National Aeronautics and Space Administration

EXPLORE EARTH TECH

Remote Sensing Technology Validation on CubeSats at NASA

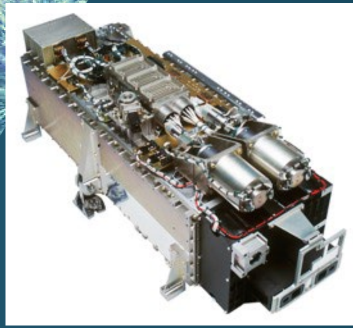
Sachidananda Babu

Parminder Ghuman

living planet symposium | BONN 23–27 May 2022

Mission Evolution: From a Large Satellite to CubeSat

Compact Spectral Irradiance Monitor (CSIM) Flight Follow-On



SORCE SIM (launched 15 Jan 2003)

- Two channel instrument (duty-cycled for stability corrections)
- Absolute ESR detector (NiP bolometer)
  - First generation (Noise 3 nW @ 40 sec.)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- Abs. accuracy: 2-10% wavelength dependent (no-SI validation)

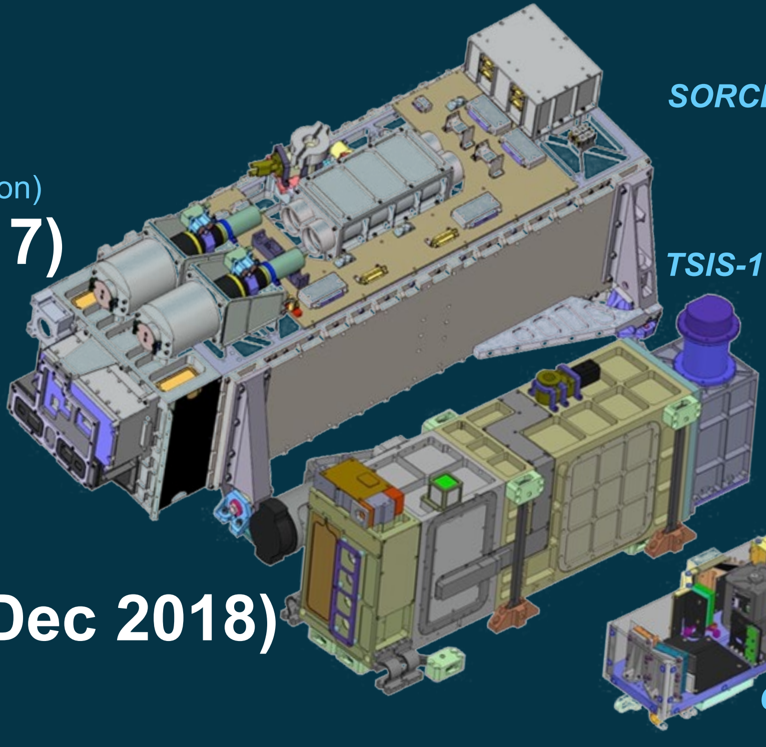
TSIS SIM (launched 15 Dec 2017)

- <u>Three</u> channel instrument
  - For long-term stability validation of duty-cycling
- Absolute ESR detector (NiP bolometer)
  - Second gen. (Noise 1.6 nW @ 40 sec.)
  - Diamond substrate
  - NiP black absorber
  - Kapton™ thermal link
- Abs. accuracy – 0.2 % (SI-traceable validation)

CSIM 6U CubeSat (launched 3 Dec 2018)

- ✓ Two channel instrument (duty-cycled)
- ✓ Absolute ESR detector (VACNT bolometer)
  - Third gen. (Noise 0.2 nW @ 40 sec.)
  - Silicon substrate
  - VACNT black absorber
  - SiNx thermal link
- ✓ 200-2400 nm (continuous)
- ✓ Abs. accuracy – 0.2 % (SI-traceable validation)

