The Compact SIM (CSIM), Compact TIM (CTIM) and Future Earth Radiation Budget Instruments

Dave Harber, Brian Boyle, Karen Bryant, Zach Castleman, Michael Chambliss, Ginger Drake, Nat Farber, Melanie Fisher, Maxwell Fowle, Karl Heuerman, Joel Rutkowski, Matt Smith, Paul Smith, Jacob Sprunck, Cameron Straatsma, Wengang Zheng, Odele Coddington, Greg Kopp, Erik Richard, Peter Pilewskie, and Tom Woods

Nathan Tomlin, Michelle Stephens, Chris Yung, Malcolm White, and John Lehman

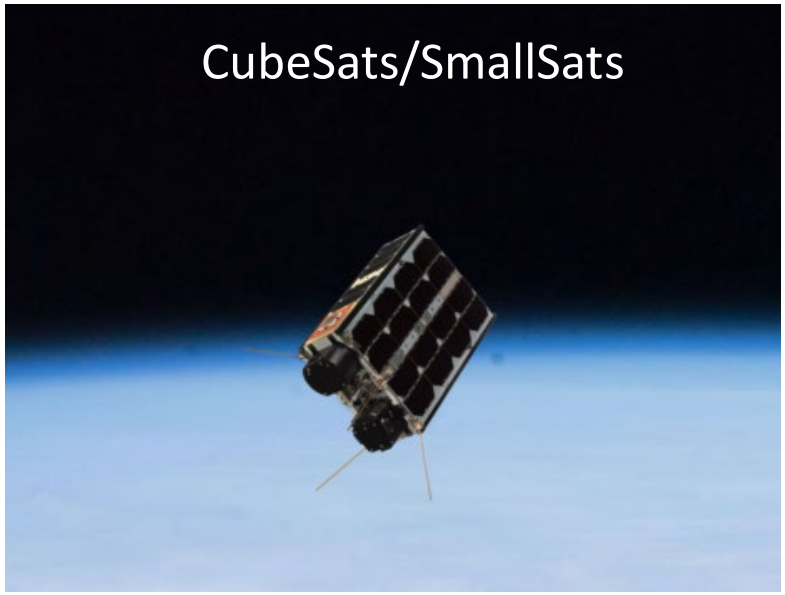
Quantum Electronics and Photonics Division, Sources and Detectors Group

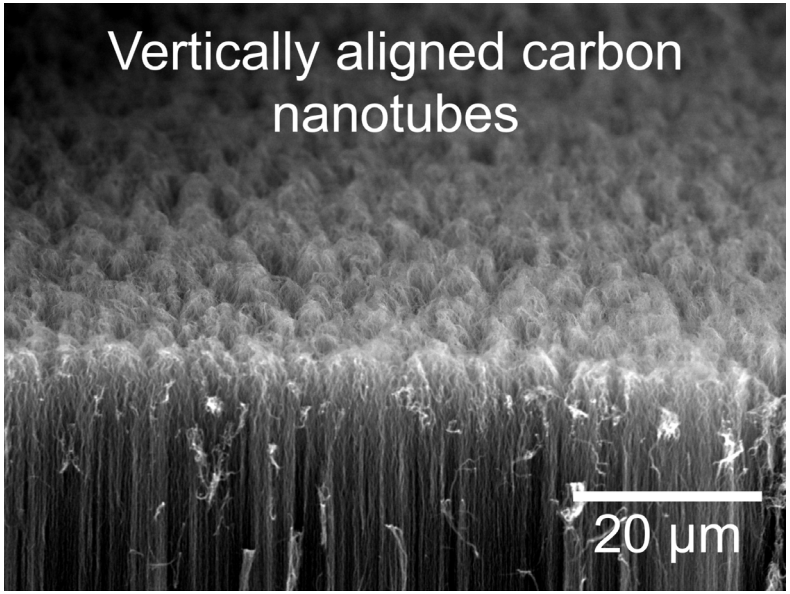
Funding

Future of TSI and SSI Instruments

What is the future of these instruments?

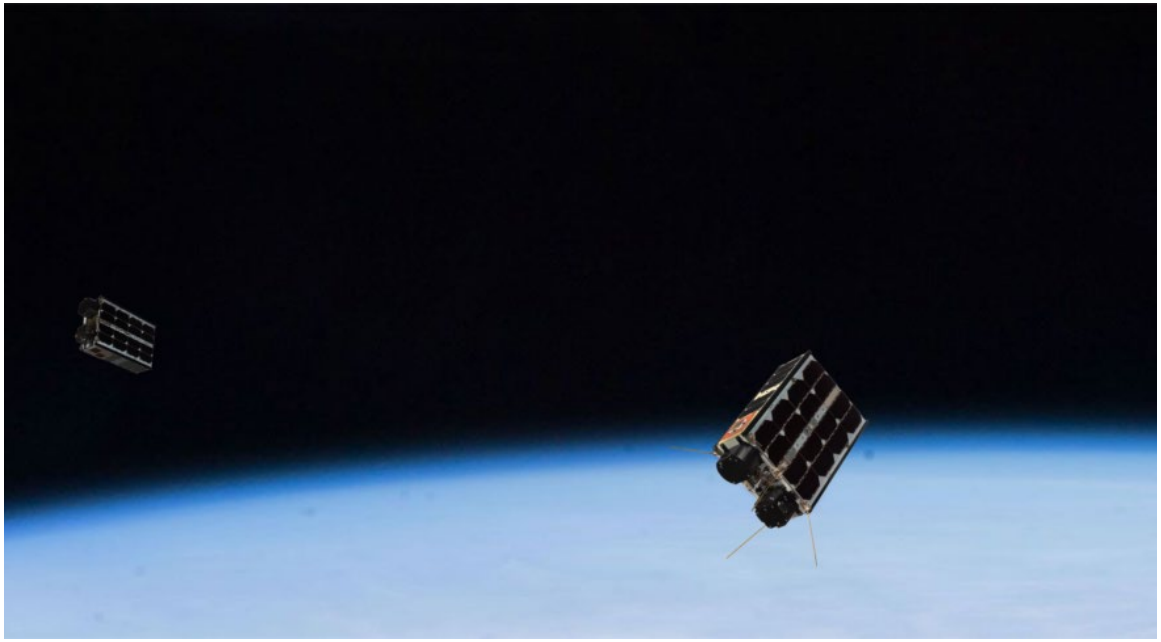
How to we inject new technology?





CubeSats?

Can future TSI and SSI measurements be performed from CubeSat platforms?



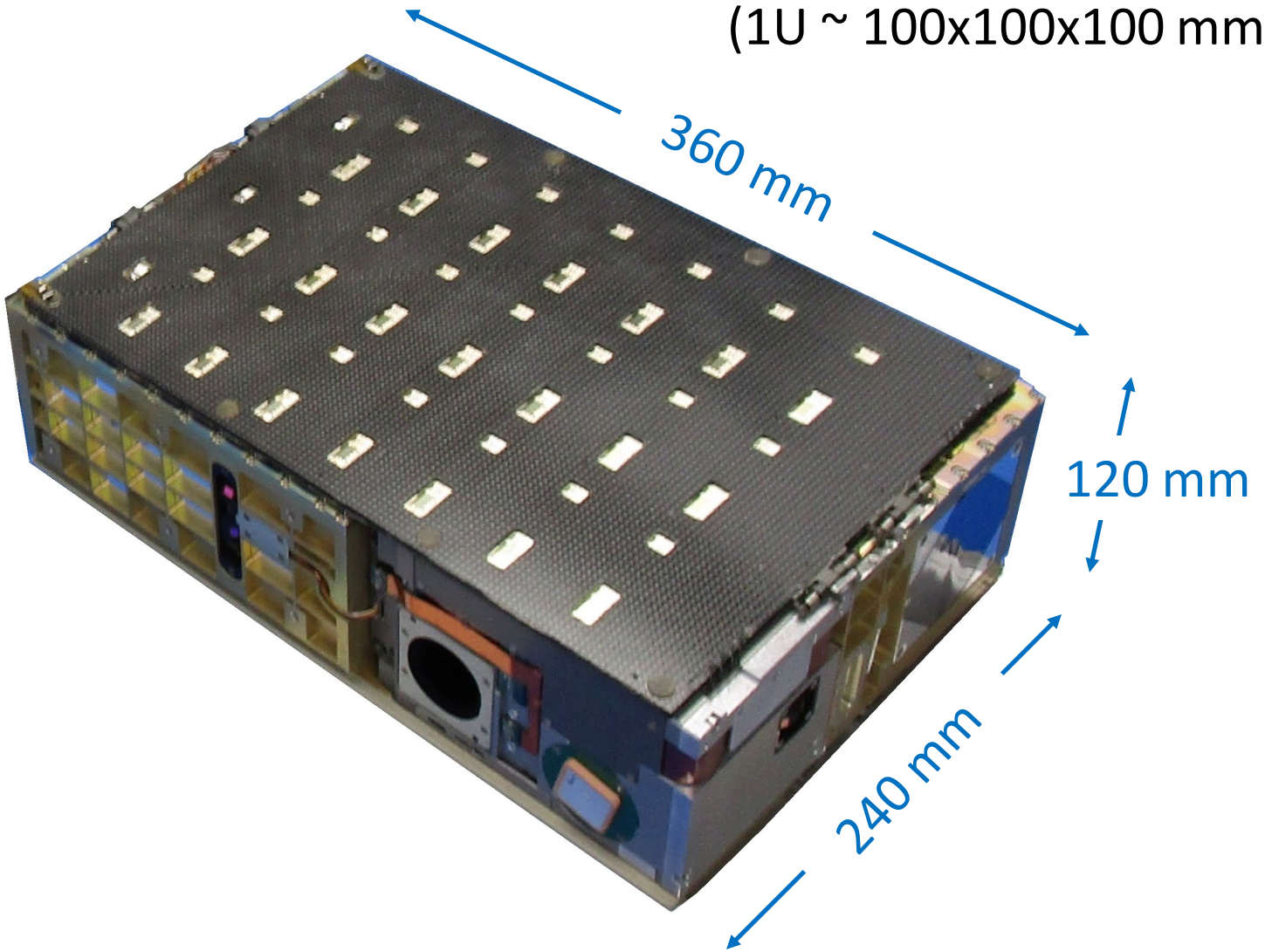
Should be possible: optical apertures are small, the measurements are possible in nearly any orbit

Challenge: the measurement requirements are very strict and measurement continuity is critical

So how big are we talking about?

