LANDSAT 9: MISSION STATUS AND PRELAUNCH INSTRUMENT PERFORMANCE CHARACTERIZATION AND CALIBRATION

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Yokohama, Japan

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Agenda

- Mission Overview
- Mission Status
- Instrument Performance
- Summary

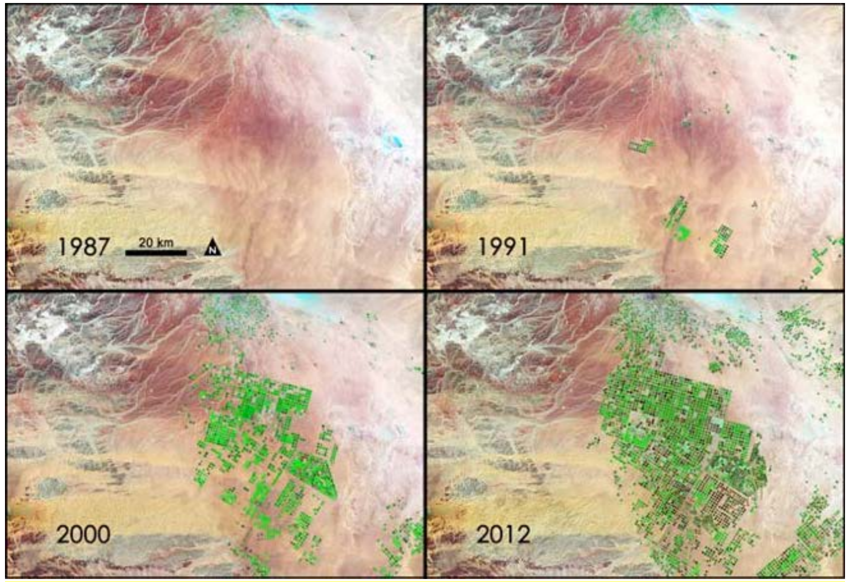
Landsat 9 Mission Overview

Mission Objectives

- **Provide continuity in multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics**
  - **Core Component of Sustainable Land Imaging program**

Mission Team

- **NASA Goddard Space Flight Center (GSFC)**
- **USGS Earth Resources Observation & Science (EROS) Center**
- **NASA Kennedy Space Center (KSC)**



Increase in pivot irrigation in Saudi Arabia from 1987 to 2012 as recorded by Landsat. The increase in irrigated land correlates with declining groundwater levels measured from GRACE (courtesy M. Rodell, GSFC)

Mission Parameters

- **Single Satellite, Mission Category 1, Risk Class B**
  - 5-year design life after on-orbit checkout
  - At least 10 years of consumables
- **Sun-synchronous orbit, 705 km at equator, 98° inclination**
- **16-day global land revisit**
- **Partnership: NASA & USGS**
  - NASA: Flight segment & checkout
  - USGS: Ground system and operations
- **Category 3 Launch Vehicle**
- **Launch: Management Agreement - December 2020**
  Agency Baseline Commitment – November 2021

Instruments

- **Operational Land Imager 2 (OLI-2; Ball Aerospace)**
  - Reflective-band push-broom imager (15-30m res)
  - 9 spectral bands at 15 - 30m resolution
  - Retrieves data on surface properties, land cover, and vegetation condition
- **Thermal Infrared Sensor 2 (TIRS-2; NASA GSFC)**
  - Thermal infrared (TIR) push-broom imager
  - 2 TIR bands at 100m resolution
  - Retrieves surface temperature, supporting agricultural and climate applications, including monitoring evapotranspiration

Spacecraft (S/C) & Observatory Integration & Test (I&T)

- **Northrop Grumman Innovation Systems (NGIS), formerly Orbital ATK (OA)**

Launch Services

- **United Launch Alliance (ULA) Atlas V 401**

Mission Operations Center (MOC) and Mission Operations

- **General Dynamics Mission Systems (GDMS)**

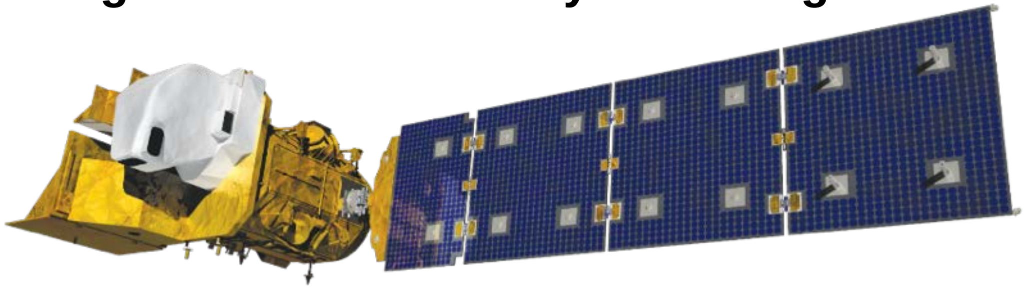
Landsat 9 Mission Status

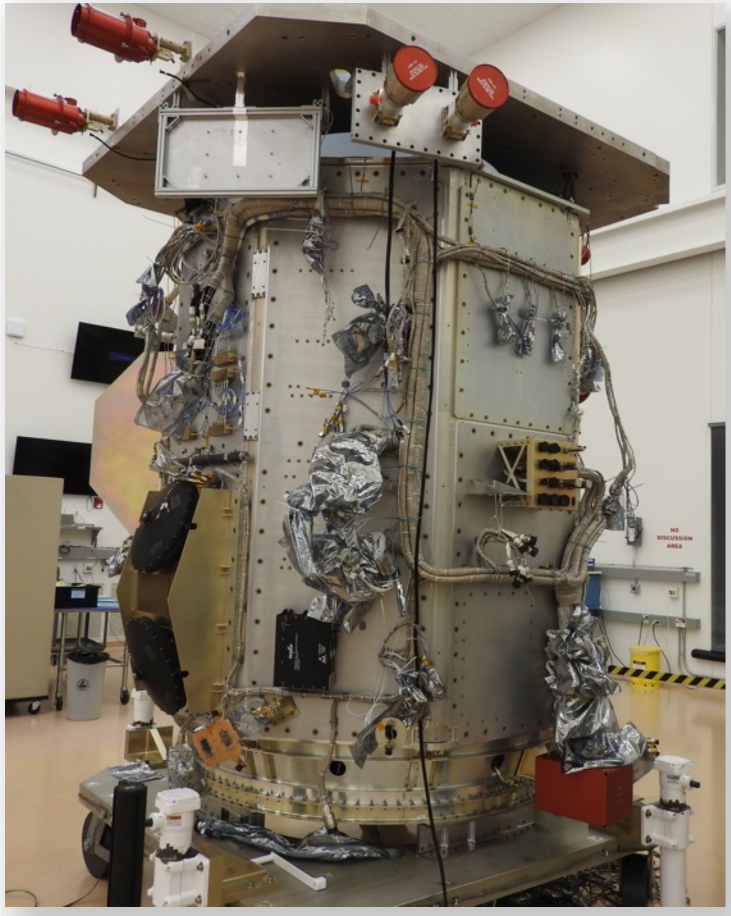
- **Overall, project is healthy and on course**
  - Continue to target December 15, 2020 Launch Readiness Date (LRD)
  - Instrument development continues to be a huge success
  - USGS ground/operations development in very good shape
    - Challenged primarily by late simulator deliveries from spacecraft provider
  - Launch services in very good shape
  - Mission integration planning maturing
- **Spacecraft bus development schedule remains challenging**
  - Challenging nature of bus development schedule recognized since project inception
  - Instrument deck is critical path to bus complete
  - Challenges also exist in bus electronics, FSW, simulators
- **Planned Observatory I&T period is healthy**
- **Project has been preparing for Mission I&T since Critical Design Review time frame**
  - Added significant horsepower to project team
- **Drawing heavily from successful LDCM experience & lessons learned**
- **Coordination between NASA and USGS continues to be extremely tight**

Spacecraft Bus

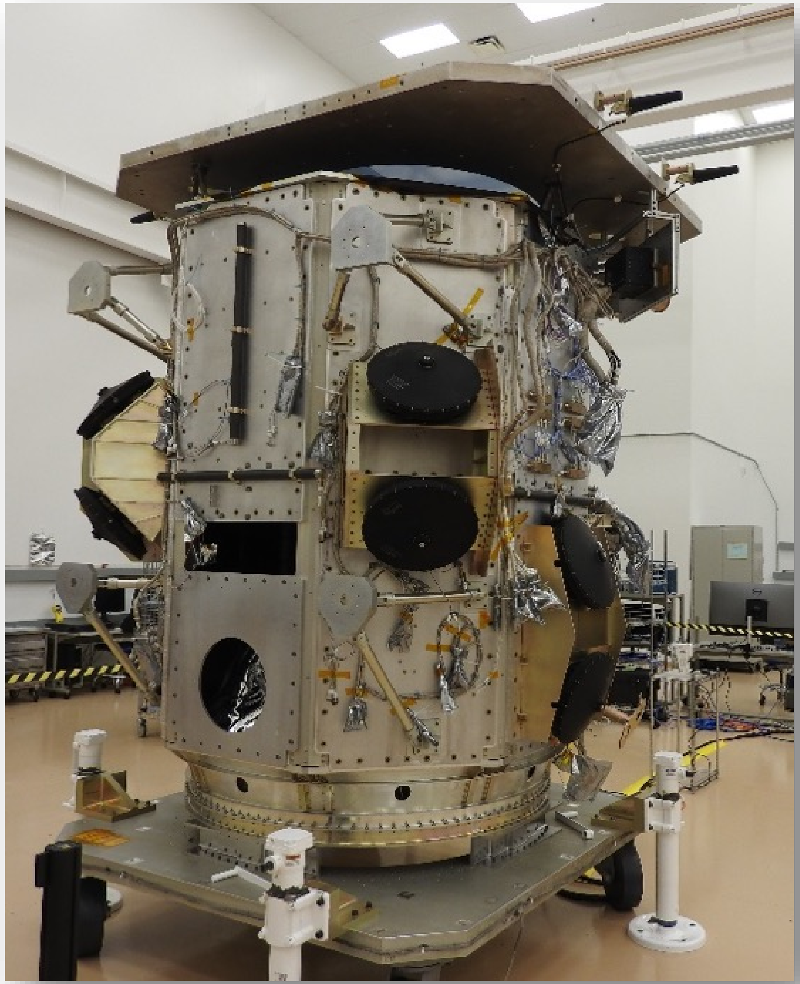
Landsat 9 spacecraft is similar to Landsat 8 that draws upon component heritage from ICESat-2 and JPSS-2 missions