Relative instrument size comparison



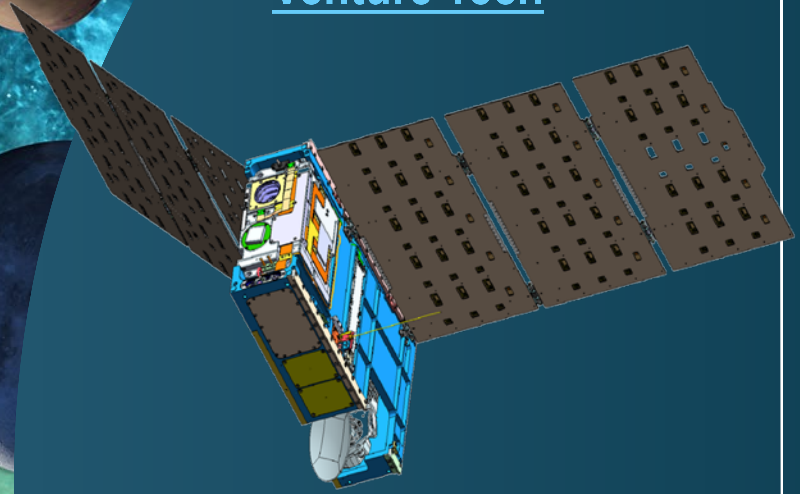
CSIM represents a significant reduction in mass (1/10th), volume (1/20th), and flight ready costs <u>and maintains maximum performance to meet SSI measurement requirements</u>

ESTO

ESTO InVEST 2015 Program

U-Class Satellites Advancing TRLs for Future Earth Science Measurements

Venture Tech



TEMPEST-D

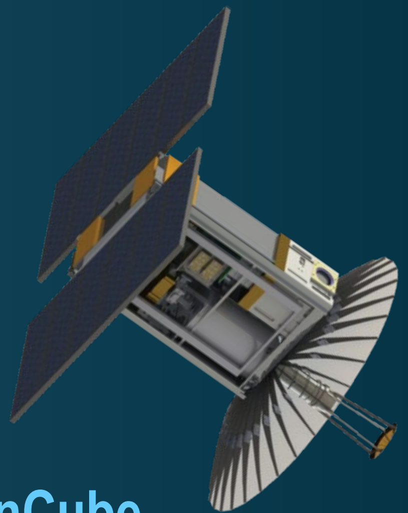
Colorado State University

Launched June 2018

5 Frequency mm-Wave Radiometer

Technology demonstrator measuring the transition of clouds to precipitation

ESTO InVEST 2015 Program



RainCube

Jet Propulsion Lab

Launched June 2018

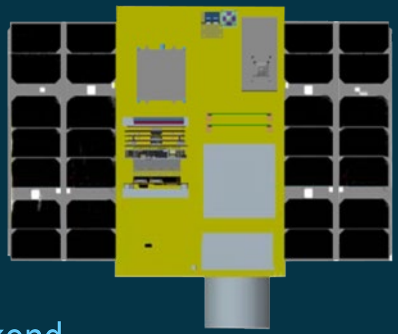
Precipitation Radar

Validate a new architecture for Ka-band radars on CubeSat platform and an ultra-compact deployable Ka-band antenna

CubeRRT

The *Ohio State University*

Launched: June 2018



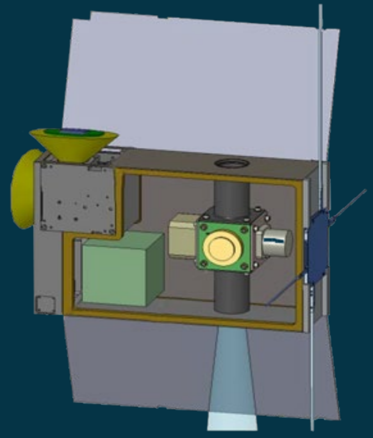
Radiometer RFI

Demonstrate wideband RFI mitigating backend technologies vital for future space-borne microwave radiometers

CIRiS

Ball Aerospace

Launch: 2019



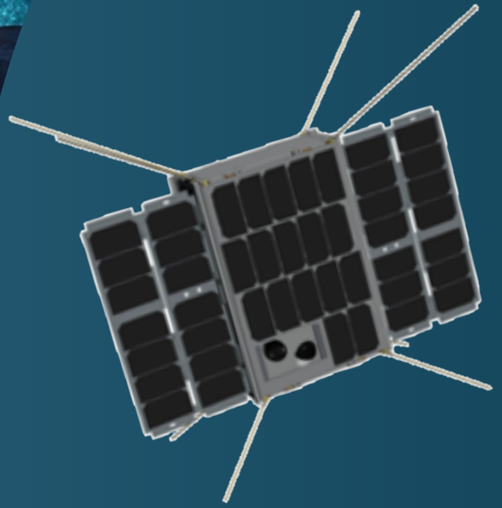
Infrared Radiometer

Validate an uncooled imaging infrared (7.5 um to 13 um) radiometer designed for high radiometric performance from LEO