CSIM and CTIM are “6U”

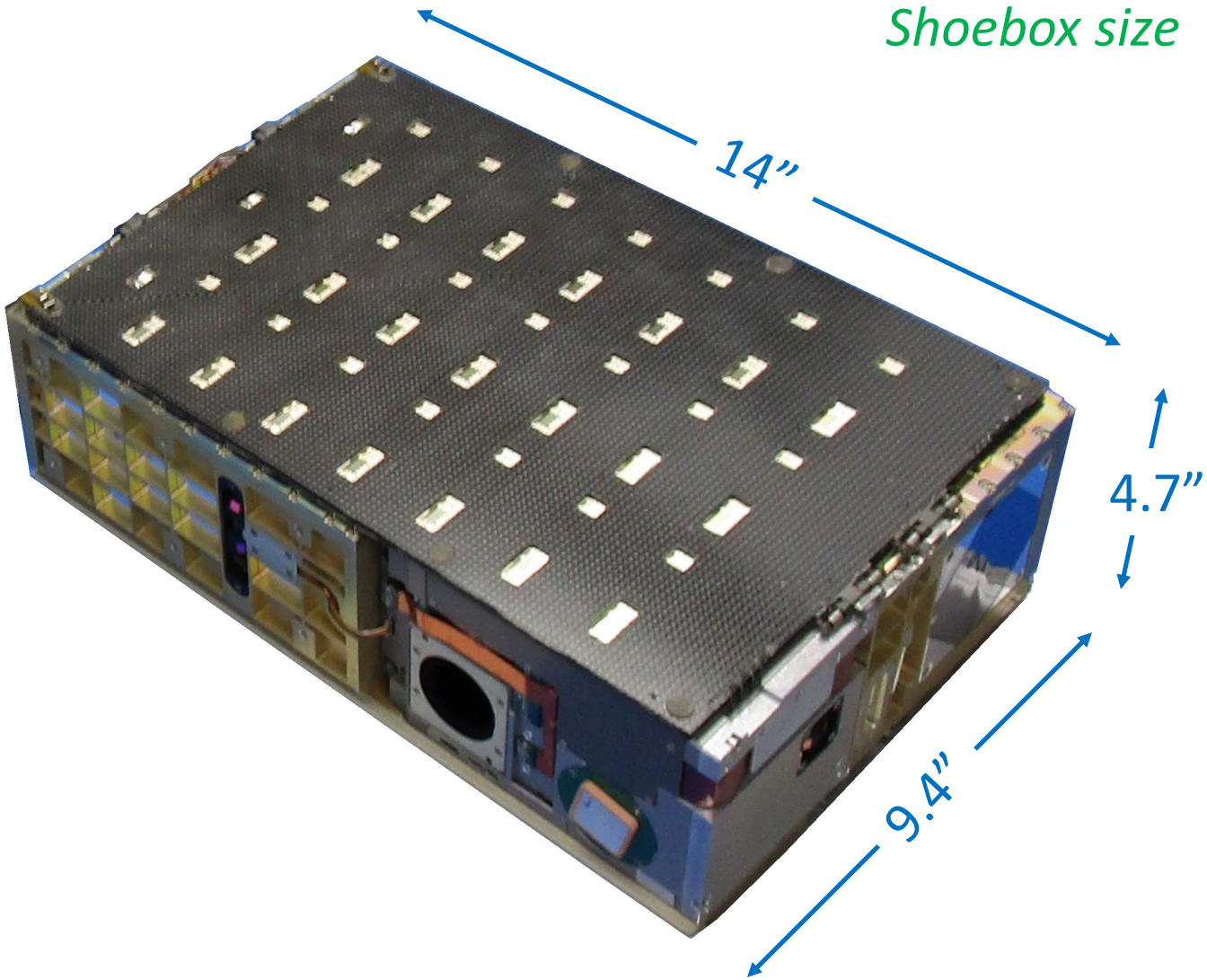
(1U ~ 100x100x100 mm)



So how big are we talking about?

CSIM and CTIM are “6U”

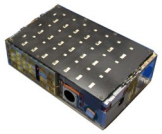
Shoebox size



Put this size in perspective

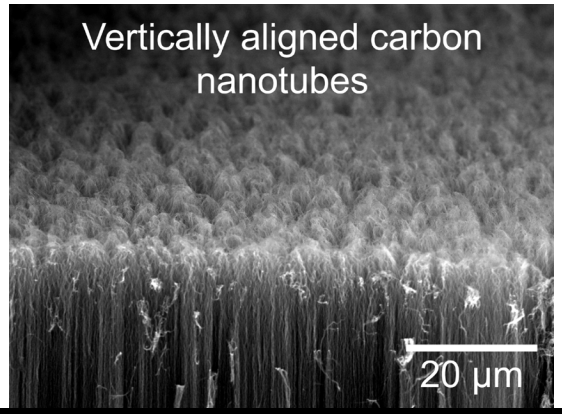
TSIS-1 ~ Buffalo

CSIM ~ Cat



Entire Satellite!

Carbon Nanotubes: *None More Black*



The New York Times

BASICS

Ultra-Black Is the New Black

Scientists are setting dark traps from which light cannot escape. But nature already has built a few of her own.

SCIENCE

Why Scientists and Artists Want The Blackest Substances on Earth

Artists and scientists are searching for ever more light-absorbing materials. To find out what's behind the quest for ultra-blacks, WIRED's Arielle Pardes talked with artist Stuart Semple and physicist John Lehman about these amazing materials.

MOST POPULAR

Vantablack - the closest thing on earth to a black hole

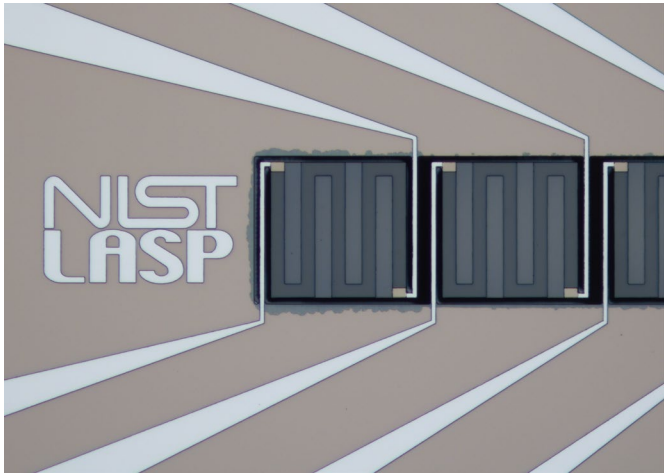
Posted July 16, 2014

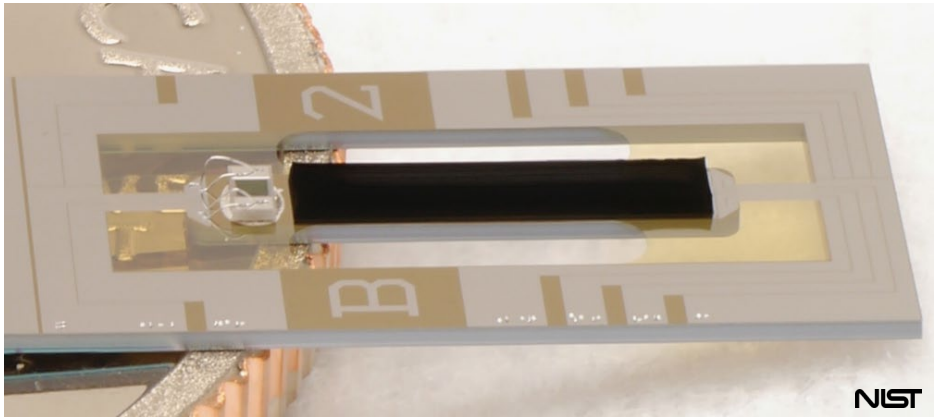
Scientists in England say they've created a new way of synthesising light absorbing material that is so black it only reflects 0.035 percent of light, which could revolutionise satellites and telescopes, and our ability to understand the universe. Joel Flynn looks in.

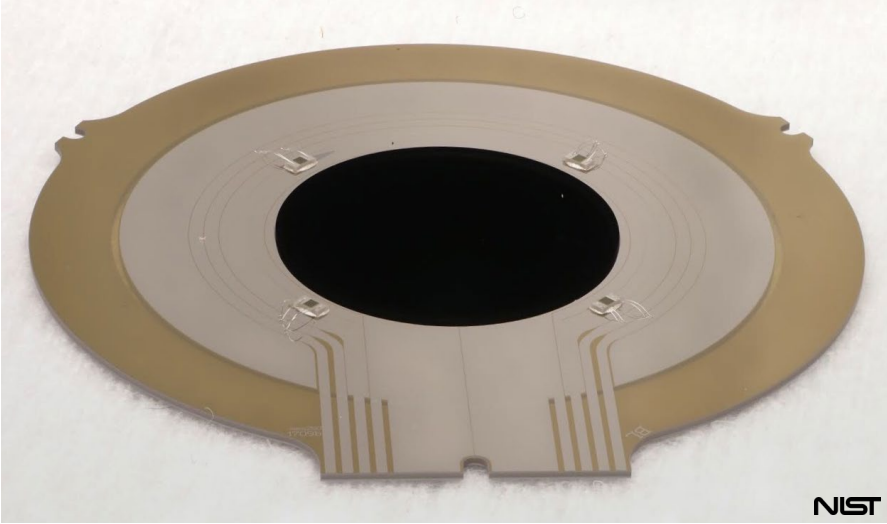
These new ultra-blacks are ideal for electrical substitution radiometers

Silicon Microfabrication: More than black

- Silicon has good thermal properties
- Metal traces for wiring & heater elements
- Silicon Nitride weak thermal links
- Patterned Carbon Nanotubes
- Micron-level control *in 2D*





