S-NPP VIIRS Thermal Emissive Bands (TEB) Performance and Uncertainty Estimates

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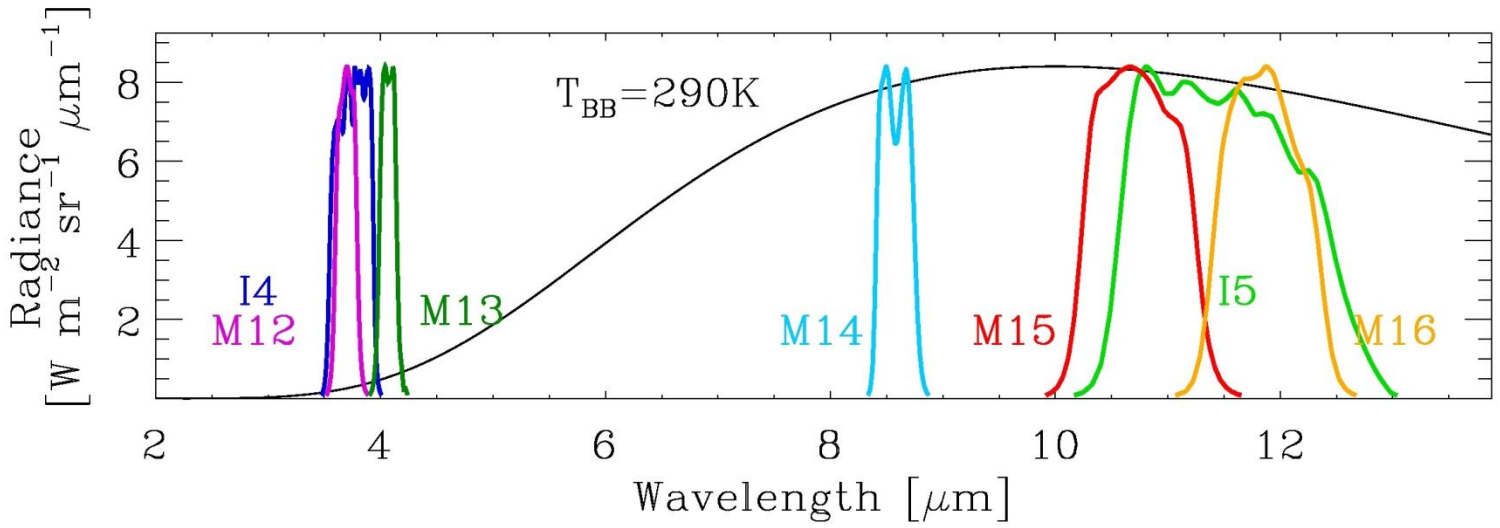
Acknowledgements: VIIRS SDR Team Members

Outline

- **TEB Calibration**
- **On-orbit Performance**
  - ✓BB Performance
  - ✓Detector short-term stability and long-term response (F-factors)
  - ✓Detector noise characterization (NEdT)
  - ✓Dynamic range verification
- **Uncertainty Estimates**
  - ✓Methodology
  - ✓Estimates
- **Issues and Future Improvements**
- **Conclusions**

Thermal Emissive Bands (TEB)

5 M-bands and 2 I-bands, covering wavelengths from 3.7-12μm



Band	I4	I5	M12	M13	M14	M15	M16
Wavelength [μm]	3.74	11.45	3.70	4.05	8.55	10.76	12.01

Calibrated using an on-board blackbody (BB):

- ✓ Scaling factor "F-factor" is derived and applied each scan.
- ✓ Warm-up and cool-down (WUCD) cycles are performed quarterly to fully characterize TEB detector response, including offset and nonlinear terms.

TEB Calibration Methodology

VIIRS Earth View radiance is retrieved by (ATBD Eq.116)

$$L_{EV}(B,\theta) = \frac{F(B)\sum_{i=0}^{2} c_i(B)dn^i(B) - \Delta L_{bg}(B,\theta)}{RVS(B,\theta)},$$

dn: detector response *
c_i: calibration coefficients
RVS: response versus scan angle

where the $\Delta L_{bg}(B,\theta)$ is the background difference between the EV and SV path:

$$\Delta L_{bg}(B,\theta) = (RVS(B,\theta) - RVS_{SV}(B))\left[\frac{(1-\rho_{RTA}(B))}{\rho_{RTA}(B)} L_{RTA} - \frac{1.}{\rho_{RTA}(B)} L_{HAM}\right],$$

the F-factor is derived each scan for each band, detector, and HAM-side:

$$F(B) = \frac{RVS_{BB}(B)L_{ap}(B) + \Delta L_{bg}(B,\theta_{BB})}{\sum_{i=0}^{2} c_i dn_{BB}{}^i},$$

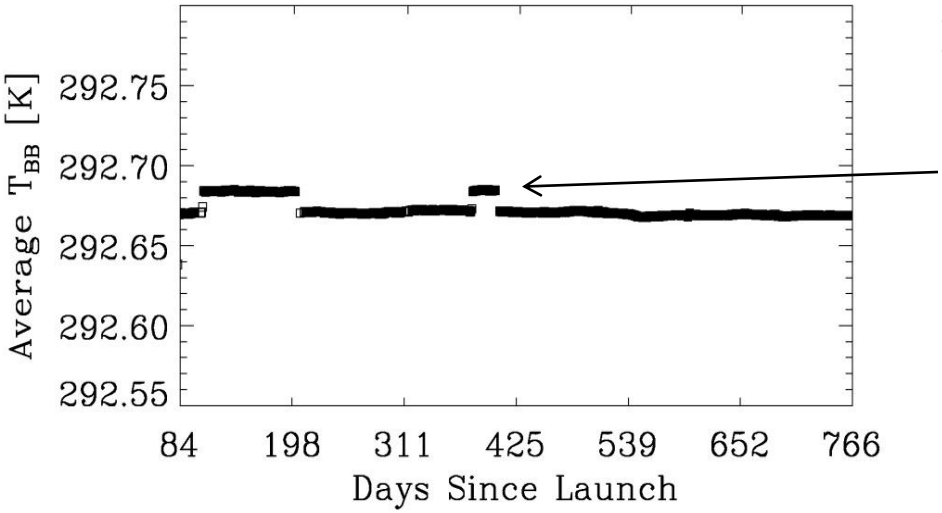
→ Estimated BB radiance

→ Retrieved BB radiance

and the aperture radiance from the BB is:

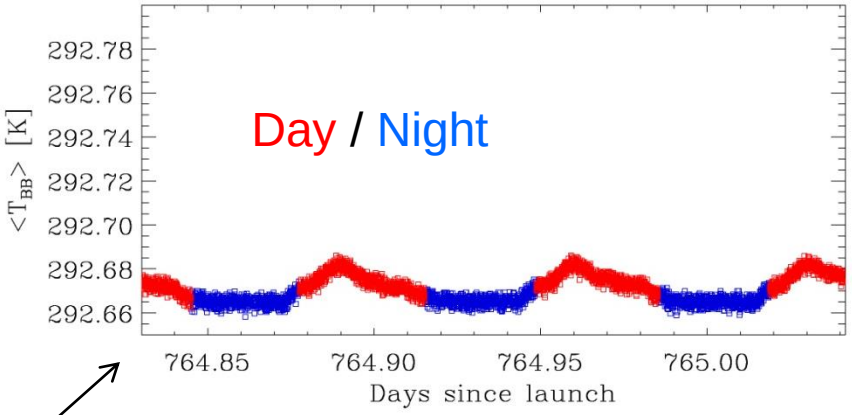
$$L_{ap}(B) = \varepsilon L_{BB} + (1-\varepsilon)(F_{RTA}L_{RTA} + F_{SH}L_{SH} + F_{CAV}L_{CAV})$$

BB Performance



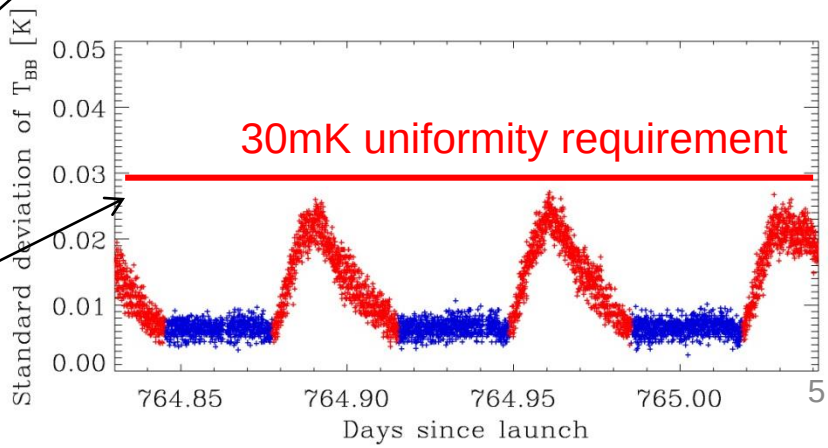
Long-term trend of daily-averaged T_{BB}

- Stable to within a few mK.
- ~15mK offsets were due to the use of different T_{BB} settings.