ESTO InVEST 2017 Program

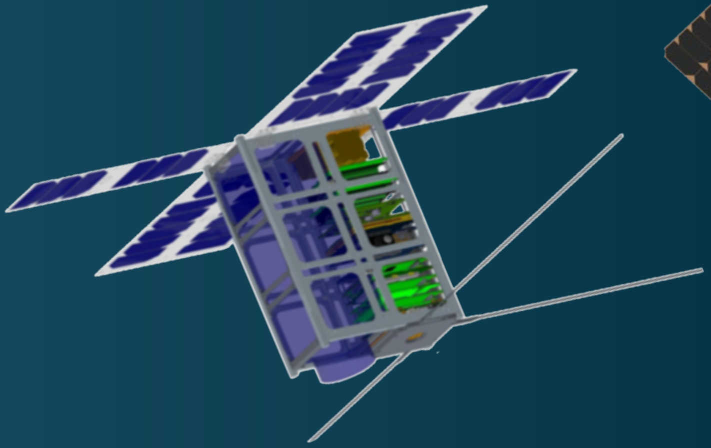
U-Class Satellites Advancing TRLs for Future Earth Science Measurements

SNoOPI
Purdue University



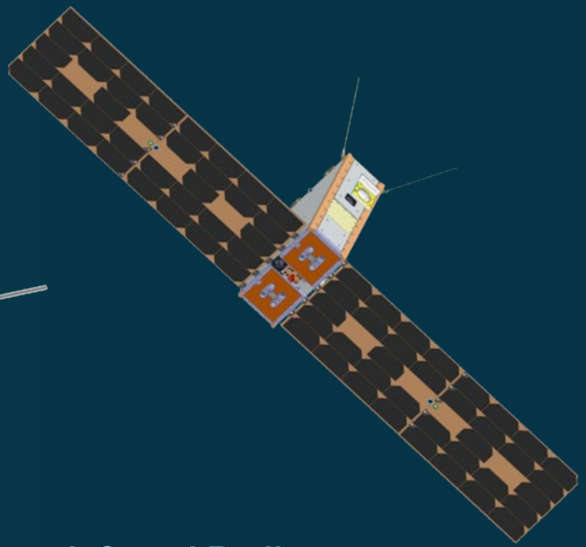
SigNals of Opportunity: P-band Investigation
Demonstrate measurement of the reflection coefficient and phase of land surface reflections from P-band communication satellite signals of opportunity

HyTI
University Of Hawaii



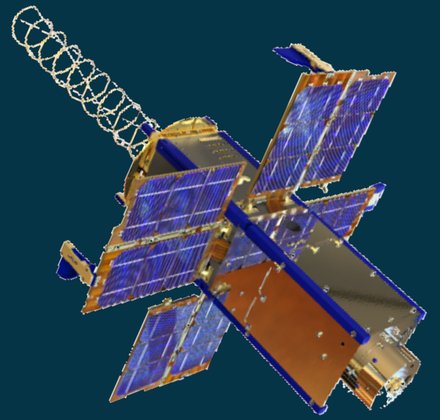
Hyperspectral Thermal Imager
Demonstrate a 6U CubeSat based LEO thermal infrared ITIR) hyperspectral imager with agile on-bard processing

C-TIM FD
LASP-Univ of Colorado



Infrared Radiometer
Validate and demonstrate science performance validate 6U CubeSat system against existing TSIS instrument

