Landsat 8 Calibration and Validation: 2 years on orbit

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***Work performed under U.S. Geological Survey contract G10PC00044**

Overview

- **Landsat 8 Overview**
- **Operational Land Imager (OLI) Overview**
- **Geometric Calibration**
  - Geodetic Accuracy
  - Band Registration Accuracy
  - Geometric Accuracy
  - OLI Edge Slope Response
- **OLI Radiometric Calibration**
  - Radiometric Stability and Absolute Calibration
  - In-orbit Calibration Trends
- **TIRS Radiometry**
  - Radiometric Performance
  - TIRS Stray Light (Ghosting)
  - TIRS Scene Select Mirror Encoder Anomaly

Landsat 8

Landsat 8 Launched from Vandenberg AFB on February 11, 2013

After 2 years on orbit L8 is performing well.

Manufactured by:
Ball Aerospace & Technologies
NASA Goddard Space Flight Center
Orbital Sciences Corp

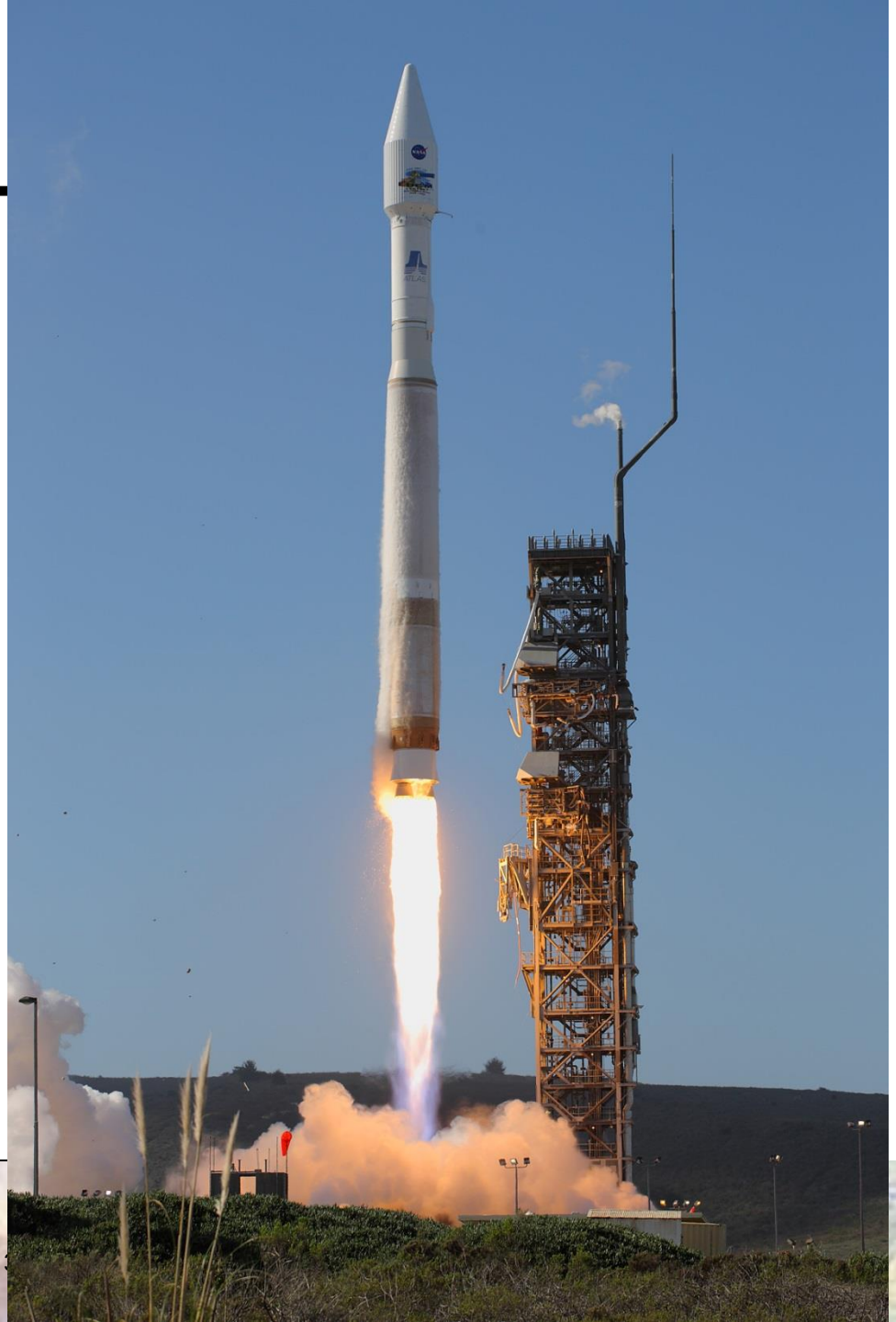
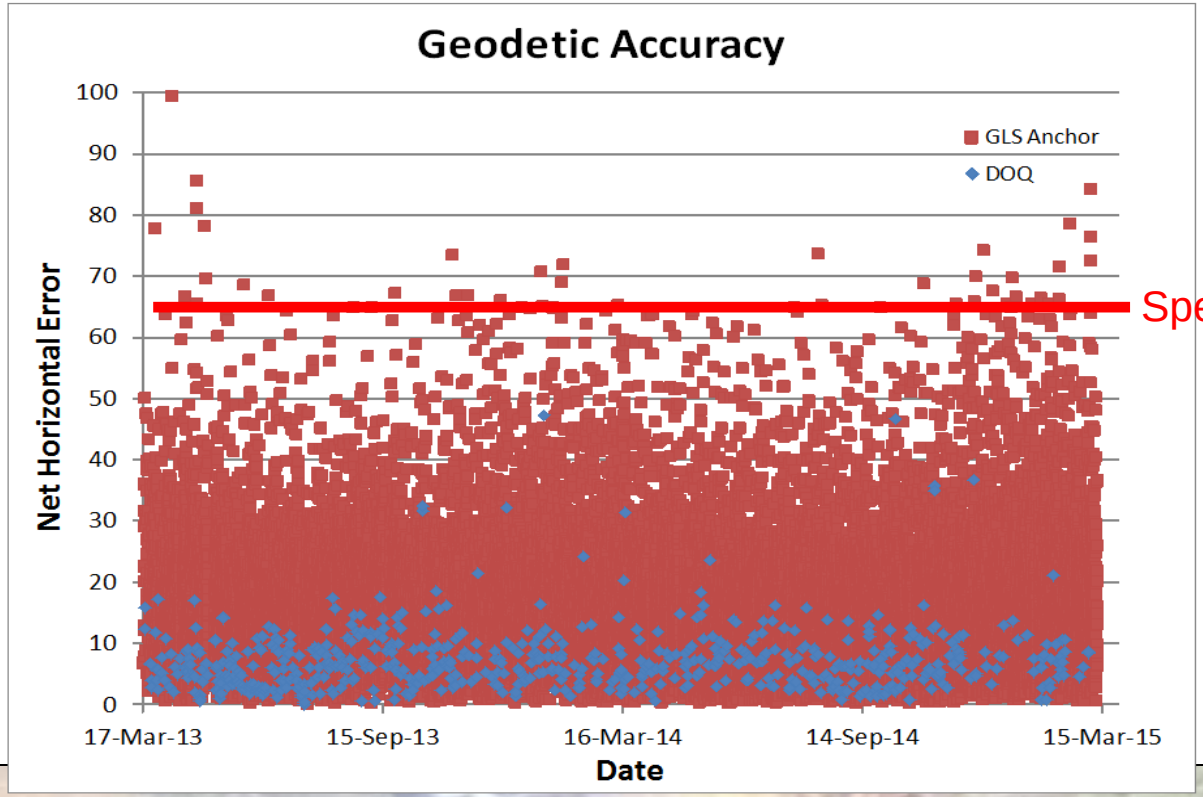


Image Assessment System (IAS)

- **IAS is the Calibration system for the Landsat mission**
  - Data characterization and calibration code was written for Radiometric, Geometric, Spectral, and Spatial aspects of Cal Val.
- **IAS Database**
  - Landsat 8 is automated to process every product through the IAS to a database
  - Geometric / Radiometric Characterization database
    - Per detector, Per SCA or Per Scene statistics trended
    - Histogram Stats trends per detector
  - Geometric Char: 20 data aspects are trended
    - Band Char, Band Cal, Focal Plan Char and Cal, Geodetic Char and cal, Image Char and Cal, MTF bridge info, Model Generation, Sensor Alignment, Precision model correction, and TIRS alignment
  - Radiometric characterizations 41 aspects are trended
    - Bias, Detector mapping, Gain, Histogram Stats, Impulse Noise, Lamp Response, Lunar characterization, NEDL, uniformity, Overlap stats, PICS, ROLO characteristics, Saturated pixels, SNR char, solar char, striping.
    - Hist Stats characterizes for every 95122 detectors in a scene that are characterized.

Geodetic Accuracy Test Scenes

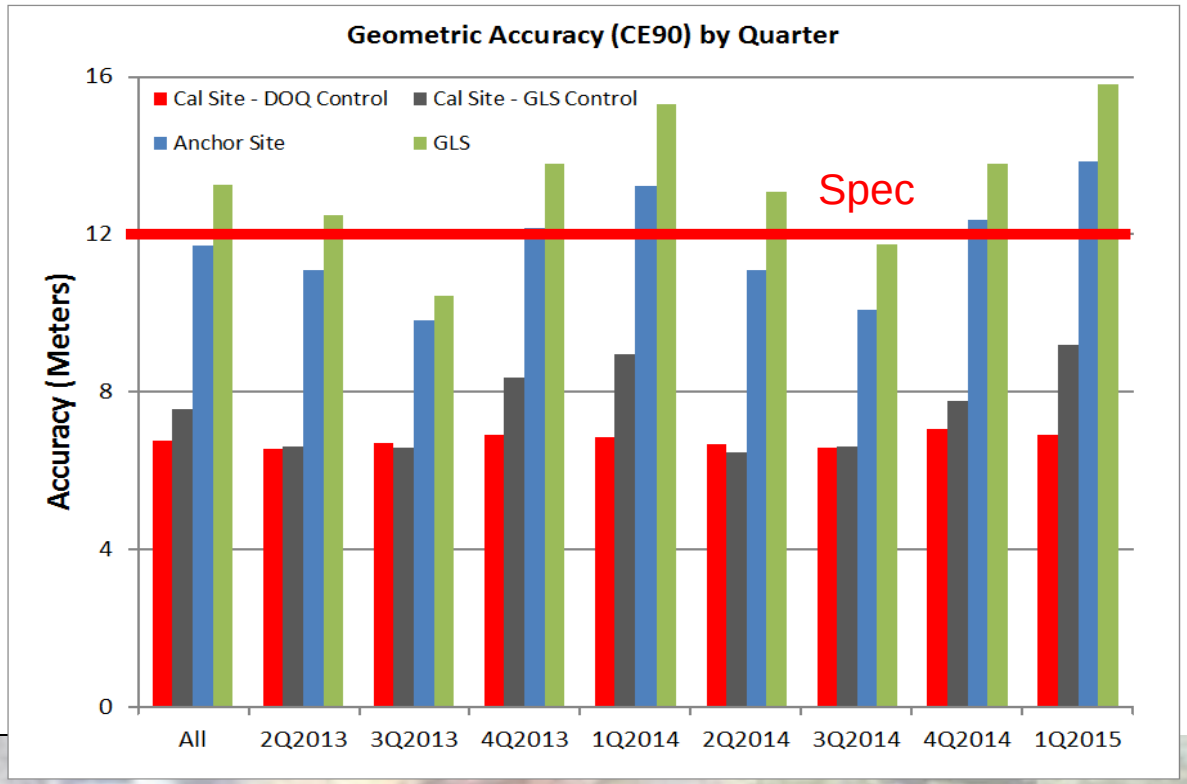
- **Geodetic accuracy measured offsets between OLI L1G (systematic) images and ground control points (GCPs)**
- **39 scenes (of 23329) are off by more than the 65 m CE90 spec:**
  - Accuracy 35.5 m CE90 spec: 65.0 m CE90



