Spectral Response Characterization of the Landsat 9 Operational Land Imager 2 using the Goddard Laser for Absolute Measurement of Radiance (GLAMR)

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calcon
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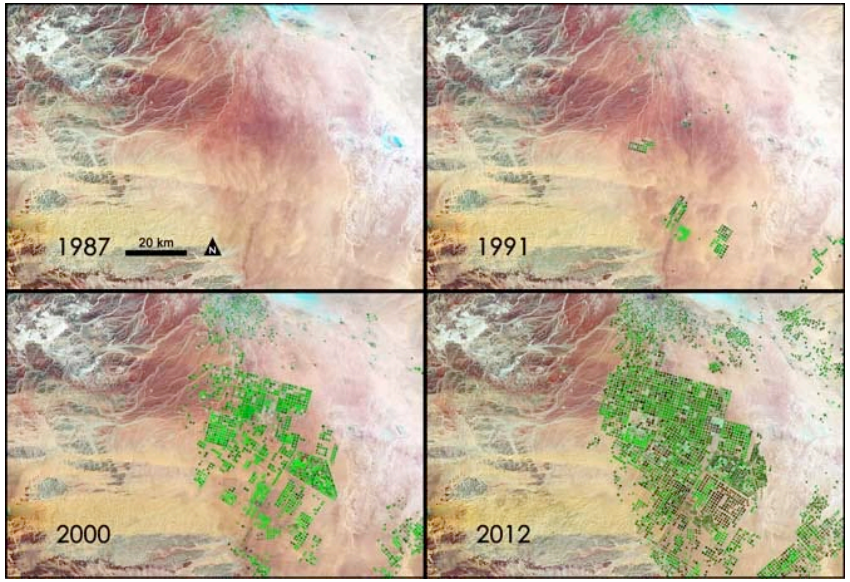
Landsat 9 Mission

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

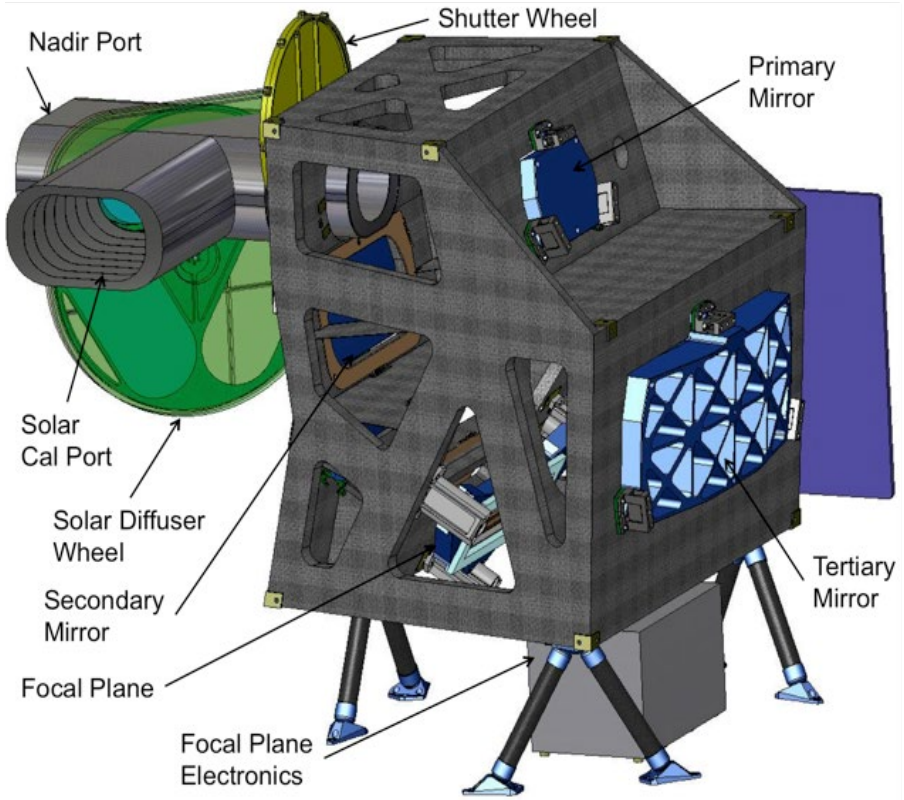
- **United Launch Alliance (ULA) Atlas V 401**

