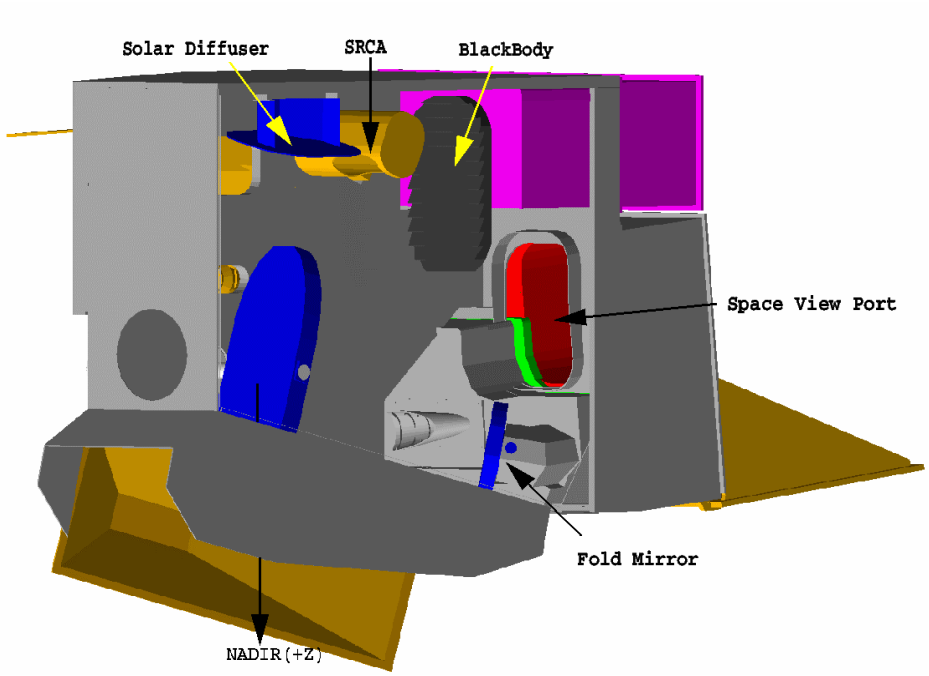
# Terra MODIS (PFM) On-orbit Calibration and Characterization

*MCST Calibration Workshop, July 22, 2002*

# MODIS


Solar Diffuser
SRCA
BlackBody
Space View Port
Fold Mirror
NADIR(+Z)

# Acknowledgements

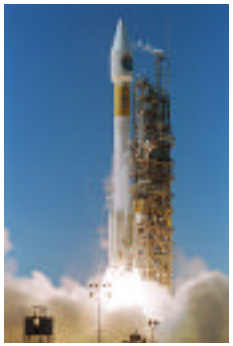
- All MCST Technical Team, including IOT and L1B Team
- Support from many of MODIS Science Team members and their representatives
- Support from SBRS MODIS technical team

# Terra MODIS On-orbit Calibration & Characterization

- Terra MODIS (PFM) status (update from last STM)
  - Operational configuration
  - L1B (algorithms) and LUTs status
- On-orbit calibration and characterization
  - Thermal emissive bands (TEB)
  - Reflective solar bands (RSB)
  - SRCA and ECAL analyses
- Current and future work

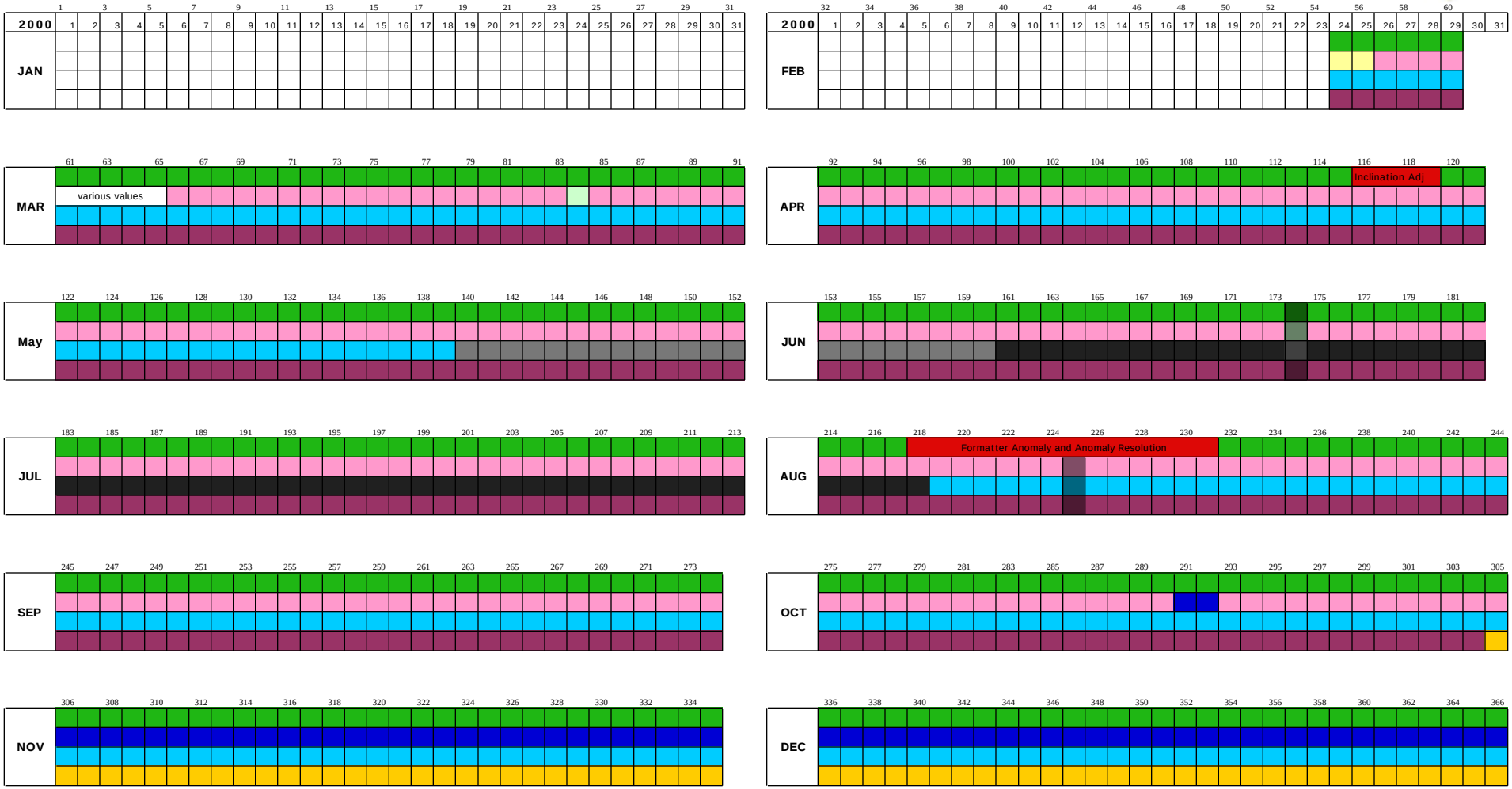
# Terra MODIS (PFM) Status

- Terra launch: Dec. 18, 1999
- MODIS first image: Feb. 24, 2000
- Launch - Oct. 30, 2000
  - A-side with SMIR Itwk/Vdet=110/226
  - Other Itwk/Vdet also used during early testing
- Oct. 30, 2000 - June 15, 2001
  - B-side with SMIR Itwk/Vdet=79/110
- July 2, 2001 - Present
  - A-side with SMIR Itwk/Vdet=79/190



# Operational Configuration - 2000

**SUMMARY OF KEY TERRA MODIS OPERATIONAL CONFIGURATIONS**

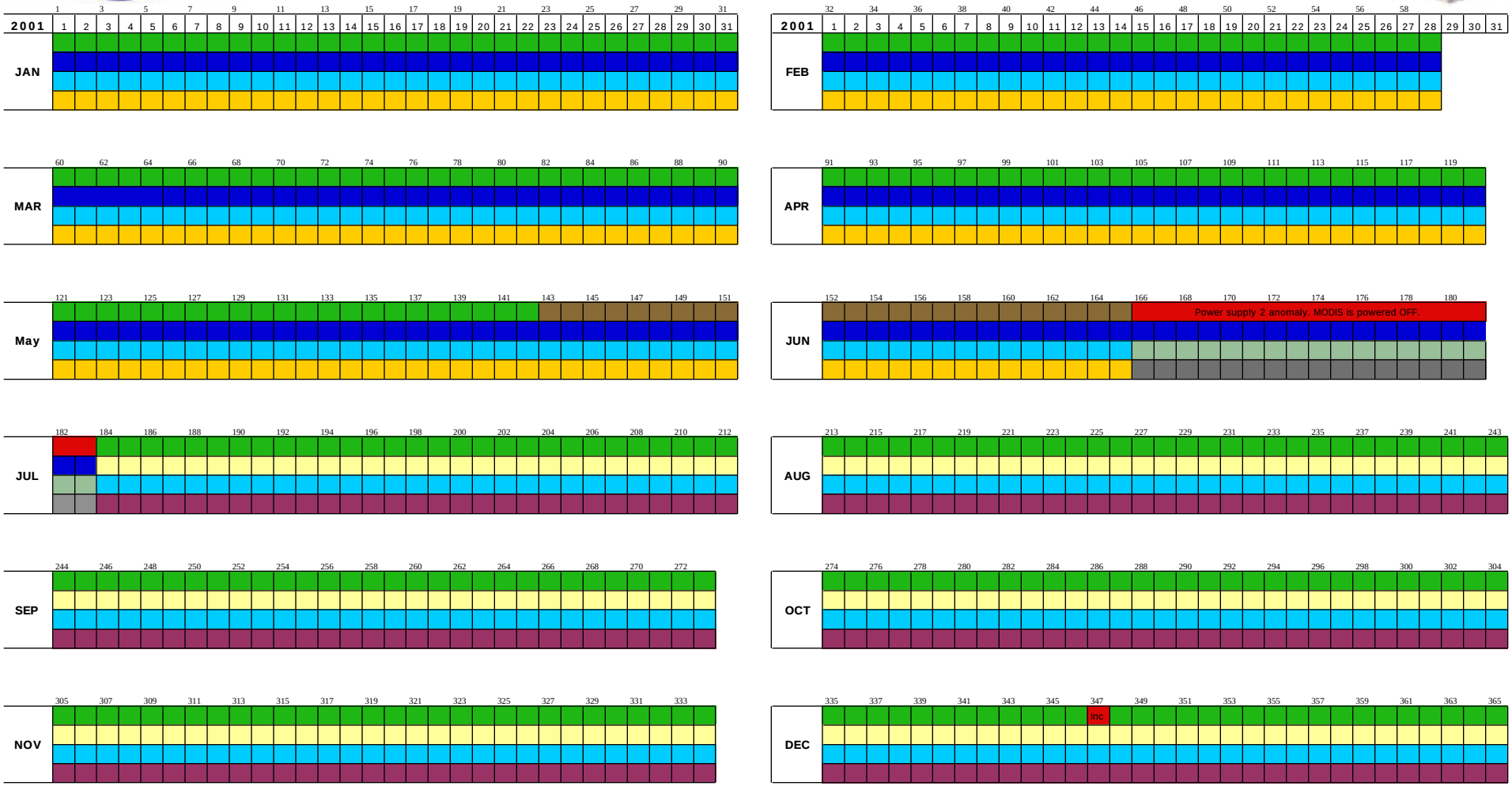



| Legend | | | | | | | |
|---|---|---|---|---|---|---|---|
| Science Data in Earth View Sector | | Yes | | No | | | |
| SW/MWIR Focal Plane Bias (DN) | | 110 | | 190 | | 218 | 226 |
| Temperature Control of Cold FPA | | Yes | | Partial Loss in orbit | | | No controlled over entire orbit |
| A-side /B-side Electronics | | A-side (PS1) | | | | B-side (PS2) | |
| Day 2000174, first formatter reset | | | | Complete cooler outgas, focal plane control returned | | | |

