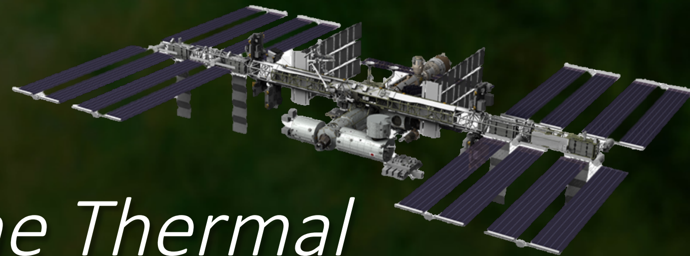


ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

ECOSTRESS Lab Performance

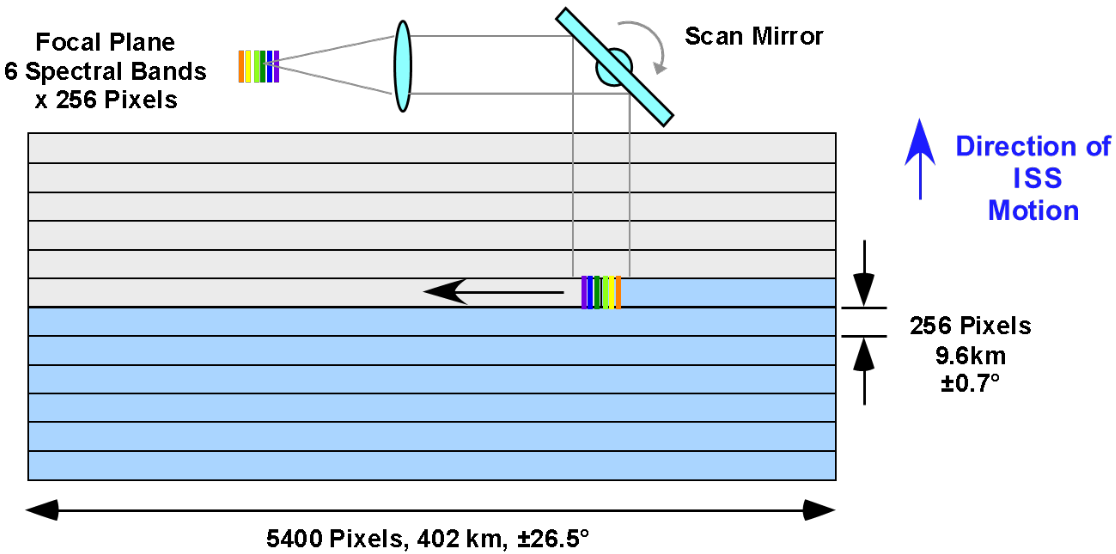
Bill Johnson

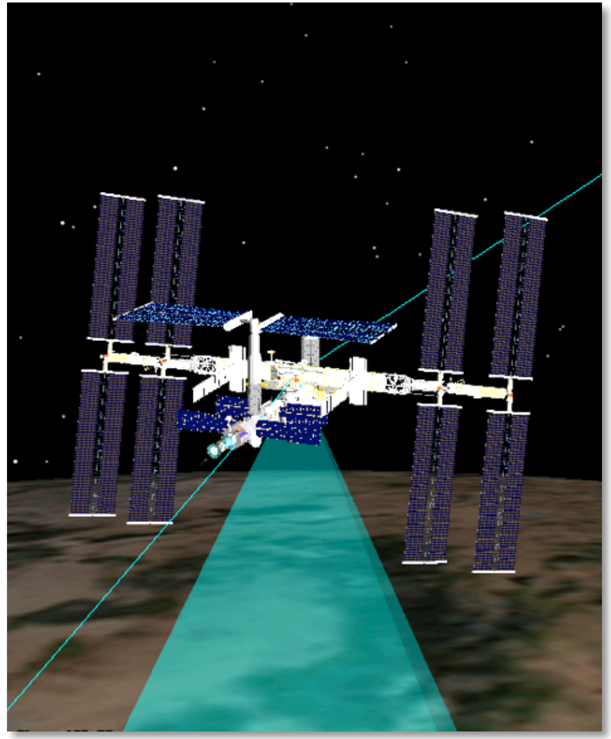
ECOSTRESS Optics & Detector Lead

Topics

- Brief Sensor Description: Optics & FPA
- Calibration Philosophy/Design
- Traceability
- Radiance Processing/List of Tests
- Telescope Alignment
- Performance
- EGSE/MGSE
- Summary

Instrument Concept

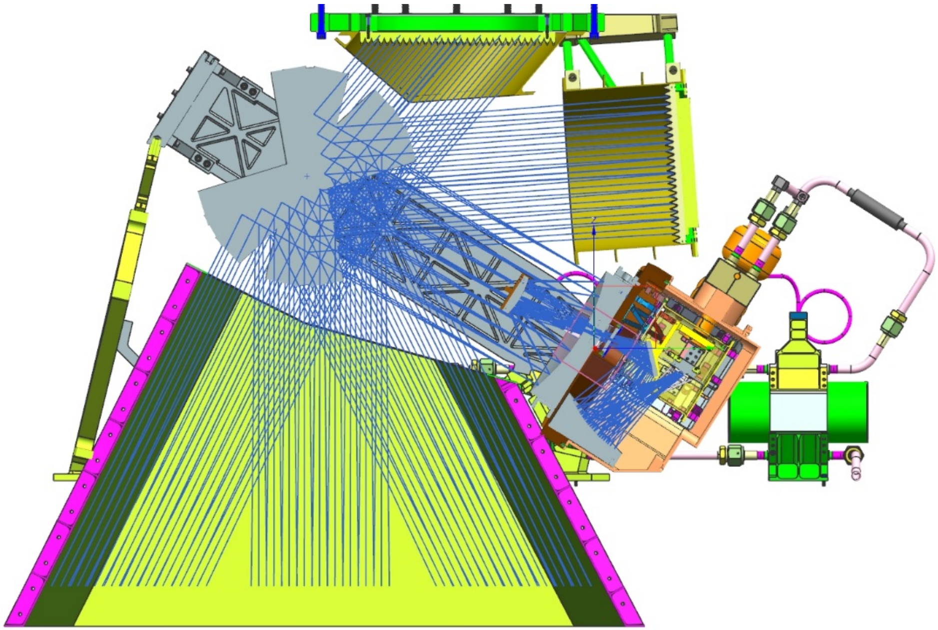


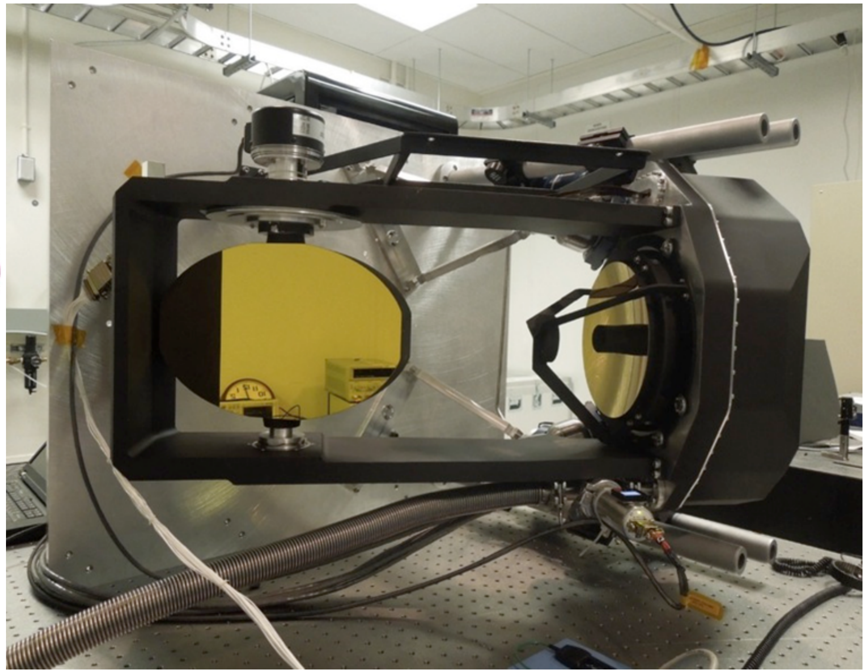


- 402 km swath width at 400 km altitude *(Requirement is ≥ 360 km)*
- 38.5 x 68.5 m Pixel Footprint at Nadir *(Requirement is ≤ 100 m)*
- Scan Mirror rotates to enable overlap between successive scans
- Pixel Dwell Time 32 microseconds