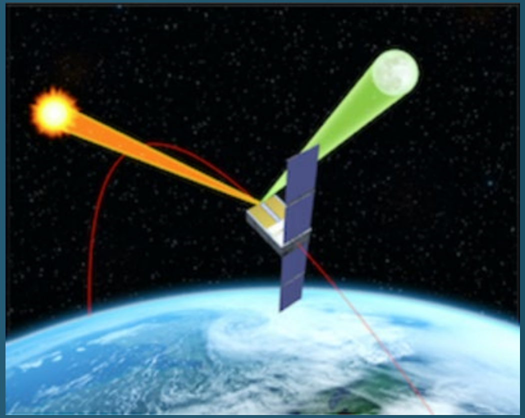
NACHOS
Los Alamos National Laboratory



NanoSat Atmospheric Chemistry Hyperspectral Observation System
Compact high-resolution trace-gas hyperspectral imagers, with agile on-board processing

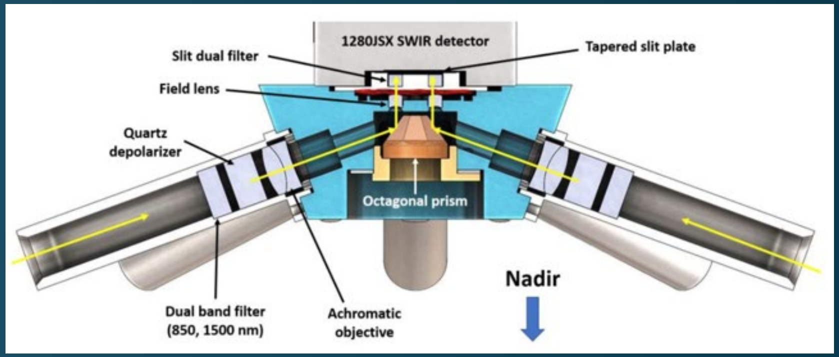
Three New Projects Selected Under InVEST-20

In late June 2021, three new projects were selected, from a total of 13 proposals, under the In-Space Validation of Earth Science Technologies (InVEST) program. The solicitation targeted small instruments and instrument subsystems that can advance technology to enable relevant Earth science measurements. Total funding for these investigations is approximately $16.6 million:



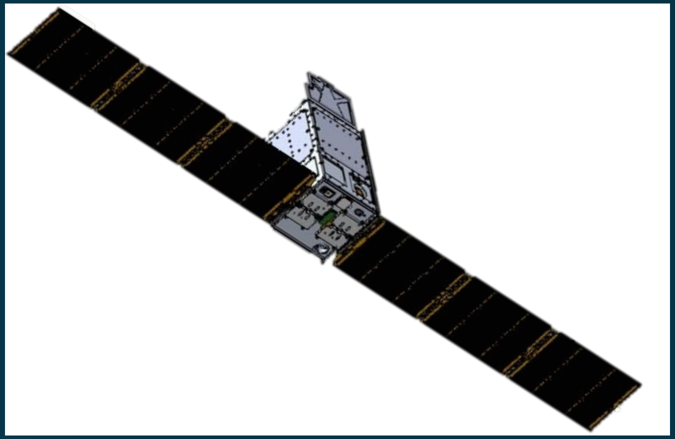
ARCSTONE: Calibration of Lunar Spectral Reflectance from Space
PI: Constantine Lukashin,
NASA Langley Research Center

A hyperspectral instrument spanning the VSWIR spectral range that is designed to be integrated into a 6U CubeSat in low Earth orbit (LEO), will provide lunar spectral reflectance measurements with a target accuracy < 0.5% (k=1), sufficient to establish an absolute, on-orbit lunar calibration standard for current and future Earth observing sensors.



The Aerosol Radiometer for Global Observation of the Stratosphere (ARGOS) Instrument
PI: Matthew DeLand,
Science Systems And Applications, Inc.,
in partnership with GSFC and Loft Orbital

ARGOS instrument will collect limb scattering data of atmospheric aerosols at several wavelengths in multiple viewing directions simultaneously. Such dense sampling could reduce the uncertainty in climate model calculations of post-volcanic eruption global aerosol loading by a factor of 2-3. ARGOS can be considered as a next generation OMPS limb profiler



Active Cooling for Methane Earth Sensors (ACMES)
Charles Swenson, Utah State University

The 6U ACMES CubeSat will demonstrate two technologies: an active architecture for thermal control of instruments on small satellites, which aims to reduce radiator size by 70% for a given application; and a filter incidence narrow-band infrared spectrometer for the detection of methane sources.