*PFM_6*

# Operational Configuration - 2001

**SUMMARY OF KEY TERRA MODIS OPERATIONAL CONFIGURATIONS**

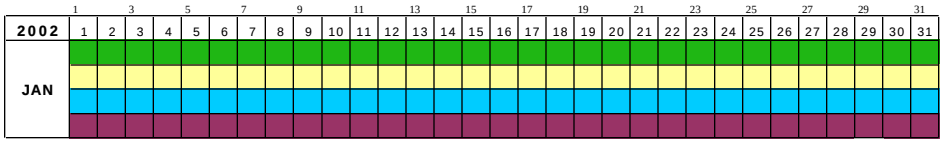


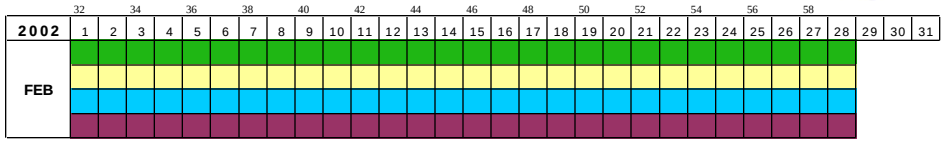

| Legend | | | | |
|---|---|---|---|---|
| Science Data in Earth View Sector | Yes | | No | |
| SW/MWIR Focal Plane Bias (DN) | 110 | | 190 | |
| Temperature Control of Cold Focal Plane | Yes | | Turned off | |
| A-side /B-side Electronics | A-side (PS1) | | B-side (PS2) | |
| SSR anonmaly, partial data lost | | | Power supply 2 anormaly. | |

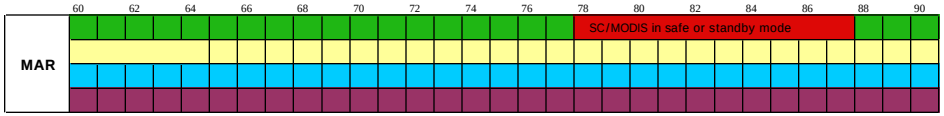
*PFM_7*

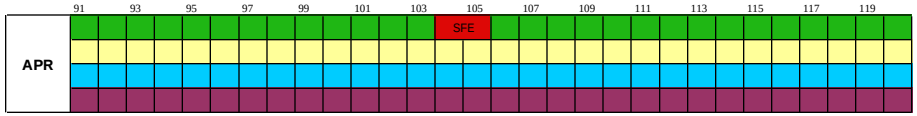
# Operational Configuration - 2002

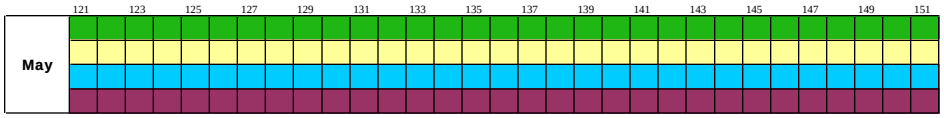
**SUMMARY OF KEY TERRA MODIS OPERATIONAL CONFIGURATIONS**

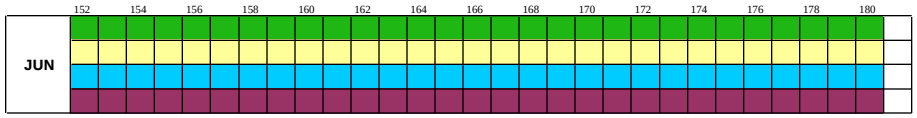


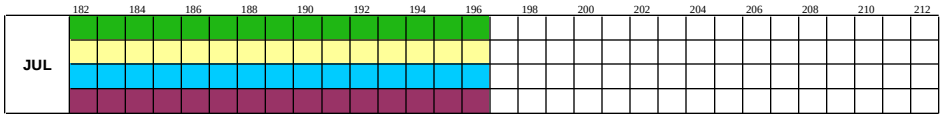



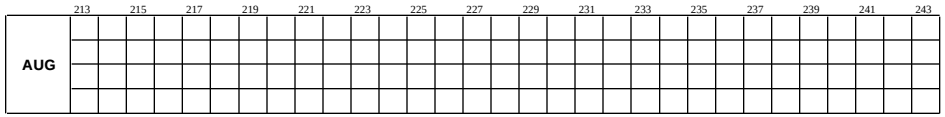



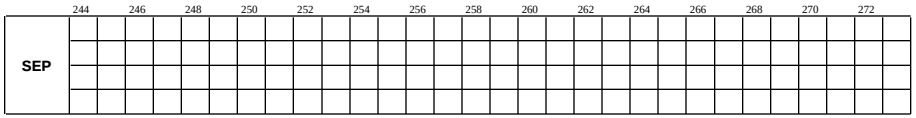



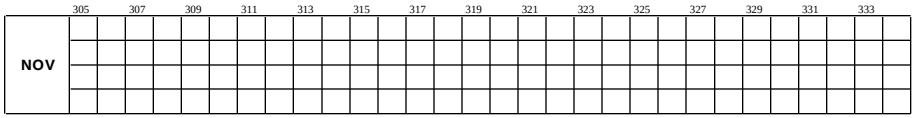



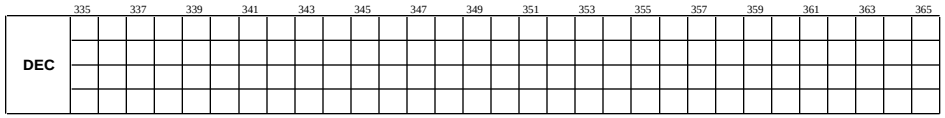






| Legend | | | | |
|---|---|---|---|---|
| Science Data in Earth View Sector | Yes | No | | |
| SW/MWIR Focal Plane Bias (DN) | 110 | 190 | | |
| Temperature Control of Cold Focal Plane | Yes | Turned off | | |
| A-side /B-side Electronics | A-side (PS1) | B-side (PS2) | | |
| SSR anonmaly, partial data lost | Power supply 2 anormaly. | | | |

*PFM_8*

# L1B & LUTs Status (What's New)

- B26 de-striping algorithm
  - Input from U. of Wisconsin
  - B26 de-striping using B5
- Time-dependent RVS LUTs
  - Capture AOI dependent scan mirror degradation
  - Impact only on B8, 9, 10, and 3
  - Tested by U. of Miami
- PC bands (B33-36) $a_0 = 0$

| Recent MODIS/Terra Level 1B Code Versions | | |
|---|---|---|
| Version # | Calendar date of 1st use | Version Description<br>Changes apply to subsequent versions unless otherwise noted. |
| V3.0.1_Terra | 2/27/2002 in GDAAC processing | • Production of 250m and 500m resolution data may be turned off when not operating in day mode.<br>• Leading/trailing granule time check inserted.<br>• Code vs. LUT version number checking<br>• Miscellaneous spelling/grammar corrections |
| V3.0.1.1_Terra | 3/12/2002 at GDAAC | LUT Update: Slope of fit for Band 3 calibration coefficients adjusted. |
| V4.0.0_Terra | Collection 4<br><br>Submitted to SDST 3/27/2002<br><br>(Not used in production) | • Band 26 Correction inserted: Band 26 corrected using aggregated Band 5 radiances.<br>• RVS correction changed to piecewise linear.<br>• New flag TEB_B1_NOT_CALCULATED added. Set if b1 cannot be calculated.<br>• Collection 4<br>• Various minor code upgrades not affecting scientific output |
| V4.0.1_Terra | Collection 4<br><br>Submitted to SDST 4/30/2002 (Used in scientific testing; not used in production) | • Code ported to LINUX machines.<br>• ADC correction algorithm stripped out.<br>• Band 26 correction algorithm turned on for testing<br>• Treatment of leading/trailing granules when 5 or fewer scans dropped changed<br>• Code logic altered for efficiency<br>• Small bug in Band 26 correction algorithm fixed |
| V4.0.5_Terra | Collection 4<br><br>To be submitted to SDST | • Band 26 Correction LUT table pieces added and Band 26 correction turned on.<br>• Data type of LUT "dn_sat_ev" changed to float64 for IRIX/LINUX agreement.<br>• Small bug in calculation of RVS coefficients fixed (did not lead to incorrect RVS values).<br>• Geolocation metadata now obtained from L1AGEO Geolocation input file, not L1A input file. |

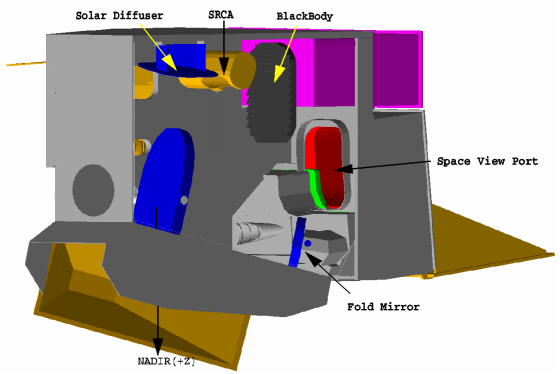
# Calibration and Characterization

- TEB
  - Response trending, NEdT
- RSB
  - SD degradation, AOI dependent response trending, SNR
- SRCA and ECAL
  - Spatial & Spectral
  - Electronic gain trending, dn_sat

# TEB Calibration (1 page summary)

*TEB product: Radiance (TOA), $L_{EV}$*

$$RVS_{EV} \;\; L_{EV} + \left(RVS_{SVS} - RVS_{EV}\right) \;\; L_{SM}$$
$$= a_0 + b_1 \;\; dn_{EV} + a_2 \;\; dn_{EV}^2$$




*Calibration coefficient, b1, from BB*

$$RVS_{BB} \;\; \varepsilon_{OBC} \;\; L_{OBC} + \left(RVS_{SVS} - RVS_{BB}\right) \;\; L_{SM} + RVS_{BB} \;\; \left(1 - \varepsilon_{OBC}\right) \;\; \varepsilon_{cav} \;\; L_{cav}$$
$$= a_0 + b_1 \;\; dn_{OBC} + a_2 \;\; dn_{OBC}^2$$

**RVS:** Response Versus Scan-angle

**ε:** Emissivity

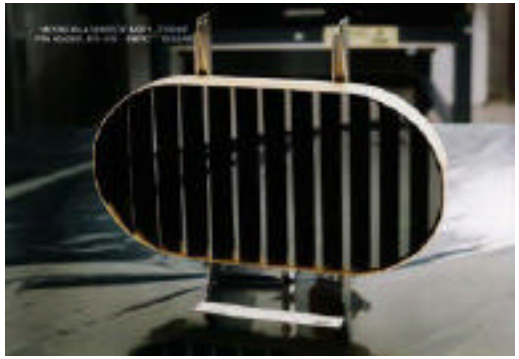
**L:** Spectral band averaged radiance

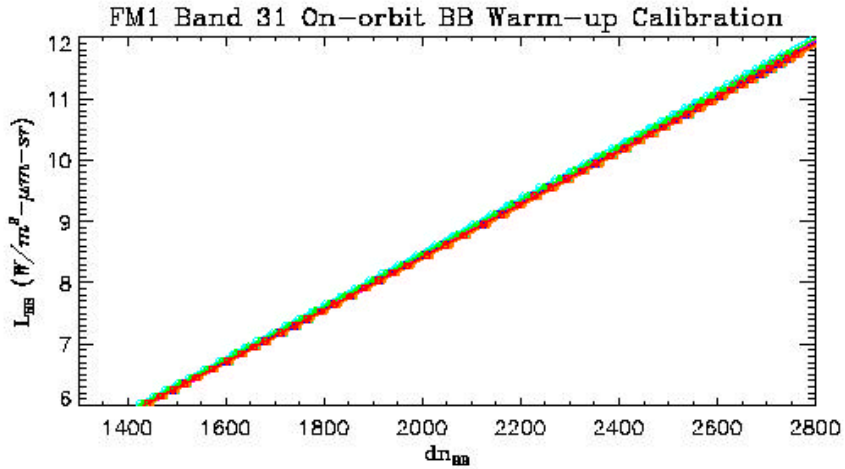
**dn:** digital count with background corrected

$$\overline{L_S} = \frac{\sum Planck(\lambda, T) \;\; RSR(\lambda)}{\sum RSR(\lambda)}$$