Geometric Accuracy by Quarter

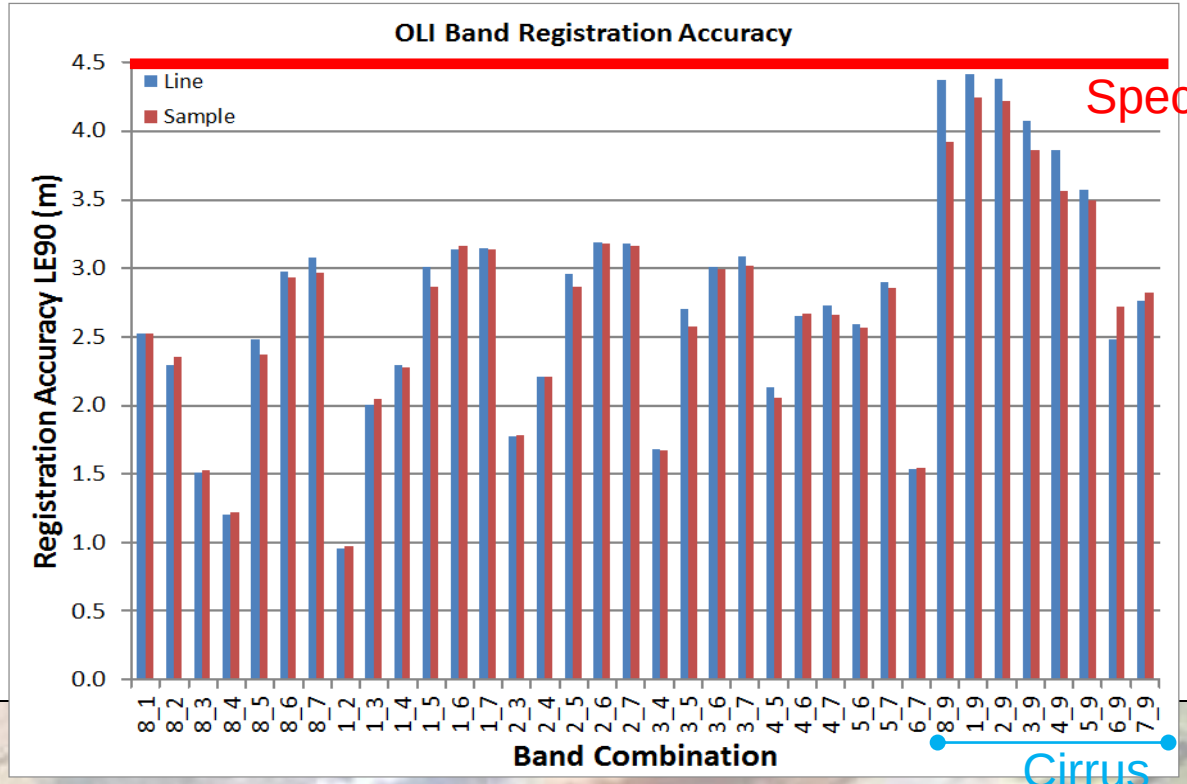
- Based on 636 calibration site scenes (DOQ control): L1T Accuracy:6.8 meters CE90
- Based on Calibration Sites with well known ground control
- Based on 16668 anchor site scenes (GLS control):L1T Acc: 11.7 m CE90 Spec:12.0 m
- Based on All trended L1T GLS fit products regardless of cloud cover

- The measured L8 L1T geometric accuracy results depend upon the type of control points used
- GCP accuracy is a significant contributor to overall measured geometric accuracy



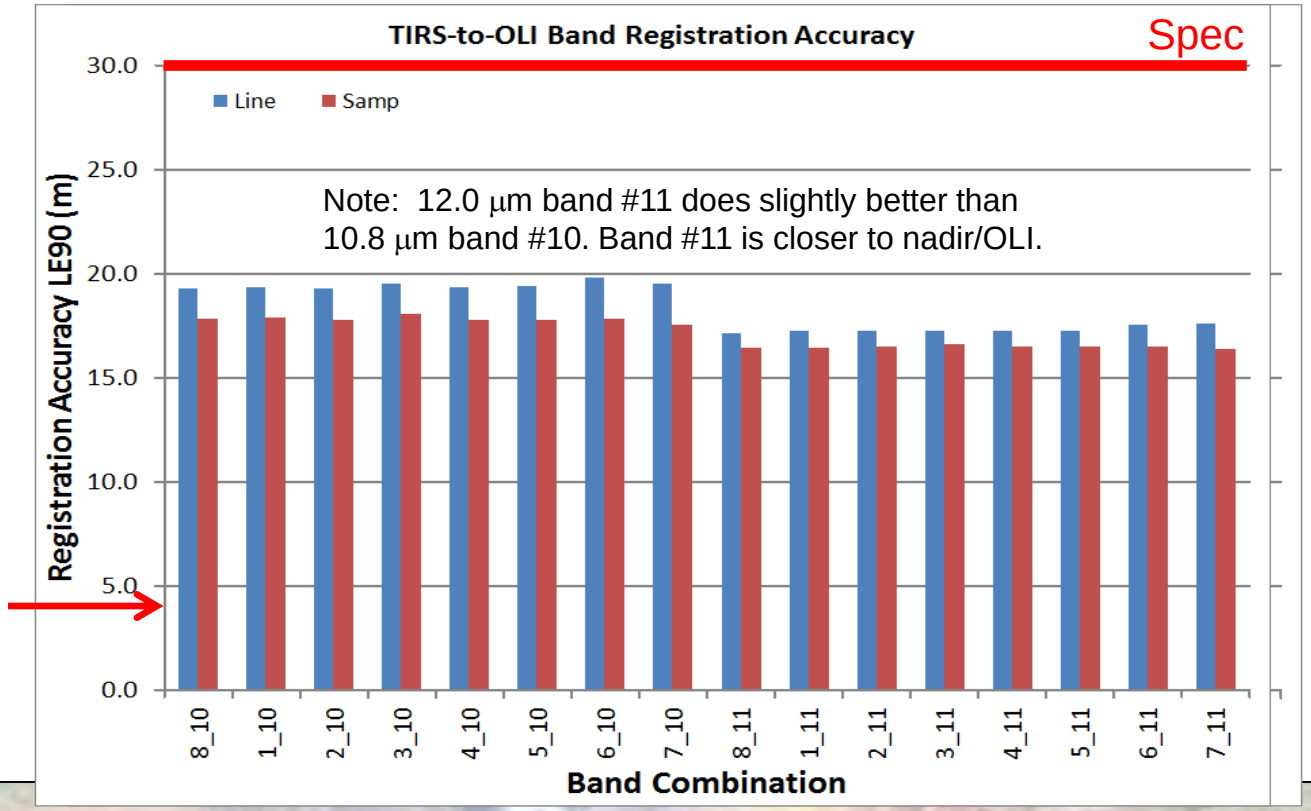
OLI Band Registration by Band Pair

- Band registration accuracy is how well the bands align
- Evaluated using cloud-free scenes of (mainly desert) test sites
- OLI band registration accuracy (worst band pair)
- Line: 4.42 m LE90 Sample: 4.24 m LE90 (cirrus) Spec: 4.50 m LE90 (with cirrus)
- Line: 3.19 LE90 Sample: 3.18 m LE90 Incentive: 3.80 m LE90 (without cirrus)



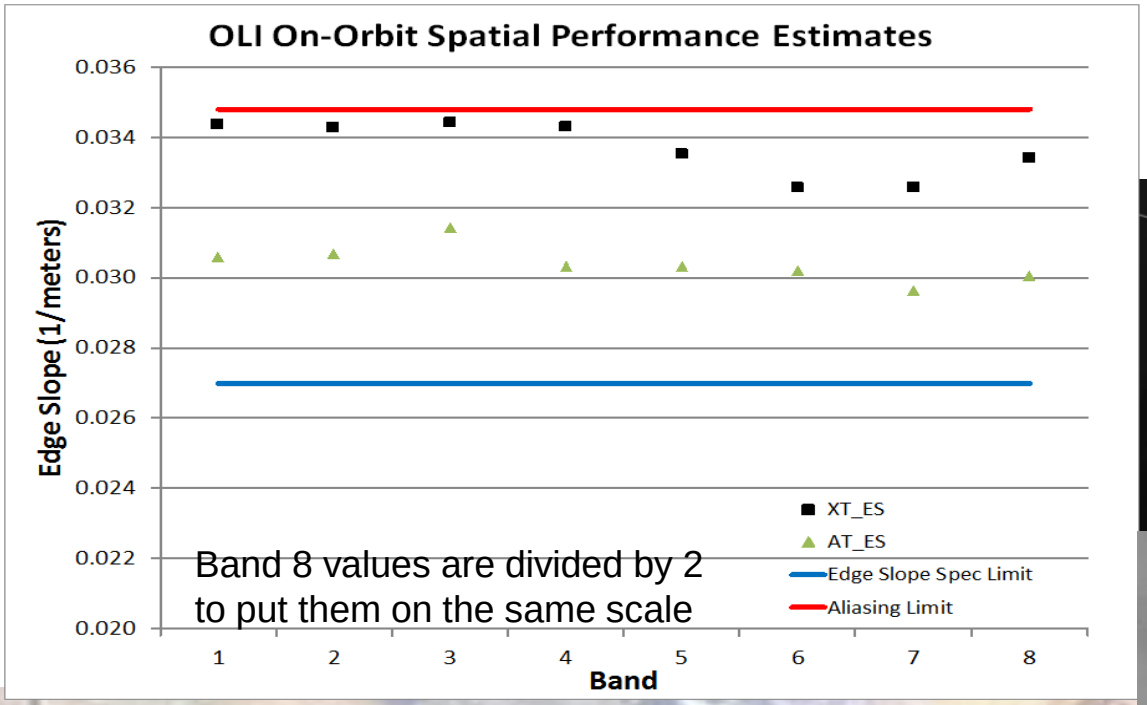
TIRS-OLI Registration by Band Pair

	TIRS to OLI	TIRS B10 to B11
Line Direction:	18.0 m LE90	7.0 m LE90
Sample Direction:	17.3 m LE90	6.8 m LE90
Specification:	30.0 m LE90	18.0 m LE90



OLI Edge Slope By Band

- Bridge targets are used to characterize the OLI system transfer function on-orbit
  - Level 1R image samples are interleaved to construct oversampled bridge profiles
  - Transfer function parameters are varied to make the modeled bridge profile best fit the image profile
  - Best fit model is used to generate spatial parameters



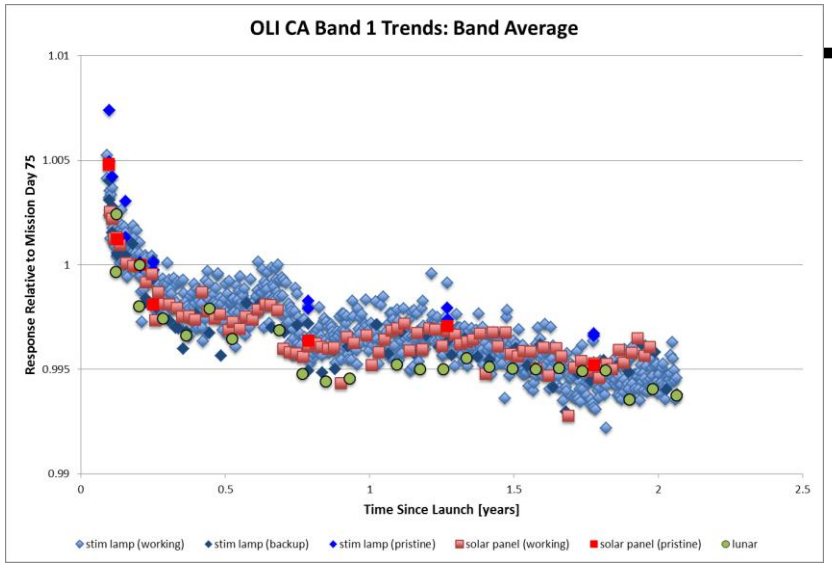
OLI Radiometric Stability and Absolute Calibration

