Evaluation of VIIRS Lunar Irradiance Measurements and Comparison Against the ROLO Reference

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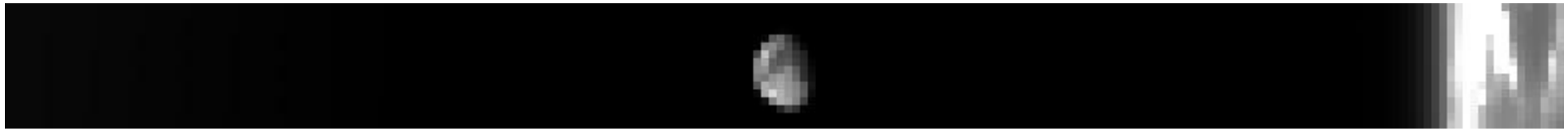
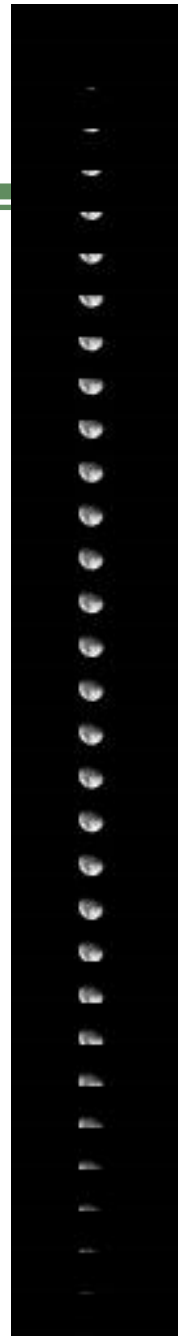
VIIRS Observations of the Moon

SNPP and NOAA-20 execute roll maneuvers each month to capture the Moon in the Earth-view sector at phase angle ~51° before Full Moon

- when the Moon is observable, typically October through June
- as the spacecraft traverses its orbit, the Moon passes through the field of view
- roll angle specified to center the Moon disk in Earth view:



SNPP VIIRS image d20170604_t1934579, band M7, scan 12



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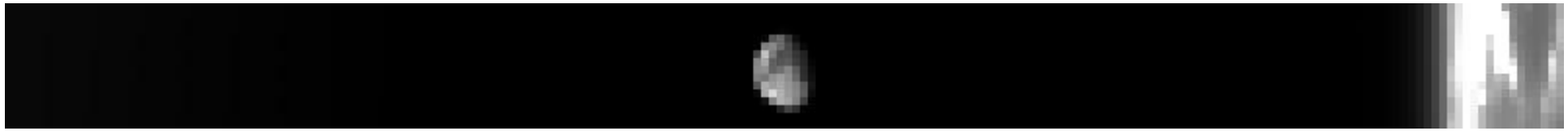

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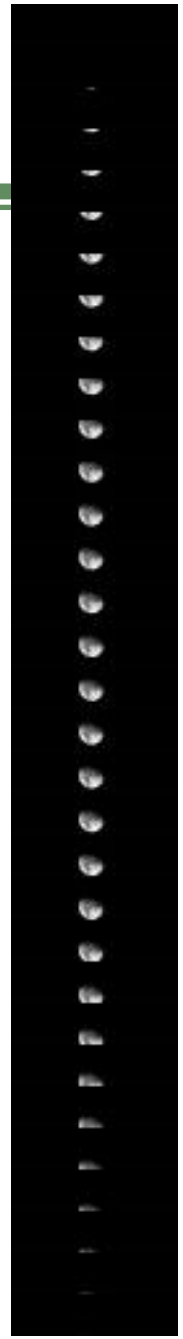
- centering avoids stray light, seen by stretching the display level:



Lunar Calibration

USGS lunar calibration works with lunar irradiances, comparing sensor measurements against corresponding computations of the ROLO model.