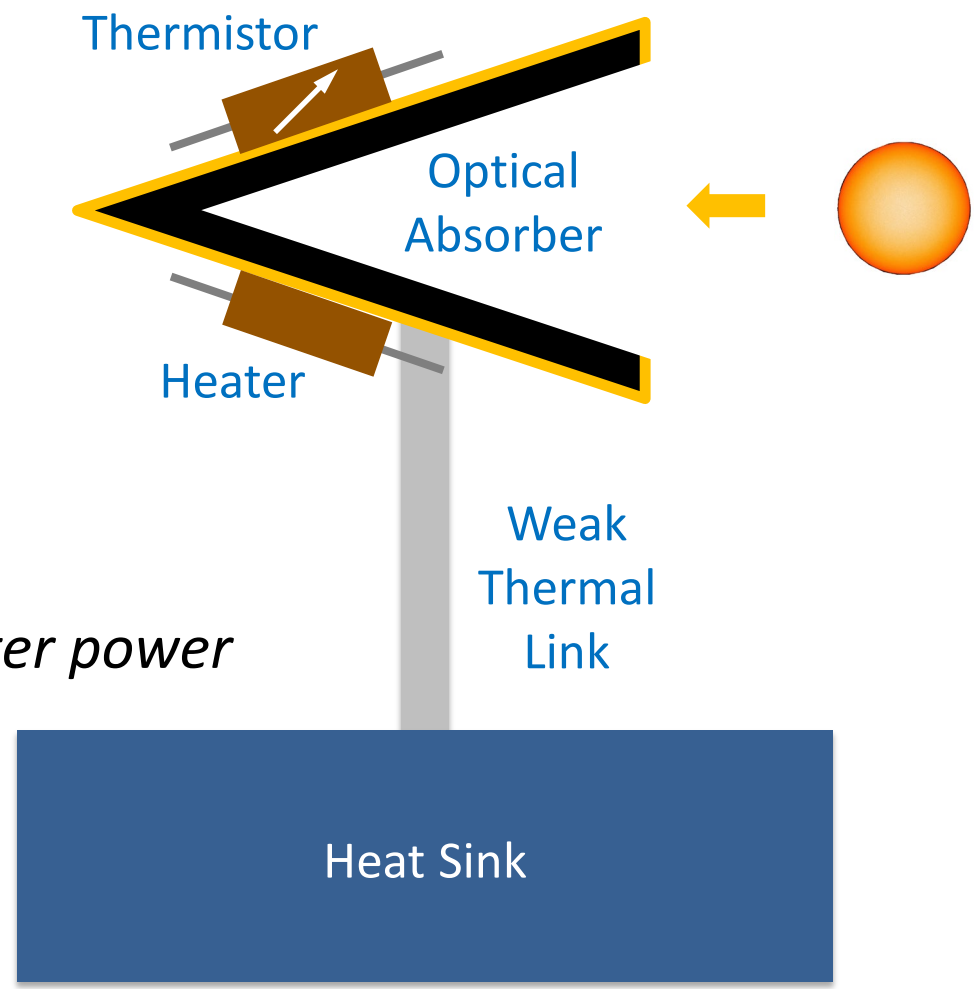


Electrical Substitution Radiometer (ESR)

Our TSI and SSI measurements rely on ESRs

- Temperature measurement
  - ~1 μK noise level
- Heater maintains constant temperature
- Optical absorber collects incoming light
  - Black surface + cavity

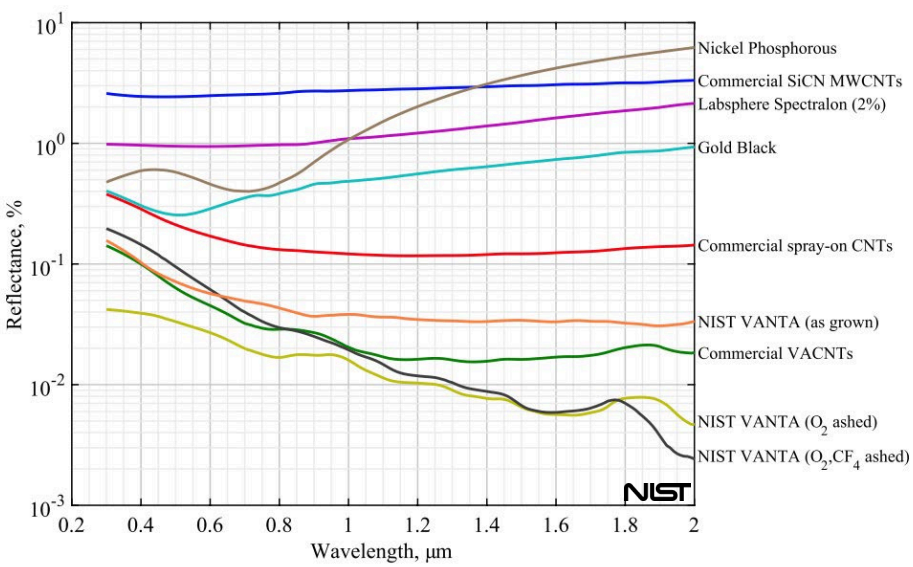
Optical power = Change in heater power

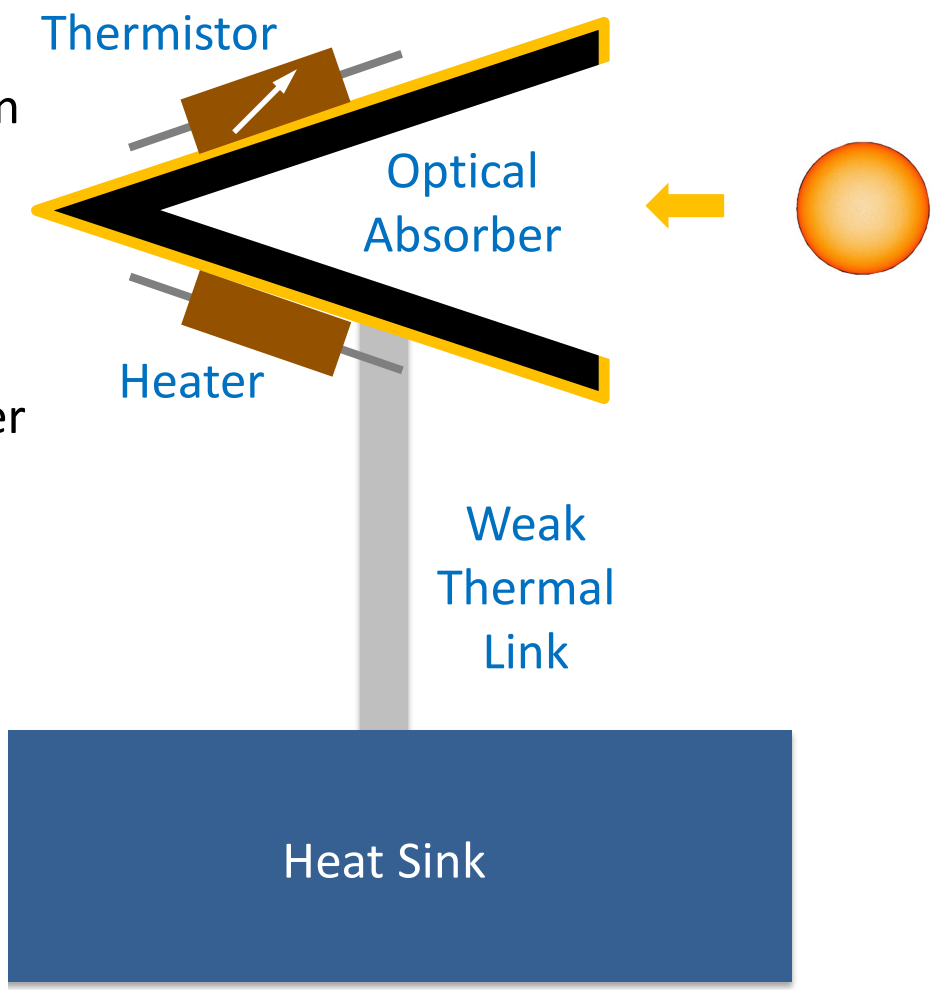


Electrical Substitution Radiometer (ESR)

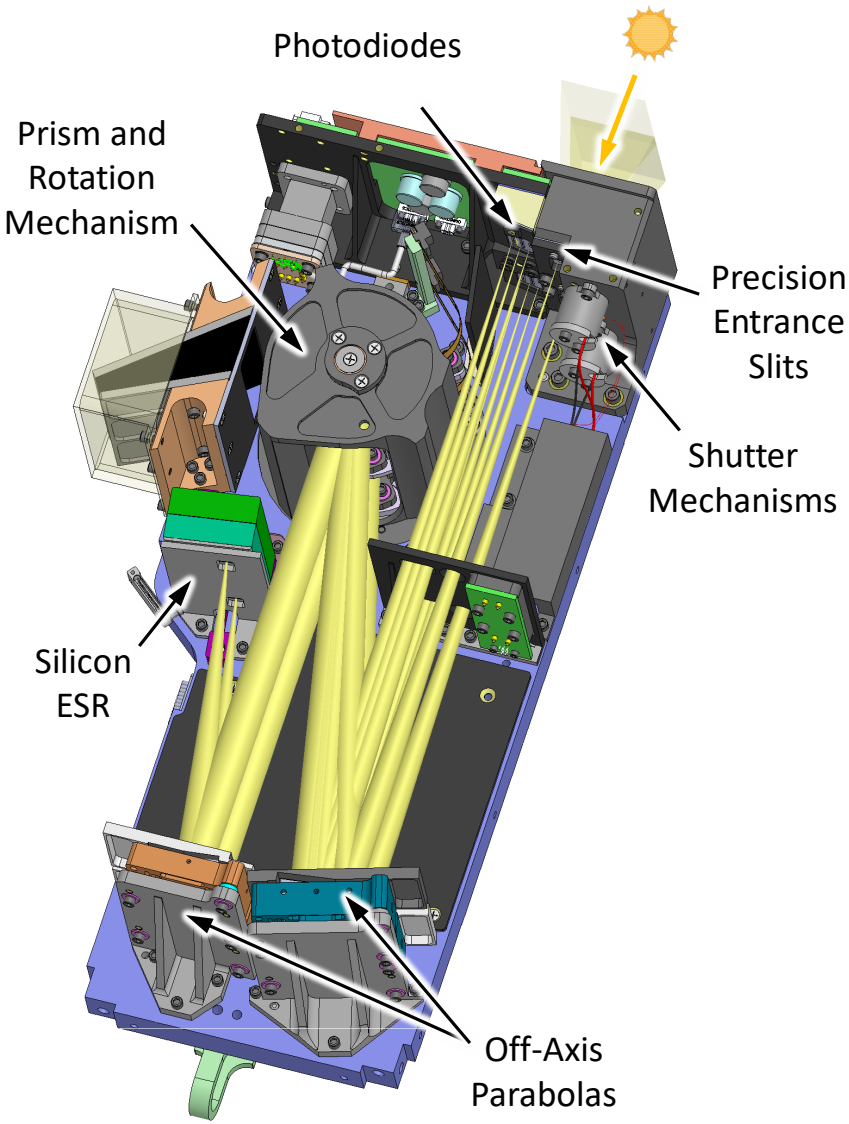
Why TSI and SSI measurements rely on ESRs?

