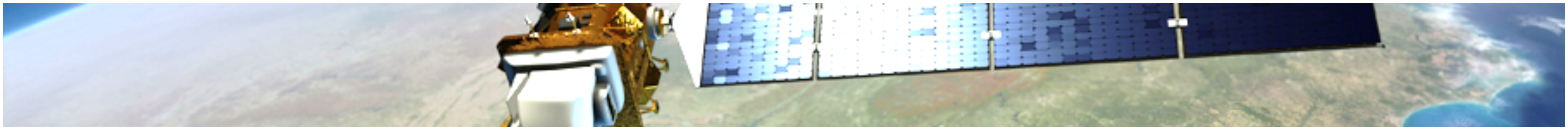


Landsat-8: Lunar Calibrations

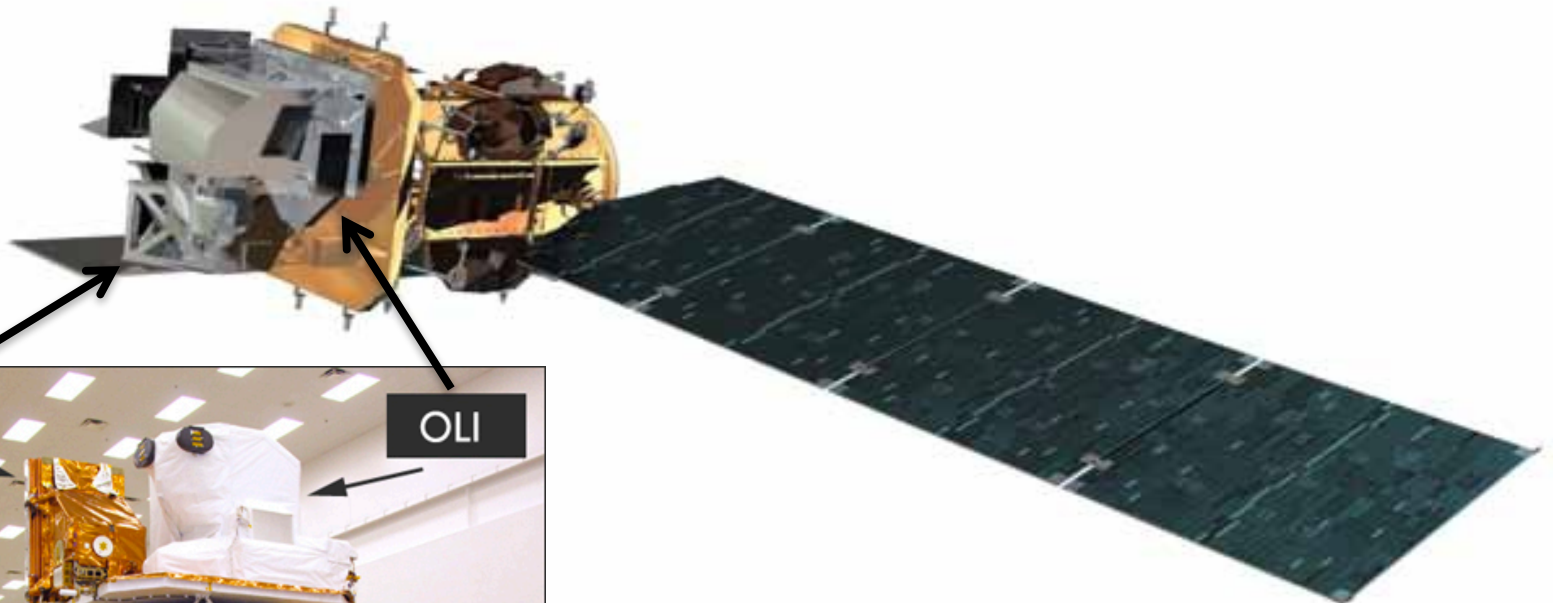
Lawrence Ong[a], Hugh Kieffer[b] and Brian Markham[c]
Landsat Calibration and Validation Team

[a]NASA/GSFC Code 618 - Science Systems Applications Inc., Greenbelt, Maryland, USA
[b]Celestial Reasonings, Genoa, Nevada, USA
[c]NASA/GSFC Code 618, Greenbelt, Maryland, USA

Topics

- Landsat-8 Mission Overview and Status
  - OLI and TIRS on-orbit performance
- Landsat-8 Lunar Calibrations
- Application in OLI Radiometric Stability Performance
- Current Model Improvement Effort
- Other uses for Lunar Observations
  - TIRS Straylight Correction
- Summary

Landsat-8 Overview

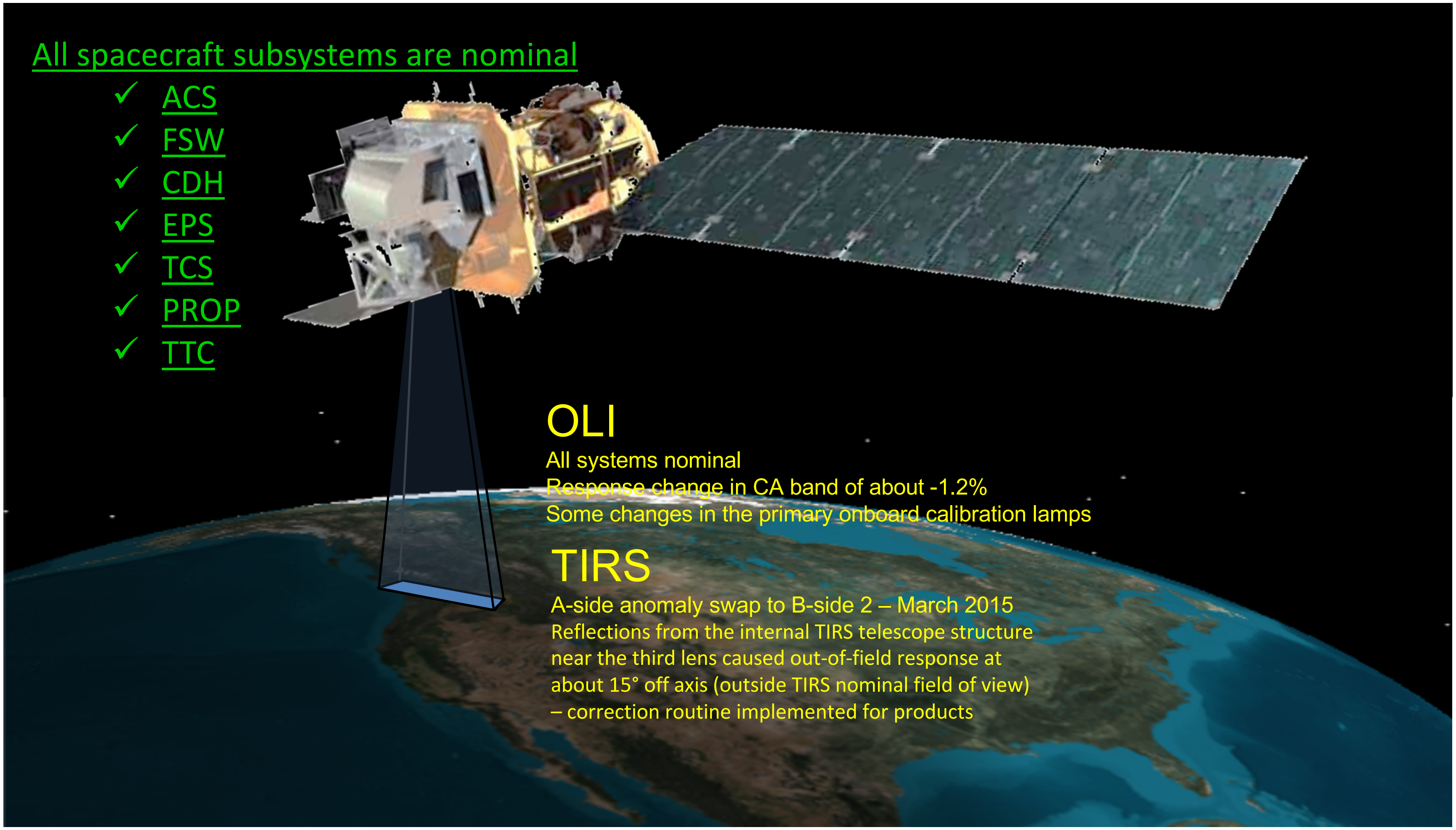


Joint project between NASA and USGS

- NASA – Instruments and spacecraft development, on-orbit checkouts, commissioning
- USGS – Ground segment and post-commissioning operations

Remote Sens. **2015**, *7*(3)

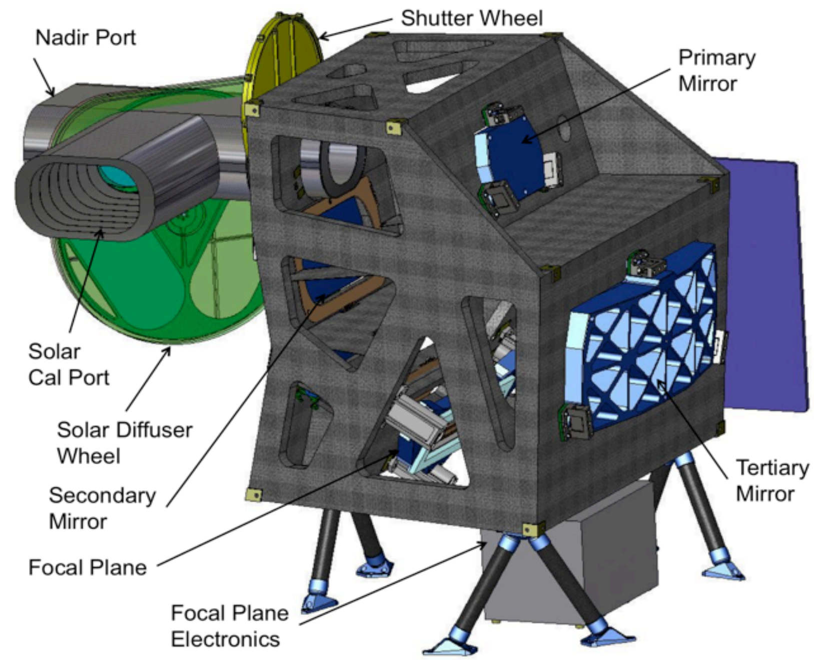
L8 Spacecraft Status

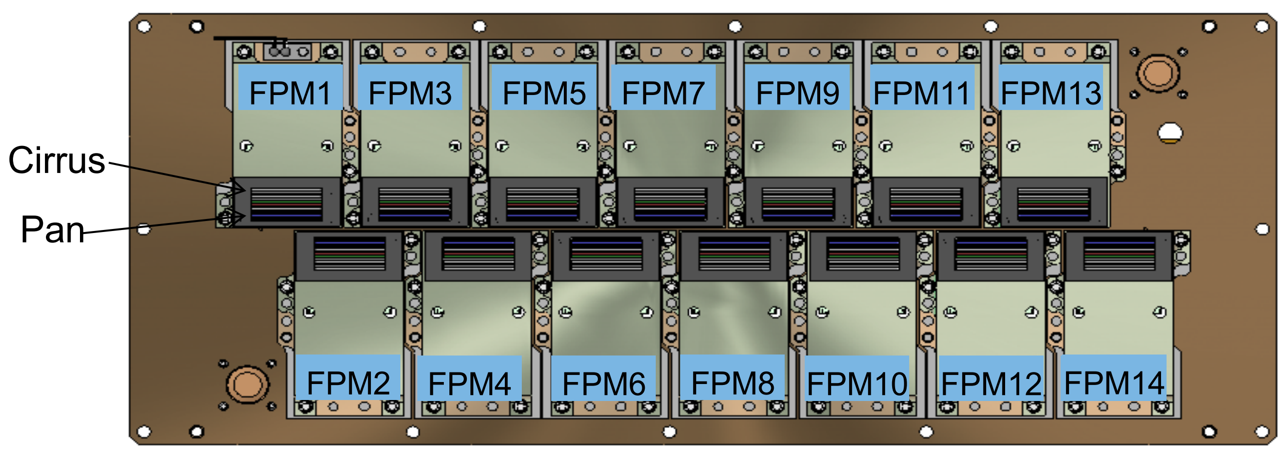


OLI Overview

- Pushbroom Radiometer, 15° FOV
- Eight 30 m multispectral bands
- One 15 m panchromatic band

Band #	Band	Center Wavelength (nm)	Bandwidth (nm)	Lower Band Edge (nm)	Upper Band Edge (nm)
1	Coastal/Aerosol	443.0	16.0	435.0	451.0
2	Blue	482.0	60.0	452.0	512.1
3	Green	561.4	57.3	532.7	590.1
4	Red	654.6	37.5	635.9	673.3
5	NIR	864.7	28.3	850.5	878.8
6	SWIR 1	1608.9	84.7	1566.5	1651.2
7	SWIR 2	2200.7	186.7	2107.4	2294.1
8	Panchromatic	589.5	172.4	503.3	675.7
9	Cirrus	1373.4	20.4	1363.2	1383.6