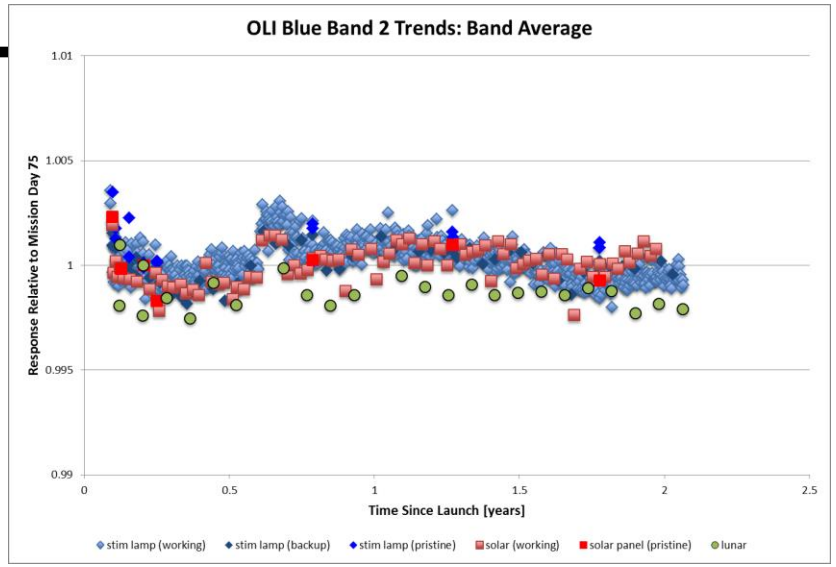
- **Extremely stable**
  - Worst band is CA (Band 1) - 1% degradation over 2 years
  - Most bands stable within ~0.3%
- **Radiometric calibration devices and methods well behaved**
  - Same trends to within ~0.3%
- **Update planned for next reprocessing – quarterly average gains**
  - CA band linear calibration trend
  - Other bands possibly

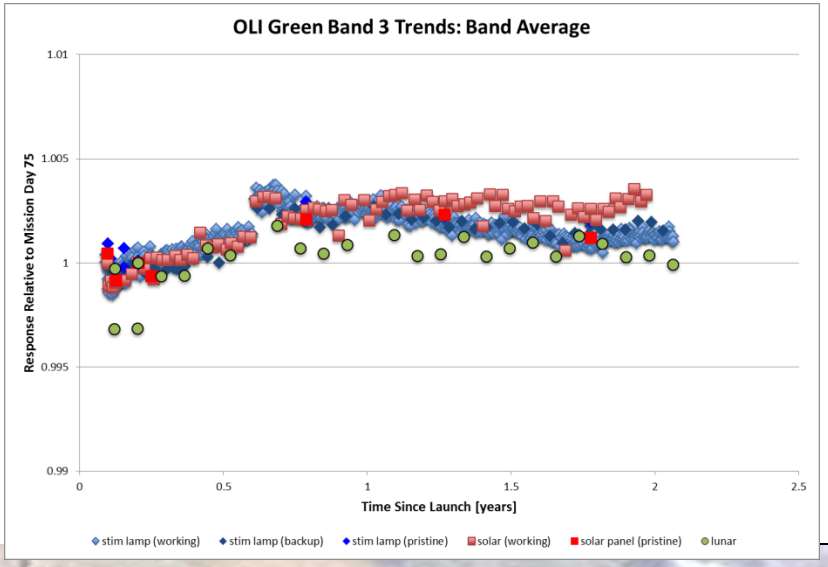
OLI Relative Gains

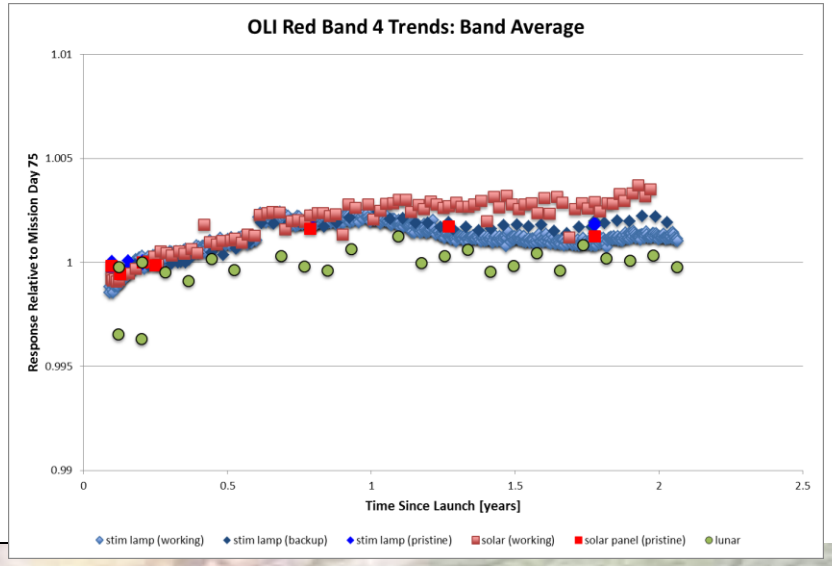
- **Striping due to relative gain differences is mostly not visible**
  - Mostly apparent in CA, blue and SWIR bands
- **Relative gains are changing slightly**
  - Monitored using solar diffuser acquisitions as well as side slither and scene statistics
  - Updated quarterly

On-Orbit Calibration Trends



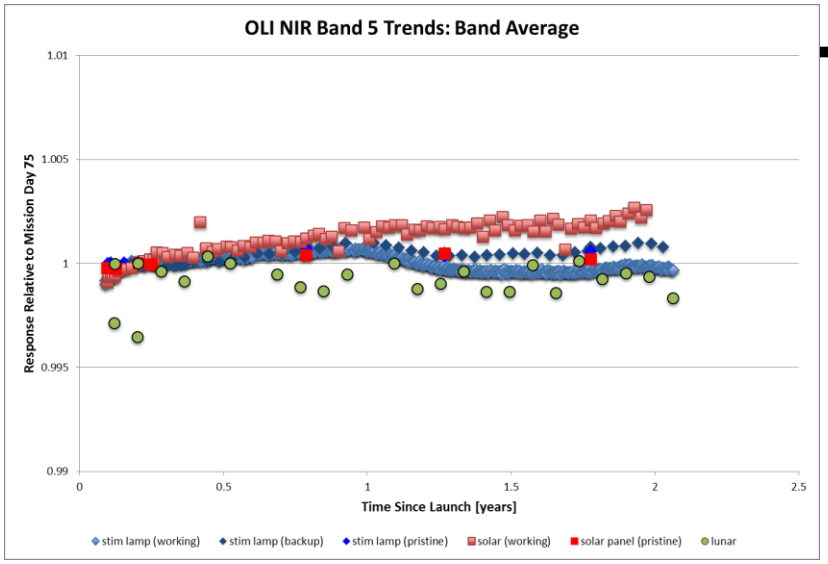


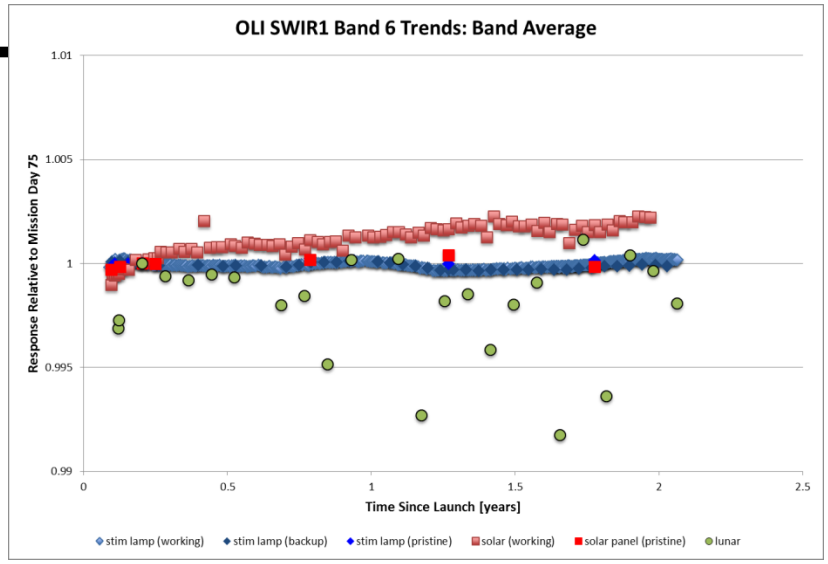


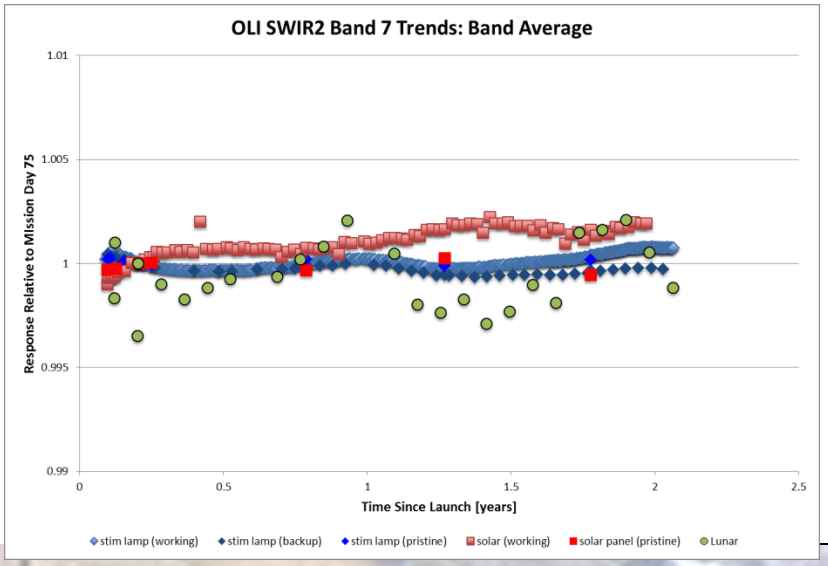


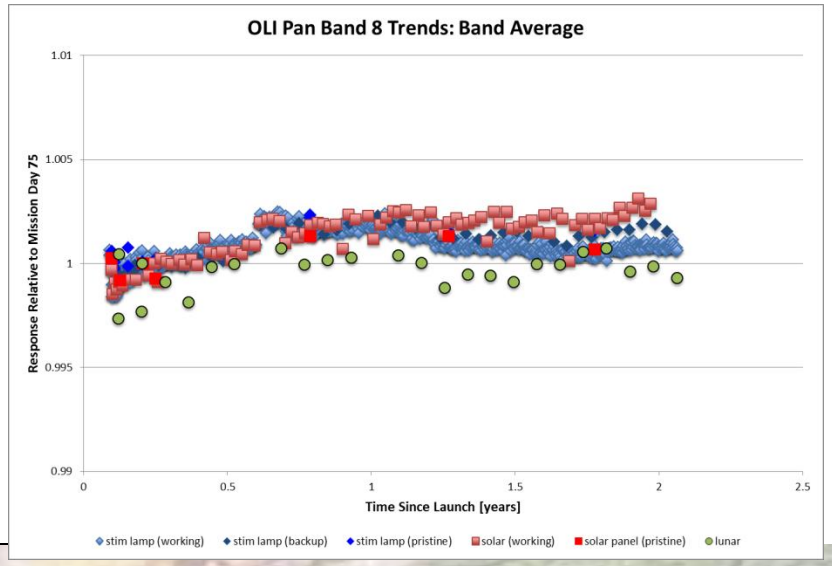
OLI on-orbit radiometric calibration results across the current mission lifetime