Mission Operations Center (MOC) and Mission Operations

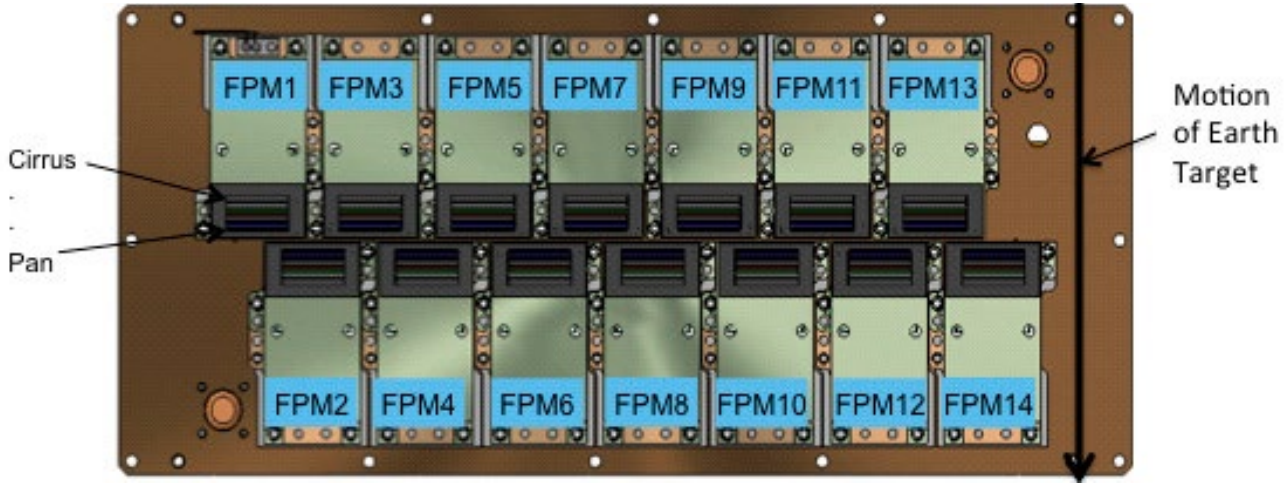
- **General Dynamics Mission Systems (GDMS)**

Operational Land Imager 2 (OLI-2)

Pushbroom 9 solar reflective band imager
15° cross track FOV
14 Focal Plane Modules (FPM's)
~7000 Detectors per 30 m band; ~70000 total
Essentially identical to Landsat 8 OLI



Band	Band Designation	Landsat-8 Band Edges (nm)	GIFOV (m)
1	Coastal Aerosol	435.0 - 451.0	30
2	Blue	452.0 – 512.1	30
3	Green	532.7 - 590.1	30
4	Red	635.9 – 673.3	30
5	NIR	850.5 - 878.8	30
6	SWIR-1	1566.5 - 1651.2	30
7	SWIR-2	2107.4 – 2294.1	30
8	Pan	503.3 – 675.7	15
9	Cirrus	1363.2 – 1383.6	30



Spectral Response Characterization (1 of 2)

Fundamental Instrument Characterization: How the instrument responds to all wavelengths of light

1) In spectral regions where response is desired (in-band spectral response)
2) In spectral regions where response in not desired (out-of-band spectral response)
3) In-band to out-of-band boundary at 1% response points for this discussion

Result: Relative Spectral Response (RSR) curves for each band and/or detector

Data Usage:

1) Pre-launch radiometric calibration -- determine sphere radiances for each band and/or detector
2) Correcting data for atmospheric effects
3) Relating instrument response to biophysical parameter being measured

Process for OLI/OLI-2

Component Level – first estimates using filter, detector and optics spectral data

Assembly Level – combined filters and detectors into Focal Plane Module (FPM)

primary out-of-band RSR for OLI

Integrated Instrument Level – complete instrument –

primary in-band RSR for OLI and OLI-2; primary out-of-band RSR for OLI-2

Challenges

Achieving adequate signal levels – typically more difficult with increasing level of integration