Short-term stability (scan-by-scan T_{BB}):

- Orbital variations of individual thermistors up to 40mK
- Variations in average temperature ~ 20mK
- Temperature difference between individual thermistors up to 60mK
- **BB uniformity meets the requirement with standard deviation less than 30mK**

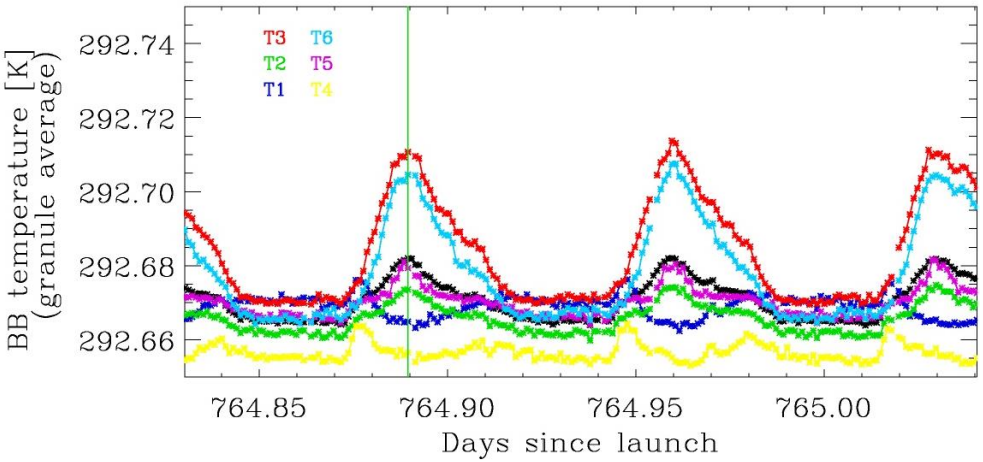


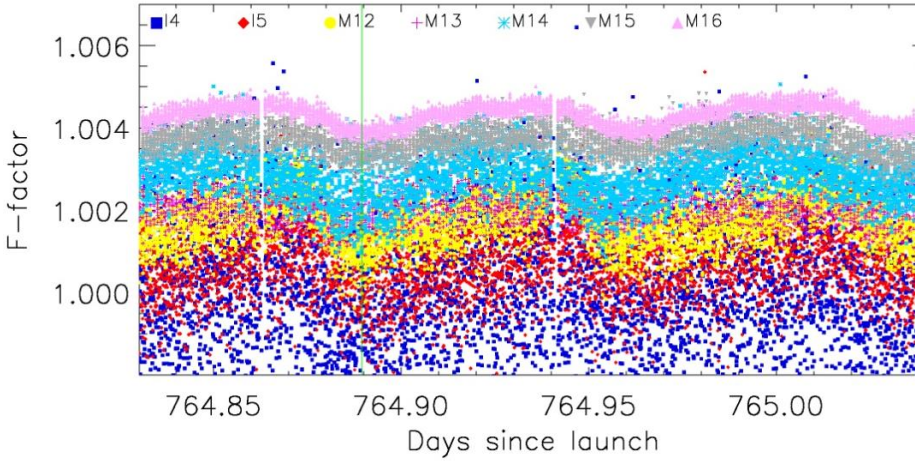
Detector Short-term Stability

Detector responses (F-factors) show small orbital variations:
- ±0.2% or less for scan-by-scan
- ±0.1% or less for granule average

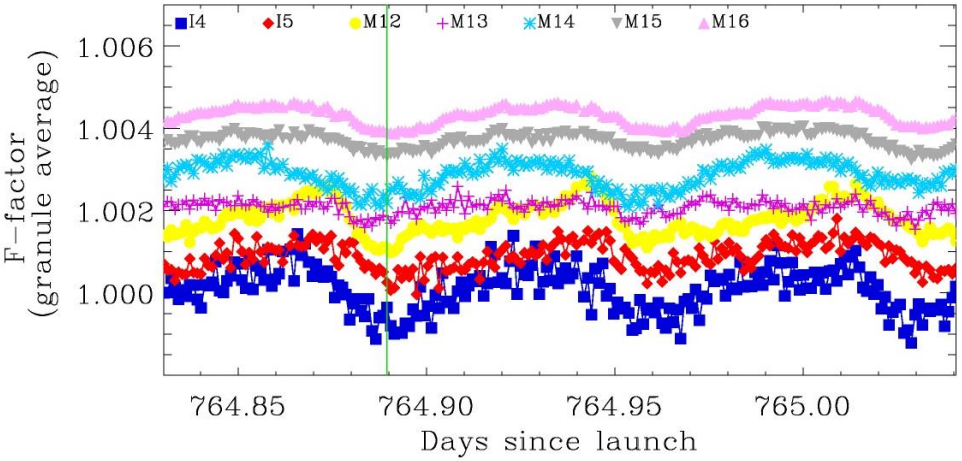
F-factor orbital variations correlate with T_{BB} variations

Orbits: 10853, 10854, 10855





Scan-by-scan (HAM-A)



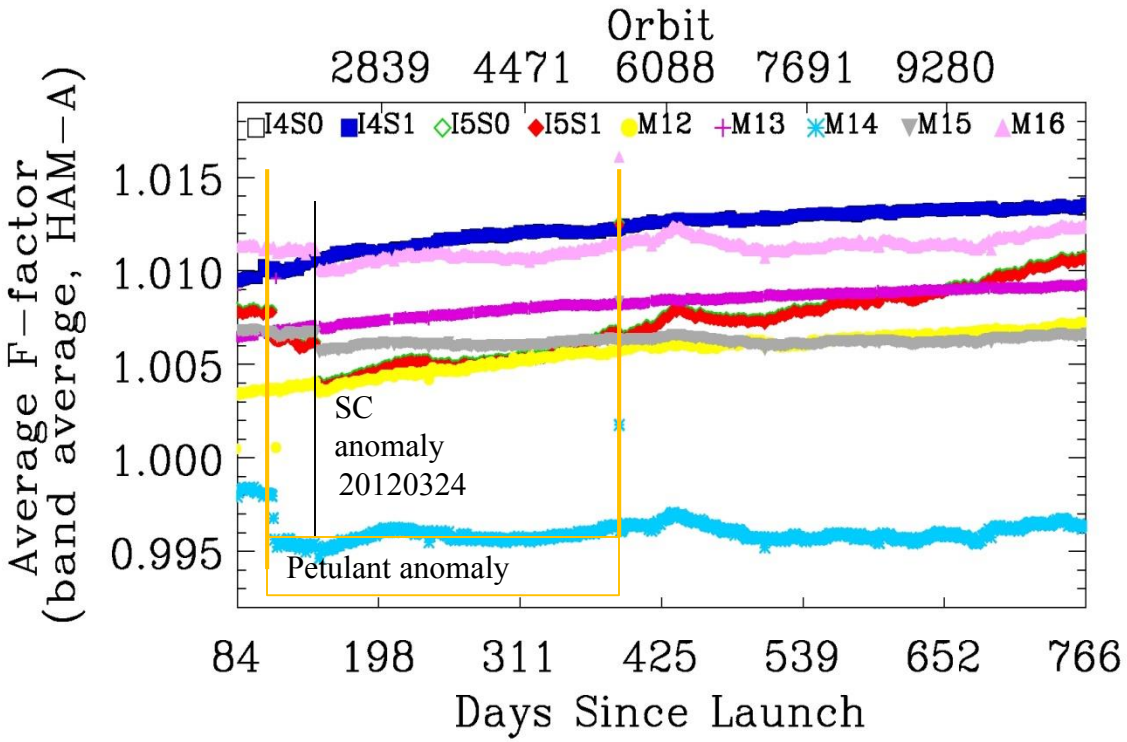
Granule average (HAM-A)

* For clarity the F-factors are shifted.

Detector Long-term Response

Daily average F-factor trend:

- From Jan 20, 2012 (orbit 1200) to Dec 02, 2013 (orbit 10869)
- I5 shows the most noticeable trend of 0.68%, followed by M12 and I4 trend of 0.37% and 0.31%, respectively
- The discontinuities in the F-factor trend are coincident with spacecraft anomalies during which the cold FPA temperatures changed

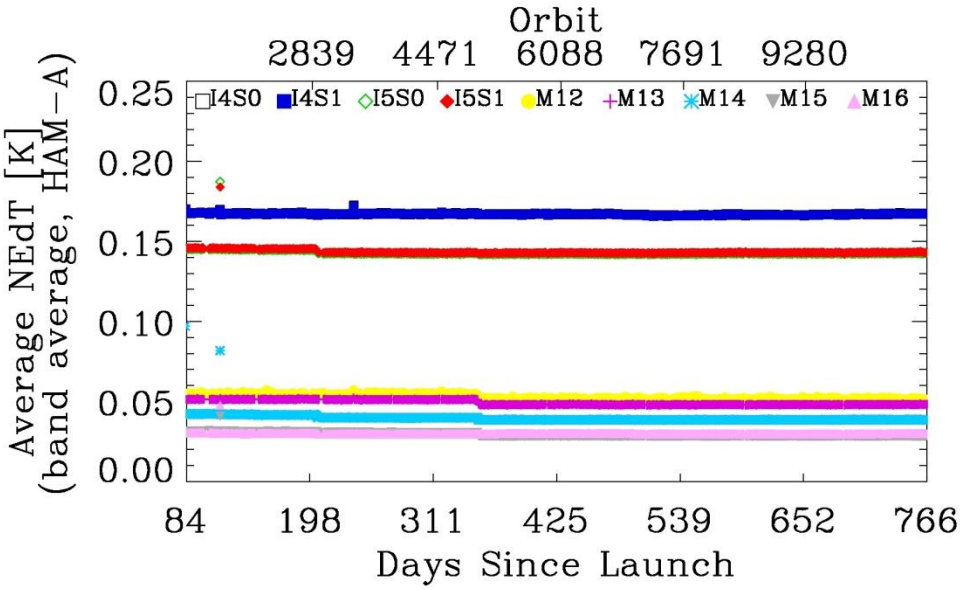


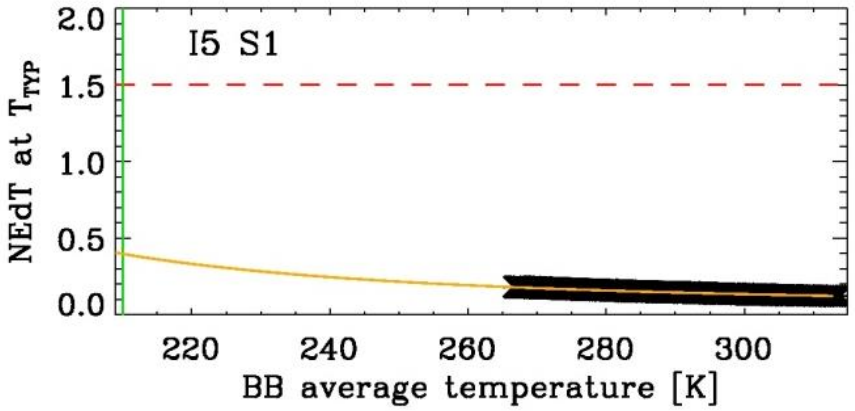
Band	I4	I5	M12	M13	M14	M15	M16
Average F-factor: 03 26 2012	1.0105	1.0040	1.0035	1.0070	0.9946	1.0056	1.0113
Average F-factor: 12 02 2013	1.0136	1.0108	1.0072	1.0093	0.9965	1.0067	1.0124
Trend [%]	0.31	0.68	0.37	0.23	0.19	0.11	0.11