- **Contract competitively awarded to then Orbital ATK in Gilbert, AZ in October 2016 (now NGIS)**
- **Spacecraft successfully completed**
  - System Requirements Review in February 2017
  - Preliminary Design Review in July 2017
  - Critical Design Review in February 2018
- **All components and subsystems in development and integration**
  - Working towards the comprehensive performance test (CPT) of Spacecraft in August
- **Instrument Integration Readiness Review planned for the end of October along with the mission System Integration Review**





Spacecraft Hardware Glamour Shots



Landsat 9 spacecraft bus structure being assembled at Northrop Grumman Innovation Systems in Gilbert, AZ

Spacecraft Structure Assembly

Landsat 9 Spacecraft Bus w/Panels

Landsat 9 Installing Harness

SC prop/rocket engine modules with thrusters on LVA. Inner ring is prop tank support ring. REMs/thrusters mounted around the outside of that. Outer ring is LVA.

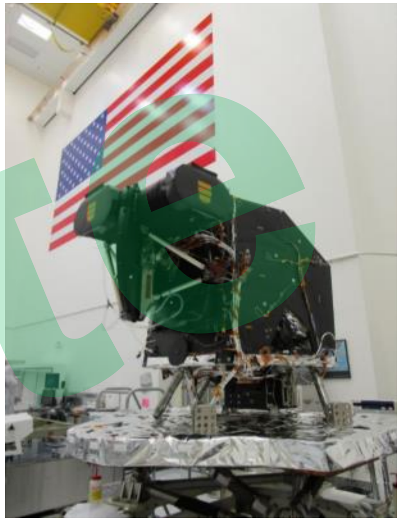
Lifting to mass props table

Operational Land Imager 2 (OLI-2) Status

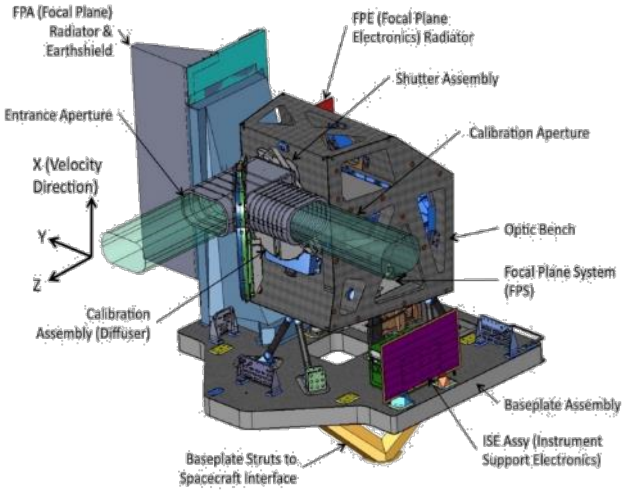
OLI-2 is, to the extent possible, a copy of OLI for Landsat 9 to maintain data continuity with Landsat 8 and to minimize cost and risk

- **Contract with Ball Aerospace in Boulder CO established in December 2015**
- **Successful OLI-2 Critical Design Review in August 2016**
- **Instrument completed spatial testing in August 2018 and calibration testing in December 2018**
    - Excellent instrument performance
- **Instrument has now completed environmental testing**
- **Pre-ship Review (PSR) successfully completed 17 July 2019**
- **Delivery to spacecraft facility planned for late summer 2019**

Complete



OLI-2

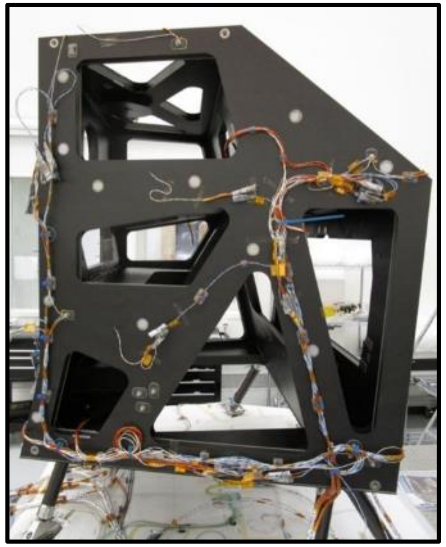


OLI-2 Hardware Glamour Shots

Installing the Tertiary Mirror into the OLI-2 Optical Bench at Ball Aerospace

OLI-2 complete at Ball Aerospace

Ball Aerospace FPA Assembly Team



OLI-2 Optical Bench

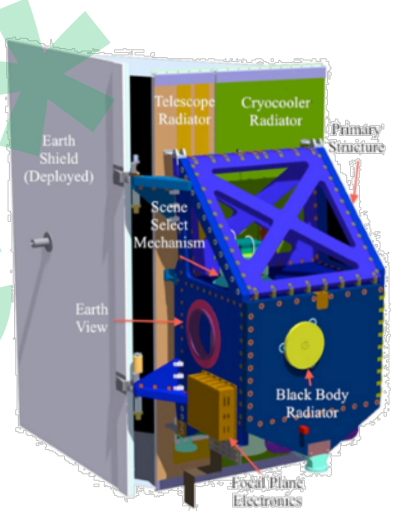
Thermal Infrared Sensor 2 (TIRS-2) Status

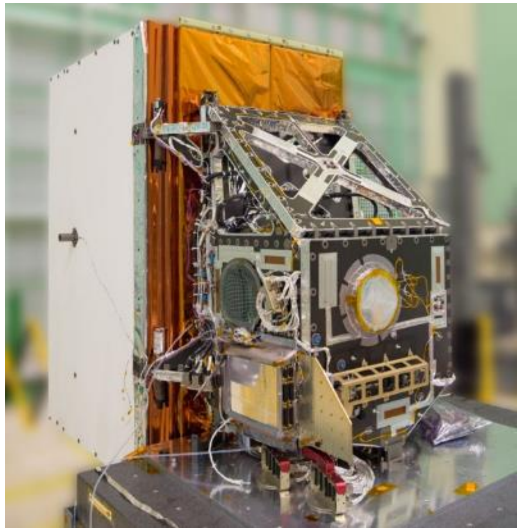
TIRS-2 is a rebuild of Landsat 8 TIRS except it's upgraded from Risk Class C to Class B for Landsat 9

- **NASA GSFC TIRS-2 team formed in 2015**
- **Successful TIRS-2 Critical Design Review in February 2017**
- **TIRS-2 image performance and cryogenic evaluation (TIPCE) testing completed**
  - Focus and stray light performance very good
- **Instrument fully integrated and completed environmental testing at NASA GSFC**
- **TIRS-2 Pre-ship Review scheduled for 12 August 2019***
- **Planned August 2019 delivery to spacecraft facility**

TIRS-2 Improvements

- Increased redundancy to satisfy Class B reliability standards
- Improved stray light performance through improved telescope baffling
- Improved position encoder for scene select mirror to address problematic encoder on Landsat 8 TIRS

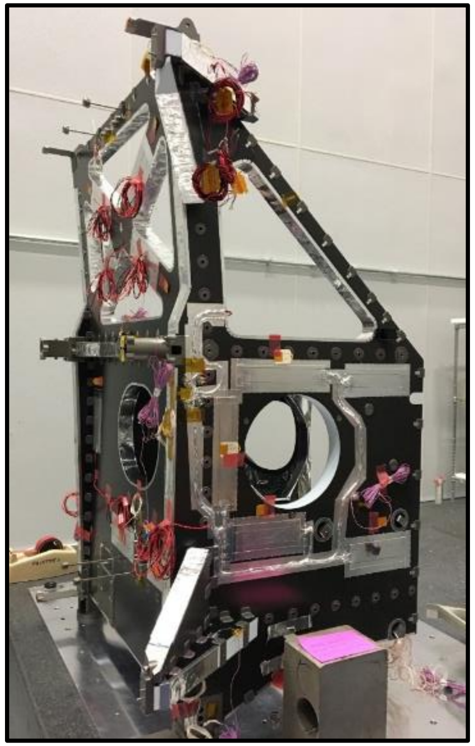




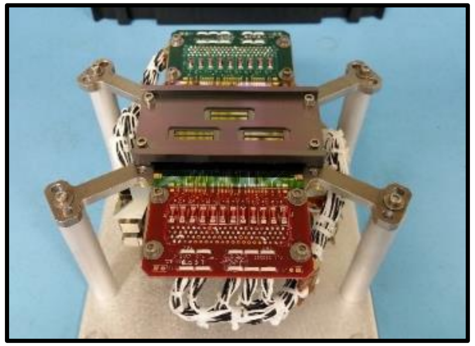
TIRS-2 being prepared for blanketing at NASA/GSFC

