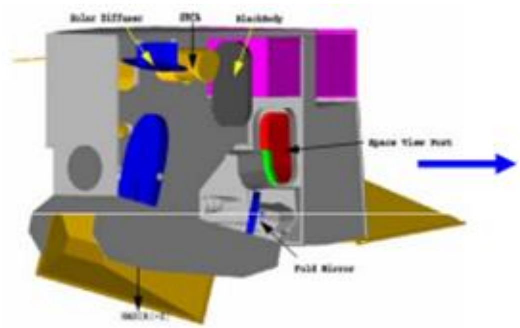
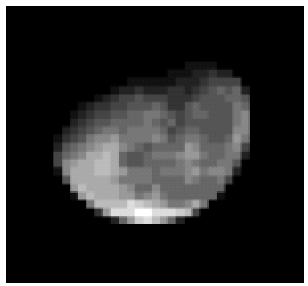
MODIS and VIIRS Lunar Calibration

MODIS Lunar Calibration Methodology

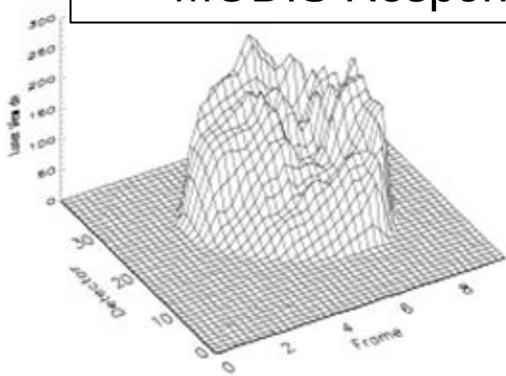
MODIS



Moon



MODIS Response



Near-monthly calibration
Phase angles between 55°- 56°

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

$$m_1^{moon} = \frac{f_{vg}}{< dn^*_{moon} >}$$

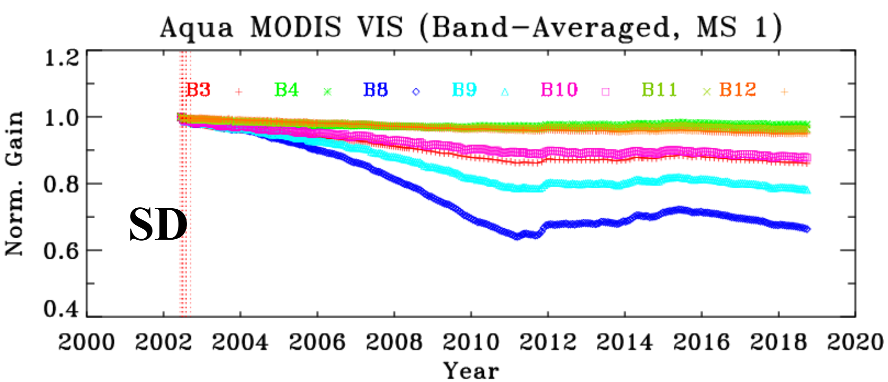
Bands 13-16 (saturated)

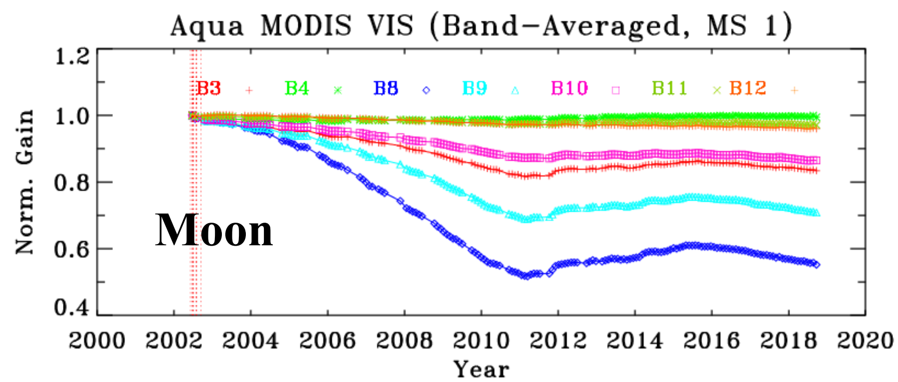
$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

View geometry correction

$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

Results: MODIS Lunar Calibration

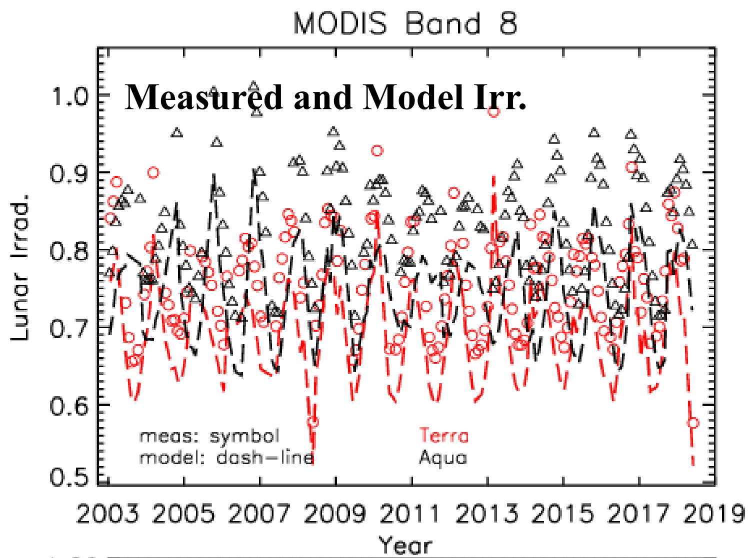


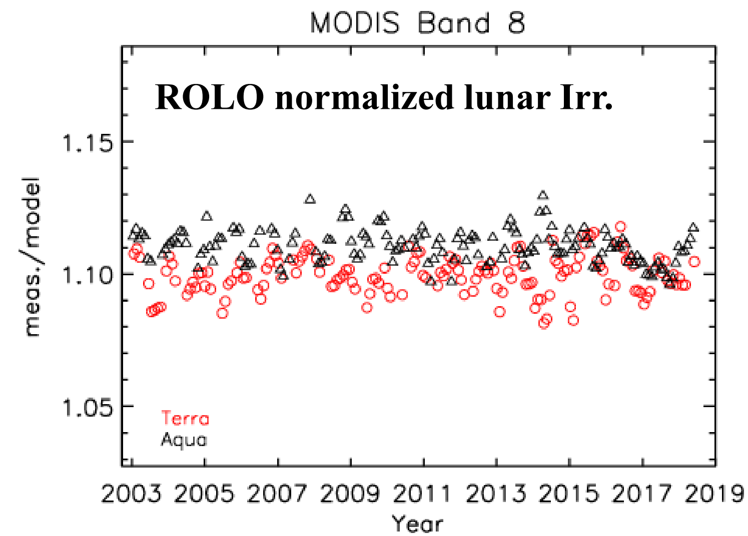


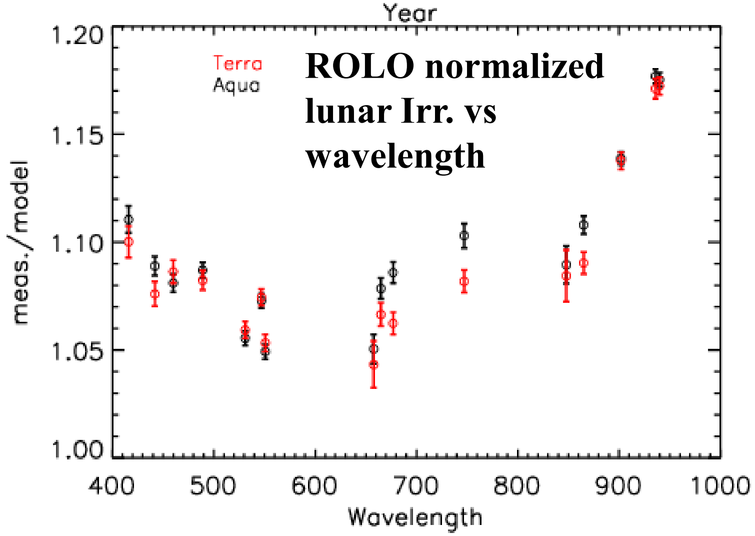
- SD and Lunar Gain for the MODIS VIS bands used in the derivation of the on-orbit RVS
  - Detector-differences from lunar measurements used in the detector-dependent RVS calculations
- Comparisons with the ROLO model to validate the long-term calibration consistency of the two instruments and also inter-compare with other instruments (such as VIIRS)

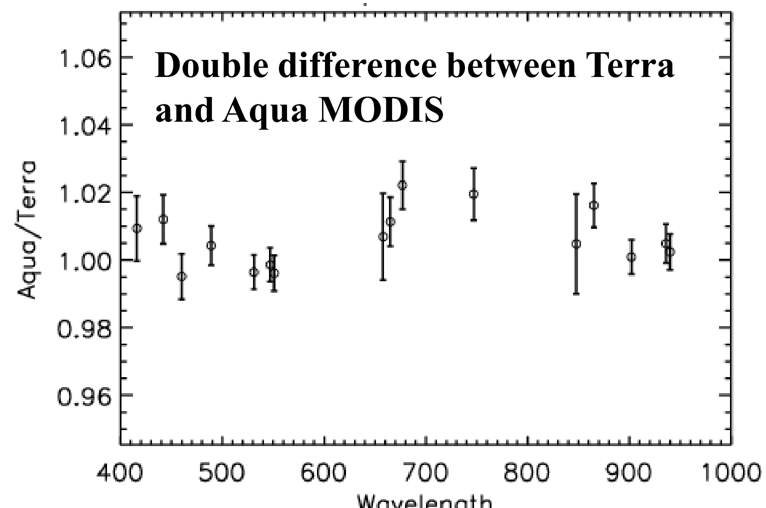
Sun, J.-Q., X. Xiong, W. L. Barnes, and B. Guenther, "MODIS Reflective Solar Bands On-Orbit Lunar Calibration", IEEE Transactions on Geoscience and Remote Sensing, vol. 45(7), 2383-2393, 2007.

