Landsat-8 On-orbit and Landsat-9 Pre-launch Sensor Radiometric Characterization

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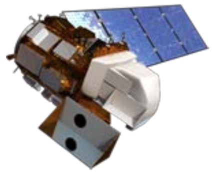


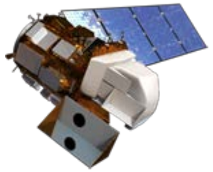
Landsat Team

The Landsat program, with the Landsat-7 and Landsat-8 satellites in orbit and the Landsat-9 observatory (instruments and spacecraft) under development, is a joint NASA and United States Geological Survey (USGS) effort.

The Landsat-8 and -9 OLI (2) instruments were built and are being built by Ball Aerospace (Leanne Presley, current project manager; Ed Knight, lead system engineer and Geir Kvaran, radiometric calibration lead) under contract to NASA. The TIRS and TIRS-2 instrument are in-house NASA/GSFC builds (Jason Hair, current project manager; Synthia Tonn, lead systems engineer; Dennis Reuter, instrument scientist).

The overall project is led by Del Jenstrom at NASA and Brian Sauer at USGS. The NASA project scientist is Jeff Masek; the NASA instrument scientist is Phil Dabney; the USGS project scientist is John Dwyer.

The Cal/Val team also includes a number of NASA and USGS contractors as well as personnel from RIT, South Dakota State University, University of Arizona.



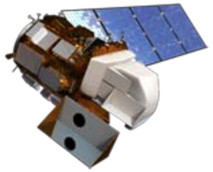
Topics

- Landsat 8, 9 Instrument Overview
  - Operational Land Imager (OLI)
  - Thermal Infrared Sensor (TIRS)
- Landsat-8 Instrument Status and On-orbit Radiometric Performance Characterization
- Landsat-9 Instrument Status and Pre-launch Radiometric Performance Characterization

Instrument Overview (1)

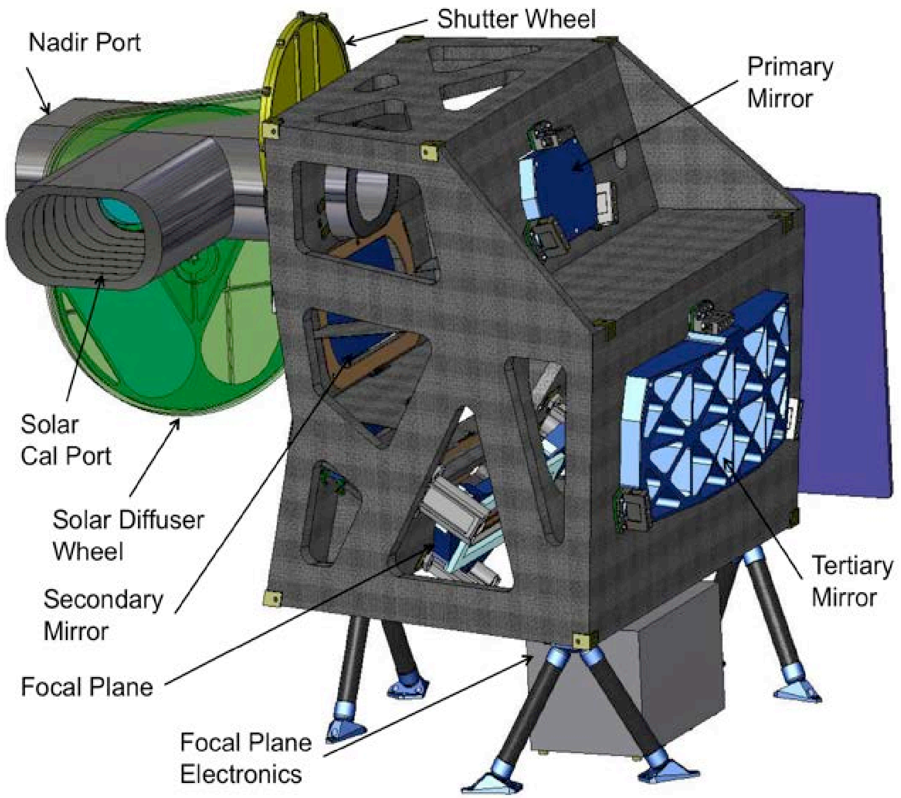
- Two sensors on both missions:
  - Operational Land Imager – reflective sensor with 9 bands
  - Thermal Infrared Sensor – thermal sensor with 2 bands

Band	Band Designation	Landsat-8 Band Edges (nm)	GIFOV (m)	Digitization (transmitted bits)
1	Coastal Aerosol	435.0 - 451.0	30	12*
2	Blue	452.0 – 512.1	30	12*
3	Green	532.7 - 590.1	30	12*
4	Red	635.9 – 673.3	30	12*
5	NIR	850.5 - 878.8	30	12*
6	SWIR-1	1566.5 - 1651.2	30	12*
7	SWIR-2	2107.4 – 2294.1	30	12*
8	Pan	503.3 – 675.7	15	12*
9	Cirrus	1363.2 – 1383.6	30	12*
10	TIR-1	10602 – 11190	100	12
11	TIR-2	11500 – 12511	100	12

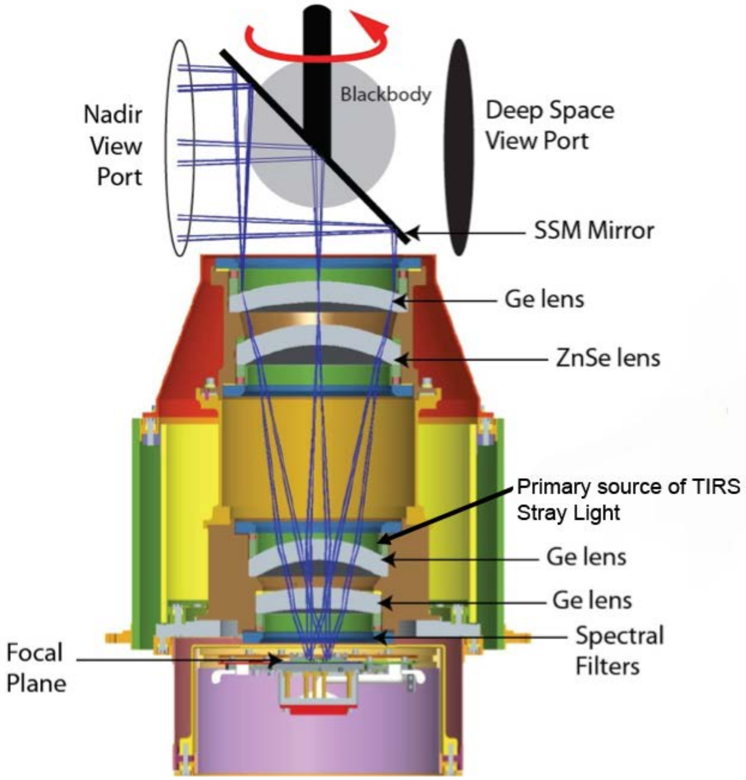


* 14 bits on Landsat-9

Instrument Overview (2)

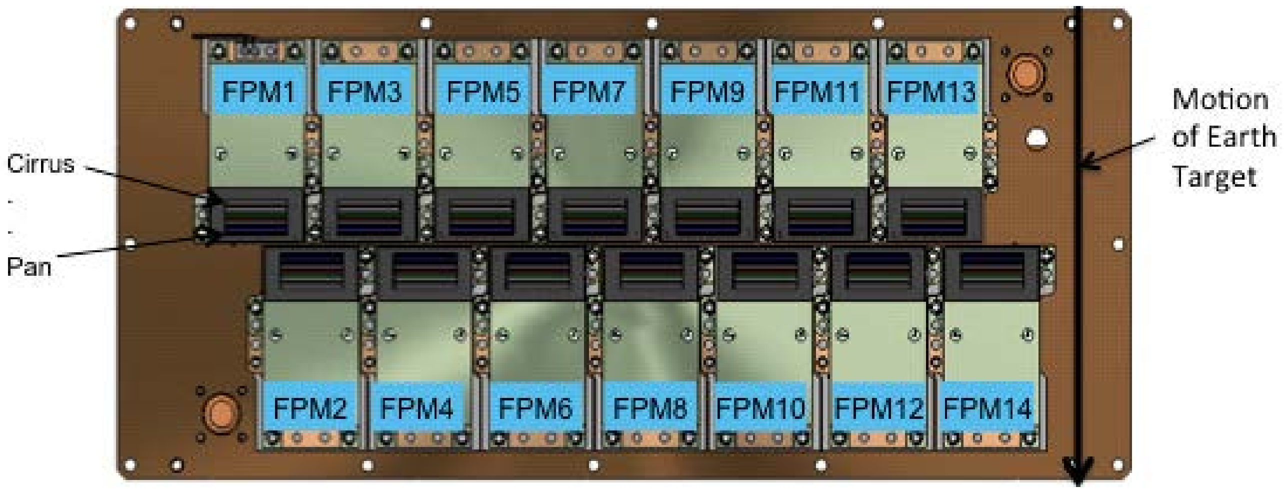


OLI (2)

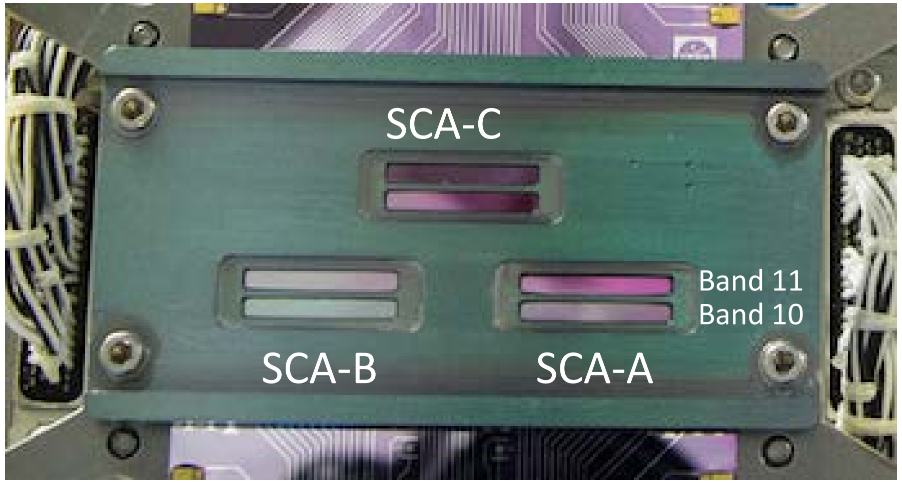


TIRS (2)