Complete*

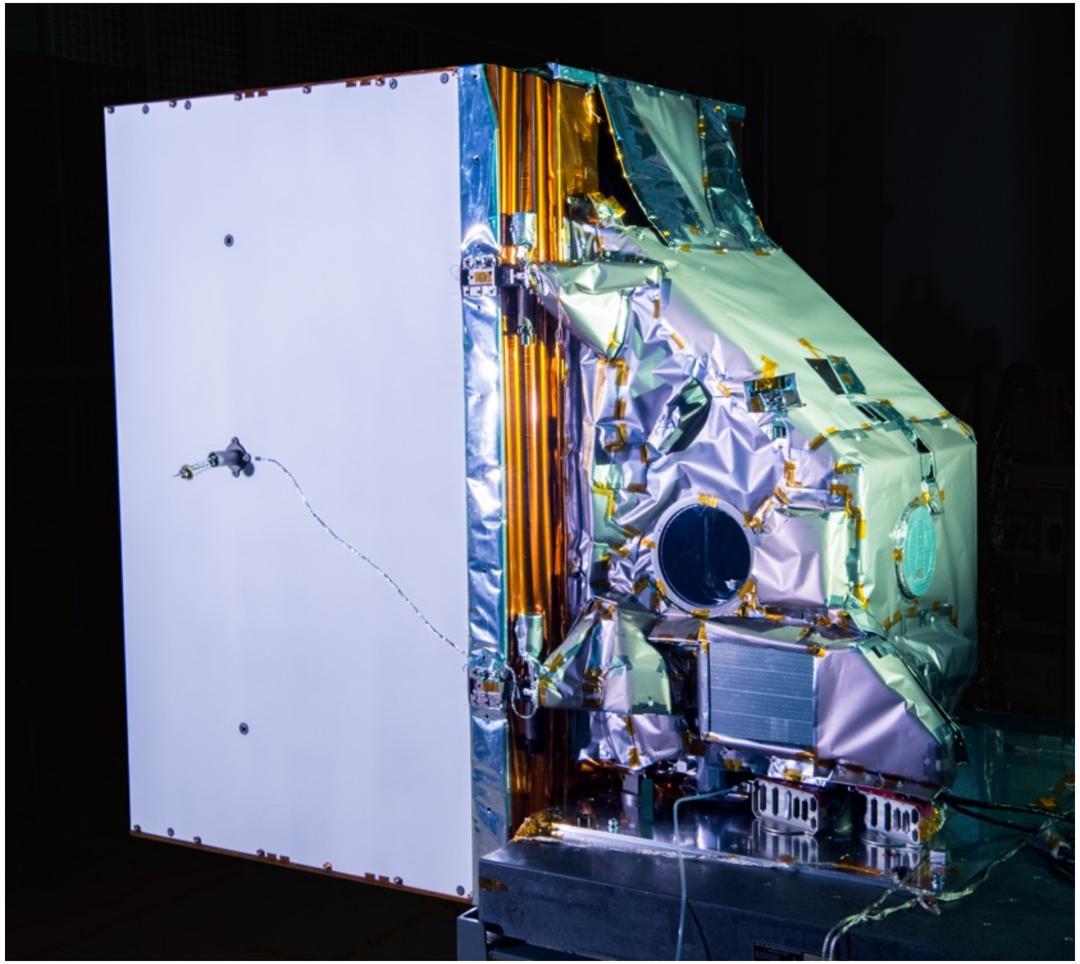
TIRS-2 Hardware Glamour Shots



Fully Assembled TIRS-2 Flight Structure

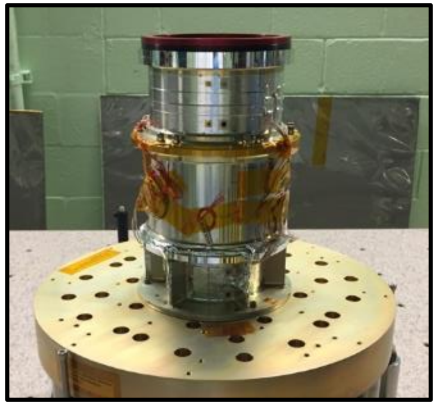


Flight TIRS-2 Focal Plane



TIRS-2 Complete at NASA/GSFC

Cryocooler (Ball Aerospace)

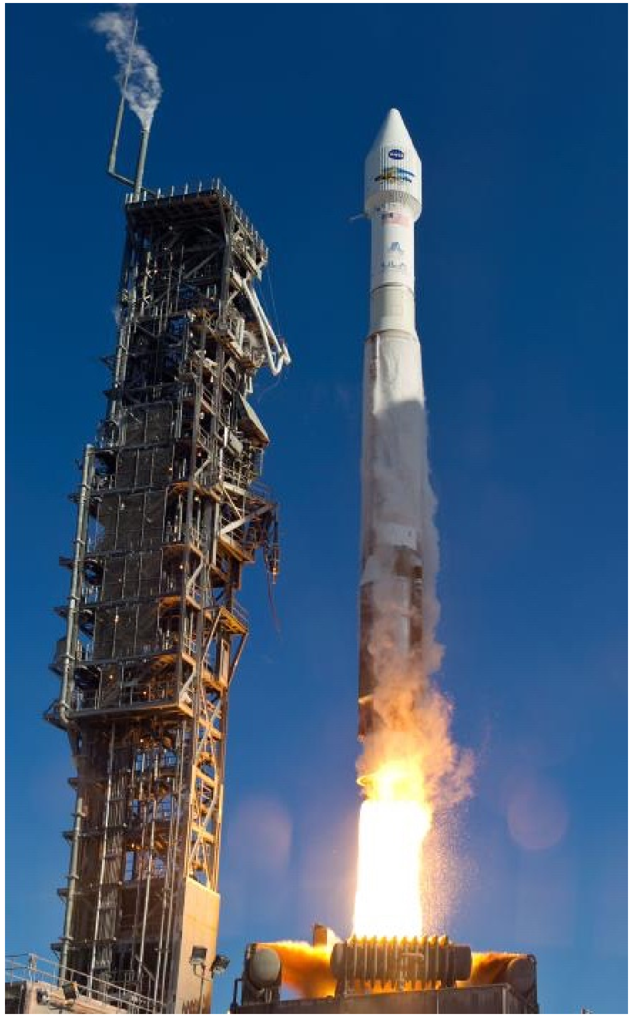


Flight Telescope

Launch Services

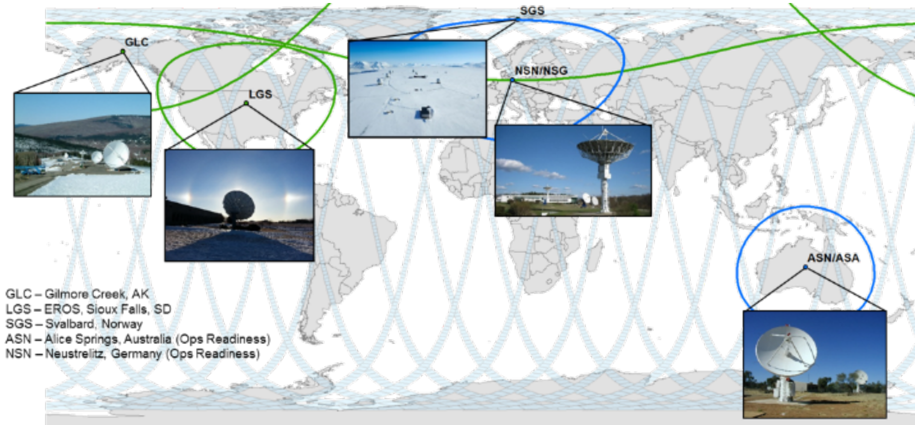
Landsat 9 launch services awarded to same provider for the same LV as Landsat 8

- **Awarded October 2017 to United Launch Alliance (ULA)**
- **Vehicle: Atlas V 401 from Vandenberg AFB SLC-3**
- **L9 launch services task order will include secondary payloads on LV**
  - NASA and the Air Force will fly an Expendable Secondary Payload Adaptor (ESPA) with payloads on L9 launch
    - NASA Science Mission Directorate and Flight Planning Board approved AF ESPA rideshare for Landsat 9 in April 2018
  - ULA analysis indicates no impact to Landsat 9
  - “Do No Harm” criteria are in place
  - Specific Implementation details in work between NASA and AF
- **Successful Requirements Review held in February 2019**
- **LV Mission Specific Preliminary Design Review planned for September 2019**
- **Ongoing routine integration/coordination between Landsat 9 and ULA Projects**
  - Finalizing LV Interface Control Documentation
- **VAFB Payload Processing Facility contract to be competitively awarded late summer 2019**



