Multichannel IR Sensor Calibration Validation Using Planck's Law for Next Generation Environmental Geostationary Systems

Aaron Pearlman[1,2], Raju Datla[1,2],
Changyong Cao[2] & Xiangqian Wu[2]

1) ERT, Inc.
2) NOAA/NESDIS STAR

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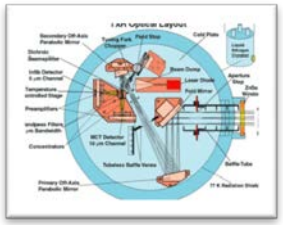
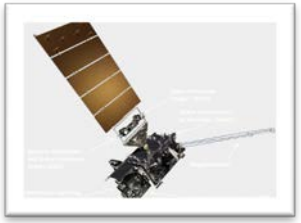
Outline

- GOES-R Advanced Baseline Imager (ABI) IR channel Calibration/Validation
  - » System Level Calibration Validation using External Calibration Target (ECT)
  - » Analysis with Planck's Law based brightness temperature adjustment
  - » Comparison to NIST Thermal-infrared Transfer Radiometer (TXR) results

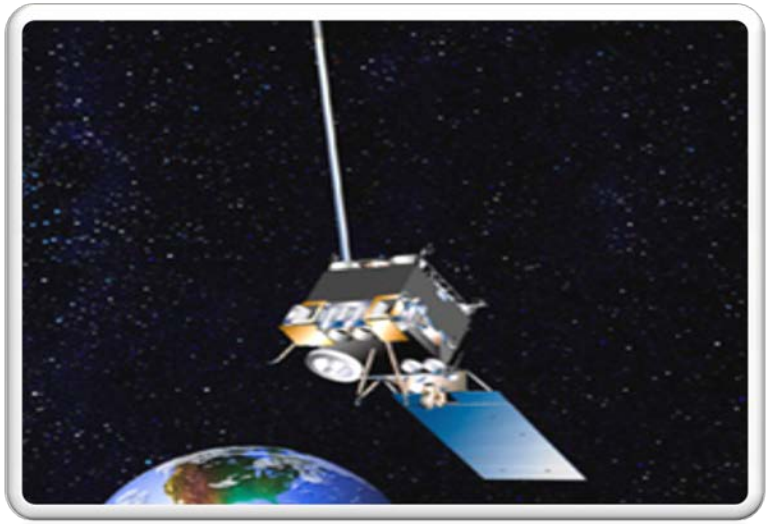
- Validation of Results using Himawari-8 (ABI like Sensor - AHI) on orbit data in comparison to IASI

- Future Work: Validation using Lunar IR images – Attempt with AHI data



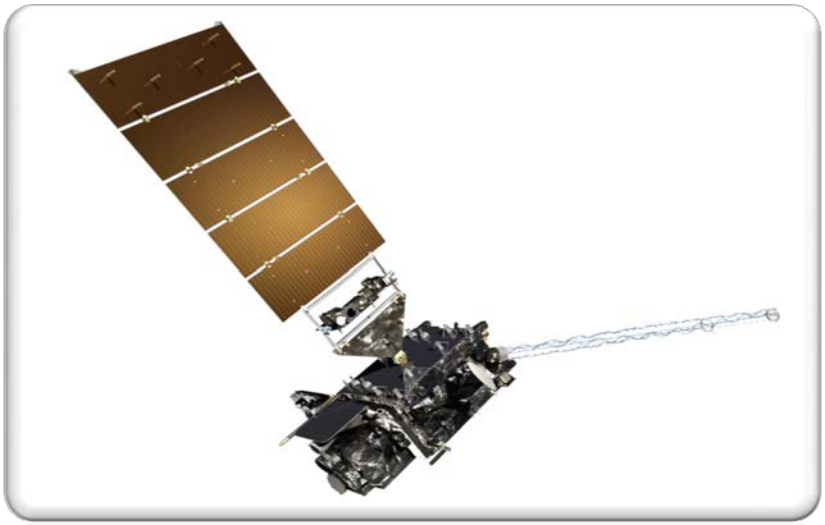


NOAA Transitioning to New Generation of Geostationary Imager



GOES Imager

5 Band Imager	
Channels	Spatial Res.
1 Visible	1 km
4 Infrared	**4 km**

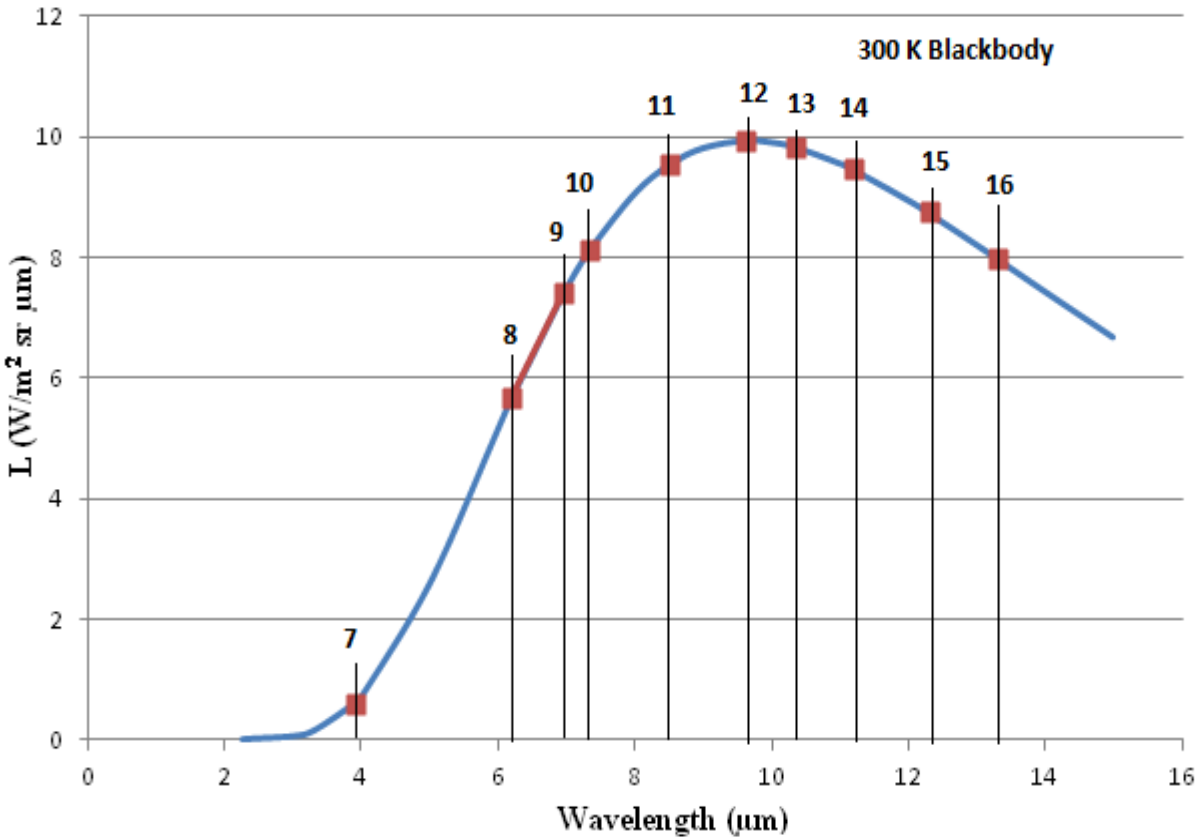


GOES-R Advanced Baseline Imager (ABI)