- Irradiance measurements from Moon images involves spatial integration of pixels on the lunar disk:

$$E_{\text{meas}} = \frac{\Omega_{\text{p}}}{\eta} \sum_{i}^{N} L_i$$

Ω_{p} = pixel IFOV (solid angle)
η = oversampling factor
L_i = pixel radiance
N = # of pixels on Moon

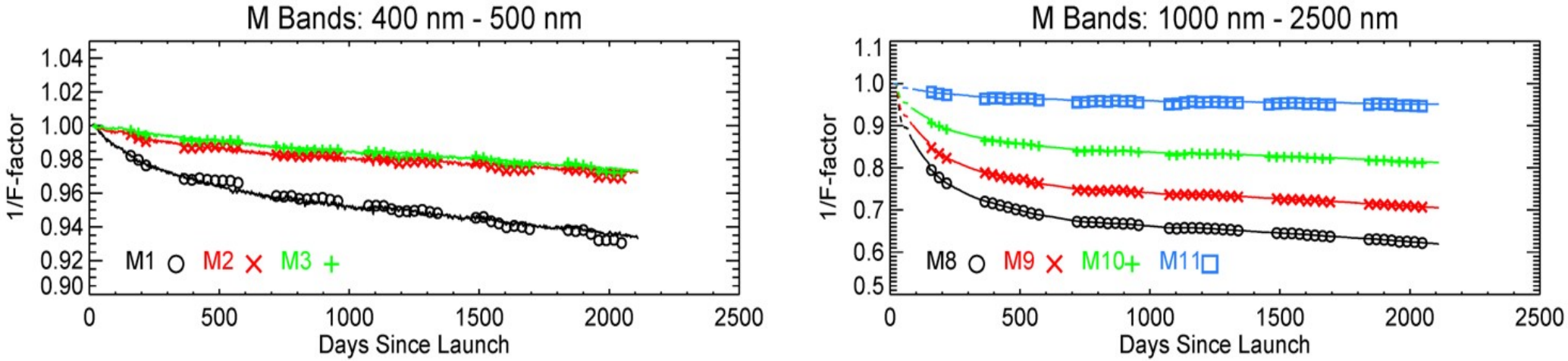
- Reference irradiances are generated for the photometric geometry of each Moon observation:

$$\ln A_k = \sum_{i=0}^{3} a_{ik} g^i + \sum_{j=1}^{3} b_{jk} \Phi^{2j-1} + c_1\phi + c_2\theta + c_3\Phi\phi + c_4\Phi\theta$$
$$+ d_{1k} e^{-g/p_1} + d_{2k} e^{-g/p_2} + d_{3k} \cos((g - p_3)/p_4)$$

Lunar Calibration

Typical usage: tracking sensor response changes on orbit

- the Moon is an exceptionally stable solar diffuser
- time series of measurement/model ratios reveal sensor response trends
- particularly useful for on-orbit calibration for ocean color