Large number of detectors, large focal plane

7000 detectors per band (x2 for pan) in 14 FPMs

14 filter sticks per band, not all from same filter wafer (within stick variation as well)

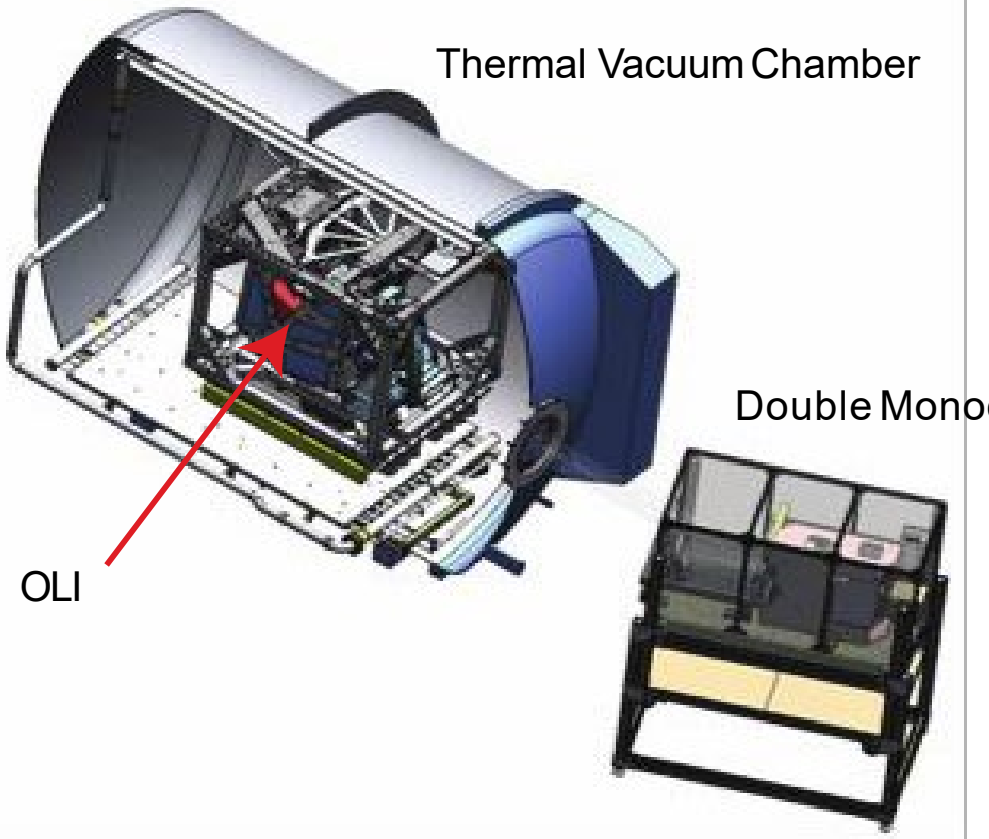
Full instrument has large aperture (13.5 cm) and large field of view (15°)

Matching illumination angles and patterns to as flown configuration – impossible to difficult below integrated instrument level (test as you fly)

