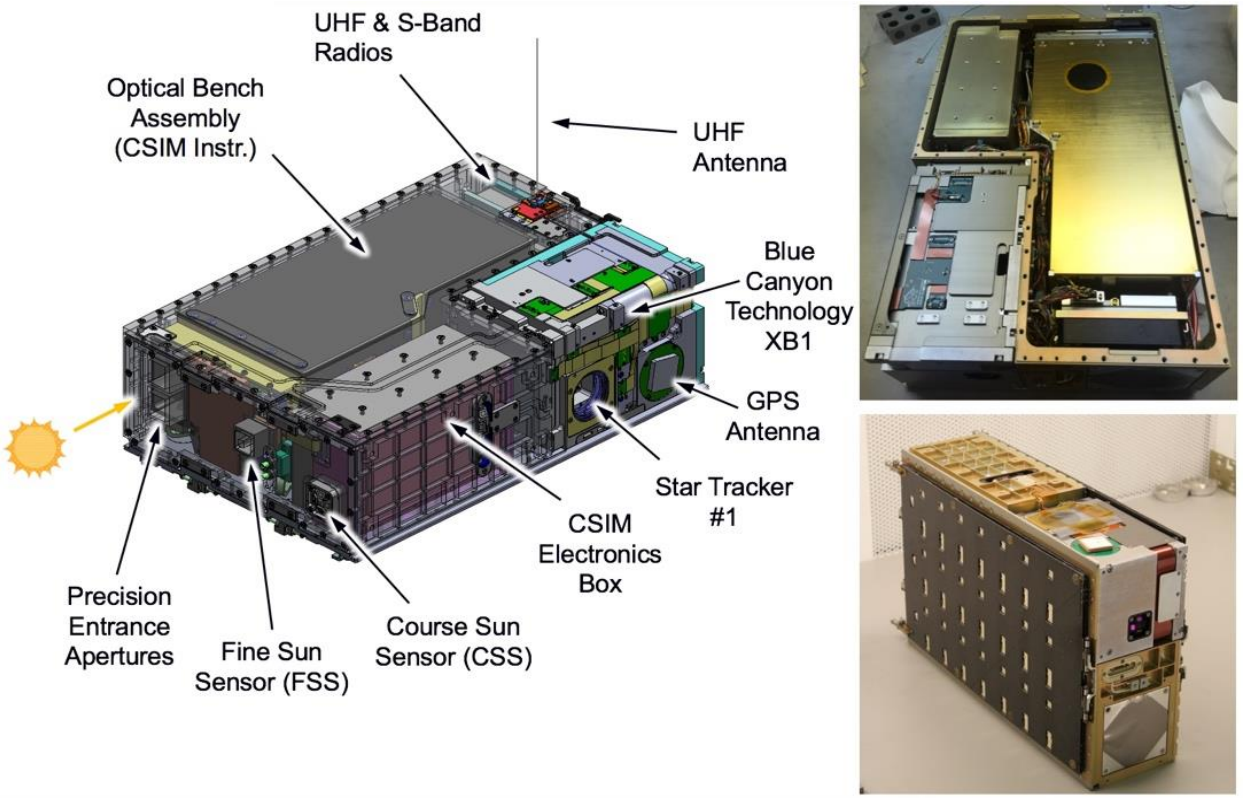
More on VACNTs

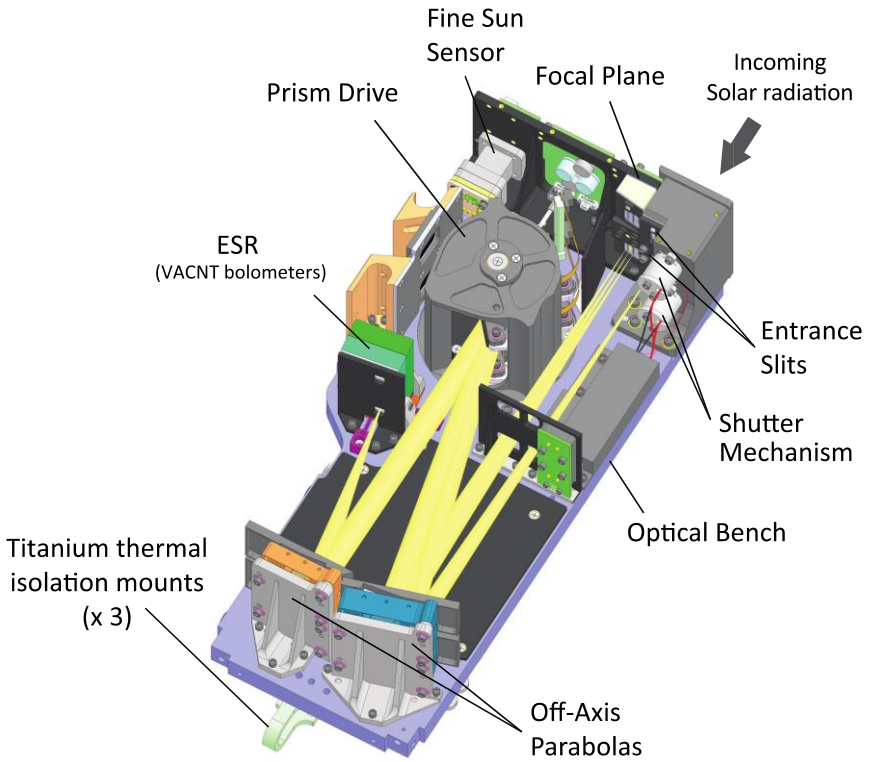






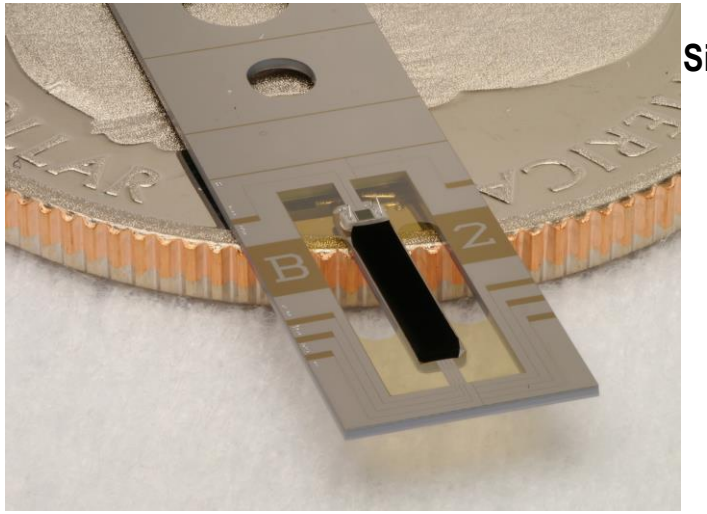
Compact Spectral Irradiance Monitor (CSIM)



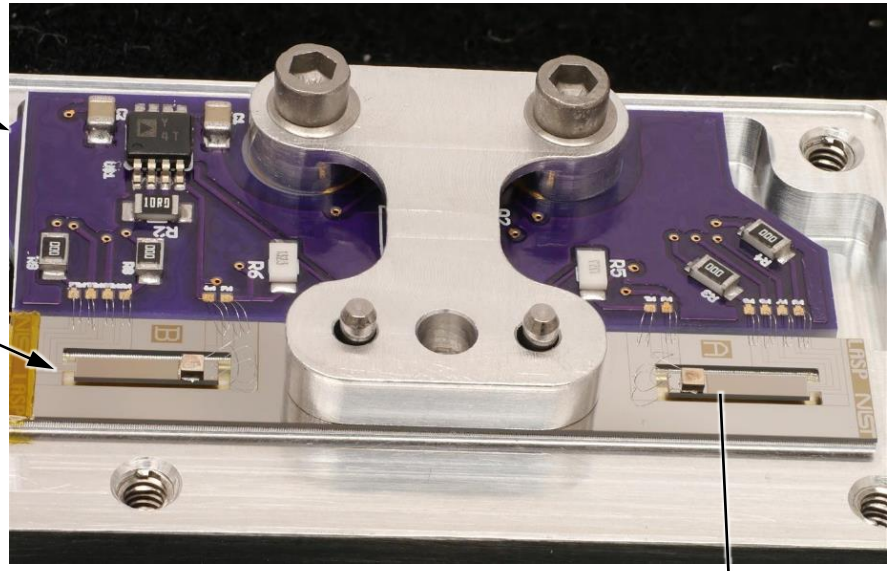


- 6U CubeSat launched on Dec. 3rd, 2018