X. Xiong — NASA GSFC

VIIRS Lunar Image Analysis at USGS

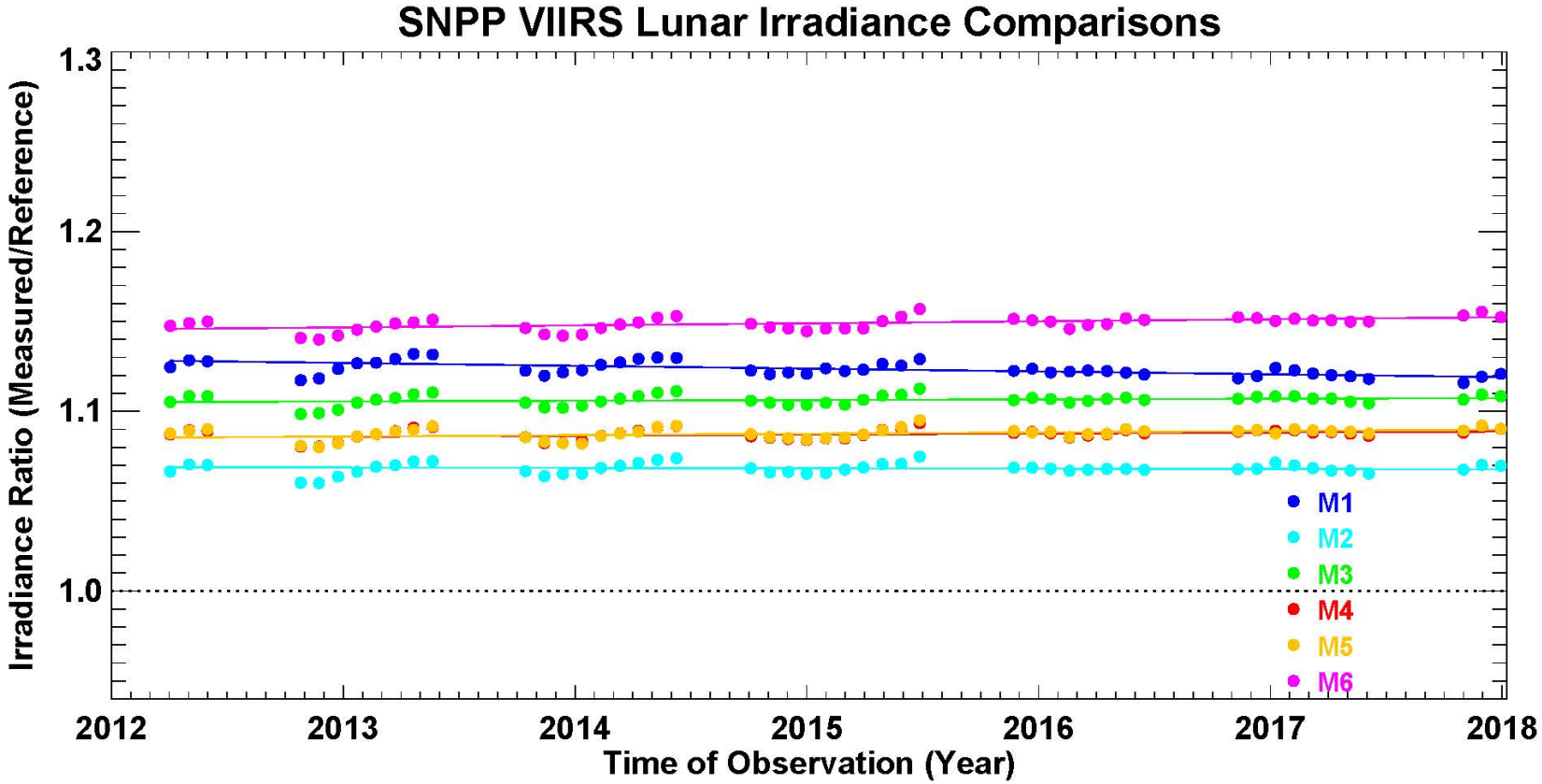
Moon image processing to irradiance, independent of VCST and OBPG

- RDRs obtained from NOAA CLASS
- SDR software system installed on USGS compute cluster: ADL 4.2.8
  - code modifications to remove time-dependent calibration components; all granules processed identically
- VIIRS moon image spatial integration routines developed at USGS
  - detector dark level evaluation from deep space regions around the Moon disk
  - radiance conversion using SDR base calibration factors, extracted from SDR files
  - pixel solid angle derived from Horizontal Sampling Interval (from geolocation ATBD)
- temporal response trends corrected using daily-average SD f-factors for days of Moon observations (thanks to VCST)

USGS results: time series of measurement/ROLO ratios, **not normalized**

USGS Results for VIIRS Lunar Calibration

Lunar irradiance ratios (VIIRS/ROLO)