16 Band Imager	
Spectral Region	Spatial Resolution
2 Visible	0.5 & 1 km
4 NIR/SWIR	1 & 2 km
10 Infrared	**2 km**

ABI IR Channels and 300 K Blackbody Radiance

Large number of thermal IR bands gives a unique opportunity to see how all the bands behave with respect to Planck's Law



Channel Number	Central Wavelength (µm)
16	13.3
15	12.3
14	11.2
13	10.35
12	9.61
11	8.5
10	7.34
9	6.95
8	6.19
7	3.9

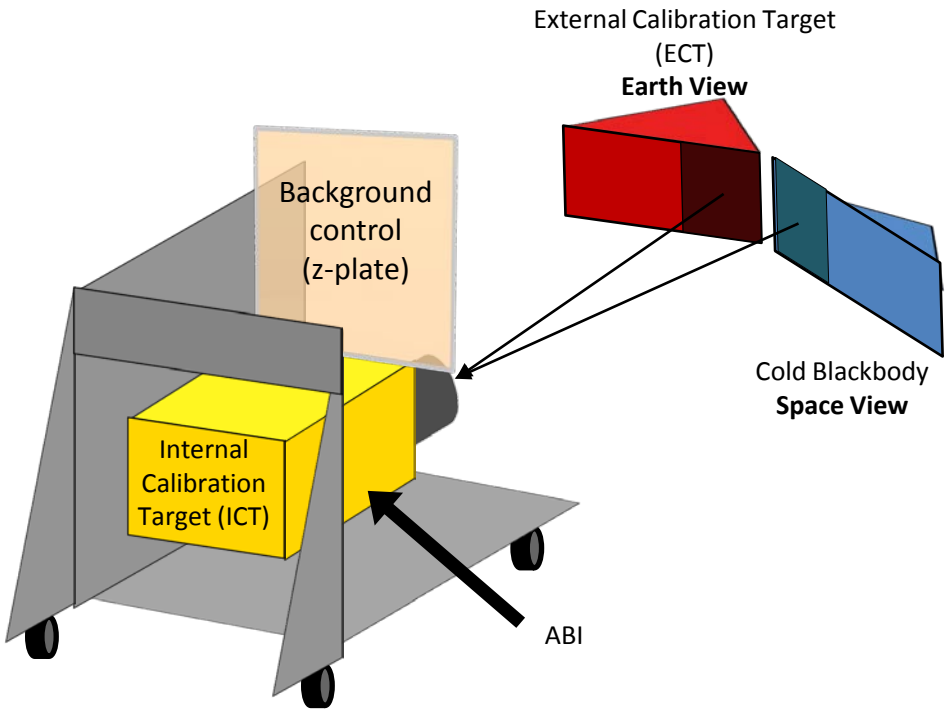
Pre-launch ABI Thermal IR Calibration Test

- ABI complies with its radiometric requirements
- We have the opportunity to conduct research to investigate smaller effects throughout pre-launch testing to reduce uncertainties even further

- System Level Calibration Validation using ECT
  - » Laboratory set up in a LN2 cooled cryogenic chamber
  - » High background and low background conditions
    - o Background created by a flat black plate hanging above in front of the ABI sensor away from its field of view of ECT.
    - o High background : 313 K; Low background :175 K
  - » Test at 7 ECT Temperature settings ranging from 200 K to 320 K

- ECT is a large Area blackbody (Harris/Exelis Proprietary)
  - » 45 cm square aperture to fill the field of view of the ABI sensor
  - » Equipped with many PRTs to control temperature setting based on thermal modeling of the blackbody structure.

- Onboard Calibrator (ICT): 294 K or 309 K during the pre-launch test



Pre-launch testing for thermal IR bands done at the vendor facility for GOES-R (FM1) GOES-S (FM2) and GOES-T (FM3) ABI

ECT Radiance Determination

ABI IR channel radiometric calibration is simple: Linear calibration using on-board blackbody (ICT) (Alternatively, may use additional quadratic coefficient but the impact is small)

$$L_{ECT} = \frac{m_{ICT}\Delta C_{ECT} - L_{Offset}^{ECT}}{\rho_N^{ECT}\,\rho_E^{ECT}}$$

→ ECT radiance found using *m*-coefficient from ICT look – "observed".

→ This ECT observed radiance is compared with radiance predicted by contact thermometry (NIST traceable PRTs).

Delta Counts

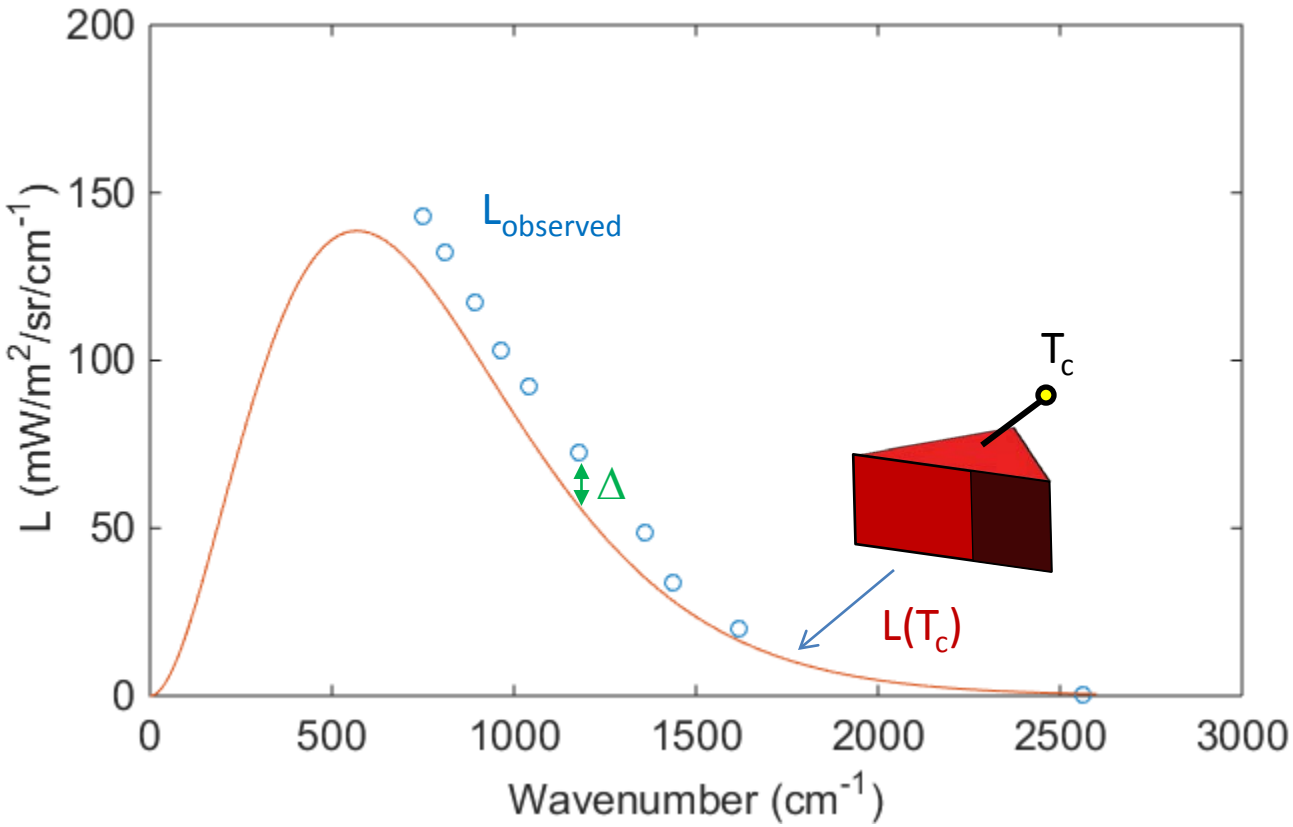
$$\Delta C = C_{bb} - \left(\frac{C_{sp1} + C_{sp2}}{2}\right)$$