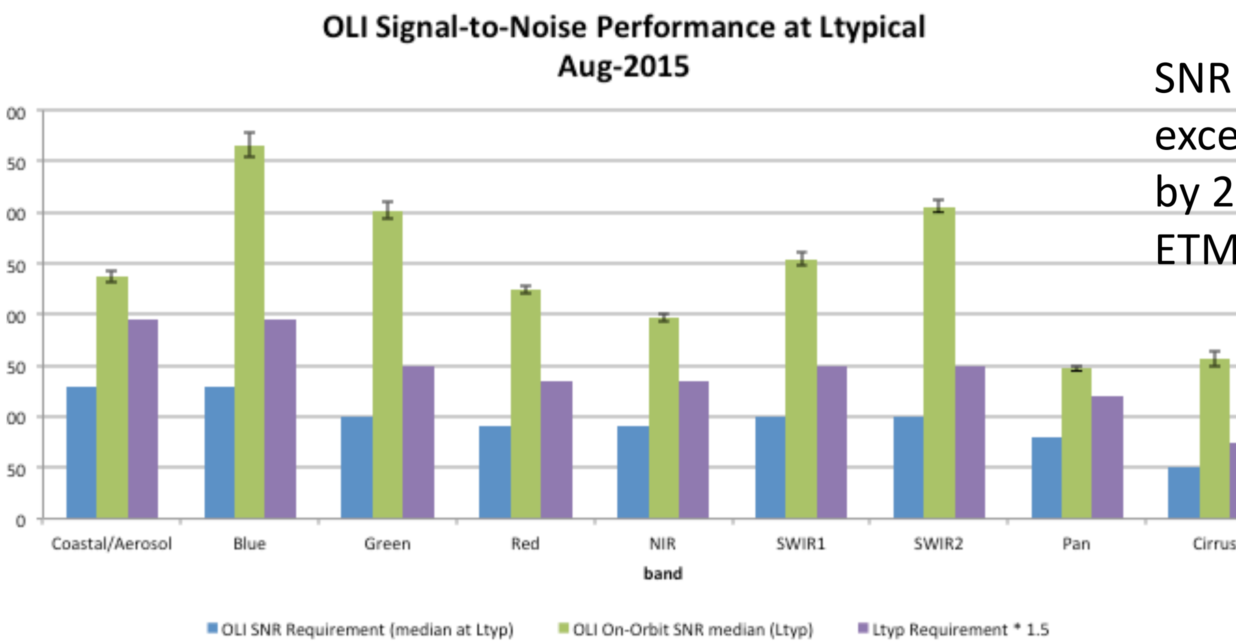




Calibration Devices
- On-board lamps
- Solar diffuser
- Lunar

~7000 Detectors per band in 14 Focal Plane Modules (FPM)

OLI Performance

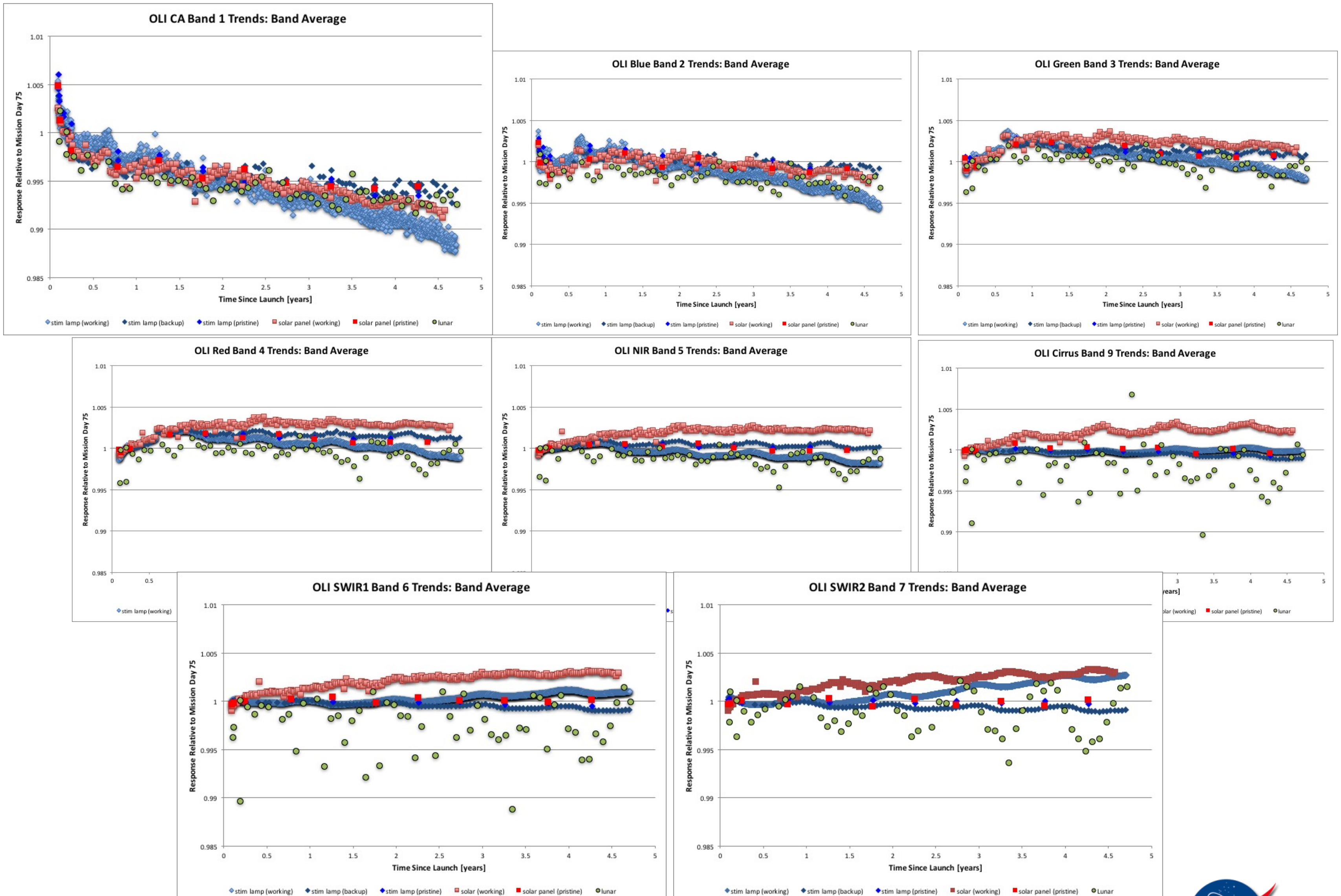


SNR continues to exceed requirements by 2-3 times; Landsat-7 ETM+ by 8-10 times

Precision of Calibrator Data (approximate range)

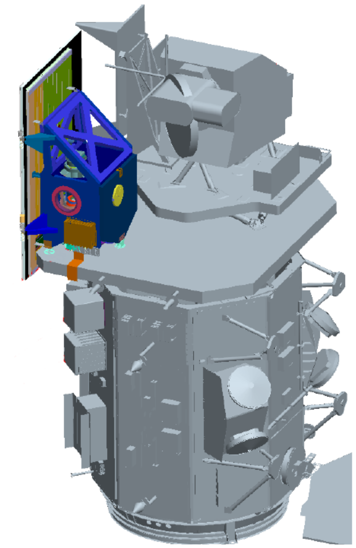
Calibrator	Coastal Aerosol	Red	NIR	SWIR-1	SWIR-2
Lamp	±0.15%	±0.02%	±0.01%	±0.01%	±0.01%
Solar	±0.10%	±0.05%	±0.05%	±0.05%	±0.05%
Lunar	±0.10%	±0.10%	±0.10%	±0.50%	±0.30%

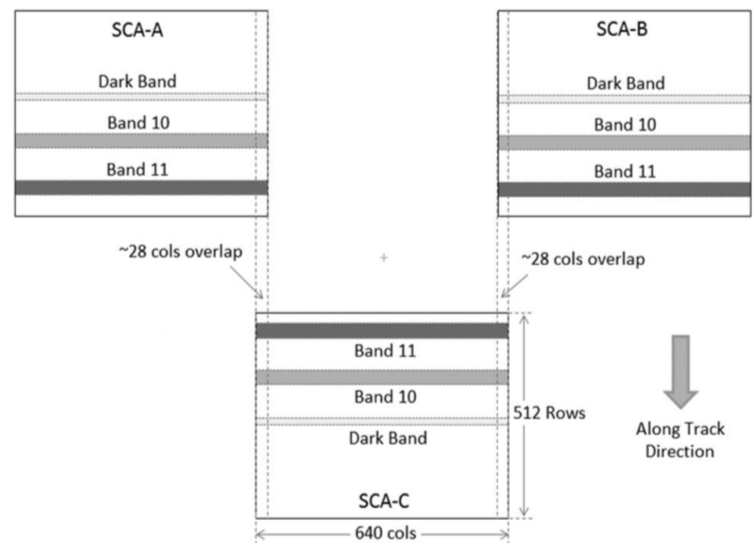
OLI Calibration Stability



TIRS Instrument Overview

- 4 optical element refracting telescope
- Focal plane consists of 3 staggered QWIP arrays
- Two spectral channels:
  10.6 µm - 11.2 µm known as “Landsat 8 band 10”
  11.5 µm - 12.5 µm known as “Landsat 8 band 11”
- Dark band to monitor focal plane drift
- Push-broom configuration: ~1850 detectors across-track per band
- 185 km ground swath (15 degree); 100 meter pixel size on ground;
  resampled to 30 meter pixels in final product
- For calibration purposes, a Scene Select Mechanism (SSM) can
  switch instrument view between:
  Nadir – Deep Space Port – Blackbody Calibrator (OBC)