Results: MODIS Lunar Calibration



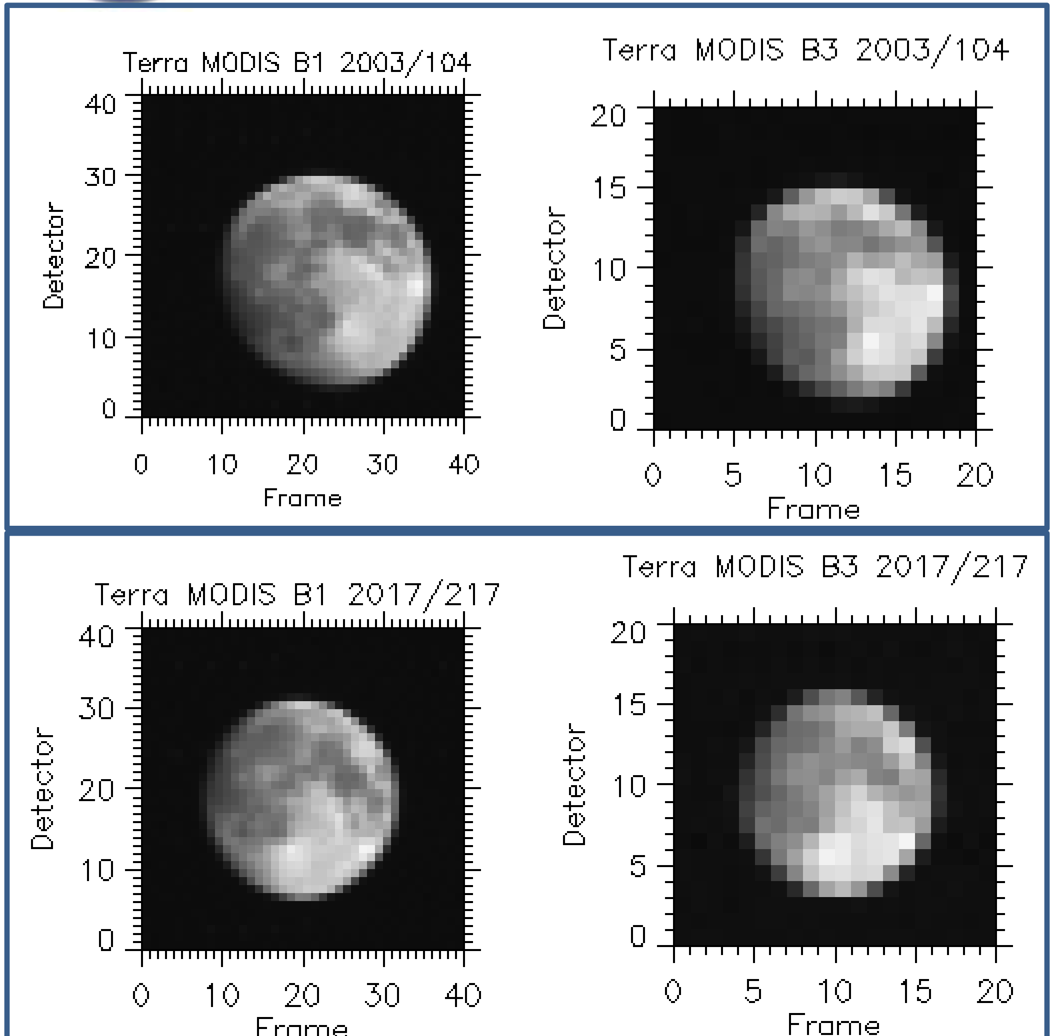


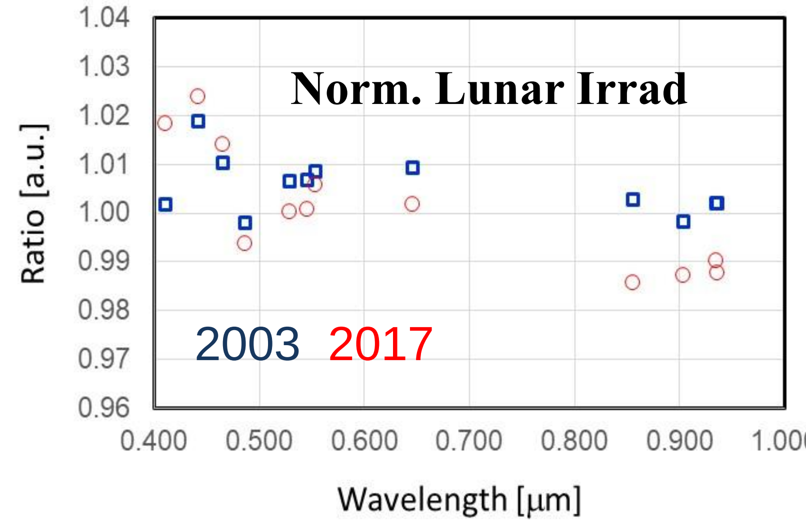




Xiong, X, J. Sun and W. Barnes, "Intercomparison of On-Orbit Calibration Consistency Between Terra and Aqua MODIS Reflective Solar Bands Using the Moon," IEEE Geoscience and Remote Sensing Letters, vol. 5(4), pp. 778-782, 2008.

Results: MODIS Lunar Calibration





Normalized Lunar Irradiance from the 2003 and 2017 Deep Space Calibration (DSC) provide a validation for the on-orbit RVS performance at nadir

Xiong, X., A. Wu, A. Angal, K. Chiang, and J. Butler, "MODIS and VIIRS on-orbit calibration and characterization using observations from spacecraft pitch maneuvers", Proc. SPIE, Earth Observing Systems XXIII, vol. 10764, pp. 107640V, 2018.

VIIRS Lunar Calibration Methodology

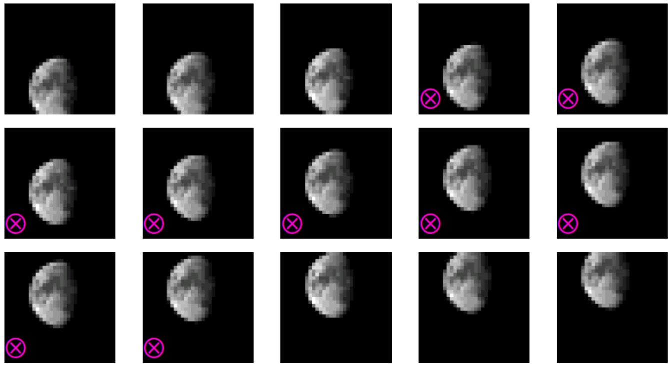
- Current lunar calibration methodologies are mainly developed for MODIS and extended to VIIRS with adaptation.
- The Moon and SD are viewed at the same AOI (60.2º) for RTA HAM.
- The lunar F-factor is defined similarly to SD F-factor.

$$F_{MOON} = \frac{I_{ROLO}}{I_{MOON,PL}}$$

- I_{ROLO}: the USGS ROLO model predicted lunar irradiance. VCST provides input photometric parameters and the VIIRS detector (prelaunch and RTA degradation modulated) RSRs.