L_{Offset}^{ECT} → Difference in radiance from the elements in optical path between ECT view and space view

$$L_{offset} = L_{NS}\left(\varepsilon_{NS}^{bb}\,\rho_{EW}^{bb} - \varepsilon_{NS}^{sp}\,\rho_{EW}^{sp}\right) + L_{EW}\left(\varepsilon_{EW}^{bb} - \varepsilon_{EW}^{sp}\right)$$

Analysis Methodology: ECT Radiance

- Calculate the differences between ECT contact temperature and ABI observed temperature
- Find a temperature adjustment for the ECT temperature that minimizes the difference using a Planck's Law fit for all of the channels



Schematic Illustration

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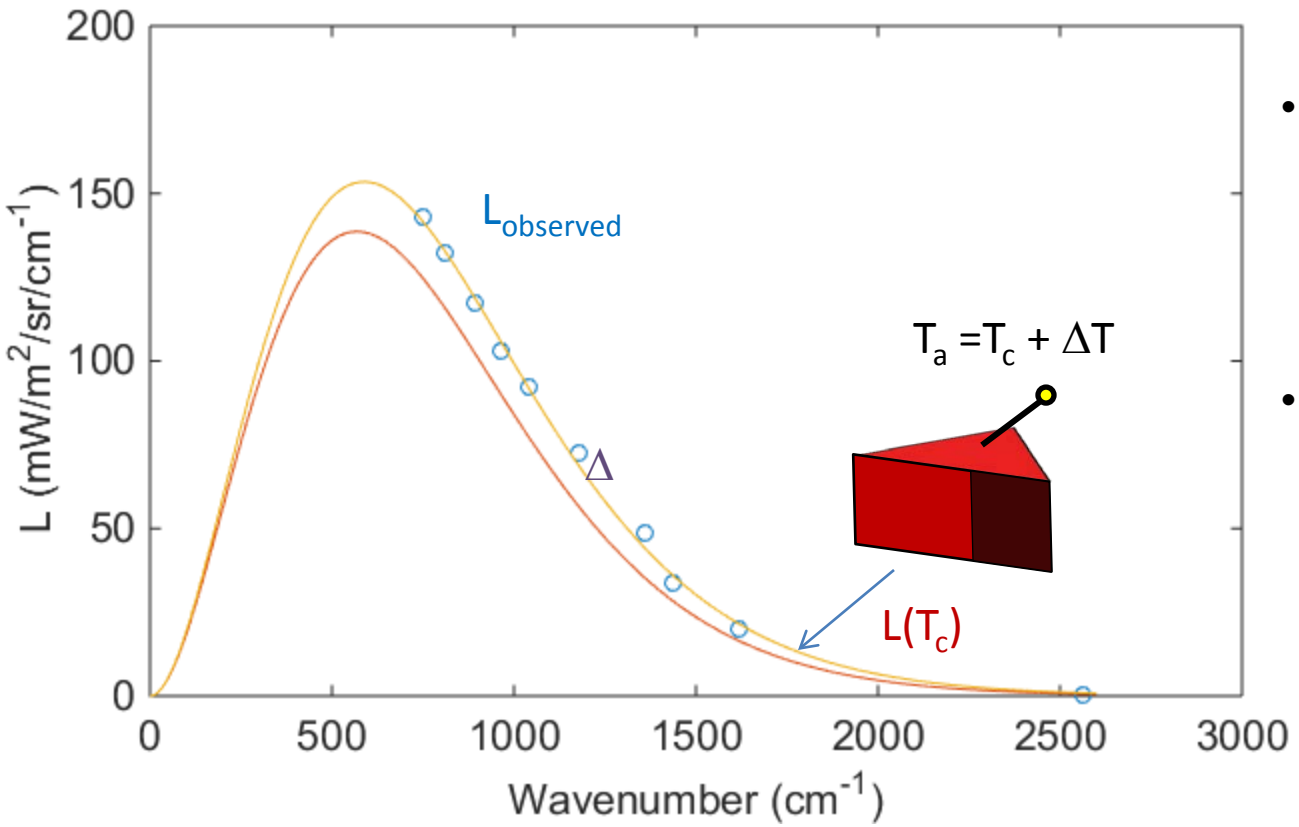