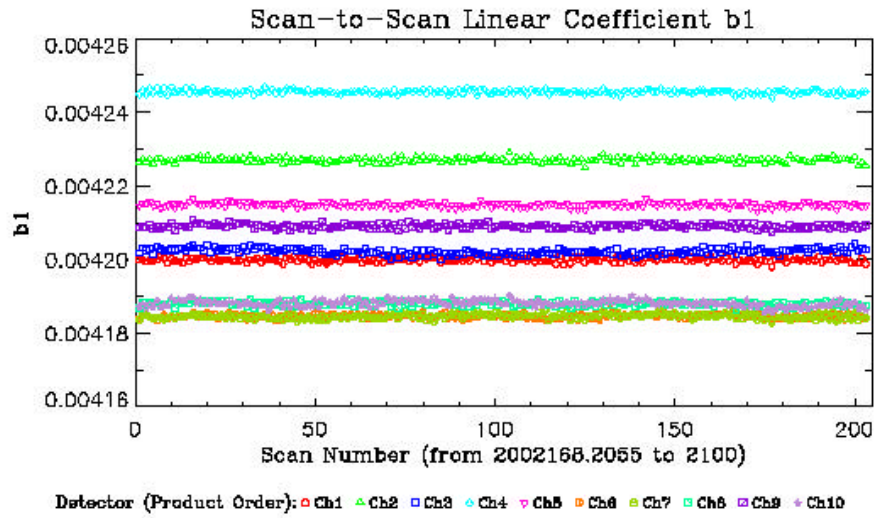
$$Planck(\lambda, T) = \frac{c_1}{\lambda^5 \;\; (e^{c_2/(\lambda\, T)} - 1)}$$

# TEB Calibration Illustration





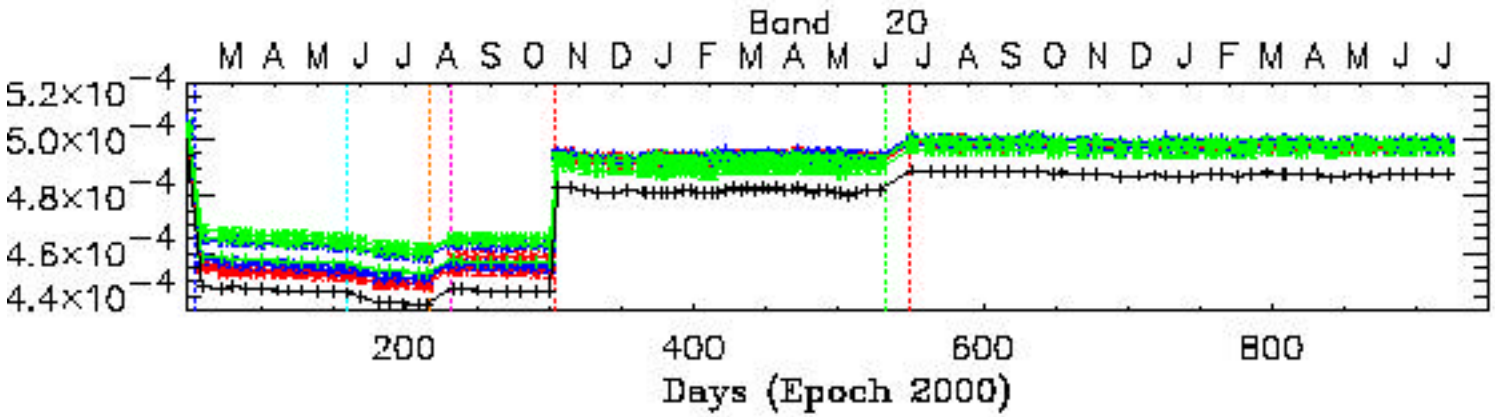

*BB from 270-317K provides a0 and a2*

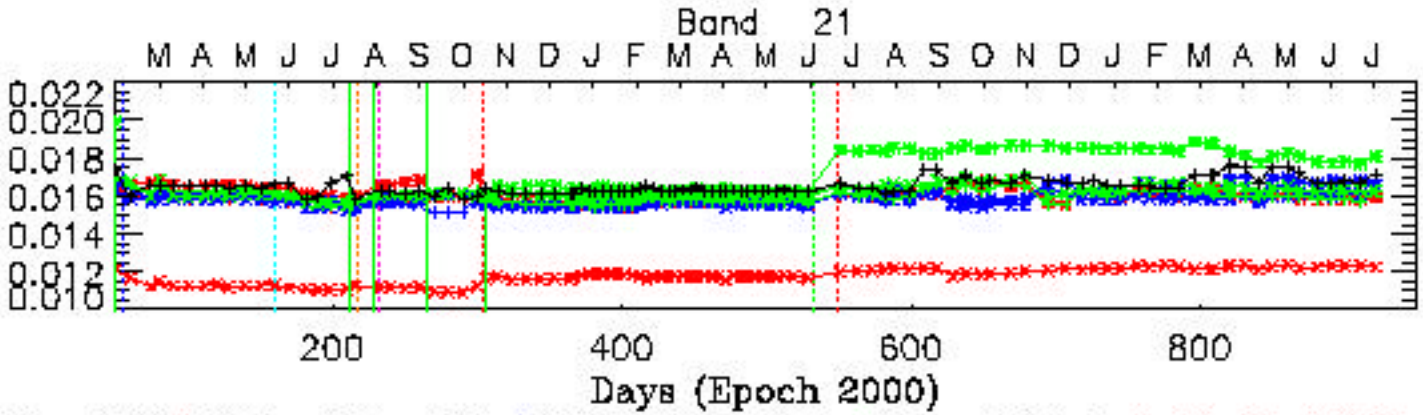



*BB at T_BB provides b1 on a scan by scan basis*

# TEB Response Trending

## MODIS PFM TEB b1 Trending



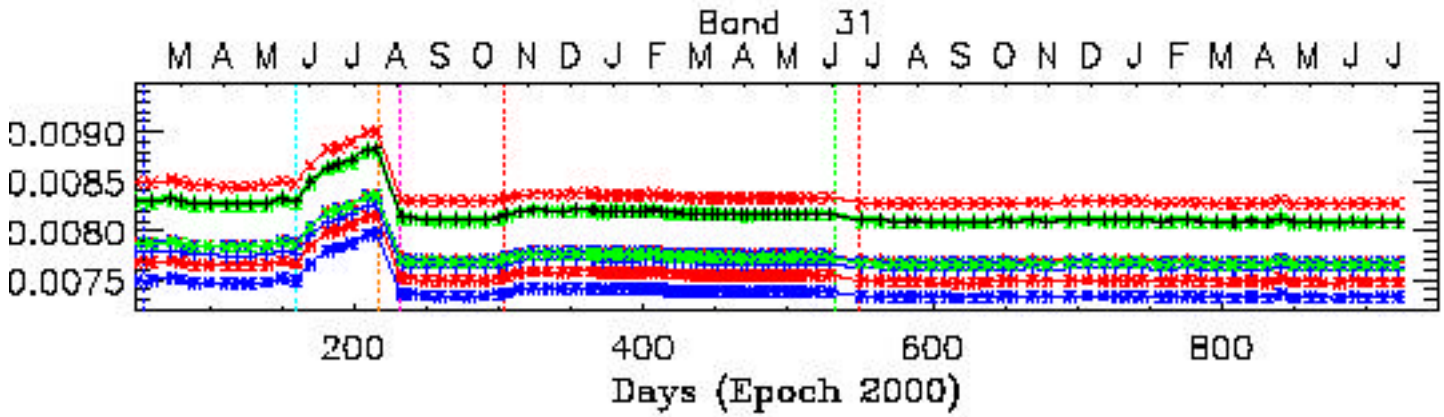

Ch1: x Ch2: + Ch3: * Ch4: x Ch5: + Ch6: * Ch7: x Ch8: + Ch9: * Ch10: + (in Product Order)

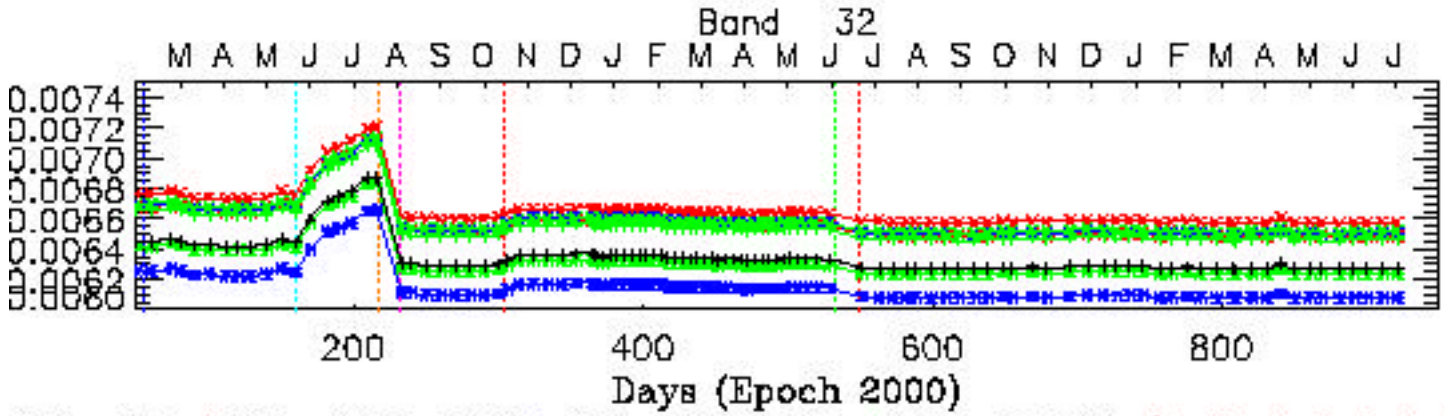
Day 55 – Nadir Door Open
Day 160 – CFPA Lost Control
Day 218 – Formatter Anomaly
Day 232 – Back in Science Mode
Day 304, 549 – switch to B side, A side
Day 532 – PS2 anomaly

(T_bb @ 290 K)

# TEB Response Trending

## MODIS PFM TEB b1 Trending

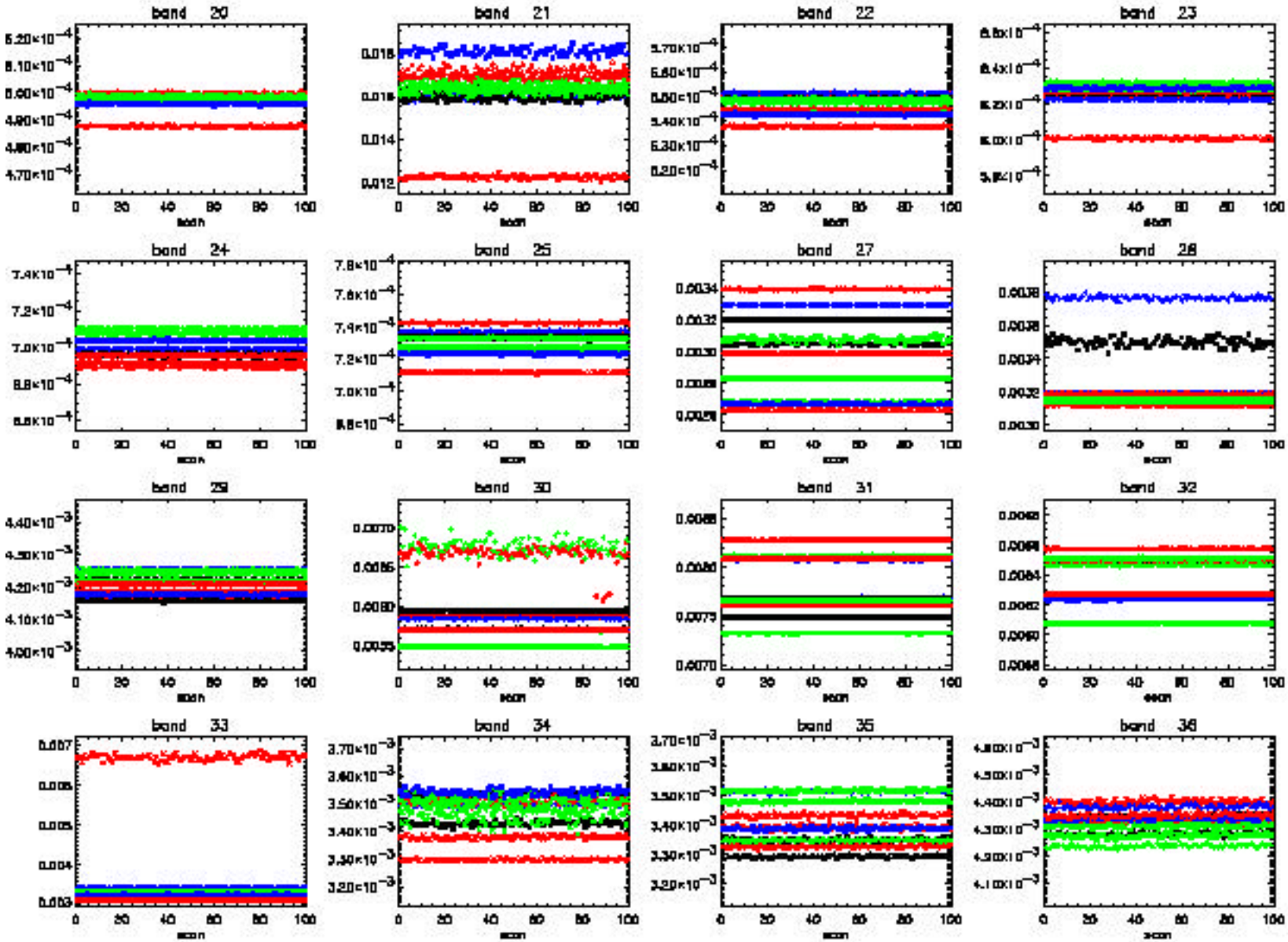



Ch1: x Ch2: + Ch3: * Ch4: x Ch5: + Ch6: * Ch7: x Ch8: + Ch9: * Ch10: + (in Product Order)