Angle of Incidence (AOI) effects

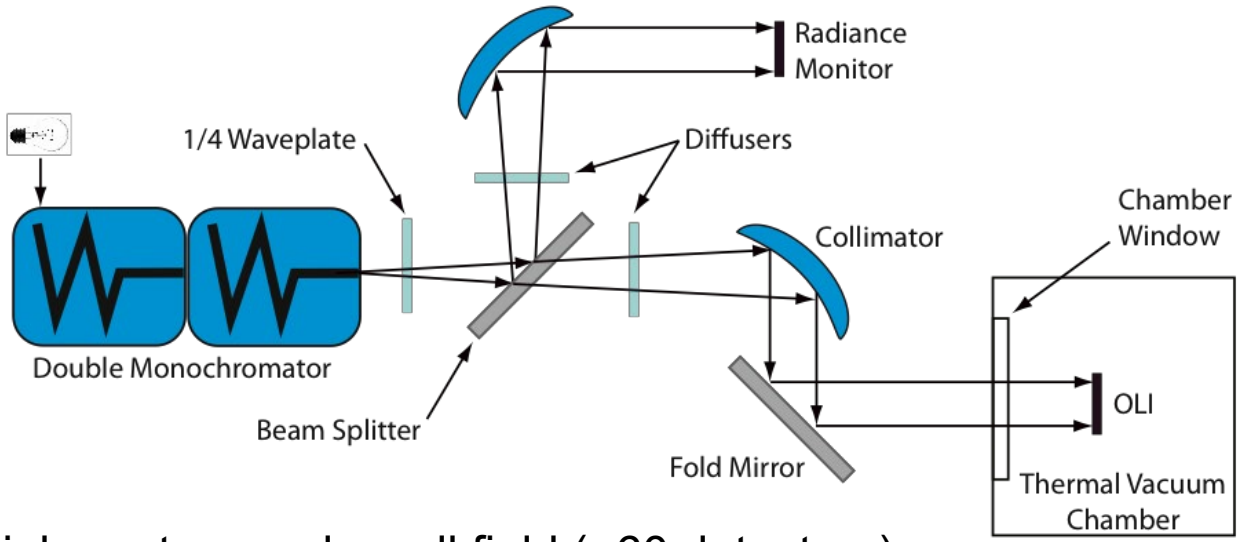
Crosstalk effects

L8 OLI Layout: Double Monochromator



Chamber and Monochromator

Optical Path



Partial aperture and small field (~60 detectors)

OLI on rotation table—16 locations on FPA pointed at source

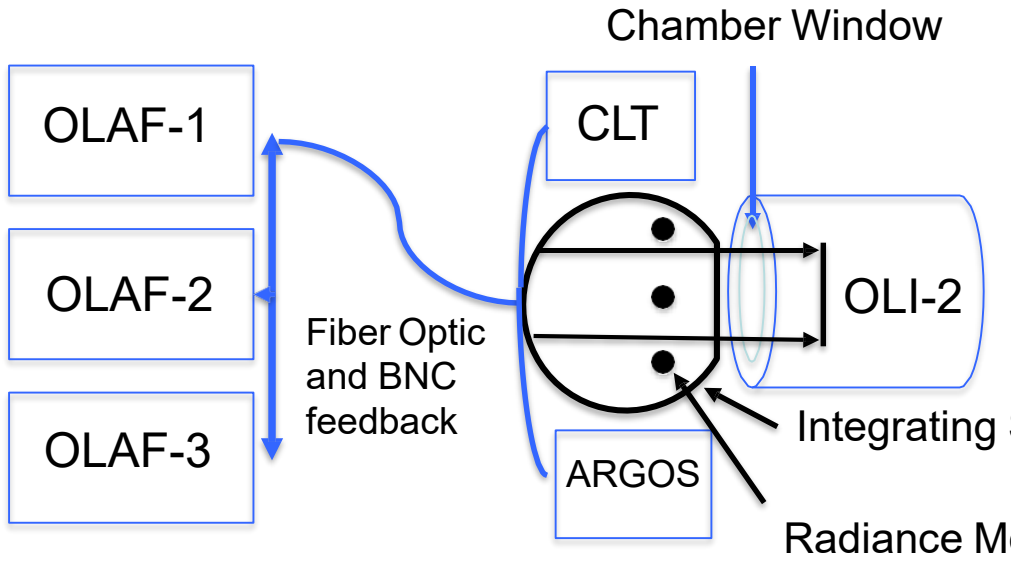
OLI-2 Layout: Goddard Laser for Absolute Measurement of Radiance (GLAMR)