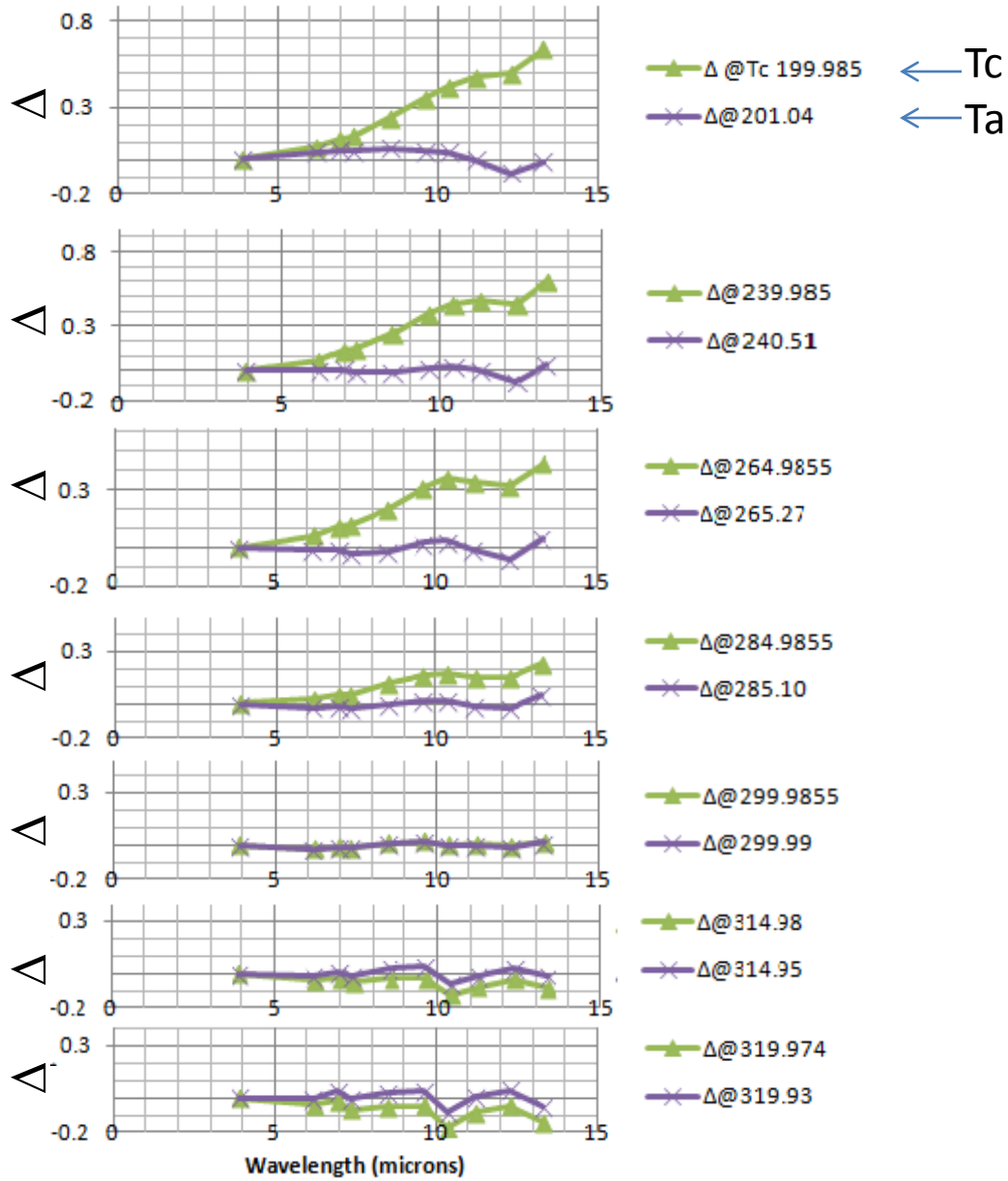
Schematic Illustration

- Best fit Planck's Law based brightness temperature (Ta) – comparison to PRT based Temperature setting (Tc)
  - » $\Delta T = Ta - Tc$
- Comparison of ECT observed radiance and the radiance predicted by ECT temperature setting
  - » Δ = L observed – L (Tc)
  - » Δ = L observed – L (Ta)

Results: ABI – FM1 (High Background)

Δ = L observed – L (Tc)
Δ = L observed – L (Ta) **[mW/m²-cm⁻¹-sr]**

- Below 300 K show radiance difference (Δ) between the observation (based on ICT calibration) and predicted by ECT Thermal model (Tc).
- The ECT is heated to higher than expected by the Harris/Exelis model for temperatures below 300 K.
- A small correction to T_c consistently removes this bias across all channels according to Planck's law.
- All channels show consistent radiance discrimination i.e their calibration by the ICT is very good.

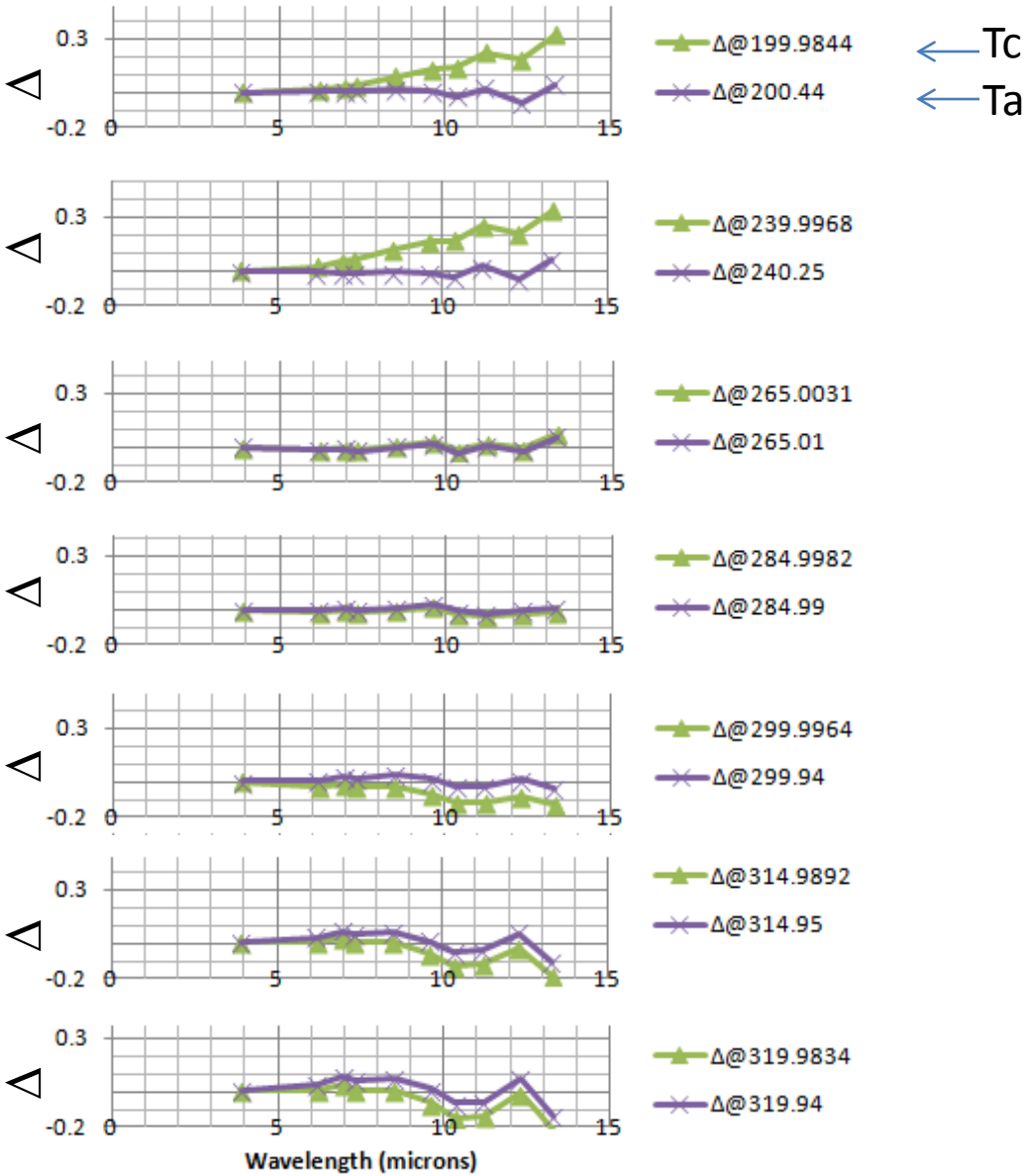


Results: ABI – FM1 (Low Background)

Δ = L observed – L (Tc)
Δ = L observed – L (Ta) **[mW/m²-cm⁻¹-sr]**

- Found consistent trends for high and low background case, but the magnitude is reduced for the low background case

- The differences between high and low background cases show that the ECT gets extra heating raising the temperature above the low background level.