Instrument Overview (3)



OLI (2) Focal Plane



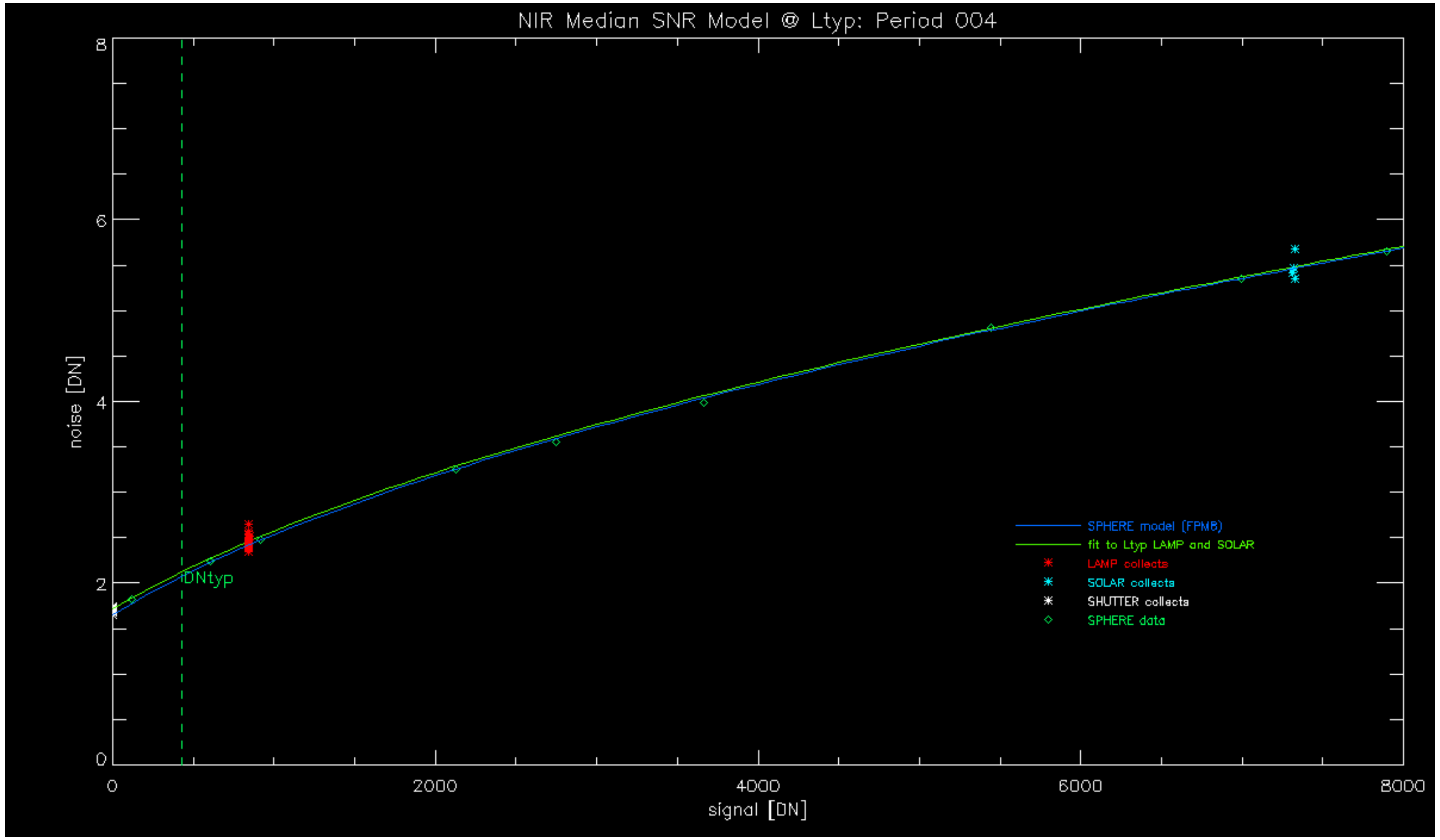
TIRS-2 Focal Plane

Landsat-8 OLI On-orbit Status and Radiometric Performance

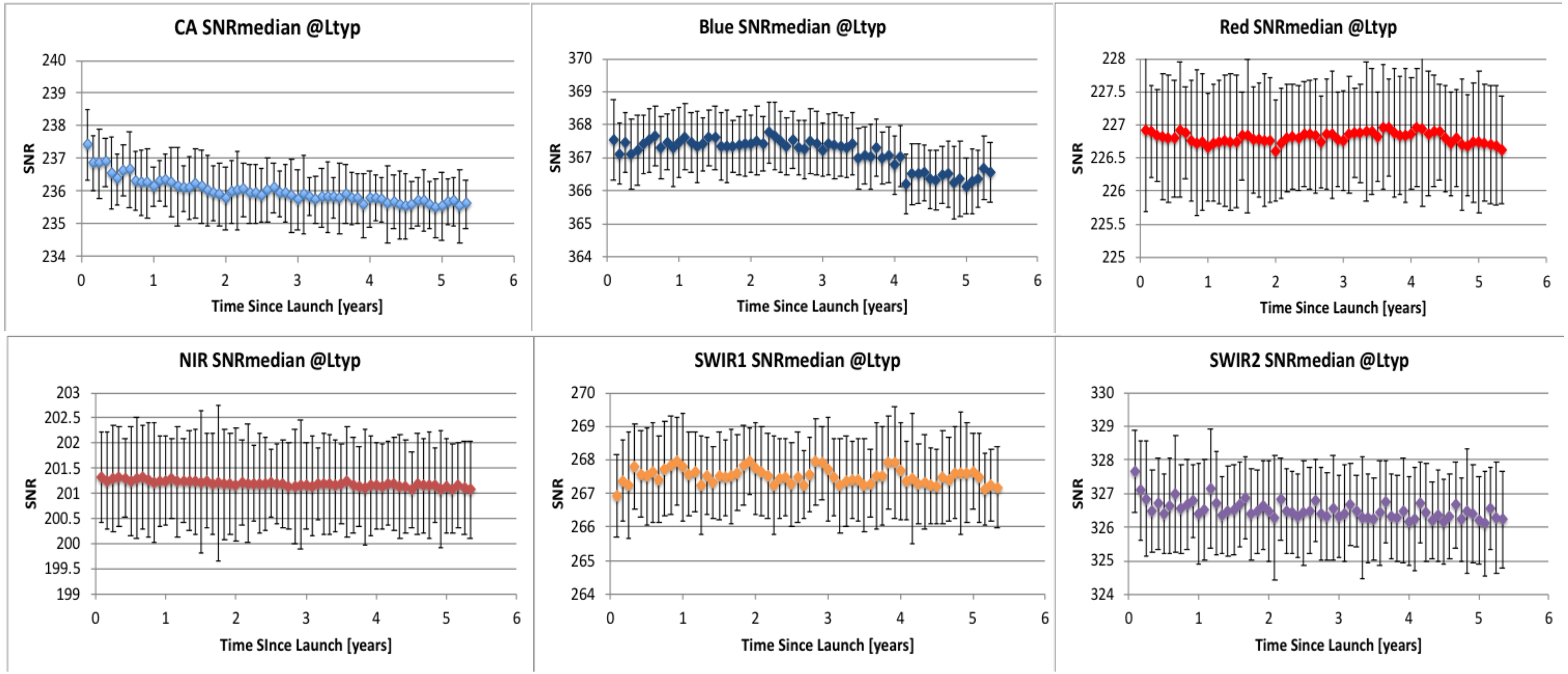
- Five and one-half years on-orbit, continuous operation on side A electronics, 100% detector operability
- Radiometric performance monitoring with:
  - Daily “working” stim lamps
  - 1/16 day “backup” stim lamps
  - 1/6 months “pristine” stim lamp
  - Weekly “working” diffuser
  - 1/6 months “pristine” diffuser
  - 1/month lunar imaging
  - *Vicarious data collections, NTE 1/16 days, two sites (RRV and Brookings, SD)*

Landsat-8 OLI Signal-to-Noise Ratio (SNR)

- Median Detector in each band trended
- Tracked using daily darks and stim lamps and weekly diffusers (2 signal levels plus dark) – modeled to provide SNR at “typical” radiance (L_{typ}).
- Reported on quarterly basis