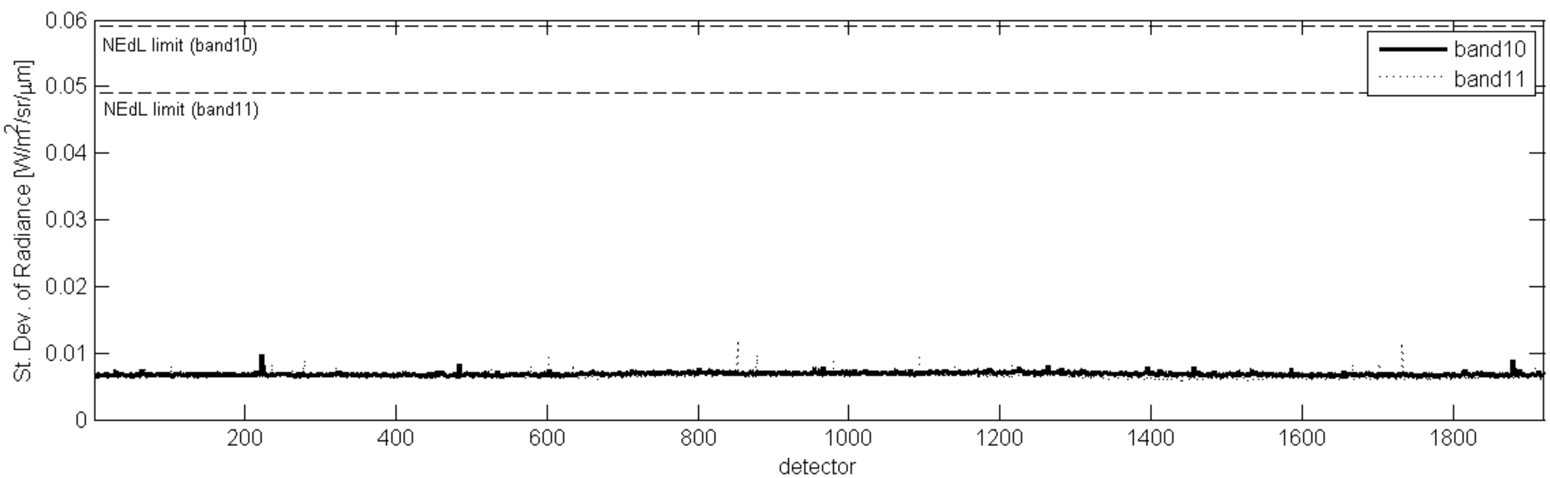




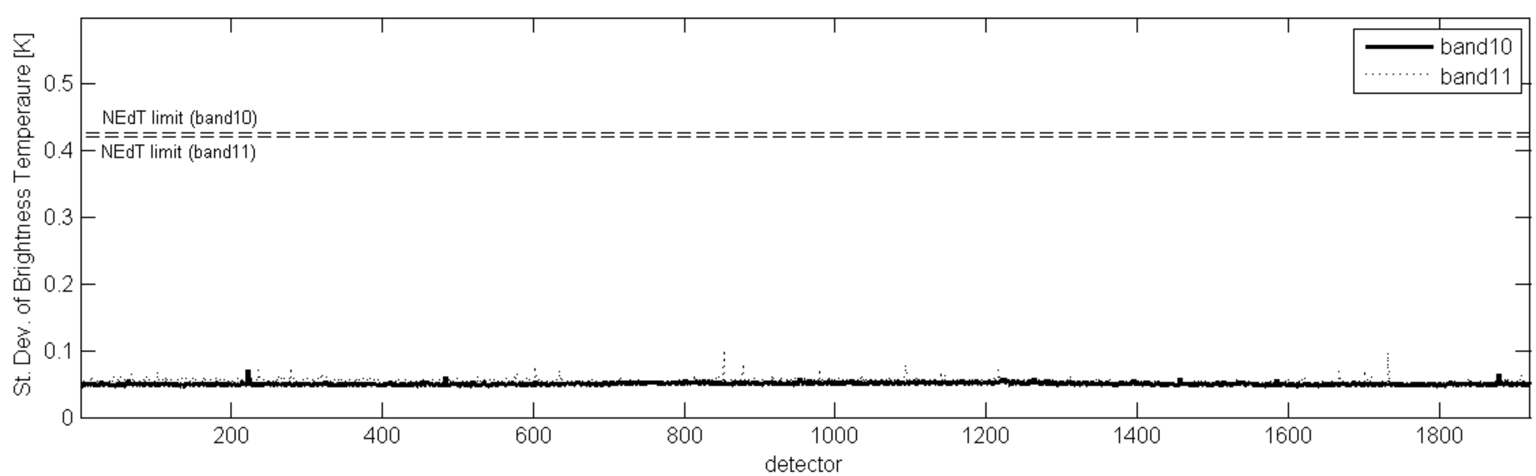
TIRS Noise

- Noise characterization based on collects of OBC

NEdL @ Source temperature of 295K



NEdT @ Source temperature of 295K



* Actual NEdL & NEdT exceed requirements

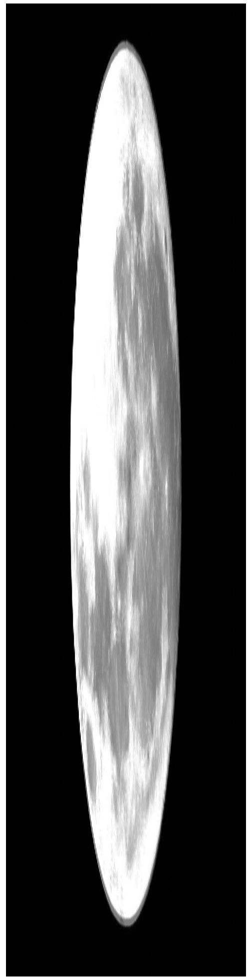
Landsat-8 Status Summary

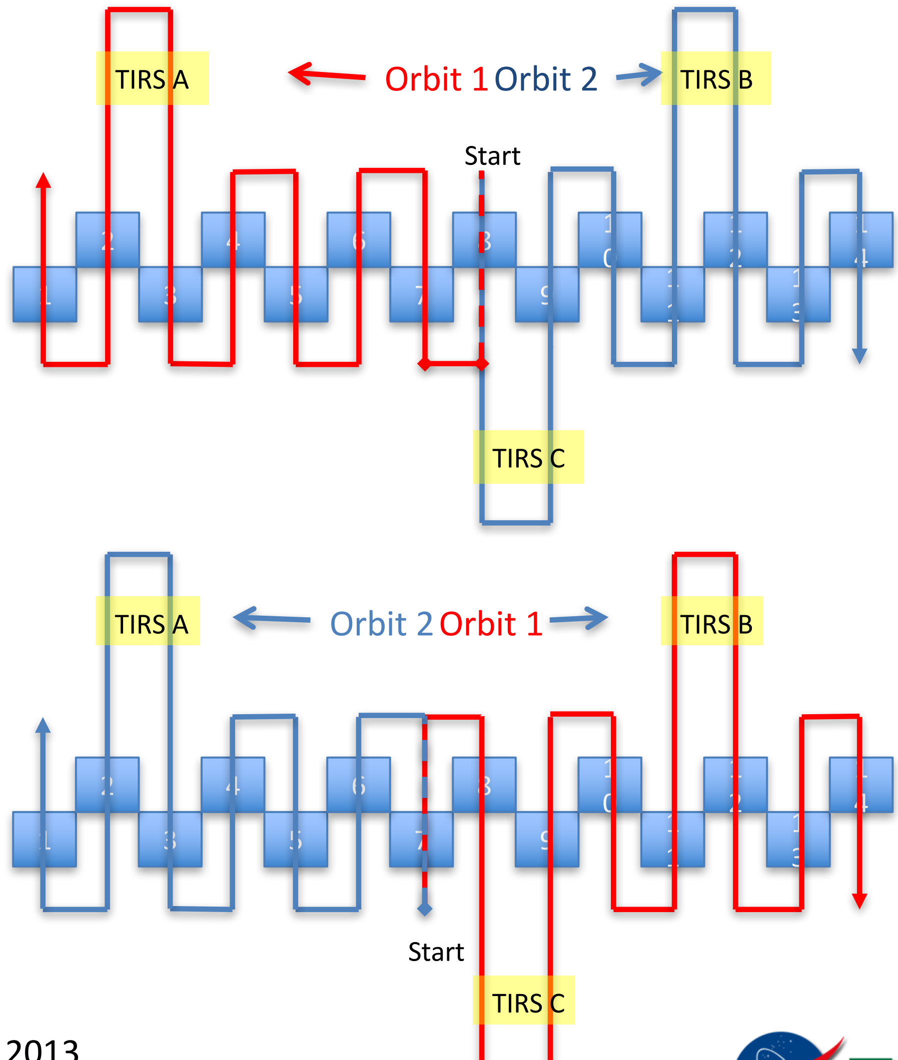
- Landsat-8 has been exceeding expectations in terms of data quantity and quality
  - currently acquires up to 740 images per day — requirements are 400 per day.
- OLI has been extremely stable on-orbit
  - At most 1% change is band average response in Band 1, Coastal Aerosol (CA)
    - variation between the calibration sources is ~0.2%
  - All calibration techniques working and consistent
    - Increase in "brightness" of working diffuser relative to other calibrators
    - Larger scatter in lunar response in SWIR bands, particularly SWIR-1 and Cirrus
    - OLI reflectance absolute calibration generally consistent to 3% with vicarious techniques
  - Small detector to detector variations (generally sub 0.1%) that are well corrected
  - SNR performance 2-3 times requirements
  - 100% detector operability
- TIRS has been extremely stable on-orbit
  - At most 0.5% change in band average response
  - Noise ~8 times better than requirements
  - 100% detector operability
  - Stray light compromises image uniformity and absolute calibration; adequately corrected in band 10 for many applications with simple bias factor

Landsat-8 Lunar Calibrations

Based on experience on EO-1 (ALI & Hyperion instruments) since 2001*

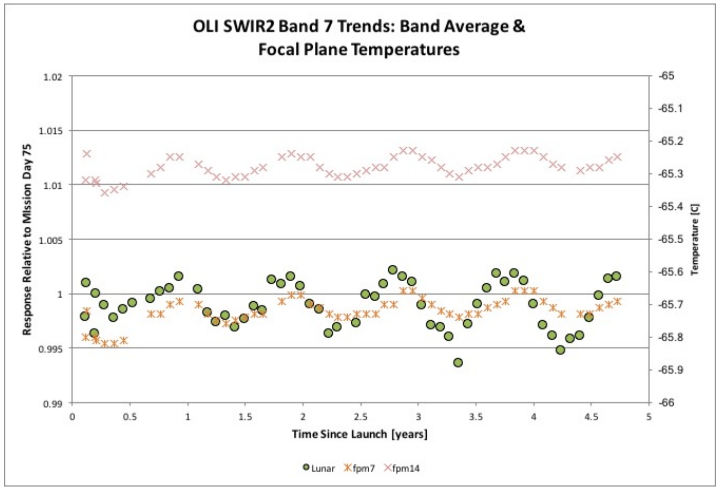
- Lunar Cals are performed monthly between 5 and 9 deg lunar phase angle
  - The moon is imaged by a spacecraft pitch motion.
  - The pitch rate is constant and well controlled during the imaging interval.
  - Roll and Yaw rates are negligible.
  - Orientation of the scan is such that the bright limbs are at the top and bottom of the image. This provides better estimates of the lunar y-size
- Irradiance values of the lunar image are integrated and compared to the Rolo model.
  - Image is filtered to remove stars and other artifacts
  - No further background correction beyond those in the L1R process.

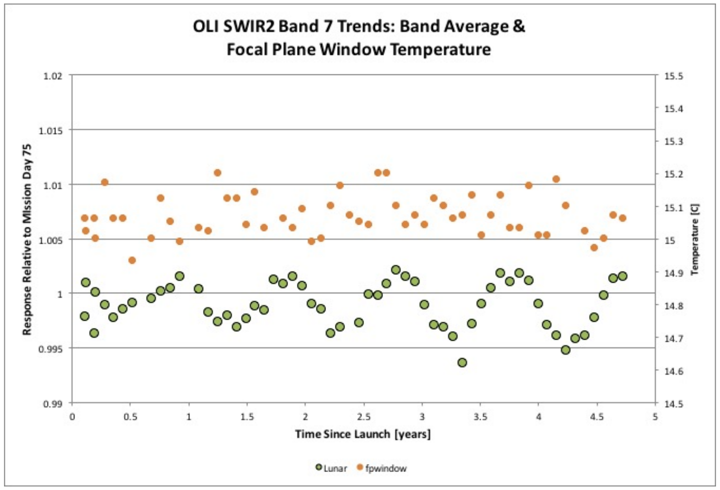


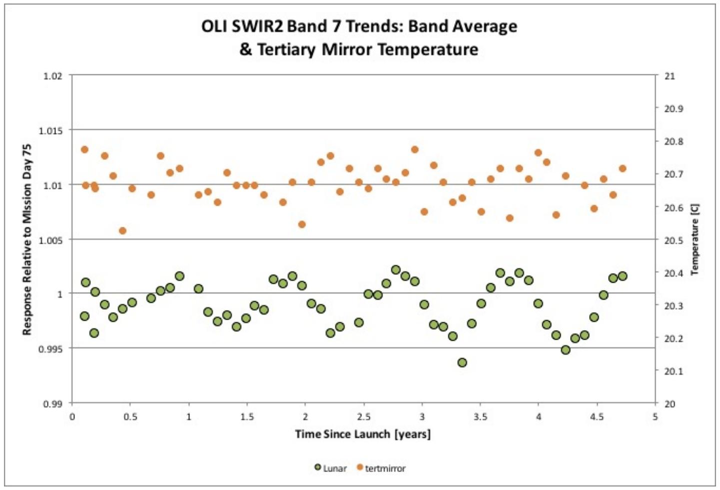


*Calcon Workshop on Lunar calibrations 2006;
IEEE JSTARS EO-1 Special Issues June 2003 & April 2013

Higher uncertainties in the SWIR Bands







The observed quasi-seasonal variations in SWIR2 does not appear to be correlated to temperature effects

Development of SLIM Lunar Irradiance Model

Hugh H. Kieffer
Celestial Reasonings
hhkieffer@gmail.com
775-782-0767

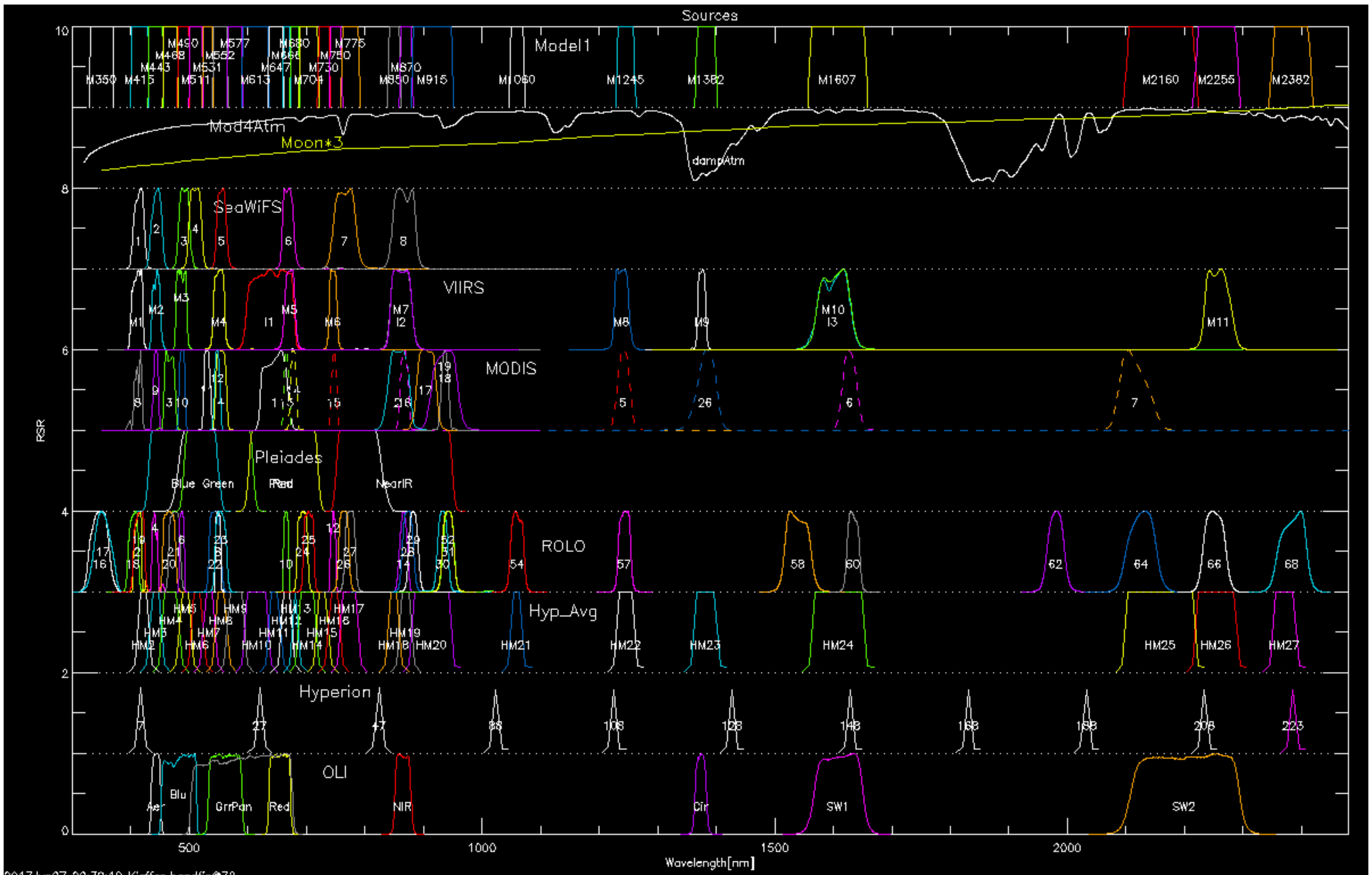
- Spacecraft and Earth-based Lunar Irradiance Model, SLIM
- Support any bands in the 330-2500 nm region
- Based on as many spacecraft as possible
- Follow many of the concepts used by be ROLO
- But, treat ROLO data as just another instrument (current effort uses version 3)
- Use a structure that can readily incorporate additional instruments