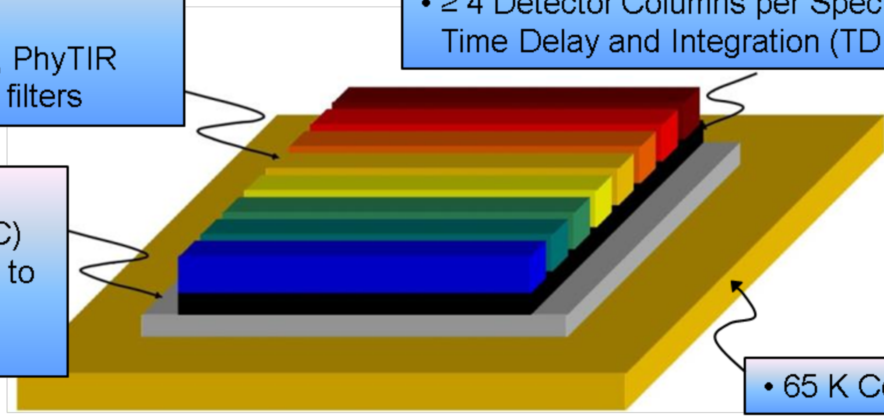
ECOSTRESS Optics

- Design: Three mirror anastigmatic (TMA) with accessible Lyot stop
- Cold focal plane filter array (Butcher-block design)
- Continuously rotating scan mirror (constant scan rate)
- Two on-board blackbodies (295K, 325K)

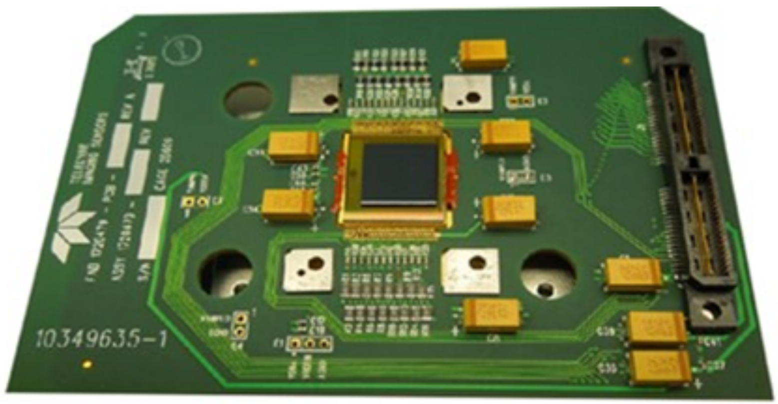




ECOSTRESS Detector Technology



- JPL has focal plane detectors and readout electror
- Digitization in off-chip ADCs
- TDI performed after digitization



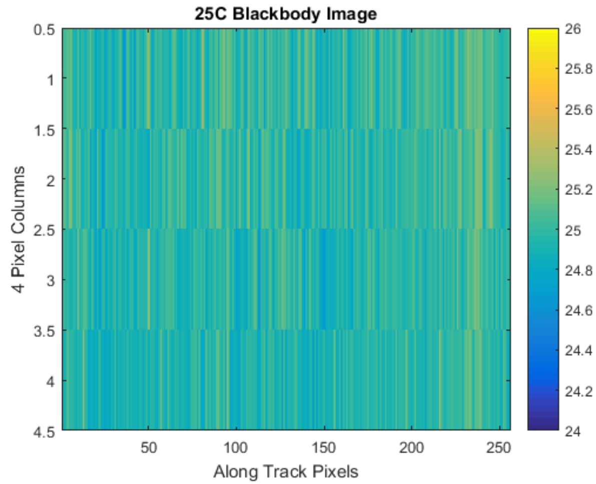
PHyTIR array

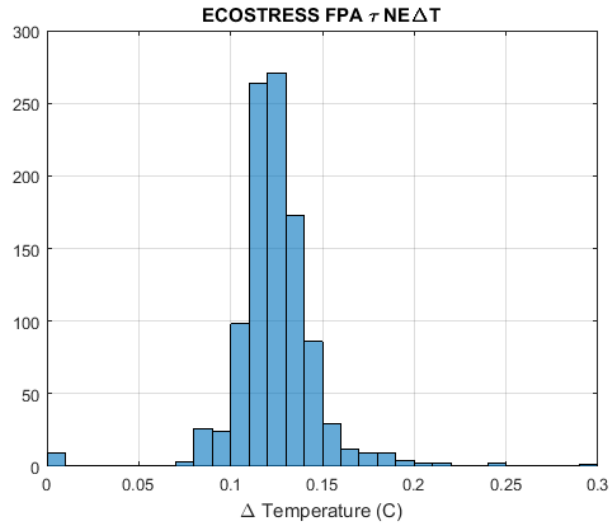
FM Detector Performance

FM detector cold cycled to 65K operating temperature.

DICE (GSE) electronics used.

Results from the FM detector in the ECOSTRESS testbed show the performance meets the noise requirements with > 99% pixel operability.





Calibration Overview

Calibration has essential parts in both Radiometer I&T and Payload I&T

- Calibration of ECOSTRESS is vitally important to its intended mission, since the quality of the calibration corresponds directly to the quality of the data obtained. ECOSTRESS is the first thermal infrared science payload on the ISS and also the first to make effective diurnal measurements from this orbit, so calibrations must set the bar high for future systems.

- Calibration ultimately relies on radiometer and payload I&T for direction and workforce, but specific rolls and responsibilities for assembly and oversight are held with each subsystem disciple lead. This includes electronics, thermal, mechanical and optics. Specific parts related to validation, cross validation, higher level products/algorithms, integrity and long term storage of calibration coefficients, and reconciliation of instrument abnormalities are deemed science team responsibilities.