- Extremely stable
  - Stability generally limited by changes in the optical absorber
- Flat spectral response
  - <200 nm to >100 µm
  - Also dependent on the optical absorber

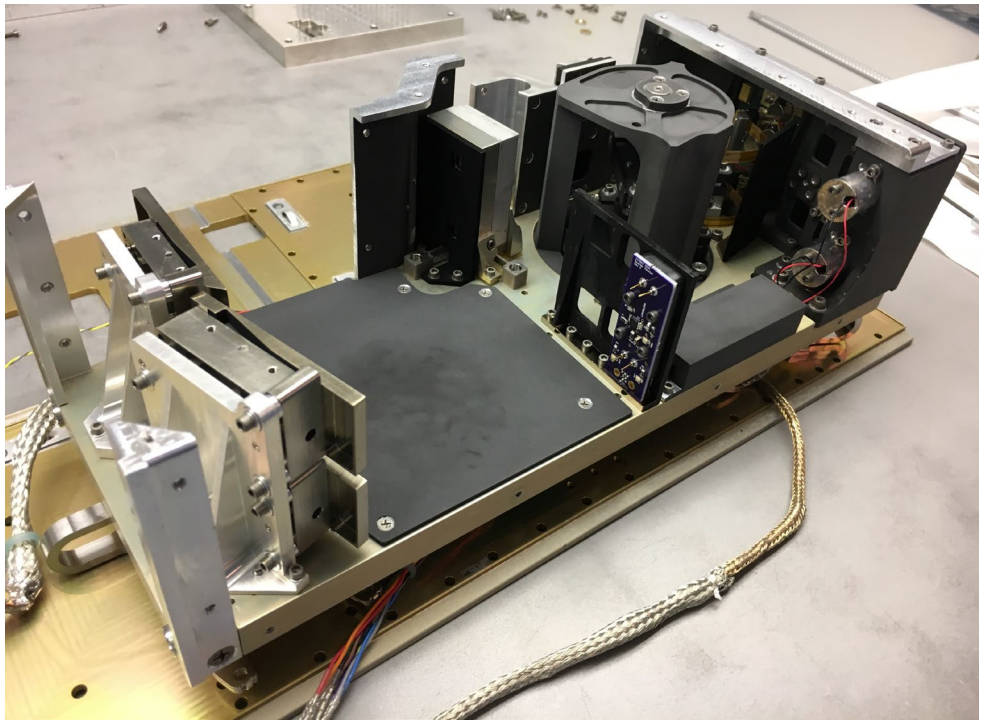




Compact Spectral Irradiance Monitor (CSIM)

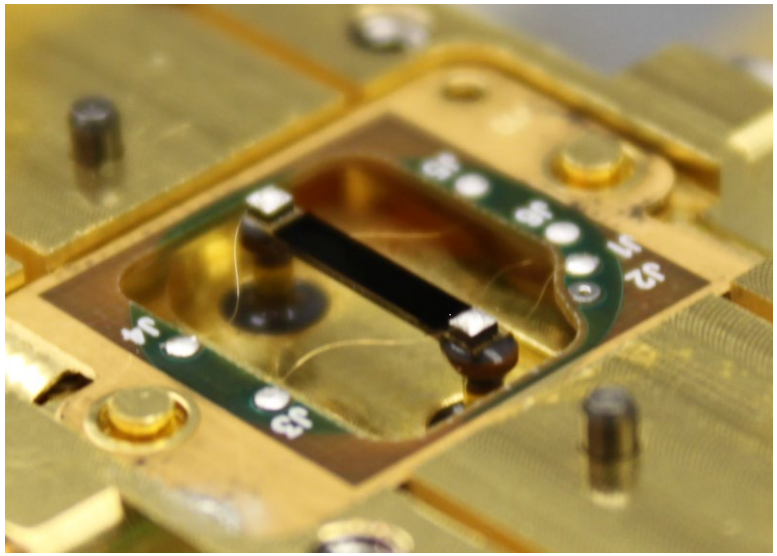


- Squeeze SIM design into 6U, but match capabilities
  - Scaled down down SIM by 45%
- 6U only allowed for two channels