There is only one Moon
We need to develop our best estimate of what it is

On-going model improvement effort

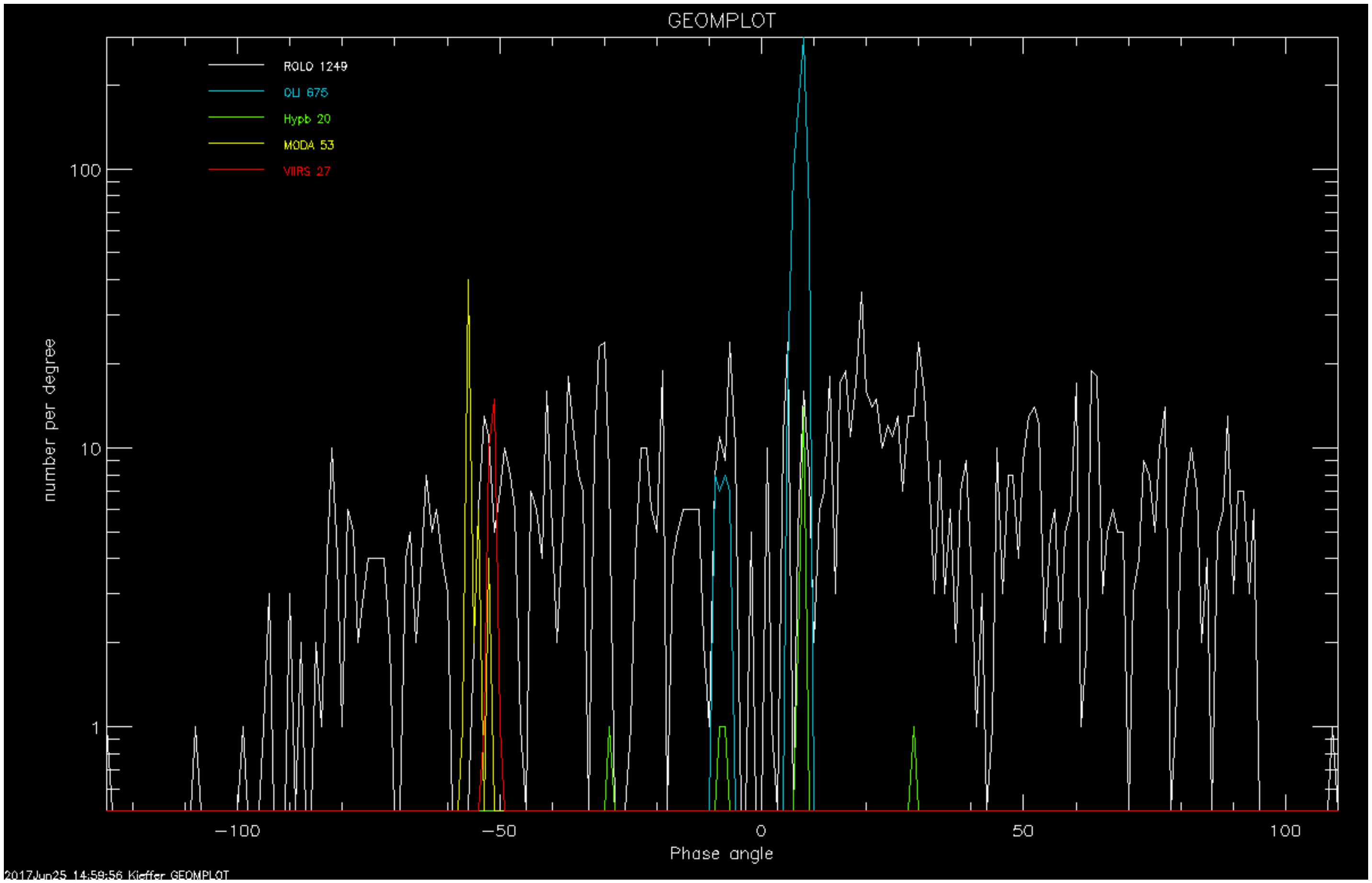
Modeling considerations -

1. Spectral coverage of model input data



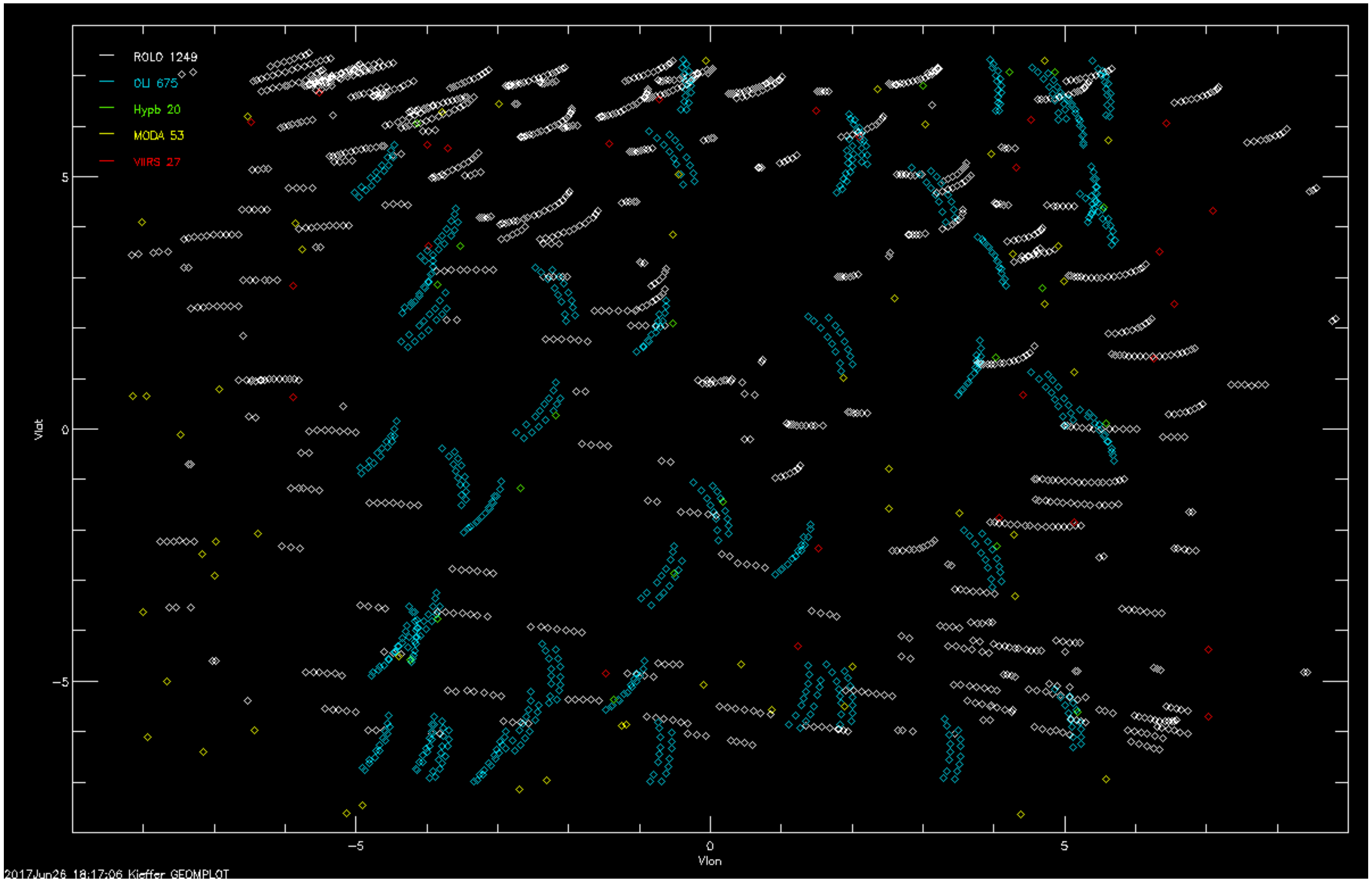
Model Considerations - continued

Phase angle coverage



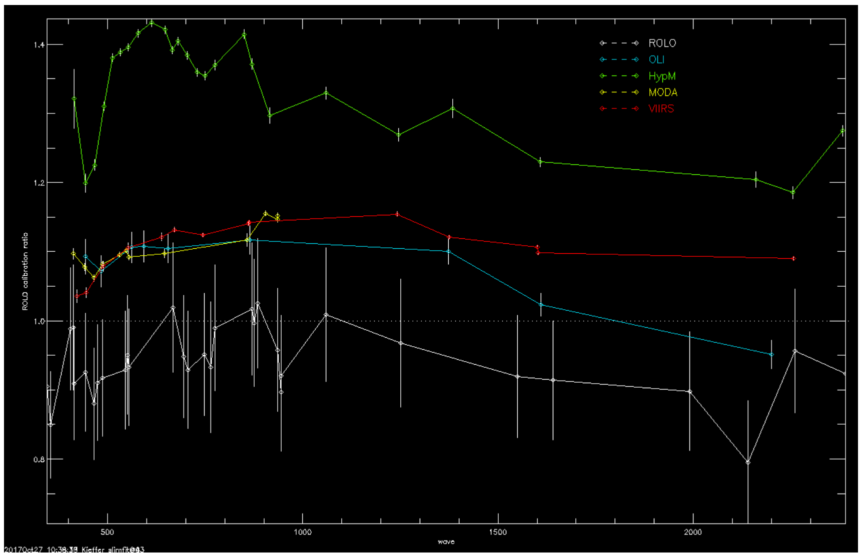
Model considerations- continued

Libration coverage



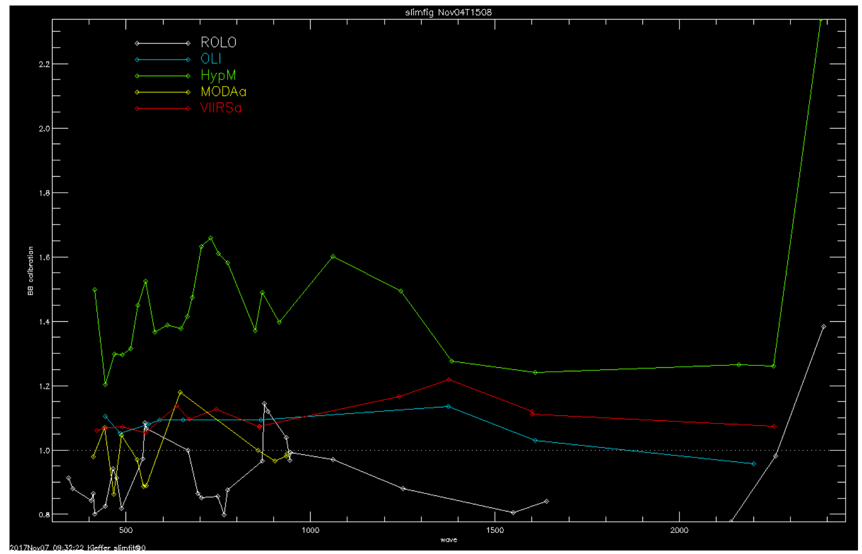
Very preliminary results

Current Rolo model



Using only OLI, Hyperion, MODIS and VIIRS

Does not include non-linear terms, eg the phase angles, residuals for solar longitude, etc.



Difference Ratio

Wavelength [nm]

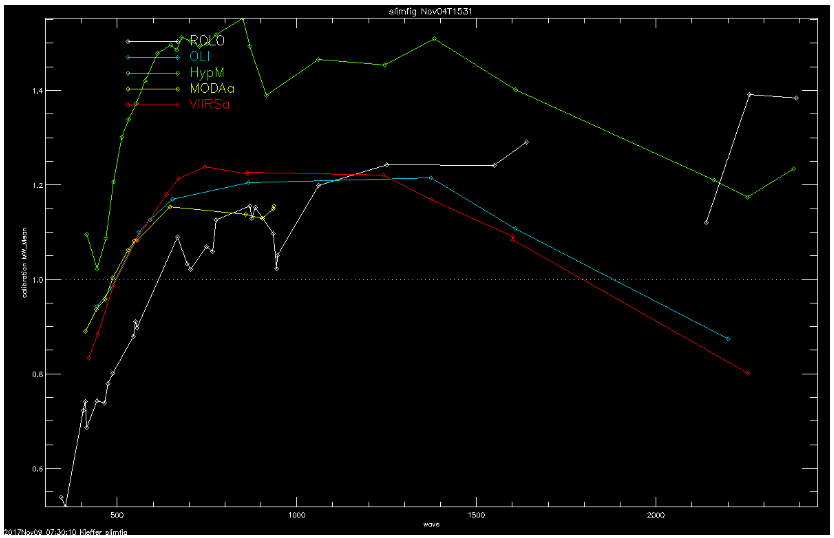
Very preliminary SLIM results

Using only OLI, Hyperion, MODIS and VIIRS

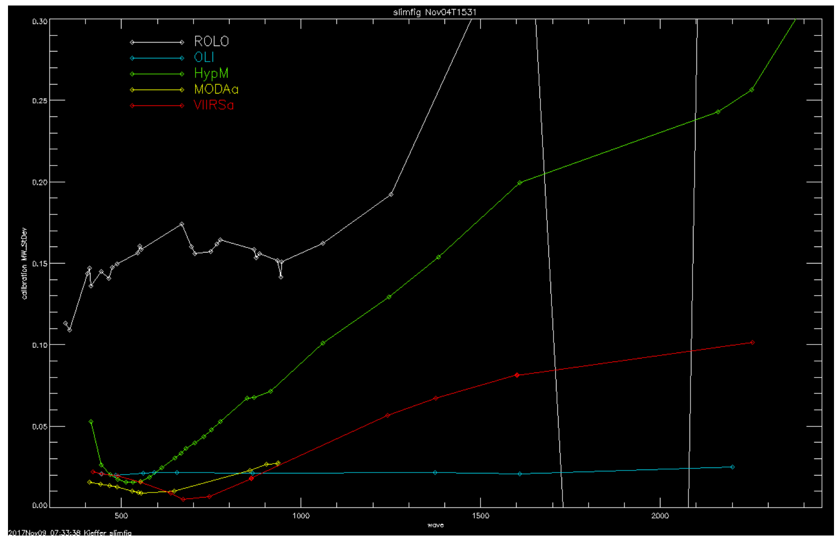
Does not include non-linear terms, eg the phase angles, residuals for solar longitude, etc.

Continuous wavelength coefficients

Input Data/SLIM



Standard deviation



Philosophic Issues/Future work

- How to adjust for large differences in the number of data points for an instrument,
  - ROLO: 1239, 32 bands each
  - OLI: 675, 9 bands
  - Hyperion: 20, 196 bands reduced to 26
  - MODIS-Aqua: 53, 12 bands provided
  - VIIRS: 27, 14 bands
- How to account for the different uncertainties among the datasets
  - Use calibration residual level to refine the uncertainty for next iteration.
- How to join the band-by-band results spectrally in a plausible manner.
  - Lab measurements of the Lunar photometric properties are smooth across wavelengths
  - The first attempt yielded promising results
- Incorporate other datasets including those from GOES, Pleiades, and others who would like to contribute to the effort.