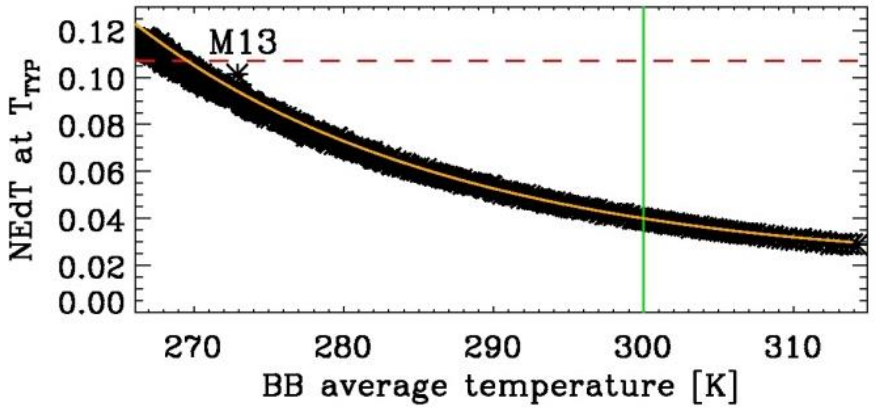
Detector Noise Characterization (NEdT)

$$NEdT = \frac{NEdL}{\partial L/\partial T} = \frac{L}{SNR\,\partial L/\partial T}$$

- NEdT routinely trended at 292.5K: stable since the cold FPA temperatures reached ~80K (orbit 1200). Band averaged values are within 0.2 K for I bands and 0.07 K for M bands
- NEdT at T_{TYP} derived periodically from BB WUCD data: stable and meet the sensor design requirement by a wide margin:







Detector Noise Characterization (NEdT)

NEdT at T_{TYP} (derived from BB cool-down data)

Band	T_{TYP} [K]	NEdT Spec	NEdT 02/12	NEdT 05/12	NEdT 09/12	NEdT 12/12	NEdT 03/13	NEdT 06/13	NEdT 09/13
I4	270	2.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
I5	210	1.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
M12	270	0.396	0.13	0.13	0.13	0.11	0.12	0.12	0.12
M13	300	0.107	0.04	0.04	0.04	0.04	0.04	0.04	0.04
M14	270	0.091	0.05	0.06	0.06	0.06	0.06	0.06	0.06
M15	300	0.070	0.03	0.03	0.03	0.03	0.03	0.03	0.03
M16	300	0.072	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Continue to meet the sensor design requirements

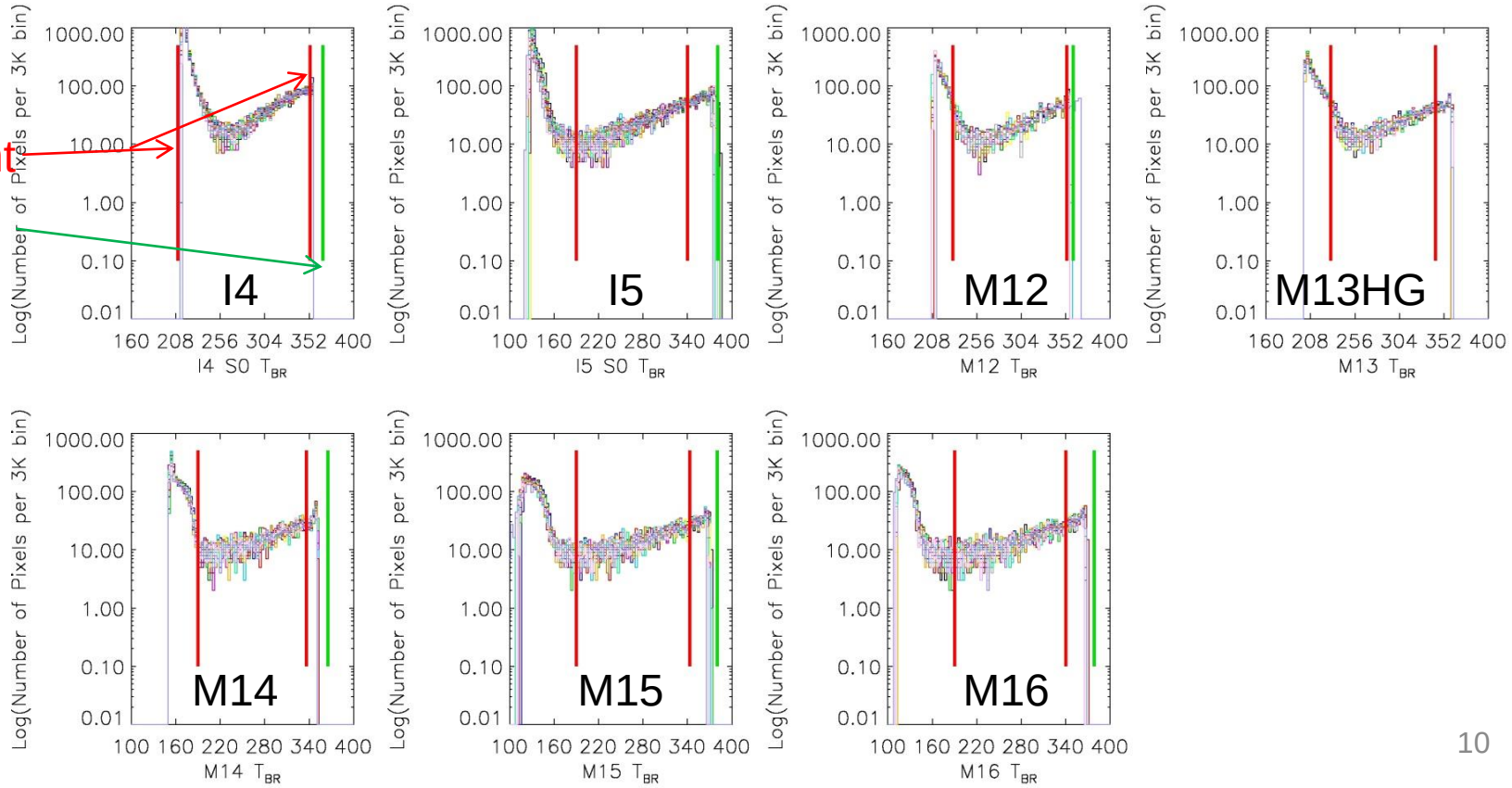
Dynamic Range Verification

Dynamic range verified using scheduled Lunar observations

- All detectors of all TEB bands meet the Tmin (marginal non-compliance at I4) and Tmax requirements
- For some detectors of some bands the radiance limits in the Radiance-to-Temperature LUT do not extend to the largest possible unsaturated radiance

Requirement

LUT limit



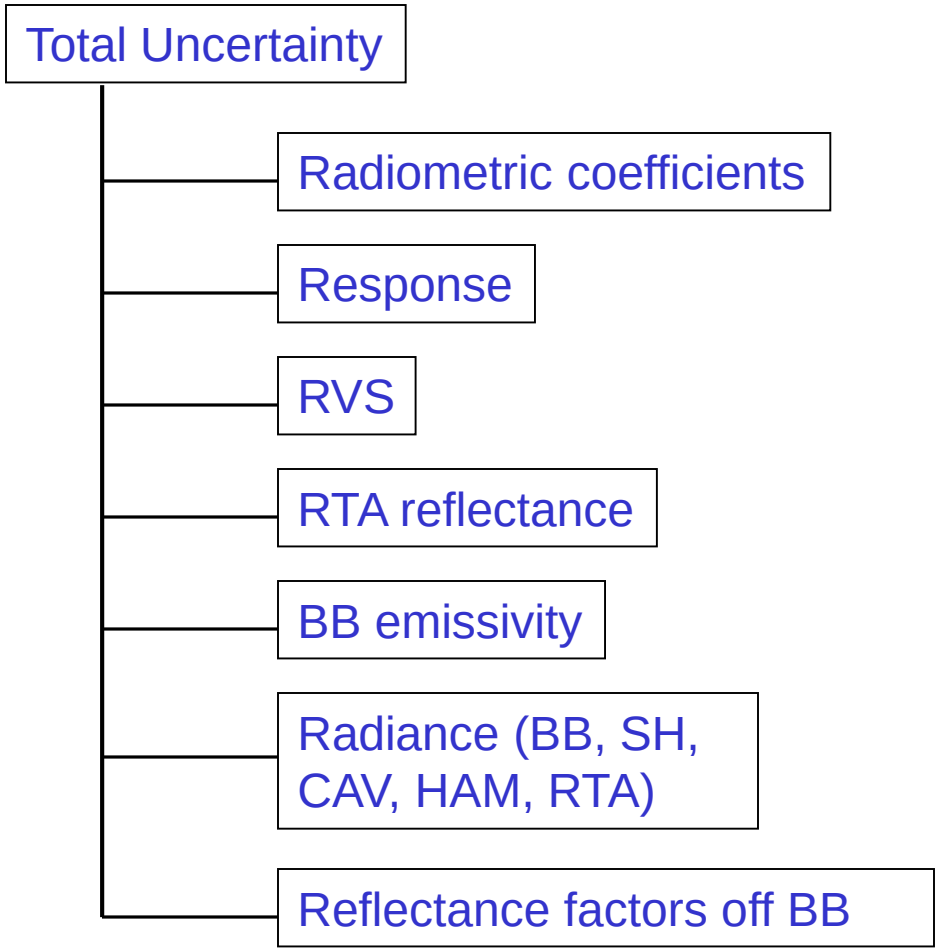
Uncertainty Estimates

- EV retrieved radiance uncertainty propagated using standard NIST formulation (k=1)