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 laser tables

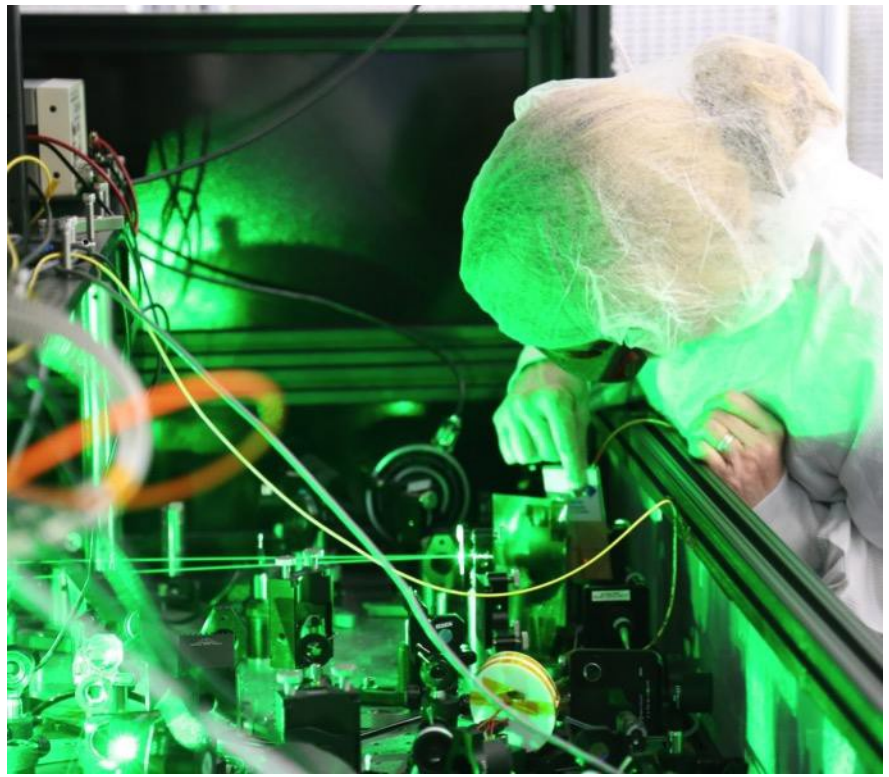
Optical Path



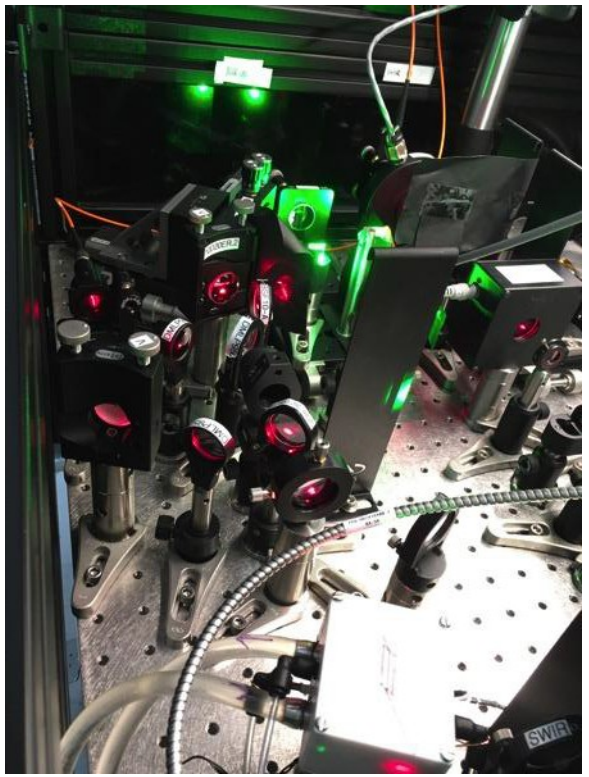
Full aperture and near-full field

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

GLAMR Fundamentals



1) Laser operator adjusts optical parametric oscillator (OPO) parameters, such as crystal temperature and cavity geometry, to produce the desired frequency.



2) A single frequency in the desired spectral region is produced. Shown here, the OPO produces 680nm light from 532nm light.

3) Fiber optic cable takes light from laser table to integrating sphere where it can be seen by the instrument under test (transfer radiometer shown here). Repeat for every required wavelength.