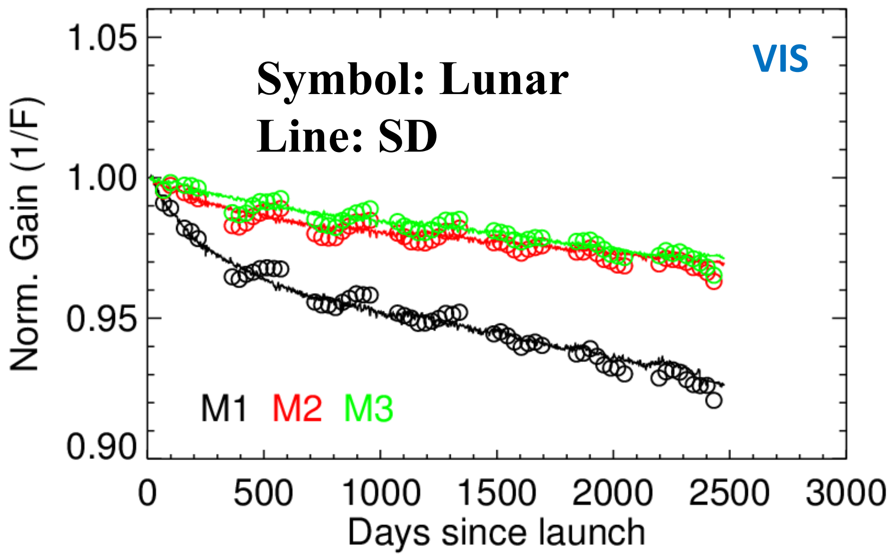
- $I_{MOON,PL}$: the lunar irradiance of individual pixels retrieved with the pre-launch gain coefficient c_0, c_1 and c_2.

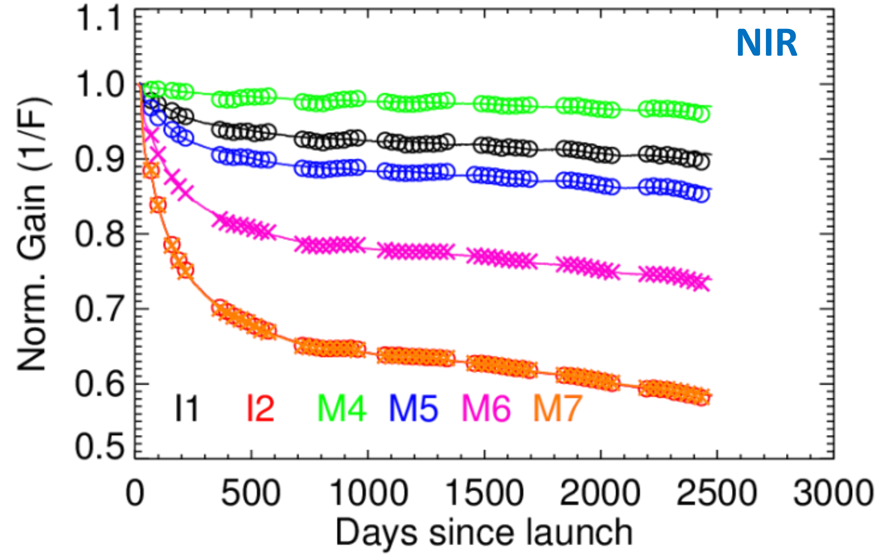
- The $I_{MOON,PL}$ summation is performed over samples and detectors for those center scans (marked in the plot) with “complete” lunar image captured

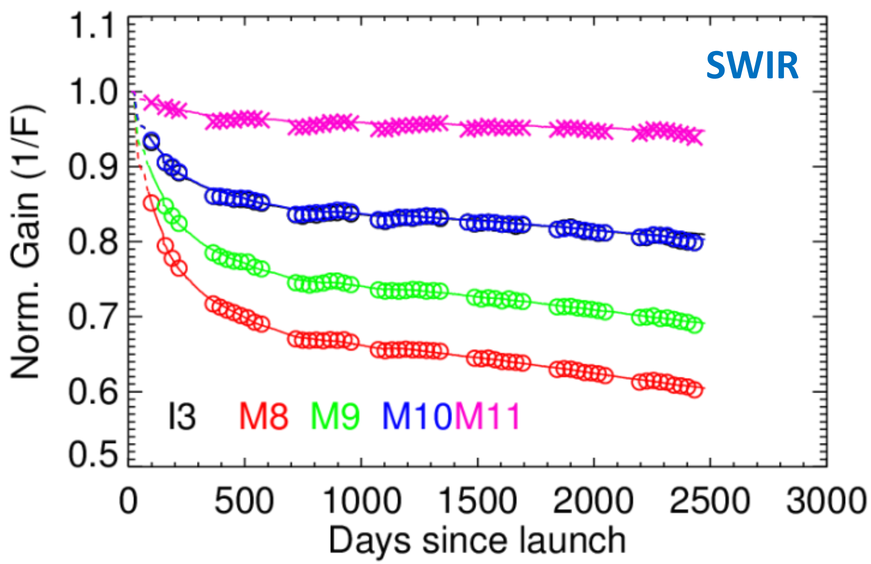


Xiong, X., J. Sun, J. Fulbright, Z. Wang, and J. Butler, “Lunar Calibration and Performance for S-NPP VIIRS Reflective Solar Bands”, IEEE Transactions on Geoscience and Remote Sensing, vol. 54, issue 2, pp. 1052-1061, 2016.

Results from SNPP Lunar Calibration







Lunar Data used to correct the H-factors (SD degradation from SDSM)

Xiong, X., J. Butler, K. Chiang, B. Efremova, J. Fulbright, N. Lei, J. McIntire, H. Oudrari, Z. Wang, A. Wu, "Assessment of S-NPP VIIRS On-Orbit Radiometric Calibration and Performance", Remote Sens., vol. 8, issue 2-84, 2016.

Calibration Inter-comparison of SNPP VIIRS and A-MODIS

- Preliminary results from the Calibration inter-comparisons of SNPP VIIRS SDR (NASA C1.1) and Aqua MODIS L1B using lunar observations
- Double difference between VIIRS and MODIS using ROLO as a common transfer mechanism
- More work underway to improve the intercomparison approaches and comparison with desert-based results

Data: 2012-2017		VIIRS/A-MODIS		VIIRS/T-MODIS	
MODIS	VIIRS	Ratio	STD	Ratio	STD
8	M1	0.994	0.009	1.004	0.011
9	M2	0.972	0.007	0.983	0.009
10	M3	1.004	0.007	1.011	0.008
12	M4	1.000	0.007	0.999	0.007
1	I1	1.018	0.006	1.018	0.011
13	M5	1.015	0.006	1.027	0.007
15	M6	0.999	0.006	1.023	0.008
2	I2	1.009	0.005	1.009	0.009
16	M7	1.002	0.005	1.018	0.006

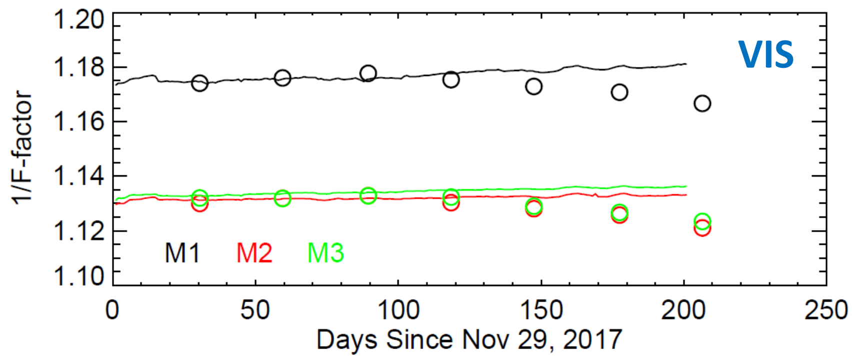
$$\frac{(I_{Meas\_Sensor\text{-}A} / I_{Model\_Sensor\text{-}A})}{(I_{Meas\_Sensor\text{-}B} / I_{Model\_Sensor\text{-}B})}$$

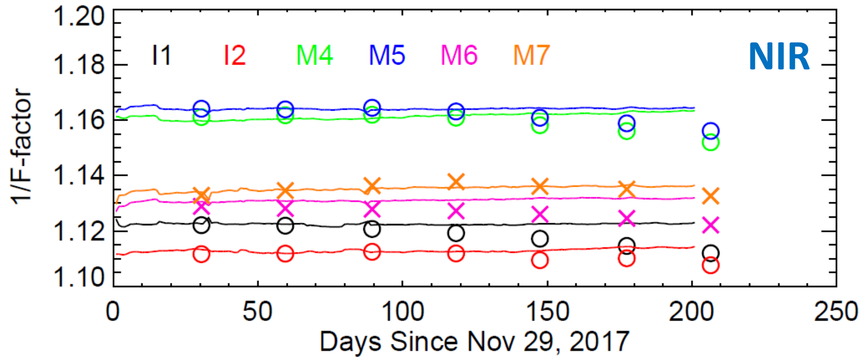
Xiong, X., J. Sun, Z. Wang, A. Angal, and J. Fulbright, "MODIS and VIIRS Reflective Solar Calibration Inter-Comparisons Using Lunar Observations", SPIE-2017 Earth Observing Systems Session