Other uses for Lunar Observations

Landsat 8 Thermal Infrared Sensor (TIRS)

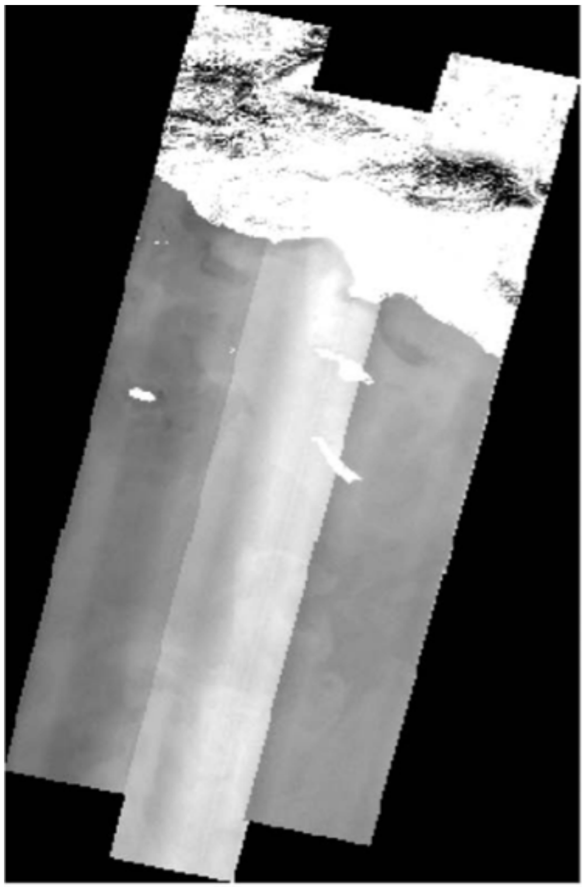
Stray Light Correction

- Aaron Gerace
- Matthew Montanaro

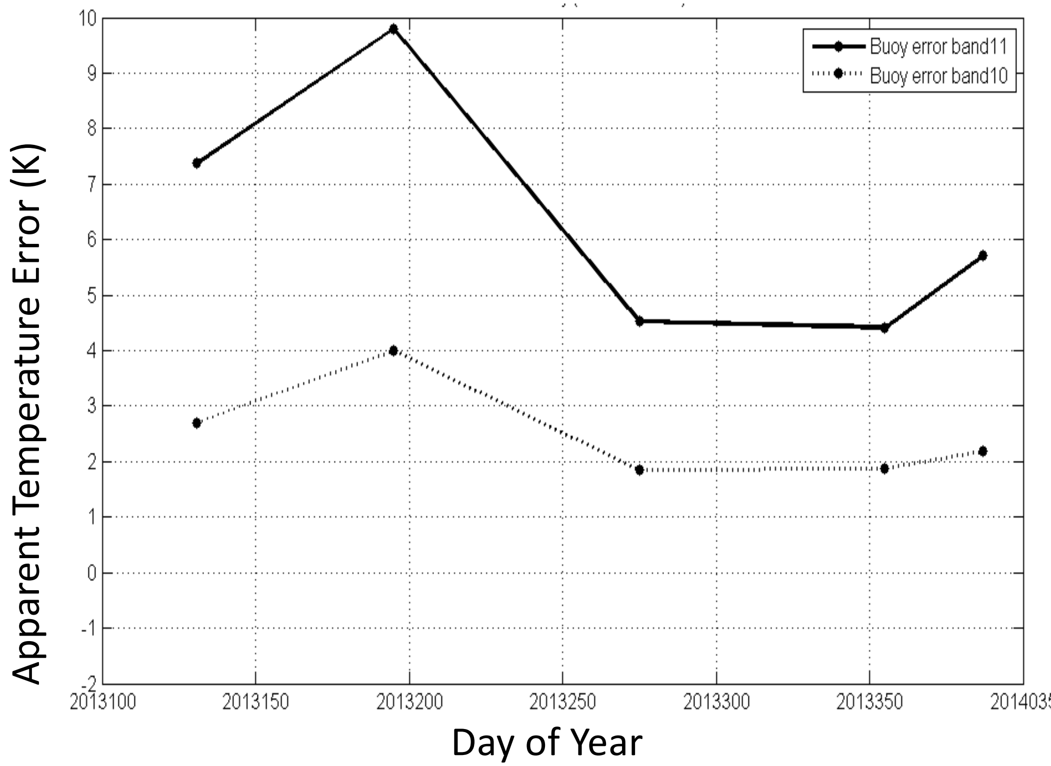
Image artifacts indicate straylight issue

Two major artifacts:

1. Non-Uniform Banding

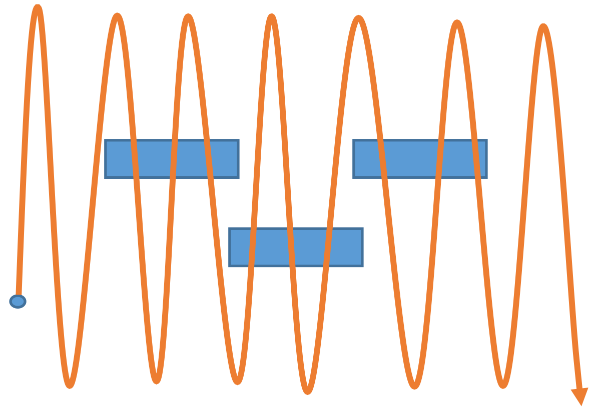


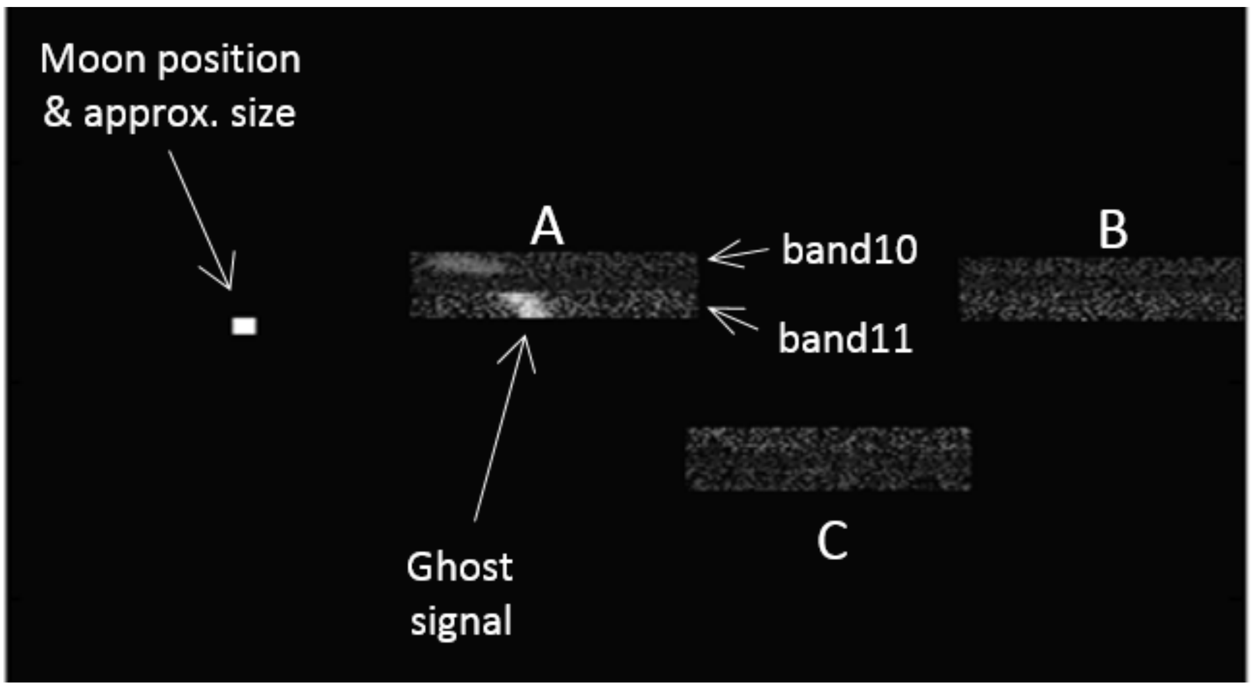
2. Absolute Calibration Error



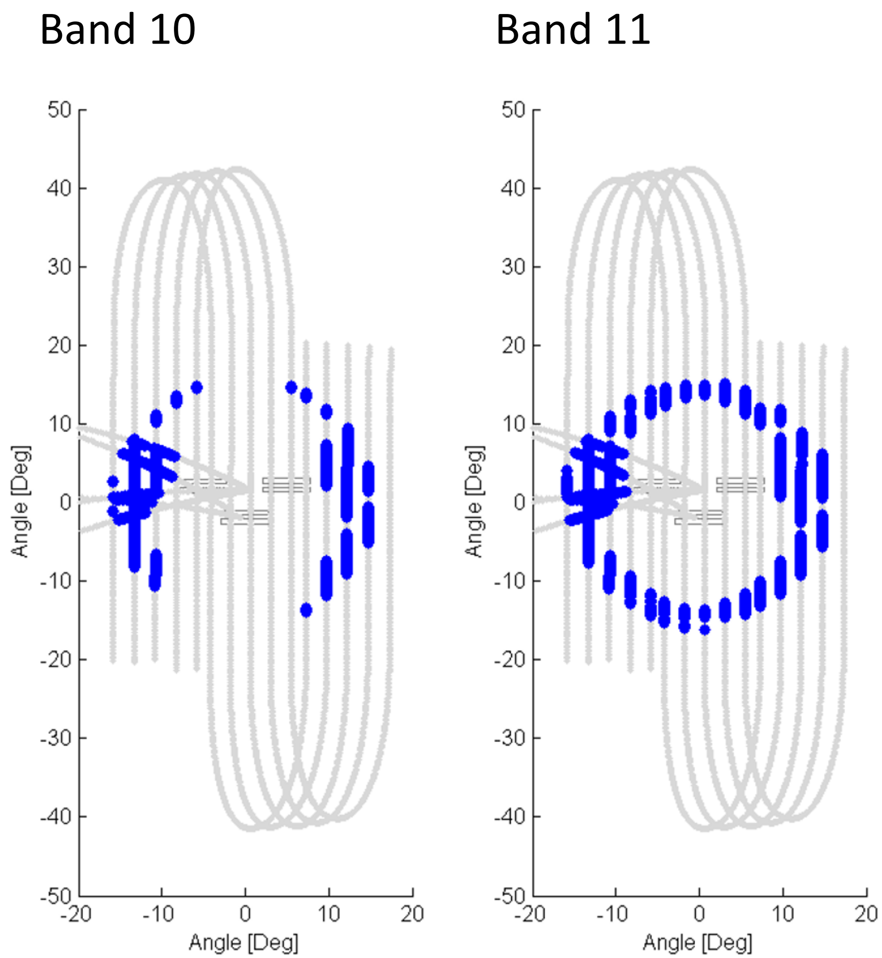
Lunar raster scan definitively showed stray light

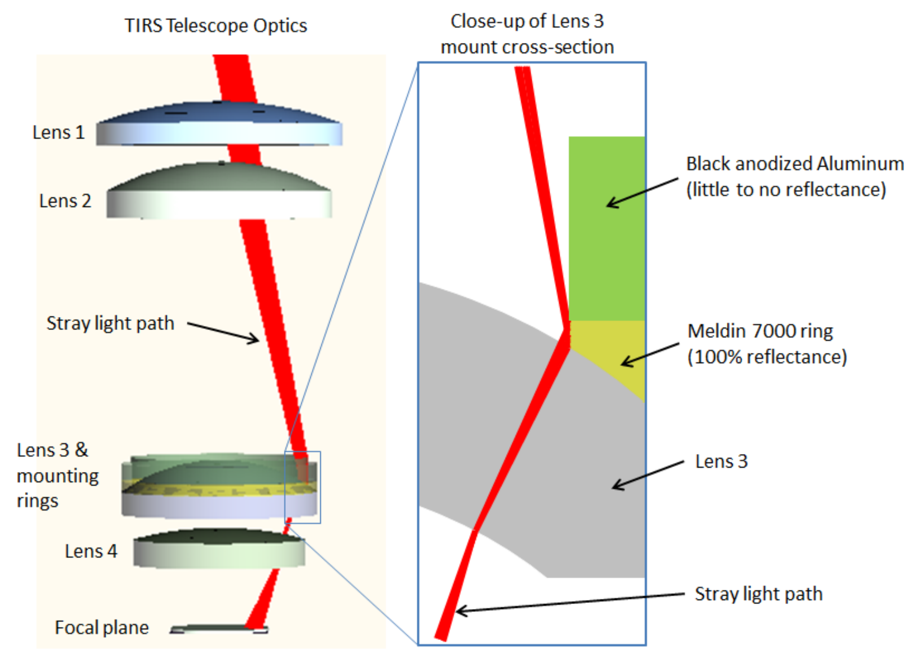
- Raster-scan the moon around the out-of-field
- Should see “nothing” when moon is outside field-of-view