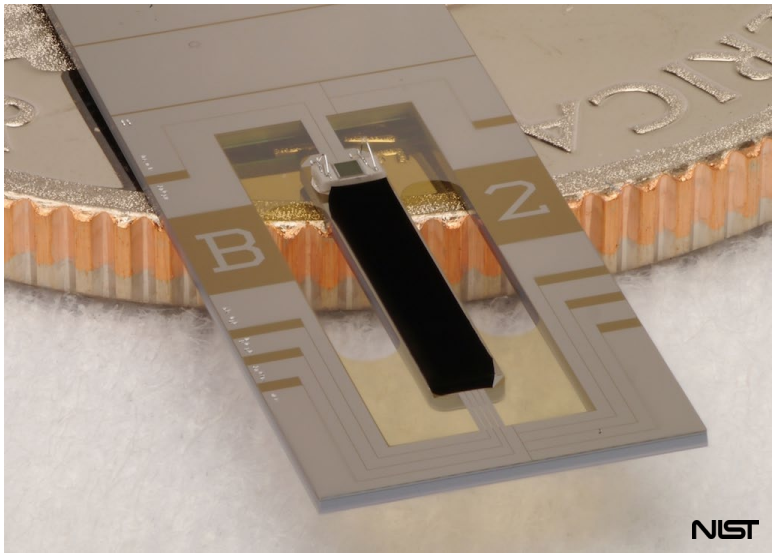


TSIS-1 SIM vs CSIM ESR Comparison

TSIS-1 SIM ESR

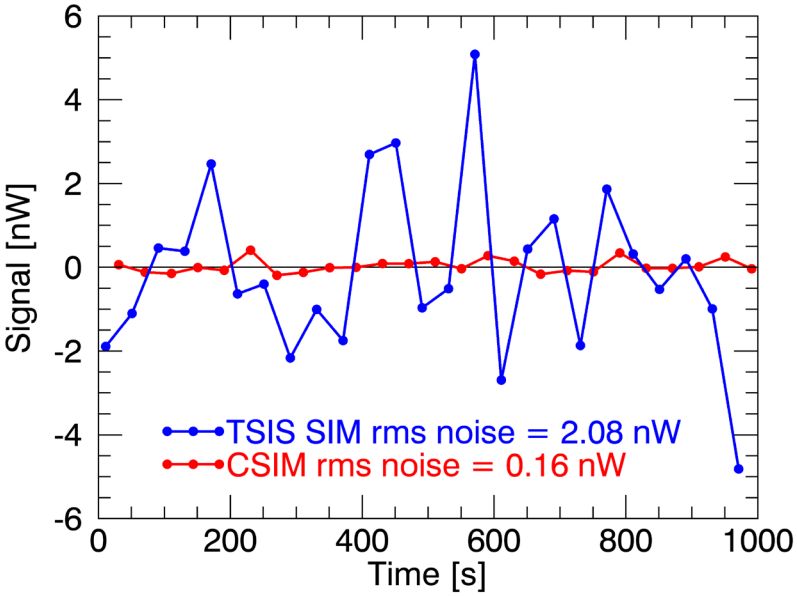


CSIM ESR



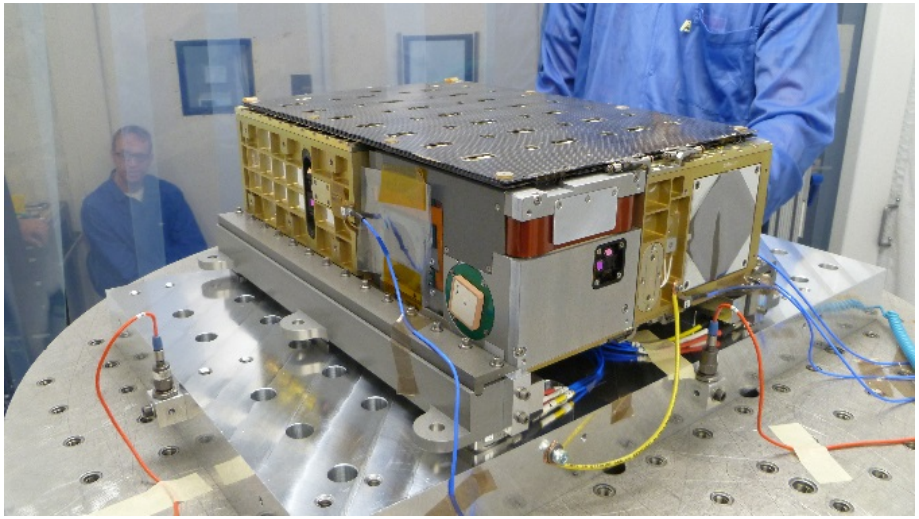
Comparison of measured on-orbit noise

10x noise reduction

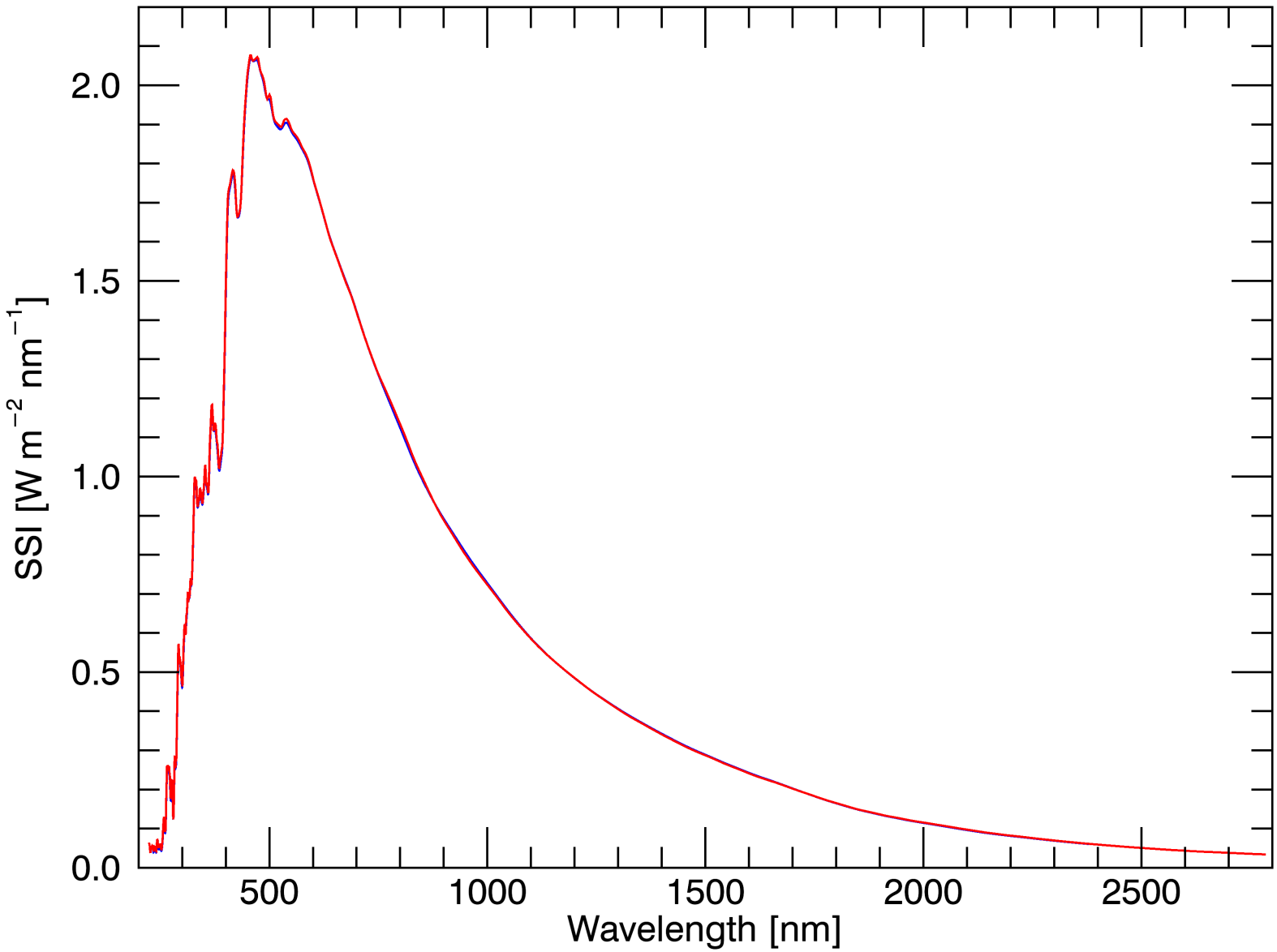


CSIM Launch & Operation

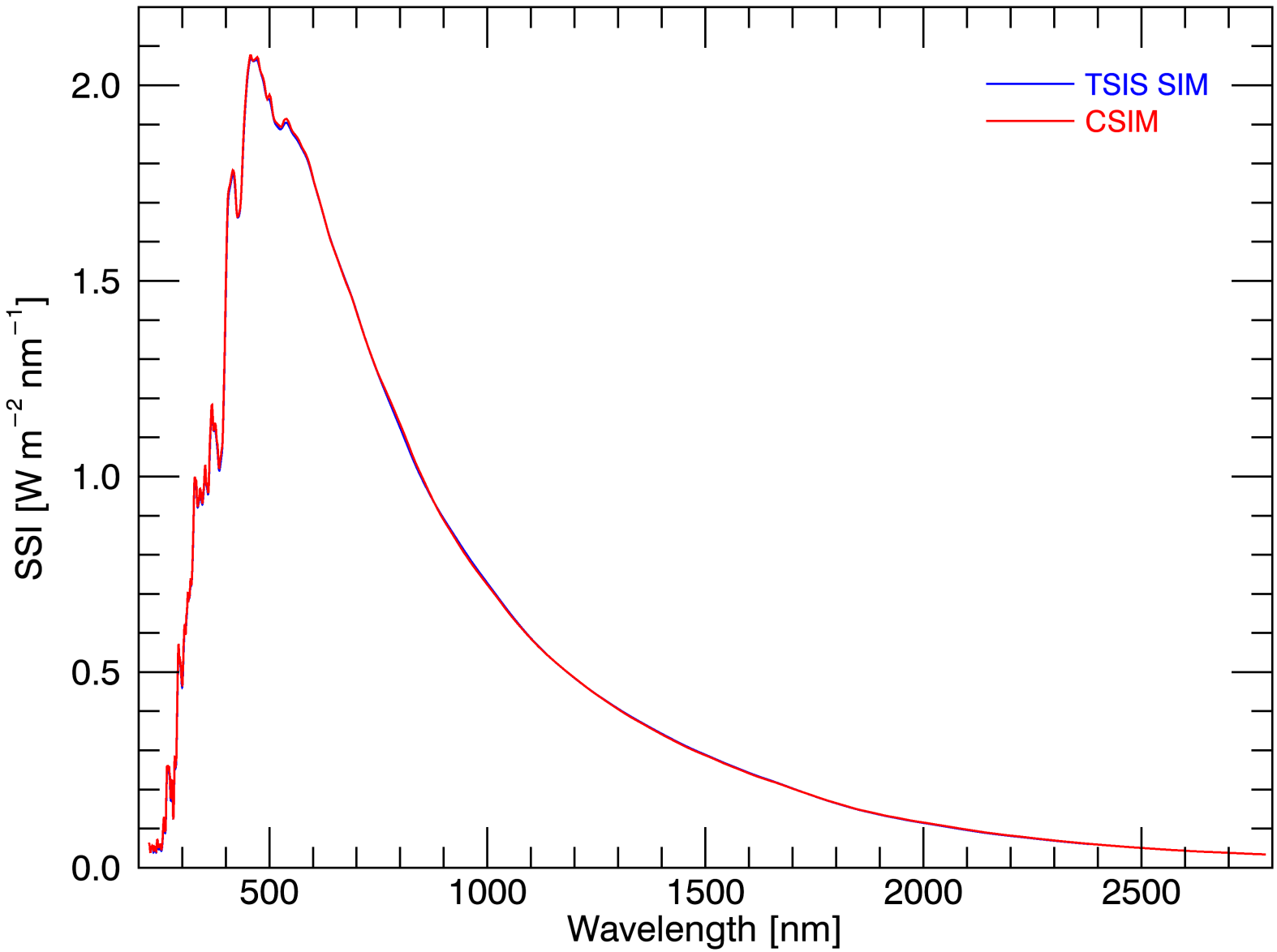
- Launched on December 3rd, 2018 with 64 (!!) other SmallSats
- Solar observations began March 2019
- *Technology demonstration mission*