On-Orbit Calibration Trends









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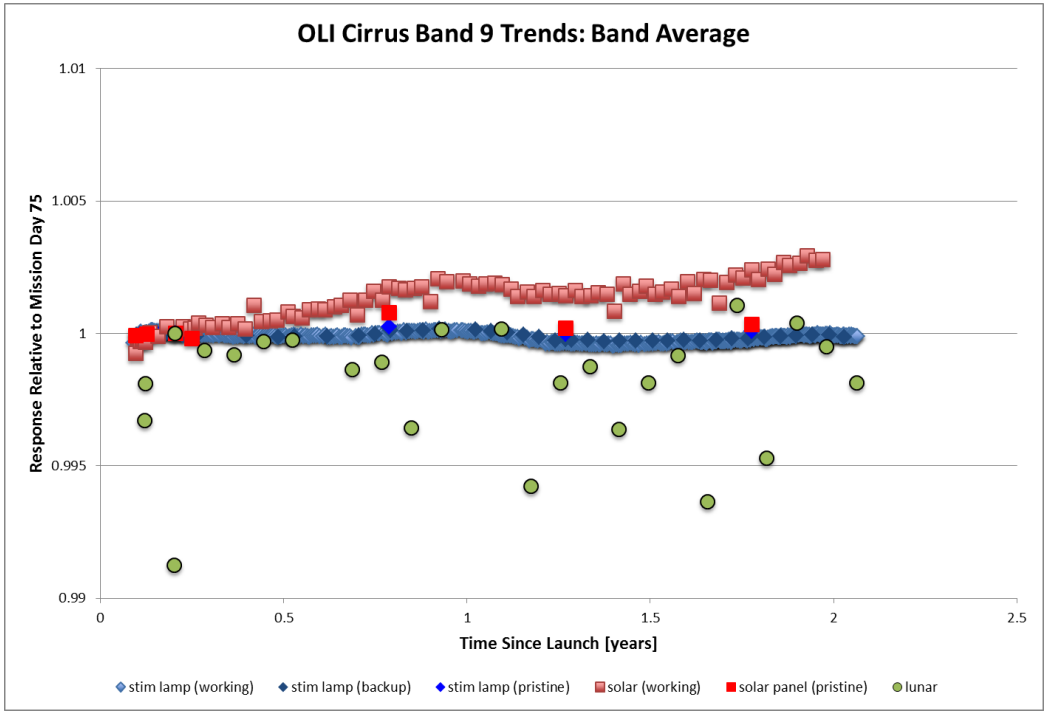
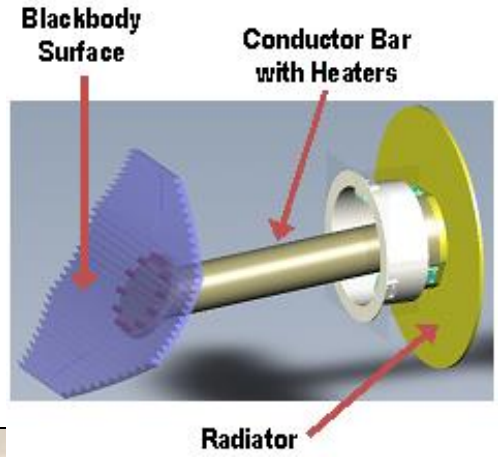
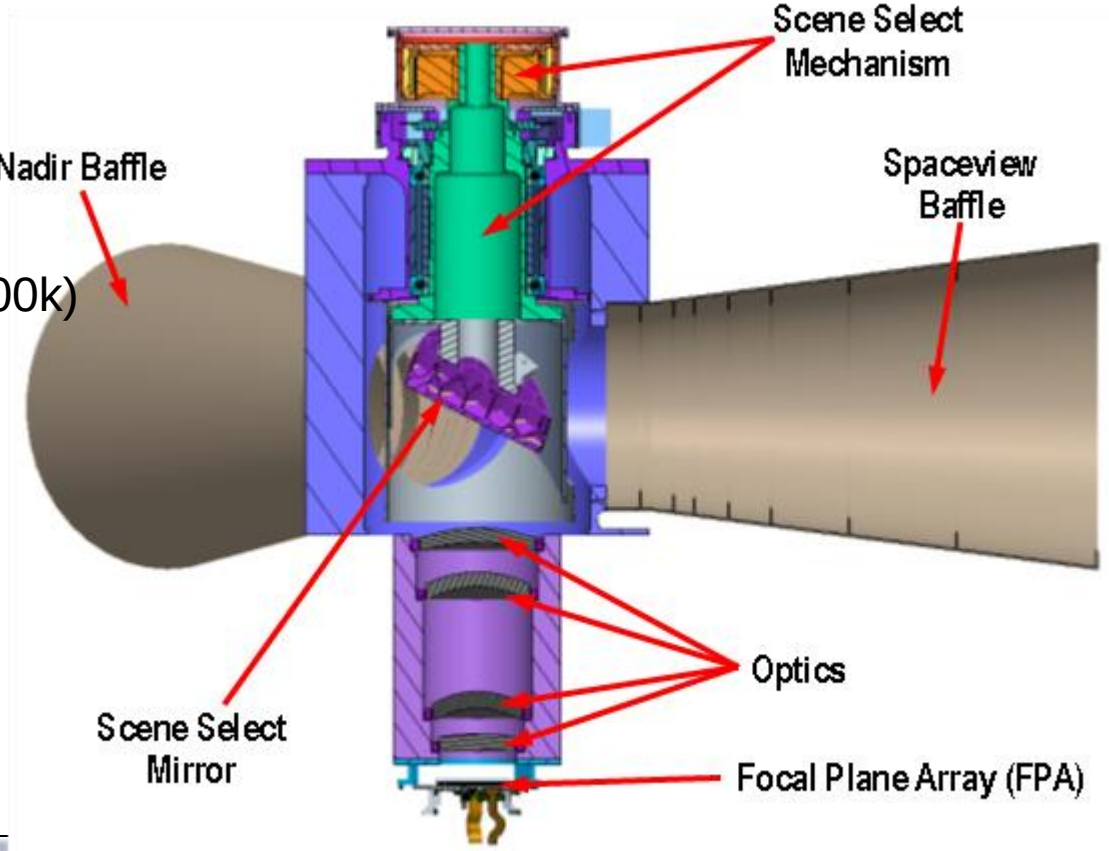
On-Orbit Calibration Trends



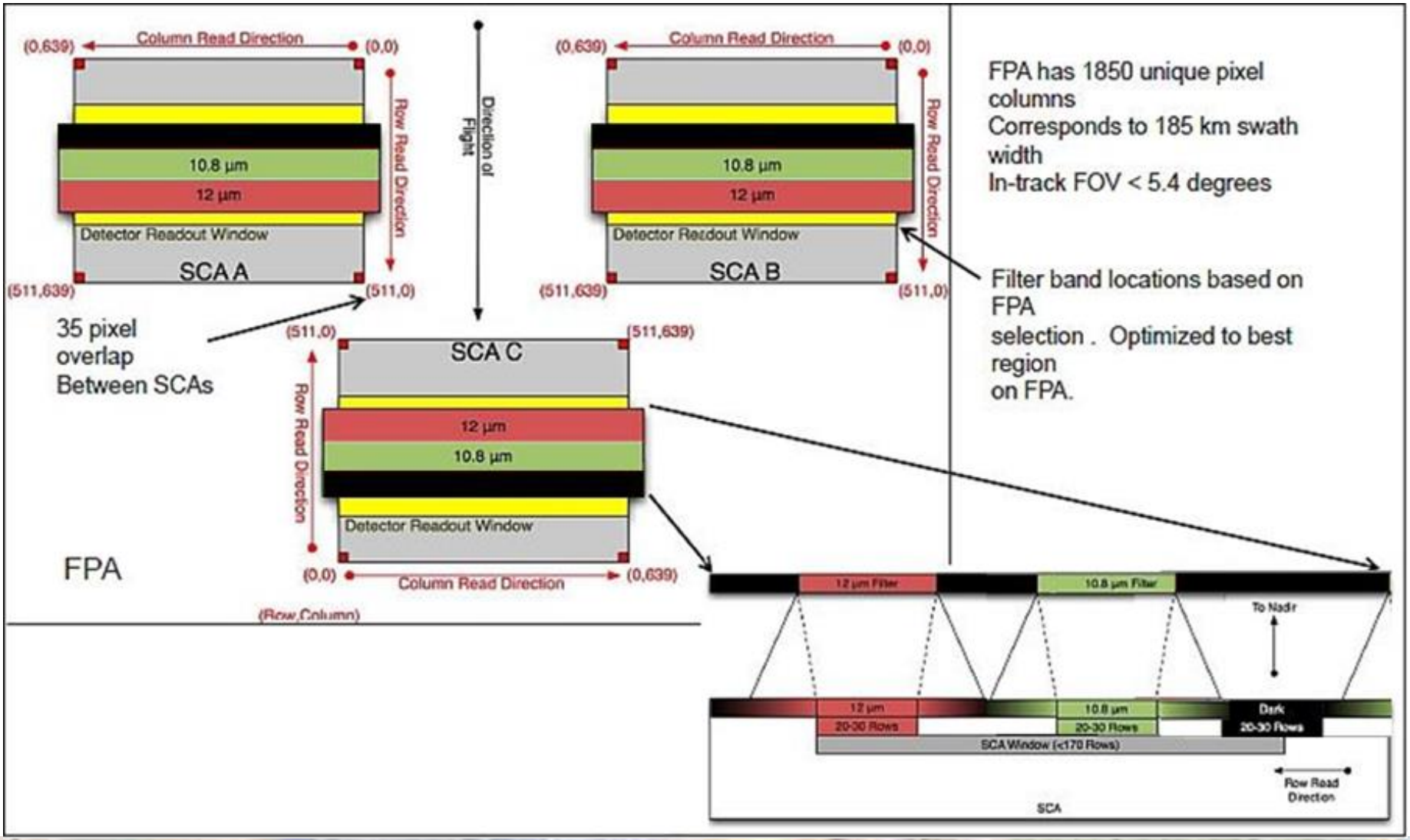
Thermal Infrared Sensor (TIRS)

- Focal Plane Array (FPA)
- 4 lenses
- Scene Select Mirror
- Scene Select Mechanism
- Nadir and Space view
- Calibration Collects every orbit
- On-board calibrators:
  - Black Body Cal source (270-300k)
  - Deep Space port



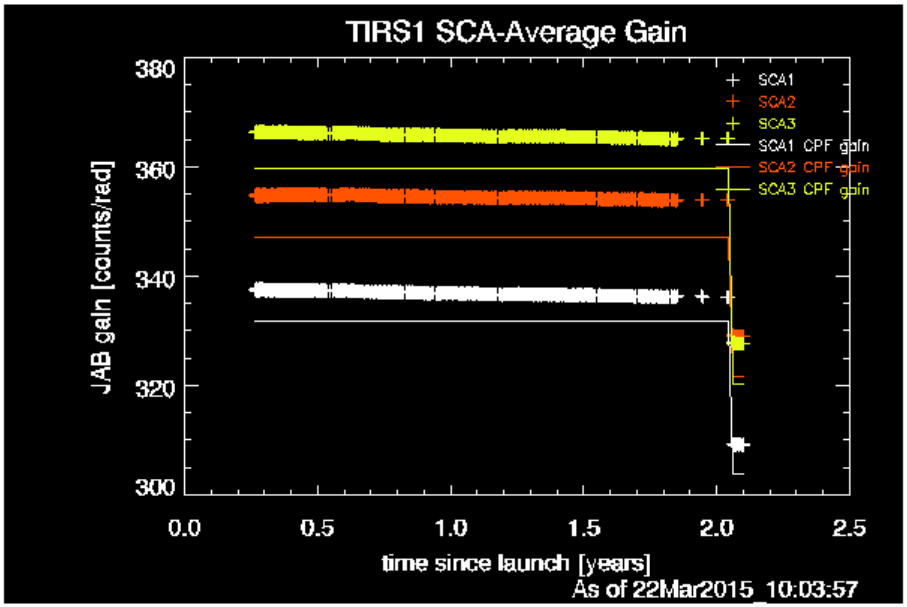


Focal Plane Layout

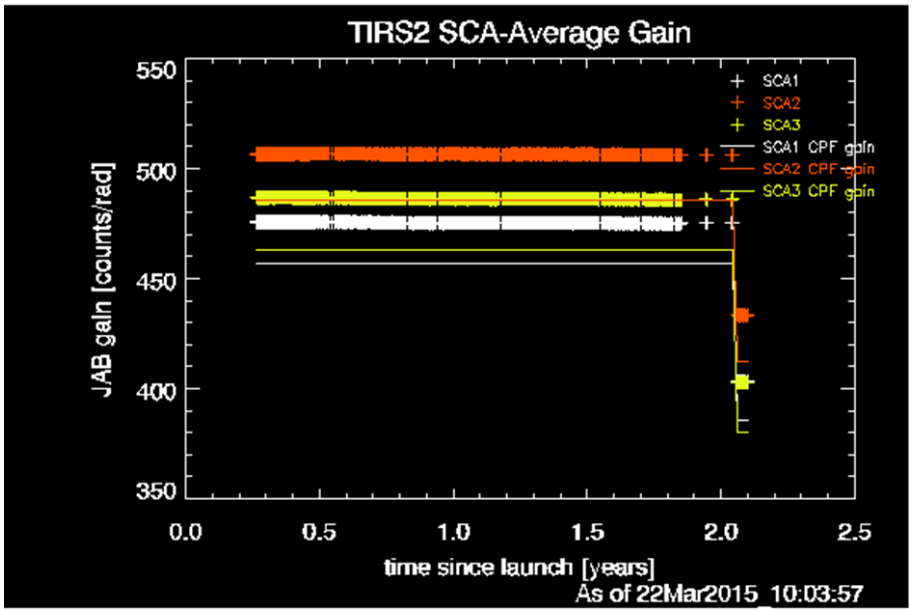


SCA Average Gain

TIRS Band 10



TIRS Band 11



TIRS On-Orbit Performance Breakdown

- **Worst case measured values for selected TIRS requirements based on on-orbit image data**