Map of stray light locations from lunar positions

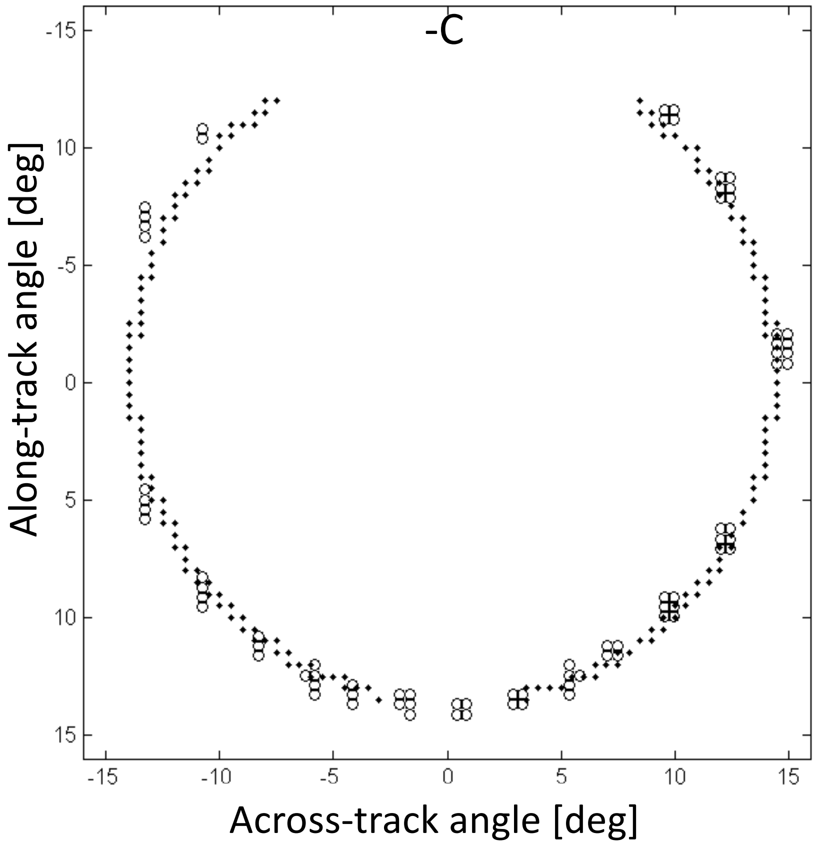




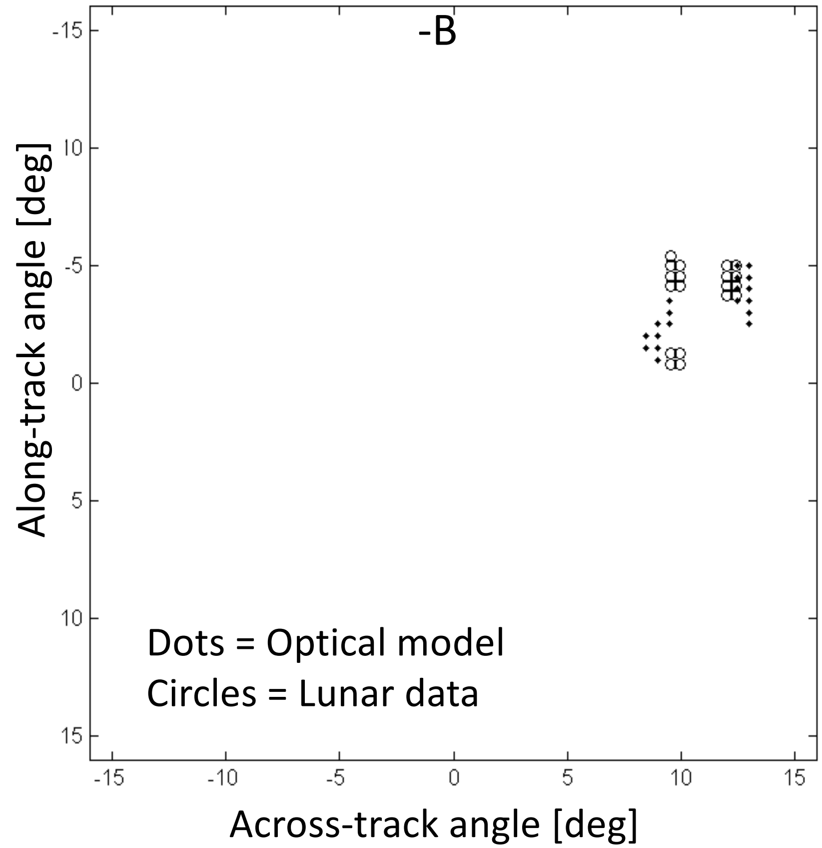
Lunar locations (blue) in which a stray light signal appeared anywhere on the detectors

Reverse ray trace produces stray light map for each detector

Stray light map for one detector on array

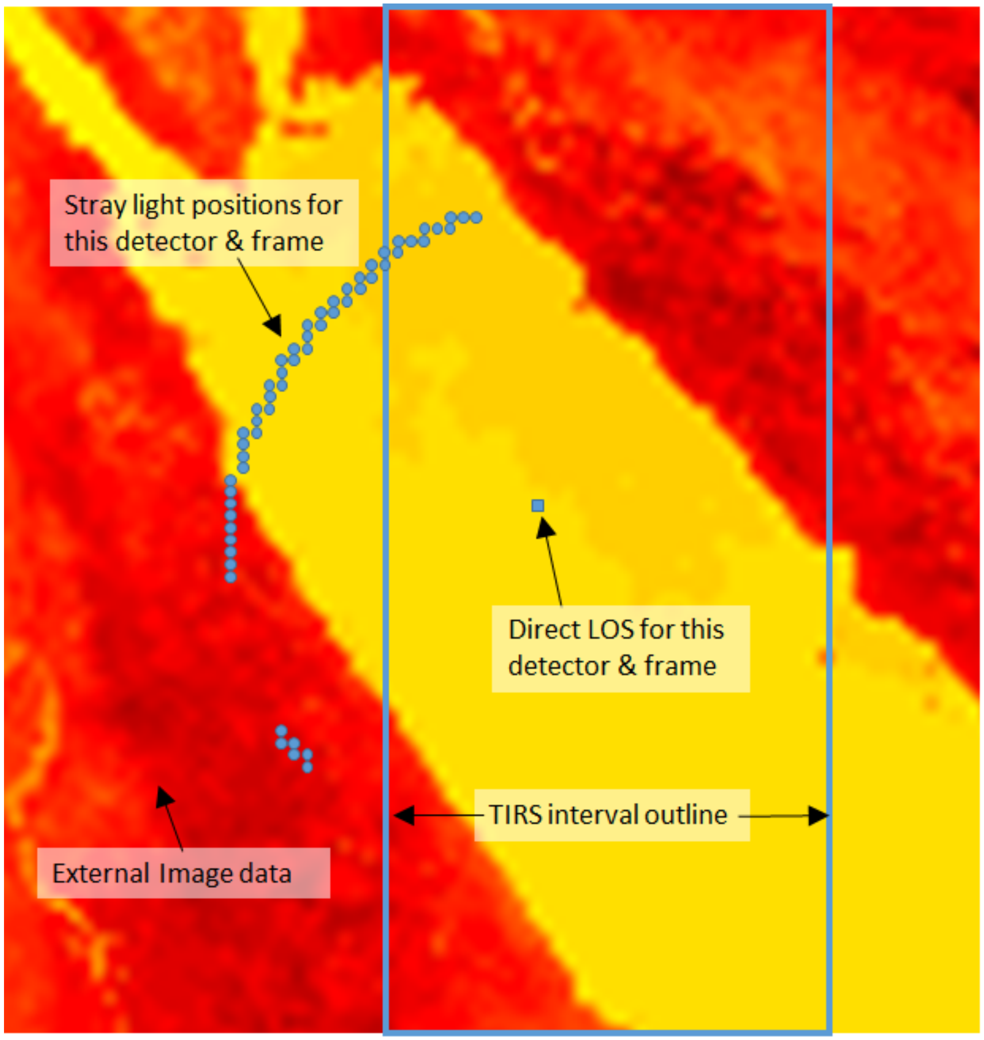


Stray light map for one detector on array



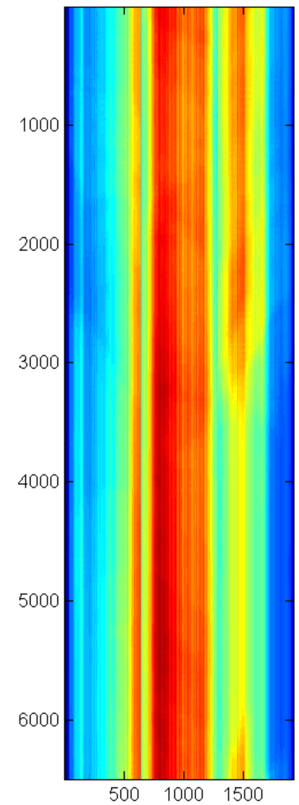
* Unique PSF for each detector (i.e.- different stray light signal for every detector)

Stray light removal algorithm: Optical model with out-of-field data

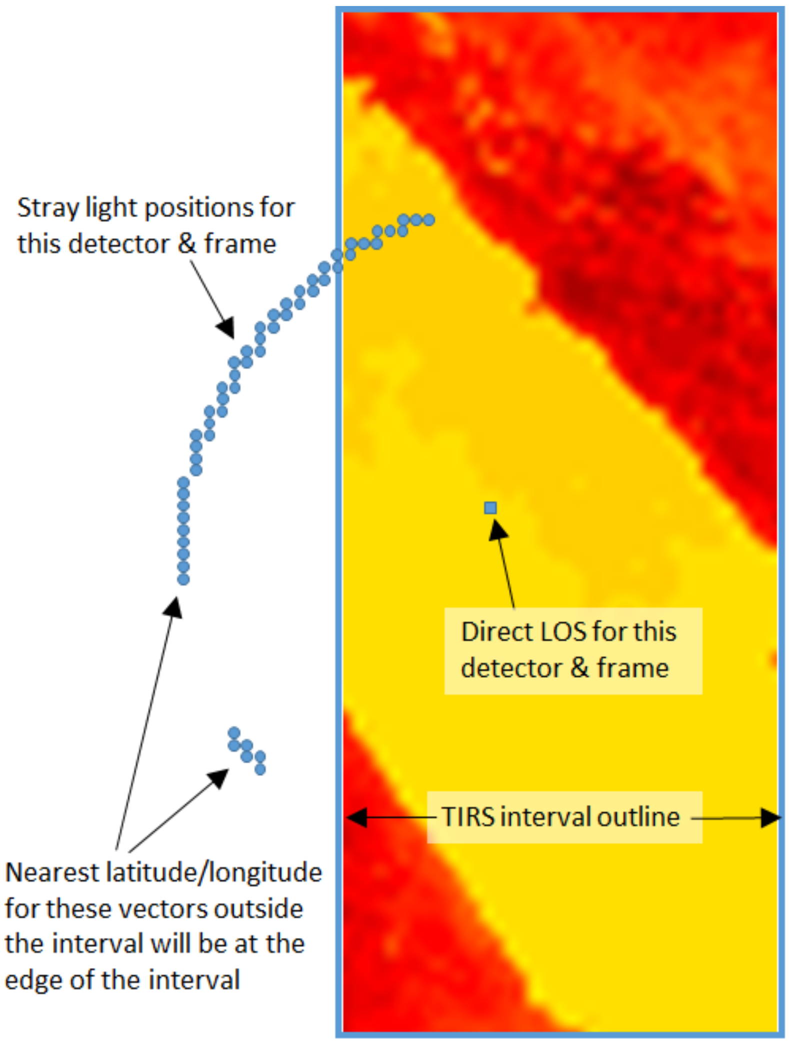


$$StrayLight = a \cdot (Ext.Sampled) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i\right) + b$$

Calculated signal to remove from TIRS interval

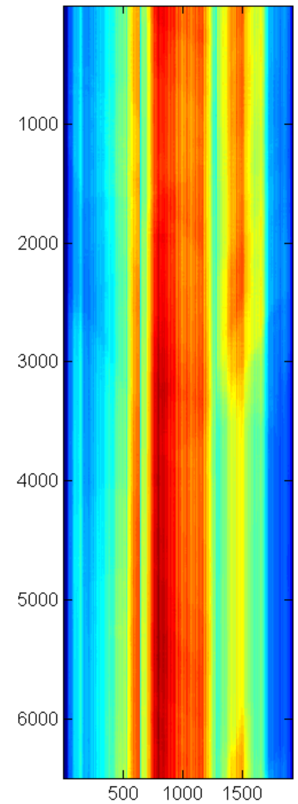


Stray light removal algorithm: Optical model with TIRS data only

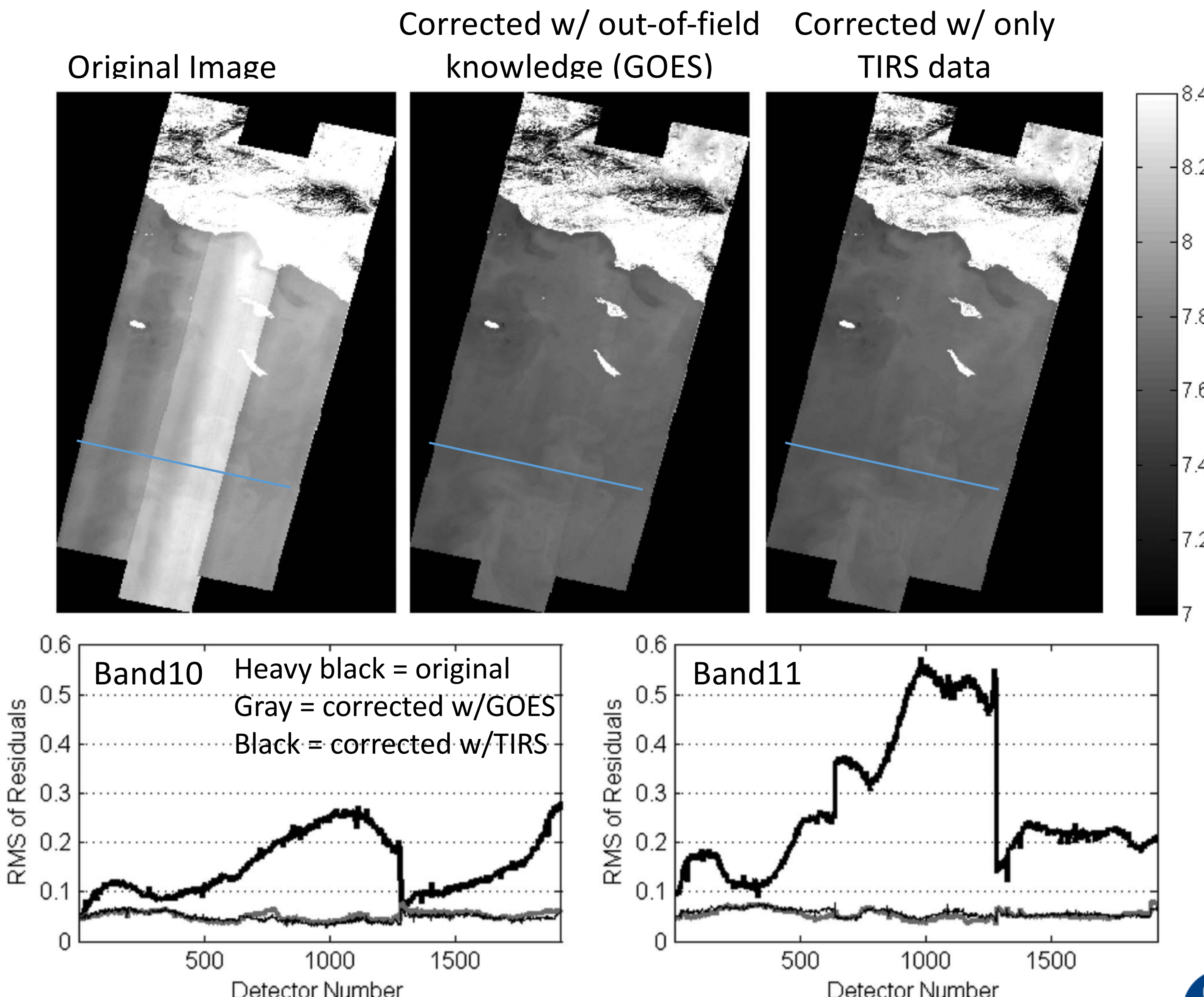


$$StrayLight = a \cdot (Ext.Sampled) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i\right) + b$$