For more details: https://esto.nasa.gov/selections-invest20/

And Now…..

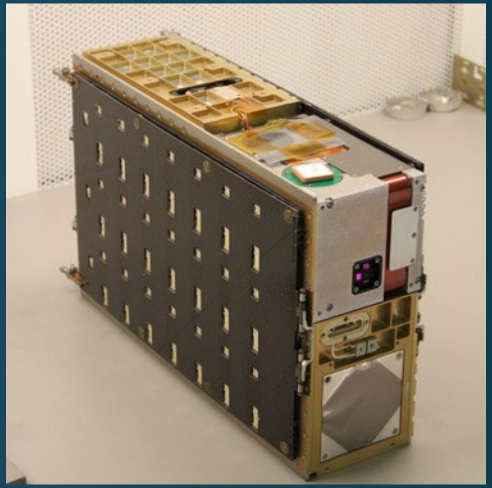
To

Calibrated data from CubeSats

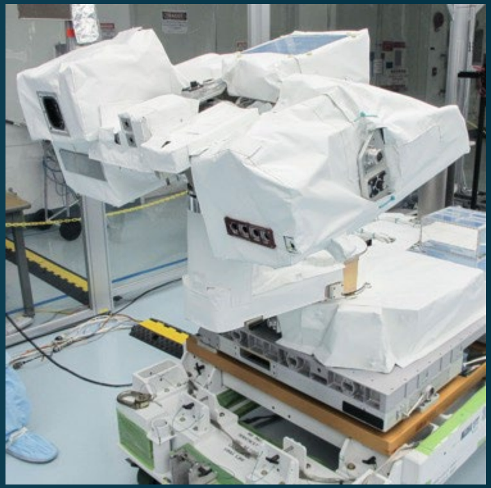
CSIM-FD

Compact Solar Irradiance Monitor Flight Demonstration

Measuring solar spectral irradiance (SSI), and how solar variability impacts the Earth's climate, contributing to long-term continuity measurements from SORCE SIM and TSIS SIM