Landsat 9 Ground System

- **Landsat Multi-satellite Operations Center (LMOC)**
  - Contract for LMOC/bLMOC development and Flight Ops Team awarded to General Dynamics Mission Systems (GDMS) in June 2017
  - Landsat Mission Operations (LMO) contract provides Landsat 8 and Landsat 9 MOC development and FOT services
  - Landsat Multi-satellite Operations Center (LMOC) and bLMOC facilities at GSFC
- **Ground Network Element (GNE)**
  - Landsat Ground Network (LGN) stations provide X- and S-band communications with the Observatory
  - LGN stations in Sioux Falls, SD; Fairbanks, AK; and Svalbard, Norway
  - Neustrelitz, Germany and Alice Springs, Australia for use after commissioning
  - Data Collection and Routing Subsystem (DCRS) gathers mission data from LGN stations into complete intervals to transfer to the DPAS
- **Data Processing and Archive System (DPAS)**
  - Provides data ingest, storage and archive, image assessment, product generation, and data access and distribution
  - Includes scope to integrate the Landsat 4-8 Level-2 algorithms into the operational system
  - DPAS facility at USGS EROS Center



Landsat 9 GS Progress

- **All Element(s) design is complete; Currently in build, integration and test**

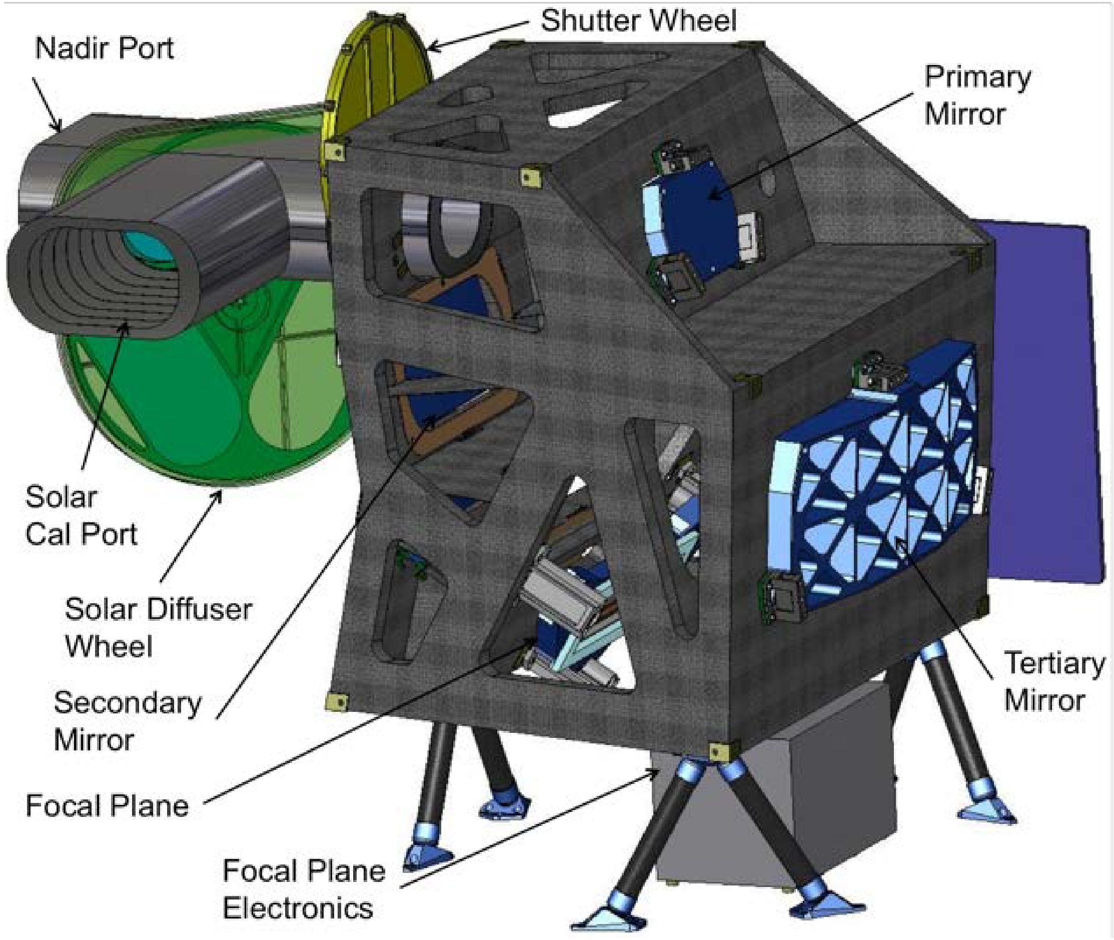
- **Ground Readiness Testing (GRT) underway**
  - Ground Readiness Test 1 completed in February 2019
    - » End to End testing of the Landsat Ground Station to the Landsat Multi-Satellite Operations Center
  - Ground Readiness Test 2 Dry-Run's underway, Run for Record in July 2019
    - » Mission planning and schedule testing that includes the Landsat Ground Station, Data Processing and Archive System and Landsat Multi-Satellite Operations Center
  - Ground Readiness Test 3 planned for December 2019
    - » Full Interval End to End testing that includes the Landsat Ground Station, Data Processing and Archive System and Landsat Multi-Satellite Operations Center

- **All Landsat 9 Ground System Launch Critical Functionality is fully verified by GRT 3**
  - Remaining element builds contain non-launch critical functionality
  - Additional GRT's planned to ensure verification of post handover operational functionality

Landsat 9 Instrument Performance

Landsat 9 OLI-2

Band #	Band Name	Lower Band Edge (nm)	Upper Band Edge (nm)	Nominal IFOV (m)
1	Coastal Aerosol (CA)	435	450	30
2	Blue	452	512	30
3	Green	532	589	30
4	Red	636	672	30
5	Near Infrared (NIR)	850	879	30
6	Short Wave Infrared-1 (SWIR-1)	1565	1651	30
7	Short Wave Infrared-2 (SWIR-2)	2105	2294	30
8	Panchromatic (Pan)	503	675	15
9	Cirrus	1363	1384	30



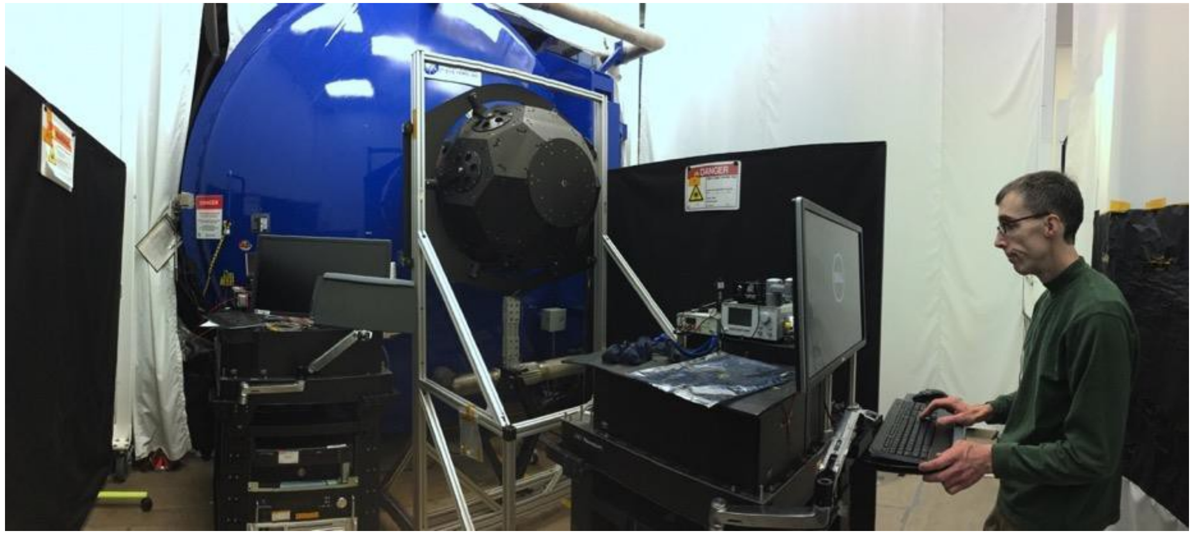
Changes from Landsat 8 OLI

- Improved spectral characterization
  - *poster presentation yesterday*
- SNR improvement
- Improved non-linearity characterization

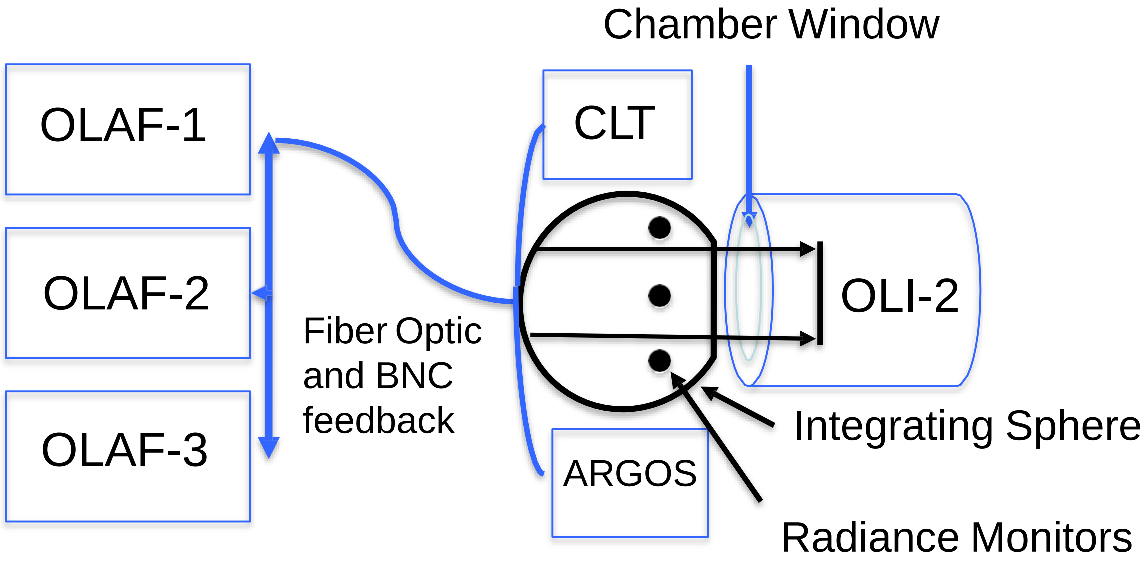
OLI-2 Layout: Goddard Laser for Absolute Measurement of Radiance (GLAMR)