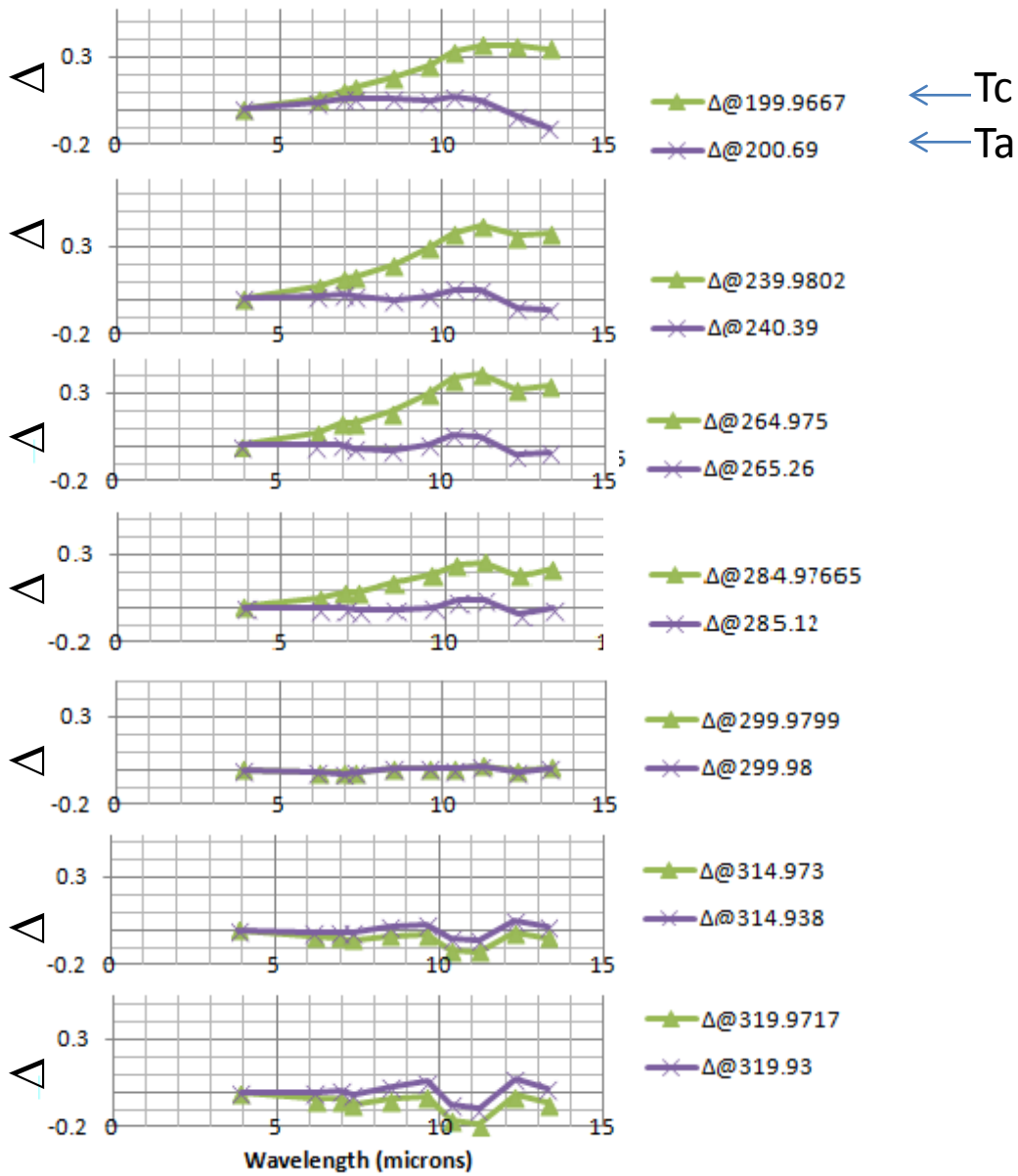


Results: ABI – FM2 (High Background)

Δ = L observed – L (Tc)
Δ = L observed – L (Ta)

[mW/m²-cm⁻¹-sr]

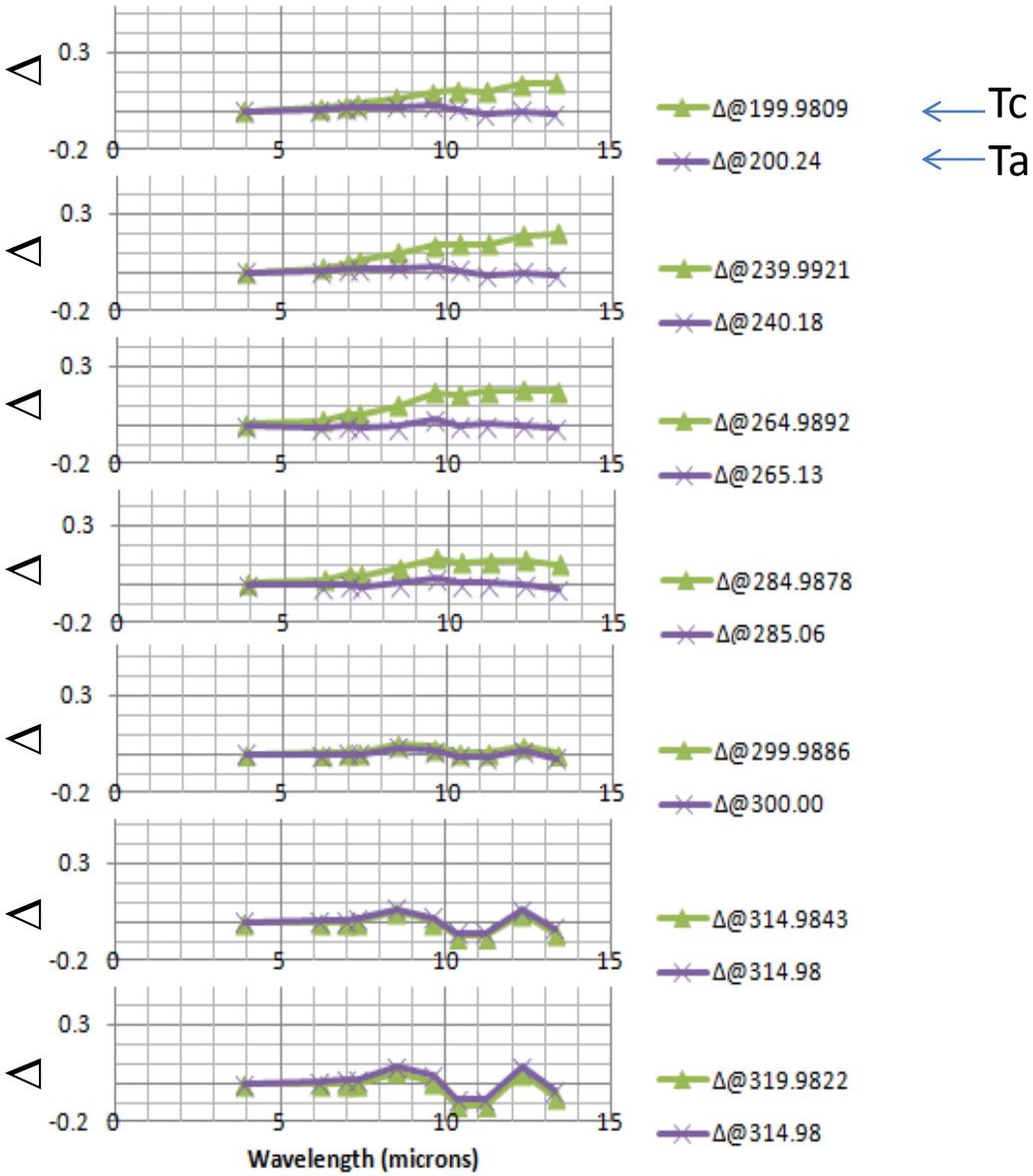
FM 2 shows similar behavior to FM 1



Results: ABI – FM2 (Low Background)