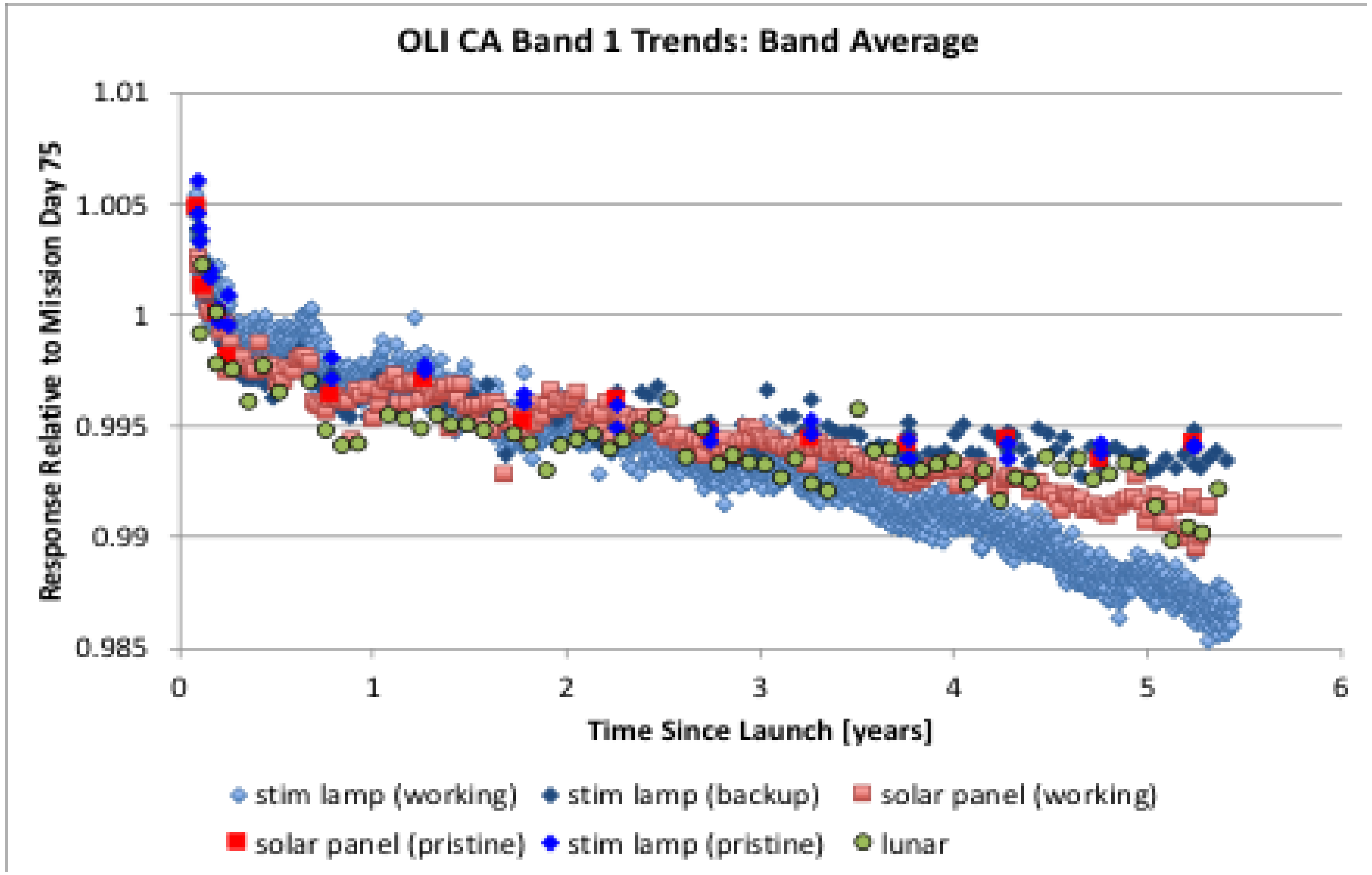
Landsat-8 OLI Signal-to-Noise Ratio (SNR)



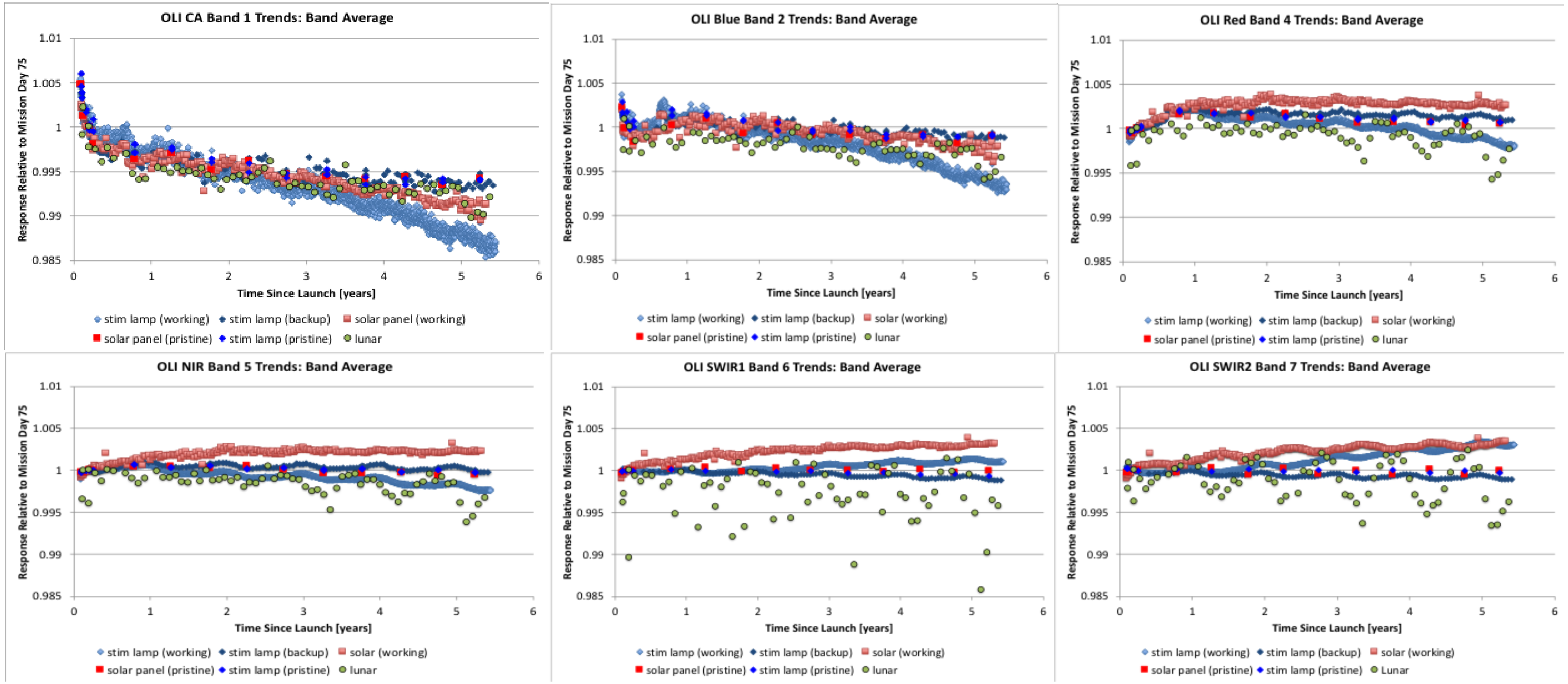
Small changes over mission <1%

Landsat-8 OLI Response Stability (1)

- Band Average
- Monitored with all on-aboard sources plus lunar views
- CA band (1) largest change, circa 1.3% over 5 plus years



Landsat-8 OLI Response Stability (2)



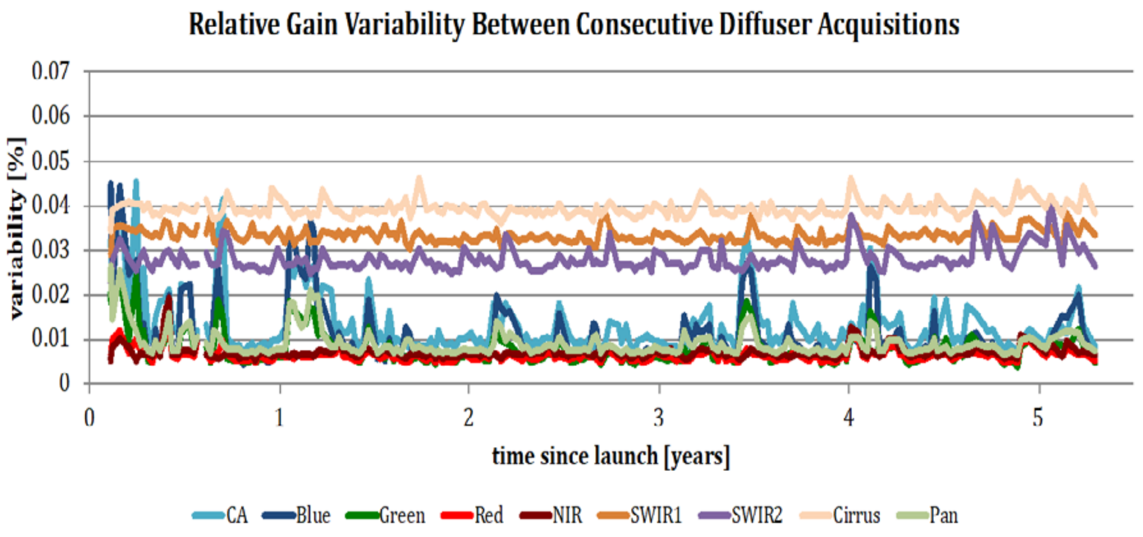
Small changes over mission <1.5%

Landsat-8 OLI Response Stability (3)

- All calibrators give comparable trends within ~0.5% over 5+ years
- All bands stable to better than 1.5% over 5+ years
- Some apparent degradation in most used calibrators
  - Working stim lamps – color temperature like shift – decreased output in blue, increased output in SWIR (operated at constant current)
  - Working diffuser – some decrease in blue, increase in longer wavelengths
- ”Pristine” calibrators best behaved
- Lunar collects have most variability in SWIR – being reduced with revised lunar model.