Day 55 – Nadir Door Open
Day 160 – CFPA Lost Control
Day 218 – Formatter Anomaly
Day 232 – Back in Science Mode (T_bb @ 290 K)
Day 304, 549 – switch to B side, A side
Day 532 – PS2 anomaly

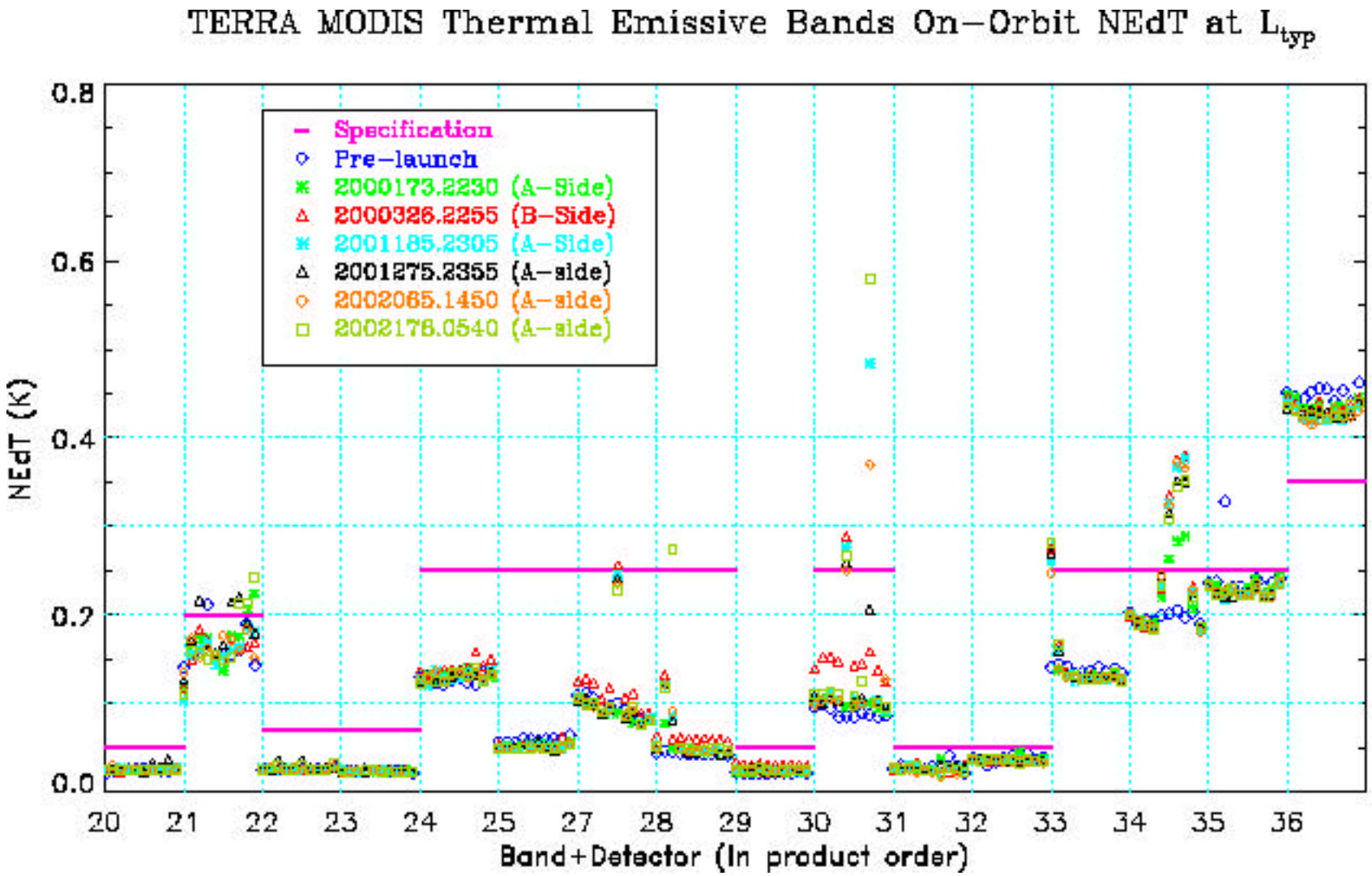
MODIS PFM On-orbit TEB b1 vs Scan (MS1) (Detector in Product order)




Ch1:Red x Ch2:Blu + Ch3:Blk ∘ Ch4:Blk Δ Ch5:Red ◇ Ch6:Grn □ Ch7:Grn x Ch8:Grn + Ch9:Blu ∘ Ch10:Red Δ

Data collected time: P2002190.1340 $T_{-00}$: from 289.963 to 290.012 ltwk/Vdat = 79/190

# TEB NEdT


TERRA MODIS Thermal Emissive Bands On-Orbit NEdT at $L_{typ}$
Specification
Pre-launch
2000173.2230 (A-Side)
2000326.2255 (B-Side)
2001185.2305 (A-Side)
2001275.2355 (A-side)
2002065.1450 (A-side)
2002178.0540 (A-side)
NEdT (K)
0.0
0.2
0.4
0.6
0.8
20
21
22
23
24
25
27
28
29
30
31
32
33
34
35
36
Band+Detector (In product order)

# Detector Noise History

## Terra MODIS TEB ***NEdT*** (*K*) Changes History

| Day/Year | Band | 27 | 28 | | 30 | 33 | | 34 | | 36 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Specification | 0.25 | 0.25 | | 0.25 | 0.25 | | 0.25 | | 0.35 |
| | Detector | 6 | 3 | 5 | 8 | 1 | 6 | 7 | 8 | 1 to 10 |
| 055/2000 | Nadir door open | 0.09 | 0.06 | 0.11 | 0.11 | 0.28 | 0.26 | 0.27 | 0.29 | 0.43 |
| 232/2000 | Back from FPA recycle | 0.24 | 0.05 | 0.31 | 0.11 | 0.27 | 0.33 | 0.37 | 0.38 | 0.42 |
| 030/2001 | - | 0.27 | 0.06 | 0.29 | 0.3 | 0.25 | 0.33 | 0.37 | 0.37 | 0.43 |
| 087/2002 | Back from safe mode | 0.24 | 0.32 | 0.26 | 0.64 | 0.25 | 0.29 | 0.32 | 0.33 | 0.38 |

| | |
|---|---|
| | In Spec |
| | out of Spec (close) |
| | Out of Spec |

# RSB Calibration with SD/SDSM

*Reflectance*

$$\rho_{EV} \cos(\theta_{EV}) = m_1 \; dn^*_{EV} \; d^2_{Earth-Sun}$$

*Scaling factor m1 from SD*

$$m_1 = \frac{plBRF_{SD} \cos(\theta_{SD})}{< dn^*_{SD} > d^2_{Earth-Sun}} \Gamma_{SD} \; \Delta_{SD}$$

*SD (BRF) degradation from SDSM*

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$

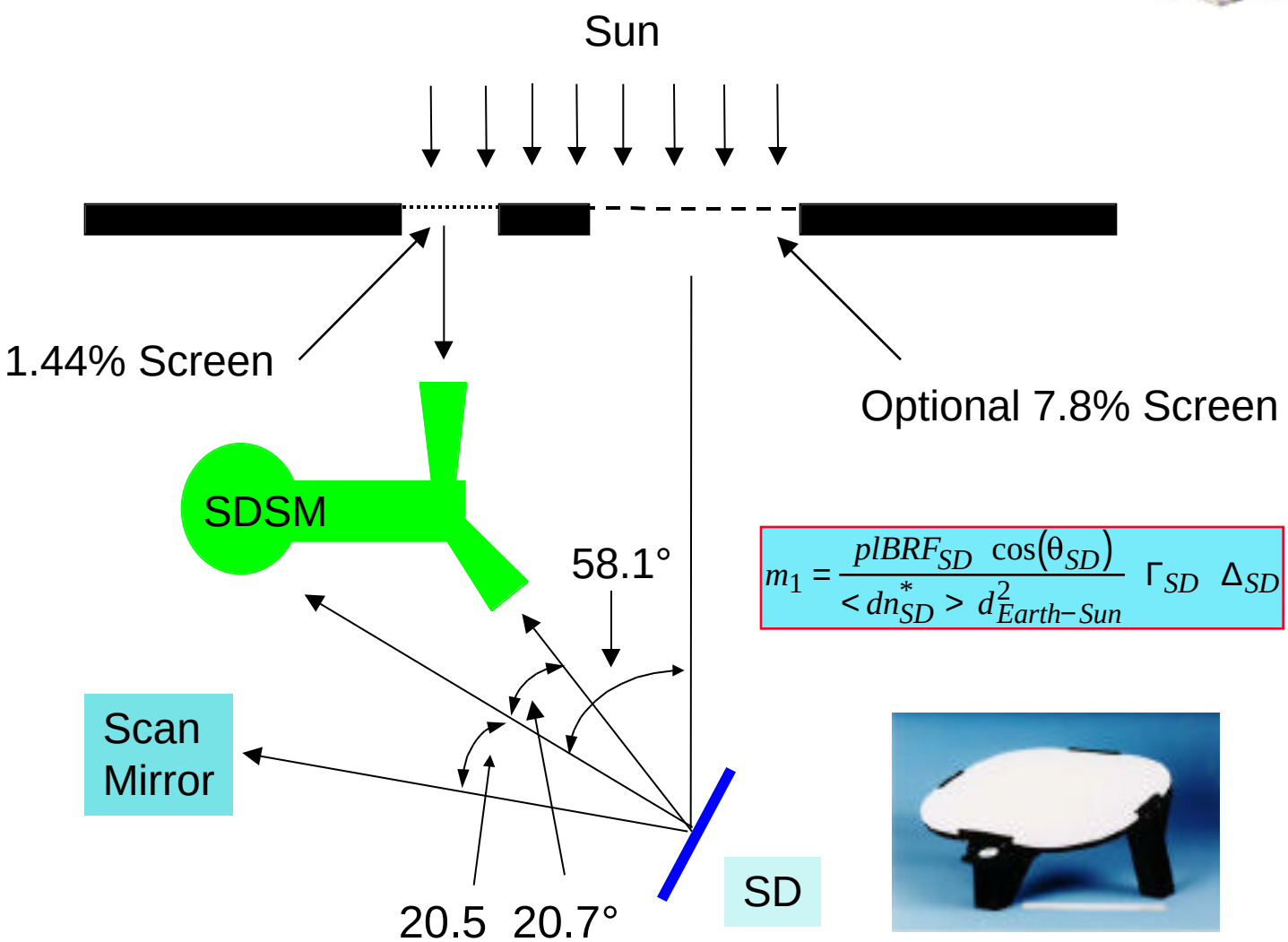
**$plBRF_{SD}$:** pre-launch SD BRF
**$\Gamma_{SD}$:** SD screen vignetting function (1 for open mode)
**$dn^*_{SD, EV}$:** MODIS detector's "corrected" digital number
**$dc_{Sun, SD}$:** SDSM detector's digital count
**$d_{Earth-Sun}$:** Earth-Sun distance