Δ = L observed – L (Tc)
Δ = L observed – L (Ta) **[mW/m²-cm⁻¹-sr]**

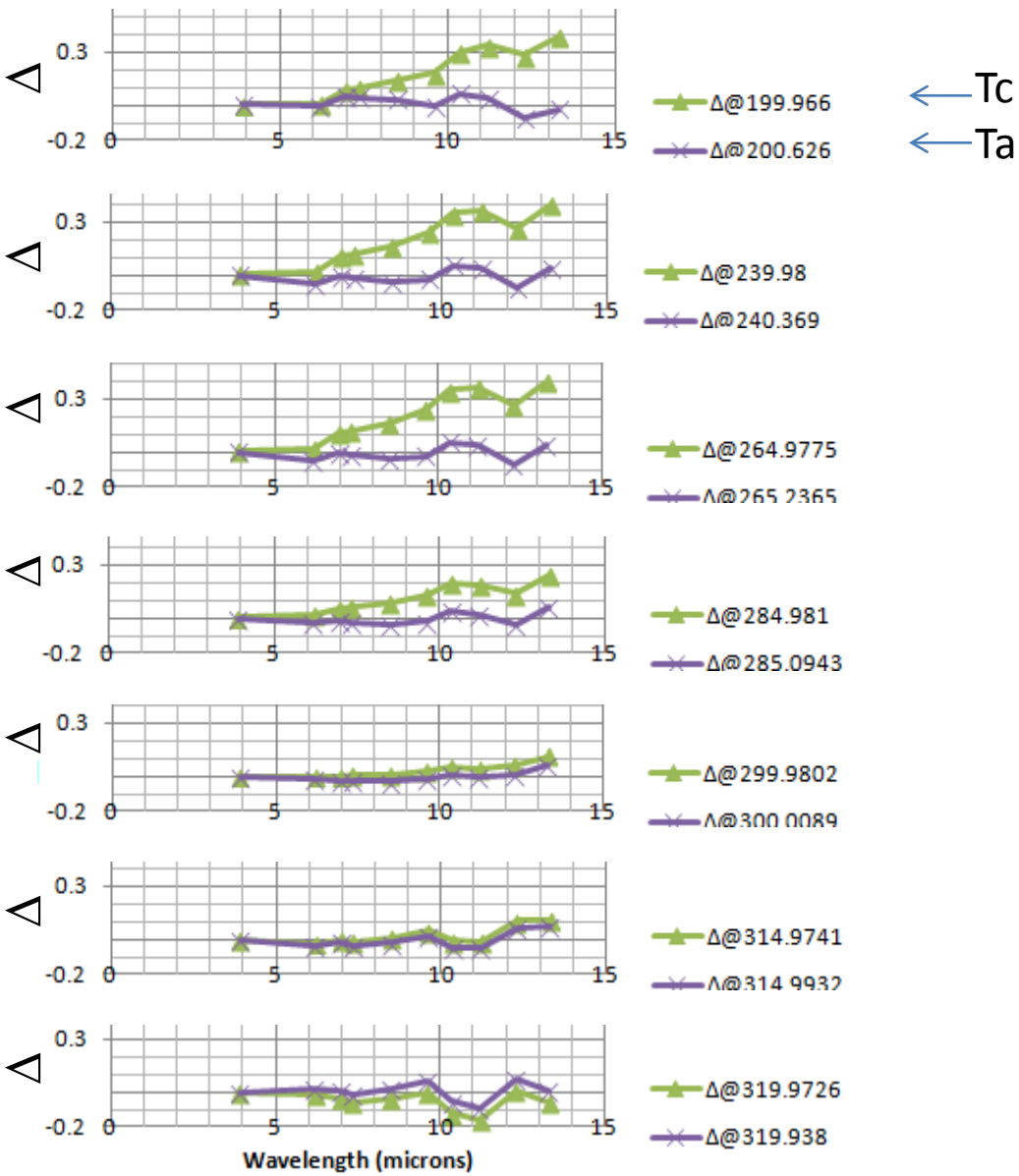
FM 2 shows similar behavior to FM 1



Results: ABI – FM3 (High Background)

Δ = L observed – L (Tc)
Δ = L observed – L (Ta) **[mW/m²-cm⁻¹-sr]**

The consistent behavior is across all flight models (FM1 & 2 & 3) shows the stability of ABI performance and the measurement setup



Results: ABI Flight Models (1,2,3): High Background

The adjusted temperature established across all ABI instruments for the **high** background pre-launch test conditions predicts the ECT temperature with low uncertainty.

T_n (K) -Nominal	T_c (K)	ΔT_{FM1} (K)	ΔT_{FM2} (K)	ΔT_{FM3} (K)	T_c (K) Average	ΔT_{ave} (K)	u_e (K)
200	199.985 199.96674 199.966	1.05	0.72	0.66	199.9726±0.0107	0.81	0.21
240	239.985 239.98018 239.98	0.52	0.41	0.39	239.9817±0.0029	0.44	0.07
265	264.9857 264.97504 264.9775	0.28	0.28	0.26	264.9794±0.0056	0.27	0.012
285	284.9855 284.97665 284.981	0.11	0.14	0.11	284.9811±0.0044	0.12	0.017
300	299.9855 299.9799 299.98	0.001	0.002	0.03	299.9818±0.00321	0.011	0.016
315	314.98 314.973 314.974	-0.04	-0.02	-0.02	314.9757±0.00379	-0.027	0.012
320	319.974 319.9717 319.9726	-0.05	-0.04	-0.03	319.9728±0.00116	-0.04	0.01

$$\Delta T_{av} = T_{observed} - T_{set} \text{ (Harris/Exelis)}$$

Adjusted Temperature

Temperature from Contact Thermometry

Results: ABI Flight Models (1,2, 3): Low Background

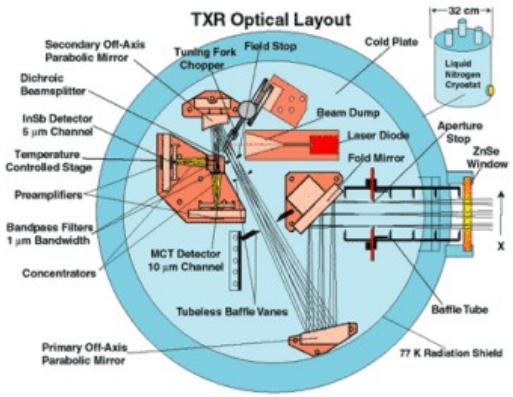
The model also established across all ABI instruments for the **low** background pre-launch test conditions predicts the ECT temperature with low uncertainty.

T_n (K) - Nominal	T_c (K)	ΔT_{FM1} (K)	ΔT_{FM2} (K)	ΔT_{FM3} (K)	T_c (K) Average	ΔT_{ave} (K)	u_e (K)
200	199.9844 199.9809 199.9797	0.46	0.26	0.28	199.982±0.002	0.33	0.11
240	239.9968 239.9921 239.9911	0.25	0.19	0.196	239.993±0.003	0.21	0.03
265	265.0031 264.9892 264.9867	0.01	0.14	0.16	264.993±0.009	0.10	0.08
285	284.9982 284.9878 284.9864	-0.01	0.08	0.09	284.991±0.006	0.05	0.055
300	299.9964 2999886 299.9885	-0.05	0.01	0.015	299.991±0.0045	-0.008	0.036
315	314.9892 314.9843 314.9859	-0.04	-0.01	-0.03	314.987±0.00379	-0.027	0.015
320	319.9834 319.9822 319.9831	-0.04	-0.02	-0.021	319.983±0.0006	-0.0267	0.012