- Some uncertainty contributors determined pre-launch by the instrument vendor: RTA reflectance BB emissivity

- Radiometric coefficient and RVS uncertainties determined from NASA pre-launch analysis

- Uncertainties investigated for a range of input signal levels and scan angles



Comparison to Requirement [%]

Uncertainty specifications

Defined in terms of %, at particular uniform scene temperatures

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

Band	267 K
I4 spec	5.00
I4 estimate	2.55
I5 spec	2.50
I5 estimate	0.41

Band	190 K	230 K	270 K	310 K	340 K
M12 spec	---	7.00	0.70	0.70	0.70
M12 estimate	---	8.98	0.71	0.27	0.32
M13 spec	---	5.70	0.70	0.70	0.70
M13 estimate	---	7.50	0.69	0.26	0.31
M14 spec	12.30	2.40	0.60	0.40	0.50
M14 estimate	4.82	0.84	0.28	0.21	0.29
M15 spec	2.10	0.60	0.40	0.40	0.40
M15 estimate	1.59	0.47	0.22	0.19	0.22
M16 spec	1.60	0.60	0.40	0.40	0.40
M16 estimate	1.24	0.37	0.21	0.18	0.20

Comparison to Requirement [K]

Uncertainty specifications

Defined in terms of %, at particular uniform scene temperatures, converted to K

Estimates exceed the specification at lower scene temperatures for bands M12 and M13

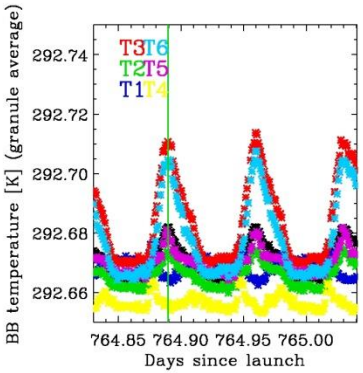
Band	267 K
I4 spec	0.91
I4 estimate	0.468
I5 spec	1.4
I5 estimate	0.226

Band	190 K	230 K	270 K	310 K	340 K
M12 spec	---	0.92	0.13	0.17	0.21
M12 estimate	---	1.11	0.13	0.07	0.09
M13 spec	---	0.85	0.14	0.19	0.23
M13 estimate	---	1.01	0.14	0.07	0.10
M14 spec	2.60	0.75	0.26	0.23	0.34
M14 estimate	0.95	0.26	0.12	0.12	0.20
M15 spec	0.56	0.24	0.22	0.28	0.34
M15 estimate	0.42	0.18	0.12	0.13	0.19
M16 spec	0.48	0.26	0.24	0.31	0.37
M16 estimate	0.35	0.16	0.12	0.14	0.19

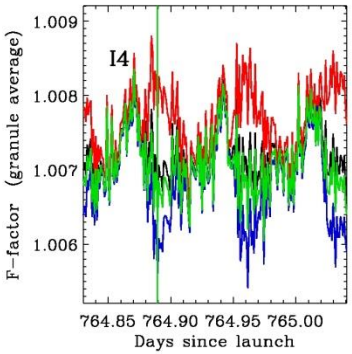
Issues and Future Improvements

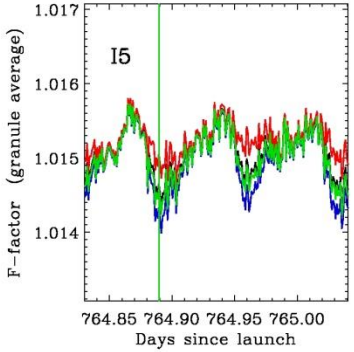
- **F-factor orbital variation reduction**
  - ✓ Apply different weighting for BB thermistors
  - ✓ Improve background model
- **M13 LG calibration**
  - ✓ Use lunar observations
- **SDR striping reduction**
  - ✓ Use lunar observations
- **TEB calibration when moon in SV**
  - ✓ Use lunar observations

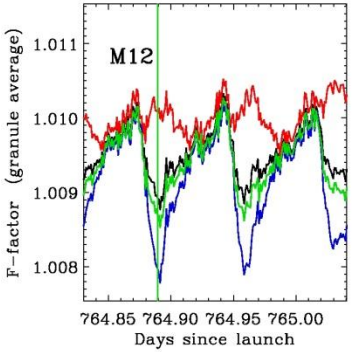
F-factors Orbital Variation Reduction

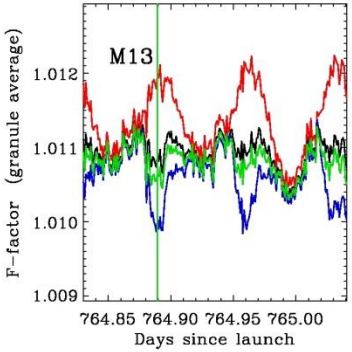


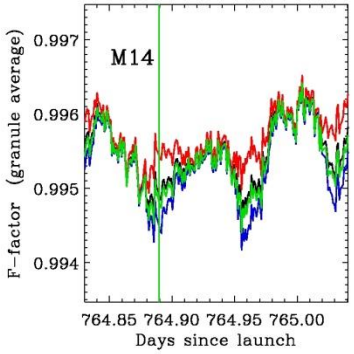
T3 & T6
T2 & T5
T1 & T4
average T1-T6

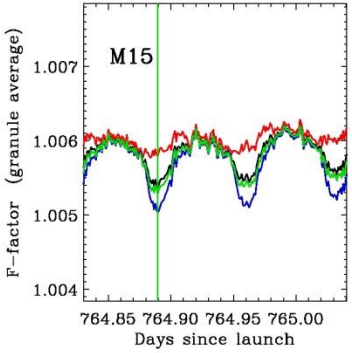


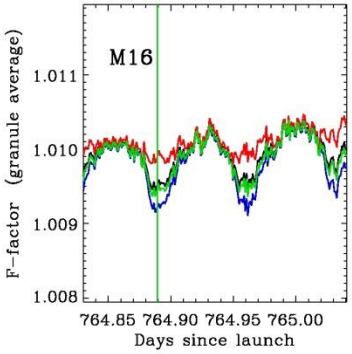












- F-factor orbital variations are present, on the order of 0.05-0.1 %.
- Changing the BB thermistor weighting can reduce the F-factor orbital variations. Using T3 and T6 yield less variation for most bands (except M13).
- There is an on-going effort by Aerospace to improve the background model which would also reduce the F-factor orbital variations.

M13 LG Calibration

M13 low gain: No scan by scan F factor correction

Prelaunch analysis differs between Government team (Aerospace and VCST) and sensor subcontractor – current LUT. Government team results are:

- ✓ $\mathbf{c_1 = 0.142}$ - 7% higher than LUT value $\mathbf{c_{1LUT} = 0.132}$;
- ✓ $\mathbf{c_0 = 0}$ - inconsistent with $\mathbf{c_{0LUT} = 1.15}$

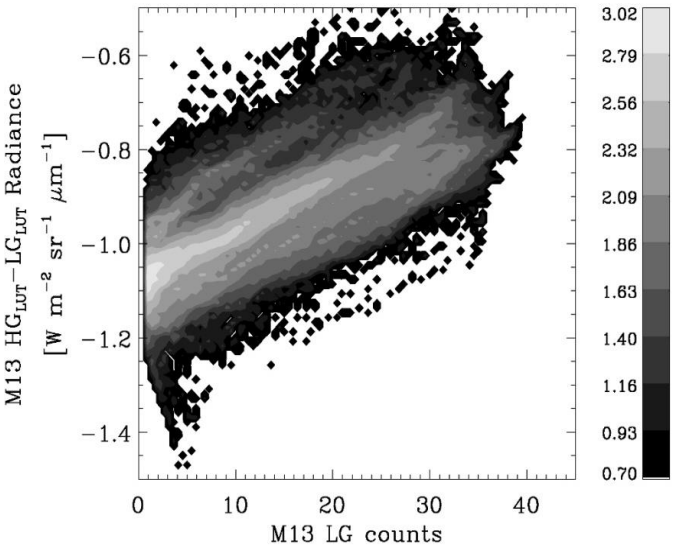
Proposal:

Update M13 low gain coefficients based on Government team pre-launch analysis, which is consistent with results from on-orbit calibration

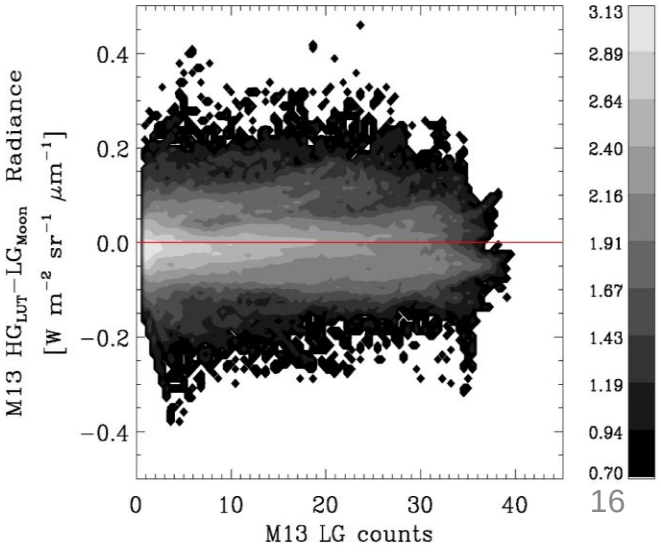
On-orbit comparison of lunar images in M13 LG and M13 HG - supports Government team pre-launch results:

- ✓ $\mathbf{c_1 = 0.142}$; 7% higher than c_{1LUT} -consistent with Gov. team pre-launch
- ✓ $\mathbf{c_0 = 0}$ consistent with Gov. team pre-launch

M13 LG c_{1LUT}, c_{0LUT}

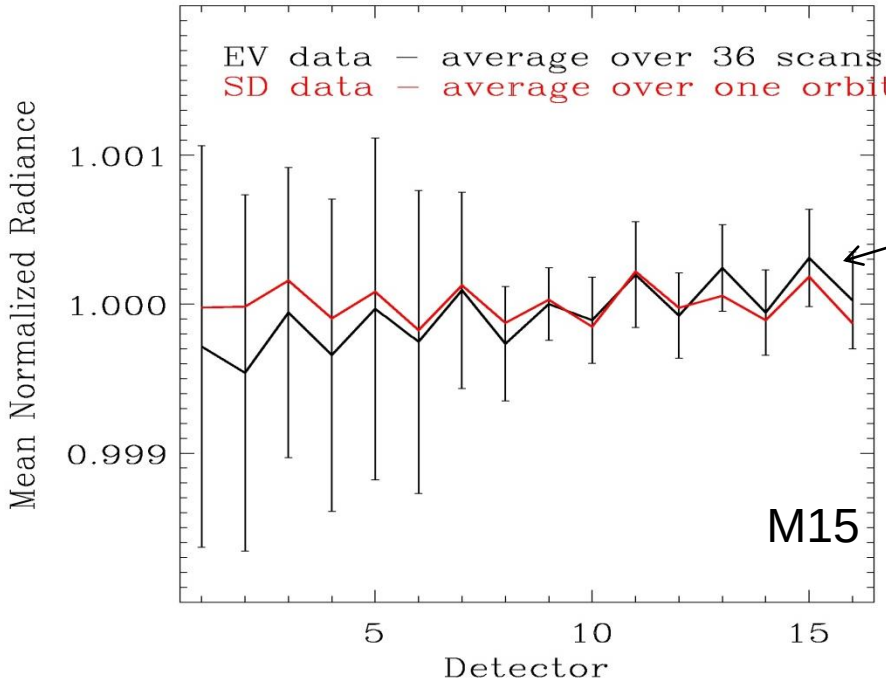


M13 LG c_1=0.142, c_0=0



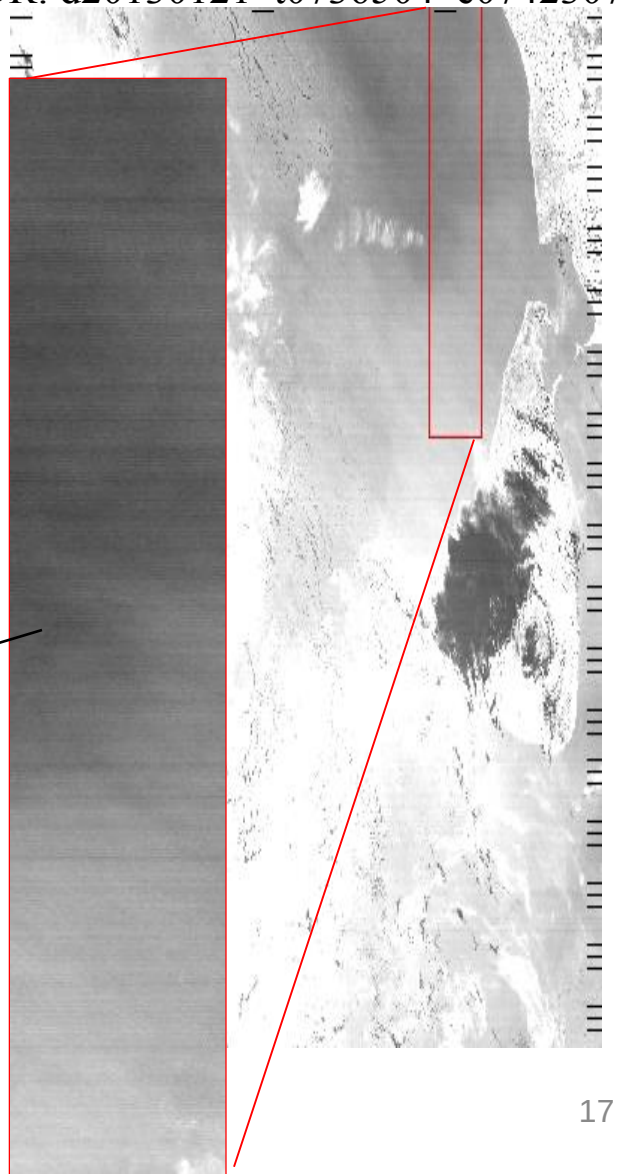
SDR Striping Reduction

- Striping on the noise level affects SST products based on M15 and M16 brightness temperatures.
- M15 radiance shows more distinct striping pattern.
- Similar pattern is extracted from various EV scenes as well as from SD-view data.
- Investigations into the cause of these small temperature errors as well as mitigation approaches (LUT updates, F factor smoothing, etc.) are being evaluated to reduce the stripes seen in the SST products.



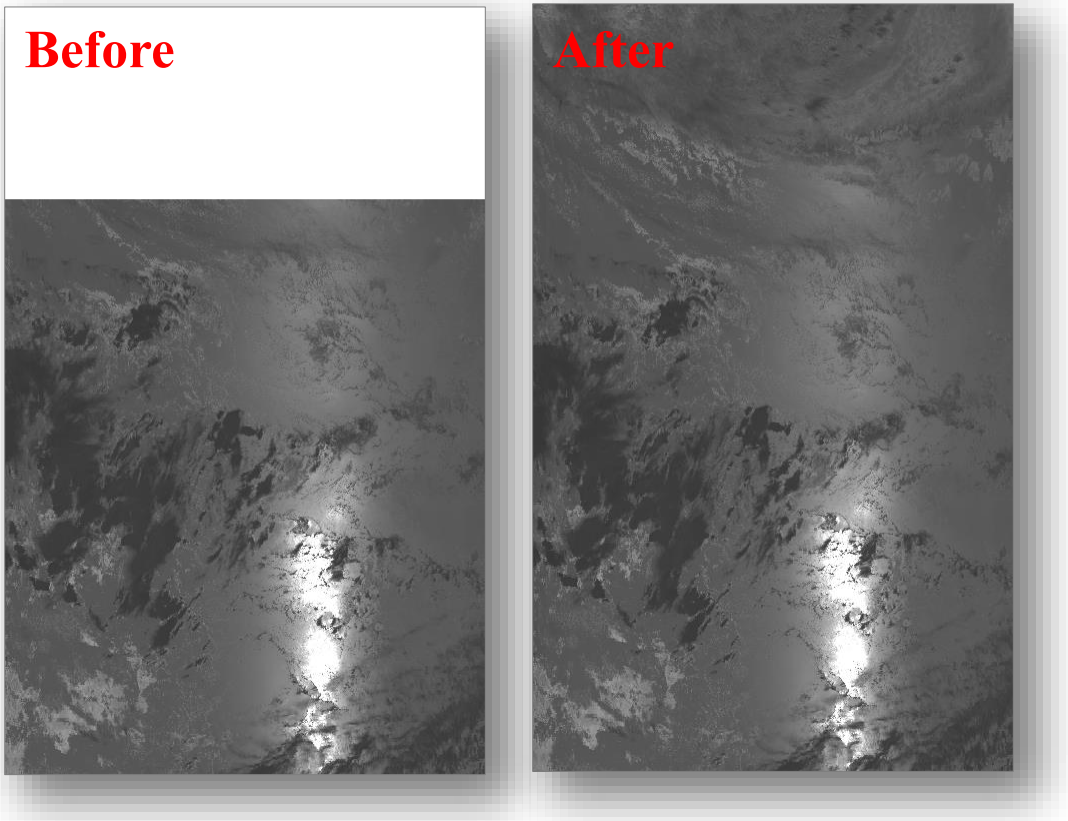
T(M15)-T(M16)

SDR: d20130121_t0736504_e0742307



TEB Calibration when Moon in SV

- Currently for TEB, Fill values are assigned in EV SDR when the Moon is in the SV.
- Improved algorithm computes the mean and standard deviation of a 48-frame sample each scan. Then the outlier samples (Moon intrusion) with selected rejection scheme are identified and excluded from the SV average for background subtraction.