*Radiance*

$$L_{EV} = \frac{m_1 \; E_{Sun} \; dn^*_{EV}}{\pi}$$

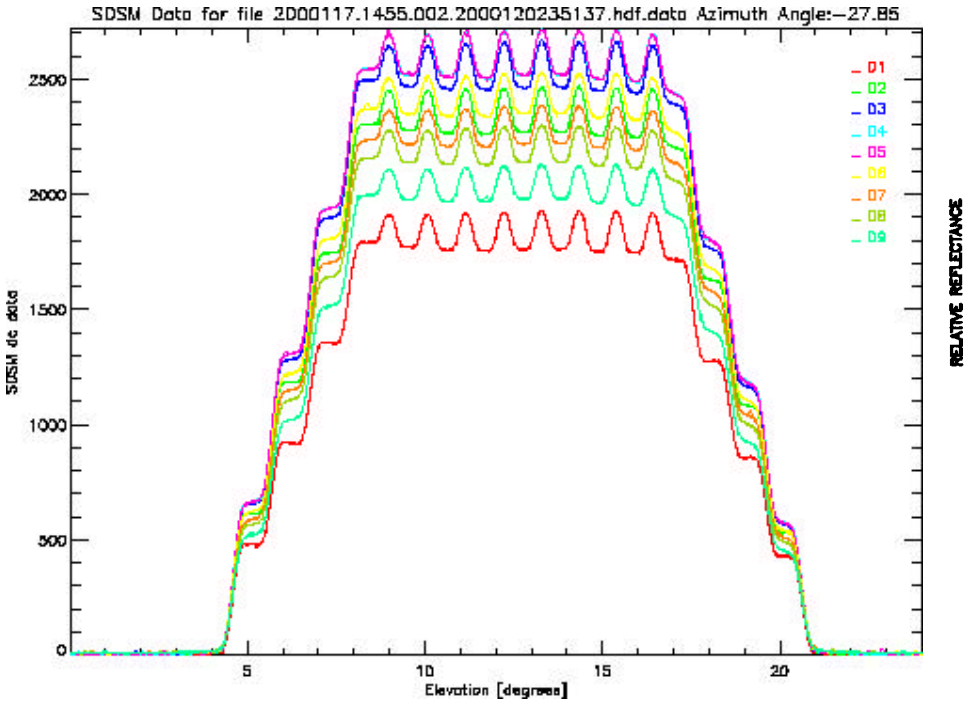
# RSB Calibration Schematic

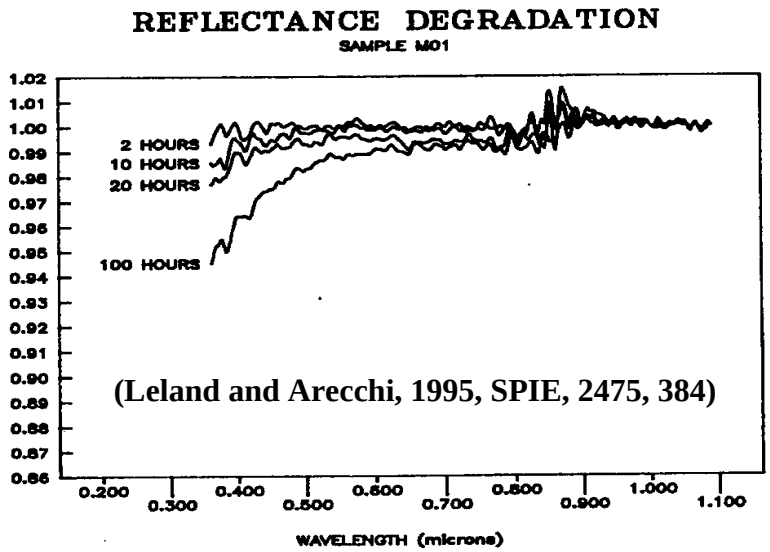
$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{\overline{dc_{Sun}}}$$




$$m_1 = \frac{plBRF_{SD} \ \cos(\theta_{SD})}{< dn^*_{SD} > \ d^2_{Earth-Sun}} \ \Gamma_{SD} \ \Delta_{SD}$$

# SD Degradation Approach



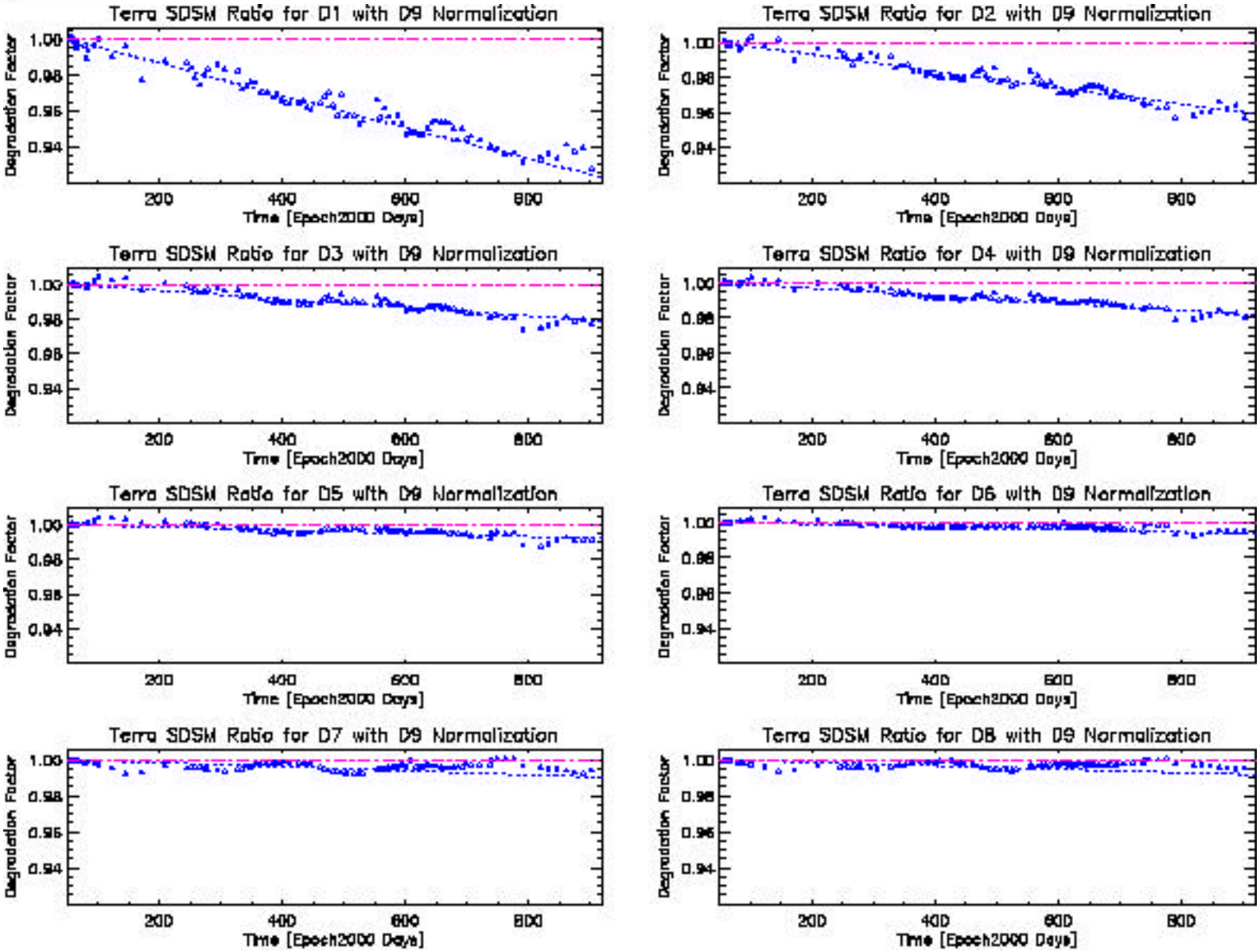




**Normalize to SDSM D9 at 936nm**

$$\Delta_{SD} = \frac{\overline{dc_{SD}}}{dc_{Sun}} \Rightarrow \left[ \frac{dc^{D1}_{SD_view} / dc^{D1}_{Sun_view}}{dc^{D9}_{SD_view} / dc^{D9}_{Sun_view}} \right]$$

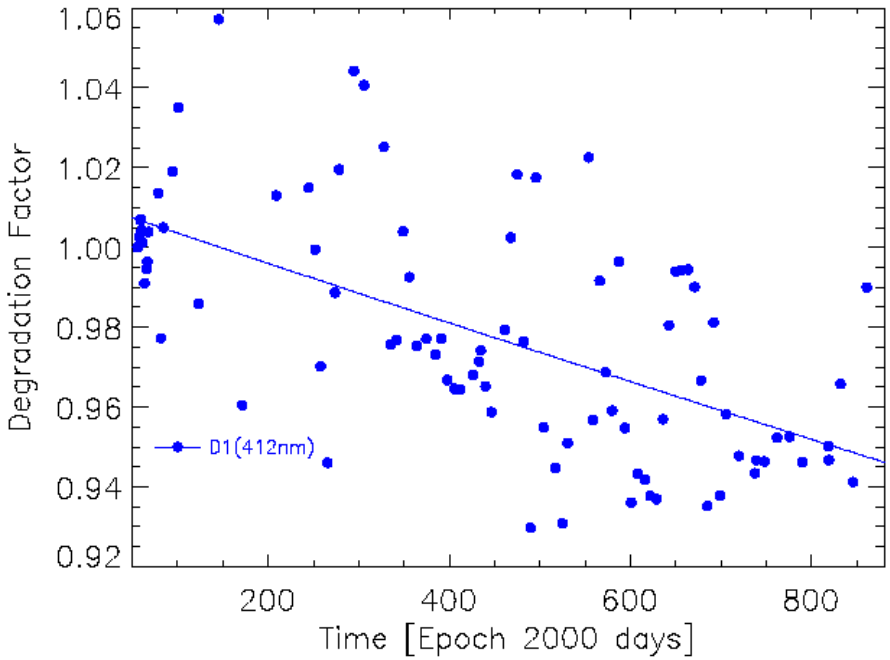
| SDSM detectors | Center wavelength (nm) |
|---|---|
| D1 | 411.97 |
| D2 | 465.69 |
| D3 | 529.74 |
| D4 | 553.75 |
| D5 | 646.14 |
| D6 | 746.62 |
| D7 | 856.49 |
| D8 | 904.29 |
| D9 | 936.23 |