Requirement	Measured Value		Required Value	Units
NEdT (@300K)	0.05		< 0.4	Kelvin
NEdL	0.008		< 0.059, < 0.049	W/m²/sr/µm
Saturation Radiances	28.4, 19.2		20.5, 17.8	W/m²/sr/µm
40 min. Radiometric Stability (1σ)	0.1		< 0.7	Percent
Inoperable Detectors	0		< 0.1	Percent
Swath Width	186.2		> 185	Kilometers
Ground Sample Distance	103.424		< 120	Meters
Band Registration Accuracy	10.4		< 18	Meters
TIRS-to-OLI Registration Accuracy	20.6		< 30	Meters
	Band 10	**Band 11**		
Absolute Radiometric Accuracy	~ 5 (~ 2*)	~ 10 (~ 5*)	< 2	Percent
Uniformity Field-of-View	~ 1 **	~ 2 **	< 0.5	Percent
Uniformity Banding RMS	~ 1 **	~ 2 **	< 0.5	Percent
Uniformity Banding St.Dev.	~ 2 **	~ 4 **	< 0.5	Percent
Uniformity Streaking	< 0.5	< 0.5	< 0.5	Percent

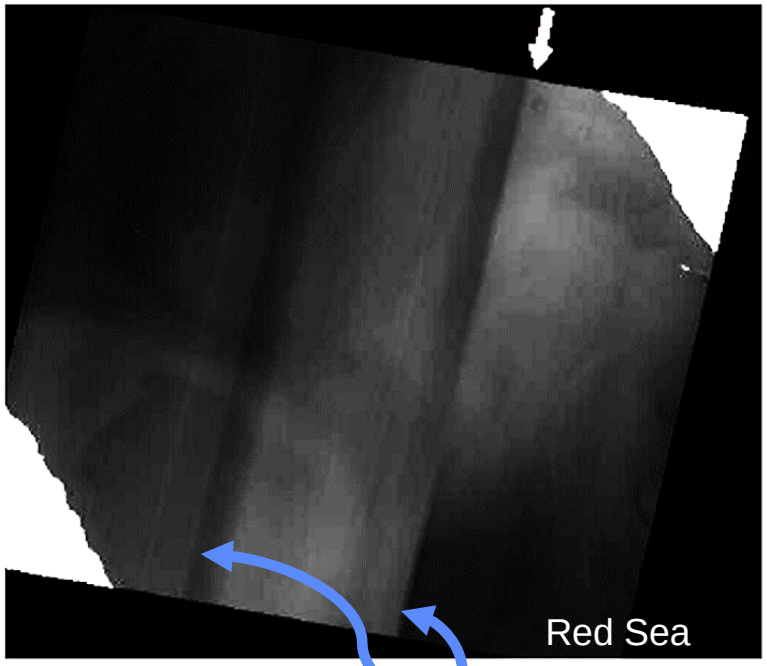
*After bias adjustment
** Scene dependent

Note: Worst case radiometric accuracy and uniformity performance occurs in band 11; band 10 approximately a factor of 2 better

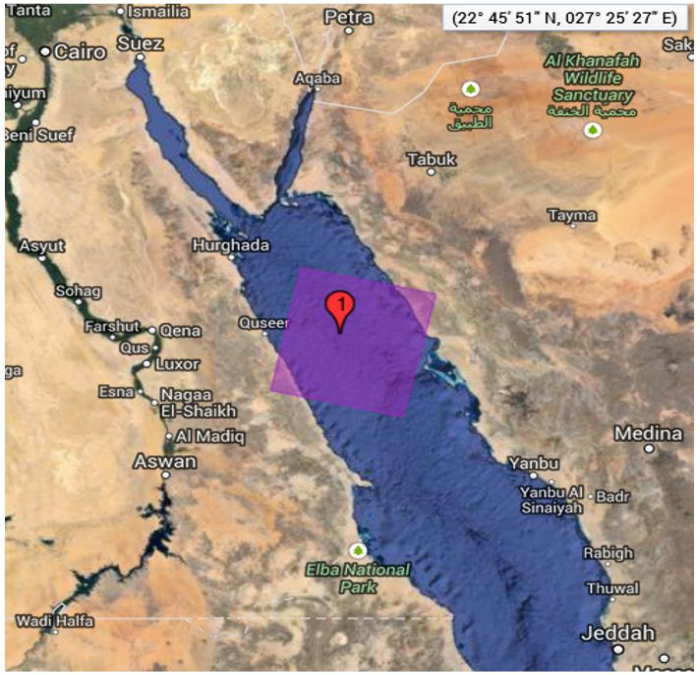
Instrument Issues: Non-Uniformity

- **Banding artifacts observed Earth scenes expected to be uniform (open water)**
- **Effect varies from scene-to-scene**
- **Effect varies within scene**

Example scene with varying along-track banding (band11)



Context view from EarthExplorer



Banding observed especially near the boundary between adjacent focal plane arrays

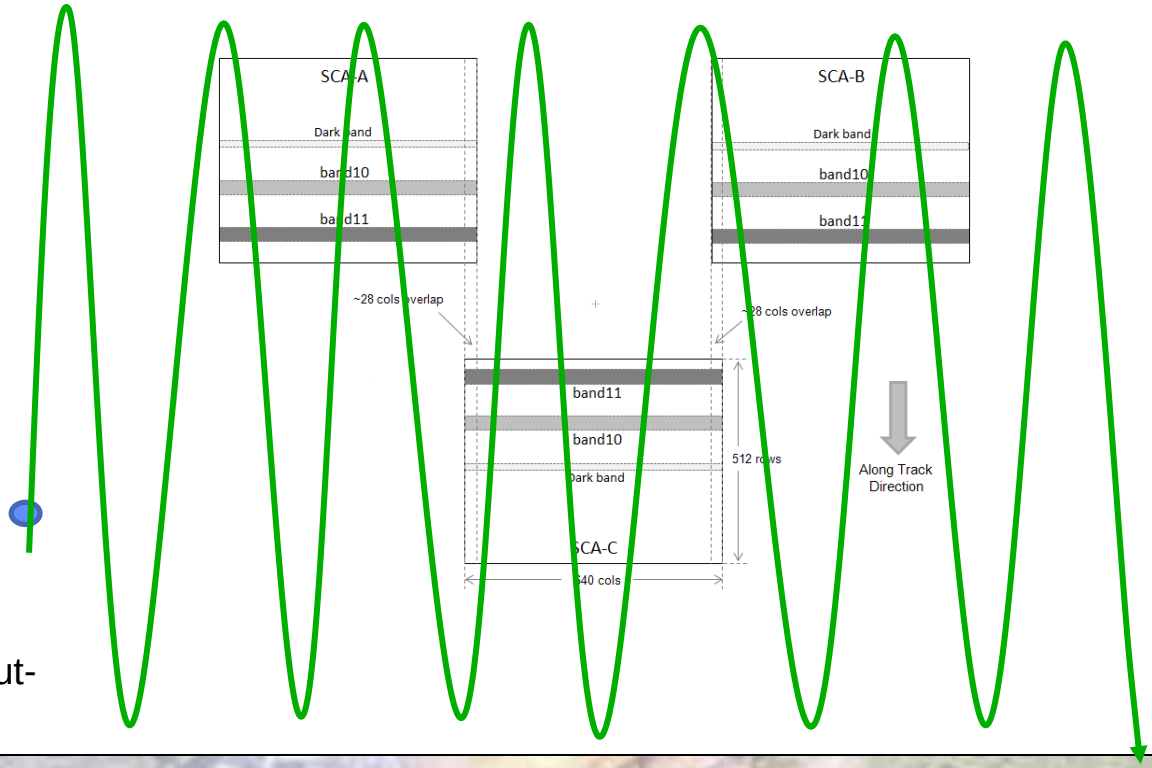
The Cause: Stray Light / Ghosting

- **Known artifacts:**
  - Absolute Calibration error
    - TIRS always reports a higher temperature than in-situ measurements
    - Error based on lake buoys varies with season (i.e. - error is larger in summer)
    - Error proportional to surrounding area temperature (e.g., in band 10 about a 10 K change in surround temp induces ~1K change in target temp)
  - Banding
    - Magnitude and shape varies from scene-to-scene
    - Magnitude and shape varies within a scene

Suspected an out-of-field radiance (stray light) was adding a spatially varying signal to the focal plane (ghosting)

Stray Light

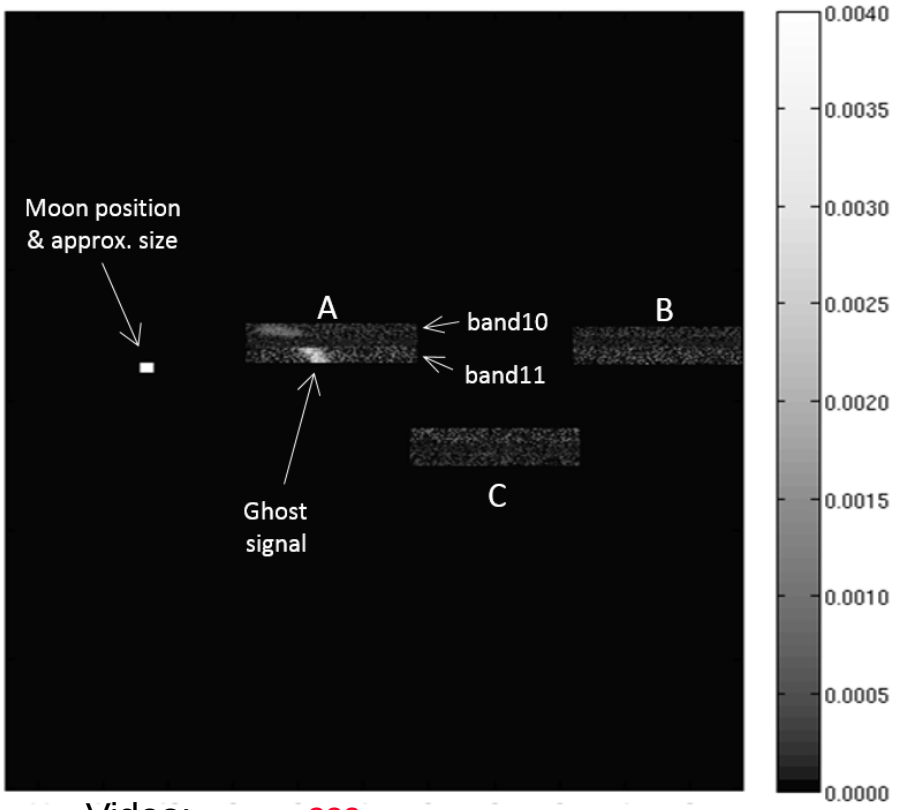
- **Investigate theory by slewing the observatory to raster-scan the moon outside the TIRS FOV**
- **Record any ghost signals on the arrays when the moon is outside the direct FOV**



Raster-scan the moon around the out-of-field

Stray Light

- **Lunar position relative to boresight known from observatory pointing telemetry**
- **Signal on arrays expressed as a fraction of direct moon signal (when moon is directly imaged)**