Images of calibrated radiance from 4 consecutive Band **M12** SDRs, generated with current SDR code (left) and modified (right) calibration algorithms (Data: Jan 22, 2013; Time 22:24:02). [Reference SPIE 2013, 8866-72]

Publications on TEB Topics

- X. Xiong et al., "**VIIRS On-orbit Calibration Methodology and Performance",** accepted JGR
- Q. Liu; C. Cao and F. Weng, **"Assessment of Suomi National Polar-Orbiting Partnership VIIRS Emissive Band Calibration and Inter-Sensor Comparisons",** IEEE JSTAR, 6, 1737-1748, 2013; 10.1109/JSTARS.2013.2263197
- D. Moyer; C. Moeller and F. De Luccia, "**VIIRS thermal emissive bands on-orbit calibration coefficient performance using vicarious calibration results"**, *Proc. SPIE* 8866, Earth Observing Systems XVIII, 88661O , 2013; doi:10.1117/12.2023809;
- J. McIntire; B. Efremova and X. Xiong, "**Calibration of NPP VIIRS fire detection band using lunar observations"**, *Proc. SPIE* 8533, Sensors, Systems, and Next-Generation Satellites XVI, 85331B 2012; doi:10.1117/12.971228
- A. Wu; X. Xiong; K. Chiang and C. Sun, "**Assessment of the NPP VIIRS RVS for the thermal emissive bands using the first pitch maneuver observations"**, *Proc. SPIE* 8510, Earth Observing Systems XVII, 85101Q , 2012; doi:10.1117/12.931013
- X. Xiong et al., "**Comparison of MODIS and VIIRS onboard blackbody performance**", *Proc. SPIE* 8533, Sensors, Systems, and Next-Generation Satellites XVI, 853318, 2012; doi:10.1117/12.977560
- D. Moyer et al., **"VIIRS thermal emissive bands calibration algorithm and on-orbit performance"**, *Proc. SPIE* 8510, Earth Observing Systems XVII, 85101D, 2012; doi:10.1117/12.930145
- S. Anderson; K. Chiang and X. Xiong. **"Alternative method for VIIRS Moon in space view process",** *Proc. SPIE 8866*, Earth Observing Systems XVIII, 88661Y, 2013; doi:10.1117/12.2024780
- X. Xiong et al., **"MODIS and VIIRS lunar observations and applications",** *Proc. SPIE 8889*, Sensors, Systems, and Next-Generation Satellites XVII, 88890V, 2013; doi:10.1117/12.2028954

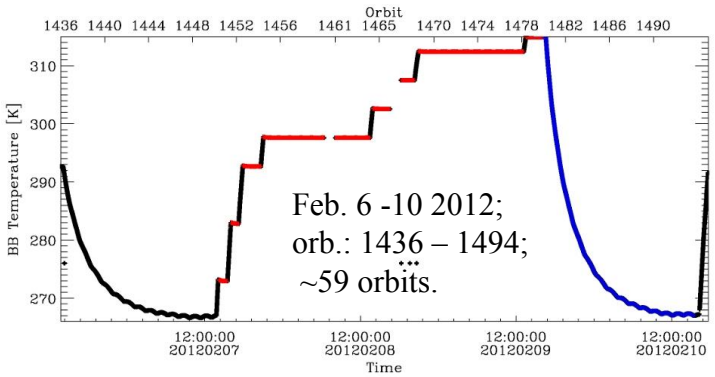
Conclusions

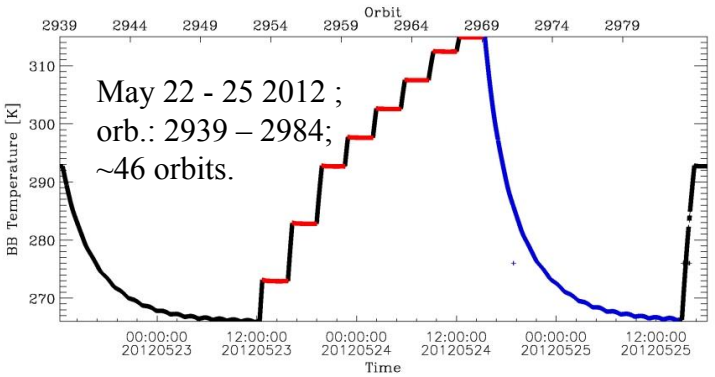
- **The VIIRS on-orbit BB long-term (2 years) performance is very stable. Short-term (orbital) temperature variations are present but within the uniformity requirement of 30mK**
- **Detector response (F-factor) trending is stable, with I5 showing maximum band-average trend of 0.67% followed by M12 and I4. Small orbital variations are present (0.05-0.1%)**
- **No change is observed for TEB detector noise characteristics. NEdT at Ttyp is in compliance with the requirement**
  - ✓ **TEB calibration coefficients derived from all seven WUCD cycles have been are consistent**
- **Uncertainty estimate**
  - ✓ **TEB meet calibration requirements for most scene temperatures**
  - ✓ **M12 and M13 have slightly larger than specified uncertainties at low scene temperatures**
  - ✓ **Larger uncertainties in M13 low gain (above 350 K)**
- **Further Improvements:**
  - ✓ **Updates to M13 LG offset and linear coefficients to improve calibration**
  - ✓ **Modifications to the OBC BB weights and thermal model to reduce orbital calibration errors observed in the F-factor trending**
  - ✓ **Adjustments of the inputs into the TEB thermal model to reduce the SDR striping affecting the EDR products**
  - ✓ **Modifications to the SDR code/algorithm to allow TEB calibration to be performed when the Moon is in SV**

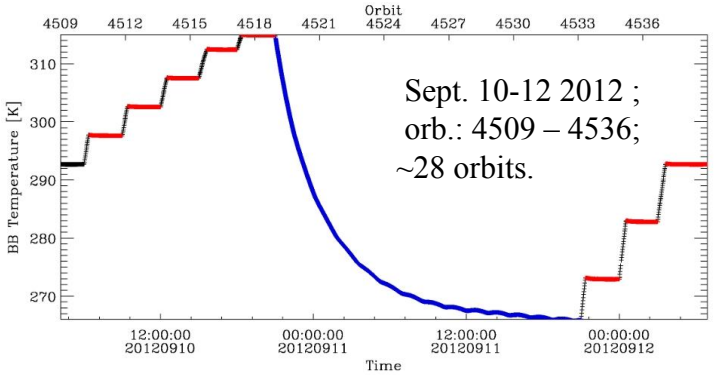
Back Up

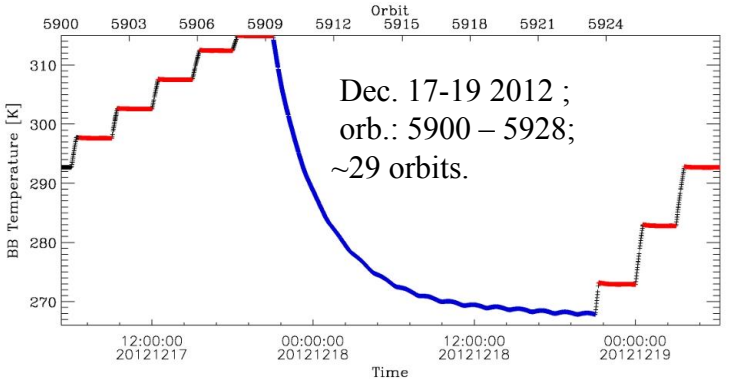
Warm-up Cool-down (WUCD) Cycles

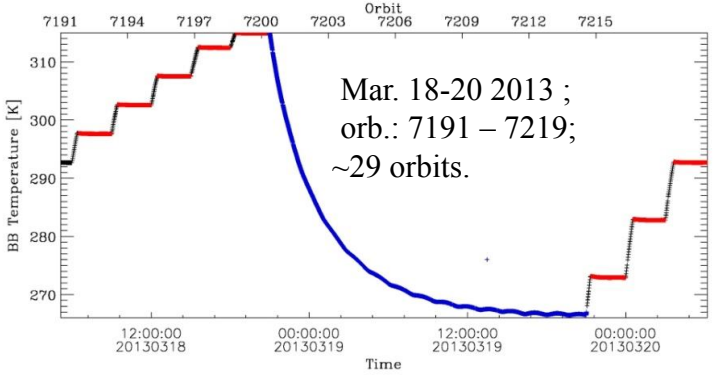
WUCD cycles performed: Feb, May, Sep, Dec 2012; Mar, Jun, Sept 2013