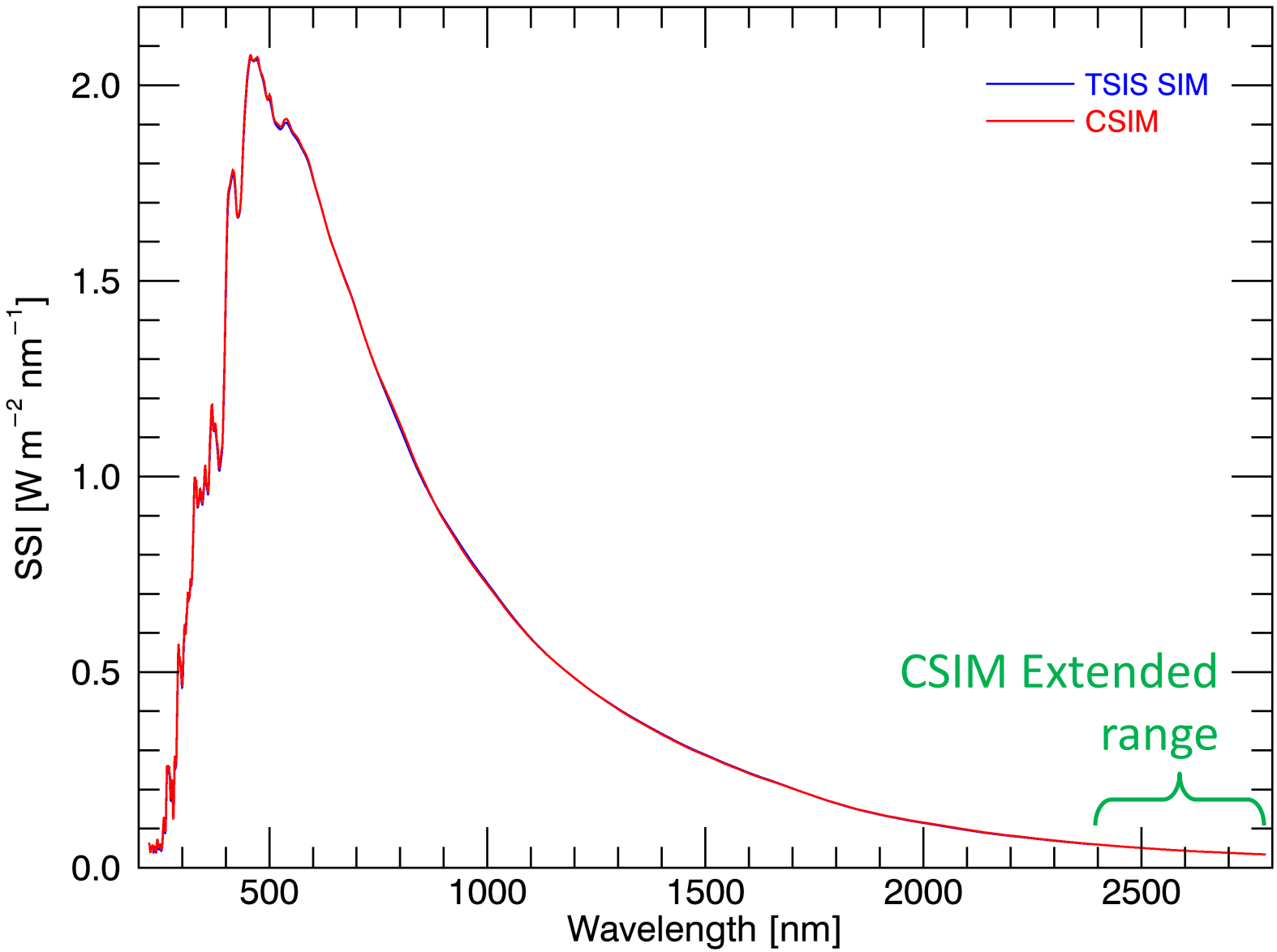
CSIM and TSIS-1 SIM Solar Spectra



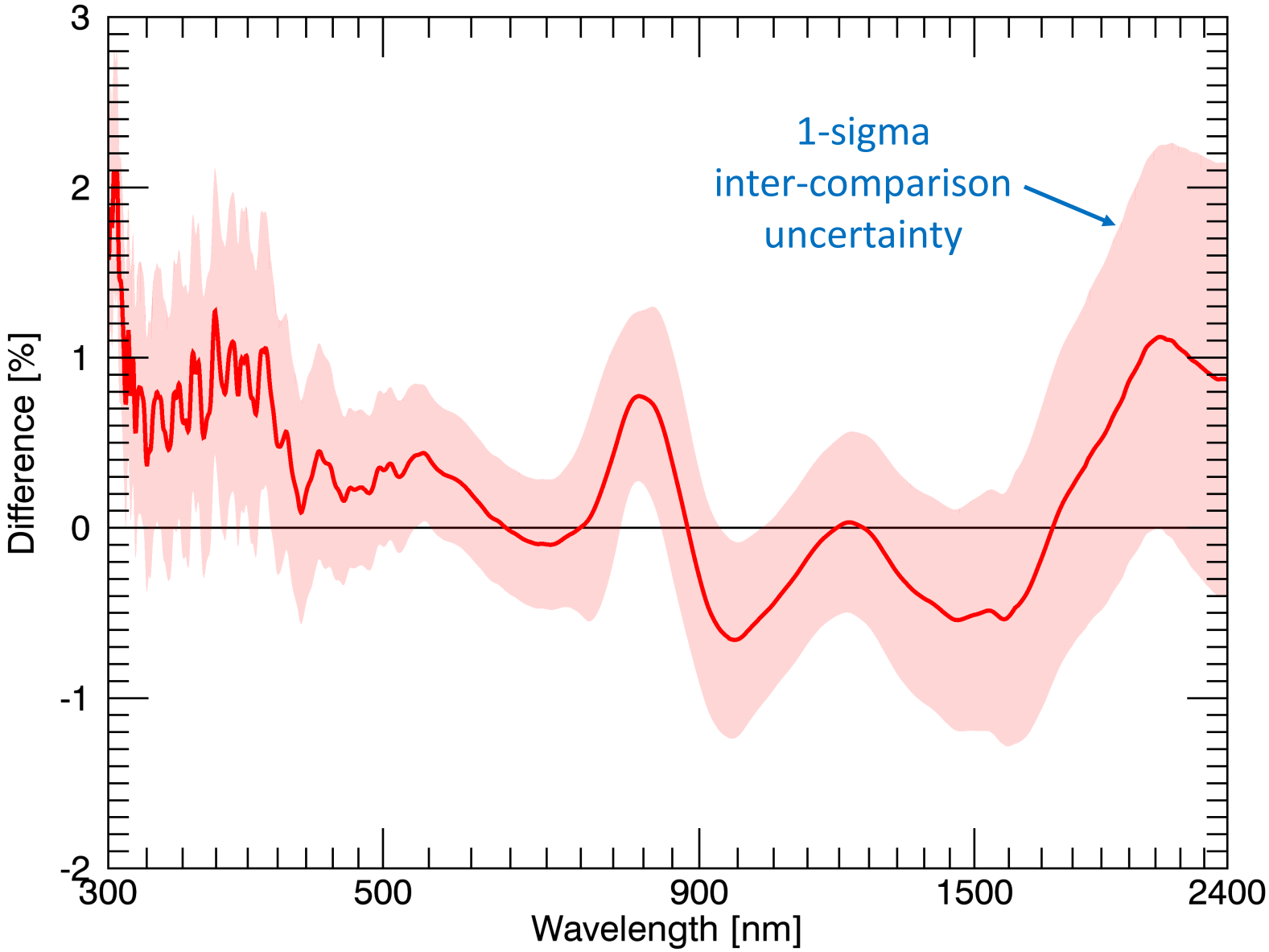
CSIM and TSIS-1 SIM Solar Spectra



CSIM and TSIS-1 SIM Solar Spectra

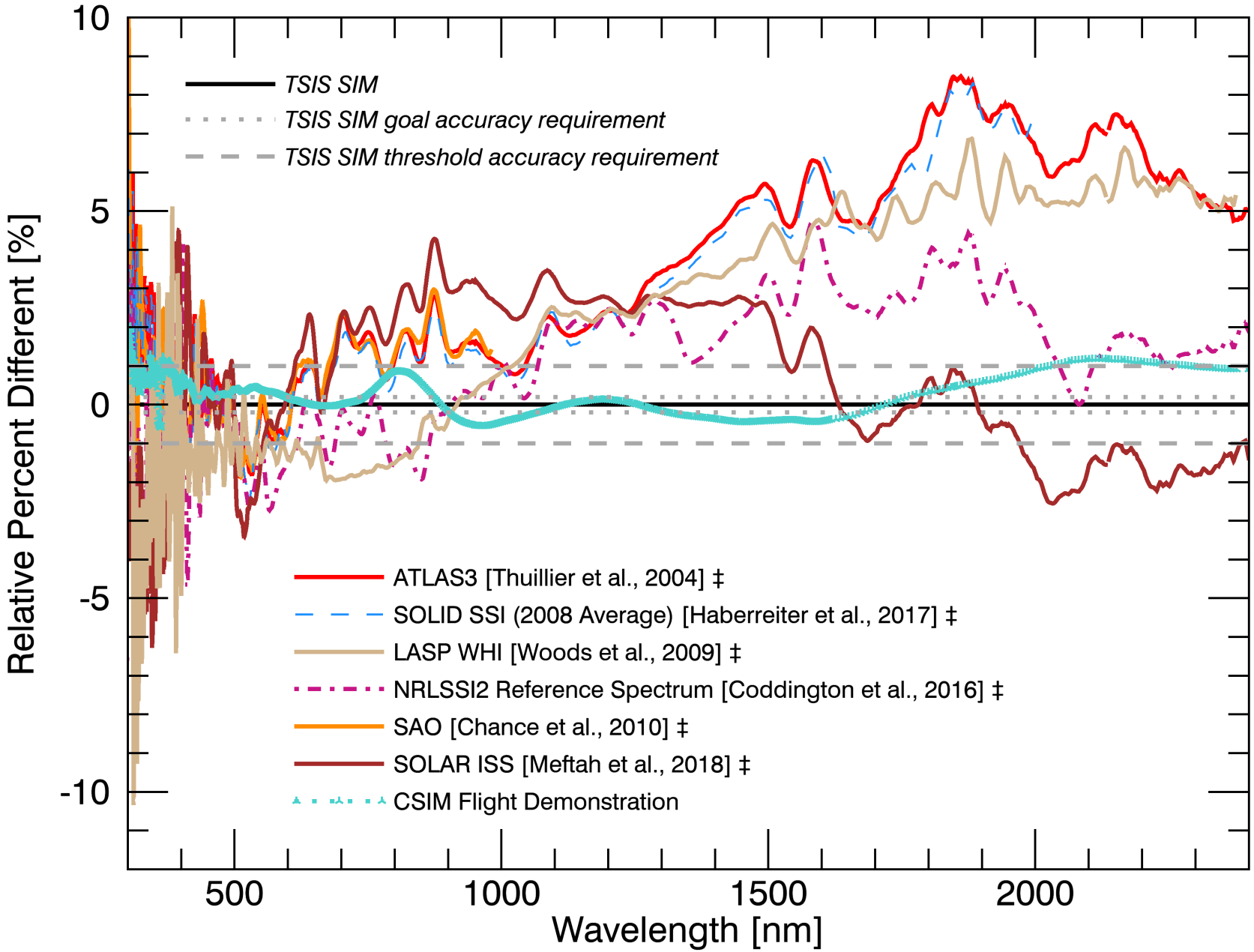


CSIM and TSIS-1 SIM Difference



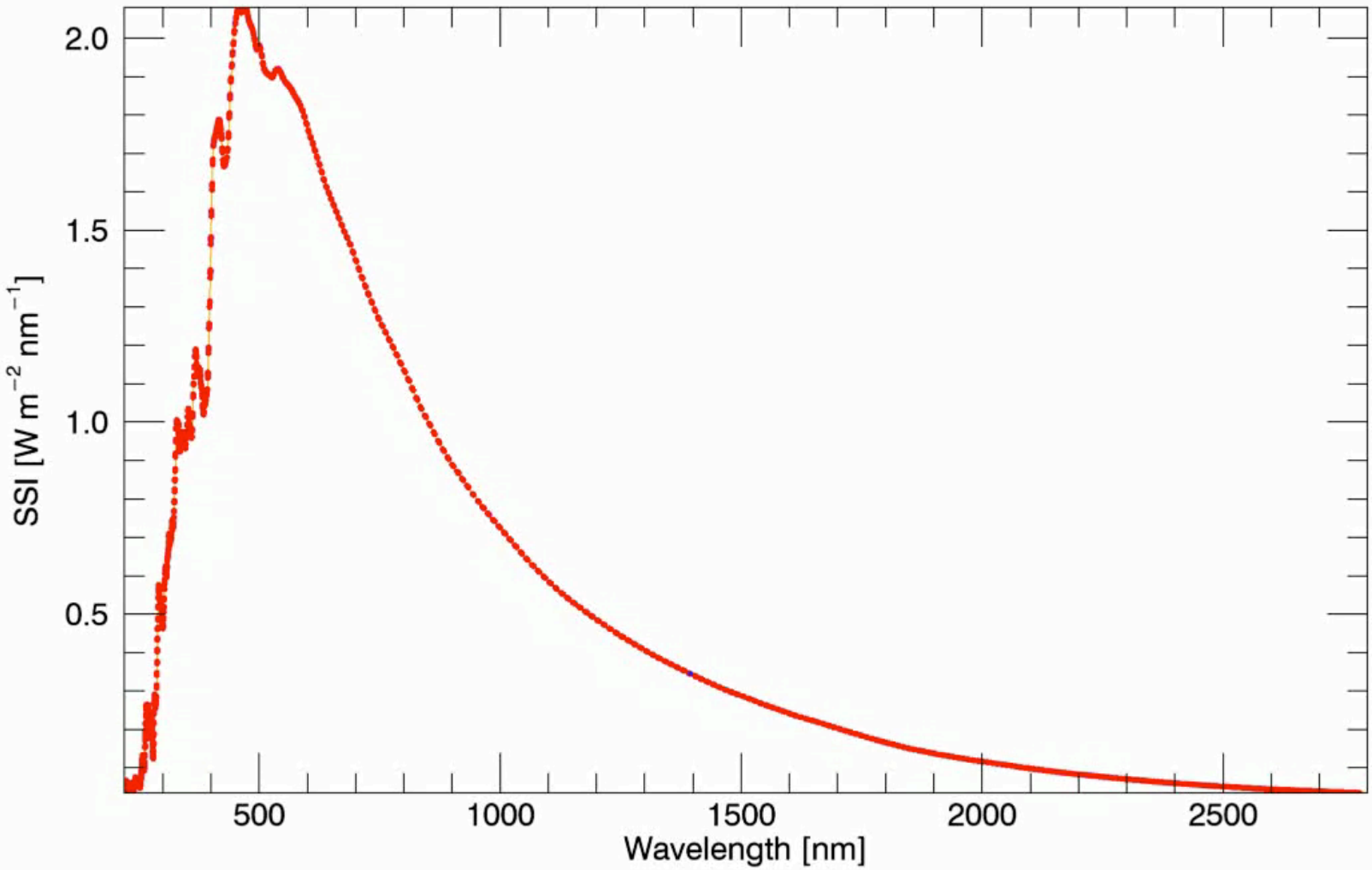
We are still evaluating the CSIM spectra & uncertainty