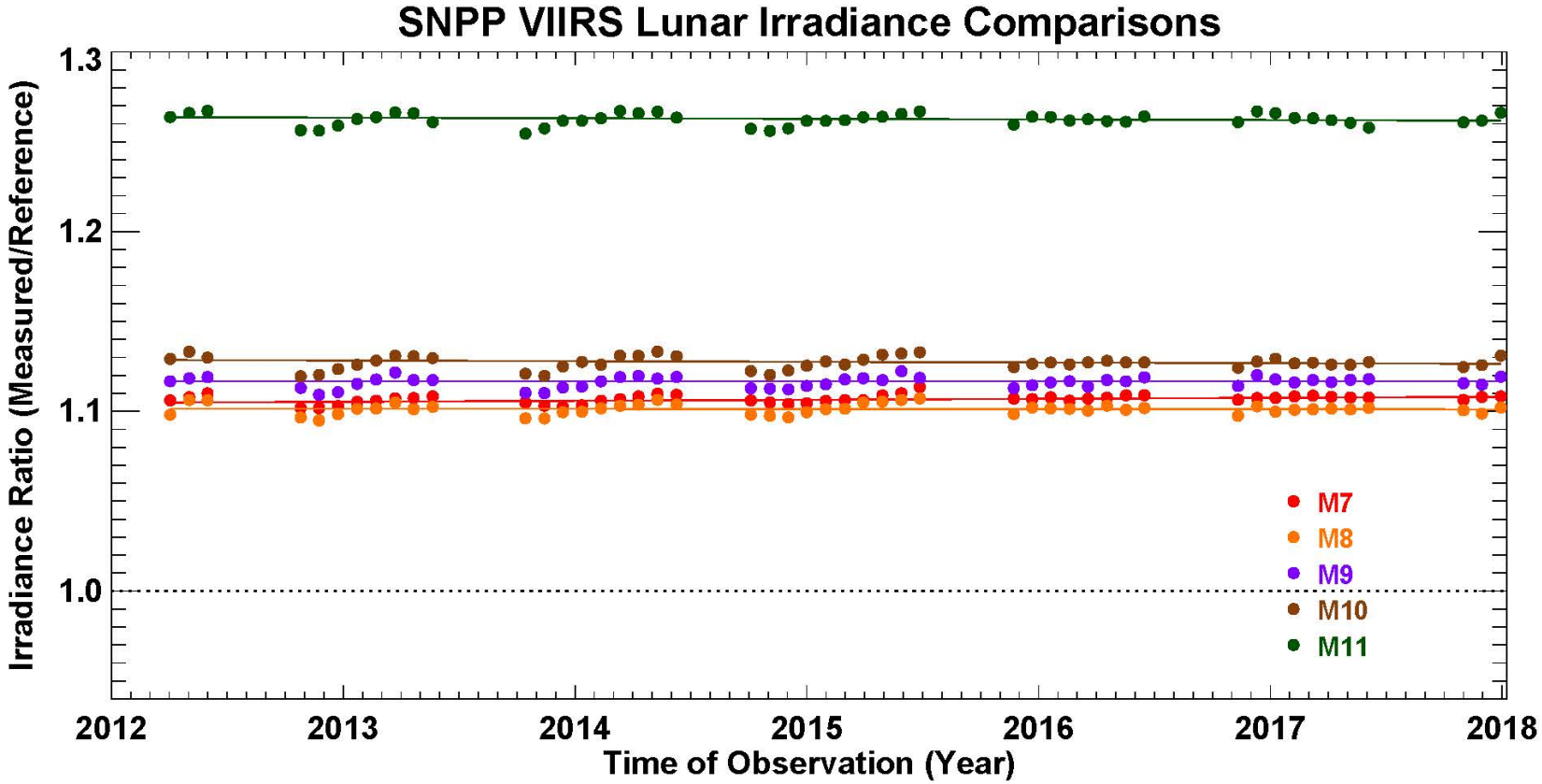
Notable features:

- discrepancies (offsets) 7-16% for M1 to M6
- band-correlated oscillation pattern

- lines show linear fits to time series
  - slopes reveal residual temporal drifts (small)