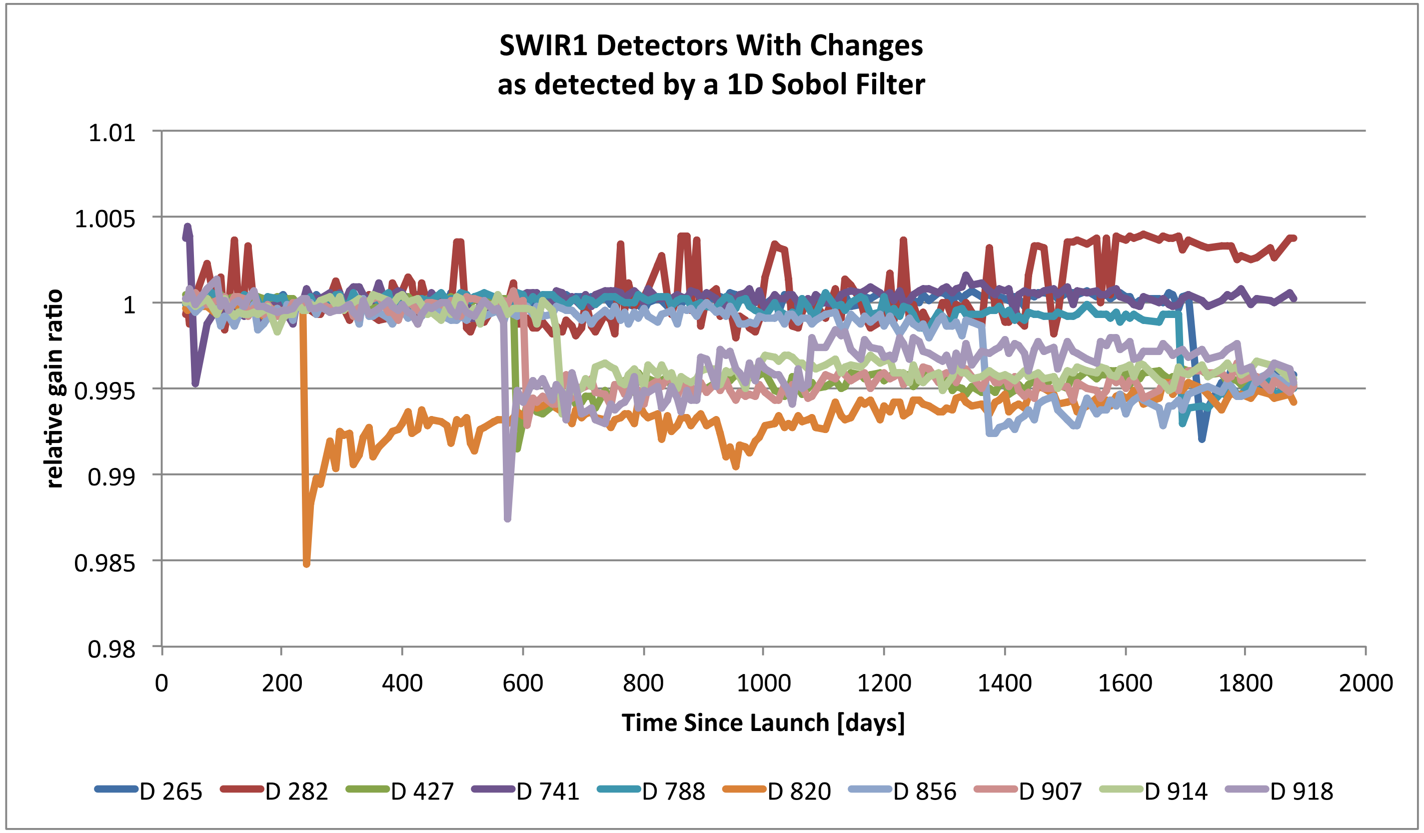
Landsat-8 OLI Response Stability (4)

- Detector-to-Detector (striping) or "relative gains"
- Using weekly diffusers- ratio responses to characterize changes
- Standard deviation of ratio quantifies changes
  - VNIR (silicon) ~0.01%
  - SWIR (HgCdTe) ~0.03%

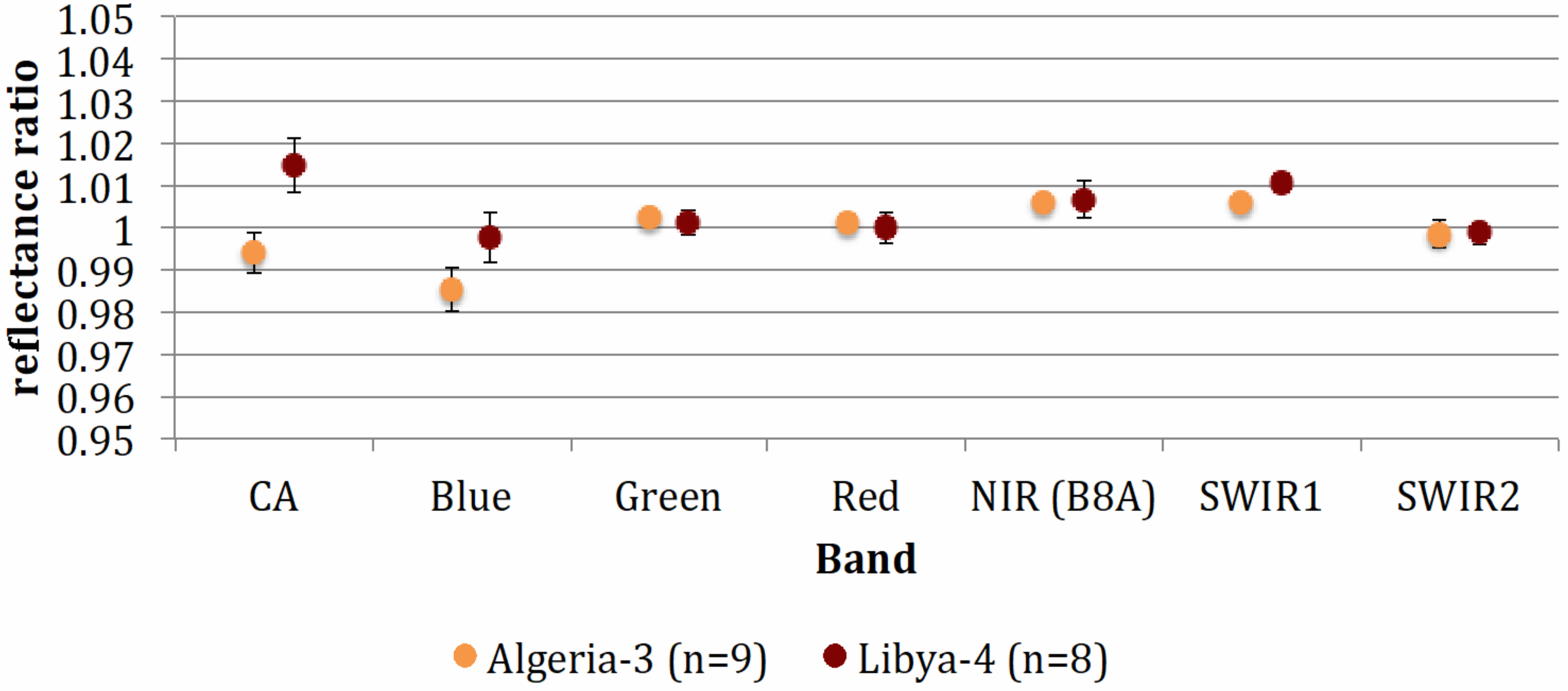


Landsat-8 OLI Response Stability (5)

- Some ‘jumpers” in SWIR
- Change by up to 1.5% “instantaneously”