- Demonstrate capabilities of solar spectral irradiance mission in low mass, compact design

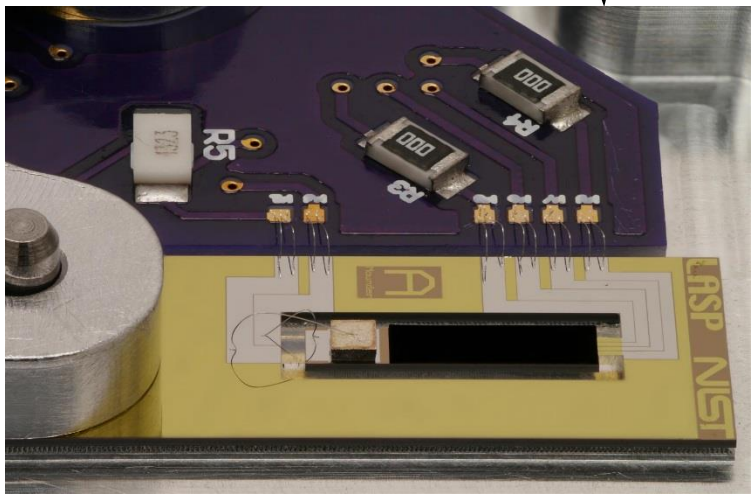
Erik Richard et al., "Compact spectral irradiance monitor flight demonstration mission," Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III, 1113105 (2019)