The ECOSTRESS calibration is a determination of those parameters which either:

a) Enter explicitly in the algorithms which accomplish the conversion from Level 1a (data numbers, DN) to Level 1b (spectral radiances), such as the use of the temperature sensors in establishing the output of the blackbody.

b) Enter indirectly into the data processing, such as the detailed shape of the spectral response function (SRF) and location of the centroids of the SRF in the pre-calculated retrieval weighting functions, or

c) Enter implicitly into the quality of the data, such as measurement stability, noise and dynamic range, and are as such specified in the *Instrument requirements document.*

Calibration: Sectioning of work to be performed

Radiometer calibration during I&T consists of the following system level measurements:

Measurements repeated during payload I&T

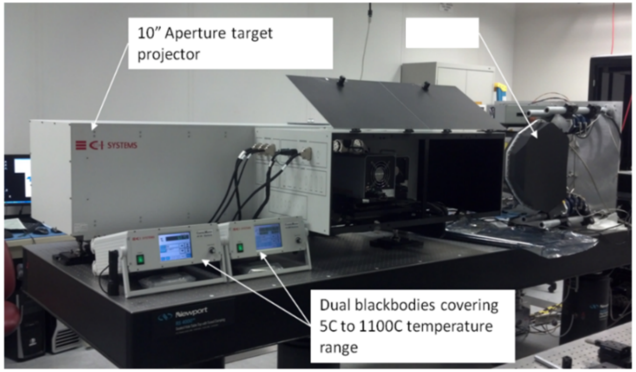
- **Noise equivalent delta temperature (NEΔT) per spectral channel**
- **Absolute radiometric accuracy (linearity) per spectral channel**
- **Modulation transfer function (x and y track)**

Measurements exclusive to radiometer I&T and do not need to be repeated

- **Saturation temperature (define thermal optics contribution)**
- **In-band and out-of-band spectral response function (SRF) using monochromator and target projector.**
- **Radiance versus angle (RVS, capture NEΔT and system linearity to input stimulus at the edges of the field of view).**
- **NIST traceability of blackbodies using transfer radiometer (in air).**

Measurements may be exclusive to payload I&T depending on the available hardware.

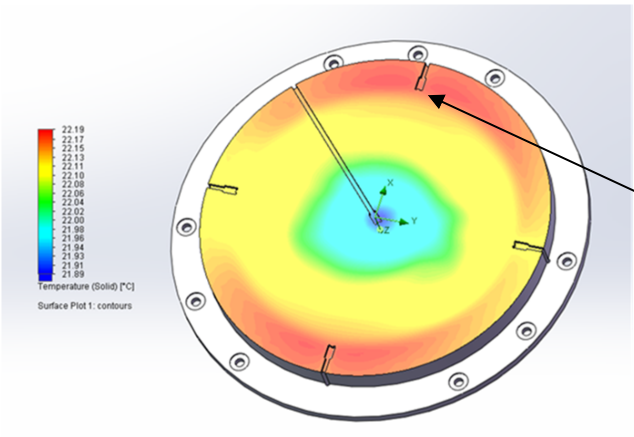
- **Out-of-field rejection to confirm stray light rejection (requires all hardware be present to raise the payload box temperature to the expected temperature).**
- **Geometrical field of view distortion map**



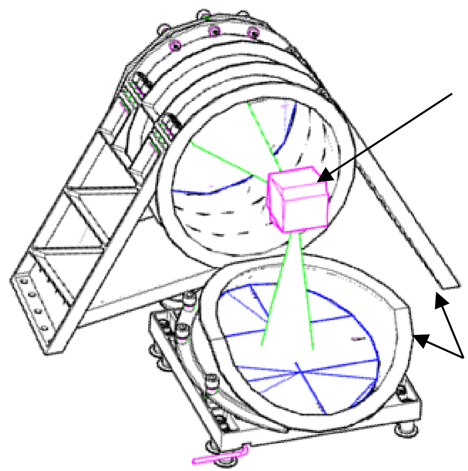
All measurements will be made in a clean room, but the unit will be held at room temperature with the optics and scan mirror exposed to air. Flight signal chain electronics will not be used but the FM buffer card will be used. The on-board calibration blackbodies will be held at temperature with a fluid loop simulator. This should mimic to some extent the behavior (gradients and temperature variation) as expected on the ISS.

Calibration Traceability

- JPL has multiple NIST traceable blackbodies with a stability at 25 C of +/- 0.0007 C and a thermistor standard probe with an accuracy of 0.0015 ° C over 0-60 ° C and stability/ yr of 0.005 ° C. (Model 5643-R). These data are readout using a system with an accuracy of 0.0025 ° C at 25° C and resolution of 0.0001 °. Calibration is performed in a ramp and soak mode where the blackbody temperature is increased by a set interval and allowed to soak for several minutes and then the temperature is measured.
- Portable radiometers will be used to transfer the traceable thermistor probes to the skin temperature of the onboard blackbodies, hence the imbedded platinum resistance temperature detectors (pt-RTDs) (PRTs).
- Stability of imbedded pt-RTDs ~50mk / 5years.

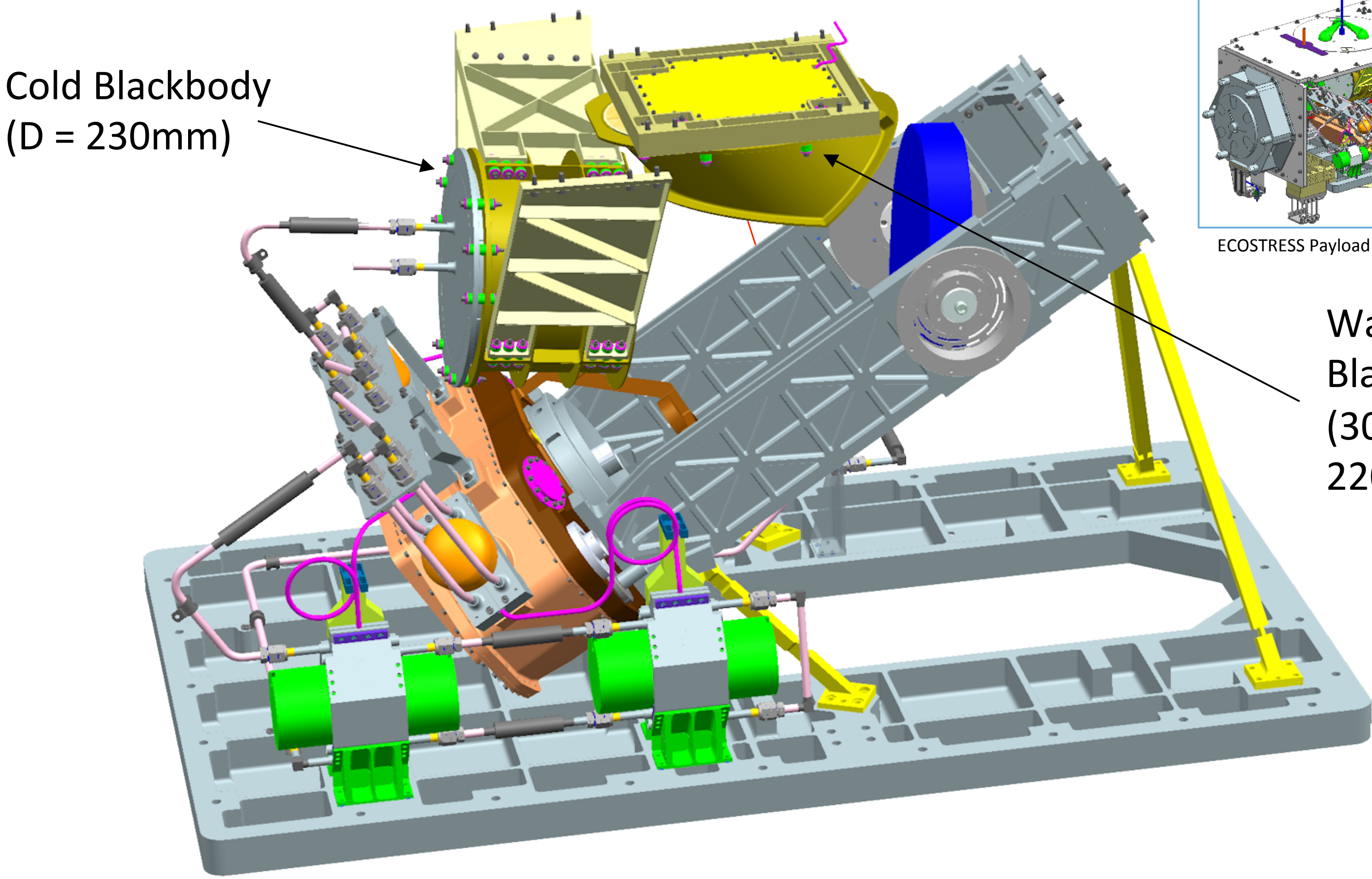


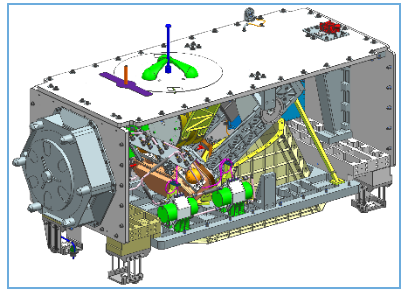
Cold blackbody gradient simulation (Jeff Cha)