Clean room laser tables

Derivative of NIST's Spectral Irradiance and Radiance Calibrations using Uniform Sources – Traveling (SIRCUS-T)



Clean tent, sphere in front of chamber and SWIR

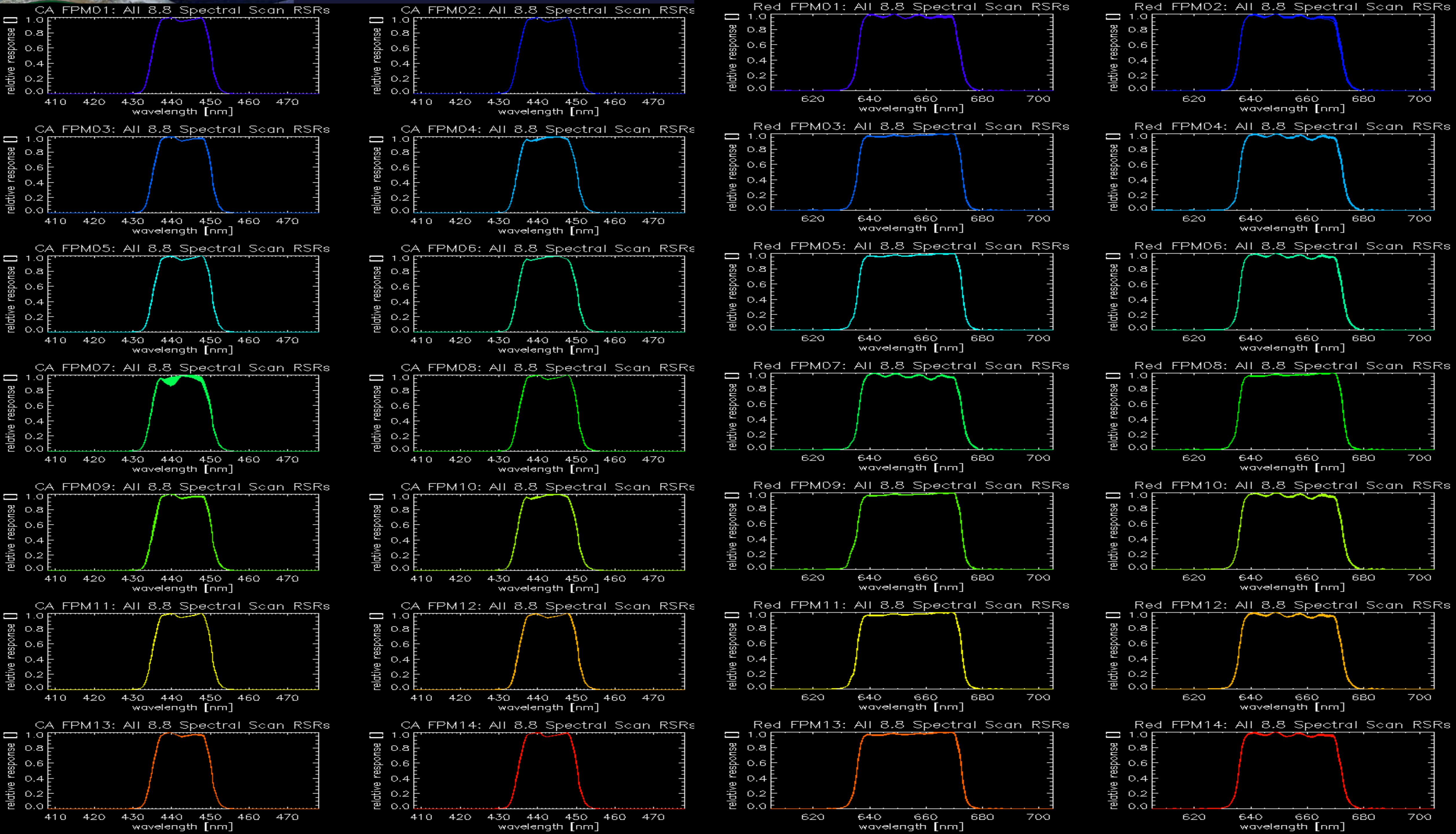


Full aperture and near-full field

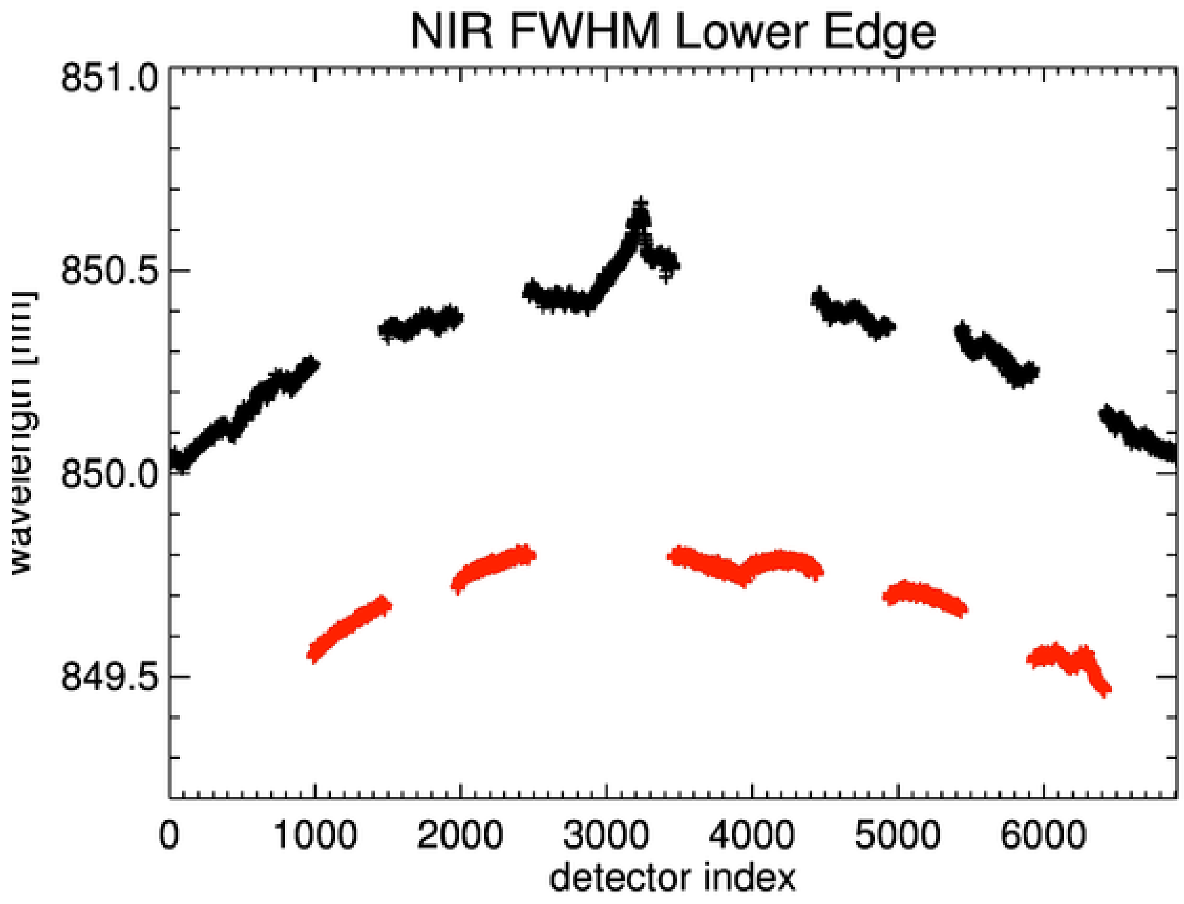
OLI on rotation table— each FPM centered on source
3-5 FPM's fully illuminated