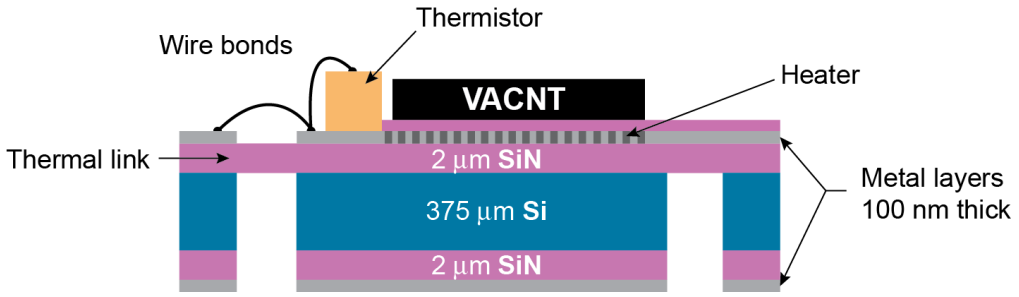


Credit: Nathan Tomlin, NIST

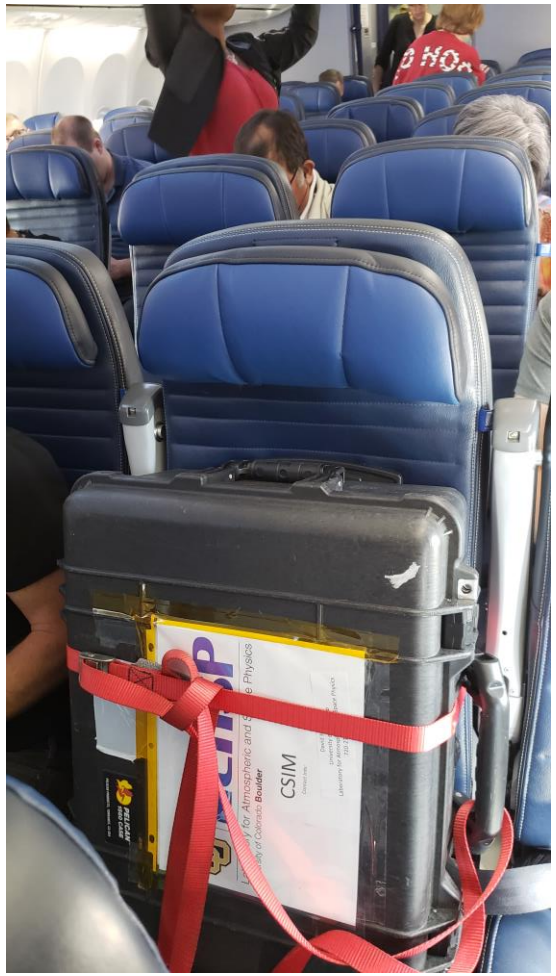


Credit: Dave Harber, LASP





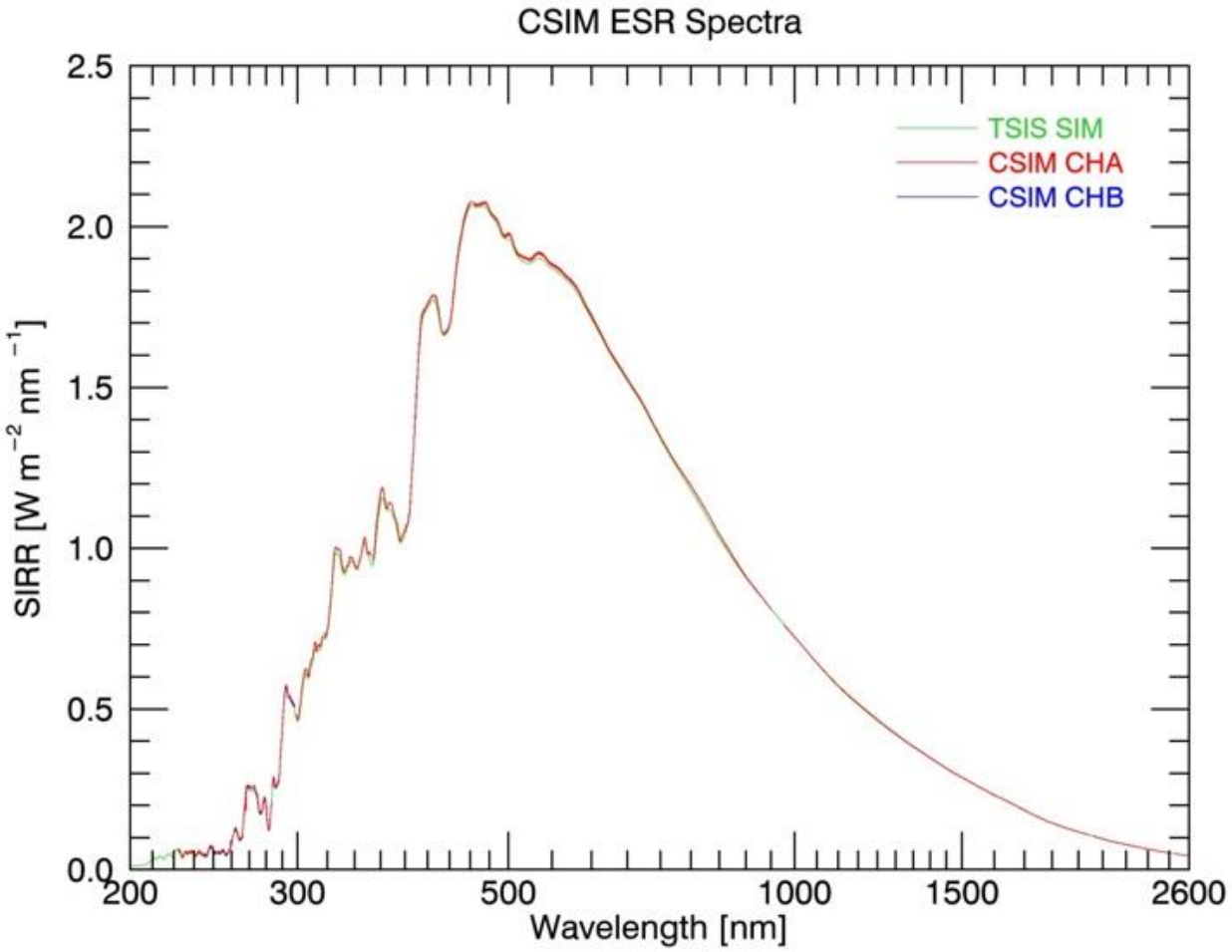
Launched Dec. 3rd, 2018 on SpaceX SSO-A: SmallSat Express