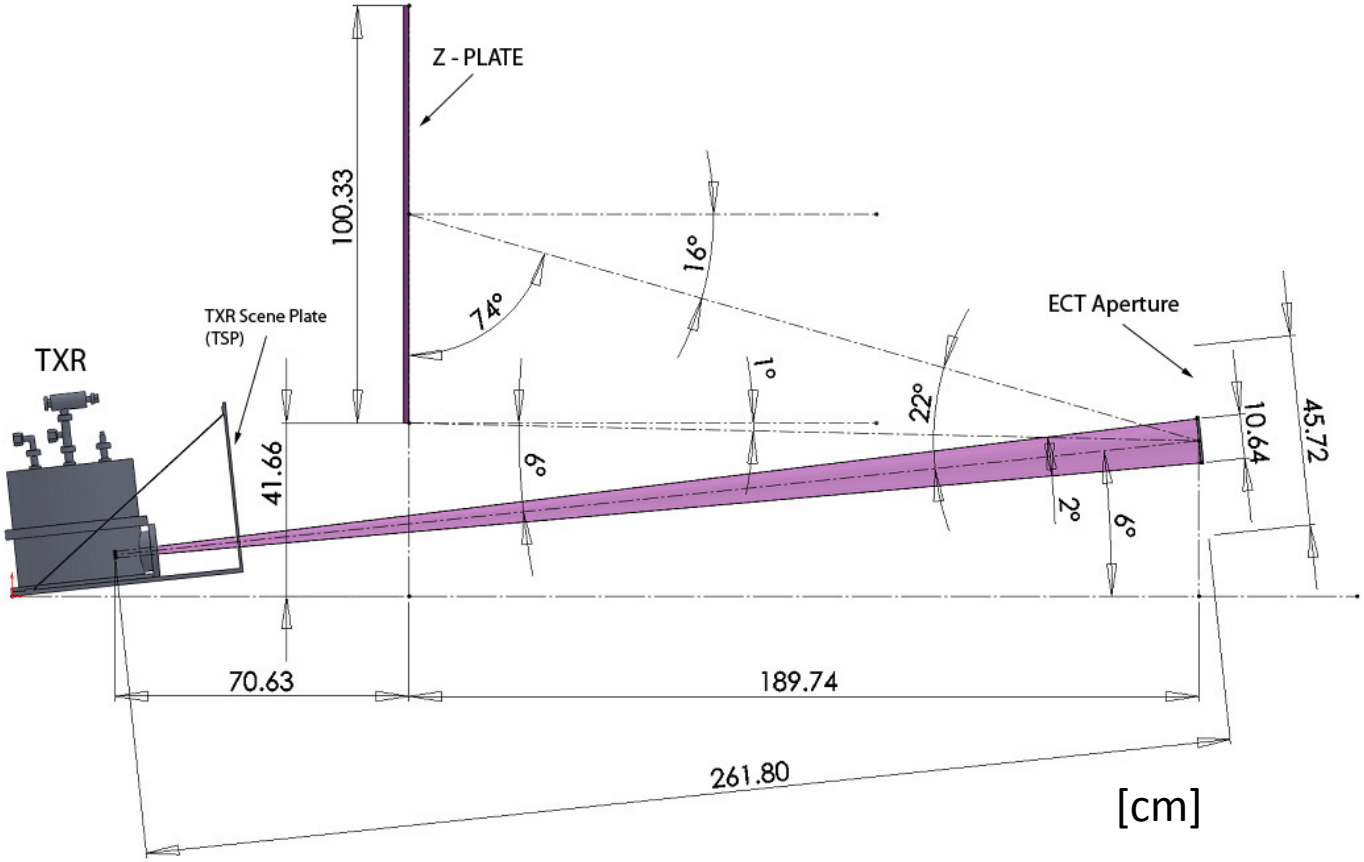
The radiance of the ECT determined by the ABI response brings to light the probable limitation in ECT thermometry based Harris/Exelis model to predict set temperature.

Deployment of the NIST Thermal-infrared Transfer Radiometer (TXR) to validate the ECT radiance

Was the temperature difference observed by ABI seen by TXR?



www.nist.gov



TXR setup to view the ECT perpendicular to its aperture plane in the Harris/Exelis/ABI cryogenic chamber. [Note: The TXR field of view of 2 degrees views only a circular area of 10.64 cm diameter of the ECT 45.72 cm x 45.72 cm square aperture area.]

TXR Test Results

TXR Ch 1 at 5 µm and Ch 2 at 10 µm

The difference between TXR measured brightness temperature and the brightness temperature predicted by contact thermometry showed consistent differences across all ECT temperatures.

Possible reasons that TXR does not observe the same effect as ABI:

1. TXR test was at the central region of ECT aperture and Its field of view being small gave a different result.
   - Could redeploy TXR and produce spatial map of ECT to investigate the temperature uniformity (new capability)
2. Other sources of emission or reflection not in TXR setup but in the ABI setup

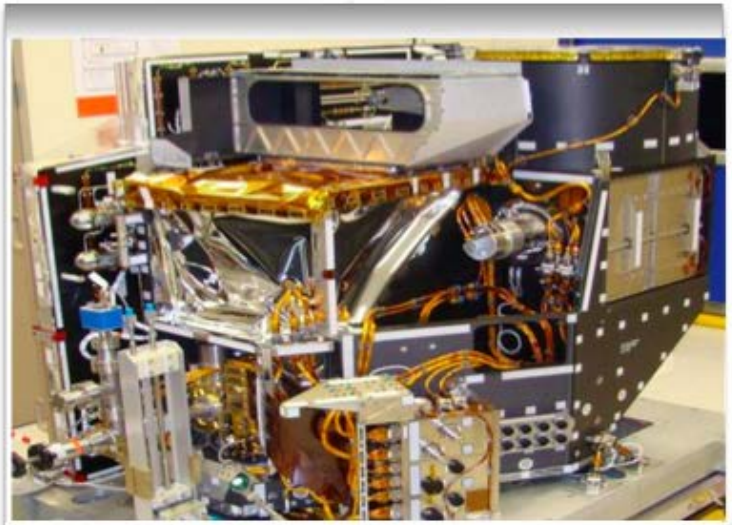
T_{ECT}	$L_1 / L_{ECT(ch1)}$	$L_2 / L_{ECT(ch2)}$	T_{NIST}	$T_{Difference}$ ($T_{NIST} - T_{ECT}$)
K			K	K
200.11	0.980	0.996	200.18	0.07
239.9	1.005	1.001	239.98	0.08
264.94	0.996	0.998	265.03	0.09
284.95	1.001	1.000	285.05	0.10
299.92	1.002	1.001	300.02	0.10
314.69	1.001	1.000	314.80	0.11
319.78	1.000	1.000	319.89	0.11

The ECT adjustment fits the data well and makes intuitive sense, but given that we don't understand the inconsistency between the TXR & ABI measurements, we want to make sure this is not an ICT effect - that the ECT gives a more accurate radiance and the ICT has a cold bias.

Using ABI-like Instrument to Analyze ABI Calibration Performance

- Himawari-8 is launched late last year and it has ABI like Sensor – (AHI) made by the same vendor Harris/Exelis
- AHI on orbit data in collocation with IASI using GSICS methodology is analyzed.