USGS Results for VIIRS Lunar Calibration

Lunar irradiance ratios (VIIRS/ROLO)



Notable features:

- discrepancies (offsets)
  9-14% for M7 to M10
  ~26% for M11
- band-correlated oscillation pattern

- lines show linear fits to time series
  - slopes reveal residual temporal drifts (small)

Investigating the Discrepancies

Analysis:

- the offsets are consistently positive (measurements are higher than ROLO), and exceed the 5-10% absolute uncertainty in the ROLO model
- these results are inconsistent with other methods for VIIRS on-orbit calibration

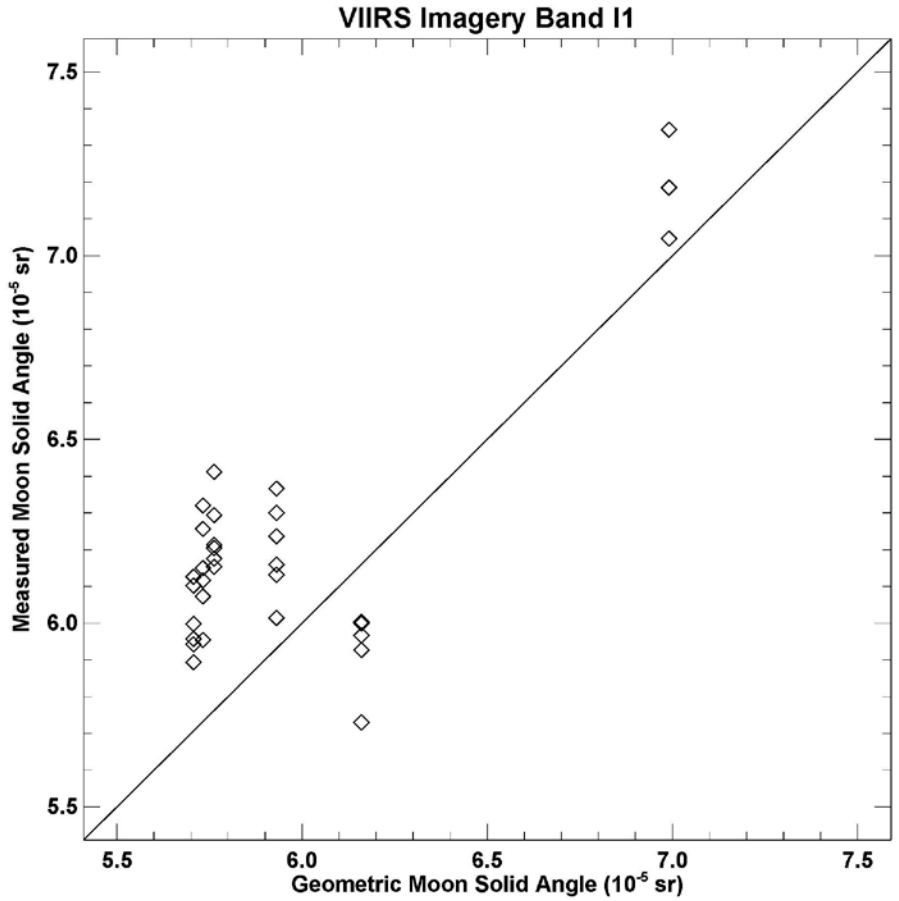
This suggests the spatial aspects of irradiance measurements as potential sources of error.