Traceability measurement during radiometer I&T

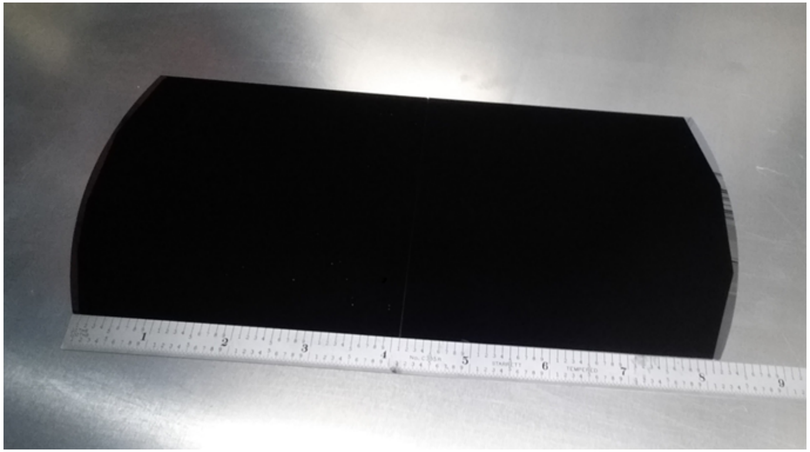
On-Board Blackbody Design



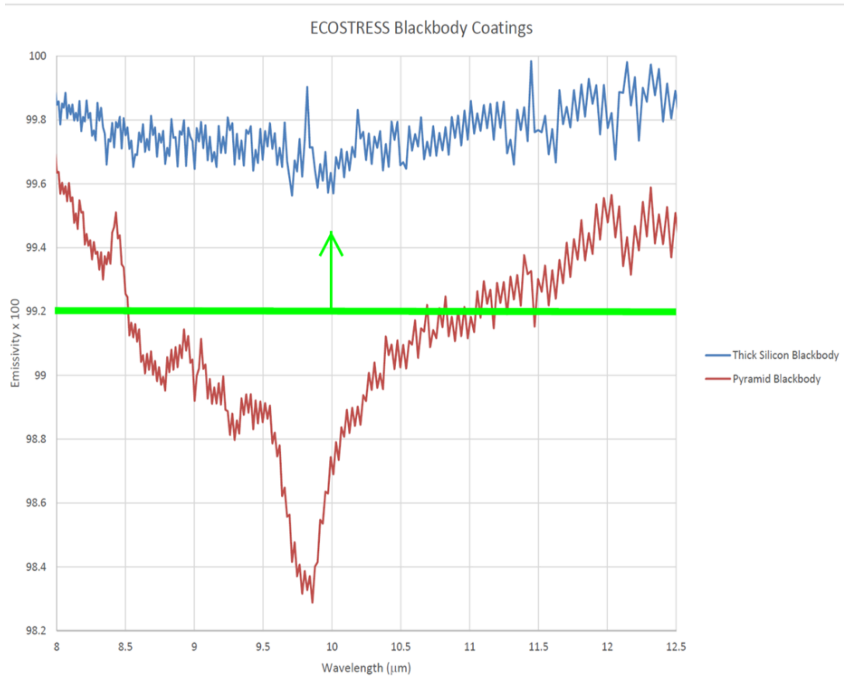


ECOSTRESS Payload (less closeout panel)

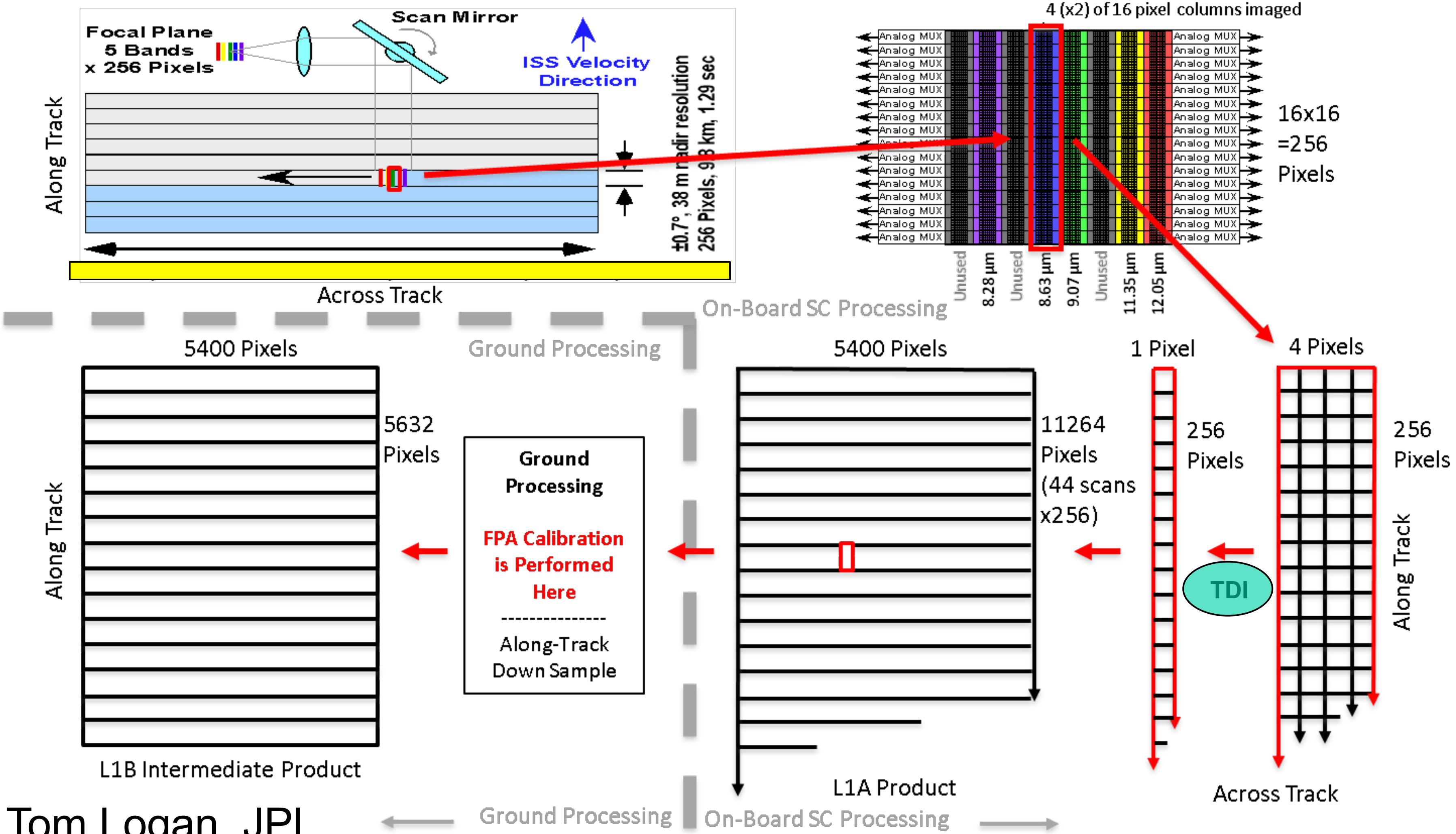
Blackbody Emissivity



220mm aperture blackbody coupon used for surface emissivity measurements. Measured hemispherical reflectance using FTS integrating sphere. Part moved to various locations and tilted up to 45 degrees