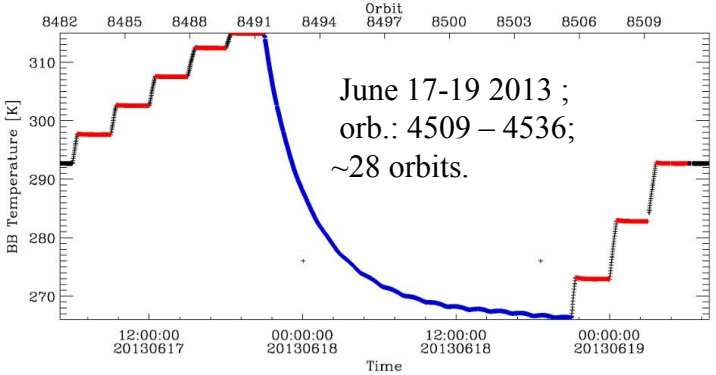












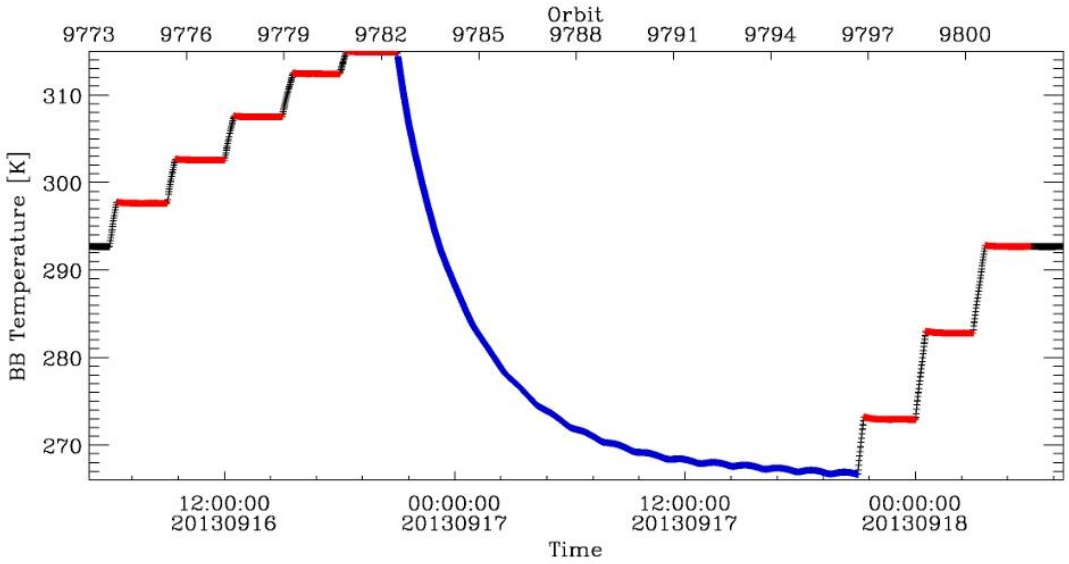
Seventh WUCD (09/13) Data Selection

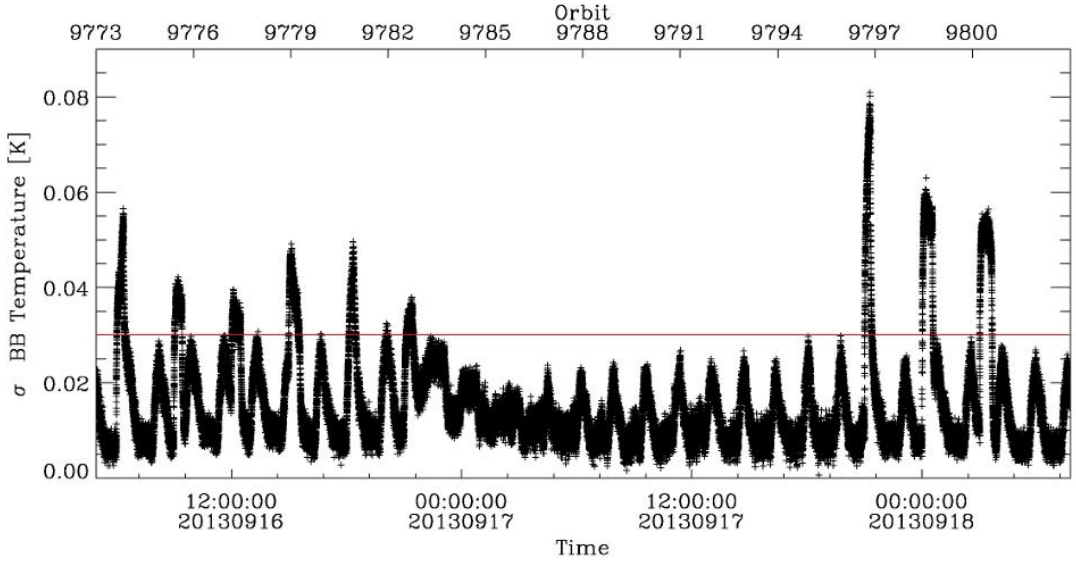
Warm-up:

- Orbits: 9773 – 9782; 9797 – 9801.
- T_{BB} set to: 297.5K, 302.5K, 307.5K, 312.5K, 315.0K and 272.5K, 282.5K, 292.5K,
- The scans used (~40900) are highlighted in red.

Cool-down:

- Orbits: 9782 – 9796.
- T_{BB} range: 266.3K to 315K;
- The scans used (~48300) are shown in blue.





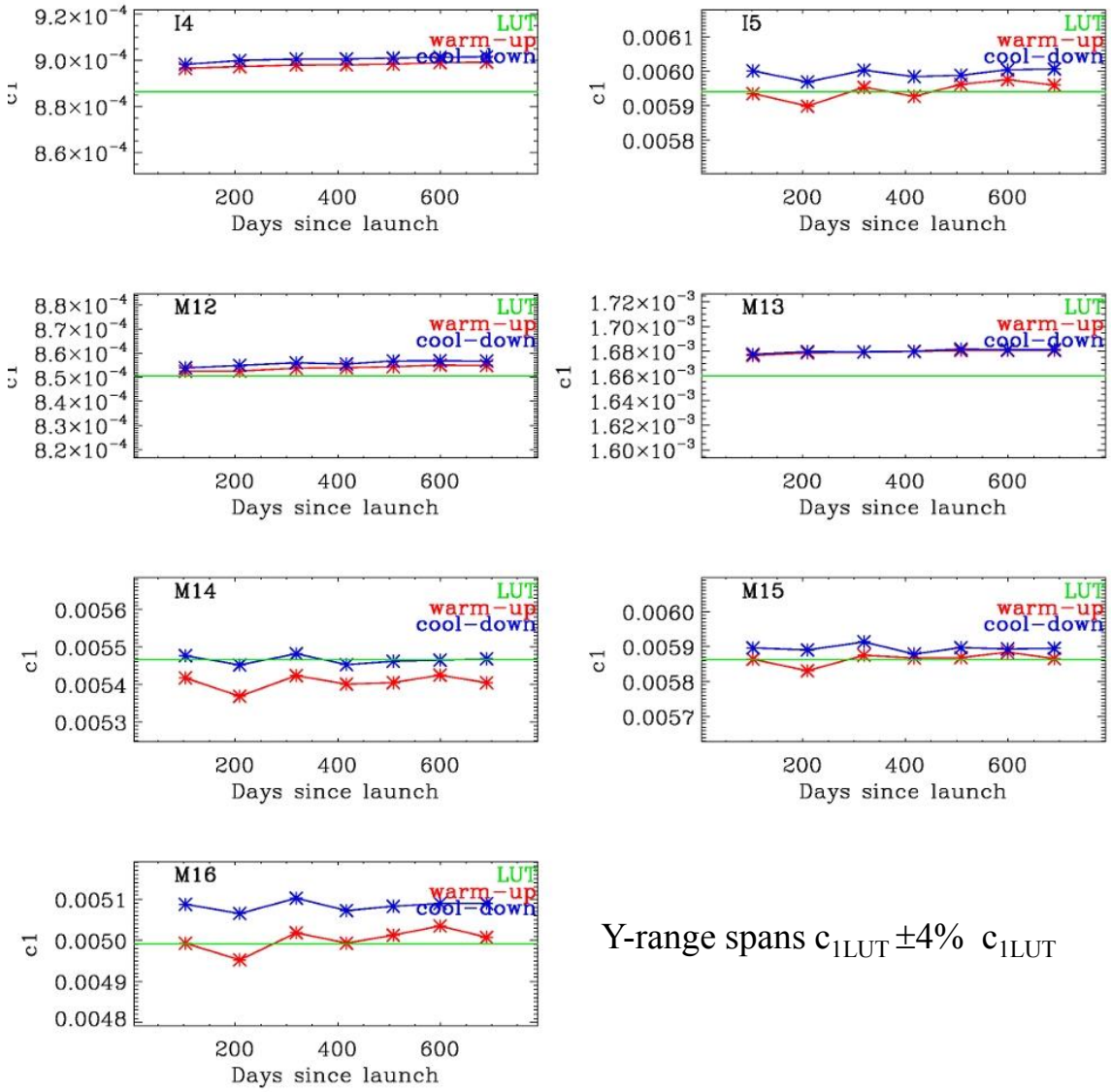
Detector Response Stability from WUCD Data - c1

- Band-average linear detector response derived from the seven WUCD cycles is stable.

✓ c1 coefficients are shown in red - WU data, and blue - CD data in comparison with pre-launch (green) values.

✓ Band-average c1 coefficients derived during WUCD cycles are within 1.8% on average (at M16 CD) from pre-launch values.

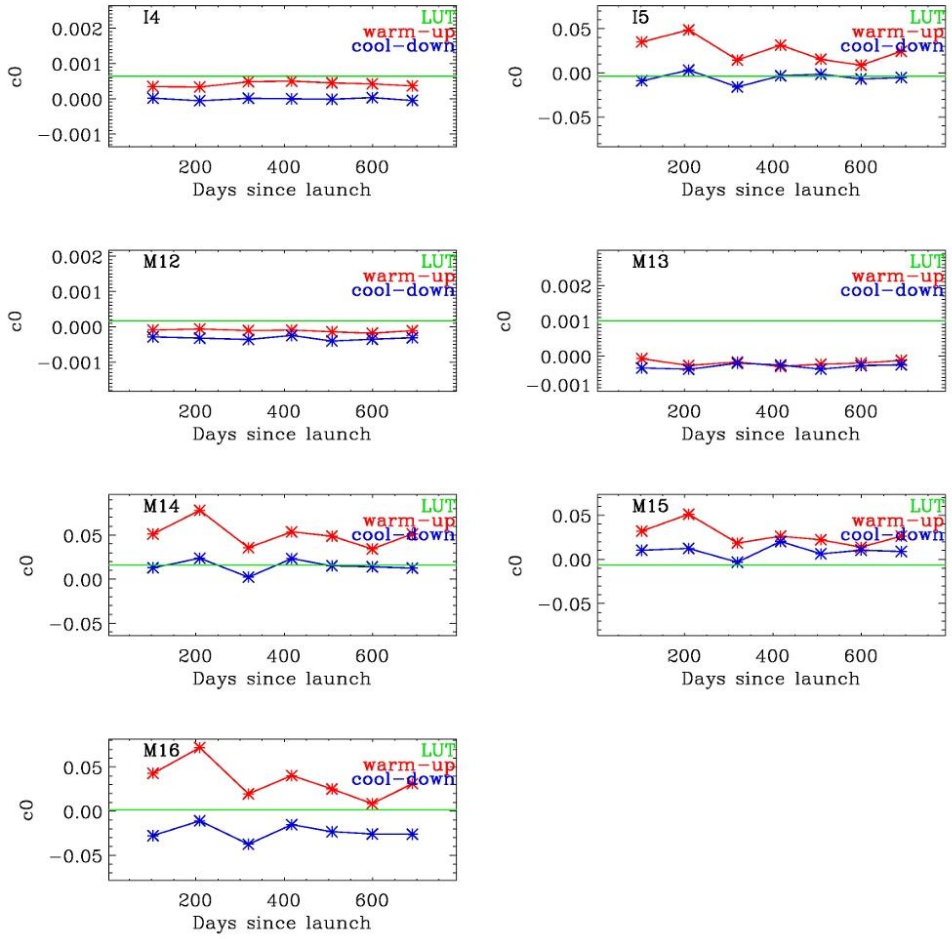
- Offsets and second-order coefficients are also consistent between the seven WUCD cycles.