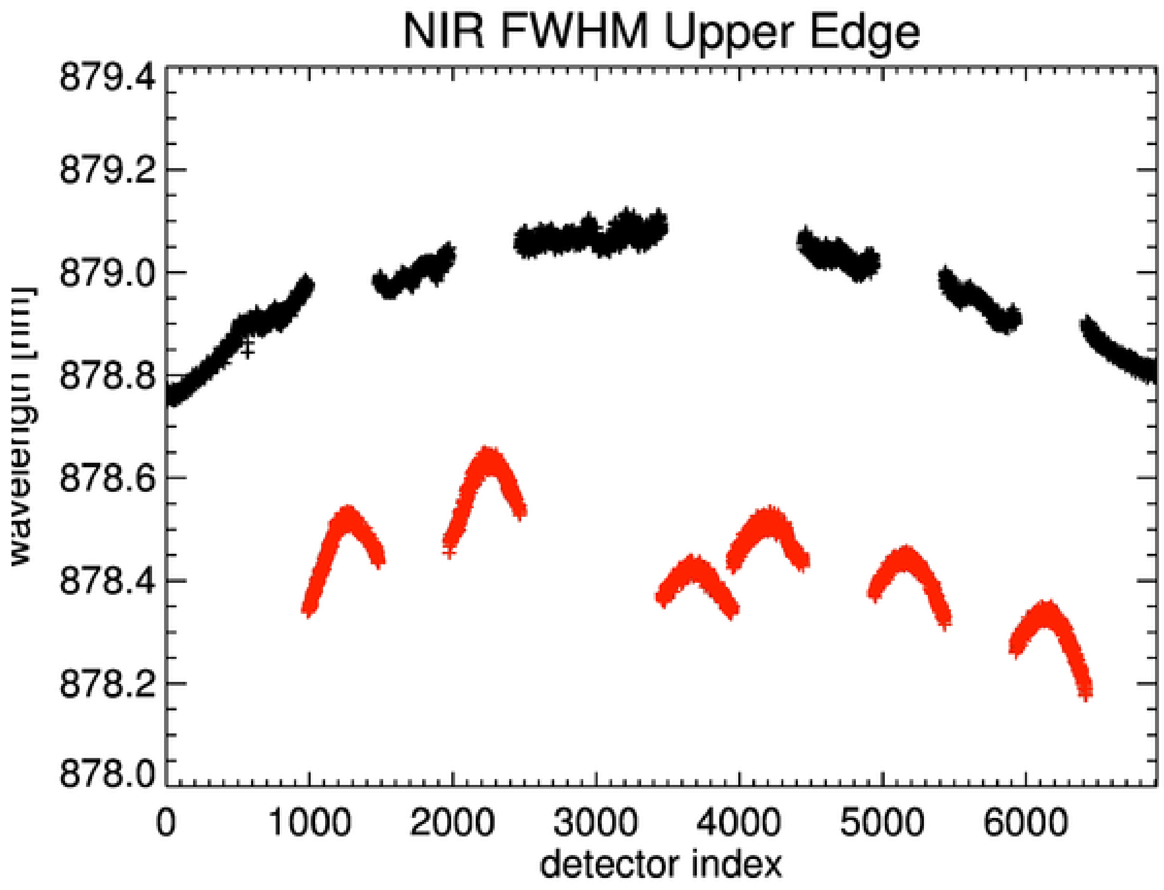
Spectral Test Comparison: OLI vs OLI-2

	OLI	OLI-2
Spatial coverage	~14% (~9600 detectors)	**100% (~70000 detectors)**
Spectral coverage	In-band regions only At 1 or 2 nm steps	**350-2500nm** In-band at 1 or 2 nm steps **Out-of-band at 10 or 20 nm steps**
Radiometric coverage	Required configuration changes to get adequate signal in the VNIR bands	**No configuration changes necessary**
Illumination	Partial Aperture; ~0.1° field (0.1 FPM)	**Full Aperture; ~ 6° field (5 FPMs)**
Absolute Spectral Response	No	**Yes**
Linearity Characterization	No	**Yes (limited attempted)**


CA FPM01: All 8.8 Spectral Scan RSRs
CA FPM02: All 8.8 Spectral Scan RSRs
Red FPM01: All 8.8 Spectral Scan RSRs
Red FPM02: All 8.8 Spectral Scan RSRs
CA FPM03: All 8.8 Spectral Scan RSRs
CA FPM04: All 8.8 Spectral Scan RSRs
Red FPM03: All 8.8 Spectral Scan RSRs
Red FPM04: All 8.8 Spectral Scan RSRs
CA FPM05: All 8.8 Spectral Scan RSRs
CA FPM06: All 8.8 Spectral Scan RSRs
Red FPM05: All 8.8 Spectral Scan RSRs
Red FPM06: All 8.8 Spectral Scan RSRs
CA FPM07: All 8.8 Spectral Scan RSRs
CA FPM08: All 8.8 Spectral Scan RSRs
Red FPM07: All 8.8 Spectral Scan RSRs
Red FPM08: All 8.8 Spectral Scan RSRs
CA FPM09: All 8.8 Spectral Scan RSRs
CA FPM10: All 8.8 Spectral Scan RSRs
Red FPM09: All 8.8 Spectral Scan RSRs
Red FPM10: All 8.8 Spectral Scan RSRs
CA FPM11: All 8.8 Spectral Scan RSRs
CA FPM12: All 8.8 Spectral Scan RSRs
Red FPM11: All 8.8 Spectral Scan RSRs
Red FPM12: All 8.8 Spectral Scan RSRs
CA FPM13: All 8.8 Spectral Scan RSRs
CA FPM14: All 8.8 Spectral Scan RSRs
Red FPM13: All 8.8 Spectral Scan RSRs
Red FPM14: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]
0.0 0.2 0.4 0.6 0.8 1.0
410 420 430 440 450 460 470
620 640 660 680 700