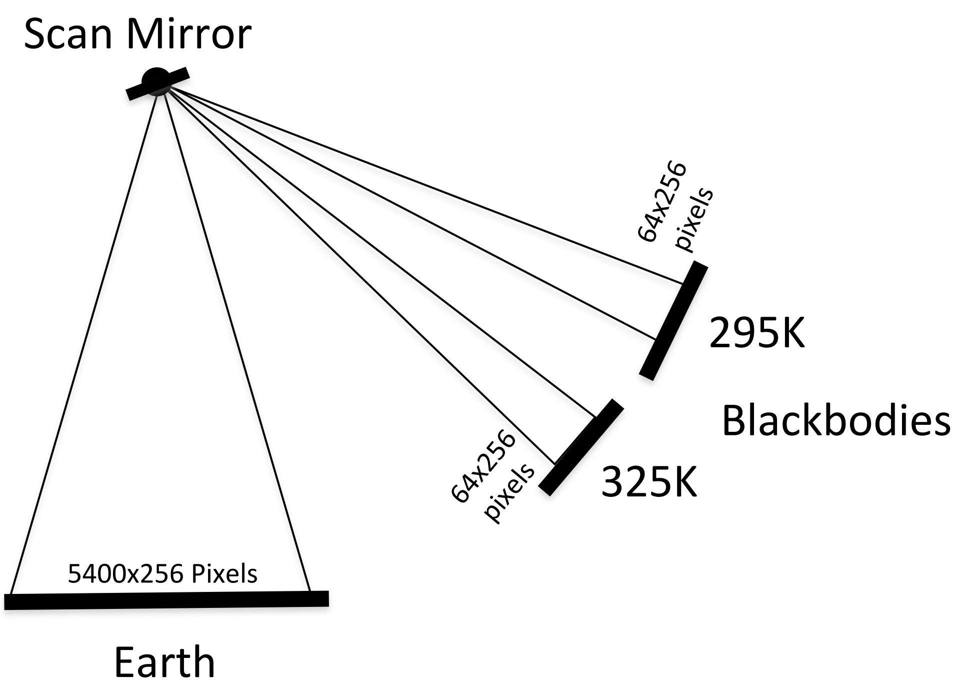
ECOSTRESS Science Data Travel Path



Tom Logan, JPL

Calibration: Blackbody Imaging

One Band / Single Scan Simplification



Blackbody measurements used for the radiometric sensor calibration are collected on-orbit every ~1.2 seconds and downloaded to the ground.

- Earth = 5400x256 pixels
- Cold Blackbody = 64x256 pixels
- Hot Blackbody = 64x256 pixels
- Total one band / single scan = 5528x256 pixels

- Earth data product assumes 44 of these scans (with 256 pixels along track). So this creates a 5400 x 11264 pixel NADIR image.
- The 128x11264 pixels of BB calibration are separated from the Earth image but assembled, and downloaded as an "image".

- On the ground each of the two BB sets are divided into their corresponding filters and combined/median/averaged to 1x256 pixel calibration files.

Digital Number (DN) to Radiance Value

$$R_\lambda = a + bD_\lambda$$

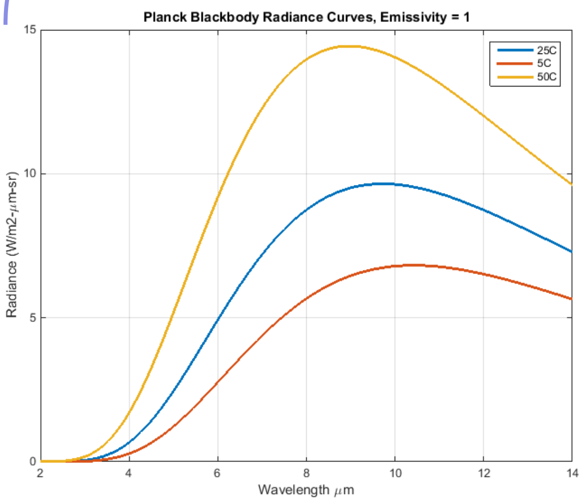
$$a = \frac{R_h D_c - R_c D_h}{D_c - D_h} \qquad b = \frac{R_c - R_h}{D_c - D_h}$$

$$R_c = P(\lambda, Tc)$$

$$R_h = P(\lambda, Th)$$

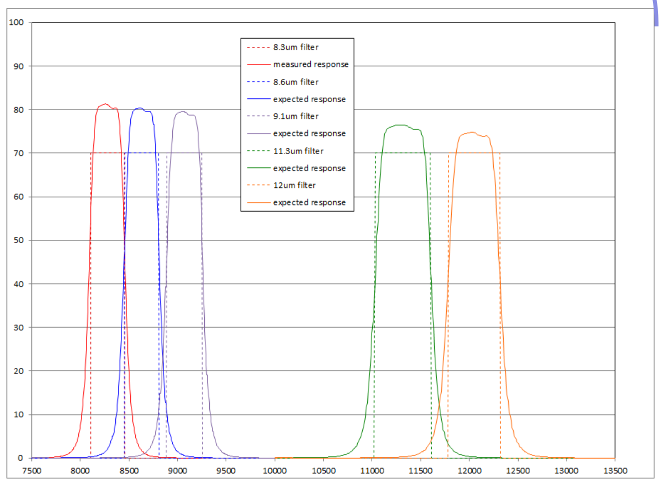
Preflight radiance linked to backside (bulk) temperature of the blackbody

Basic Two Point Calibration is Satisfactory



Planck function model

X



Empirically derived spectral response functions (SRF)

Radiance Value to Brightness Temperature

Brightness temperatures are calculated on a pixel-by-pixel basis by inverting the Planck function which has the form :

$$T_b(\lambda) = \frac{c2}{\lambda \cdot \ln\left(\frac{c1}{\lambda^5 \cdot \pi \cdot L_\lambda} + 1\right)}$$

where:

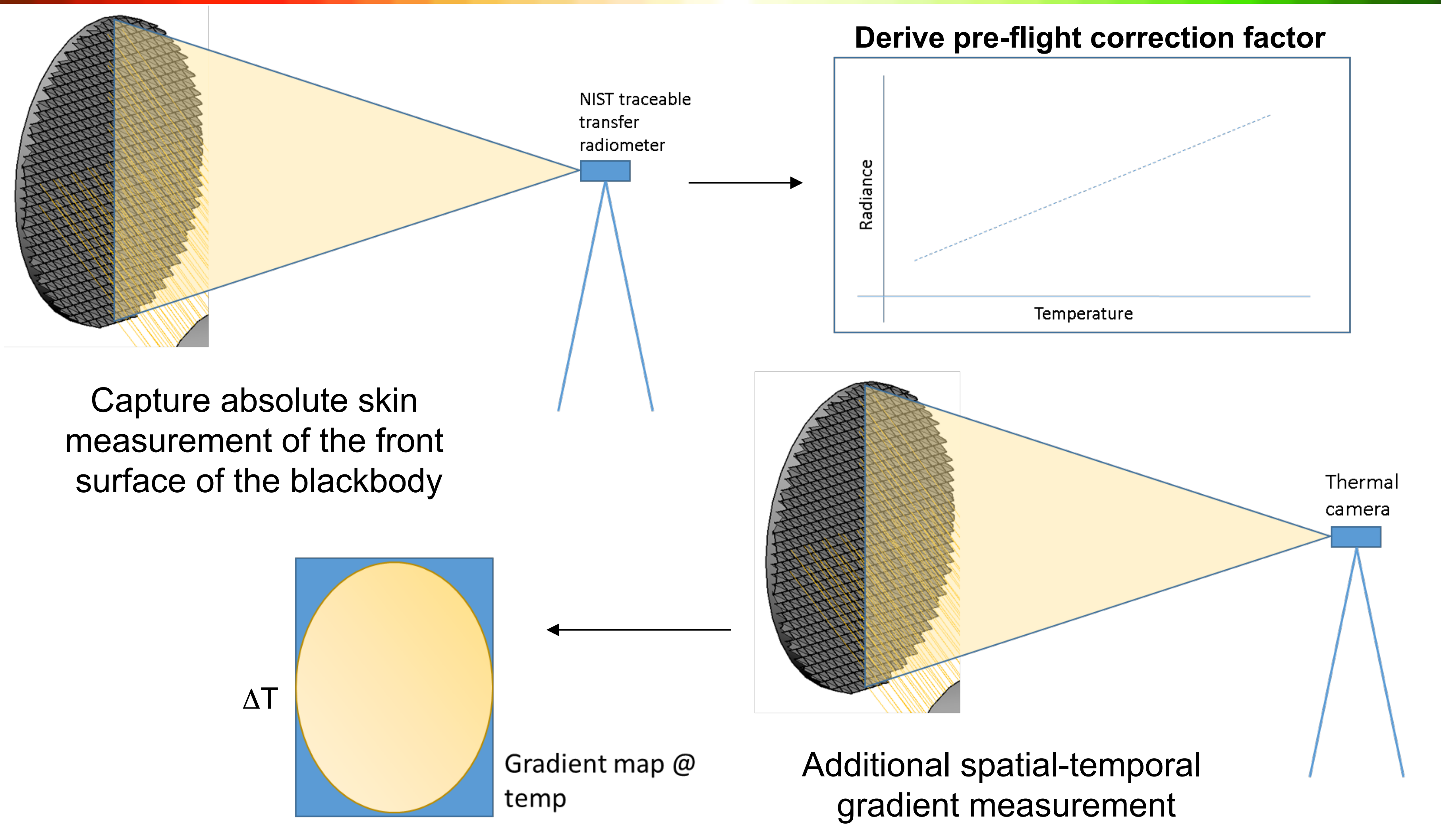
λ is wavelength in μm

$c1 = 0.0143877$

$c2 = 3.741775e\text{-}22$

L_λ is the at-sensor spectral radiance in $W/(m^2 \cdot sr \cdot \mu m)$

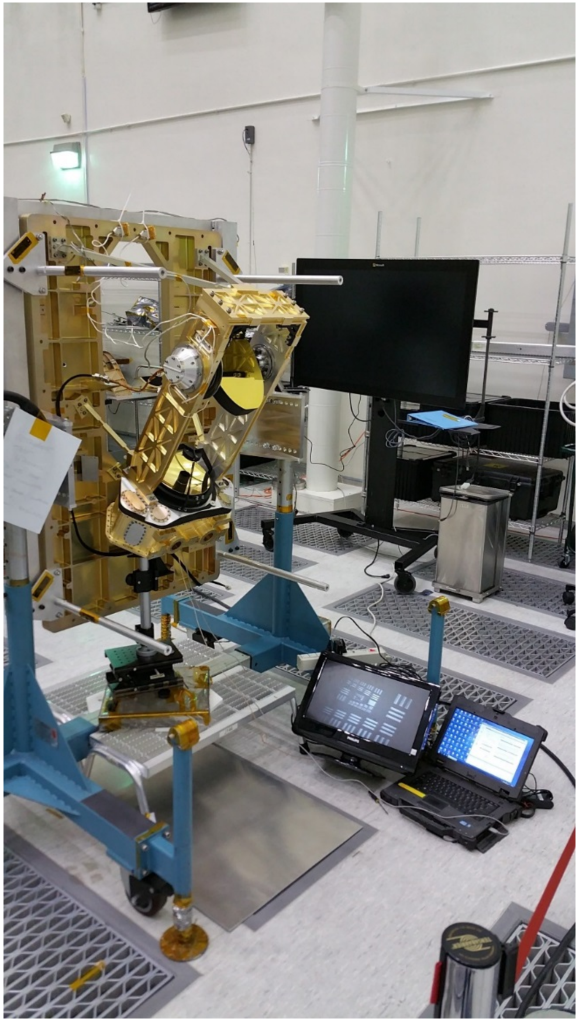
Measuring Pre-flight Correction Factor for Blackbody Surface Radiance

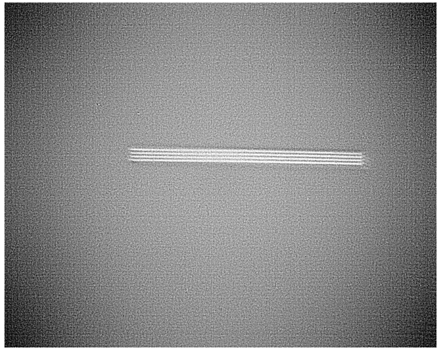


Radiance Processing

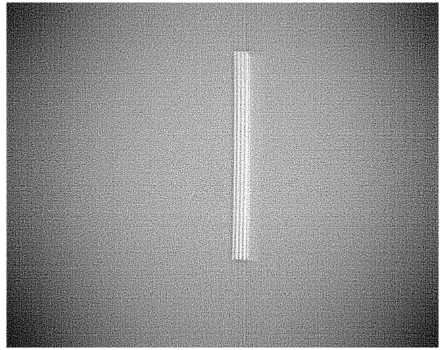
- 2-band correction eliminates the need for a separate dark current subtraction operation.
- 2-band correction effectively acts as a flat fielding operation, so a separate numerical operation isn't needed.
- Calibration coefficients will be determined by measuring the stable relationship between the bulk (pt-RTD) and skin temperature measurements (NIST transfer radiometer) of each blackbody before launch. On-orbit monitoring of the blackbody bulk temperature will be required to interpret the coefficient.
- There will be a control loop for the warm blackbody while the cool blackbody will float using the fluid loop as the heat exchanger.
- The SWIR band, will use a single point offset correction to remove fixed pattern artifacts. The limiting noise is from the readout and not dark current or 1/f noise.