Credit: LASP

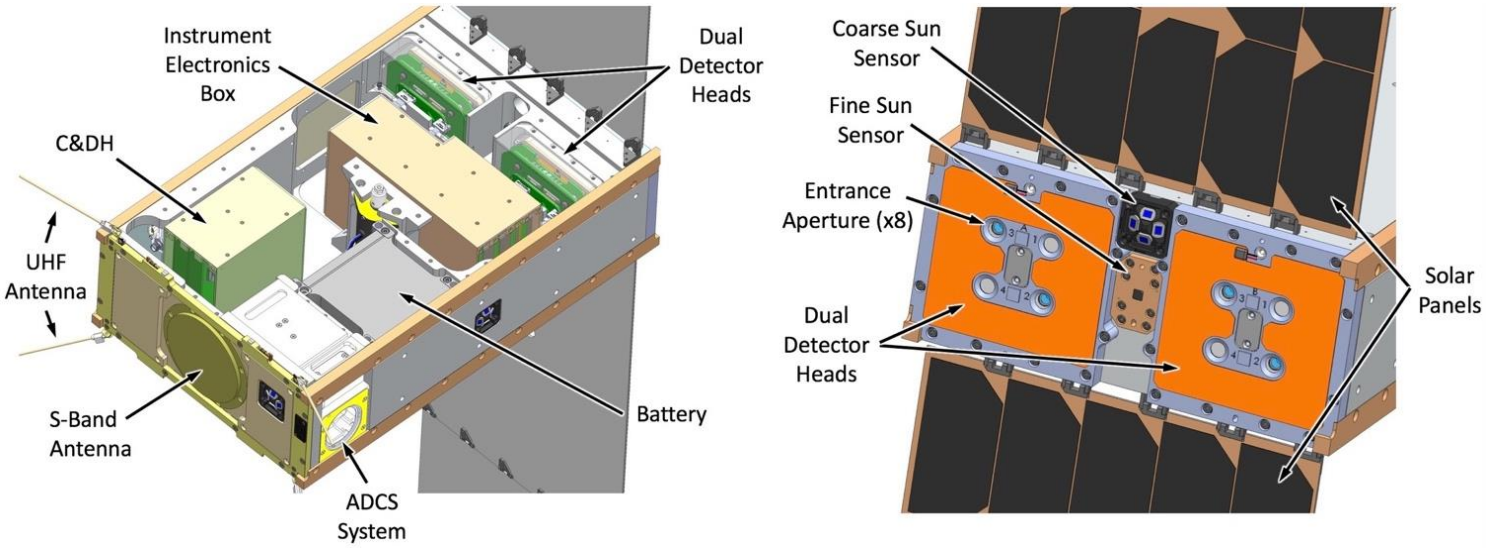
Credit: SSO-A: SmallSat Express Mission

CSIM Performance



Agreement at ~0.5% spectral average between 300-2400 nm between existing Total and Spectral Solar Irradiance Sensor (TSIS) and CSIM

Compact Total Irradiance Monitor (CTIM)