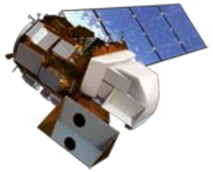


S2A MSI and OLI
Lifetime Average Ratios Between Coincident Acquisitions

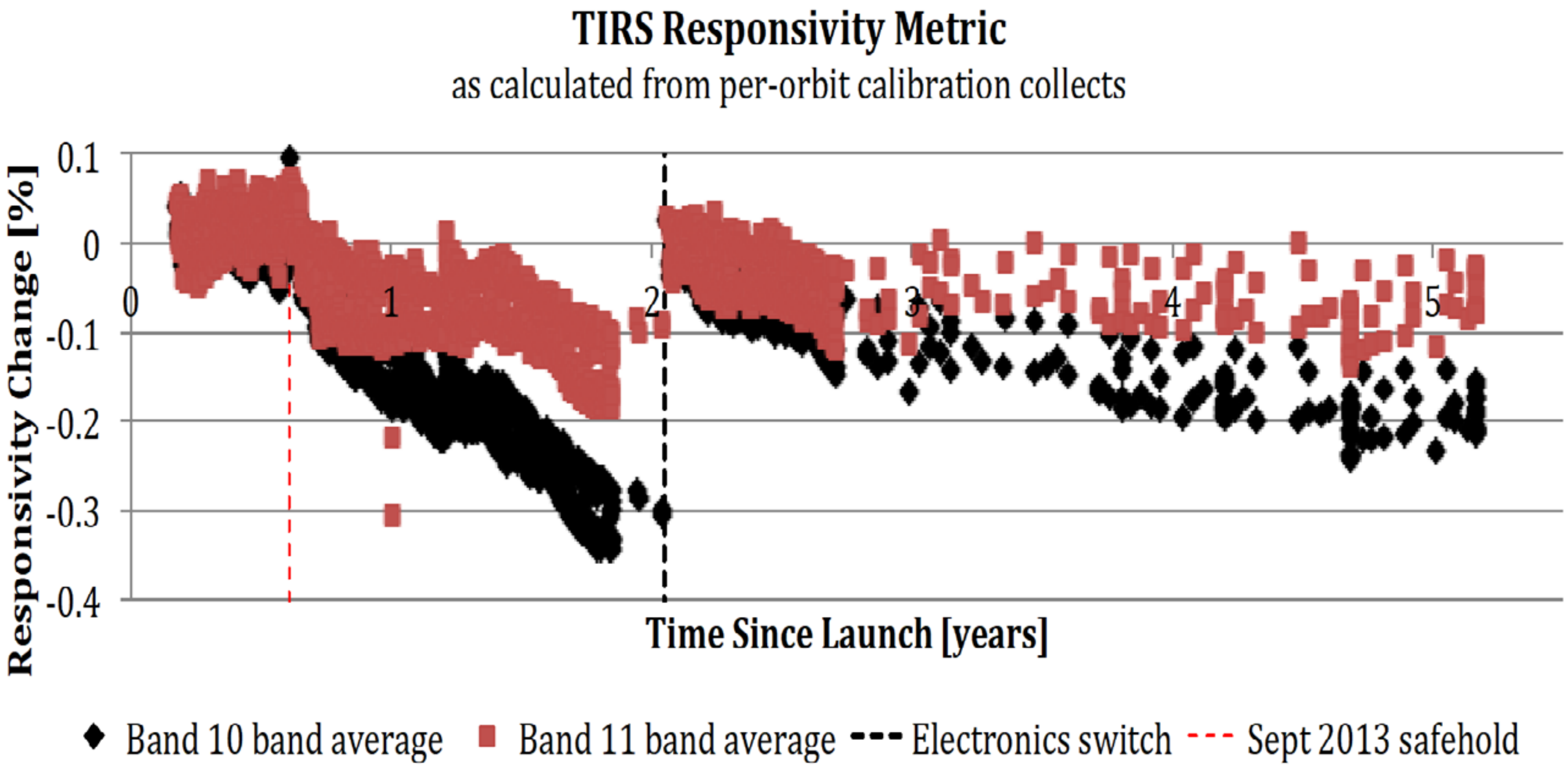


Landsat-8 TIRS On-orbit Status and Radiometric Performance

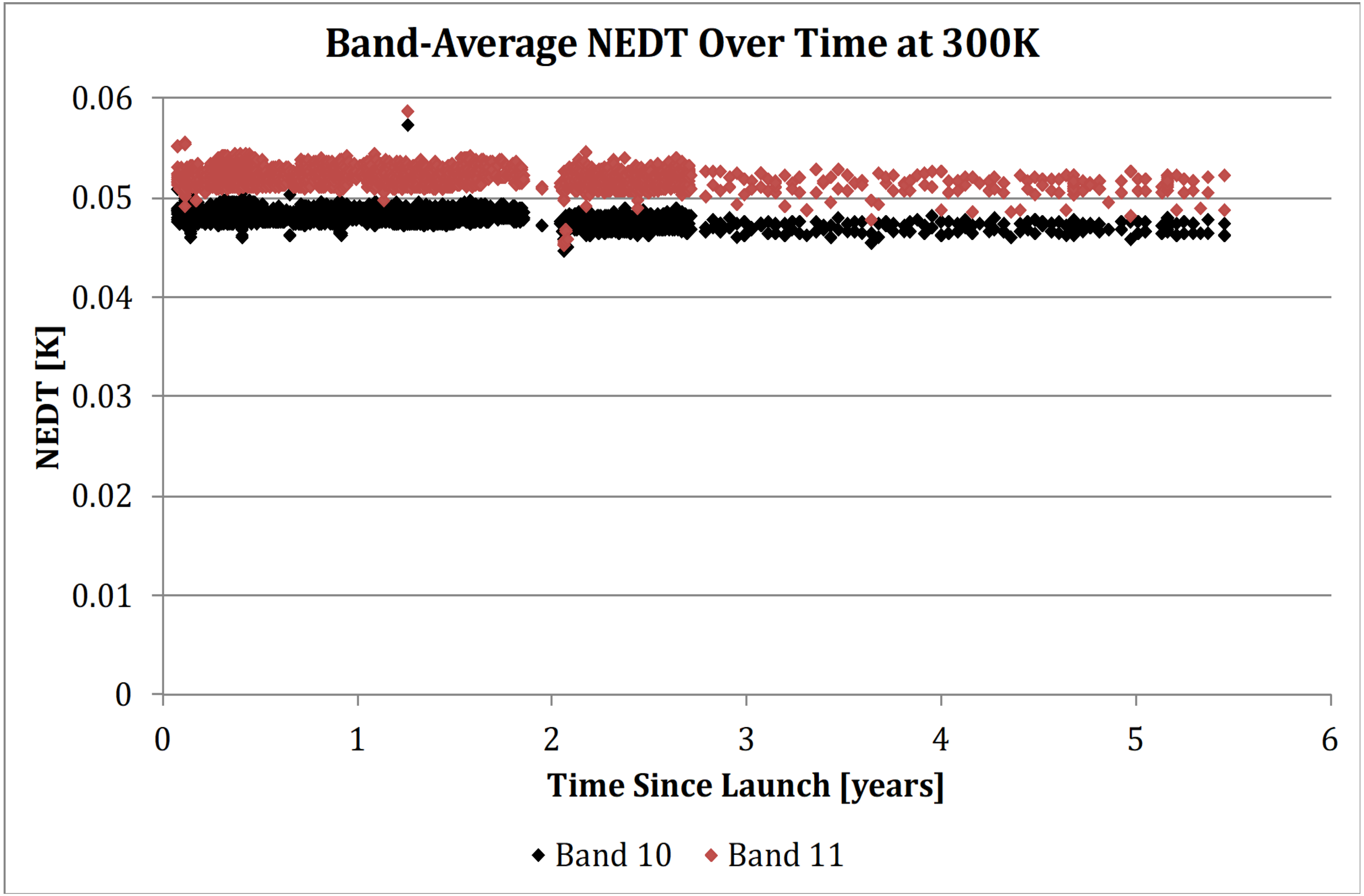
- Five and one-half years on-orbit, 100% detector operability, Scene Select Mirror (SSM)encoder issues caused side-B switch and alternate operations concept
  - SSM encoder turned on once/2 weeks
    - Radiometric calibration 2/month versus original 2/orbit
- Radiometric performance monitoring with:
  - Blackbody and Deep Space views (originally 2/orbit – now 2/month)
    - Blackbody temperature variable from 270K to 320K
  - Vicarious data collections, two teams (JPL- Tahoe, Salton Sea, RIT- NOAA buoys)



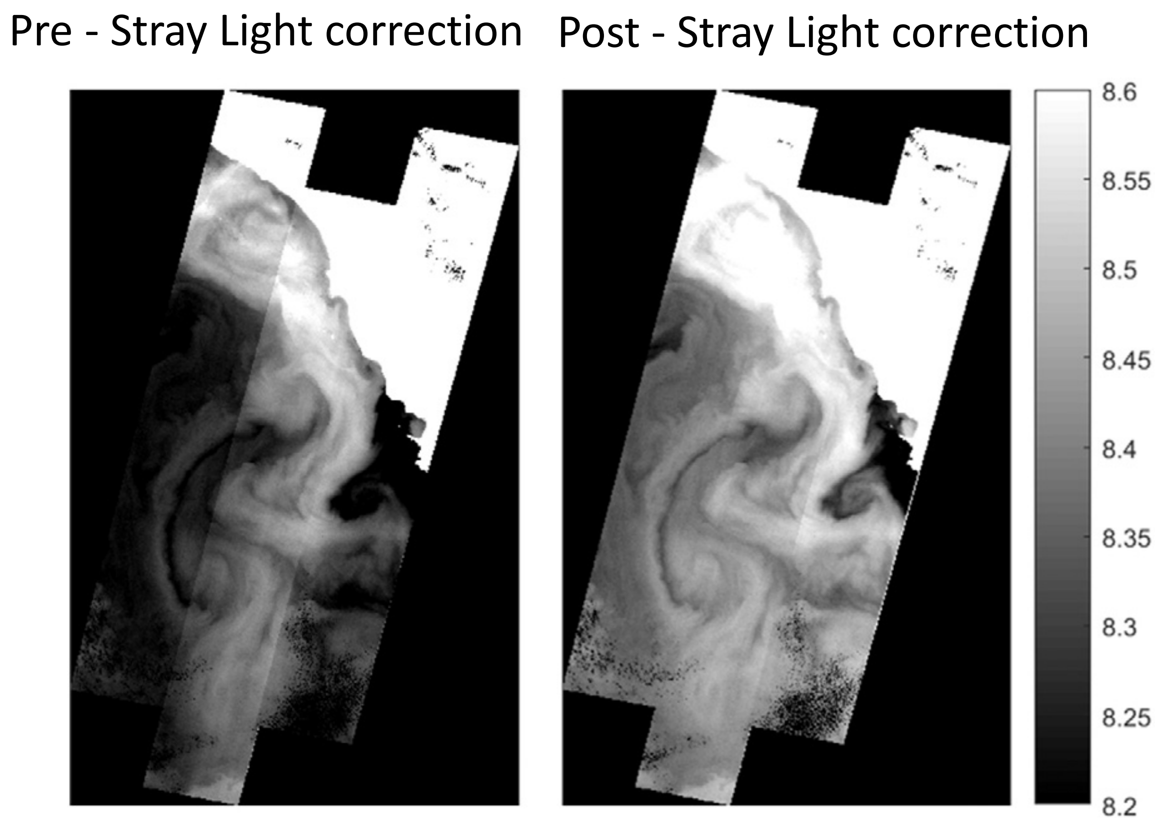
Landsat-8 TIRS On-orbit Response Stability



Band average - 0.3% or less apparent responsivity change

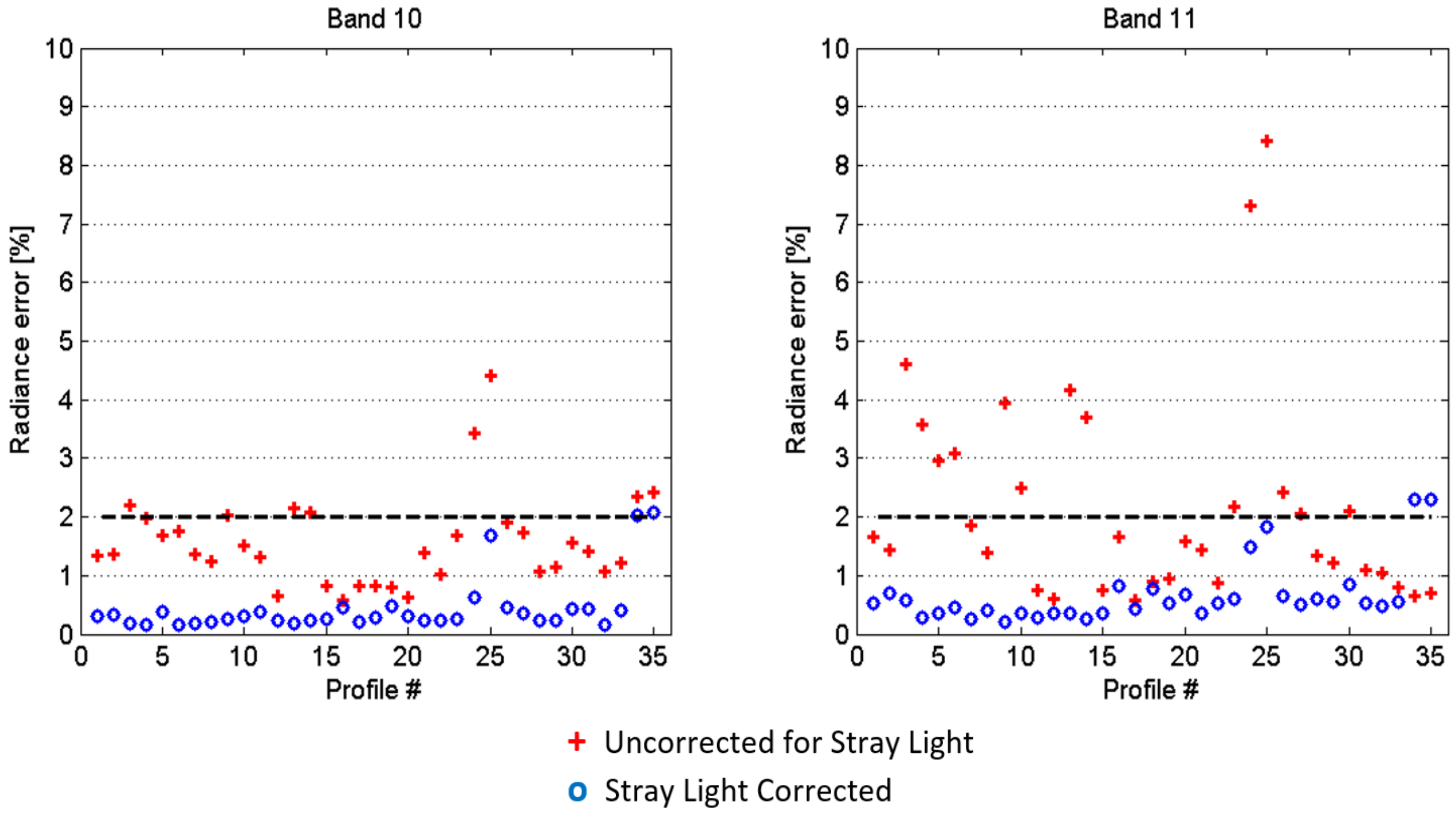

Band-Average NEDT Over Time at 300K
0.06
0.05
0.04
0.03
0.02
0.01
0
NEDT [K]
0
1
2
3
4
5
6
Time Since Launch [years]
Band 10
Band 11