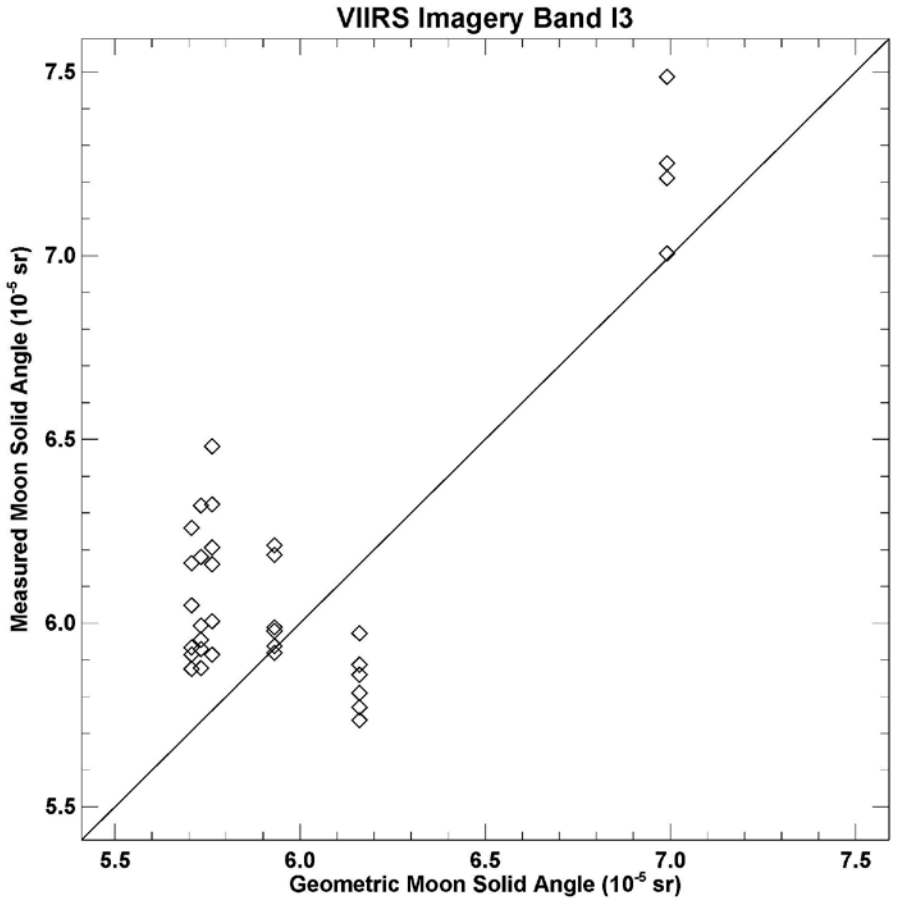
Initial study: attempt to verify the pixel solid angle by comparing the size of the Moon disk to its geometric extent

- only the VIIRS imagery bands have sufficient spatial resolution to do this
- disk image size was determined by fitting a circle to the bright limb edge
- large scatter found in the measured disk sizes; outcome was inconclusive

Moon Size Comparisons

Solid angle of the lunar disk: measured from VIIRS I-band images versus the geometric size of the Moon from the SNPP location





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Potential Sources of the Discrepancies

Other spatial aspects of VIIRS Moon observations to examine:

- the presumed 1.0 oversampling factor
  - detector fill factor
  - RTA rotation and sampling synchronization
  - along-track sensor spatial response (PSF)
- motion of the Moon relative to the line of sight during scans
- possible effects of pixel aggregation