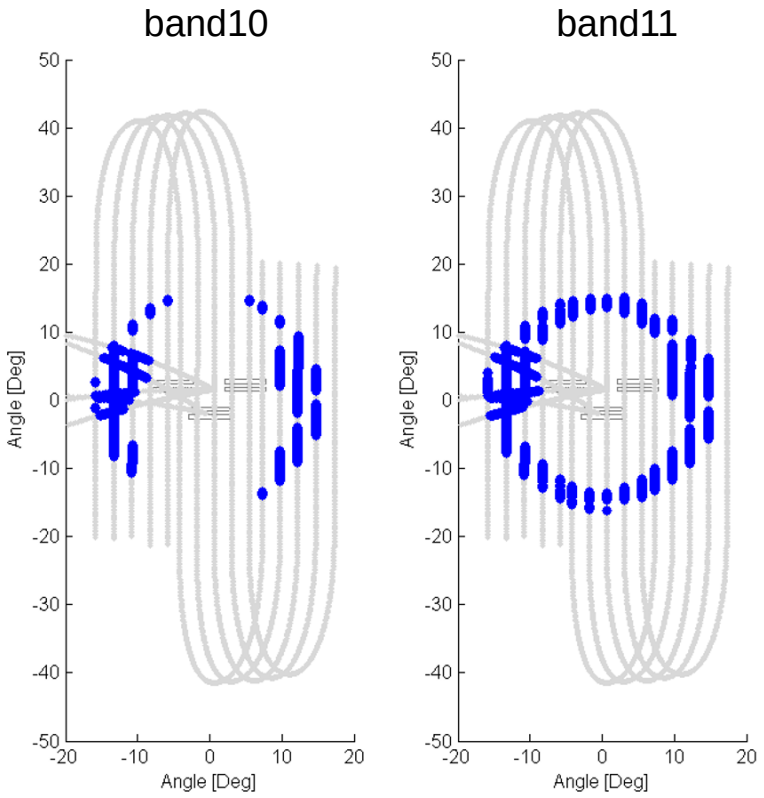


Ghost signal location and magnitude is a function of lunar position

Video: moon322.mpg

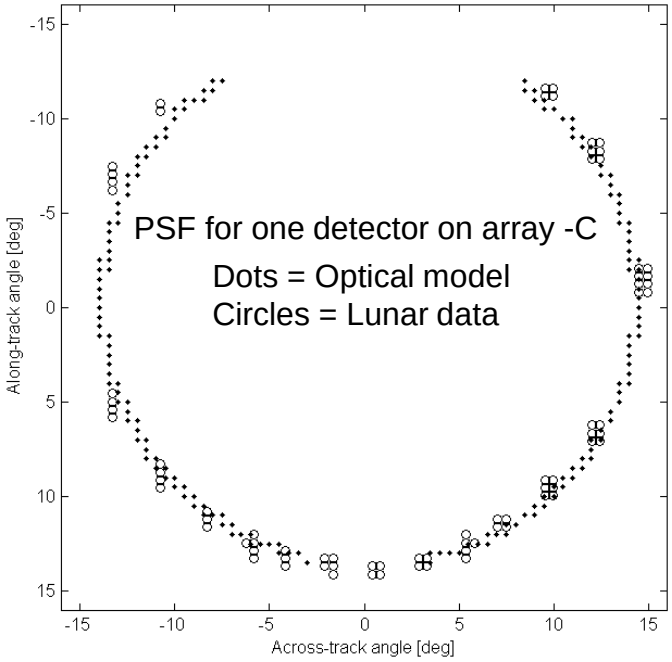
Stray Light

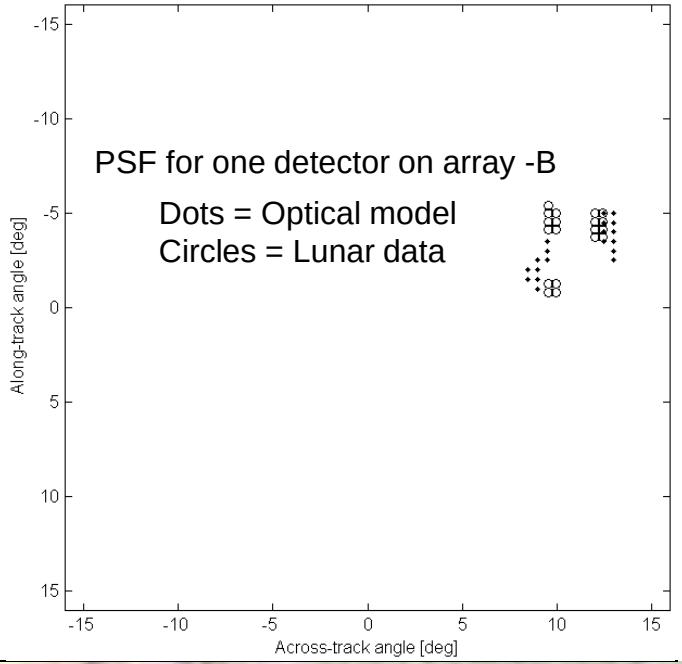
- Plot lunar locations (blue) in which a ghost appeared anywhere on the detectors
- Provides a sense of how far off-axis the offending signals are originating
- Able to produce a sparse map of lunar locations that produced a ghost for each detector
- Stray Light is ~ 15° off axis and the WRS-2 is only +/- 7.5 °
- Sent this information to the TIRS optics team for optical modeling



Stray Light Optical Modeling

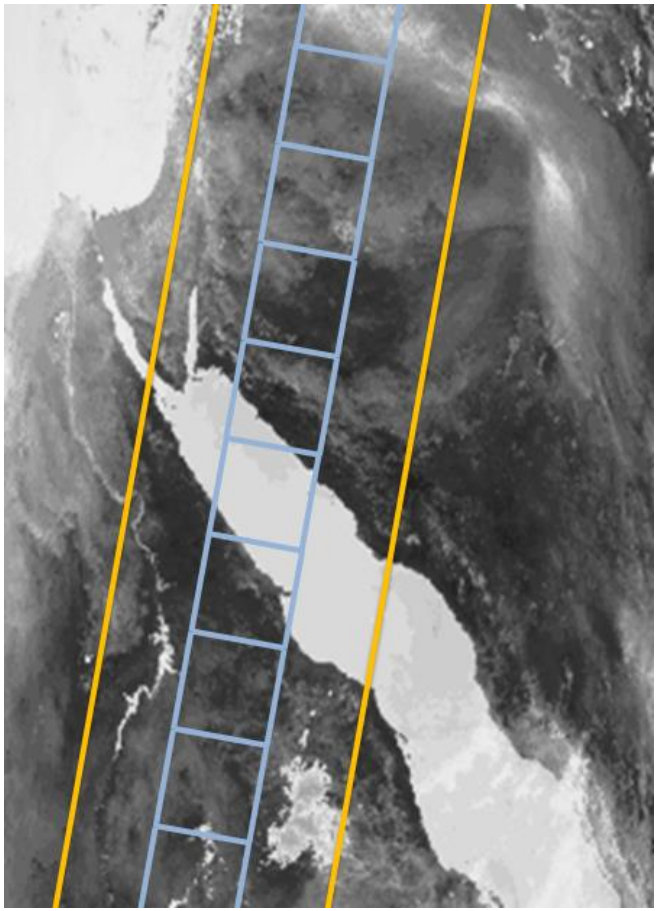
- **Optical stray light model now fits observed lunar data**
- **Have a complete stray light PSF for every detector**
- **Since the raster scan plots and the optics model matched pretty close, we had confidence in the optical model**
- **The Optics group determined that the source was a mounting ring in the telescope**
- **Optical model has been refined with new lab measurements of reflecting surfaces in the telescope assembly**





Correction Strategy

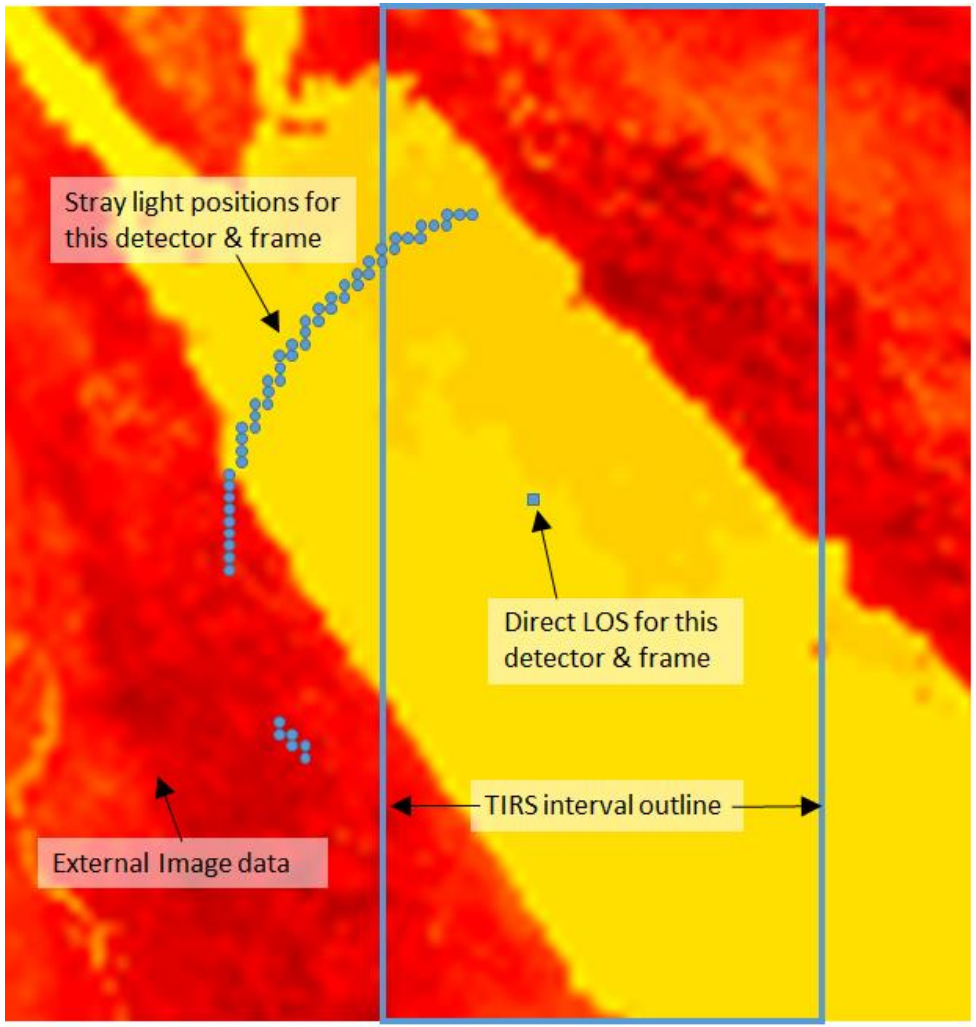
- **External Sensor Data:**
  - Coincident thermal band data (GOES, Meteosat, etc.) provides out-of-field radiance
  - Optics Stray Light Model provides locations of stray light sources
  - Most accurate (realtime clouds); Most computationally intensive (also requires external sensor data)
- **TIRS In-Scene Data:**
  - Use in-scene TIRS radiance as a surrogate for the out-of-field radiance
  - Making assumption than in-scene radiance correlates to out-scene radiance; only requires given TIRS scene (no other data necessary)



* All strategies depend on knowledge of out-of-field radiance

Total signal = direct signal + ghost signal

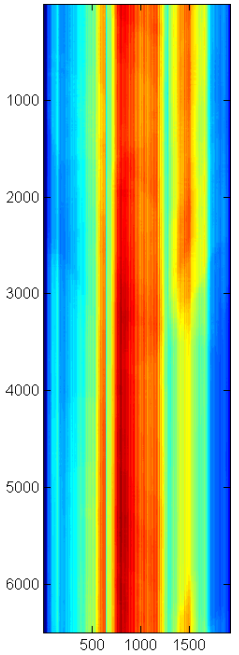
Stray Light Effect Correction Strategy: External Sensor Data