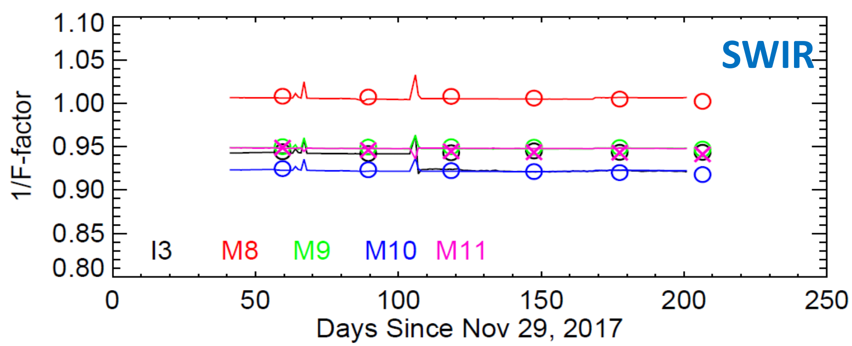
Special considerations for NOAA-20 VIIRS Lunar Calibration

- **Special Considerations**
  - The lunar image is located in the Agg-zone 1 (agg zone 3 for SNPP)
  - **DeltaC LUT**
    - All the results are reprocessed using the updated delta-C LUT (transformation of the matrix).
  - **I3 detector 29**
    - Non-functional detector in I3 impacts the band-averaged lunar irradiance and F-factor values derived.
    - Average of the neighboring detectors response to "fill" in the I3 band 29 response
  - **M7 saturation**
    - Unlike SNPP (that showed gain degradation), M7 shows saturation for large signal levels. For unsaturated pixels, a linear correlation between M7 and M5 is obtained to re-derive the results. Impacts less than 0.1%

Early Results from N20 Lunar Calibration





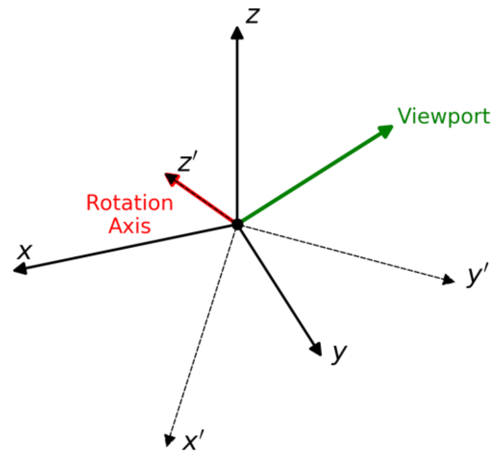


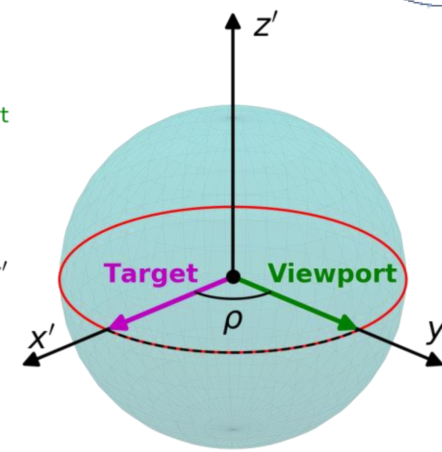
- Lunar F-factors normalized to the SD F to track the long-term comparison (symbols-moon, line-SD)
- Need a long-term time-series (at least a complete year of lunar measurements) to identify the effects due to libration.
- Overall, a stable trending of the gain is observed across all bands (no RTA-anomaly type behavior from SNPP observed here)

Xiong, X., A. Angal, J. Butler, H. Chen, K. Chiang, N. Lei, Y. Li, and K. Twedt, "Performance assessments and comparisons of S-NPP and NOAA-20 (JPSS-1) VIIRS on-orbit calibration", Proc. SPIE 10785, Sensors, Systems, and Next-Generation Satellites XXII, 1078514, 2018.

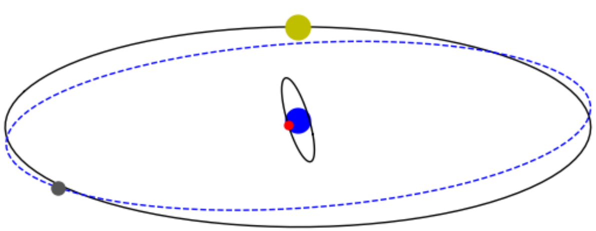
Scheduling Lunar Observations

- MCST has developed a lunar scheduling tool based on the SPICE toolkit's Geometry Finder
- Can find observations for an arbitrary rotation axis and arbitrary viewport
- Can find lunar, planetary, stellar and Earth-view observation times
- Can use simulated orbits of an arbitrary satellite

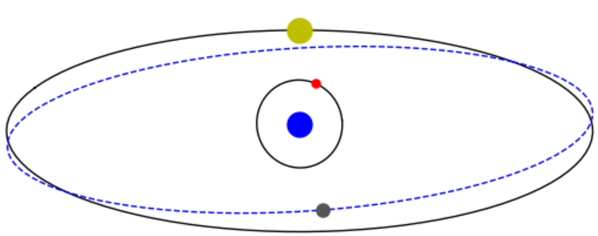




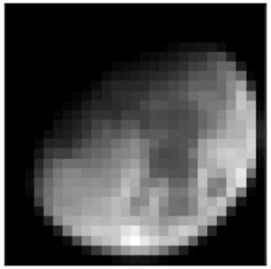
NPP (13:30)
-51° Phase



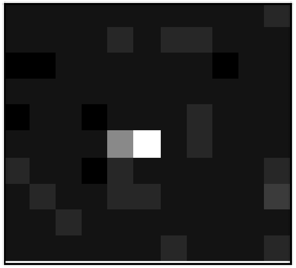
SIM (19:30)
+4° Phase



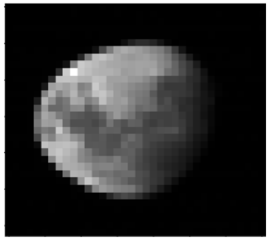
Aqua MODIS - Moon



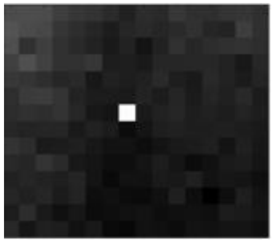
Terra MODIS - Jupiter



N20 VIIRS - Moon



SNPP VIIRS – Star (M, +6.0)



Stars seen in the DNB HGS

Lunar Roll Maneuvers

Instrument	*No. of Obs.	Phase Range	Roll Range	Timing Accuracy
Terra MODIS	183	55° to 56°	-20° to 0°	0.20 ± 0.44 s
Aqua MODIS	167	-55° to -56°	-20° to 0°	0.53 ± 0.48 s
SNPP VIIRS	59	-50.5° to -51.5°	-15° to 0°	-0.22 ± 0.56 s †
N20 VIIRS	7	-50.5° to -51.5°	-15° to 0°	0.81 ± 0.24 s †

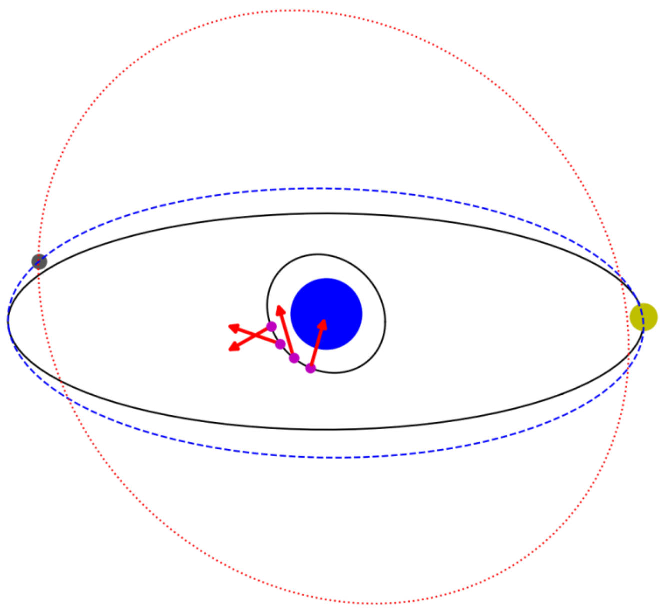
* As of October 18, 2018

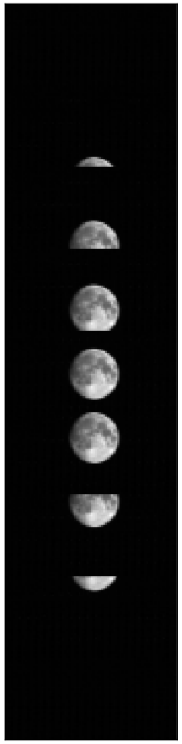
† SNPP and N20 are in a **geodetic** and not **geocentric** pointing configuration. Using geocentric pointing increases the standard deviation to greater than 2 seconds.