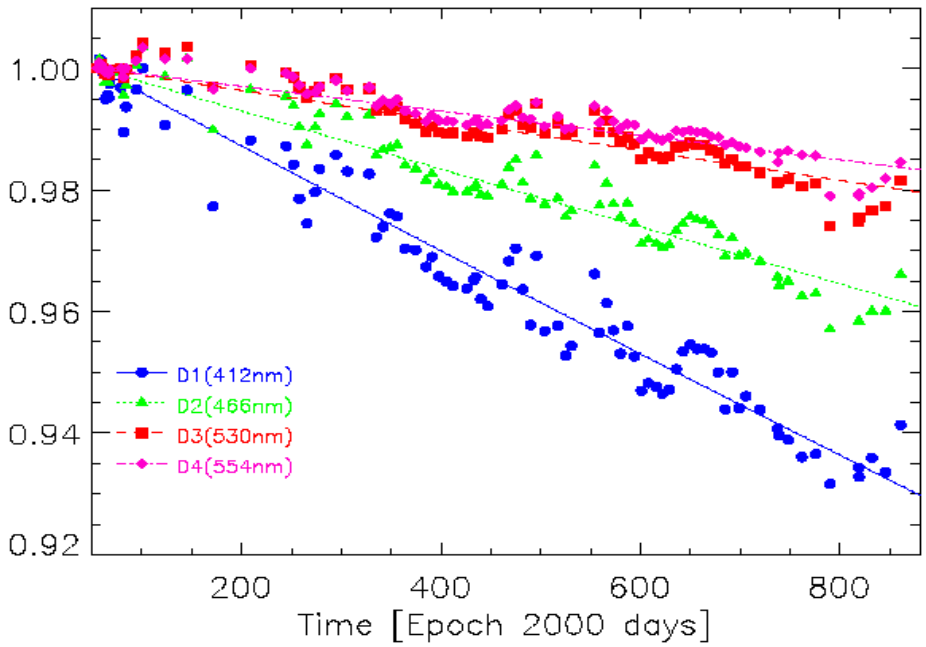
# SD Degradation Results



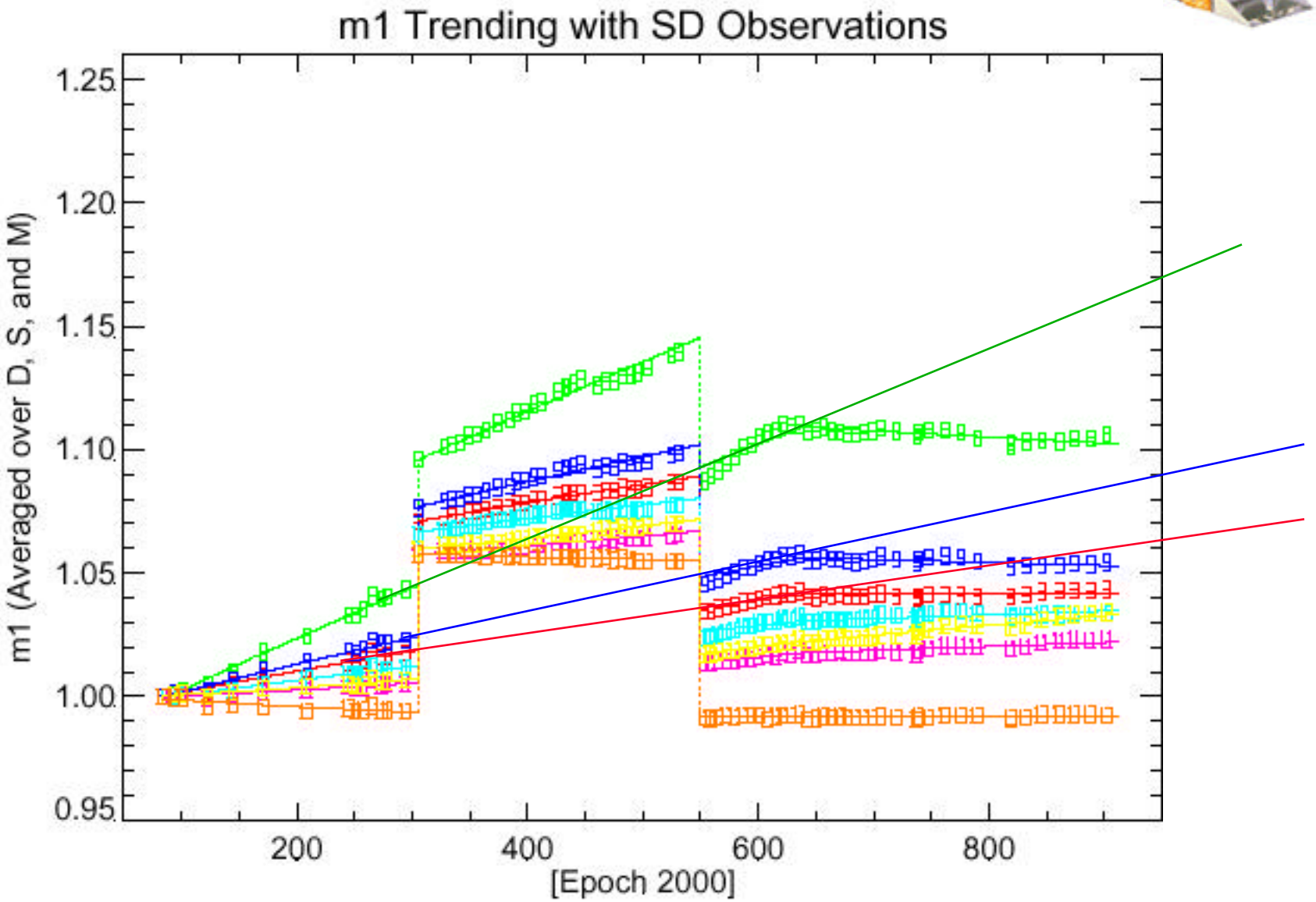
# SD Degradation Results

**Comparison of Original (left) and Alternative Approach (right)**

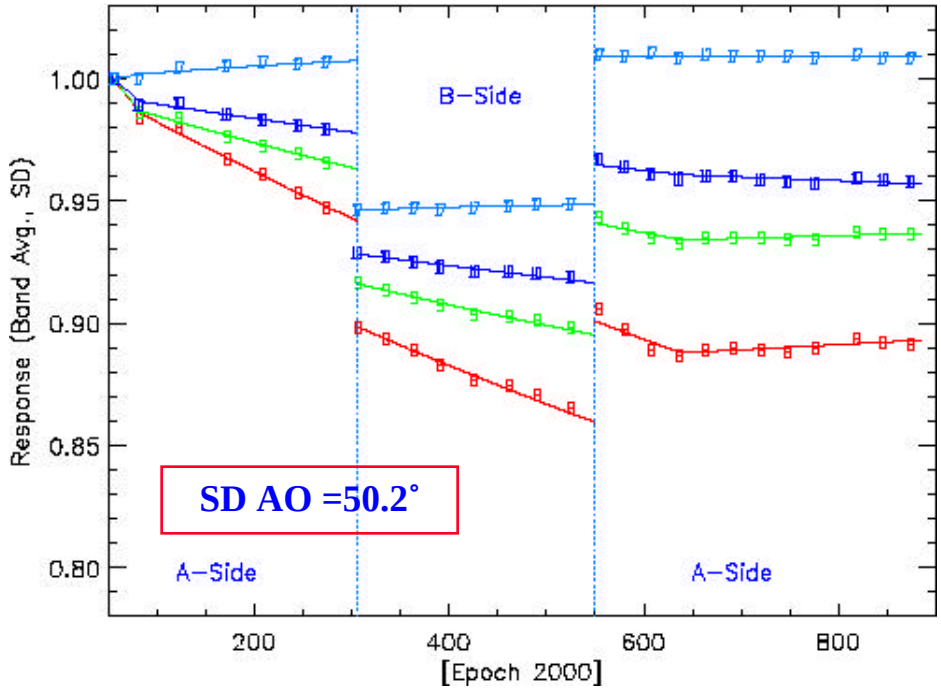


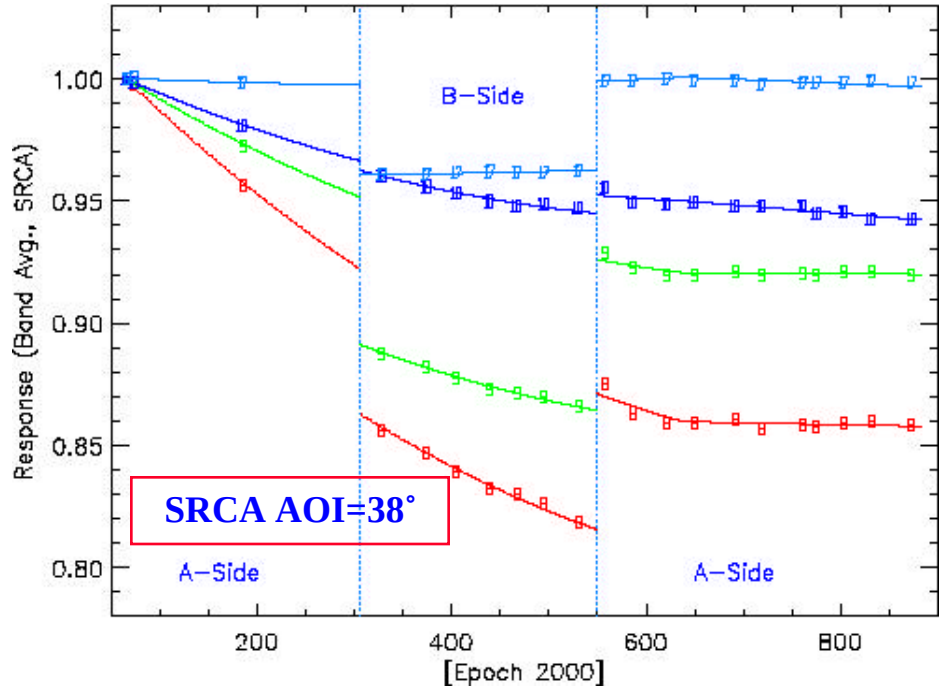



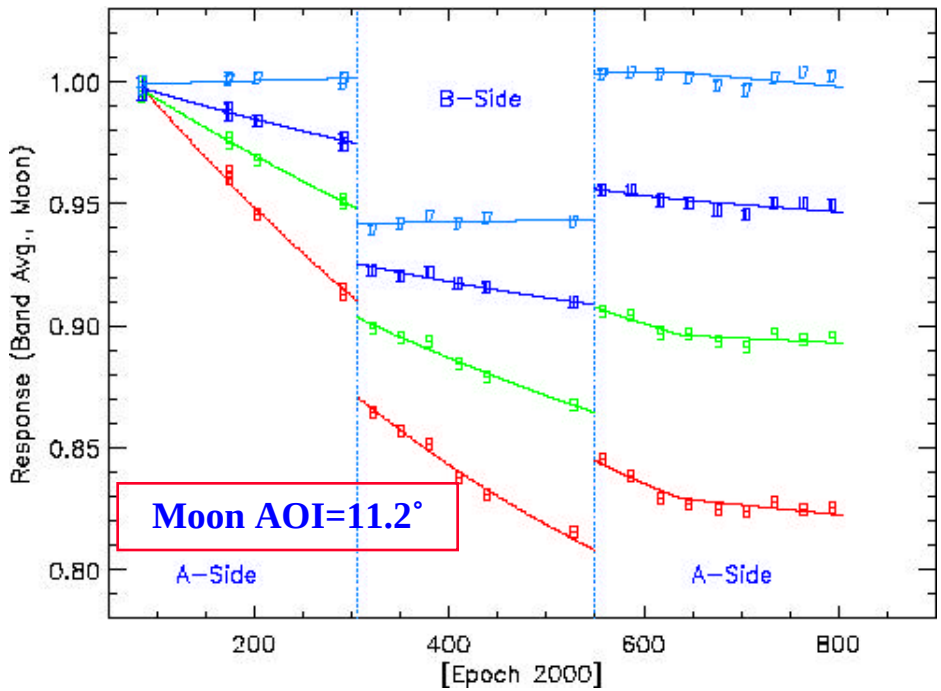
# RSB Response Trending Results




*PFM_24*

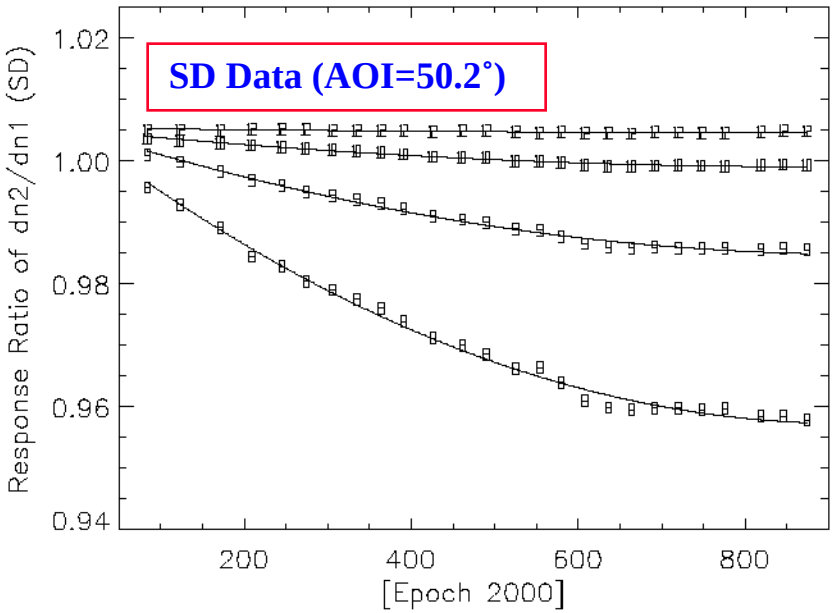


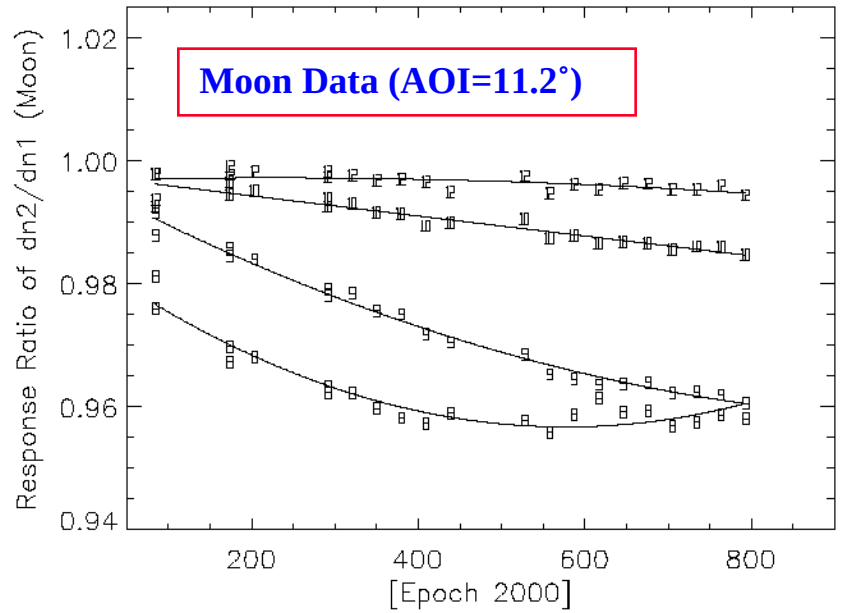



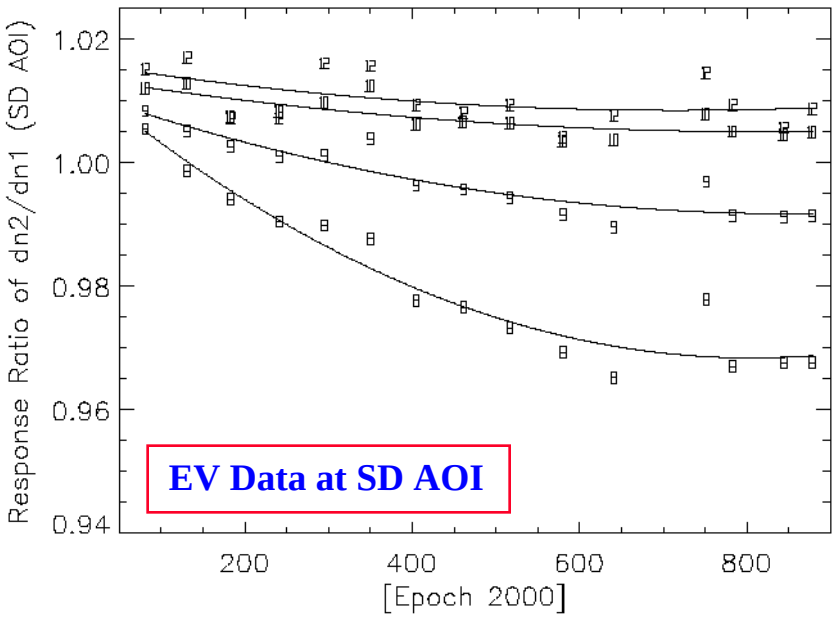



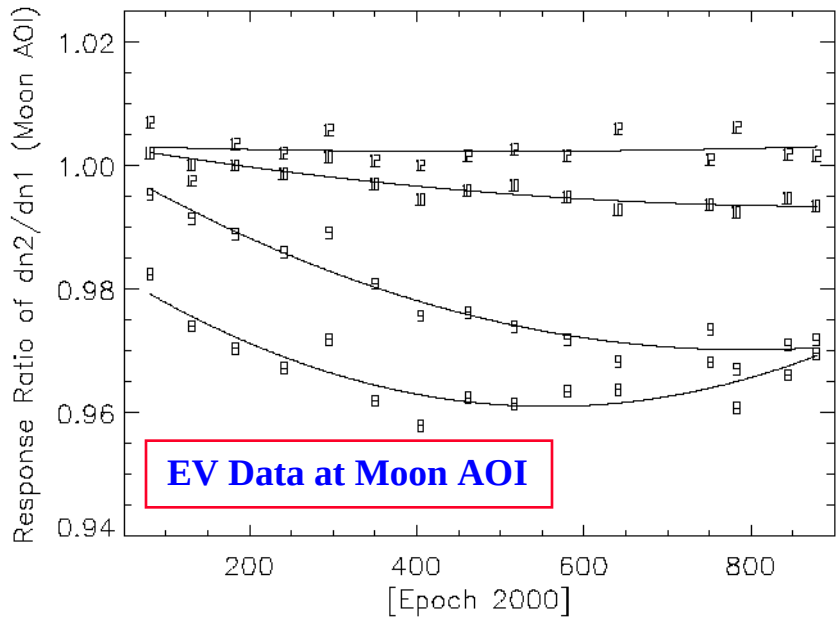