NOAA: GOES-R ABI



JMA: Himawari 8 AHI

16 Band Imager	
Spectral Region	Spatial Resolution
6 VNIR/SWIR	0.5,1 & 2 km
10 Infrared	2 km

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Spectral Region	Spatial Resolution
6 VNIR/SWIR	0.5,1 & 2 km
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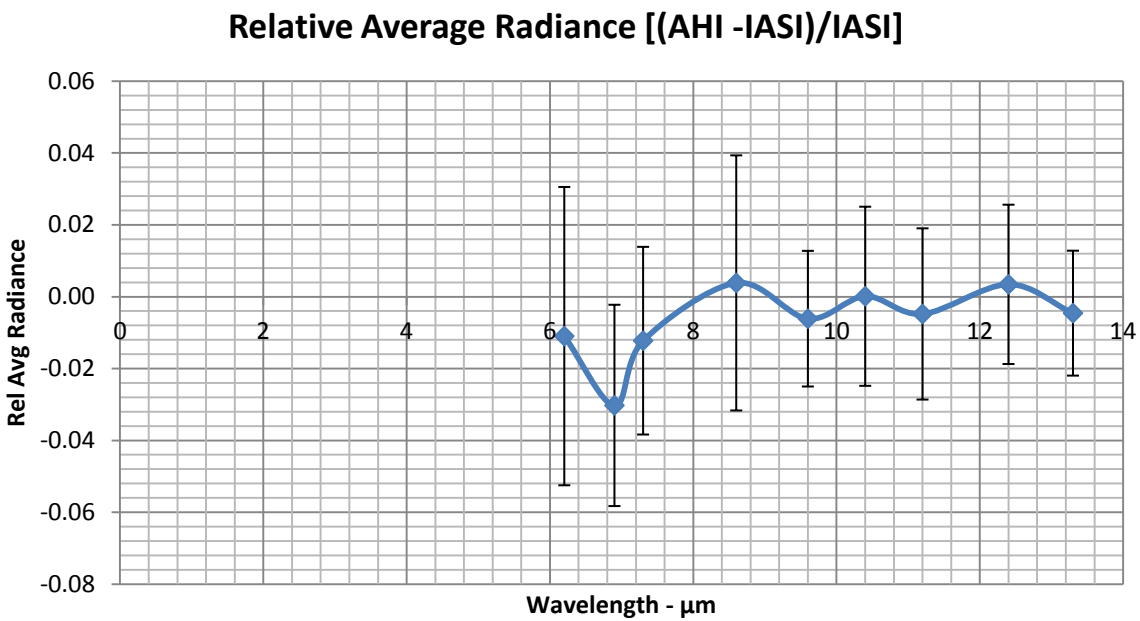
Comparison of AHI and IASI

Results for all collocations

Example: Low temperature scene showing close agreement.



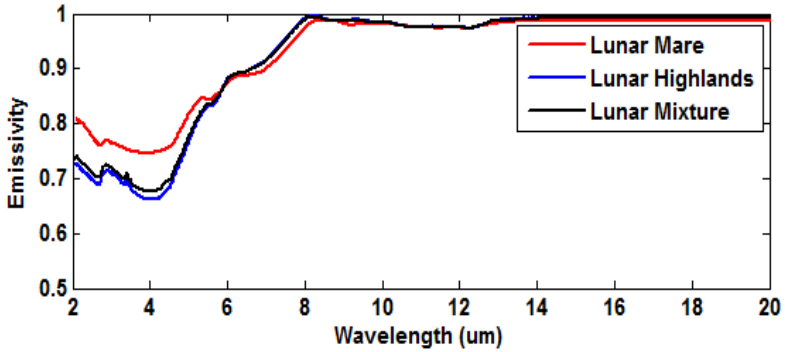
		AHI Radiances	Brightness	IASI Radiances
	µm	mW/m2srcm-1	Temp(Tb)	mW/m2srcm-1
Ch 16	13.3	32.813	214.4	32.816
Ch 15	12.4	27.894		27.858
Ch 14	11.2	21.637		22.049
Ch 13	10.4	18.083		18.582
Ch 12	9.6	17.404		17.784
Ch 11	8.6	8.41		8.928
Ch 10	7.3	3.272		3.493
Ch 9	6.9	2.2		2.368
Ch 8	6.2	1.023		1.081

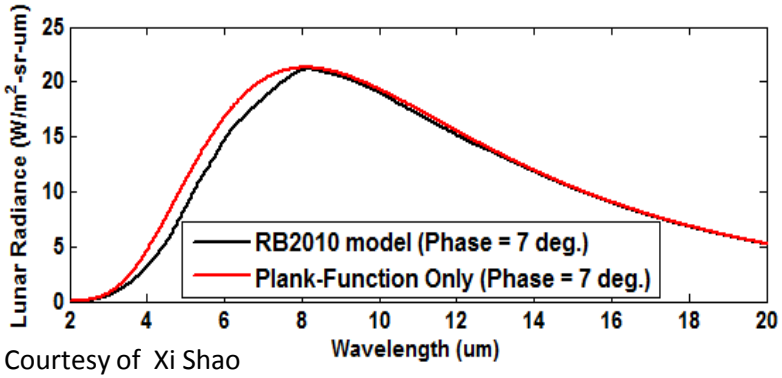
- AHI – IASI radiance data of April 17th and 18th (2015) of nearly 60 collocations over scenes ranging from 215 K to 280 K.
- The IASI observations validate AHI radiances for wide range of temperatures in the arbitrary scenes (215 K to 285 K).
- We found no cold bias seen on-orbit as shown in the prelaunch ABI data using ECT.

- **The comparison validates the calibration using the on board blackbody (ICT).**

Future Work: IR Lunar Image for ABI Calibration Validation using AHI

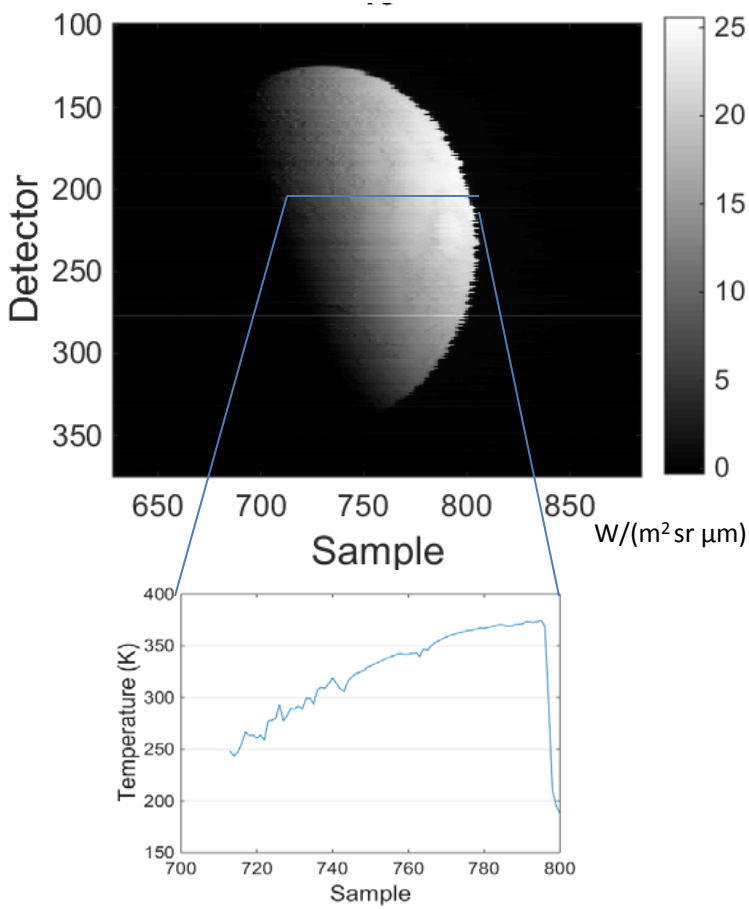
Challenges:
- Spatial temperature variation
- Lunar surface emissivity.





Courtesy of Xi Shao

AHI Lunar Image for ch. 13 (10.35 µm)



- Disk-averaged lunar radiance model incorporates emissivity spectra of mixture of lunar mare and highland material (measured from *Apollo* lunar samples)
- Close to Planck-Function [Tansock et al., 2006 CalCon]

Conclusion

- We used Planck's law based fitting to determine an ECT temperature correction to better understand pre-launch test artifacts.
- TXR could be redeployed to the Harris/Exelis test facility to investigate the "Cold Bias" observed using the ECT setup.
- We confirmed the stability of ICT calibration using the Planck's law based relative channel to channel analysis:
  - » Monitoring calibration coefficients of each channel would reveal any temporal variation of responsivity channel by channel considering ICT as stable.
- Comparison with IASI collocation using GSICS methodology is helpful for post launch calibration validation.
- IR Lunar Image analysis could be another possibility for calibration validation provided uniform lunar scenes can be identified.