- There are also several hundred "unscheduled" lunar observations that occur without a maneuver.
- A manuscript on the new version of the scheduling tool is in production. The previous version of the tool is described here:
  - T. Wilson and X. Xiong, Proc. SPIE 10000, 1000011 (2016); DOI: 10.1117/12.2240648

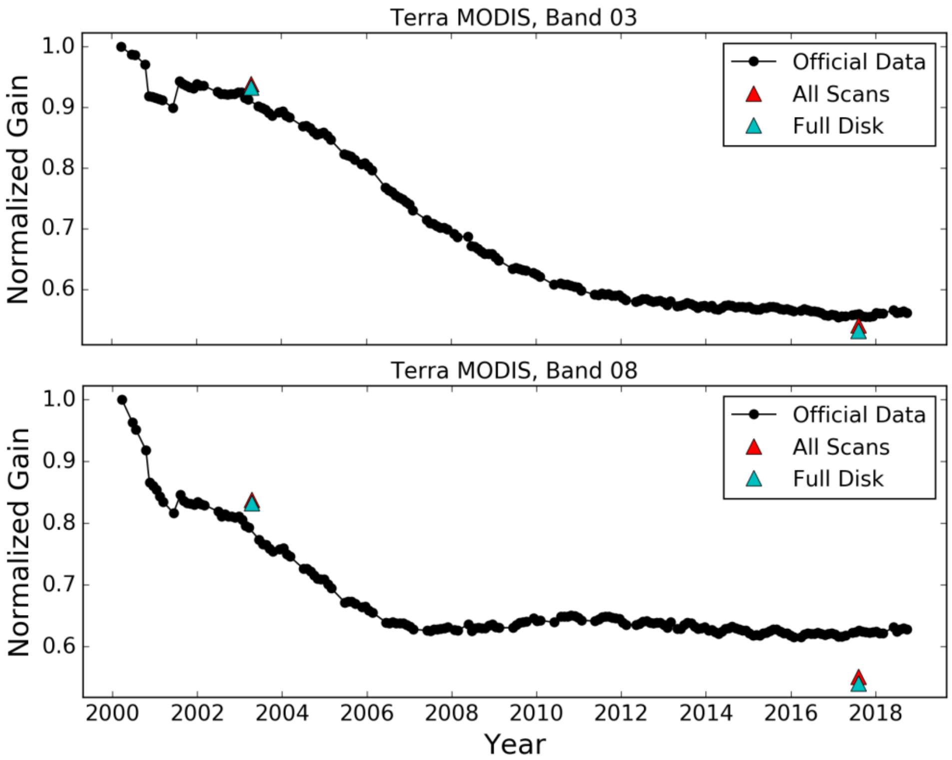
Pitch Maneuvers

- To date, Terra has performed 3 pitch maneuvers, SNPP and N20 have performed 1. Aqua has not performed a pitch maneuver on-orbit.
- SNPP and N20 performed pitch maneuvers during a new Moon, but Terra viewed the Moon at the nadir AOI at -27.7° and -20.4 ° phase angles for 2 of the maneuvers (2003, 2017).

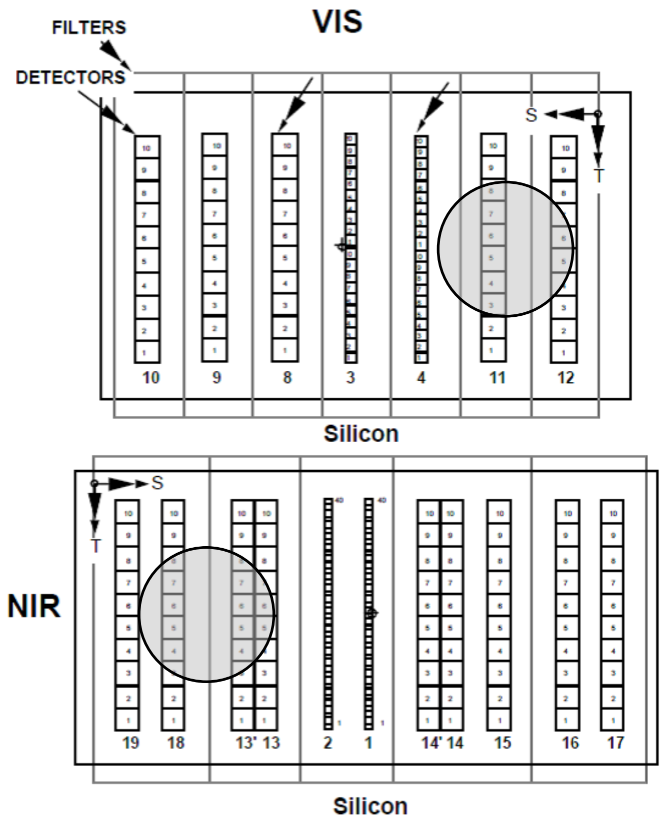


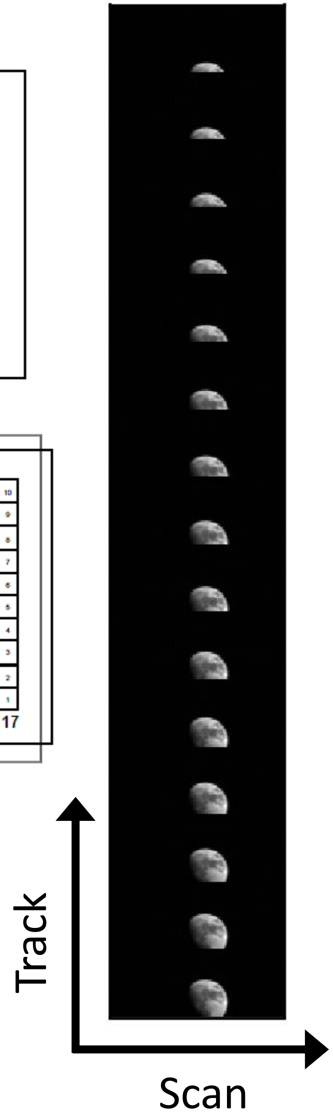


Terra Band 1, 2017



Lunar Spatial Characterization

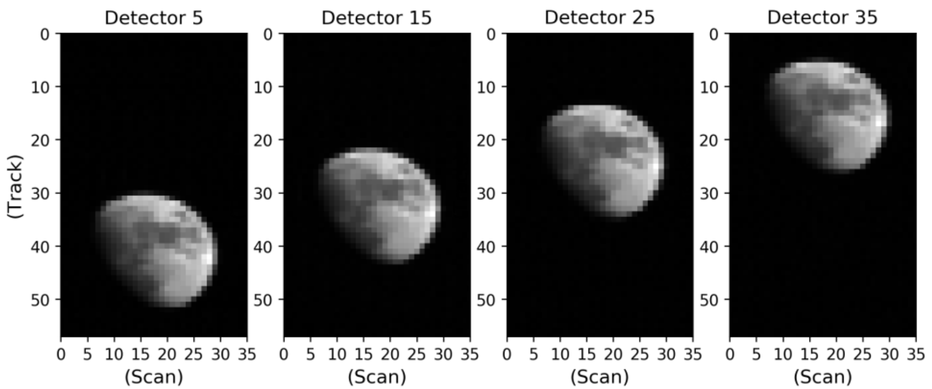




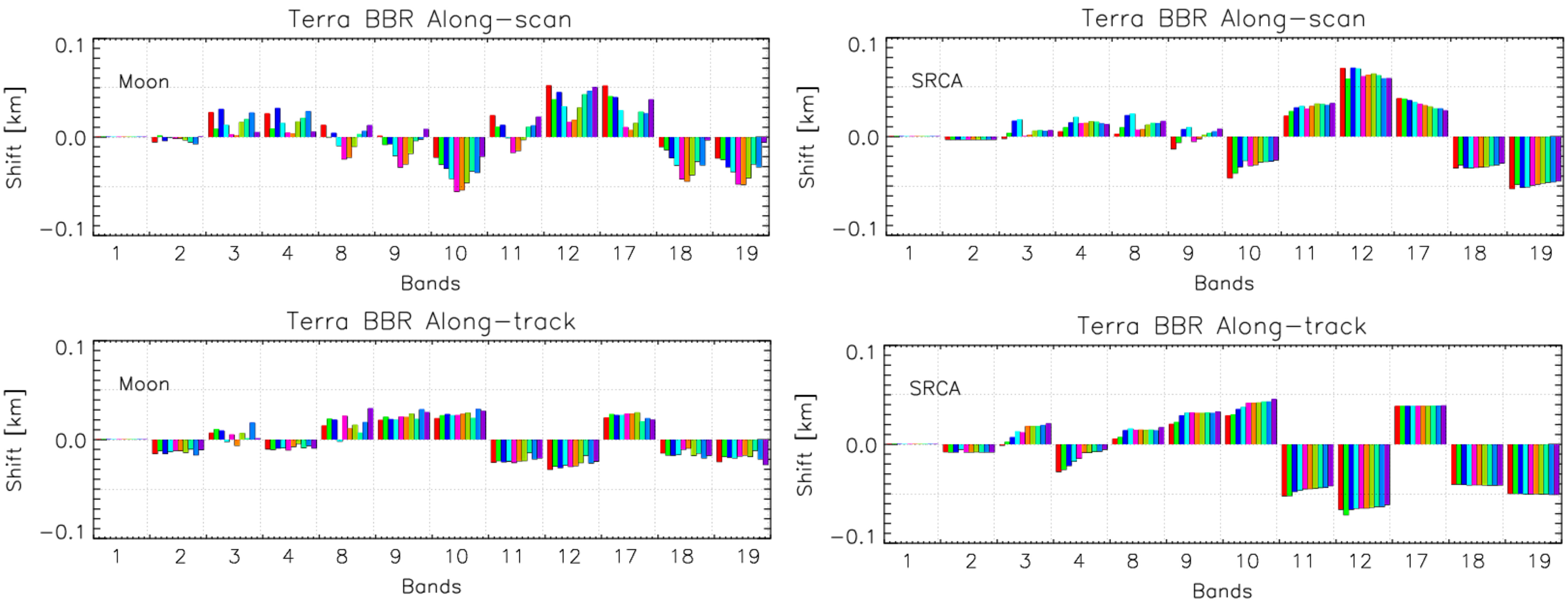
- The MODIS bands are spatially separated on the FPAs, and the OBC product applies a frame shift with the nominal frame offsets to align the images spatially.