Aligning the telescope

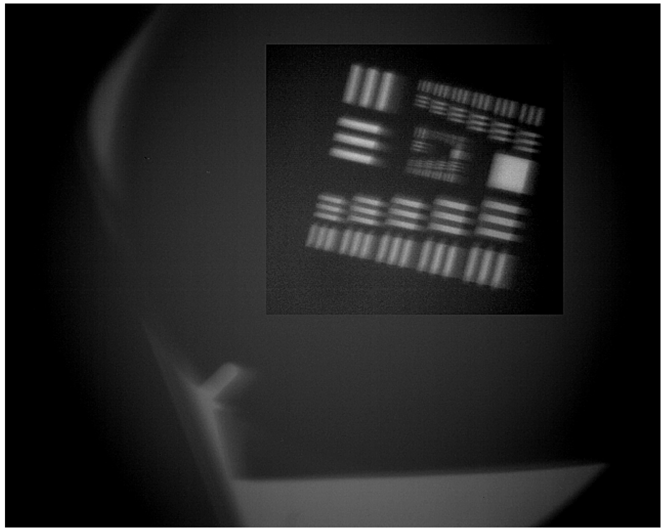




Sagittal Focus



Tangential Focus



Multi-frequency Bar Chart

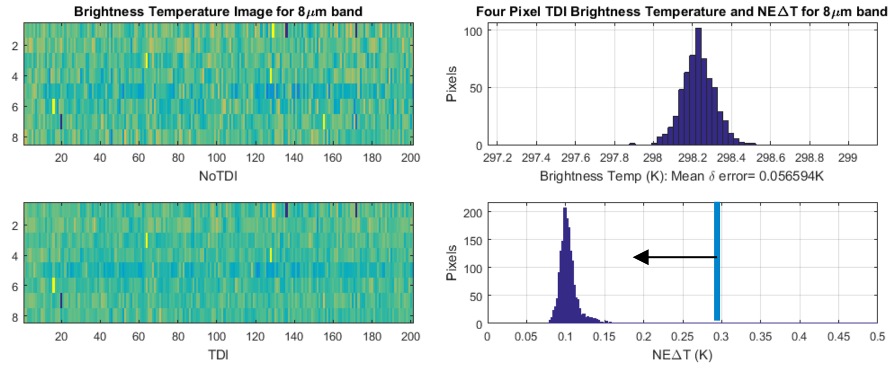
Sensor performance

Parameters:

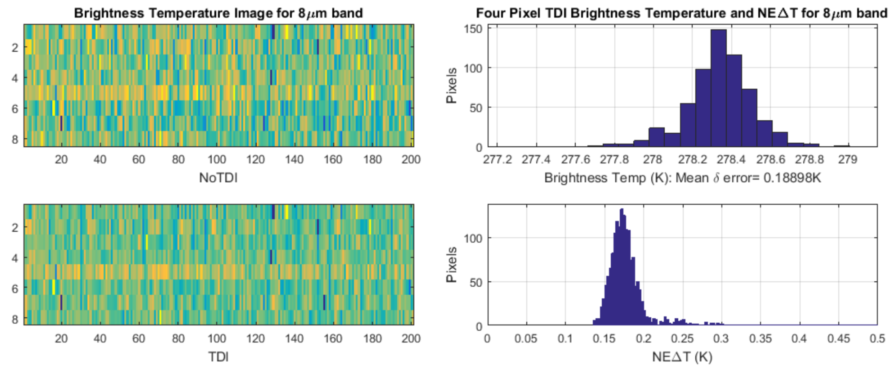
- 2-point correction using full aperture, high emissivity, GSE blackbody at 5C and 50C.
- Measured data using same blackbody at 25C.
- Vacuum/Contamination enclosure held at ~40C using patch heaters on the outside of the container.
- TDI = 4 pixels (8 for 12μm to mimic 2X filter)

Operational Results

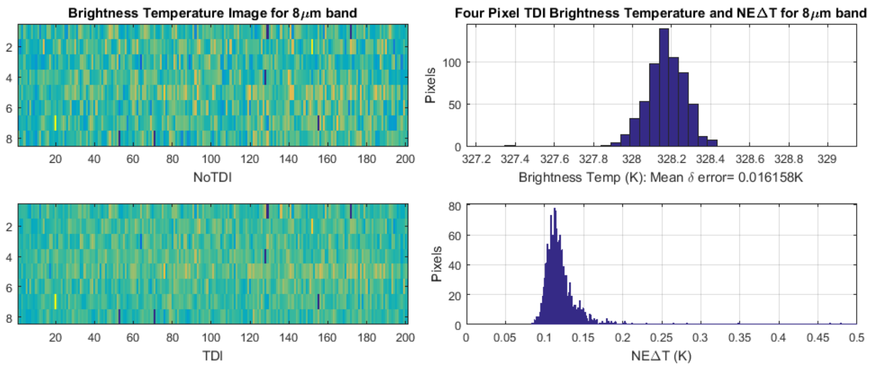
Histograms of brightness temperature precision and accuracy for various scene temperatures (2-point calibration performed at 295K and 320K)



Scene Temp: 25C

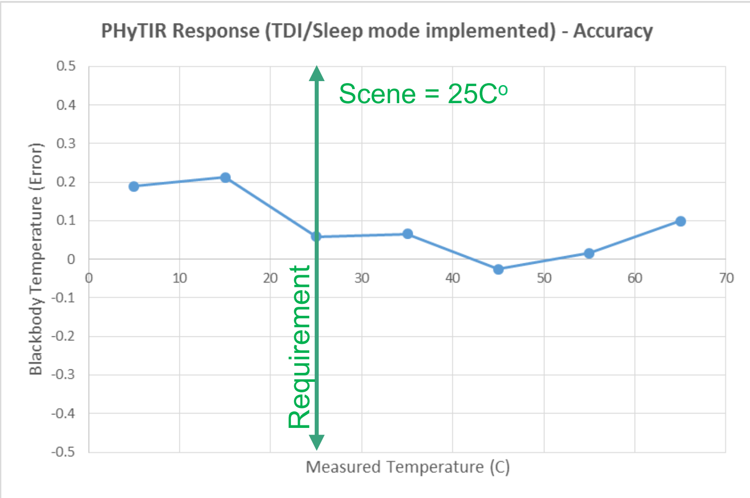


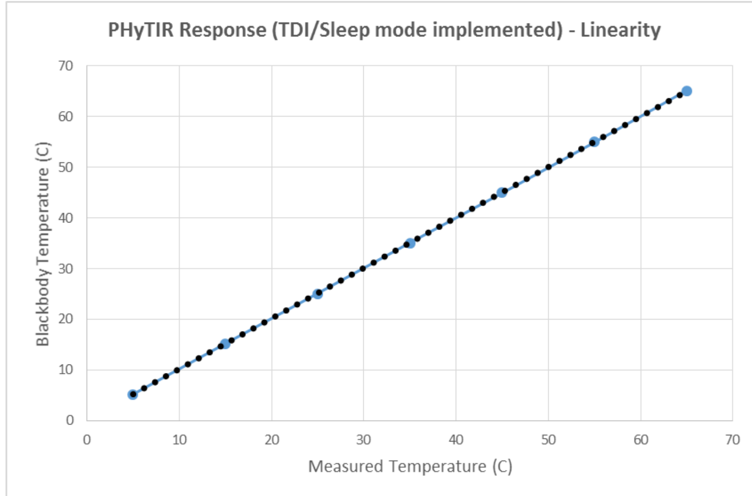
Scene Temp: 5C



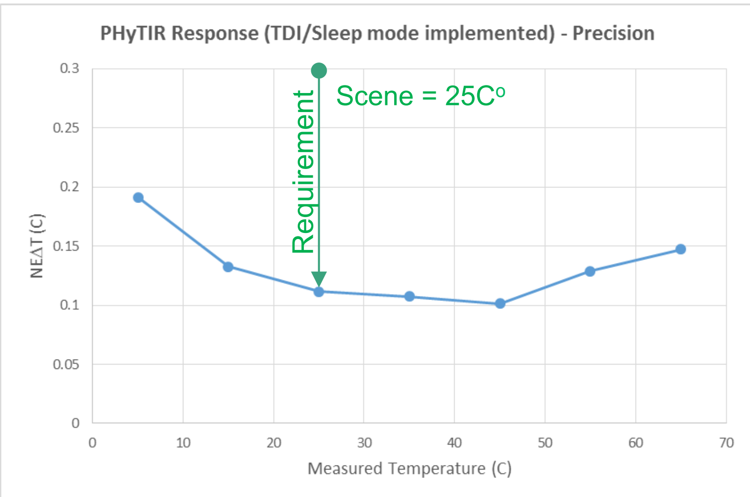
Scene Temp: 55C

Operational Results





Error using 2-point calibration at 295K and 320K



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where:

λ is wavelength in μm

$c1 = 0.0143877$

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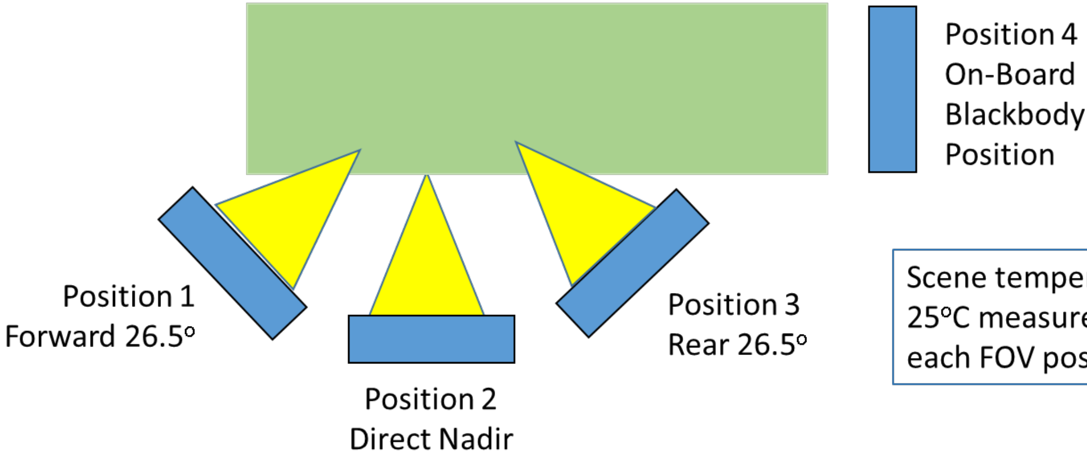
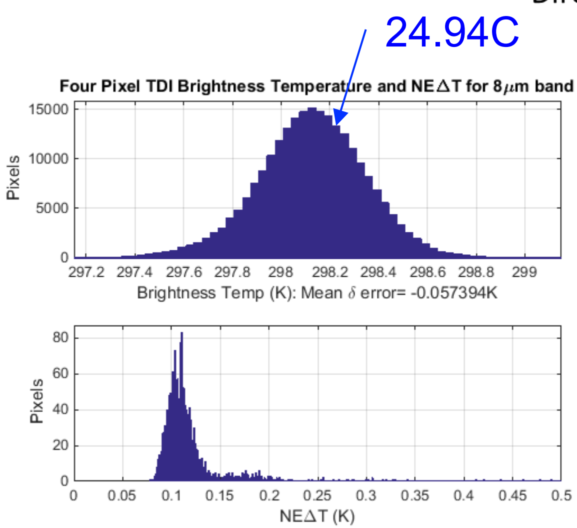
L_λ is the at-sensor spectral radiance in $W/(m^2 \cdot sr \cdot \mu m)$

Operational Results

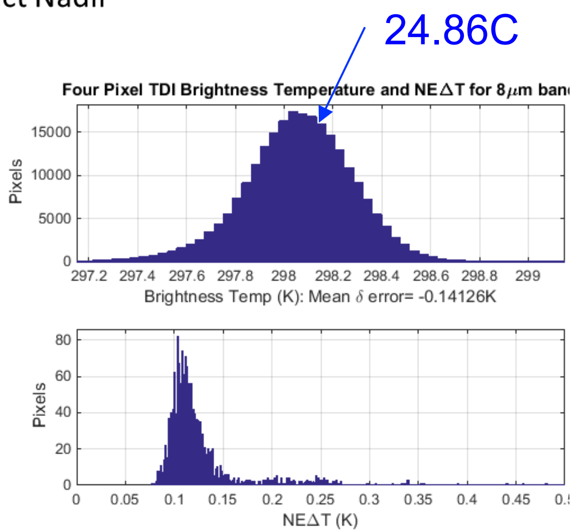


2-point calibration using measurements from this blackbody (5°C and 50°C)

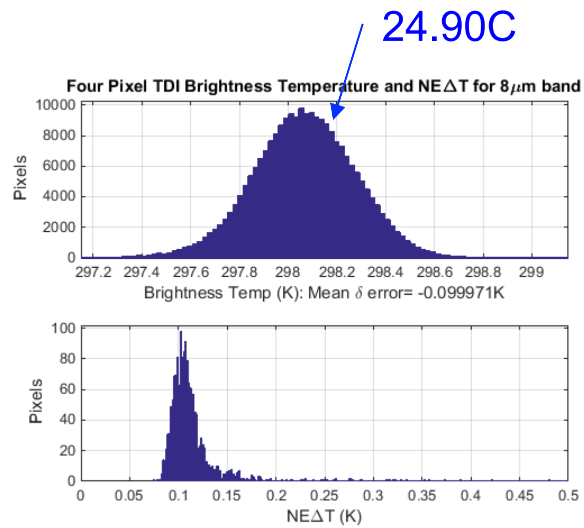
Scene temperature of 25°C measured at each FOV position



Position 1



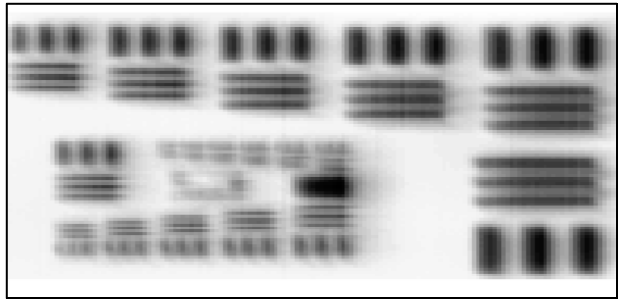
Position 2



Position 3

Operational Results

- Imaging quality currently limited by filters ($\lambda = 8\mu m$)
- Target projector has a 10" clear aperture, 70" (1778mm) focal length
- Full aperture provides 4.18X demagnification.
- Target USAF 1951 Clear Optical Path 1.5"
- Requirements referenced in the chart below.
- $\lambda = 8.28\mu m$, scanning 31,065fps, 25.4rpm
- Time delay and sleep mode operating.



Measured Air Force target image from PHyTIR testbed.

$$M625 = Amax - Amin / Amax + Amin = 57\%$$

$$M833 = Amax - Amin / Amax + Amin = 44\%$$

Ref. G. D. Boreman, Modulation Transfer Function in Optical and Electro-Optical Systems, SPIE Press, Bellingham, WA (2001).

Lab Performance

- Sensor meets radiometric and resolution requirements.
- Currently transiting into payload I&T.
- The Radiometer Integration and Test approach is detailed and comprehensive
  - We have a plan for what we have to do, when we have to do it, and how we are going to do it
- GSEs, procedures, facilities
  - All equipment has been accounted for and will be ready for Radiometer I&T start
  - EGSE is accounted for and currently being used for FPA testing which will be delivered for Radiometer I&T start
  - Facilities have been reserved and currently there are no conflicts
  - Staffing (by the subsystems) has been identified and will be available for Radiometer I&T start