*$1/m_1$ (gain) trending at different AOI*

**Optics (scan mirror) degradation at different angle of incidence (AOI)**



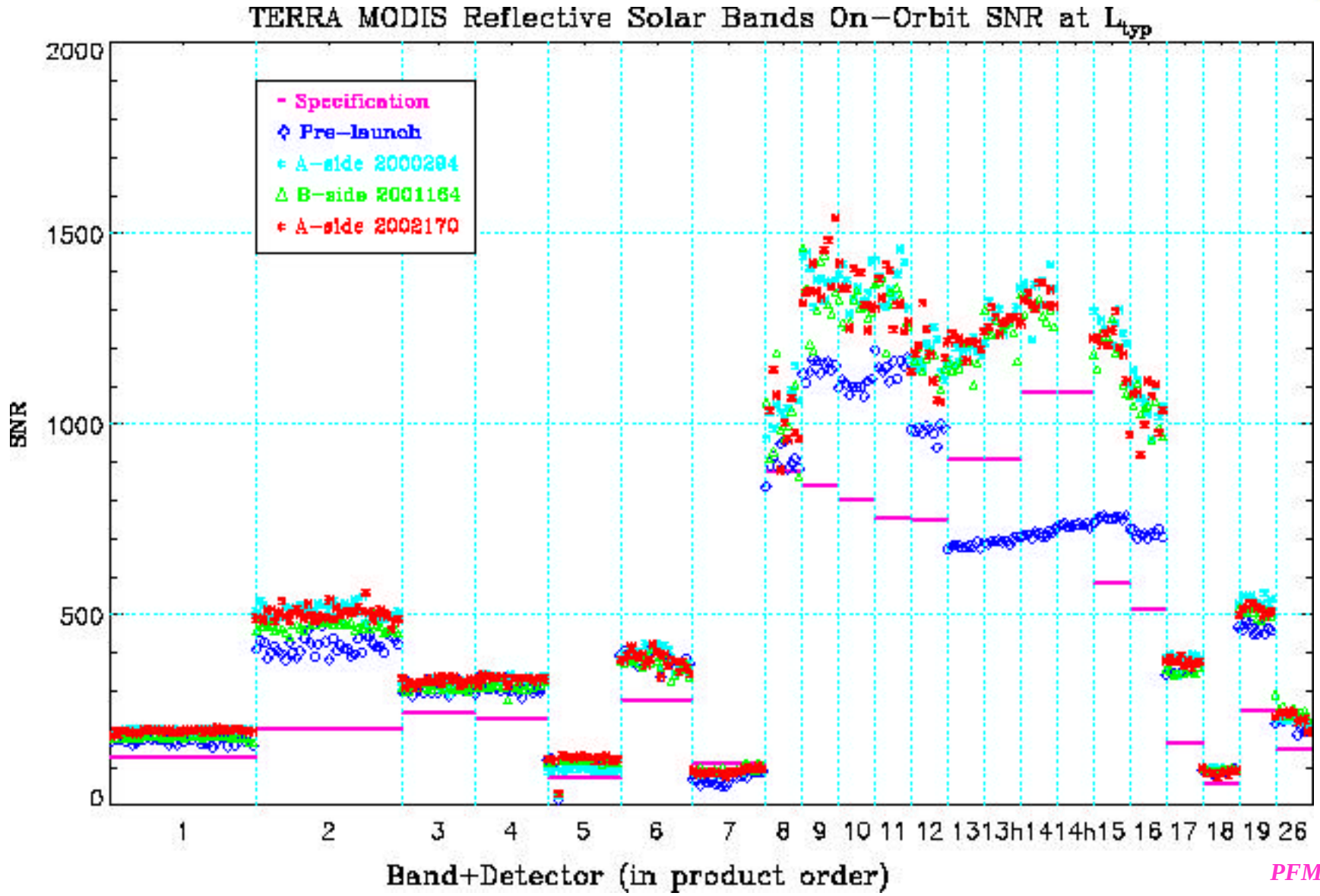




**Degradation is AOI MS dependent** → **Time and AOI dependent LUTs**

# RSB SNR



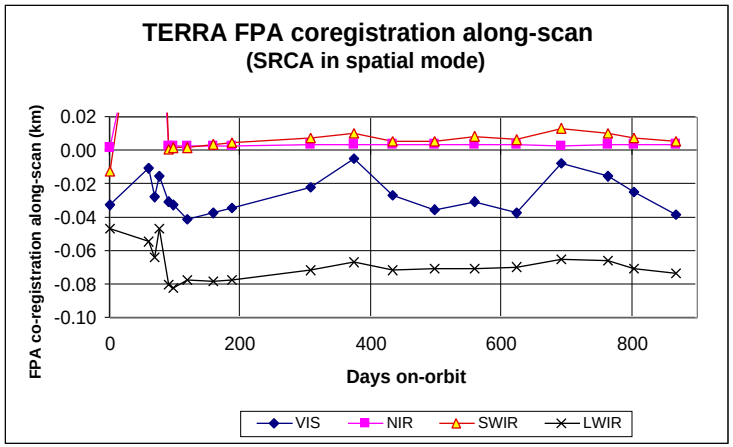

*PFM_27*

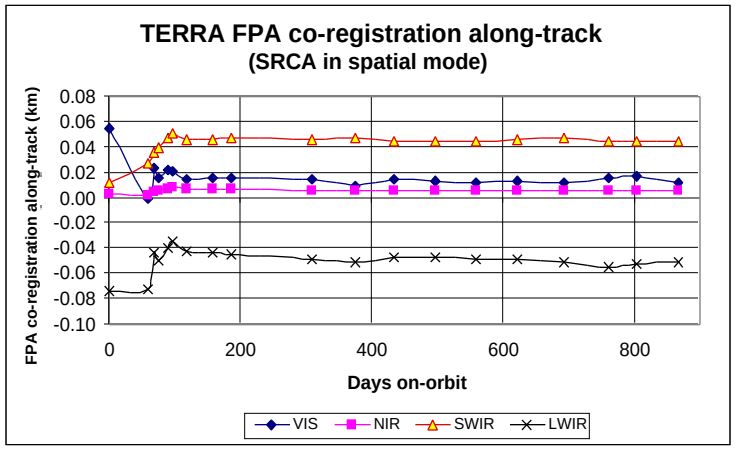
# Spatial and Spectral Characterization with SRCA

- Spatial characterization - stable
  - BBR
  - FPA shift
- Spectral characterization - stable
  - Center wavelength
- Radiometric mode used for response trending to support RSB calibration