Relative to other References



Uncorrected CSIM ESR Data

20 CSIM ESR Spectra from April-October 2019



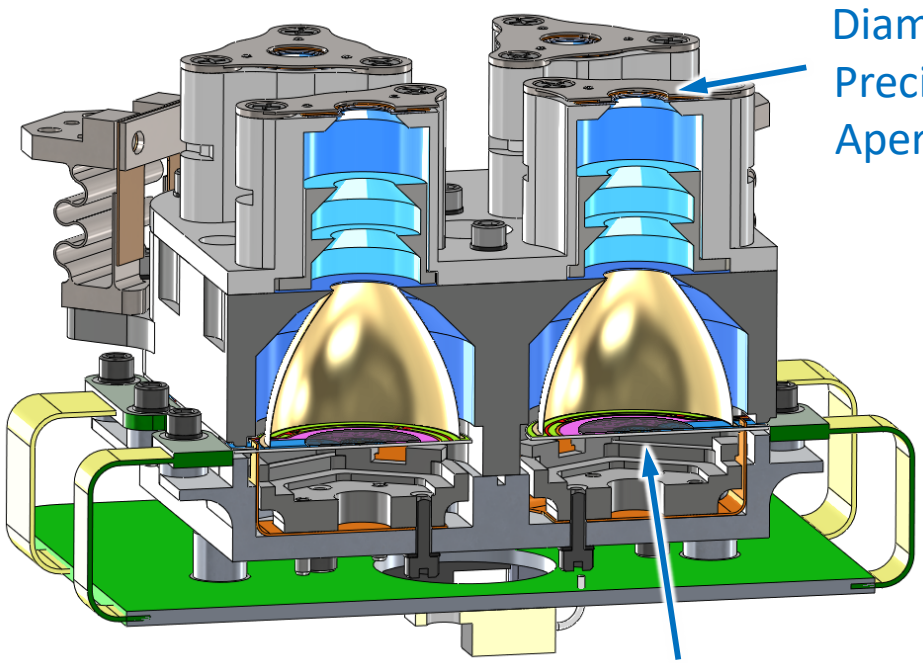
Compact Spectral Irradiance Monitor Status

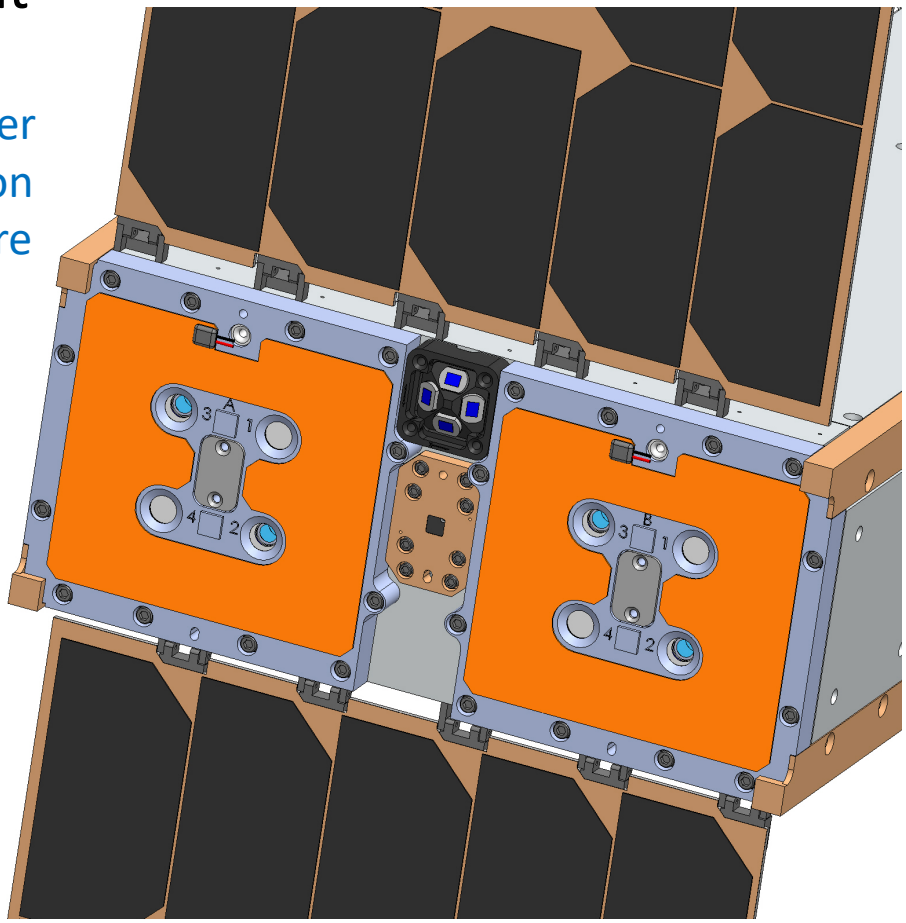
- Continuing to analyze the data from our 2019 measurement campaign
- Working on recovering from another SD card failure, will resume science operations once we have
- What has worked
  - The new ESR, photodiodes detectors, prism drive (COTS encoders)
  - All analog electronics (many op-amps, ADC/DAC, etc.), and most digital electronics
- What has caused issues
  - CSIM orbit: 600 km polar, much harsher than typical ISS deployments
  - SD Card
  - CSIM FPGA configuration flash (now using redundant device)
  - Xilinx Zync – no failures but many resets (avg. every 6 days)

These are easily addressed

Compact Total Irradiance Monitor (CTIM)

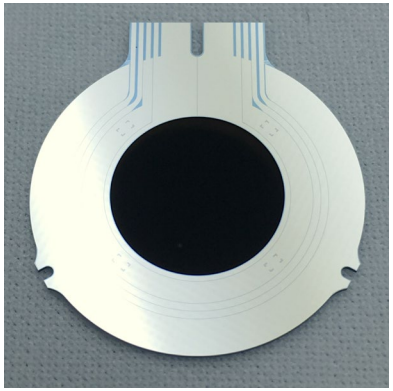
- Squeeze TIM design into 6U, but match capabilities
  - Scaled down down TIM by ~40%
- Total of 8-Channels in 6U CubeSat





CTIM ESR

Silicon Detector



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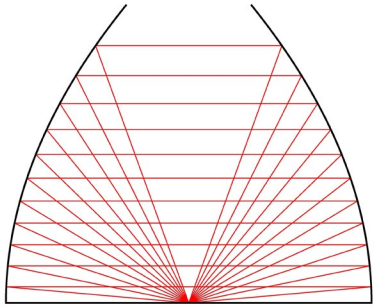
Reflector



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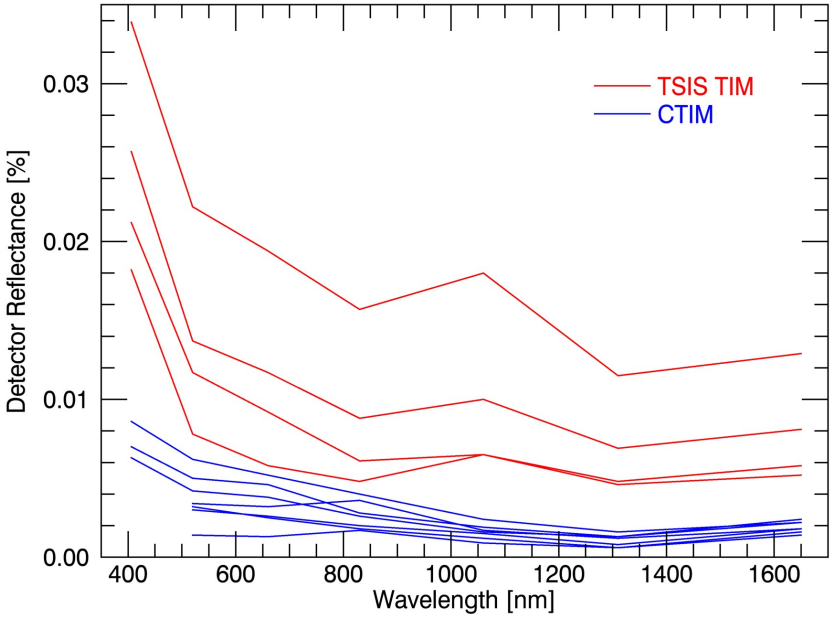
CTIM Detector

- More stringent accuracy for TSI
  - Reflectance uncertainty of <0.005%
- Thermally integrated reflector
  - Only 51 μm thick
- ~10x darker with reflector
  - Absorbance >99.99%

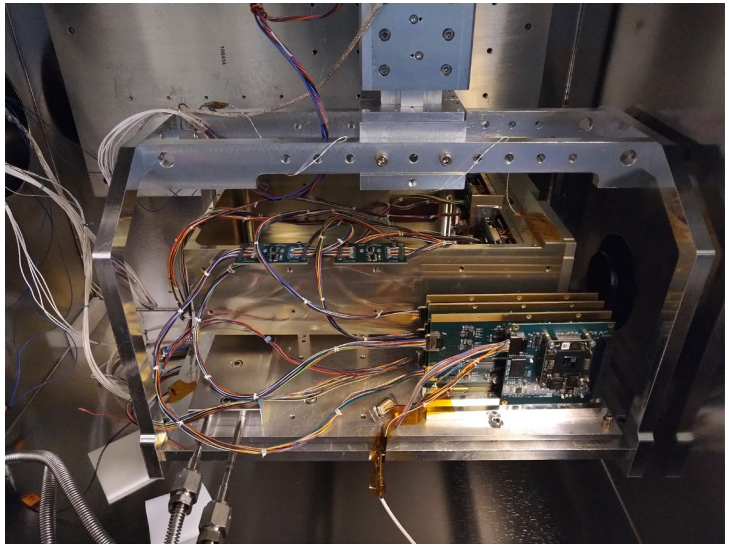
Detector Reflectance



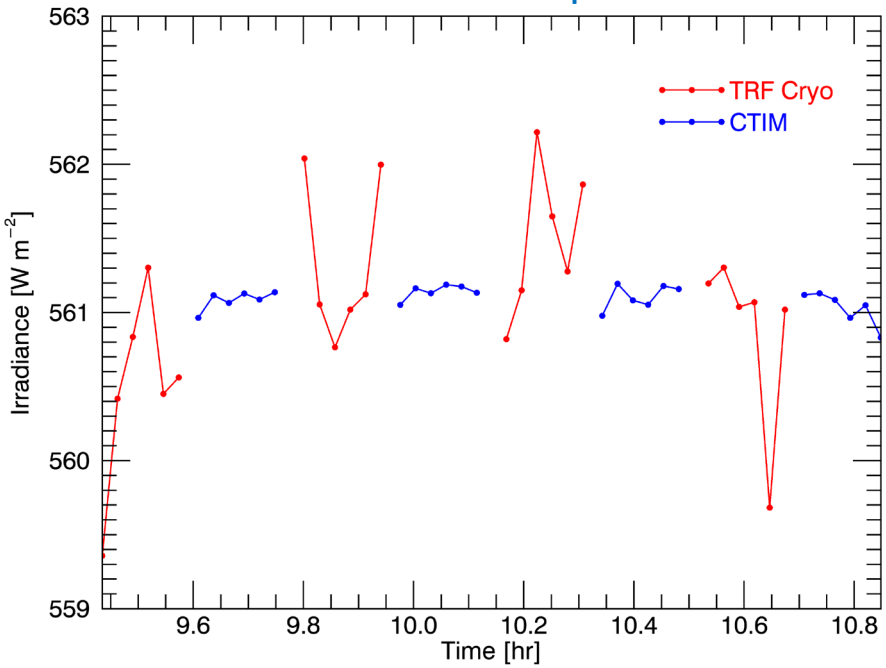
CTIM Performance

- The CTIM engineering model tested in the LASP TSI radiometer facility
  - CTIM radiometric scale validated to ~0.05%
  - Limited by noise in our cryogenic radiometer
    - Working with 60% less power