Landsat-8 TIRS On-orbit Response Uniformity (1)



- Focal plane location dependent stray light produces image artifacts (striping, banding)
- Stray light algorithmic correction reduces artifacts

Landsat-8 TIRS On-orbit Response Uniformity (2)



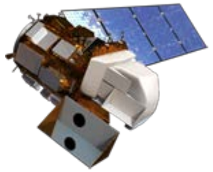
- Stray light algorithmic correction reduces RMS radiometric error (compared to MODIS [during commissioning] – 20 minutes later)
- Few outlier points were land targets

Landsat-8 TIRS On-orbit Calibration Uncertainty

Comparison to surface buoy water temperature measurements and atmospheric propagation

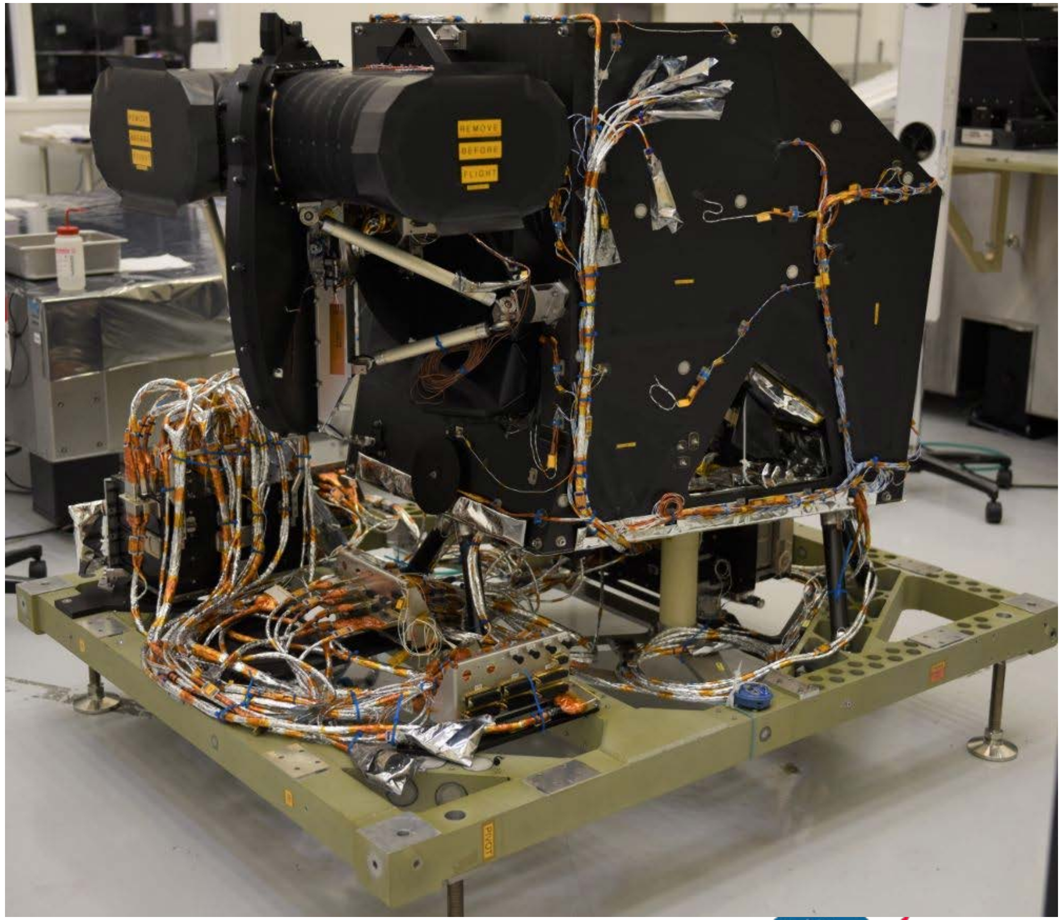
Daytime Side-A	N	Calibration Version 6 Whole focal plane [W/m2 sr um]	Calibration Version 6 Whole focal plane [K]	Calibration Version 6 RMSE [K]
B10	141	-0.02 +/- 0.01	-0.15	0.47
B11	141	0.06 +/- 0.02	0.53	0.53
Daytime Side-B				
B10	275	-0.06 +/- 0.01	0.43	0.42
B11	275	0.00 +/- 0.01	0.00	0.74

Small bias (probably correctable) and RMSE now comparable to previous Landsat thermal sensors



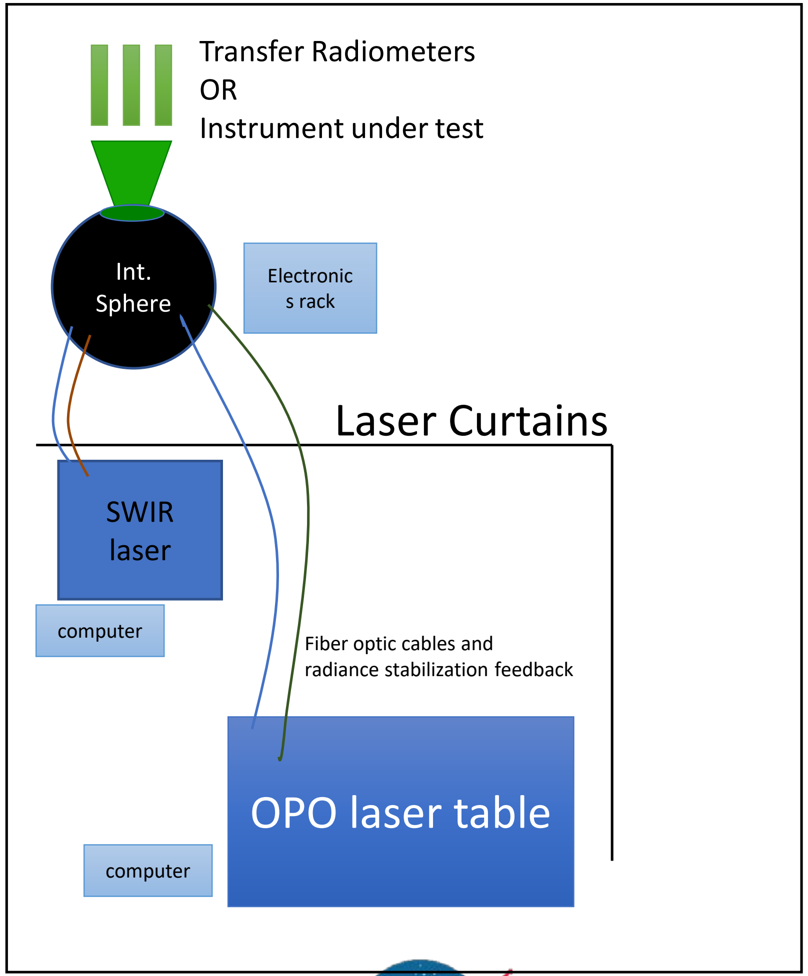
Landsat-9 OLI-2 Pre-Launch Status and Radiometric Performance

- Nearly a carbon copy of Landsat-8 OLI
- Instrument fully integrated (minus baseplate, thermal hardware and flight diffusers)
- Recently completed spatial characterization (focus, edge response, ghosting, bright target recovery) thermal vacuum testing (9/6/18)
    - Performance generally comparable to Landsat-8 OLI
- Preparing for spectral (new test set) and radiometric characterization (revised procedures) in thermal vacuum, starting ~mid-November 2018
- Current delivery to observatory integrator, ~ late summer 2019