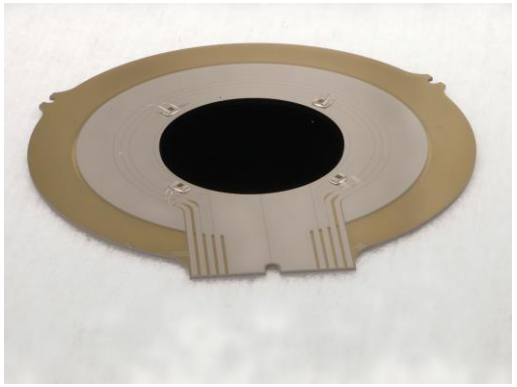


Credit: Nat Farber, LASP

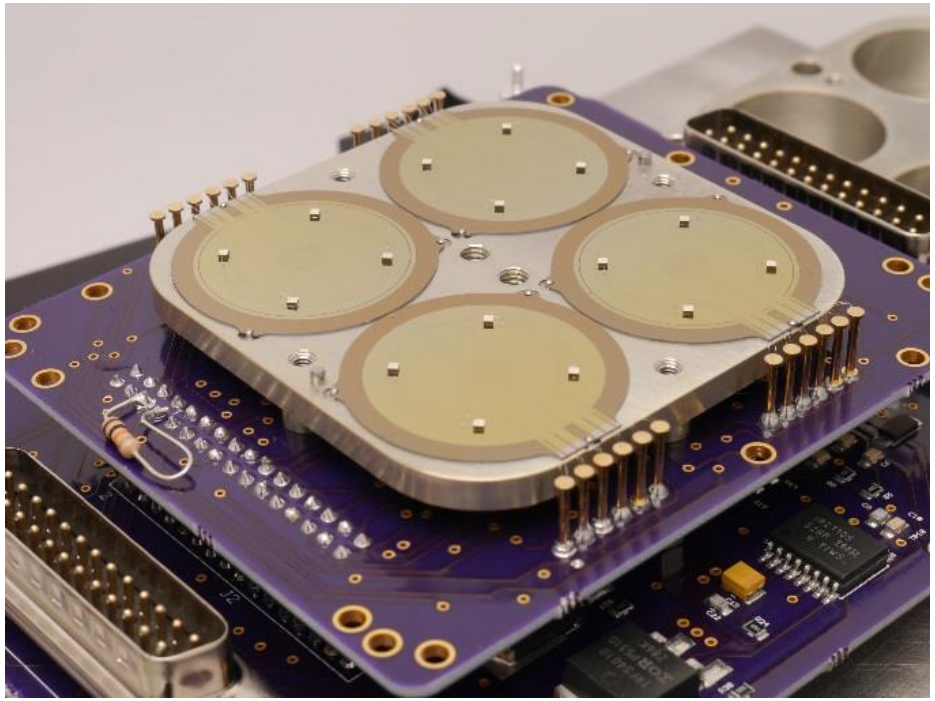
- 6U CubeSat to launch in early 2020
- Demonstrate next generation technology for total solar irradiance mission in low mass, compact design
- Total solar irradiance measurement at 0.01% accuracy

Dave Harber et al., "Compact total irradiance monitor: flight demonstration," Proc. SPIE 11131, CubeSats and SmallSats for Remote Sensing III, 111310D (2019)