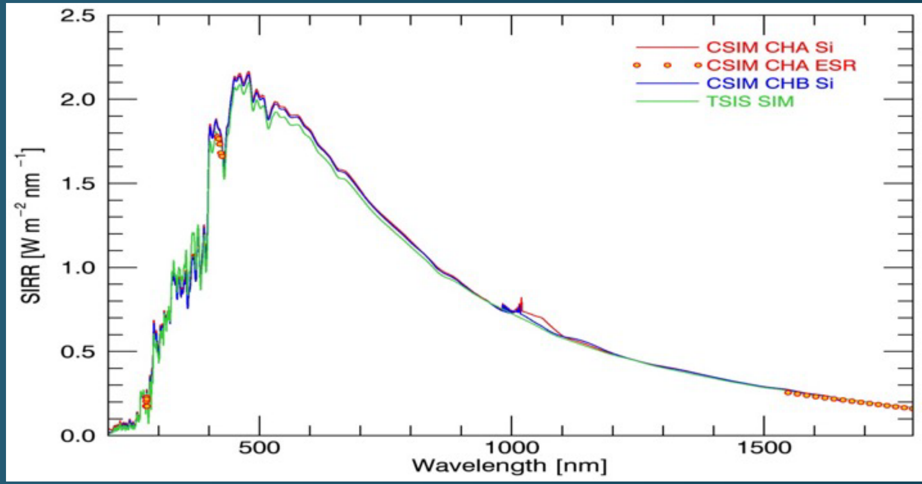


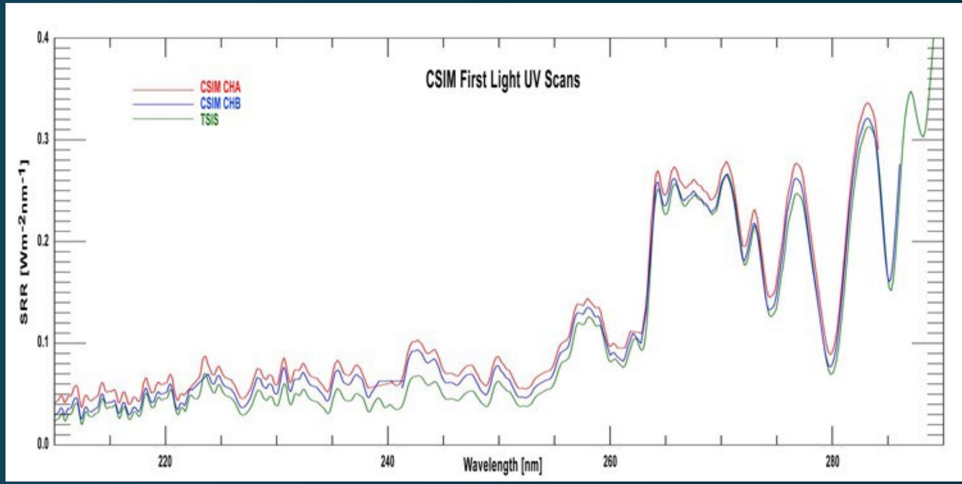
CSIM is 11 kg based on a Blue Canyon Technologies bus



TSIS-1 is 363 kg built by LASP mounted to the ISS

SORCE is 290 kg based on an Orbital LEOStar-2 bus





Latest full spectrum and First Light uncorrected CSIM data (channels A and B) compared to TSIS data in a portion of the UV spectrum

The new solar spectral irradiance spectrum used by the scientific community has just adopted the TSIS-1 spectrum as the worlds reference. This extends that spectrum from 2400-2700 nm based on the data and findings of our tiny warrior, CSIM

The objective of CIRiS system design is to optimize on-orbit calibration performance

The CIRiS instrument as a “calibration laboratory in space”

Three different calibration views on-orbit, via scene-select mirror

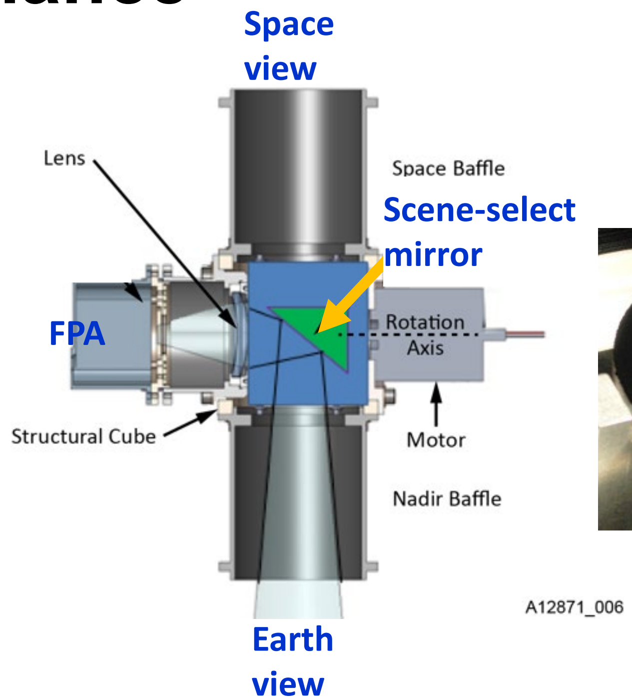
- Two carbon nanotube calibration sources (different temperatures)
- View to deep space

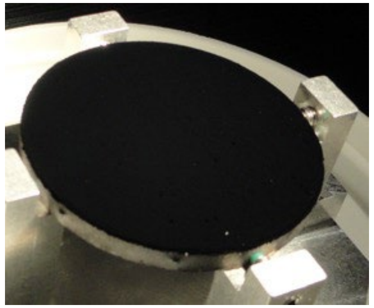
Multiple parameters selectable on orbit

- Calibration sequence, timing, temperatures, others

Additional features to optimize calibration performance:

1. End-to- end calibration
2. Multiple temperature controlled zones
3. Multiple temperature sensors for background correction





Carbon nanotube films on 1/8-in thick flat panel substrates

- Fit two calibration sources in 10 cm length- difficult with conventional cavity sources

High measured emissivity in CIRiS bands $\varepsilon > 0.996$

- Reduces emissivity uncertainty in calibration
- Reduces stray light reflections during calibration