- We can create images of the Moon using single detectors multiple scans.

- We use the relative position of the detector images to calculate the band-to-band registration (BBR) and detector-to-detector registration (DDR).



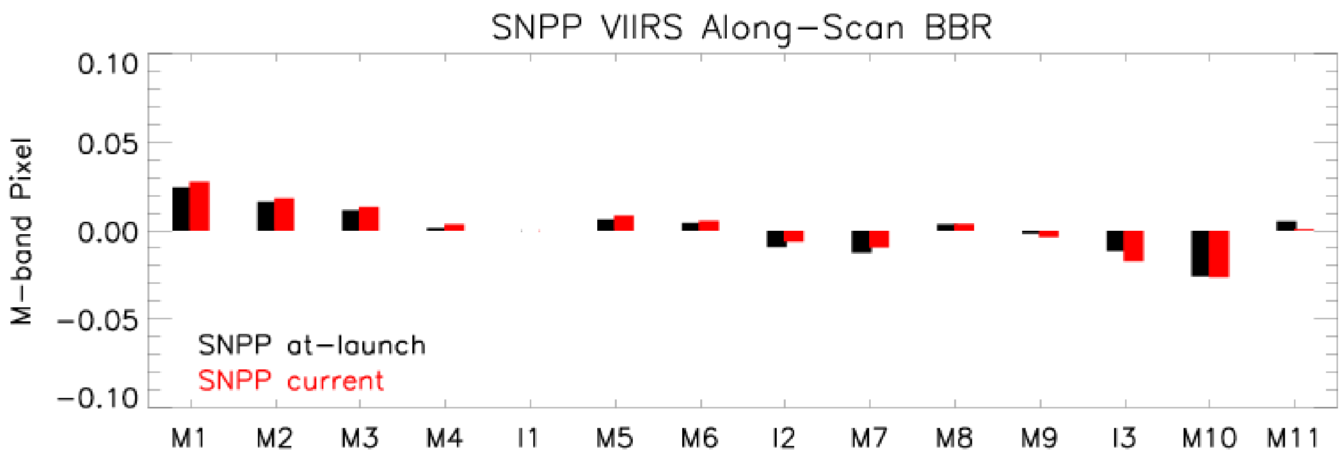
Terra MODIS - BBR

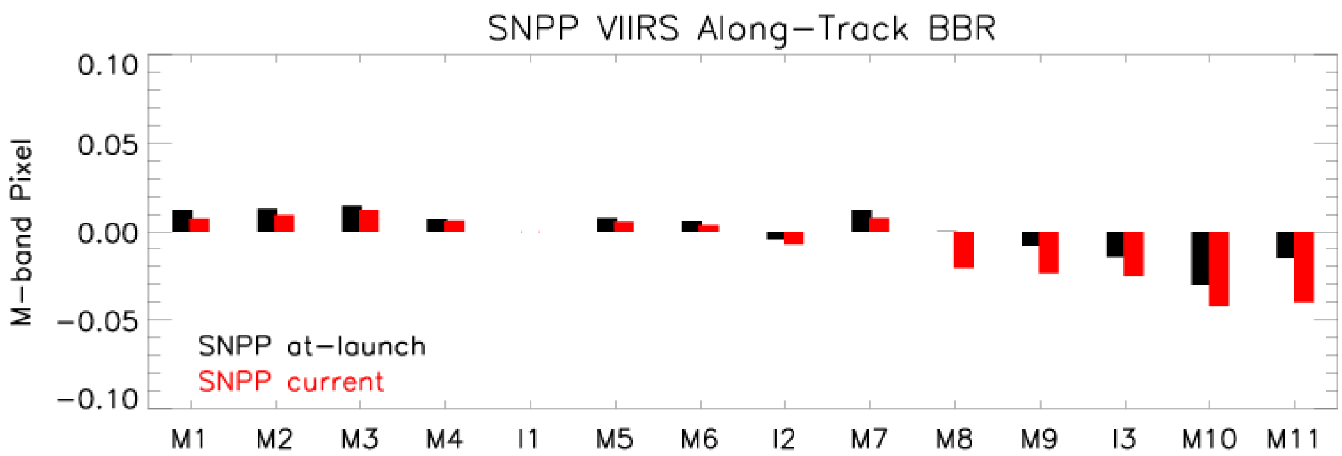


- The BBR derived from lunar observations shows similar behavior to the results derived from the SRCA
- The results shown here are the annual average for each band, plotted for every other year in a different color.

Xiong, X., J. Sun, A. Angal, Y. Xie, T. Choi, and Z. Wang, "Results of MODIS band-to-band registration characterization using on-orbit lunar observations," Proc. SPIE 8153, Earth Observing Systems XVI, 81531R, 2011.