Y-range spans $c_{1LUT} \pm 4\%$ c_{1LUT}

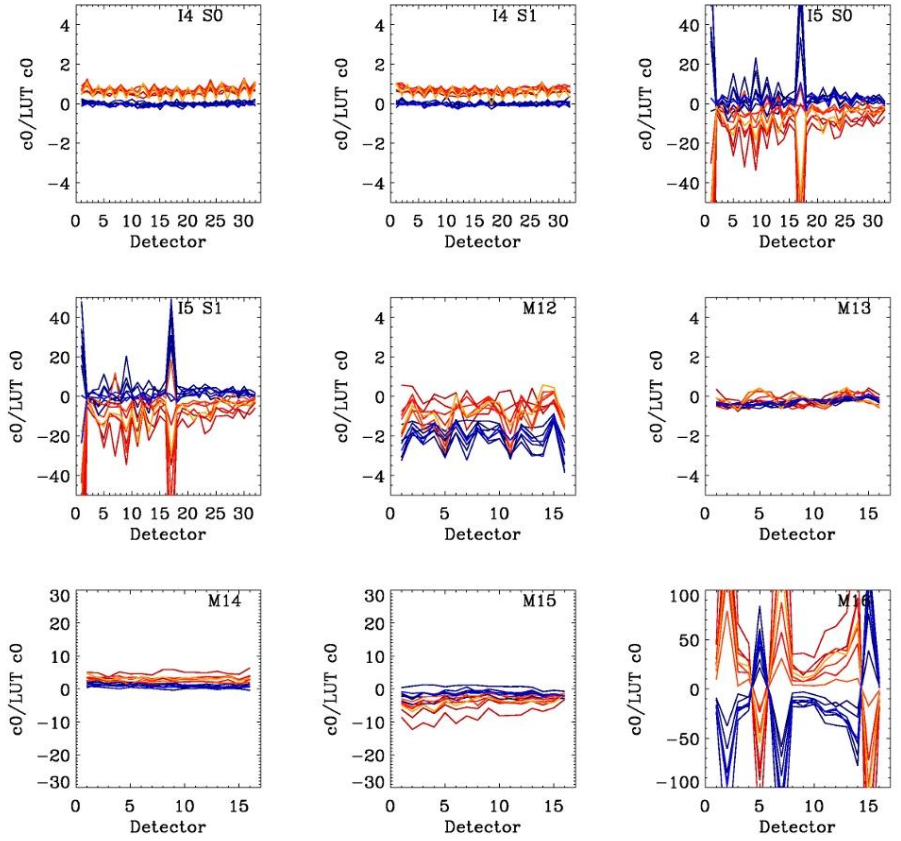
WUCD C0 Coefficients

Band average c_0



Y-range spans: $c_{0LUT} \pm 0.002$ (SMIR),
$c_{0LUT} \pm 0.1$ (LWIR)

Detector specific c_0/c_{0LUT}

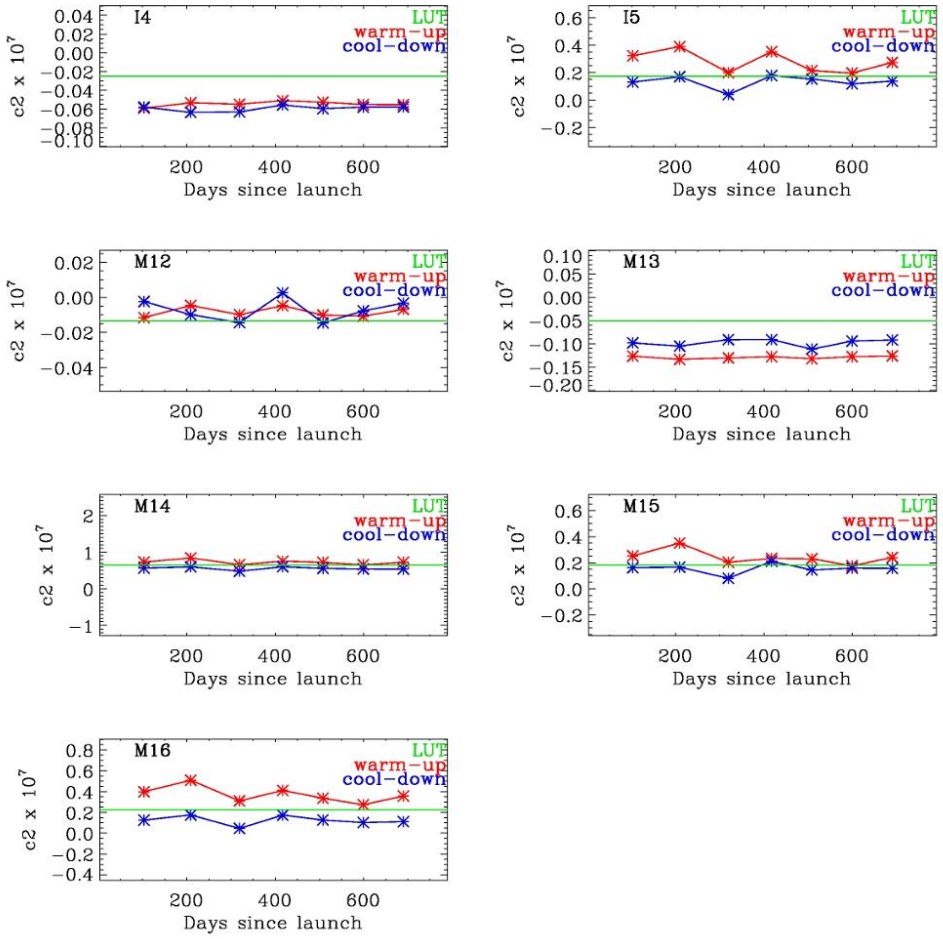


Warm-up 02/2012 HAM-A
Warm-up 05/2012 HAM-A
Warm-up 09/2012 HAM-A
Warm-up 12/2012 HAM-A
Warm-up 03/2013 HAM-A
Warm-up 06/2013 HAM-A
Warm-up 09/2013 HAM-A

Cool-down 02/2012 HAM-A
Cool-down 05/2012 HAM-A
Cool-down 09/2012 HAM-A
Cool-down 12/2012 HAM-A
Cool-down 03/2013 HAM-A
Cool-down 06/2013 HAM-A
Cool-down 09/2013 HAM-A

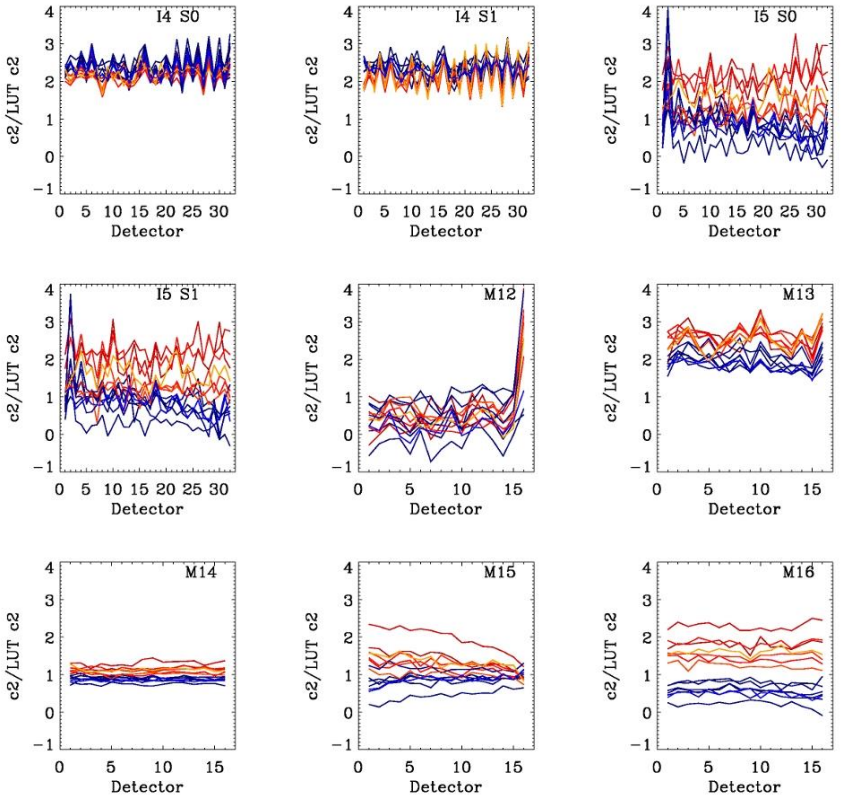
WUCD C2 Coefficients

Band average c_2



Y-range spans $c_{2LUT} \pm 3 \times c_{2LUT}$

Detector specific c_2/c_{2LUT}



Warm-up 02/2012 HAM-A
Warm-up 05/2012 HAM-A
Warm-up 09/2012 HAM-A
Warm-up 12/2012 HAM-A
Warm-up 03/2013 HAM-A
Warm-up 06/2013 HAM-A
Warm-up 09/2013 HAM-A

Cool-down 02/2012 HAM-A
Cool-down 05/2012 HAM-A
Cool-down 09/2012 HAM-A
Cool-down 12/2012 HAM-A
Cool-down 03/2013 HAM-A
Cool-down 06/2013 HAM-A
Cool-down 09/2013 HAM-A