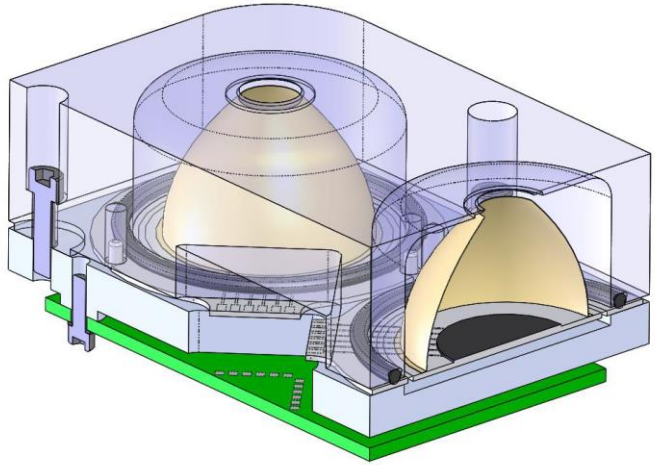
CTIM Detector



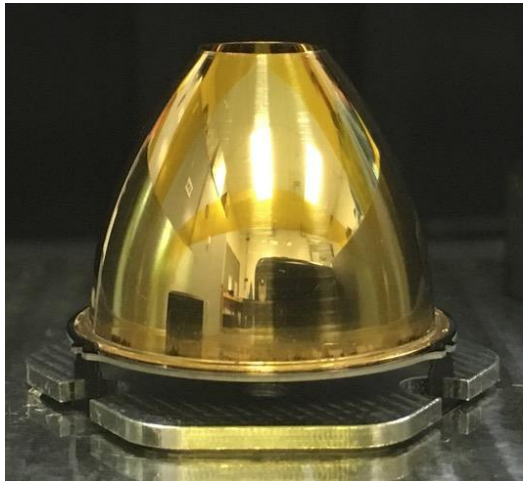
Credit: Nathan Tomlin, NIST



Credit: Dave Harber, LASP



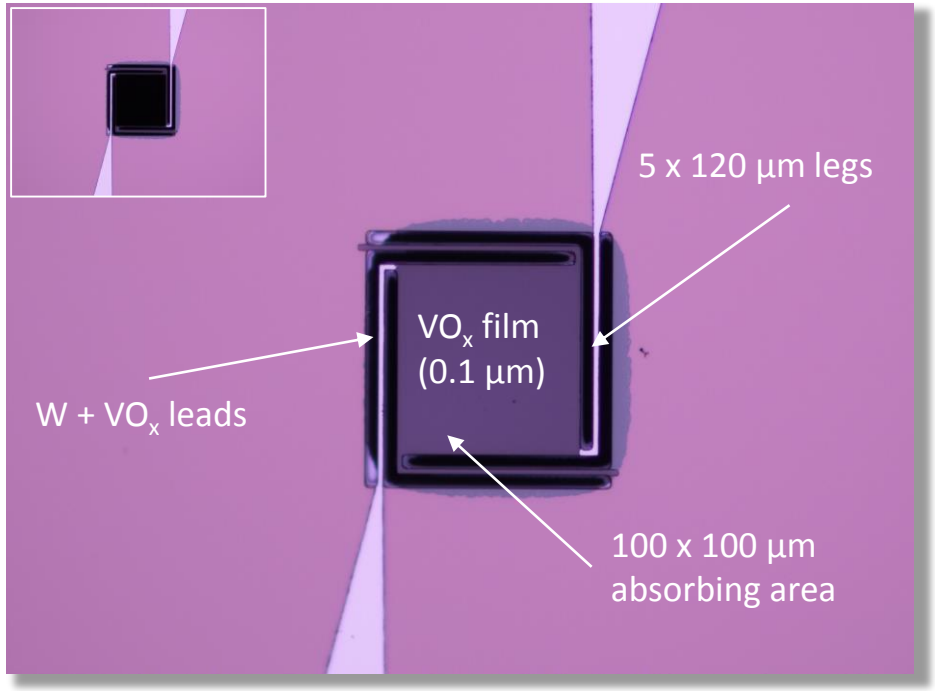
Credit: Dave Harber, LASP



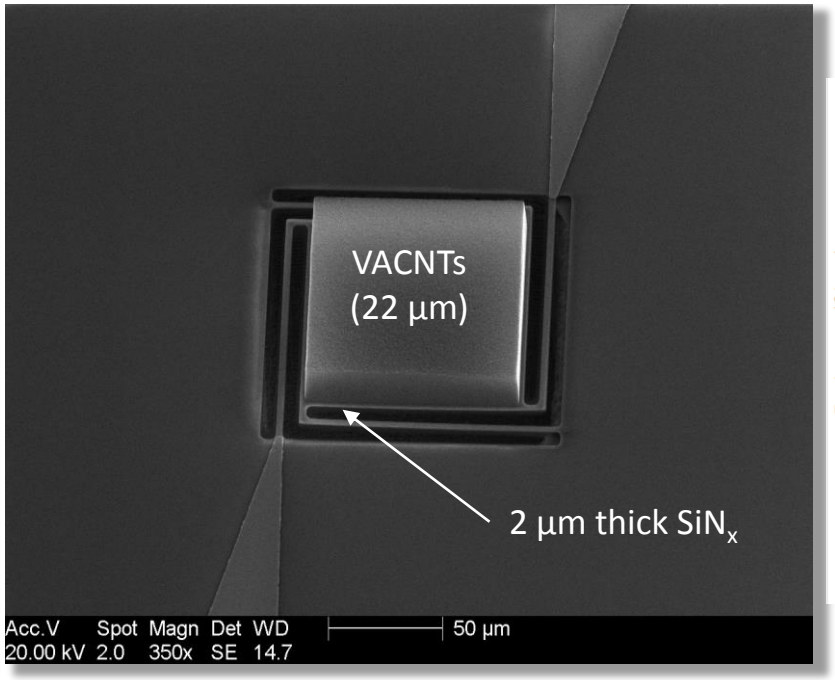
Credit: Dave Harber, LASP

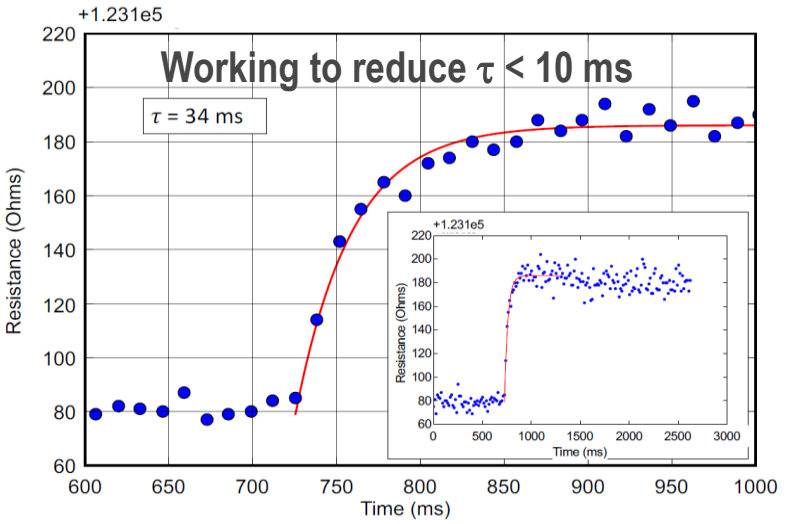
Microbolometer Arrays for Earth Radiance