GLAMR Laser Tables

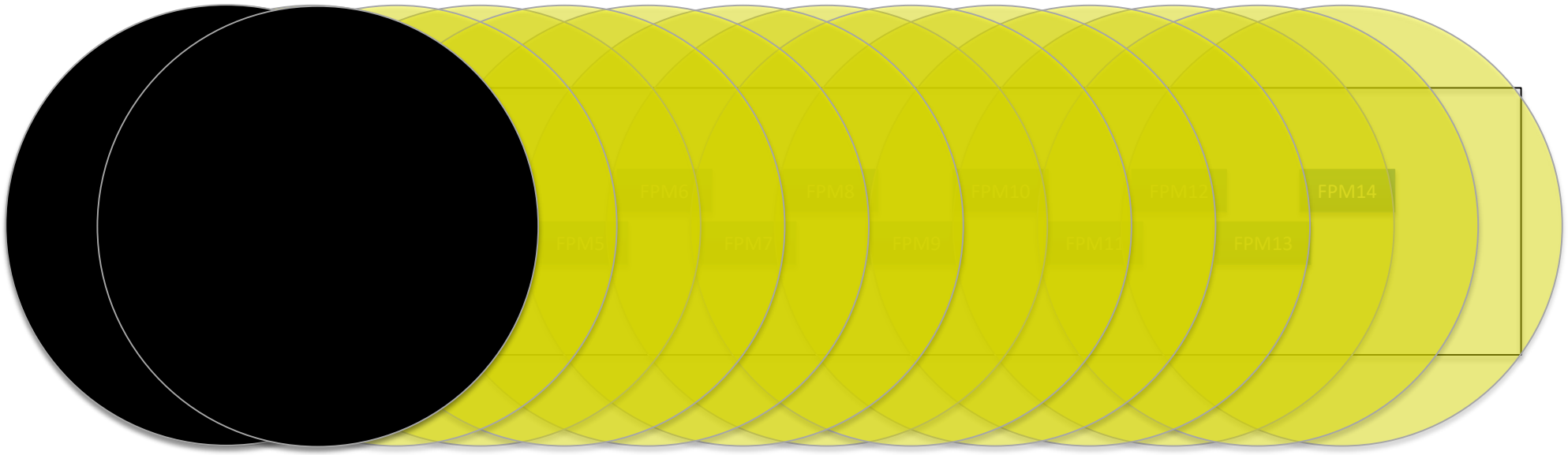
Table	Wavelength Range - method	Comments
OLAF-1 (20 W pump)	OPO_NIR_SHG - 350-550 nm OPO_SWIR_SHG - 550-700 nm OPO_NIR - 700-1100 nm OPO_SWIR - 1100-1350 nm OPO_NIR_Idler - 1350-2200 nm	Pulsed
OLAF-2 (20 W pump)	OPO_NIR_SHG - 350-550 nm OPO_SWIR_SHG - 550-700 nm OPO_NIR - 700-1100 nm OPO_SWIR - 1100-1350 nm OPO_NIR_Idler - 1350-2200 nm	Pulsed
OLAF-3 (36 W pump)	OPO_SWIR_SHG - 550-700 nm	Pulsed
CLT	1900-2500 nm	CW speckle
ARGOS	2200-2500 nm	CW – speckle not apparent

Updates to GLAMR for OLI-2 Testing

- TiSapphire laser (on loan from NIST) spectral coverage replaced by OPO_NIR
- Dye Lasers (on loan from NIST) spectral coverage replaced by OPO_NIR_SHG and OPO_SIR_SHG
- Fully redundant support between multiple tables.
- Better attempt at coverage in degeneracy region (532 nm) with specialized etalons.
- Systematic monitoring of linewidth
- Communication (one way) between GLAMR computer and OLI-2 controller and data acquisition system
- Two SWIR Laser systems (Argos and CLT) added
- Extended InGaAs transfer radiometer added and calibrated

Spectral Test at Ball

Output from GLAMR sphere illuminates slightly more than one OLI-2 module.
To cover the whole focal plane, move OLI-2 to center each module on the GLAMR beam while GLAMR is at a single wavelength
Instrument-level per-detector RSR builds up one module at a time
Illuminated acquisitions bracketed by background collects