Variation in Spectral Response Across Focal Plane - example

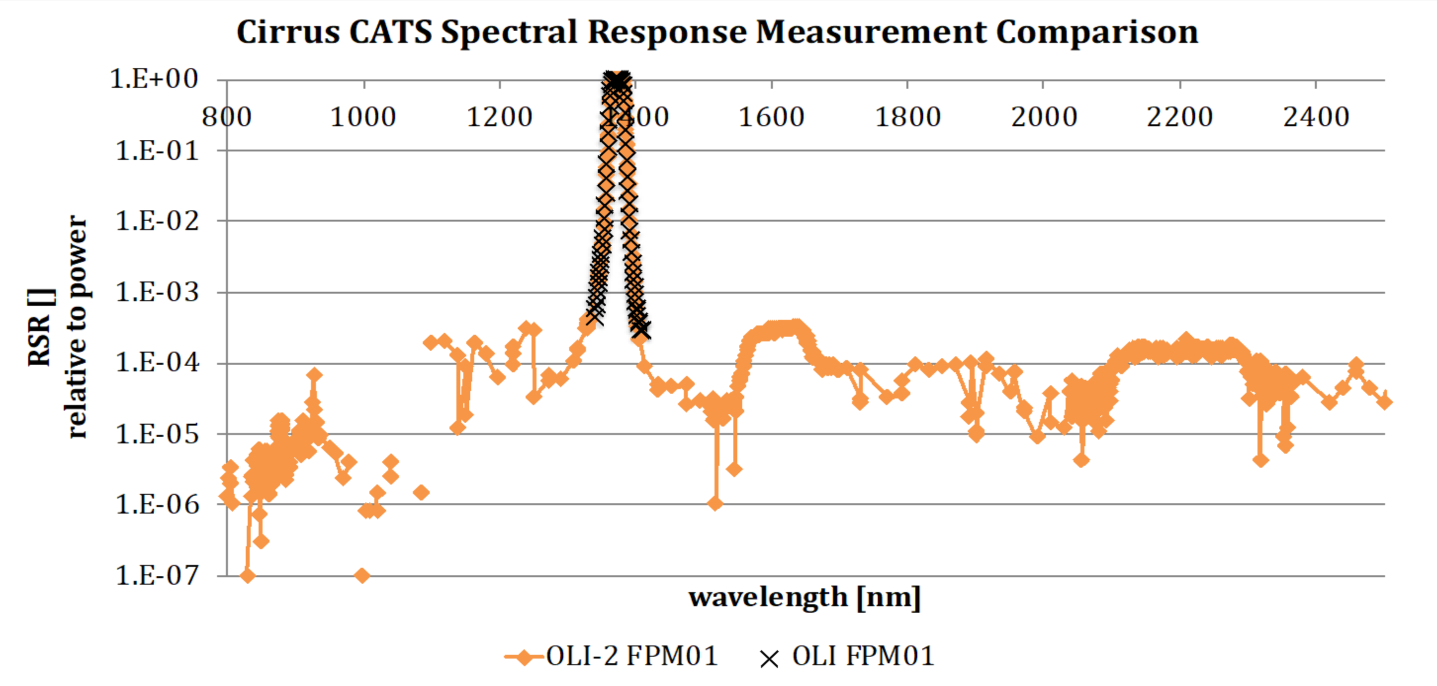


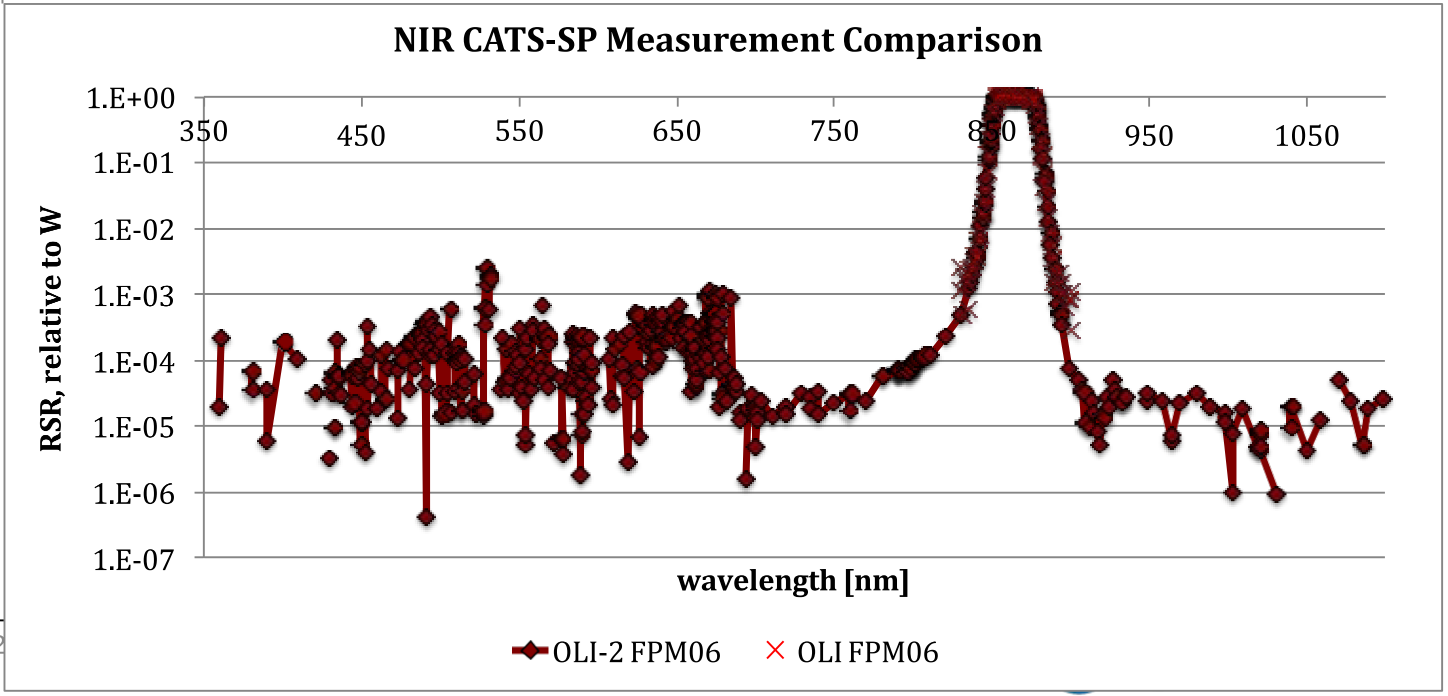


Band edges vary as expected with filter wafer source for filters (red and black colors) and with Angle of Incidence (AOI) variation across focal plane (variability all within requirements)

Out-of-band characterization

- GLAMR provided enough signal for out-of-band characterization across much of the spectral range
- The SWIR1 and Cirrus cross talk features are apparent
- The signal below 700nm is marginal for out-of-band assessment in the configuration used





OLI-2 Transmitted data SNR improvement (median values)

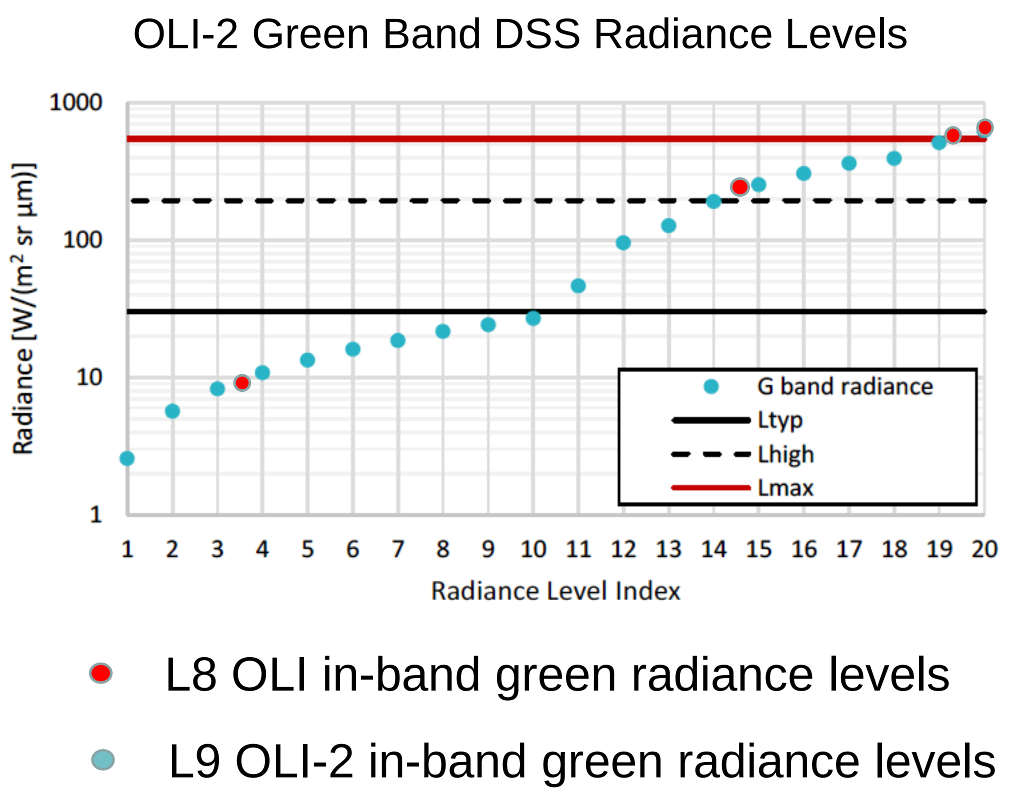
Band	$L_{typical}$ (W/m^2 sr µm)	L8 OLI SNR (12 bit)	L9 OLI-2 SNR (14 bit)
1	40	232	262
2	40	355	441
3	30	296	365
4	22	222	268
5	14	199	249
6	4	261	316
7	1.7	326	368
8	23	145	161
9	6	162	173

Instruments comparable:

- L9 satellite will transmit all 14 bits of OLI-2 data
- L8 satellite transmits upper 12 bits of OLI data (except shutter and special requests)

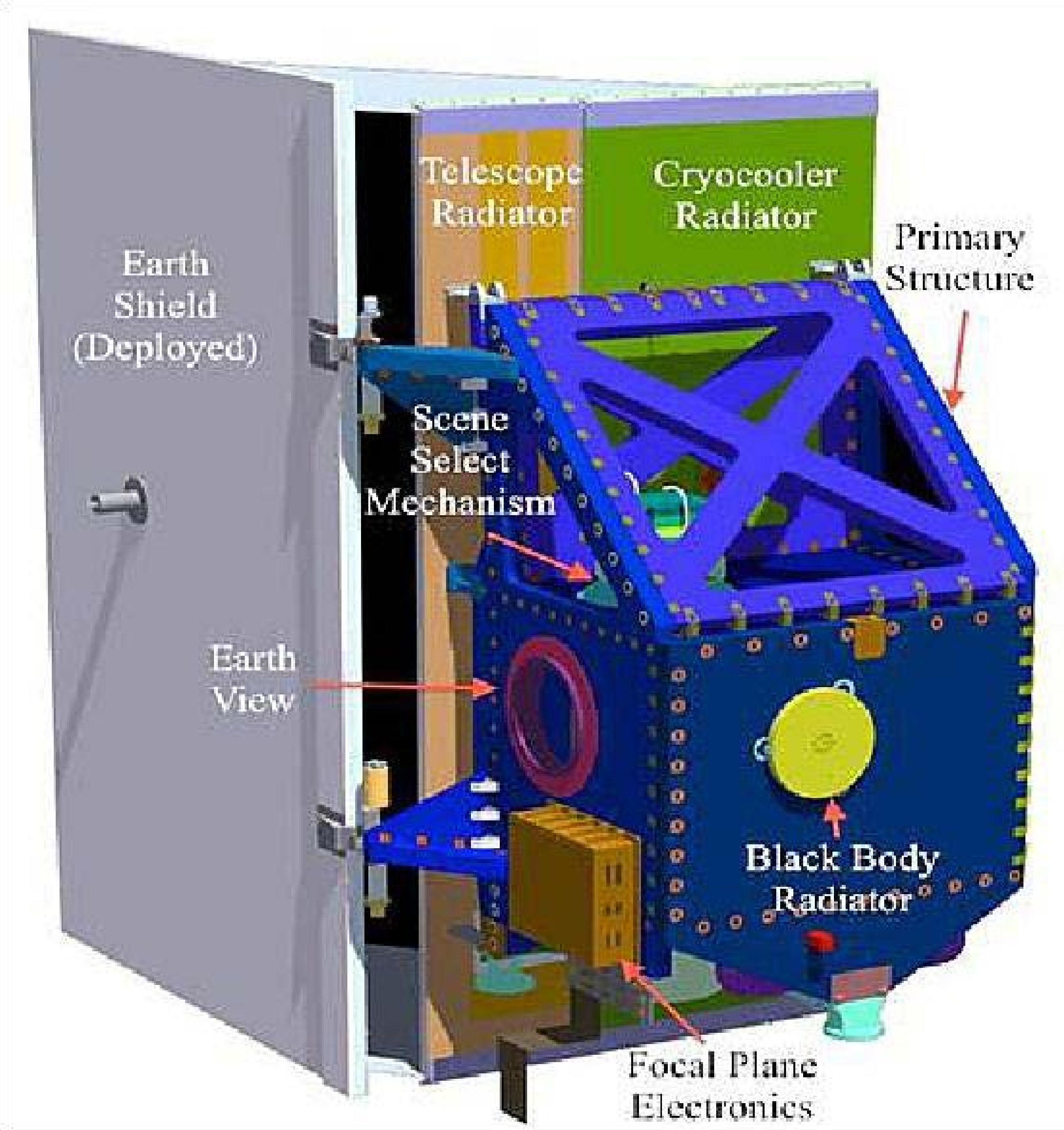
OLI-2 Non-Linearity Characterization

- **Radiance feedback controlled integrating sphere is primary radiometric calibration source (the Death Star Source – DSS)**
  - For L8 OLI used a total of 41 sphere levels
    - Typically only a few were radiance controlled in-band for any given band
    - Non in-band controlled sphere levels generally not useful for characterizing instrument linearity (source only sufficiently stable when controlled in band)
    - Used varying integration time collects as surrogate for varying radiance levels
      - Varying integration time does not exercise full signal path
      - Reciprocity assumed, though not fully demonstrated
  - For L9 OLI-2 used a total of 180 sphere levels
    - 20 in-band radiance controlled levels for each band
      - 10 levels in low radiance range (below about 5% reflectance)
- **A/D linearity measurements (± 1 DN)**
- **SWIR-1 and NIR GLAMR-based linearity validation measurements**