microscope



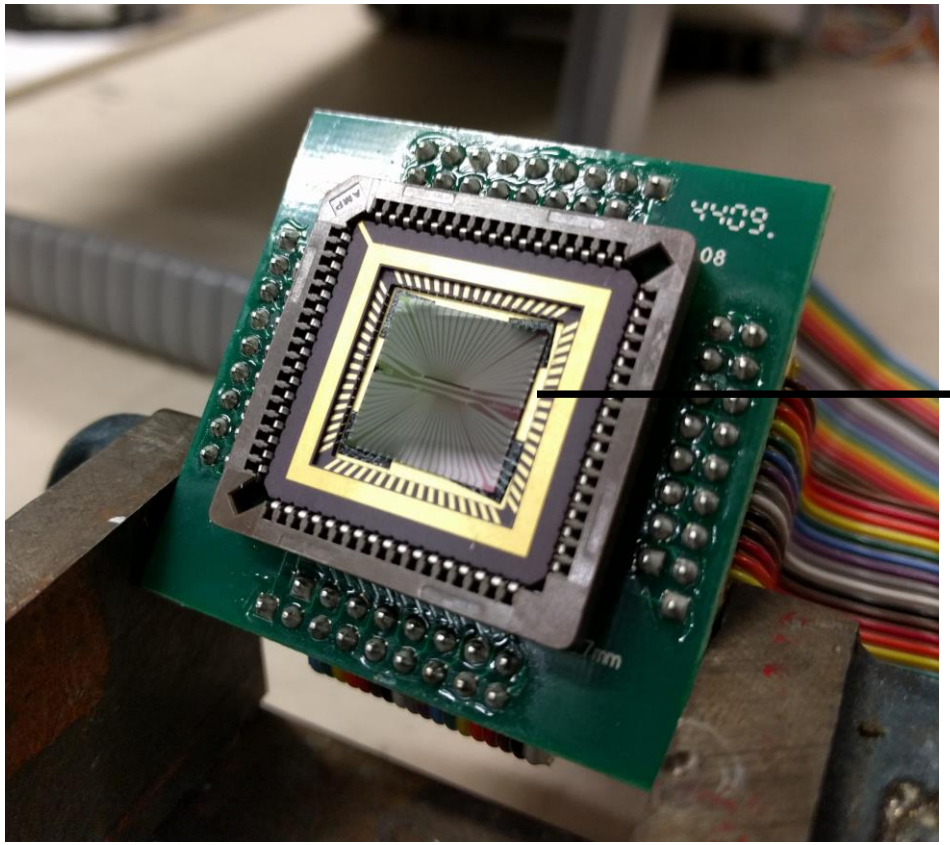
Scanning electron microscope

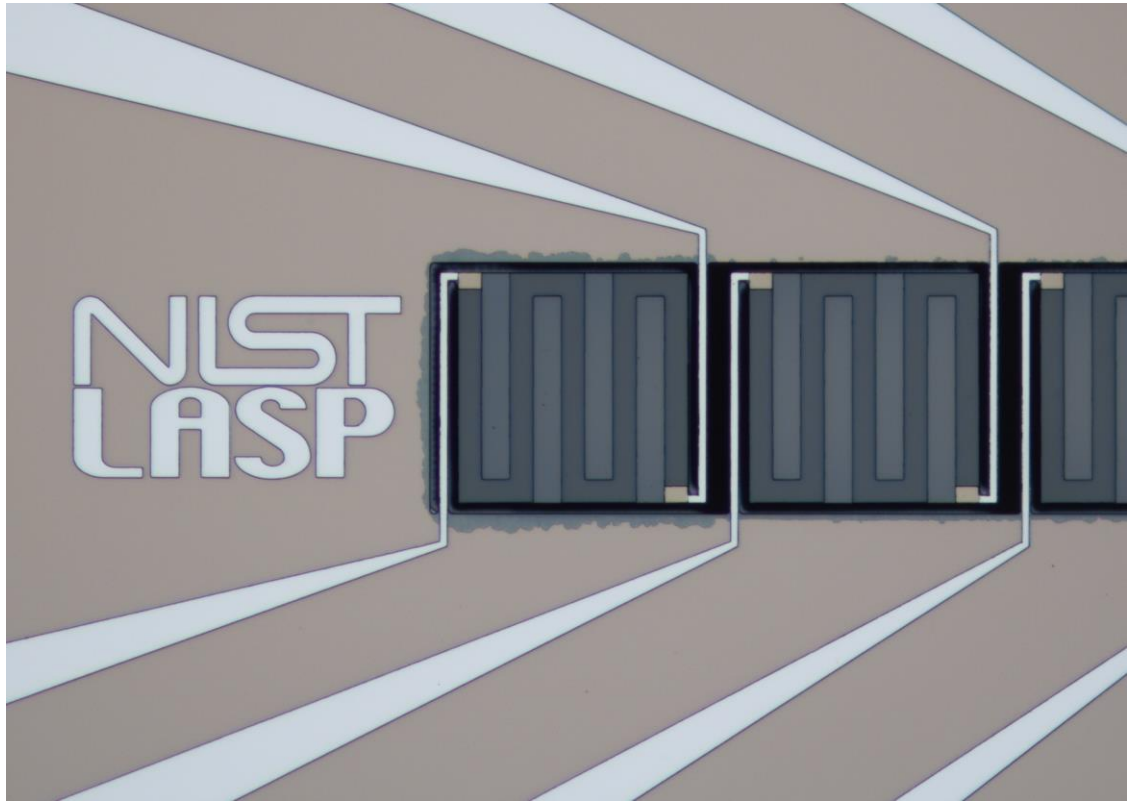




Chris Yung et al., "BABAR: black array of broadband absolute radiometers for far infrared sensing," Proc. SPIE 10980, Image Sensing Technologies: Materials, Devices, Systems, and Applications VI, 109800F (2019)