Calculated signal to remove from TIRS interval

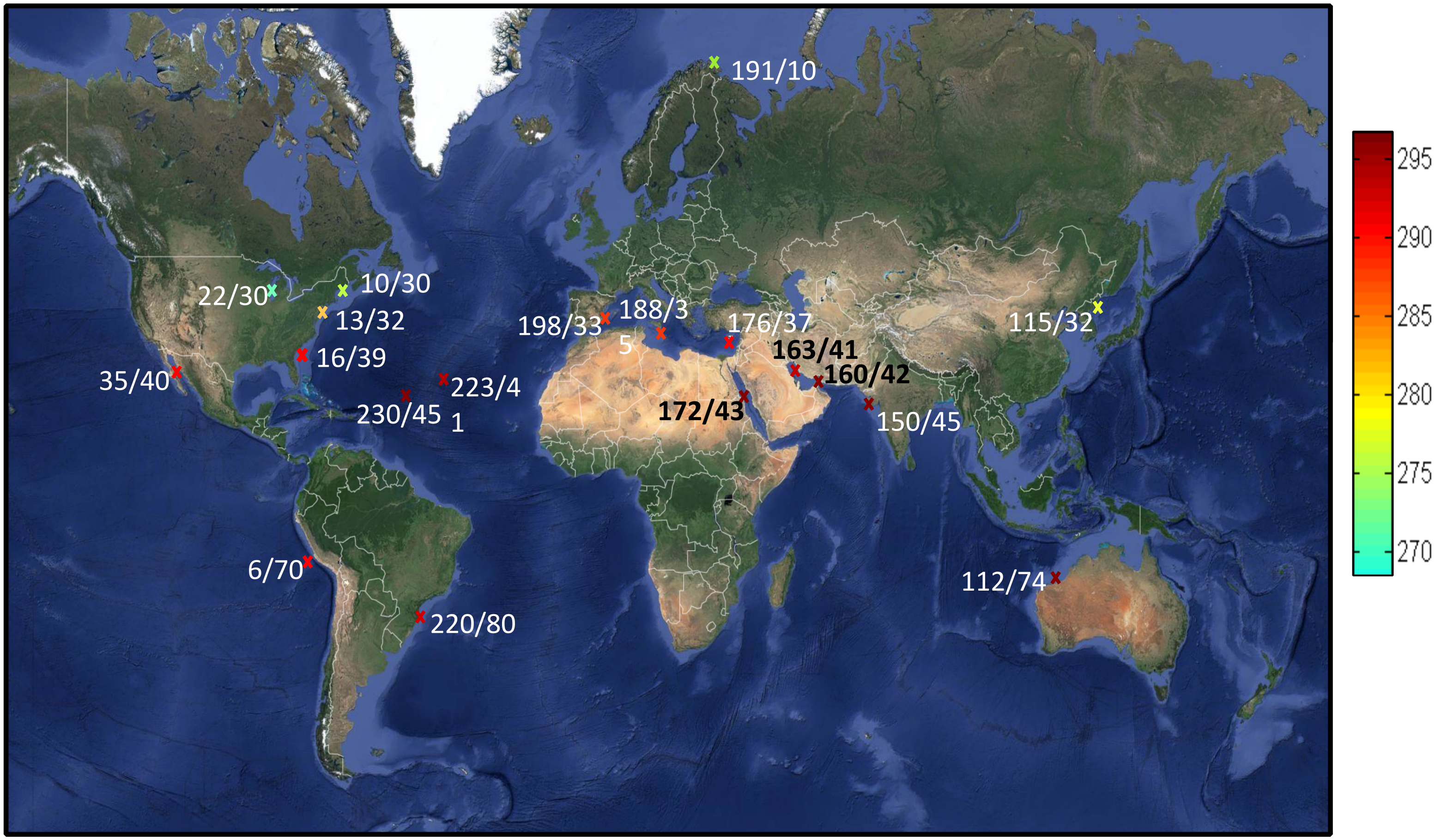


Stray light correction with and without out-of-field knowledge

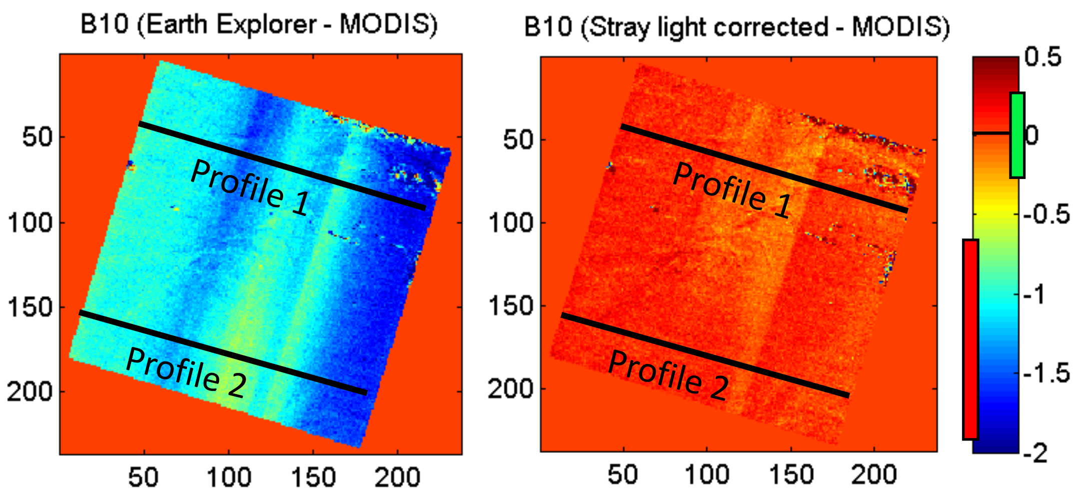


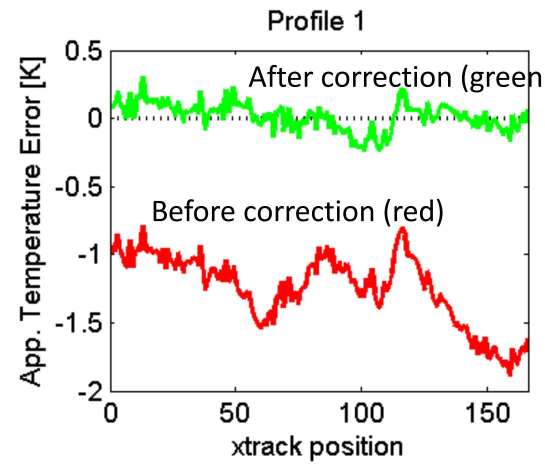
Full Scene Correction Validation

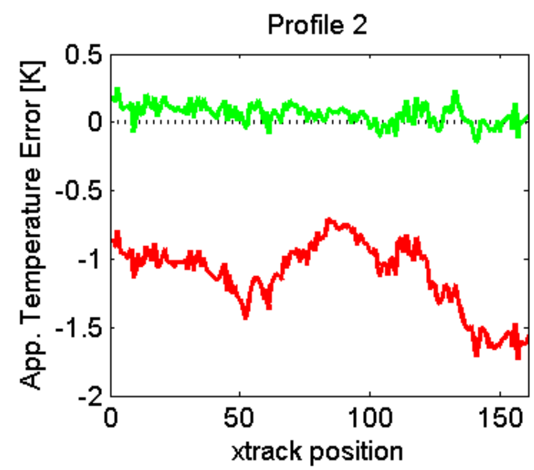
- During L8/Terra underfly period, TIRS centered on MODIS field-of-view
- Compare TIRS current product and corrected product to Terra/MODIS for all of the following locations:

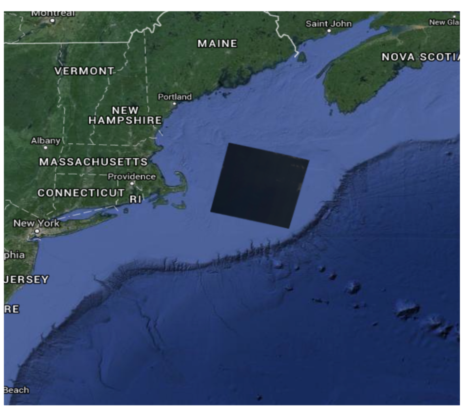


Example validation data using Path 010, Row 030: Band 10



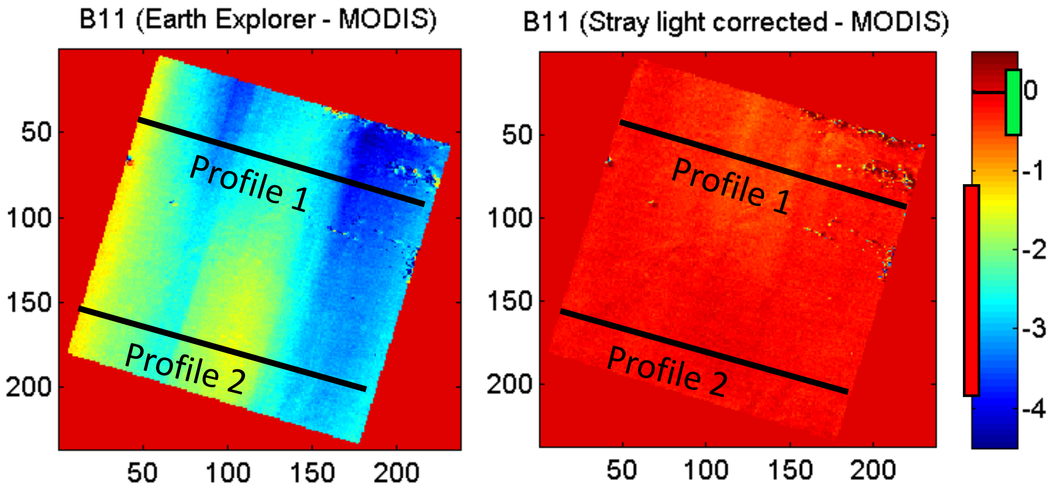


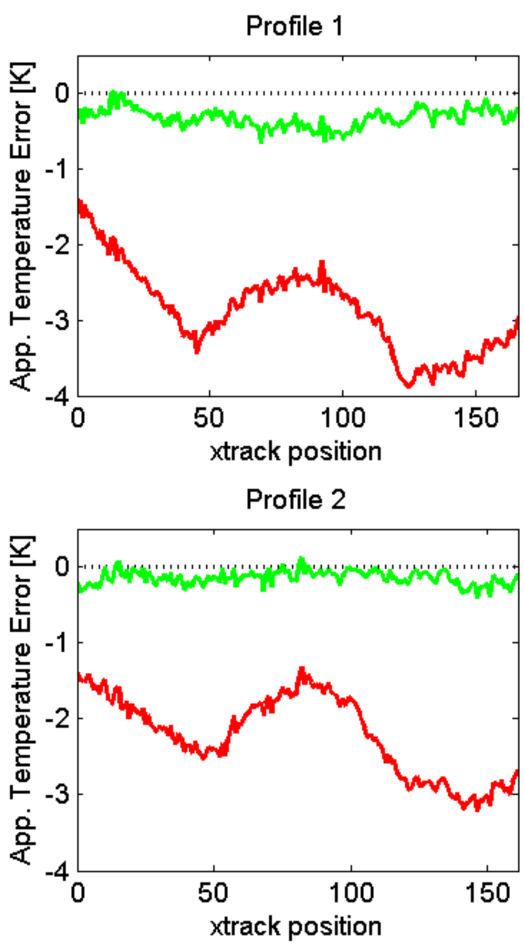


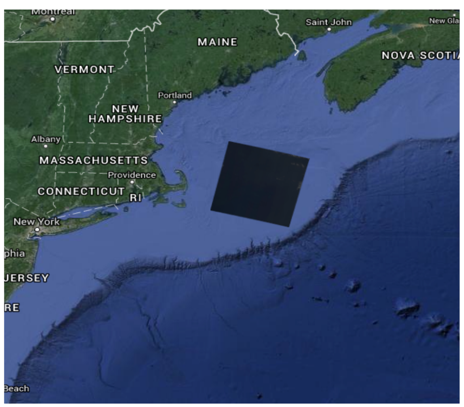


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.258	0.102	1.275	0.103	-1.248	0.013
Profile 2	0.253	0.074	1.145	0.094	-1.117	0.058

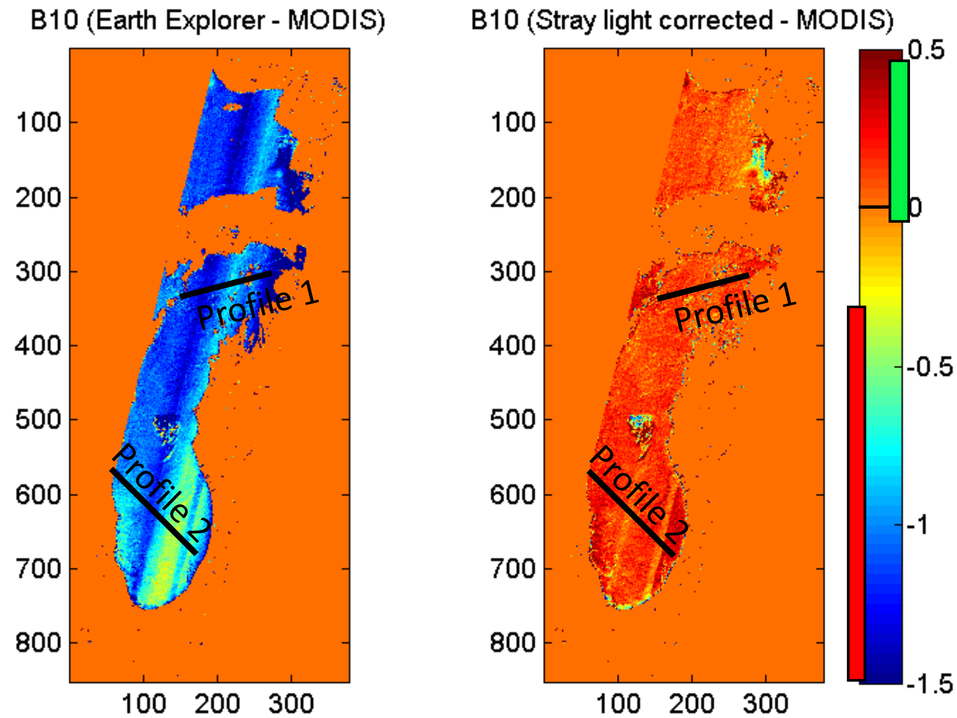
Example validation data using Path 010, Row 030: Band 11