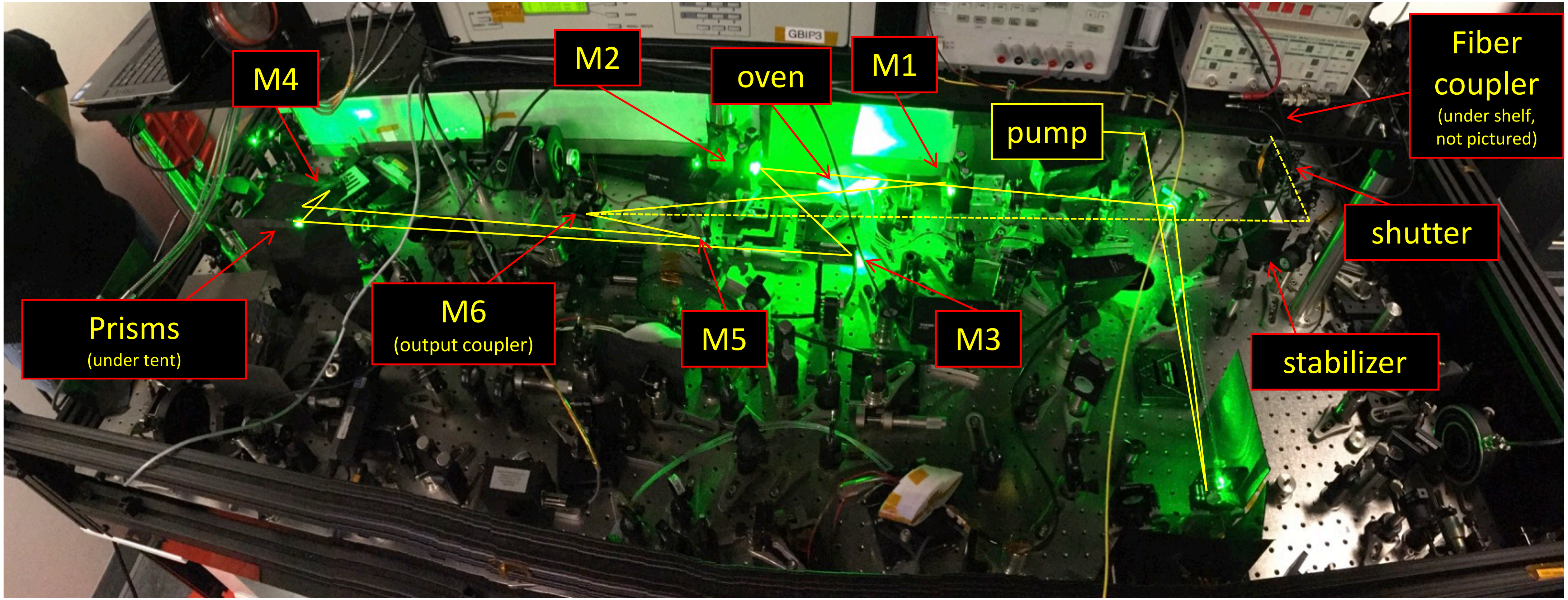


Landsat-9 OLI-2 Spectral Calibration Changes: Goddard Laser for Absolute Calibration of Radiance (GLAMR)

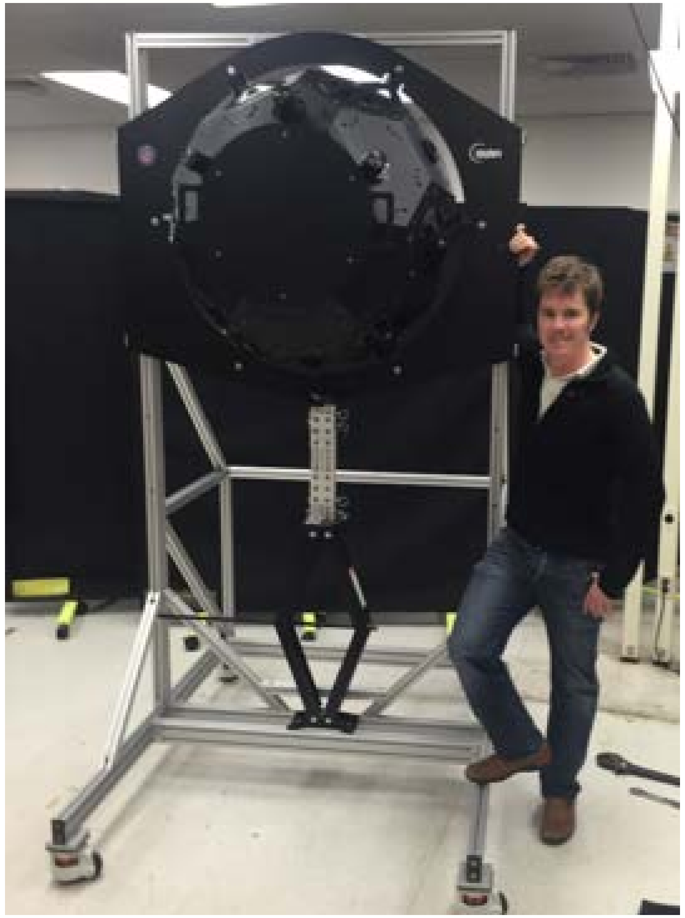
- Multiple tunable wavelength, narrow linewidth laser systems
  - Provides complete coverage over earth-observing systems spectral range
- In-house built optical parametric oscillator (OPO) systems with two ring cavities each, for coverage 350-2200nm
  - Tables referred to as OPO Laser Alignment Facilities (OLAFs)
- Two COTS systems, Argos and CLT, for coverage above 2200nm
- Illumination from lasers fed to sphere via fiber optic cables
- Three radiometers inside the sphere monitor the radiance from the laser
  - Provide feedback to the power stabilizer on the OLAFs for radiance-stabilized signal
- Output of radiance from 30” integrating sphere viewed by instrument under test
- External transfer radiometers transfers NIST-traceable calibration to sphere monitor radiometers
- All tuning is computer controlled
  - Allows for efficient scanning operation over large wavelength ranges
- Can be used for relative spectral response and absolute response



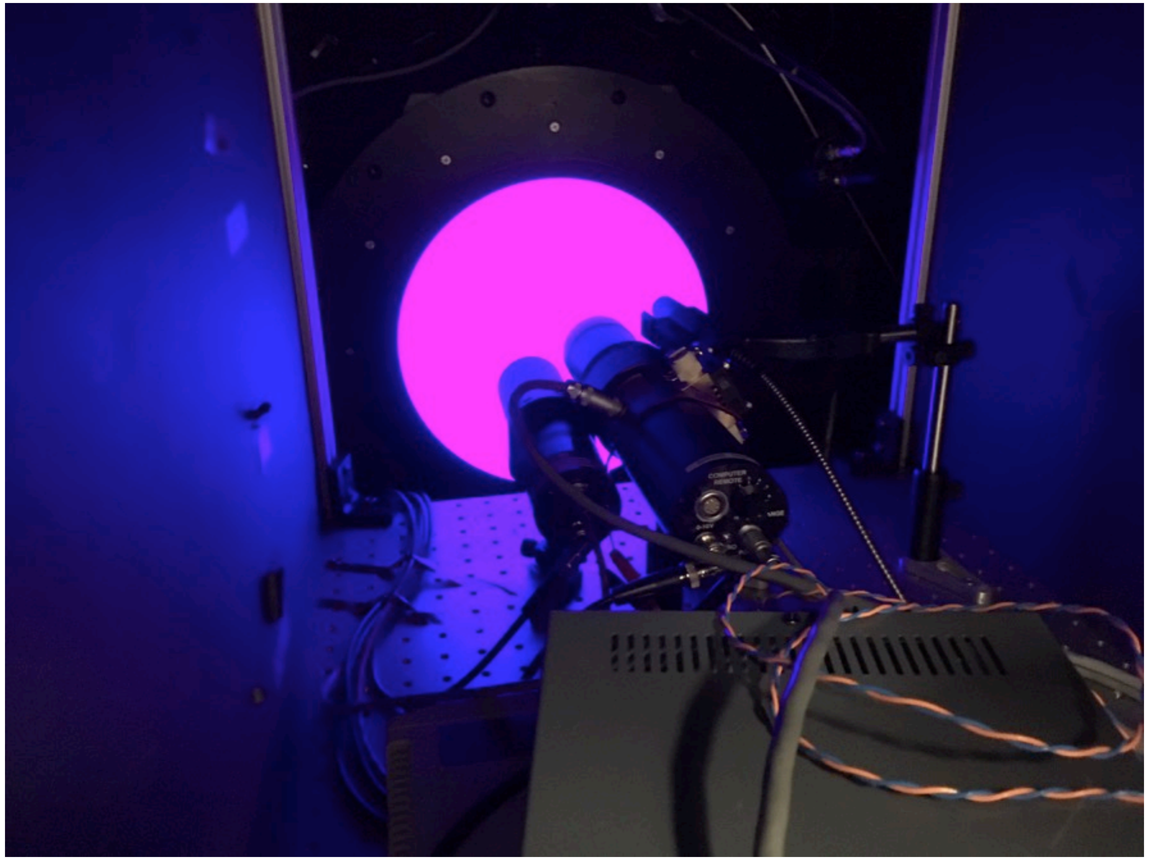
OLAF1 in operation
OPO_NIR beam path for 868nm



GLAMR Integrating Sphere

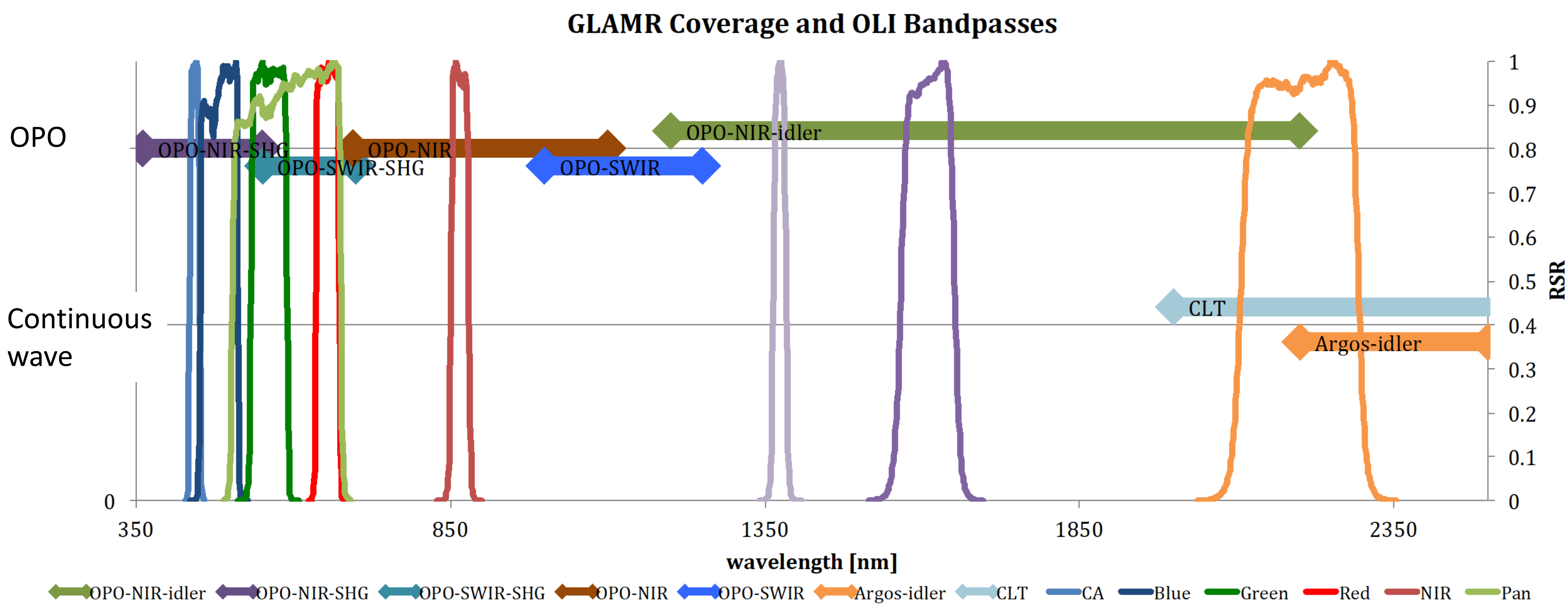


Sphere at approximately OLI-2 deployment height



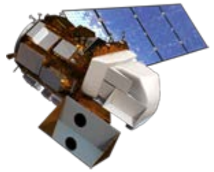
Sphere output at ~443nm. Three transfer radiometers monitor the output.