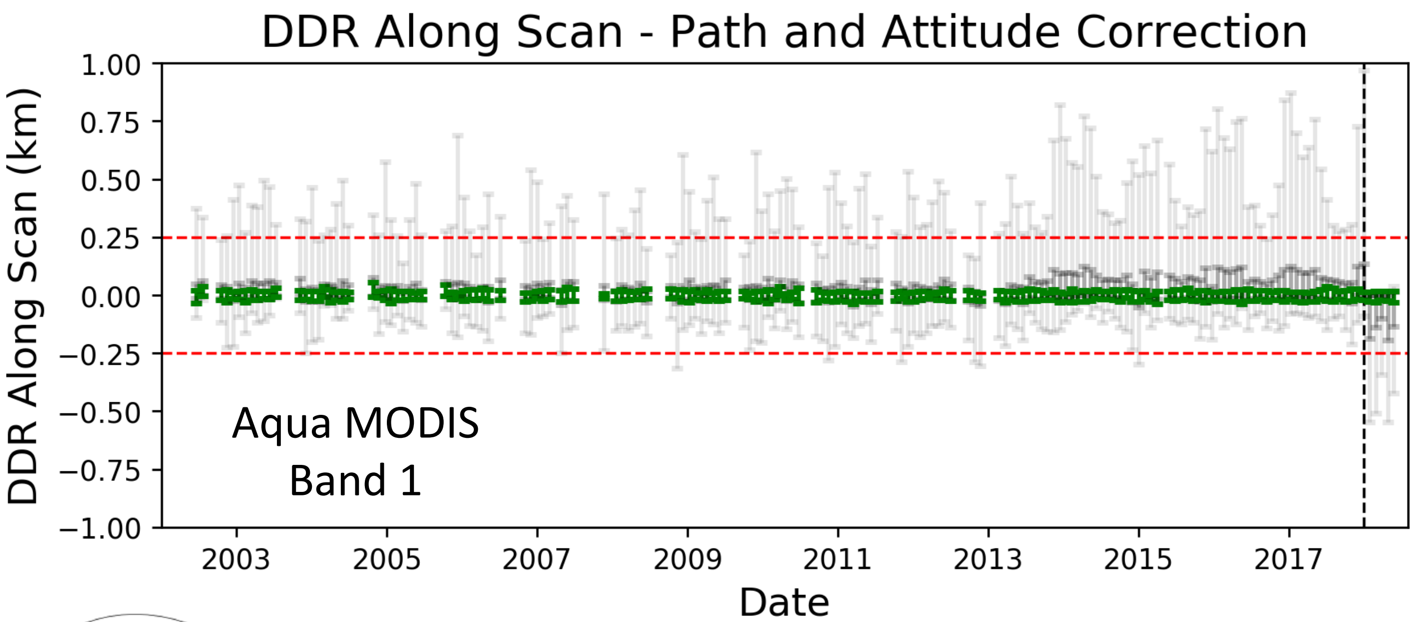
SNPP VIIRS - BBR

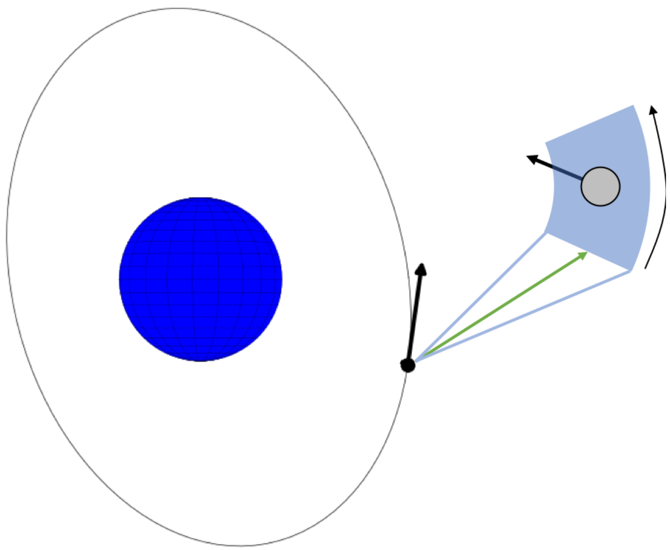


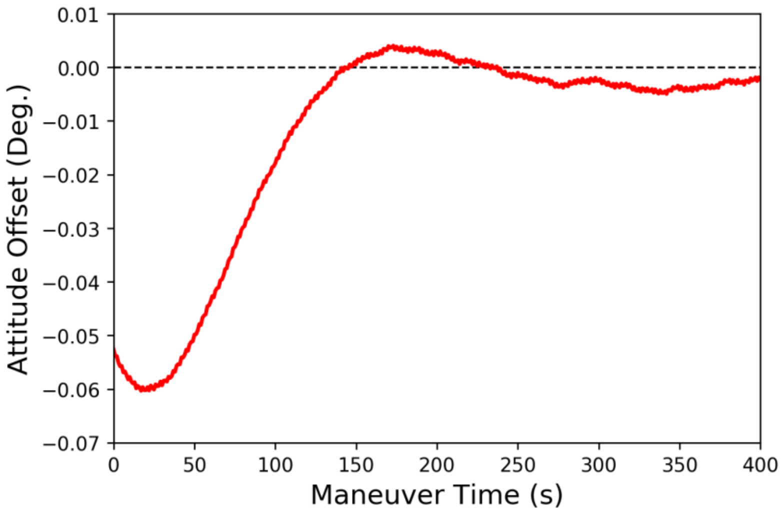


Wang, Z., X. Xiong, and Y. Li, "Update of VIIRS On-Orbit Spatial Parameters Characterized With the Moon", IEEE Transactions on Geoscience and Remote Sensing, vol.53(10), 5486-5494, 2015.

DDR with Pointing Correction





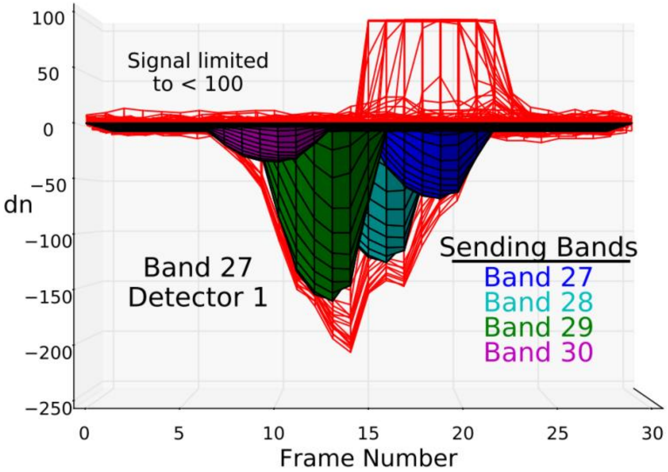


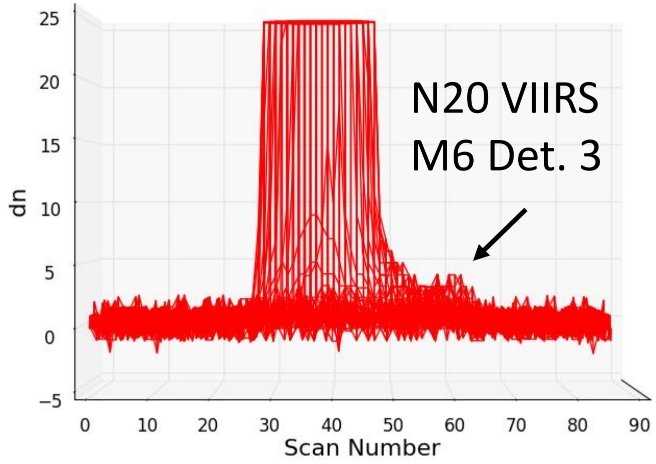
T. Wilson, A. Angal and X. Xiong, Proc. SPIE 10785, 1078519 (2018); doi: 10.1117/12.2324873

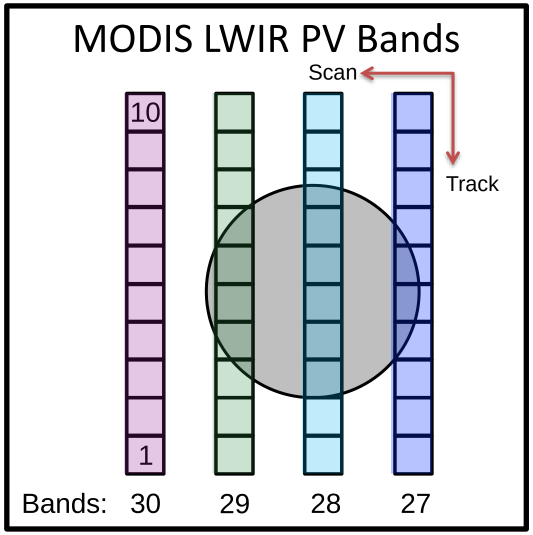
Crosstalk Characterization

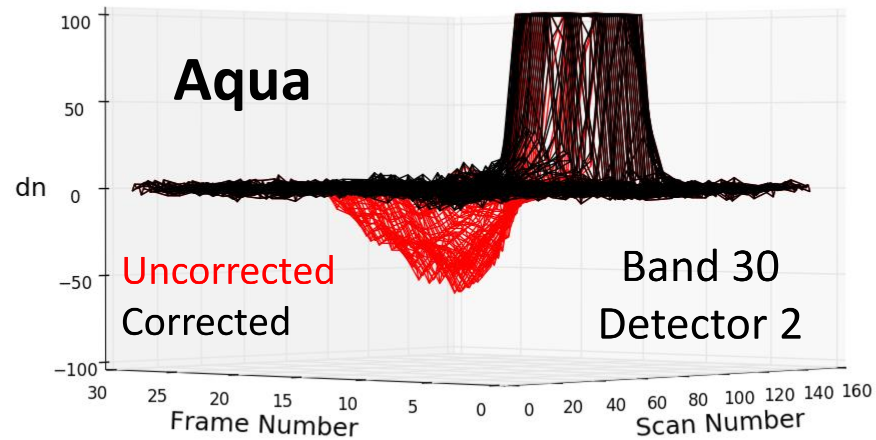
- The Moon has been used extensively for electronic and optical crosstalk characterization and correction for both MODIS and VIIRS.