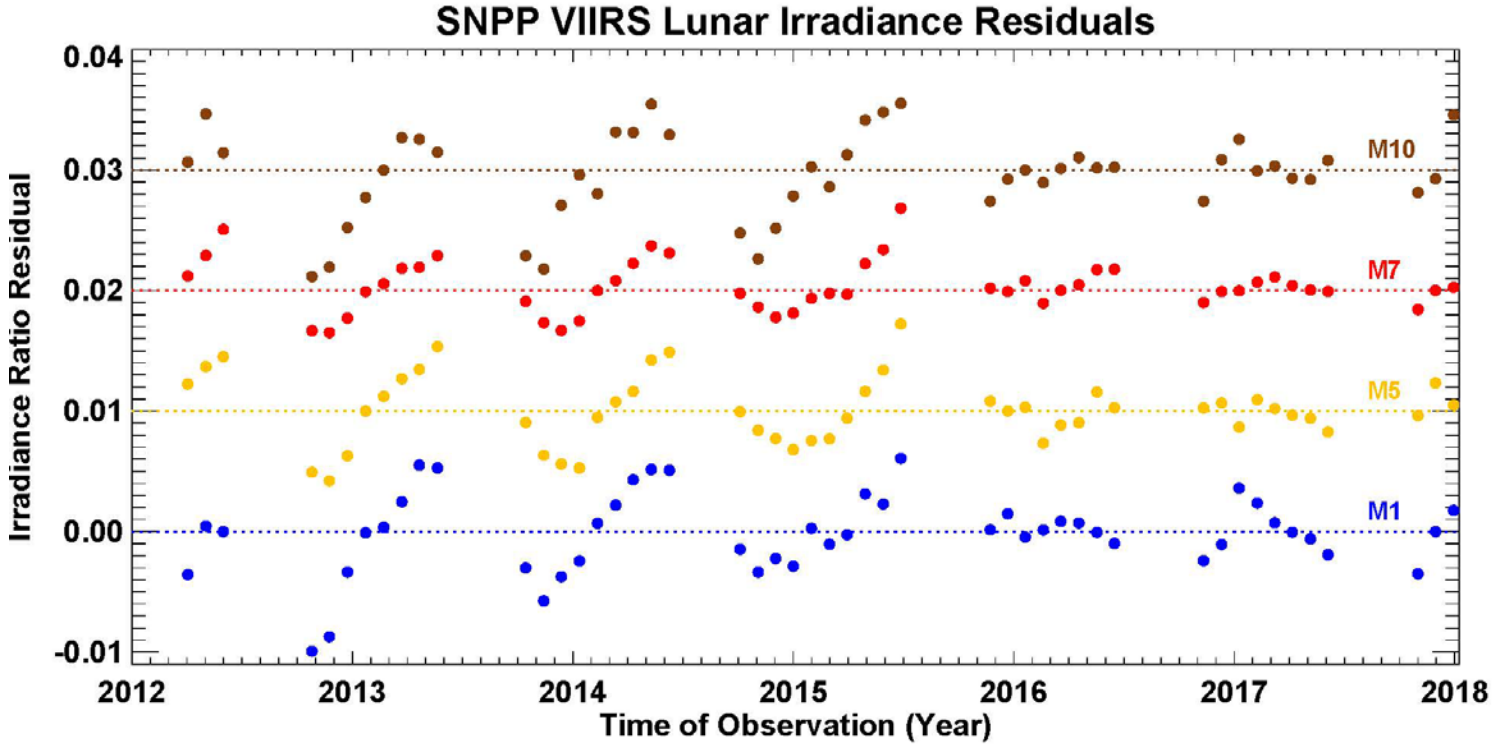
Investigating the Oscillation Patterns

The cross-band correlation suggests an origin in the ROLO lunar model.

- for a given sensor band, the model results are governed by only the phase angle and lunar librations
  - the only significant correlations were found with the observer (sensor) lunar librations

Analysis approach:

study residuals to the linear trend fits (offset for clarity)