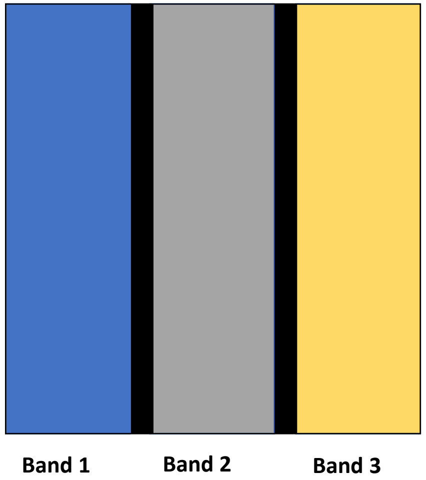
CIRiS acquires calibrated images in three infrared bands

Three bands selected for imagery of Earth’s surface temperature

Two bands enable correction for atmospheric water absorption

Parallel images acquired in each band from LEO by pushbroom scanning

Band	FWHM wavelengths Lower, upper
1	7.40 um, 13.72 um
2	9.85 um, 11.35 um
3	11.77 um, 12.60 um



3 band filter over focal plane

Scan direction

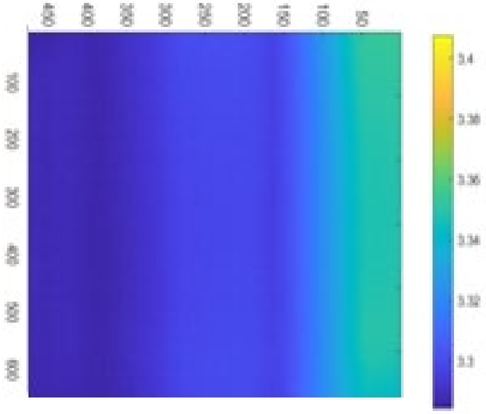


Image in 3 bands from flat field source

“Shadowing” at filter boundaries

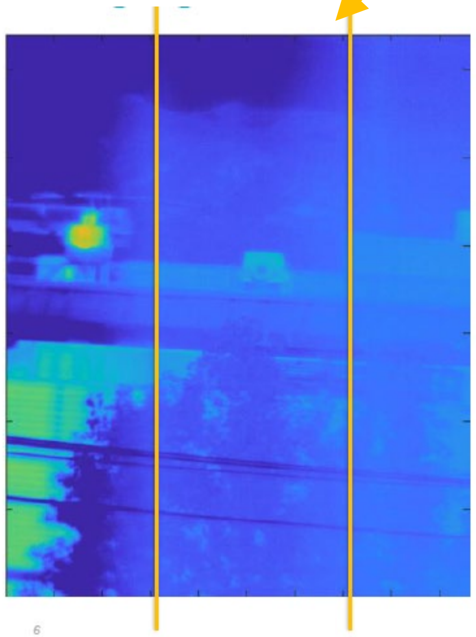
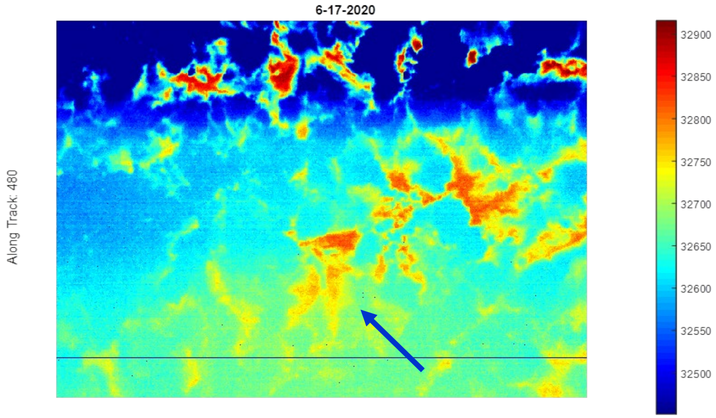