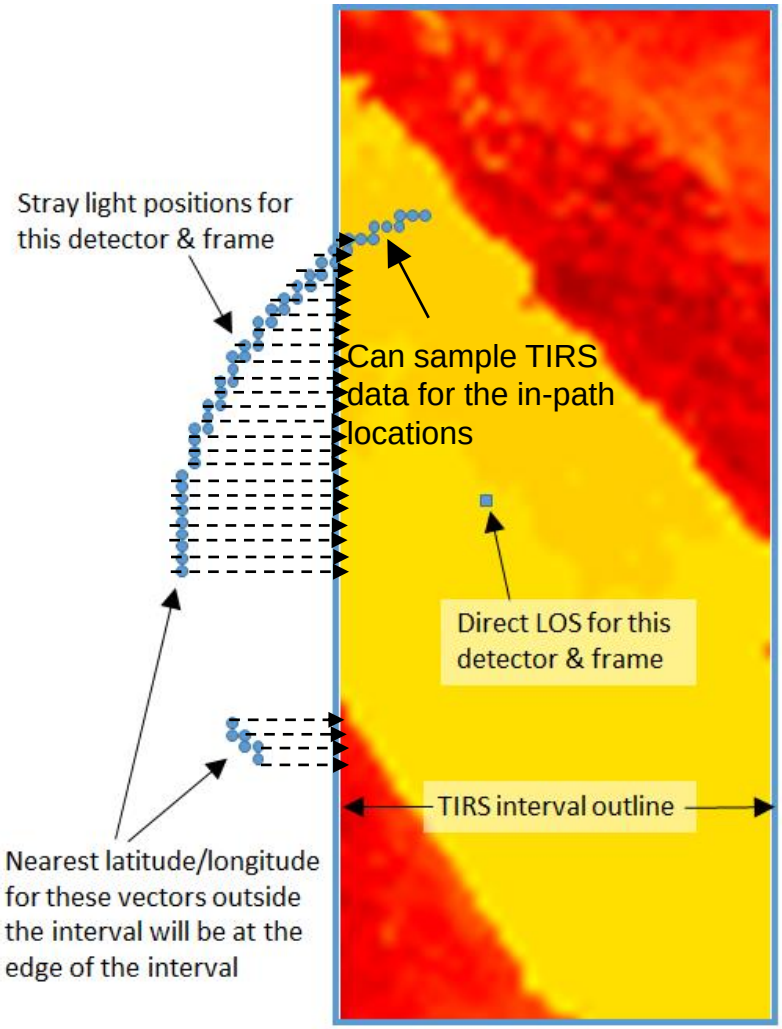
$$Ghost = a \cdot \left(Ext.Sampled \right) + b$$
$$= a \cdot \left(\sum L_{ext_i} \cdot w_i \right) + b$$

- Repeat for every frame
- repeat for every detector

Calculated ghost signal



Stray Light Effect Correction Strategy: TIRS Data ONLY



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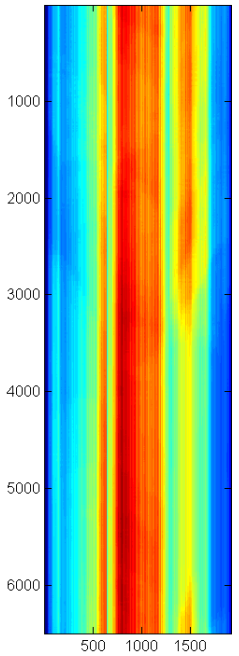
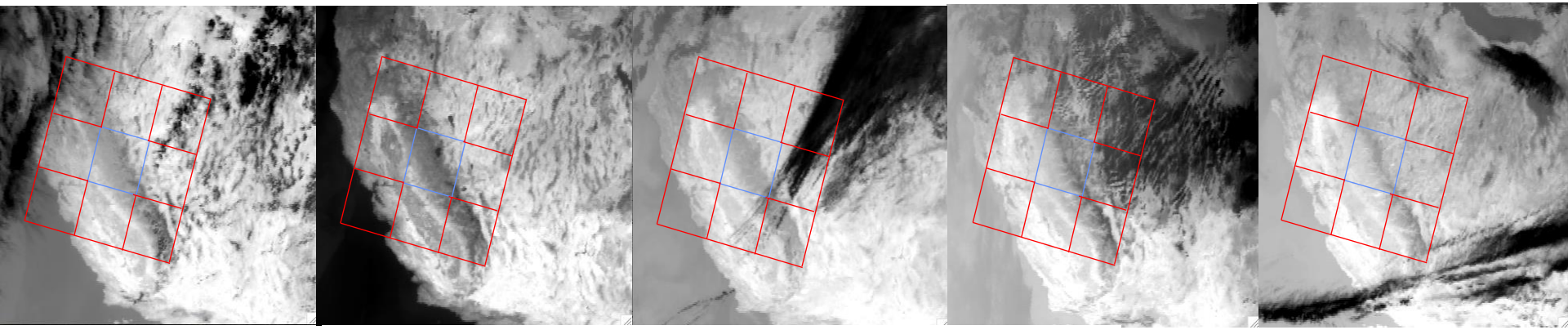
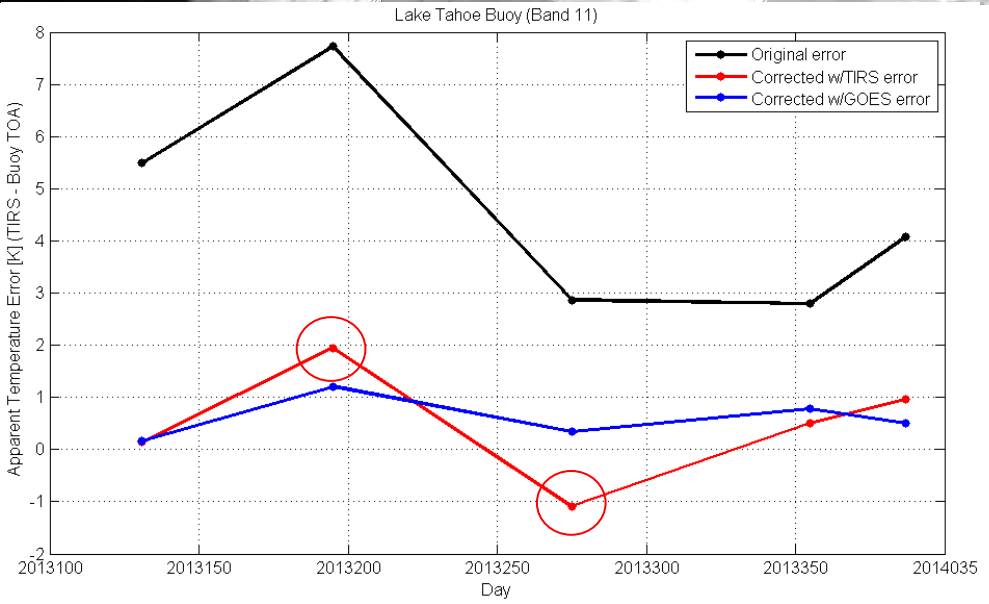


Results: Absolute Radiometry Calibration (Lake Tahoe)

Day 131, 2013 | Day 195, 2013 | Day 275, 2013 | Day 355, 2013 | Day 22, 2014





Paths Forward

- **USGS EROS has the TIRS correction method prototype currently in the Image Assessment System (IAS) System Test (ST)**
- **RIT working to improve the correction capability and apply new model**
- **L8 Image Assessment System (IAS) 3.6 will have the TIRS Stray Light product correction installed. Level 1 Product Generation System (LPGS) 2.6.1**

- ***More information for Stray Light & effects in TIRS in:***
  - Montanaro, M.; Gerace, A.; Lunsford, A.; Reuter, D. Stray Light Artifacts in Imagery from the Landsat 8 Thermal Infrared Sensor. Remote Sensing 2014, 6, 10435-10456. http://www.mdpi.com/2072-4292/6/11/10435
  - Montanaro, M.; Lunsford, A.; Tesfaye, Z.; Wenny, B.; Reuter, D. Radiometric Calibration Methodology of the Landsat 8 Thermal Infrared Sensor. Remote Sensing 2014, 6, 8803-8821. http://www.mdpi.com/2072-4292/6/9/8803
  - Barsi, Julia A., John R. Schott, Simon J. Hook, Nina G. Raqueno, Brian L. Markham, and Robert G. Radocinski. "Landsat-8 Thermal Infrared Sensor (TIRS) Vicarious Radiometric Calibration." Remote Sensing 6, no. 11 (2014): 11607-11626. http://www.mdpi.com/2072-4292/6/11/11607

Special Thanks

The information in this presentation is from the Landsat Calibration Team. I would like to give special thanks to:

Jim Storey, Mike Choate, Esad Micijevic also with SGT and Ron Morfitt with USGS.

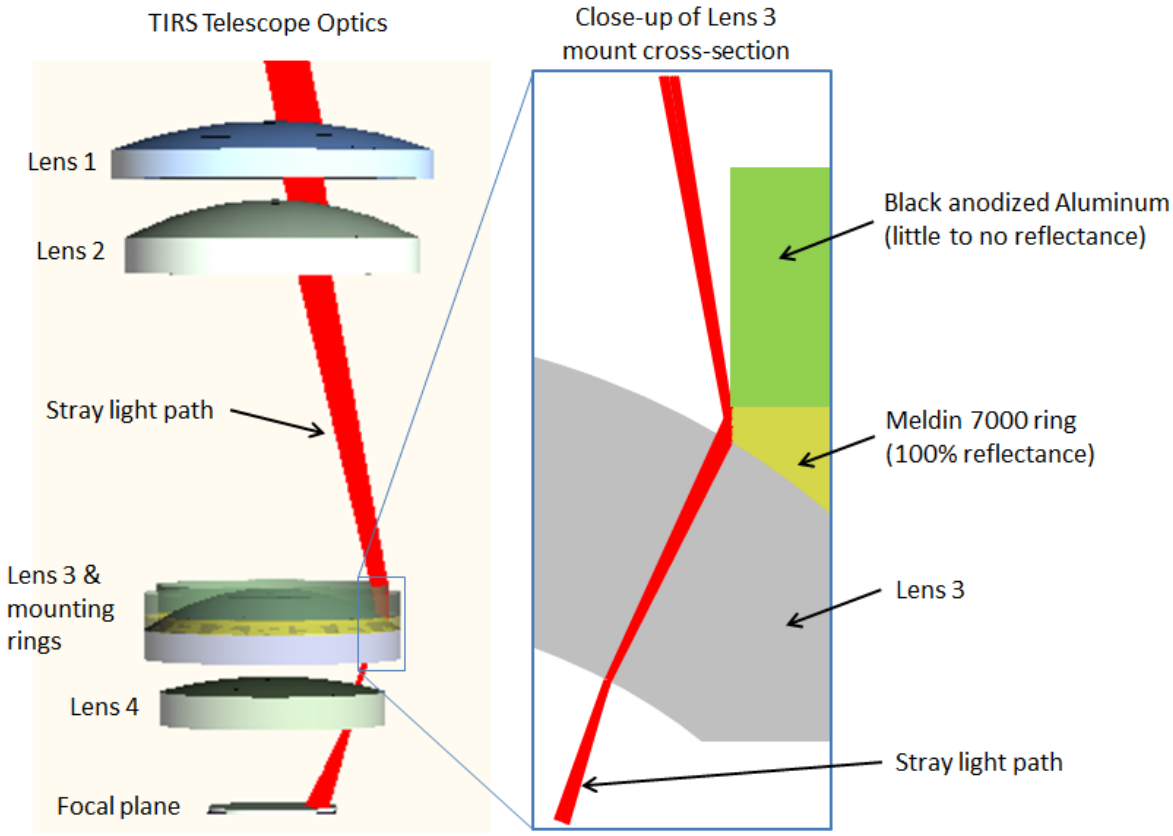
For Landsat 8 Journal Articles please reference:
http://www.mdpi.com/journal/remotesensing/special_issues/landsat8#published


Questions?