Landsat 9 TIRS-2

Band #	Band Name	Lower Band Edge (nm)	Upper Band Edge (nm)	Nominal IFOV (m)
10	Thermal-1	10450	11200	100
11	Thermal-2	11600	12500	100



Changes from Landsat 8 TIRS

Improved stray light control

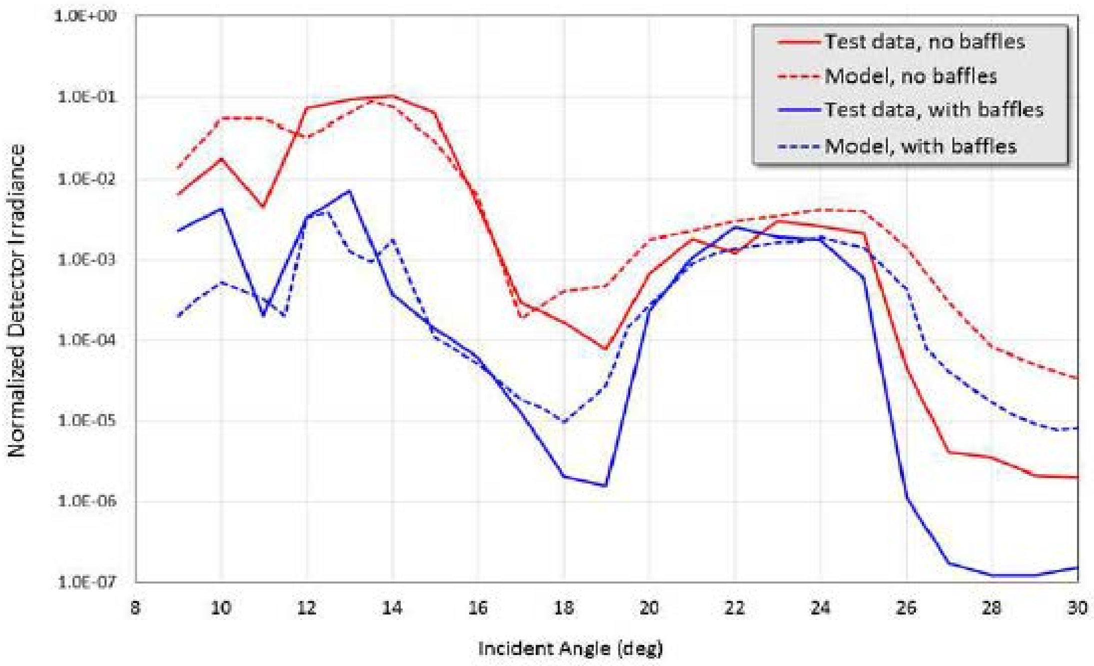
Improved spectral characterization

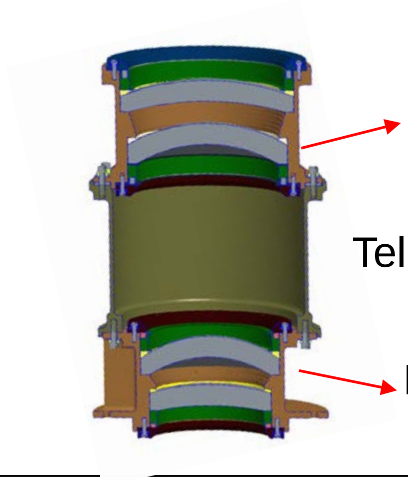
presentation yesterday

Noise Comparable to Landsat 8 TIRS

Landsat-9 TIRS -2 Stray Light Performance

- **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°**





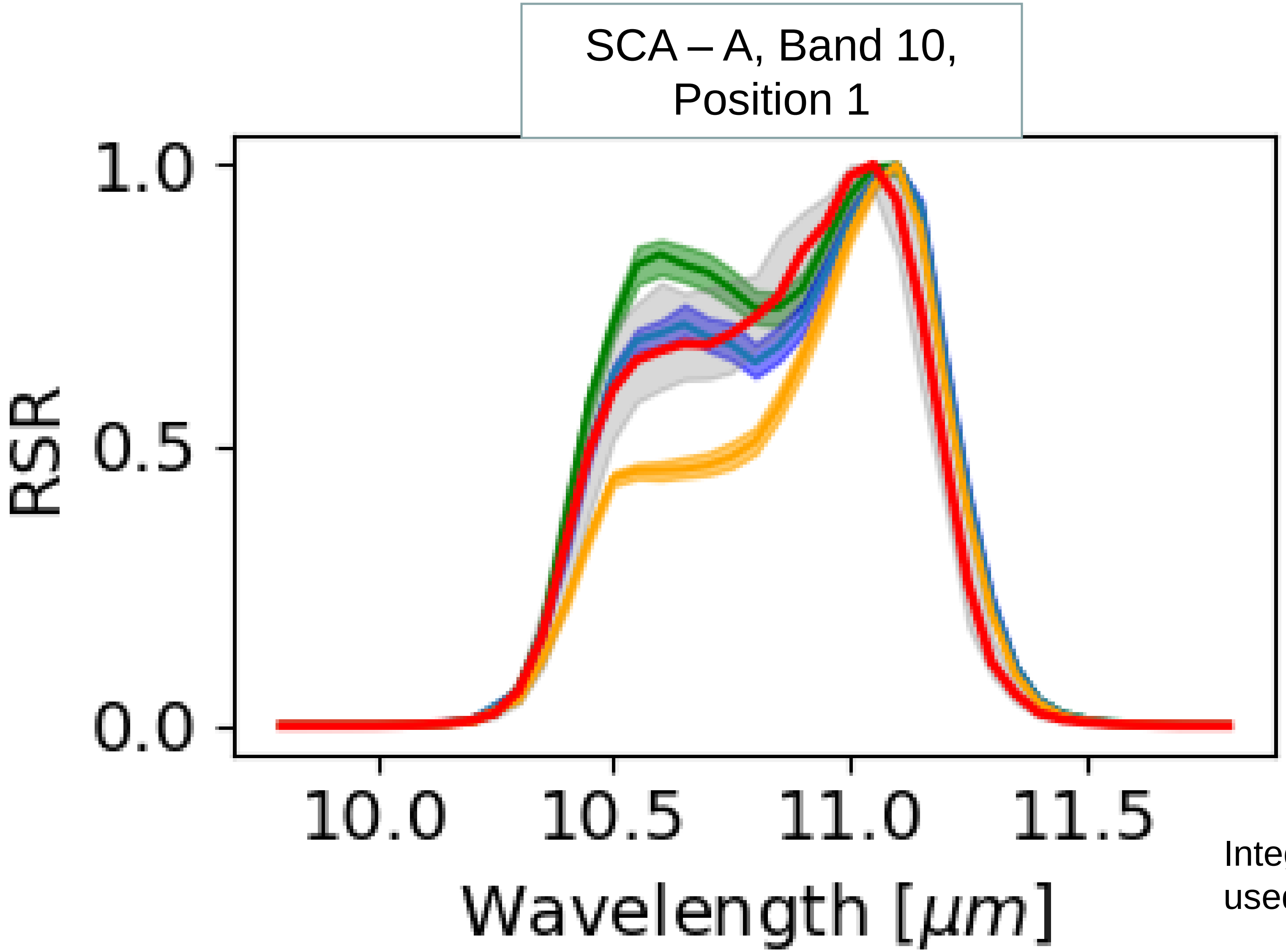
L2 (baffles added below)

Telescope Cross-section

L3 (baffles added above)

TIRS-2 Spectral Characterization:

Better Match to components when angular detector sensitivity considered



Component:

Incidence angle corrected:

FPA-level

SCA-level

Normal incidence

Integrated Instrument

Integrated instrument RSR to be used to represent instrument

L9 TIRS -2 Noise : Comparable to L8 TIRS

Noise Equivalent Delta Temperature (NE∆T)

Instrument	Band	270K	300K	320K
L8 TIRS	10	0.06	0.05	0.05
	11	0.06	0.05	0.05
L9 TIRS-2	10	0.05	0.05	0.05
	11	0.08	0.07	0.06

Summary

- **Mission on schedule for December 2020 Launch Readiness Date**
  - Instruments complete; scheduled for delivery to spacecraft late summer 2019
  - Spacecraft proceeding, some challenging elements
  - Ground System on schedule
  - Launch vehicle on schedule
- **Instruments' performance is excellent**
  - L9 OLI-2 comparable to L8 OLI
    - » Improved spectral and radiometric characterization will benefit user community
      - – Greatest benefit at low signal levels, e.g, water quality
    - » Improved SNR of transmitted data as all 14 bits retained
  - L9 TIRS-2 improvements in performance and characterization
    - » Stray light significantly reduced
    - » Improved spectral characterization will benefit user community