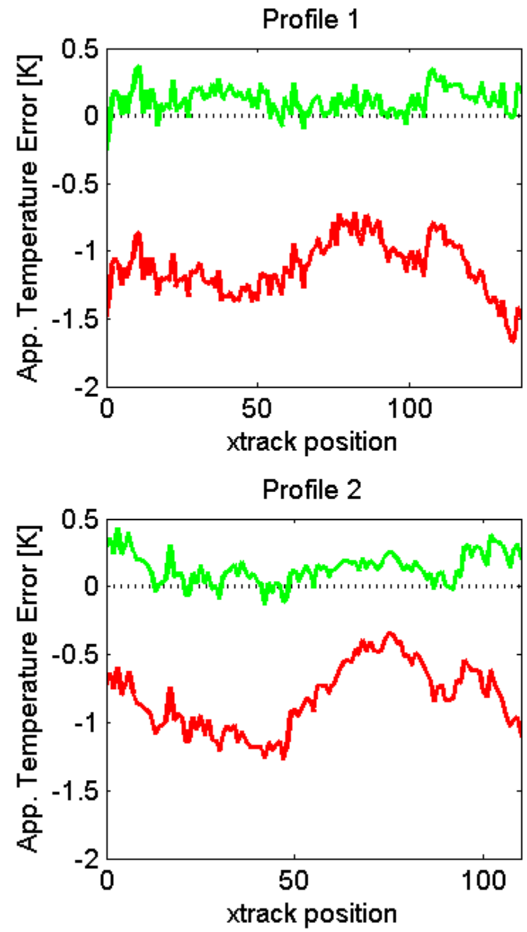


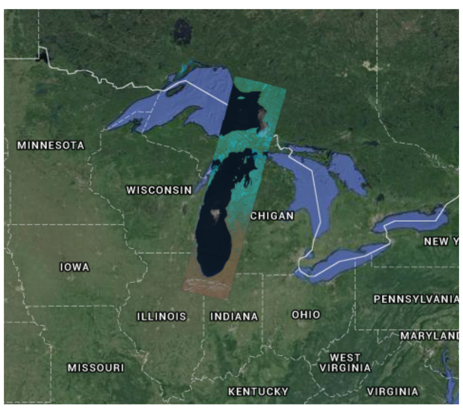




	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.573	0.127	2.935	0.357	-2.879	-0.334
Profile 2	0.529	0.093	2.281	0.175	-2.220	-0.149

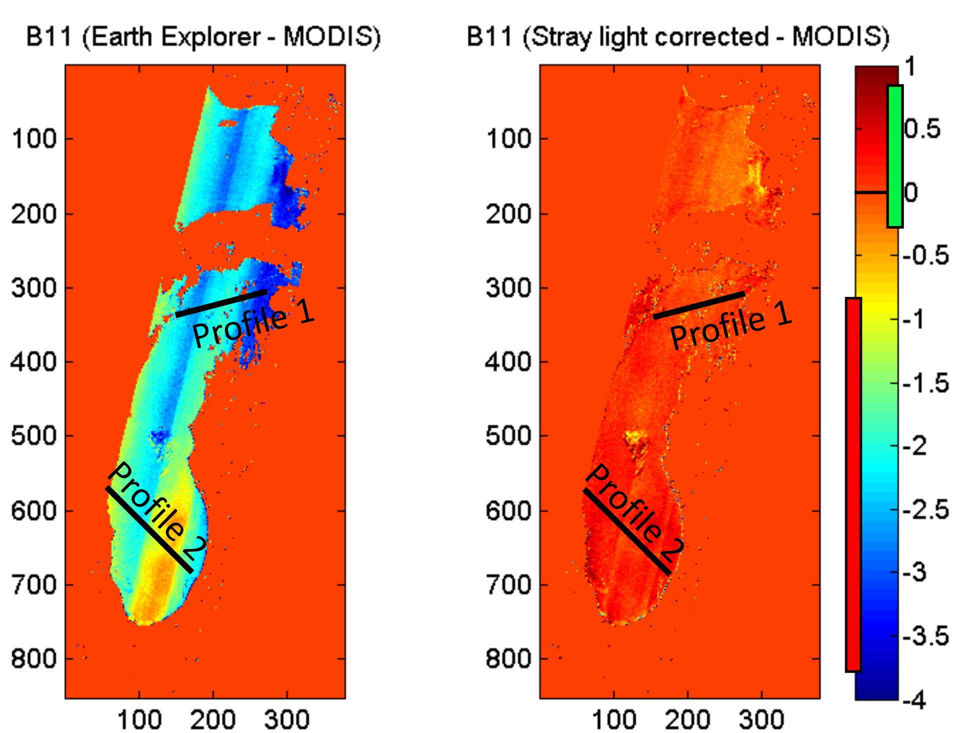


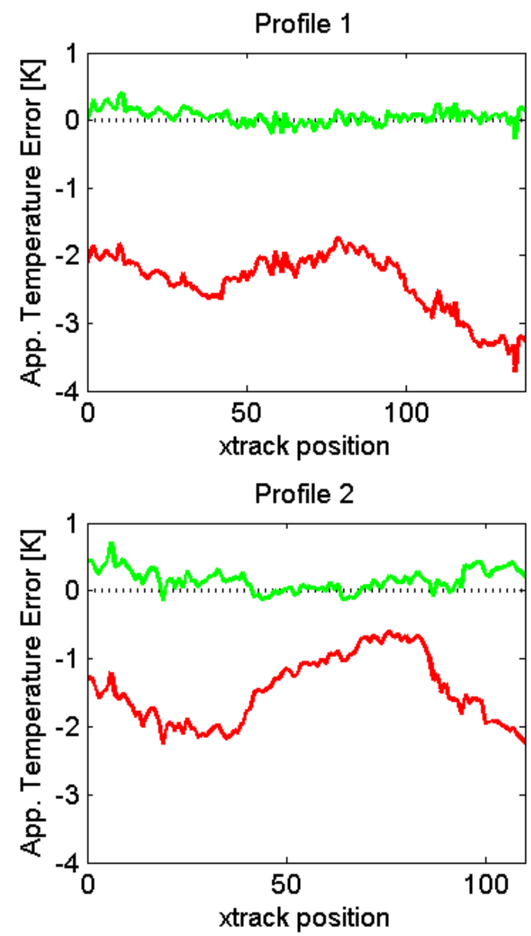


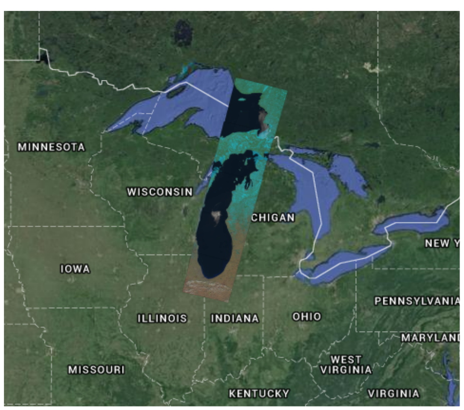


	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.201	0.101	1.141	0.151	-1.123	0.113
Profile 2	0.246	0.114	0.856	0.176	-0.820	0.135

Example validation data using Path 022, Row 030: Band 11







	Std. Deviation [K]		RMS Error [K]		Mean Error [K]	
	Current	Corrected	Current	Corrected	Current	Corrected
Profile 1	0.451	0.113	2.448	0.124	-2.406	0.054
Profile 2	0.494	0.163	1.552	0.227	-1.472	0.158

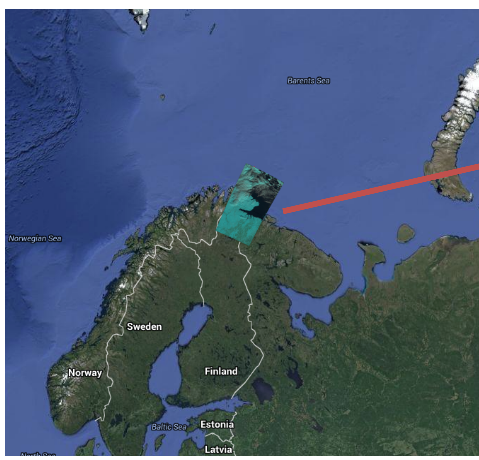
RMSE summary (“absolute calibration”):

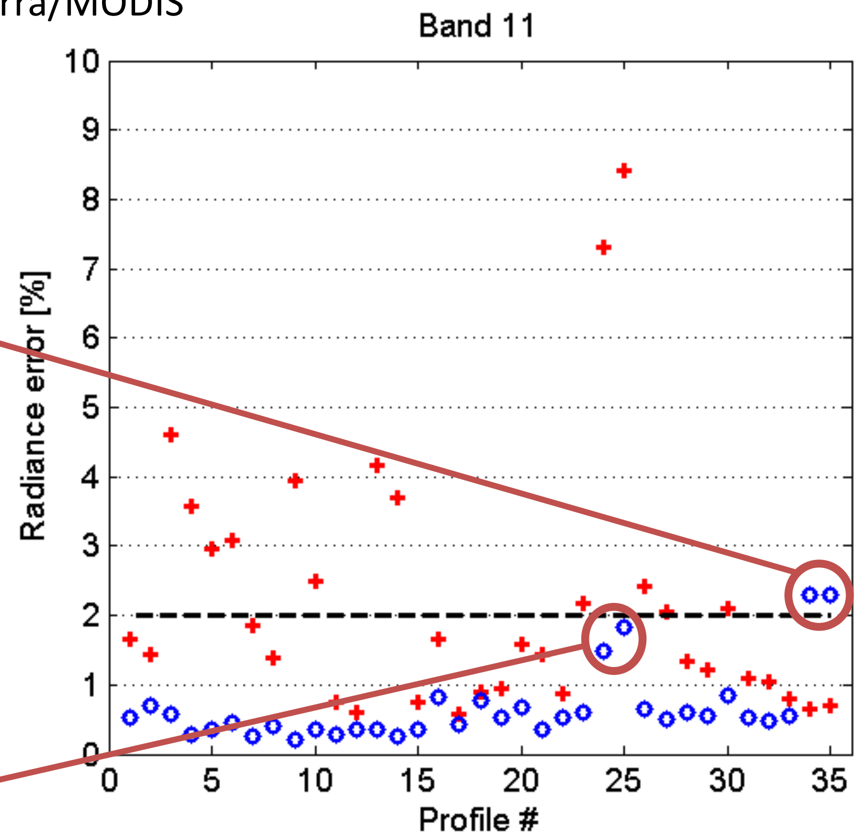
In terms of <u>Percent Radiance</u> error with Terra/MODIS

Large difference between TIRS and MODIS due to the Earth changing between the two overflight times

Path 198 desert

Path 191 clouds





+ Current Product

o Stray Light Corrected

Correction Algorithm Summary

- Algorithm uses only TIRS interval data (no other sensor data) with optical model
- Able to be run in "real time" (i.e.- no significant processing lag) to produce corrected TIRS scenes
- Significant issues with external sensor (e.g. - GOES) data limit its utility:
  - Band shape
  - View angle
  - cross-cal between sensors required for global coverage
- TIRS-on-TIRS was implemented into USGS ground processing system. Products available through "Landsat 8 Collection 1" data archive.
- Validated correction using Terra/MODIS data during the Terra/Landsat 8 under-flight period following launch.

TIRS Stray light references

Publications:

- Gerace, A., Montanaro, M., & Connal, R. (2017). Leveraging intercalibration techniques to support stray-light removal from Landsat 8 Thermal Infrared Sensor data. *Journal of Applied Remote Sensing*, 12(1), 012007. [doi: 10.1117/1.JRS.12.012007]
- Gerace, A., & Montanaro, M. (2017). Derivation and validation of the stray light correction algorithm for the Thermal Infrared Sensor onboard Landsat 8. *Remote Sensing of Environment*, 191, 246-257. [doi: 10.1016/j.rse.2017.01.029]
- Montanaro, M., Gerace, A., & Rohrbach, S. (2015). Toward an operational stray light correction for the Landsat 8 Thermal Infrared Sensor. *Applied Optics*, 54(13), 3963-3978. [doi: 10.1364/AO.54.003963]
- Montanaro, M., Gerace, A., Lunsford, A., & Reuter, D. (2014). Stray light artifacts in imagery from the Landsat 8 Thermal Infrared Sensor. *Remote Sensing*, 6(11), 10435-10456. [doi:10.3390/rs61110435]

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Summary

- Landsat-8 approaching 5 years of service
- OLI-2 is stable
  - Good agreement among all calibration devices
  - Higher uncertainty for the SWIR bands in the lunar data
- On-going effort to improve the model for both relative and absolute radiometry
  - Developing algorithms to incorporate differences among the instruments/data sources.
- Lunar observations was useful to examine and diagnose image artifacts in both the OLI and, especially for the TIRS
  - Straylight correction routine for successfully incorporated in the Landsat-8 TIRS image products.

Landsat Calibration Validation Team

- USGS Earth Resources Observation and Science (EROS)
  - http://landsat.usgs.gov/
- NASA Goddard Space Flight Center (GSFC)
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- NASA Jet Propulsion Laboratory (JPL)
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- Rochester Institute of Technology (RIT)
  - http://www.cis.rit.edu/
- South Dakota State University (SDSU) Image Processing (IP) Laboratory
  - http://iplab2out.sdstate.edu/
- University of Arizona (UofA) Optical Sciences Laboratory
  - http://www.optics.arizona.edu/

- Thank you