Image in 3 bands of parking structure

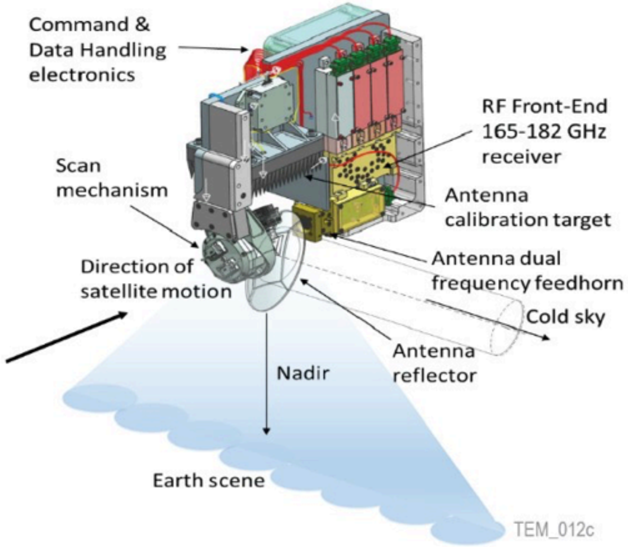
First light data from CiRIS instrument



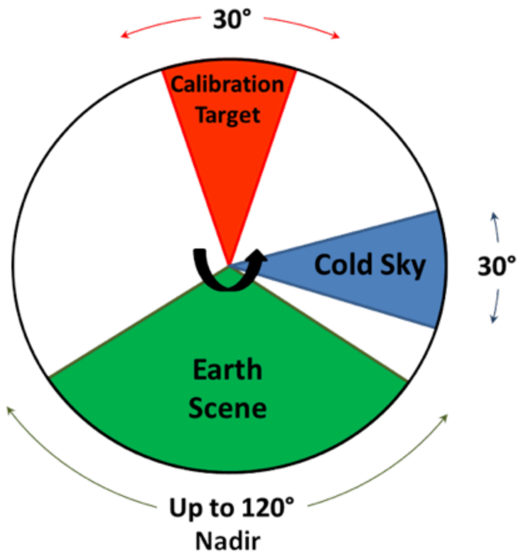
Clouds in South Indian Ocean off Australian coast

TEMPEST-D Instrument Performs End-to-End Radiometric Calibration

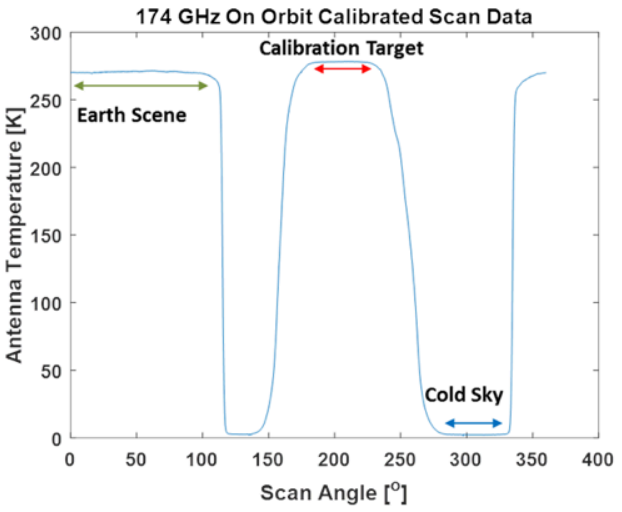
TEMPEST-D Instrument



Observing Profile



Time Series of Output Data



- Five-frequency millimeter-wave radiometer measures Earth scene up to ±60° nadir angles, for an 1550-km swath width from a initial orbit altitude of 400 km. Spatial resolution ranges from 13 km at 181 GHz to 25 km at 87 GHz.
- TEMPEST-D performs two-point end-to-end calibration every 2 sec. by measuring cosmic microwave background at 2.73 K ("cold sky") and ambient blackbody calibration target each revolution (scanning at 30 RPM).

EXPLORE EARTH

Summary

- ESTO Programs have been instrumental in development of breakthrough technology for past, present and future NASA missions.

- Investments to advance components, sensors and information technology will yield affordable observations

- Continuous pursuit of miniaturization and reducing SWaP translates to:
  - improving affordability and sometimes simplification
  - enabling implementation options, such as constellations, that can improve spatial coverage and temporal frequency

- The successful infusion of technologies into Earth Venture program line is expected to expand to the Venture Continuity strand

- Rest of the session will be more in depth presentations on few of these missions

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https://esto.nasa.gov