Terra MODIS

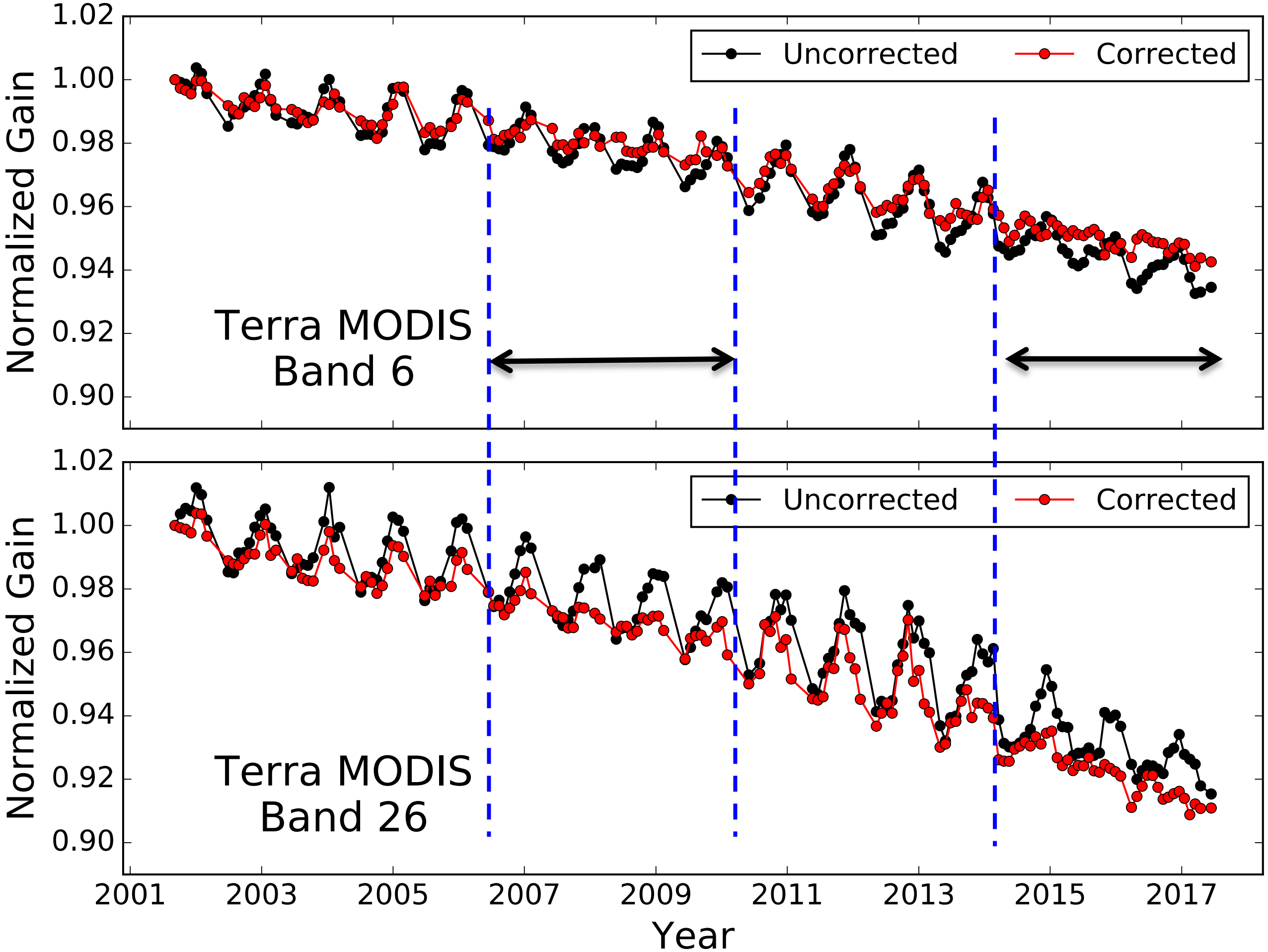








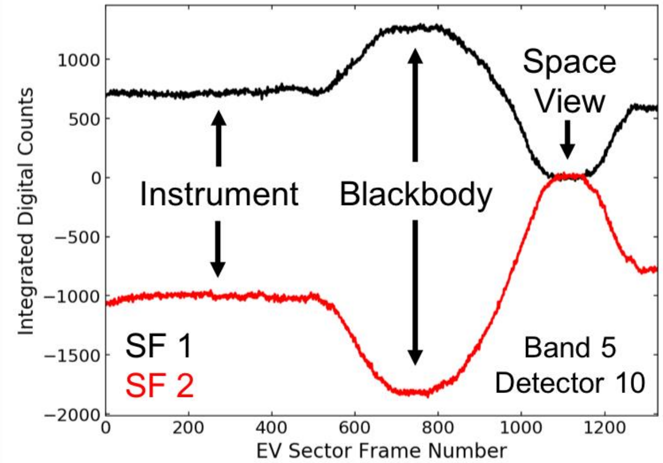
Terra SWIR Lunar Calibration Correction

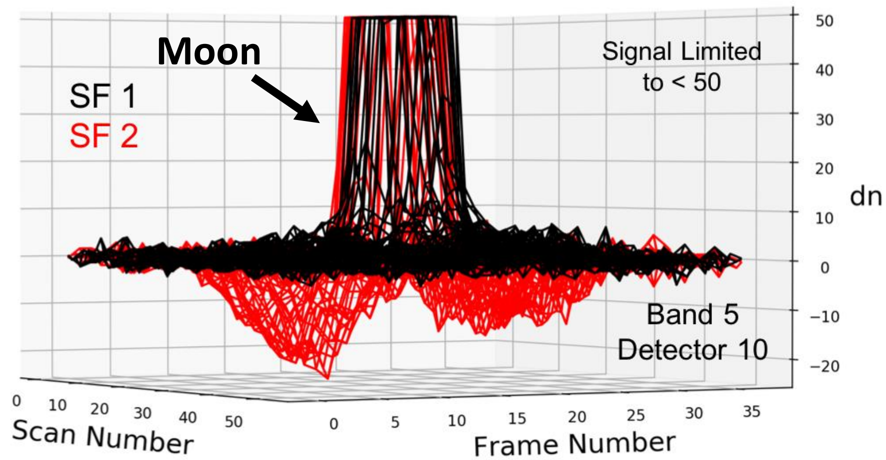


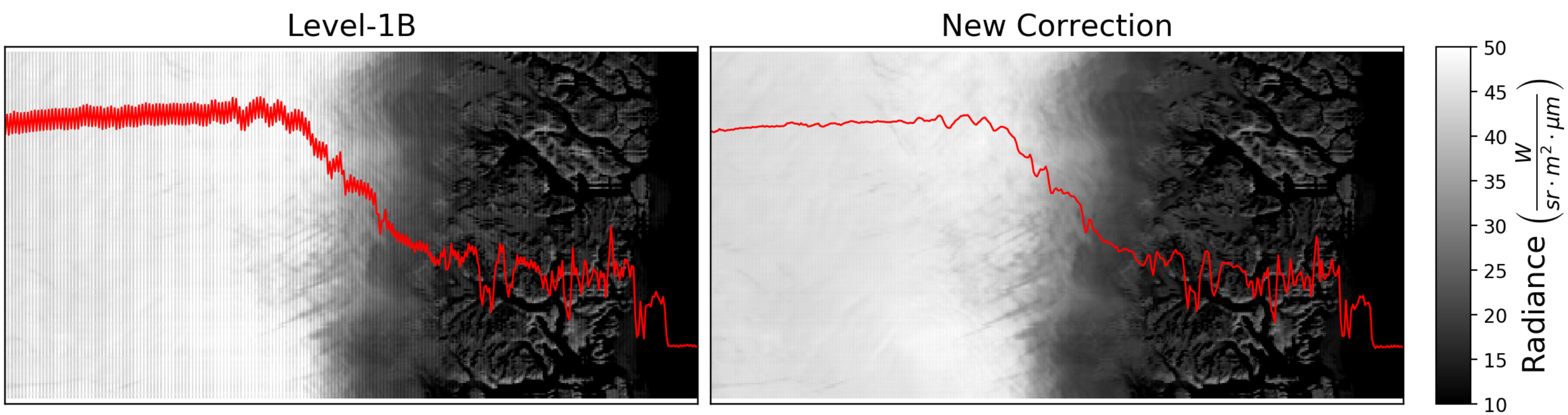
- Applying a crosstalk correction to the SWIR band data in Terra MODIS reduces the oscillations
- The beat pattern of the remaining oscillations can be attributed to the frequencies of the lunar libration oscillations
- These oscillations are present at varying magnitudes for each MODIS RSB

T. Wilson, A. Angal, A. Shrestha, and X. Xiong, Proc. SPIE 10423, 1042313 (2017); doi: 10.1117/12.2277950

Terra SWIR Subsample Correction







- Band 5 image from Terra MODIS over Greenland in 2015.
- This correction is still under internal testing and is not implemented in the official product. For more information, see:
  - T. Wilson and X. Xiong, Proc. SPIE 10785, 107851B (2018); doi: 10.1117/12.2324968

Summary

- The Moon plays a vital role in the on-orbit radiometric calibration of the MODIS and VIIRS RSB
  - Near-monthly lunar observations (at a different AOI than the SD) facilitate an accurate characterization of the on-orbit RVS for the MODIS RSB
  - VIIRS also observes the Moon (at same AOI as the SD) on a regular basis (8-9 months/year). The lunar measurements are used to derive additional corrections to the SD degradation (H-factors)
  - Moon-based correction algorithms have been developed and implemented to correct for electronic crosstalk (especially in Terra MODIS)
- Predicted Lunar Irradiances provided by the ROLO model are used to normalize the measured lunar irradiances from each instrument and therefore facilitate an intercomparison.
- Both MODIS and VIIRS employ the Moon to perform the on-orbit spatial characterization for the RSB (BBR and DDR)
  - Recent improvements in the DDR characterization approaches using pointing correction
- Lunar calibration scheduling tools developed for MODIS and VIIRS to be employed for future JPSS instruments lunar calibration