Backup slides

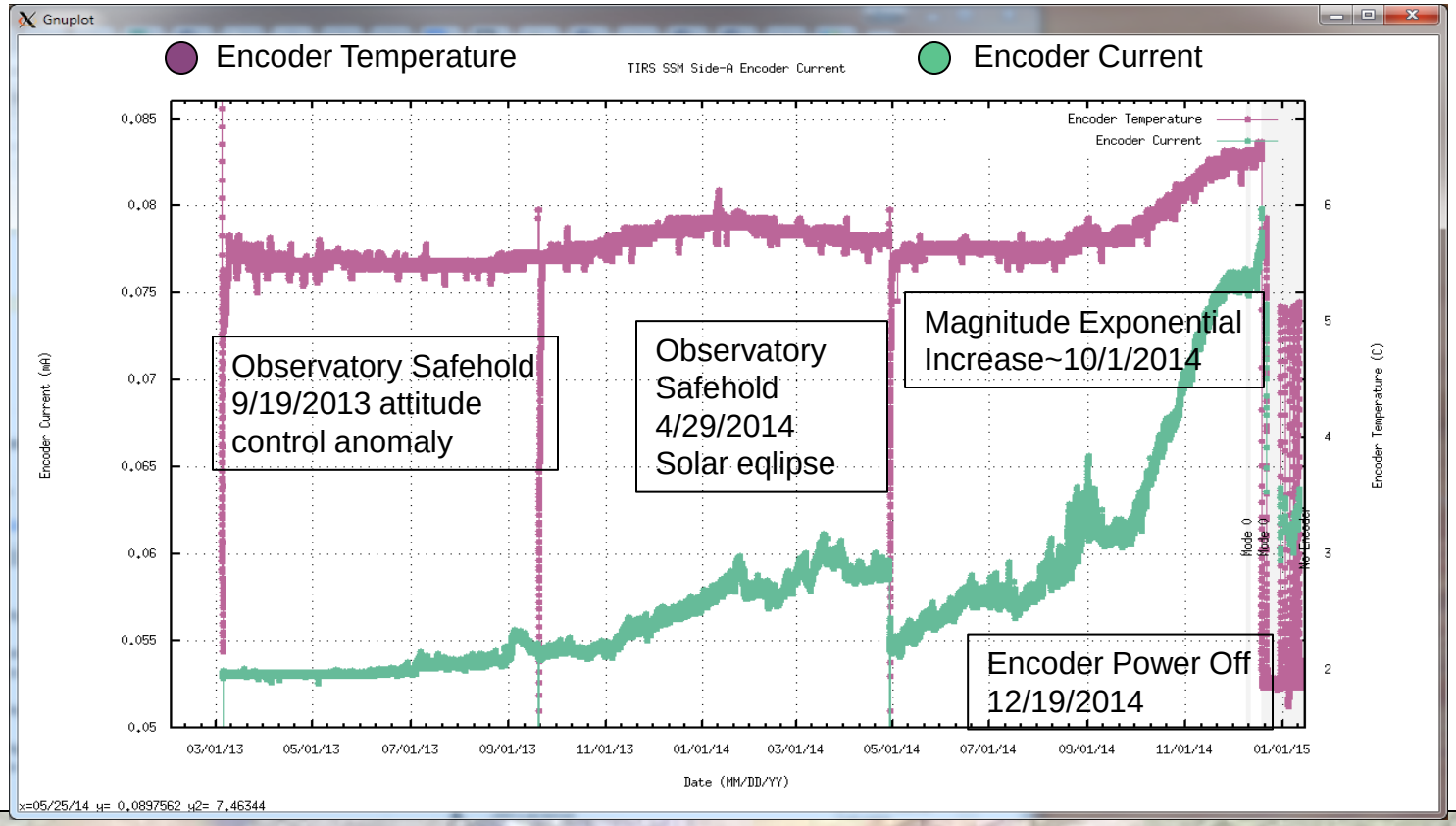
Stray Light Optical Modeling

- **Lunar stray light data provided to Optics group* at NASA/GSFC**
- **Stray light artifacts in TIRS have been correlated to far out-of-field light reflecting from the mounting ring contacting the first surface of Lens 3 in the TIRS Telescope**



TIRS Scene Select Mechanism Anomaly

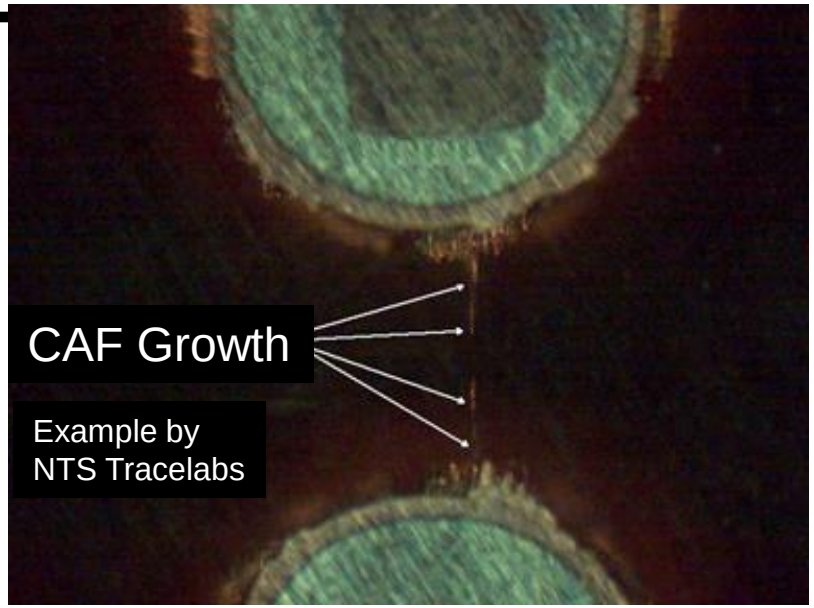
- **In the fall of 2014 a deviation in the Motor Control Electronics (MCE) current was noted. Over the first year of the mission the MCE current had been stable, however starting mid 2014 the MCE current had begun to display a noisy signature. On 19 December 2014 the Encoder was powered off.**



Note: Plot is –EV MCE current abs value

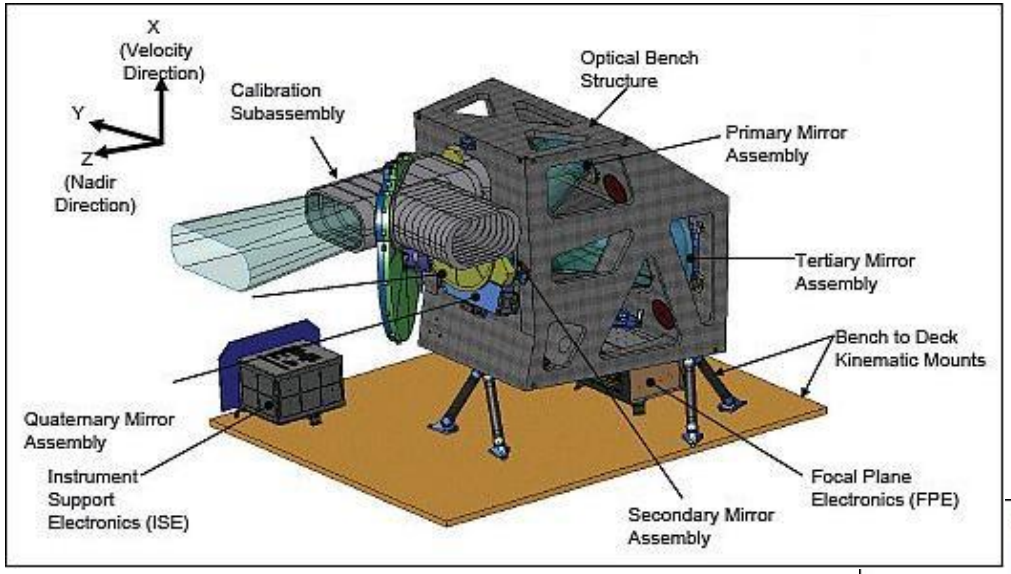
TIRS Scene Select Mechanism Anomaly

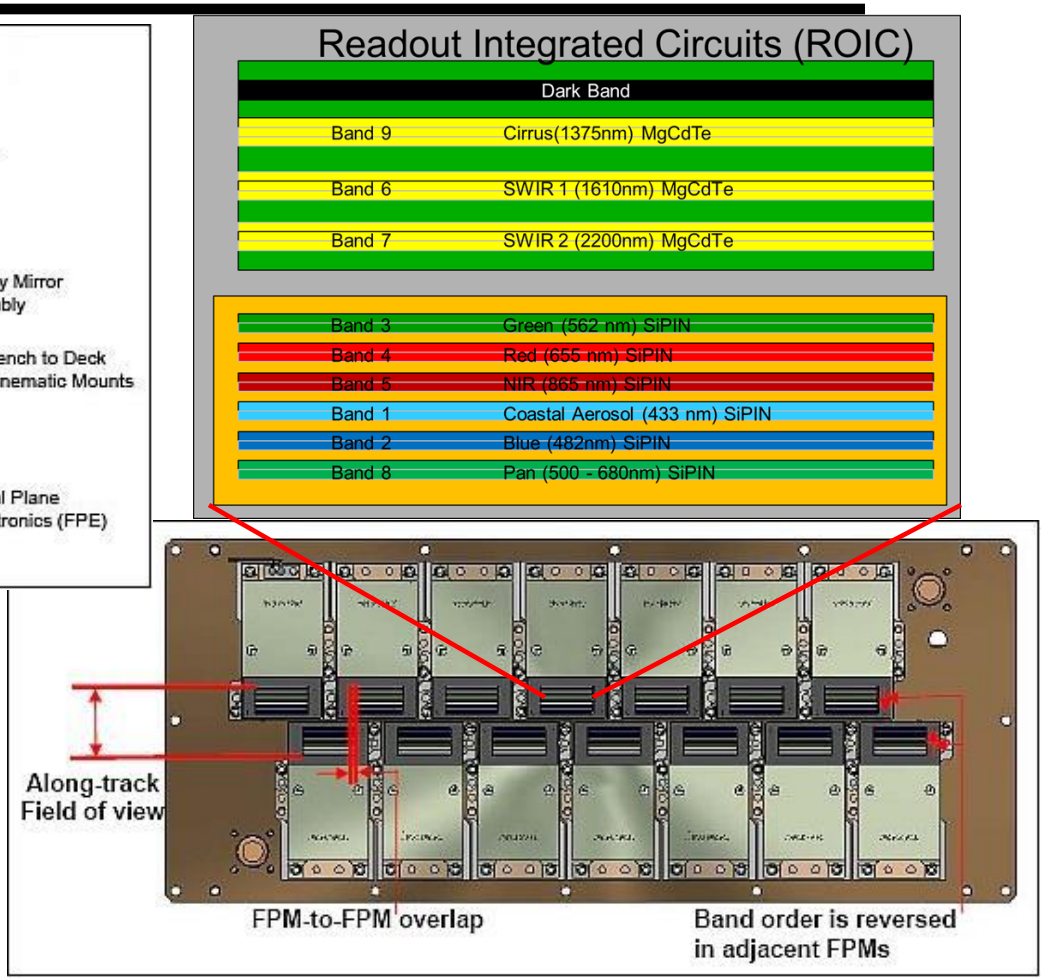
- **Conductive Anodic Filament (CAF) is the probably cause.**
- **Conductive filament forms in the laminate dielectric material between two adjacent conductors or plated through under an electrical bias.**
- **The CAF partially heals when powered down**



- **On March 6, 2015 the Landsat 8 Thermal Infrared Sensor (TIRS) switched from A side to B side electronics to resolve a problem with the A side encoder electronics.**
- **The Calibration Team updated the calibration based on prelaunch testing and then refined those calibrations during the first week of Side B testing.**
- **Since going to side B electronics the encoder current and temperatures have been stable.**
- **Beginning April 30, 2015, Landsat 8 scenes acquired from December 19, 2014 to March 13, 2015 began reprocessing to repopulate the TIRS data in the products.**

Operational Land Imager (OLI)





- **Pushbroom VIS/SWIR sensor**
- **Four-mirror telescope**
- **Focal Plane Assembly (FPA)**
- **6916 active detectors per band**
- **Each FPM is 494 detectors wide**
- **Resolution 30 m (15 m pan)**
- **185 km swath**

Thermal Infrared Sensor (TIRS)

- **4 optical element refracting telescope**
- **Focal plane consists of 3 staggered QWIP arrays (operates at 43 k temp)**
- **Two spectral channels:**
  - Band 10: 10.6 µm - 11.2 µm
  - Band 11: 11.5 µm - 12.5 µm
- **Push-broom configuration: ~1850 detectors across-track per band**
- **185 km ground swath; 100 meter pixel size on ground**
- **For calibration purposes, a Scene Select Mechanism (SSM) switches instrument view between nadir, deep space port, and blackbody**