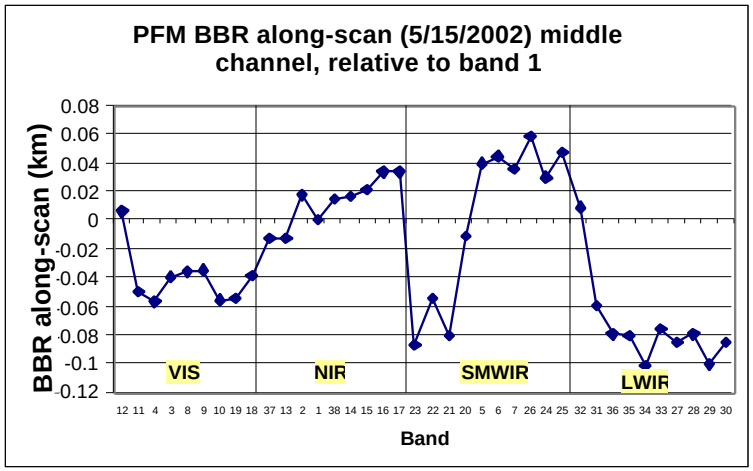
# Spatial Characterization

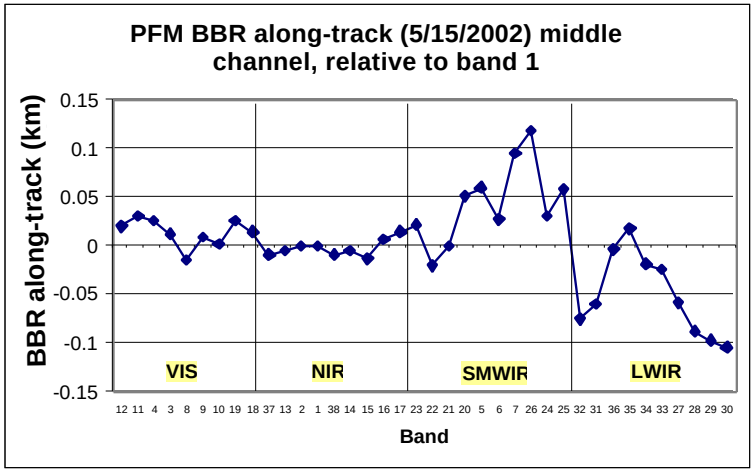
## ♦ On-orbit FPA co-registration tracking ( relative to band 1)



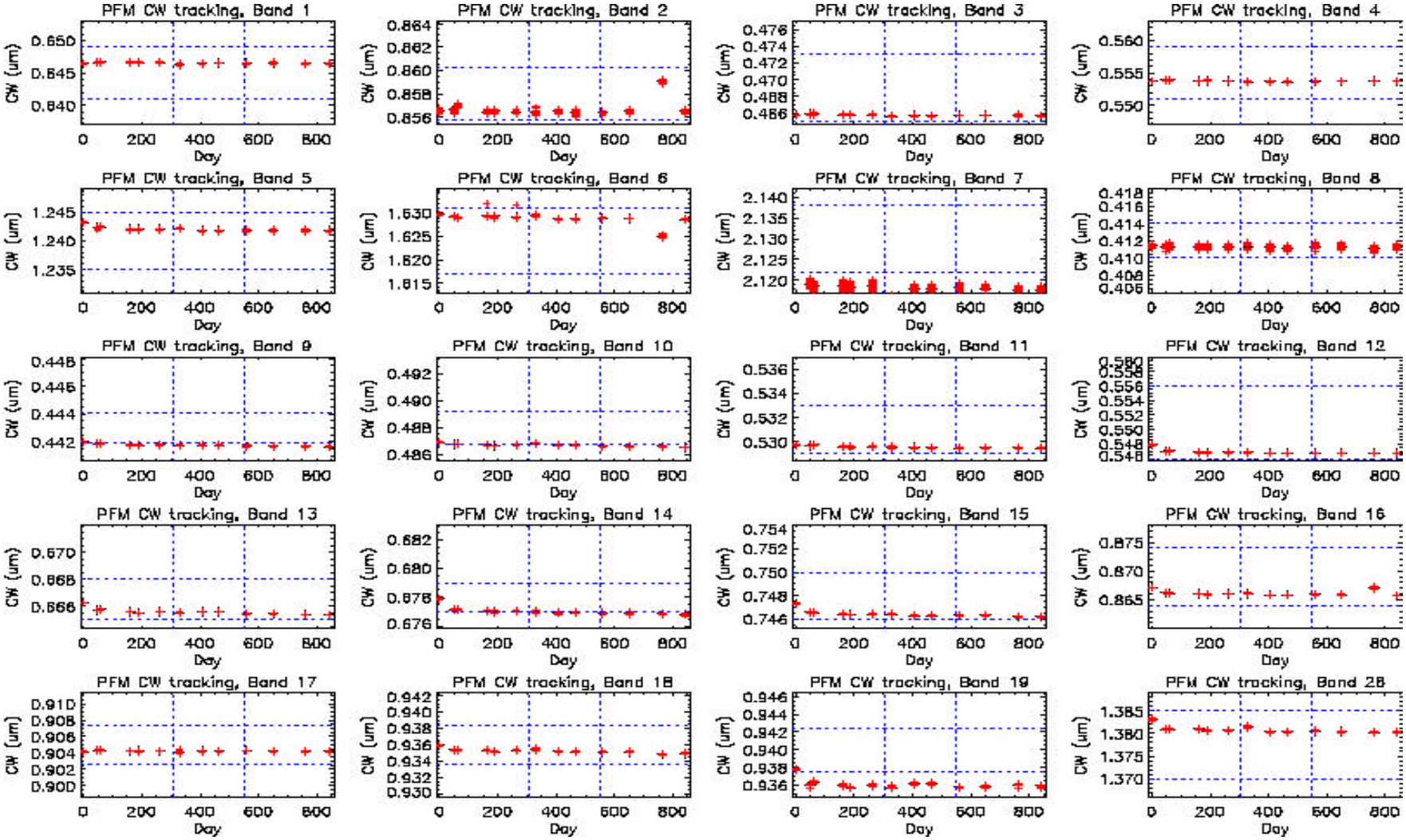




## ♦ Current BBR ( relative to band 1)



# Spectral Characterization

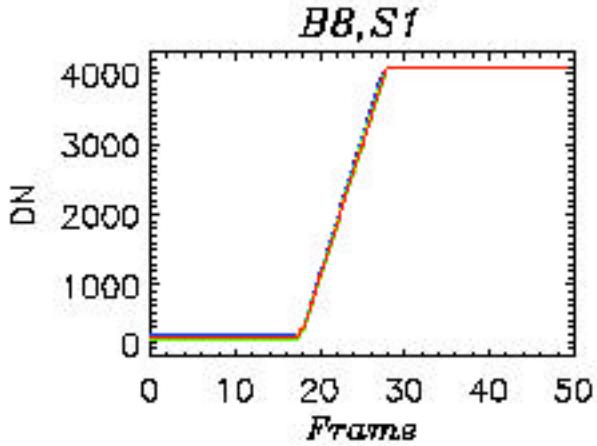


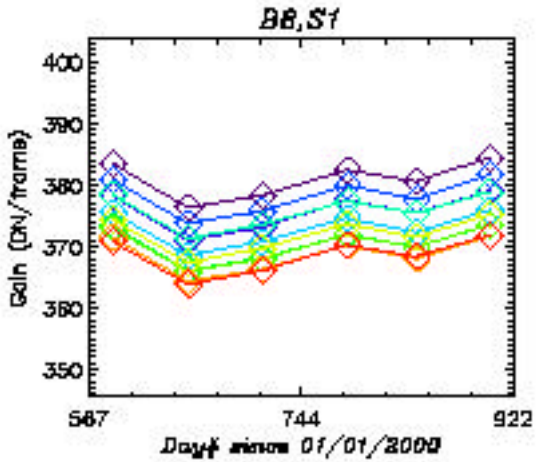

**Two horizontal lines are the specification limits. Two vertical lines are where side changes.**

# Spectral Characterization (Table)

| PFM Center wavelength (nm) | | | | |
|---|---|---|---|---|
| Band | Specification | Δλ | SpMA | Orbit_109-02 |
| 1 | 645 | ±4 | 646.3 | 646.5 |
| 2 | 858 | ±2.2 | 856.4 | 856.6 |
| 3 | 469 | ±4 | 465.7 | 465.7 |
| 4 | 555 | ±4 | 553.7 | 553.7 |
| 5 | 1240 | ±5 | 1242.1 | 1242.0 |
| 6 | 1640 | ±7 | 1629.4 | 1628.5 |
| 7 | 2130 | ±8 | 2115 | 2117.6 |
| 8 | 412 | ±2 | 411.9 | 411.3 |
| 9 | 443 | ±1.1 | 442.2 | 441.6 |
| 10 | 488 | ±1.2 | 487 | 486.6 |
| 11 | 531 | ±2 | 529.8 | 529.4 |
| 12 | 551 | ±5 | 546.9 | 546.7 |
| 13 | 667 | -2, +1 | 665.7 | 665.4 |
| 14 | 678 | ±1 | 676.9 | 676.8 |
| 15 | 748 | ±2 | 746.6 | 746.2 |
| 16 | 869 | ±5 | 866.4 | 865.8 |
| 17 | 905 | ±2.3 | 904.2 | 904.2 |
| 18 | 936 | ±2.3 | 935.7 | 934.9 |
| 19 | 940 | ±2.4 | 936.3 | 935.9 |
| 26 | 1375 | ±6 | 1382.2 | 1380.3 |

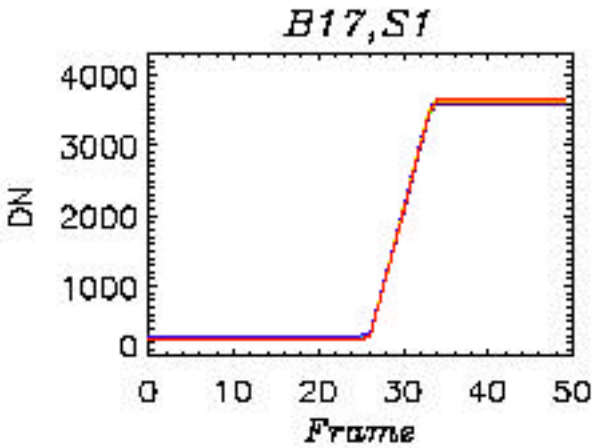
# ECAL Trending

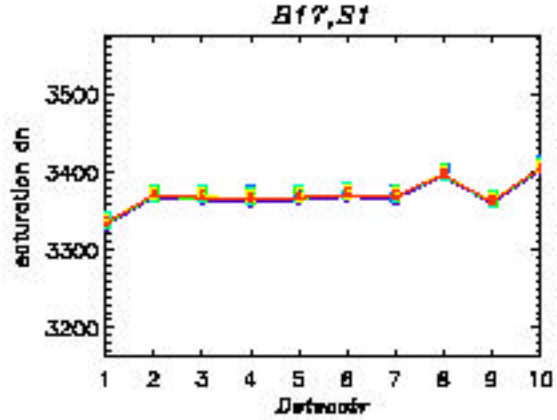



**Applications:**

**Electronic gain trending**




**Electronic gain saturation (dn_sat)**

# Current and Future Work

- Support ST and Public on General Instrument Calibration and Characterization Information
  - RSB, TEB, Spatial, and Spectral
- Maintain L1B and Update LUTs
  - SD and scan mirror degradation
  - Tracking RVS variation in RSB and TEB
  - Algorithm improvement
  - L1B code maintenance
- Support Instrument Flight Operation for MODIS and On-orbit Activities
- Prepare Change to B-side Formatter (TBD)

# Useful Sites

**MCST Web**
***http://www.mcst.ssai.biz/***
**Instrument Operations Team (Daily and Weekly Reports)**
***http://www.mcst.ssai.biz/IOT/***
**L1B Product Information and Change History**
***http://www.mcst.ssai.biz/product.html***
**MCST Contacts**
***http://www.mcst.ssai.biz/mcststaff.html***

**MODIS PFM RSR**
***ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/PFM_L1B_LUT_4-30-99/***
**MODIS FM1 RSR**
***ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/FM1_RSR_LUT_07-10-01/***

**MCST - Solar Spectral Irradiance Data Sets**
***ftp://ftp.mcst.ssai.biz/pub/permanent/MCST/Solar_Irradiance/***