CTIM in TRF

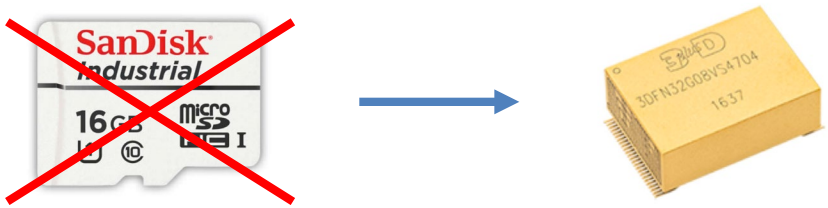


Irradiance Comparison

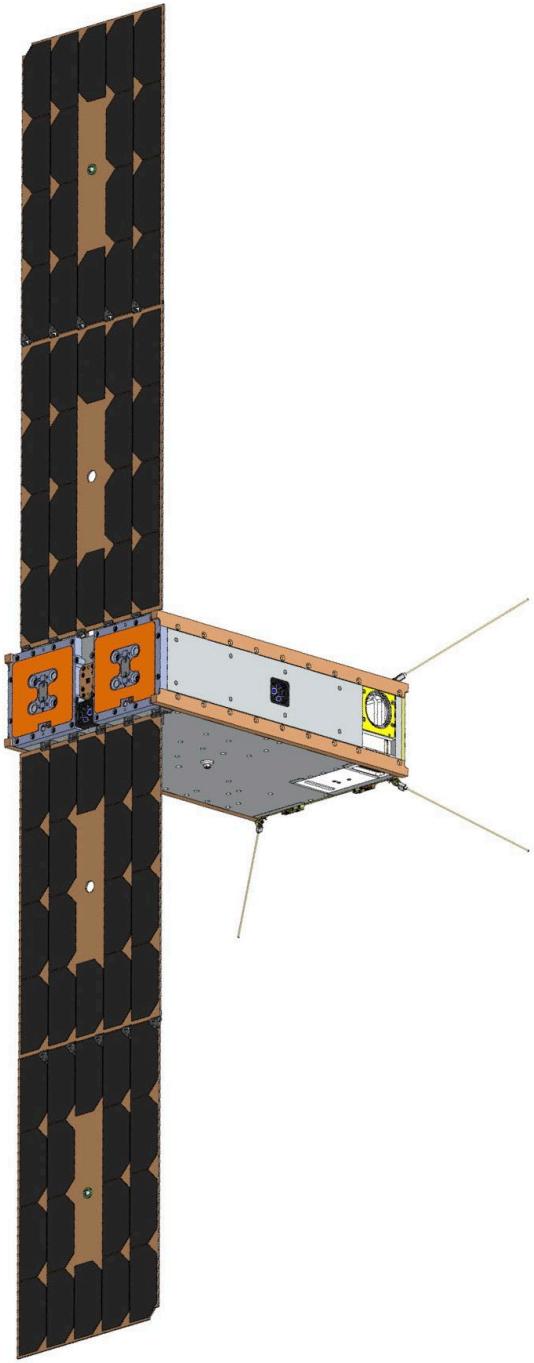


CTIM Mission

- Technology demonstration mission
- CubeSat design borrows from CSIM
  - Implements lessons learned from CSIM operations



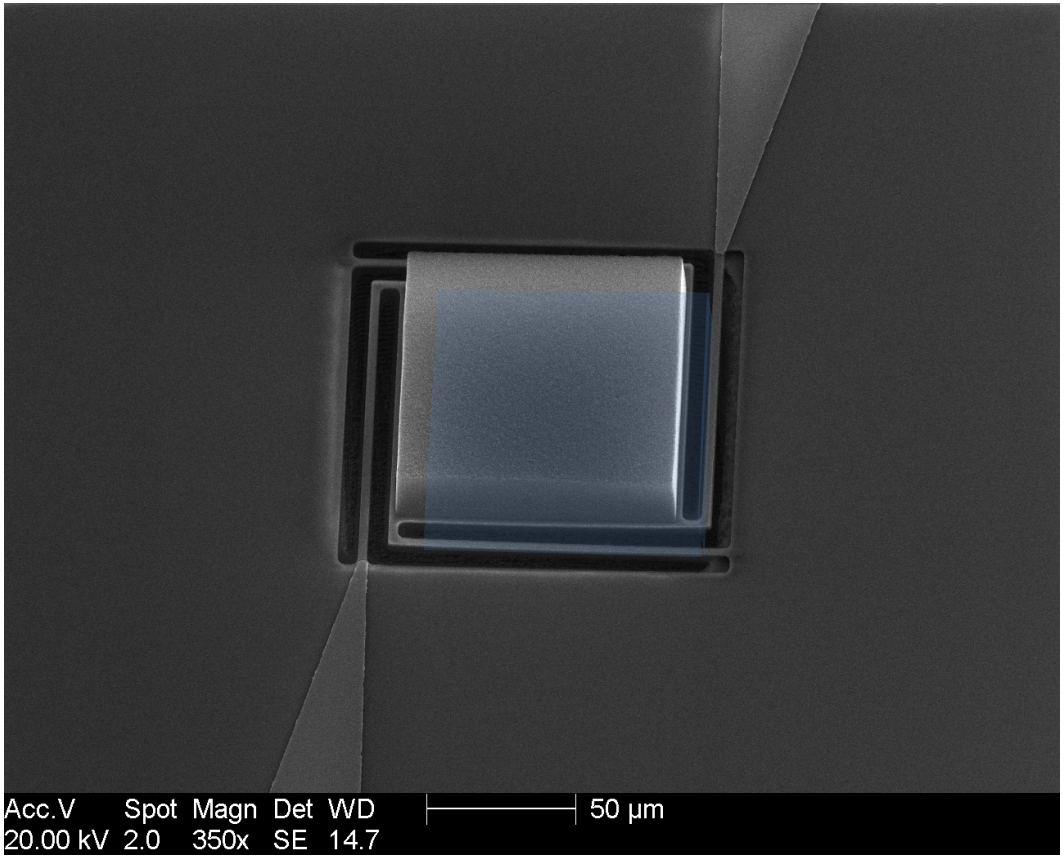
- CTIM EM Instrument has undergone full environmental test
- Flight instrument build is starting now
- CubeSat assembly & test spring-fall 2020
- Delivery late 2020
- Launch early 2021
  - Baseline 1 year mission



Further Detector Progression

- How far can we push these ESRs?
- Silicon processing technology permits miniaturization:

~100 µm ESR with Carbon Nanotubes (SEM Image):



Turning towards Earth

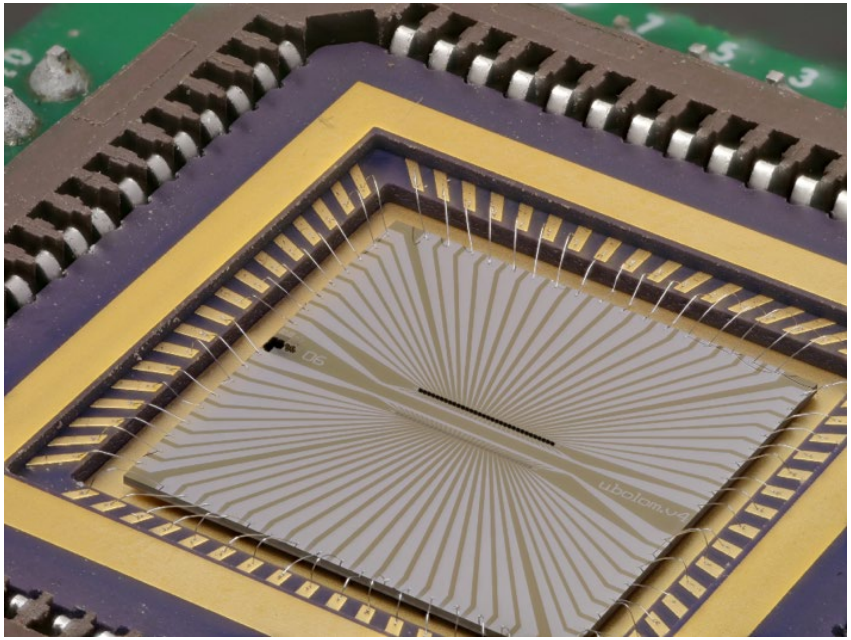
Black Array of Broadband Absolute Radiometers (BABAR) Project:

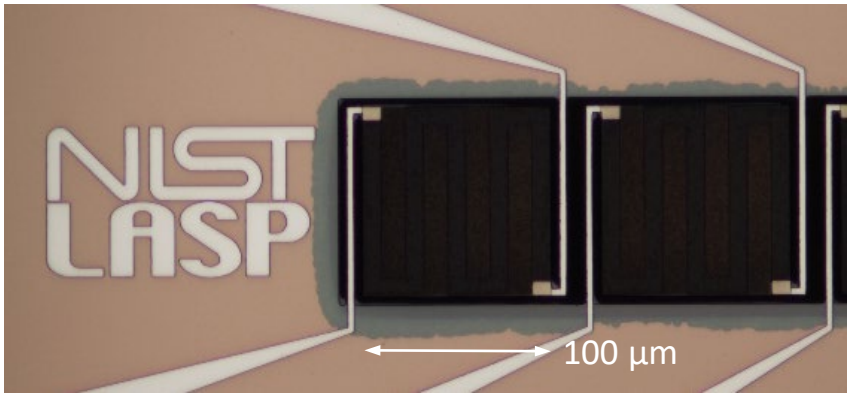
- Developing 32 element ESR array

Black Array of Broadband Absolute Radiometers for Imaging Earth Radiation (BABAR-ERI):

- Integrate this array with a reflective telescope to develop a push-broom broadband earth imager
  - Target ground pixel size of 1 km

32 Element ESR Array





Summary

- We are “doing the work” to develop next-generation instruments for monitoring solar irradiance
- CubeSats are an ideal platform for technology demonstration
- CubeSats *may* prove to be a good platform for continuity measurements
  - Working in increasing the robustness of CubeSats
- Silicon + Carbon Nanotubes are ideal for ESRs
- They will never match the sensitivity of quantum detectors (photodiodes, CCDs)

However

- They have superior stability and wavelength coverage
- Ideal for climate record measurements