GLAMR Spectral Coverage and OLI Spectral Response



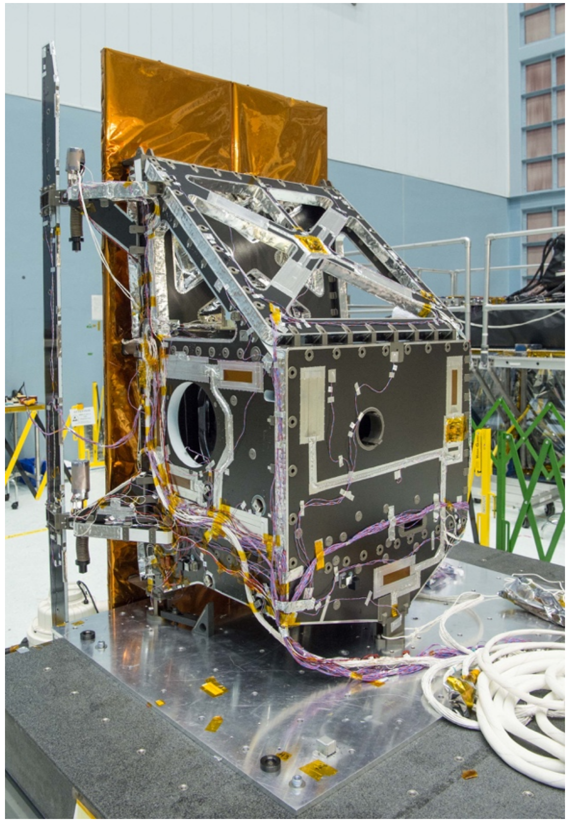
Improvements to OLI-2 Spectral Characterization

- Full focal plane characterization
  - OLI monochromator-based test only illuminated about 60 detectors at a time
    - 16 positions on the focal plane were tested (~15%)
- In-band and out-of-band characterization at instrument level
  - For OLI, out-of-band response was characterized at the module level
- Larger field full aperture illumination
  - All bands within a module illuminated as well as adjacent modules
  - Within module and between adjacent module crosstalk effects now included
- NIST traceable radiance
  - Can provide a check on the DSS absolute calibration



Landsat-9 TIRS -2 Pre-Launch Status and Radiometric Performance

- Largely a copy of Landsat-8 TIRS
  - Revised baffling for stray light control
  - Revised SSM encoder design for reliability
  - Increased redundancy for reliability
- Instrument fully integrated
- Completed stray light, spatial and spectral tests in partially integrated form (minus SSM and front baffles)
  - Stray light reduced by about an order of magnitude
  - Spectral and spatial (Not final test) performance generally comparable to Landsat-8 TIRS
    - Spatial and spectral response better understood
- Two thermal vacuum performance tests planned *(November 2018, February 2019)*
- Current delivery to observatory integrator, ~ late summer 2019



Landsat-9 TIRS -2 Stray Light Performance (1)

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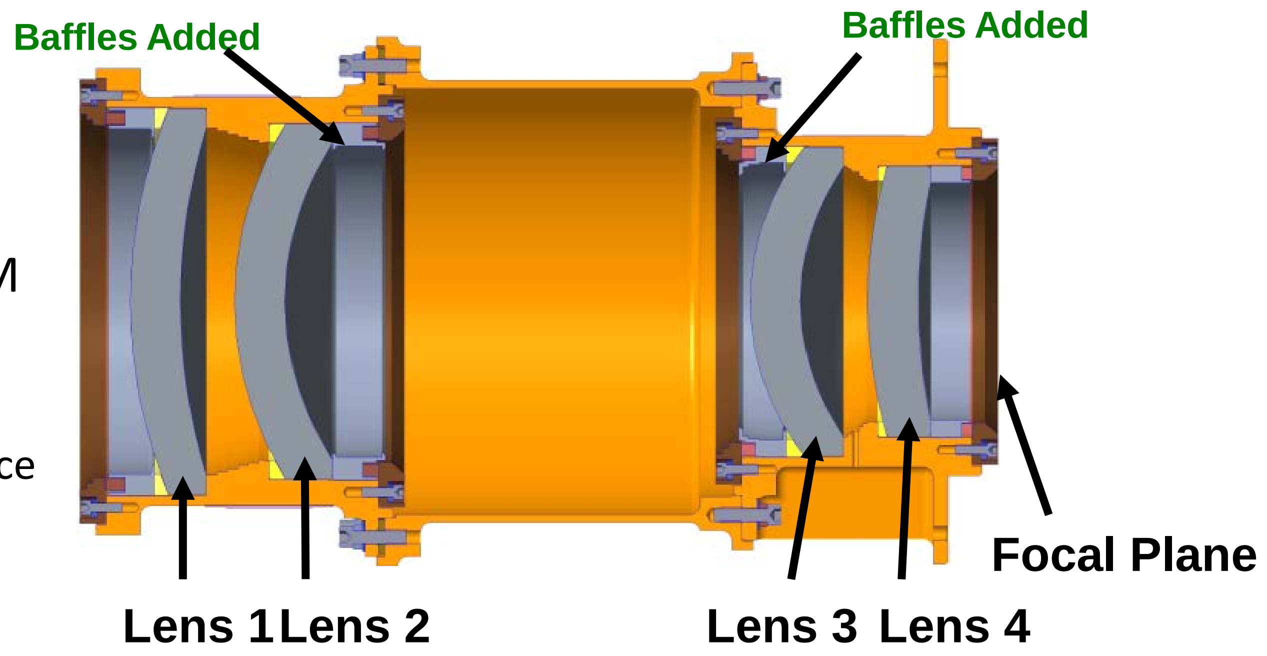
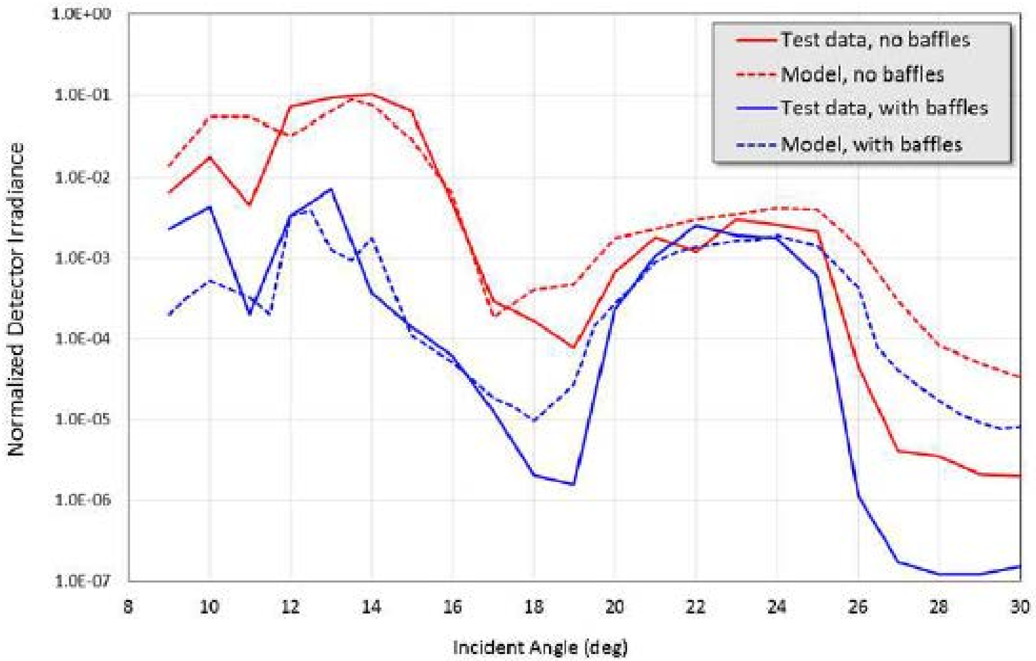
TIRS-2 Optical Telescope System



Landsat-9 TIRS -2 Stray Light Performance (2)

- Modeling and measurement indicated that primary source of stray light was lens 3 mounting structure (13° feature)
- Models also showed affect from lens 2 mounting structure (22° feature not originally seen on-orbit, but found later - weak)
- Added new baffles at both lens 2 and 3 – models predicted ~10x reduction in stray light at 13 ° off axis – measurements confirmed ; smaller change (and original problem) at 22°
- New design should have comparable radiometric uncertainty to previous Landsat thermal radiometers, with possible exception of extreme background and target temperature differences *(>50K)– I made this number up*



Summary

- The Landsat-8 TIRS and OLI sensors continue to operate well on-orbit.
- Both are very radiometrically stable. The TIRS stray light correction algorithm improves both absolute and relative radiometry of the data products.
- The Landsat-9 TIRS-2 and OLI-2 instruments have entered the integrated instrument test phase.
- Partially integrated instrument test results indicate that TIRS-2 and OLI-2 will have comparable noise, operability and stability behavior.
- Added baffles to the TIRS-2 design have reduced stray light by about an order of magnitude, which should allow comparable performance to historical Landsat-7 ETM+ thermal data without algorithmic stray light correction.
- Expect Landsat-9 to launch in December 2020 at which point there will be two Landsat and two Sentinel-2 spacecraft on-orbit, providing high quality multispectral data every few days on average.