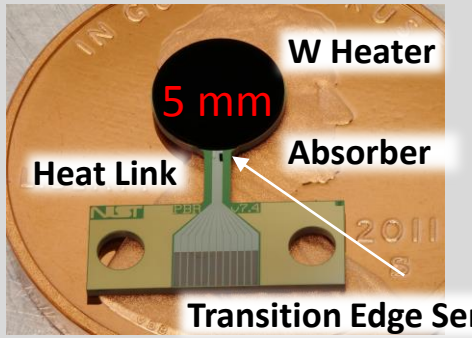
Prototype 32-element Linear Array



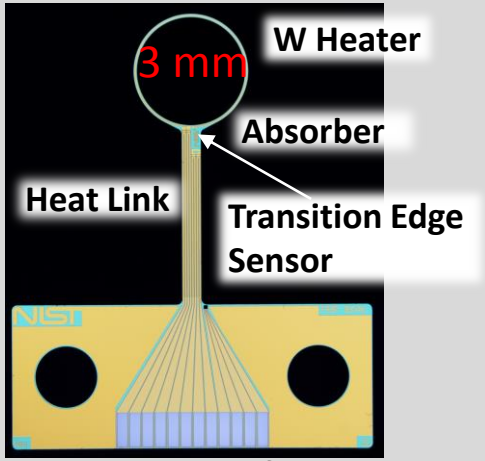


Microfabricated Absolute Electrical Substitution Bolometers at NIST

Cryogenic (4 K)



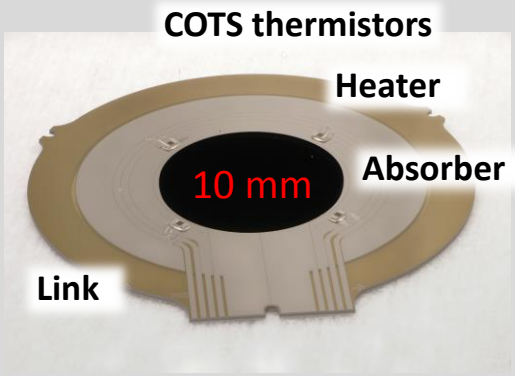
Cryogenic Optical Fiber Power Standard



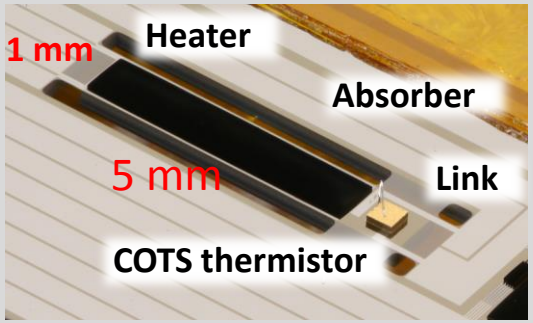
Fast Far Infrared Bolometer (50 Hz)

Space Applications

(with LASP at CU Boulder)

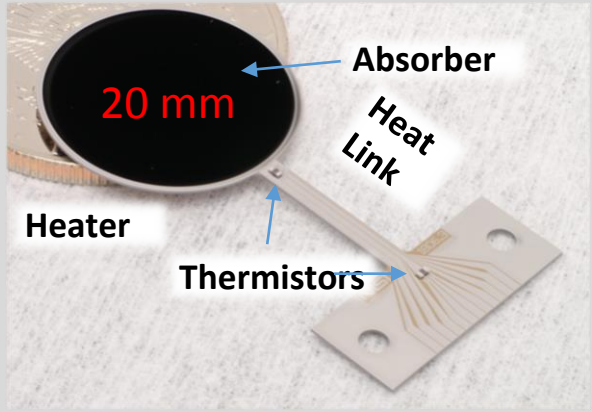


Compact Total Irradiance Monitor



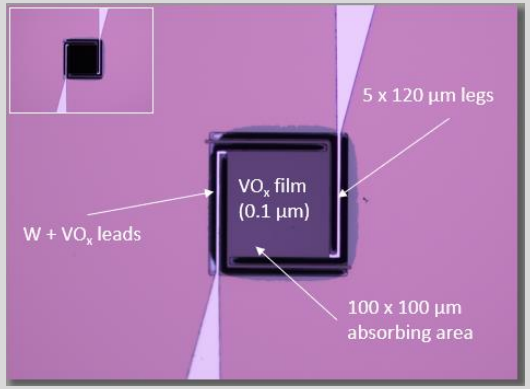
Compact Spectral Irradiance Monitor

Room Temperature



NextGen-C

Microbolometers



Broadband Array of Black Radiometers (BABAR)

- Si substrate
- W heater around perimeter
- Vertically aligned carbon nanotube (VACNT) absorber
- Superconducting or W
- Transition edge sensor (TES) for cryogenic/commercial off-the-shelf (COTS) for room temperature measurement/VOx for microbolometers