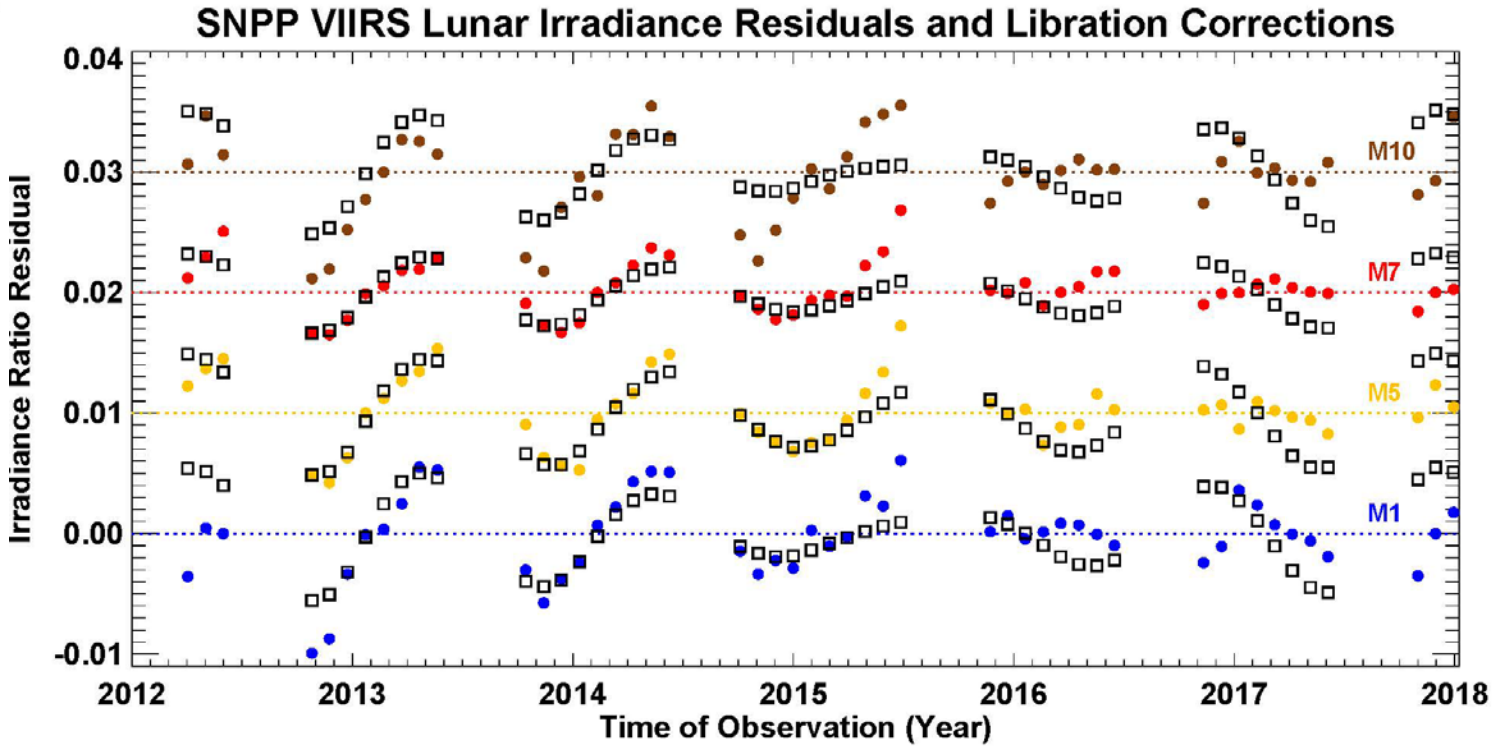
Investigating the Oscillation Patterns

Developed correction to the ROLO model irradiances — a combined linear function of observer libration longitude and latitude:

$$E'_{\mathrm{ref}} = E_{\mathrm{ref}}\ (1 + c_0\,\phi + c_1\,\theta)$$

ϕ = sub-observer longitude
θ = sub-observer latitude

- corrections scaled to irradiance residuals
- good correlation for years 2013-2015, then breaks down
- suggests a different mechanism must be responsible



Summary and Conclusions

- Comparisons of VIIRS lunar irradiances measured from images to ROLO results show discrepancies larger than the absolute uncertainties in ROLO
  - this suggests examining the spatial nature of the irradiance measurements
  - other spatial aspects of VIIRS lunar imagery to examine:
    - the presumed 1.0 oversampling factor
    - motion of the Moon relative to the line of sight during scans
    - possible effects of pixel aggregation
- The oscillatory pattern seen in the time series of irradiance comparisons shows correlation with the lunar librations only until ~2015
  - breakdown suggests a different mechanism must be responsible for the oscillations
- Future work: limited in scope and extent
  - new TASNPP (ROSES-2017) project primarily to provide lunar calibration support to VCST and MODIS/VIIRS Science Team Ocean Discipline

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