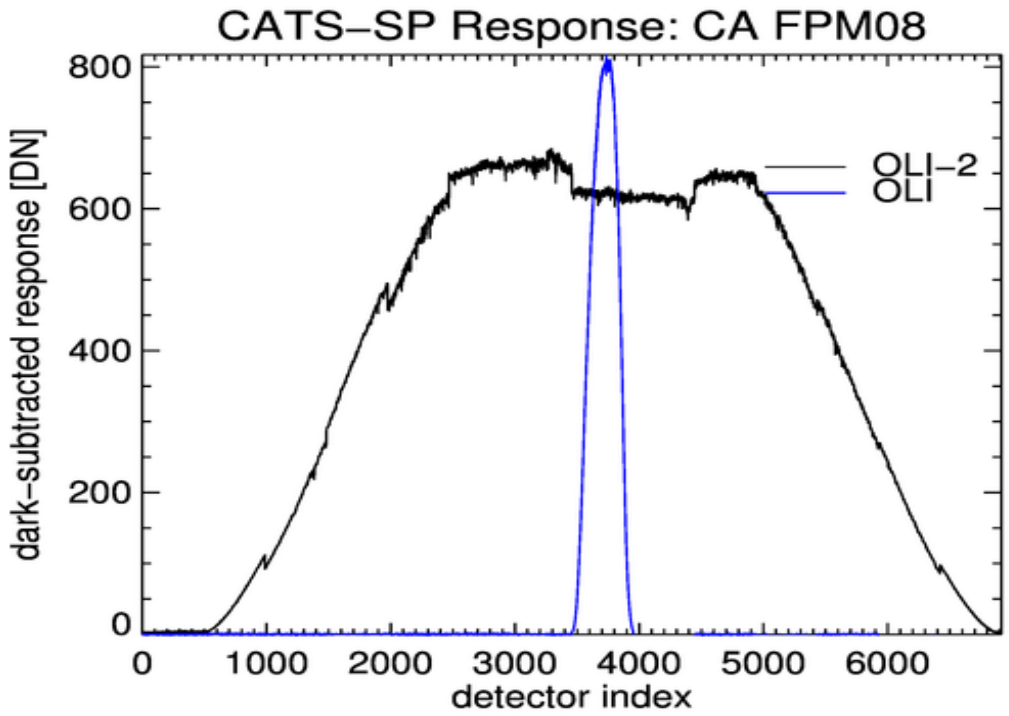


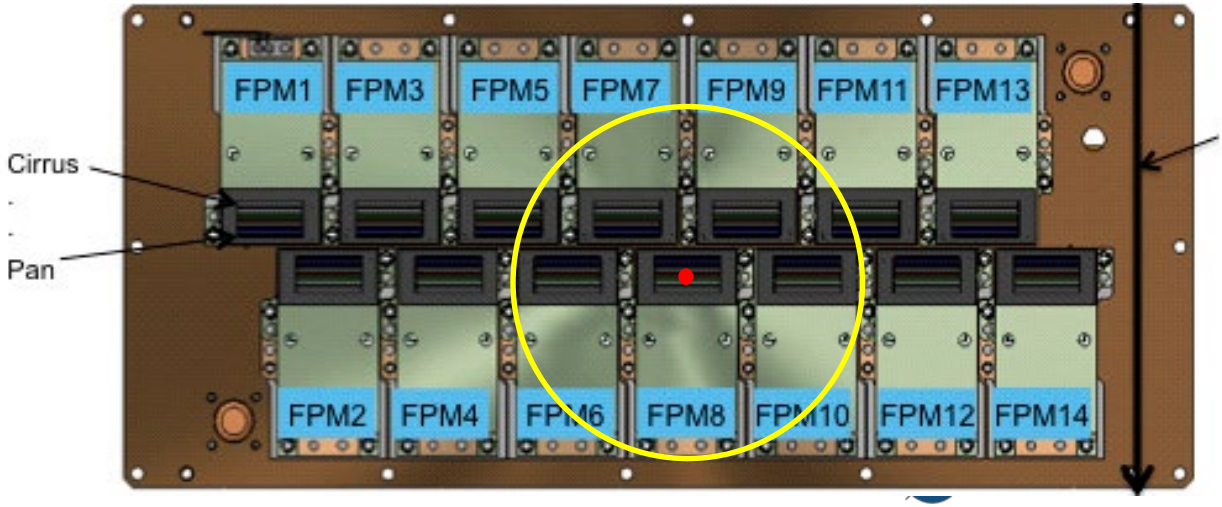
Spectral Test Comparison: OLI vs OLI-2

	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)**

Spatial Coverage for Spectral Test: OLI vs OLI-2

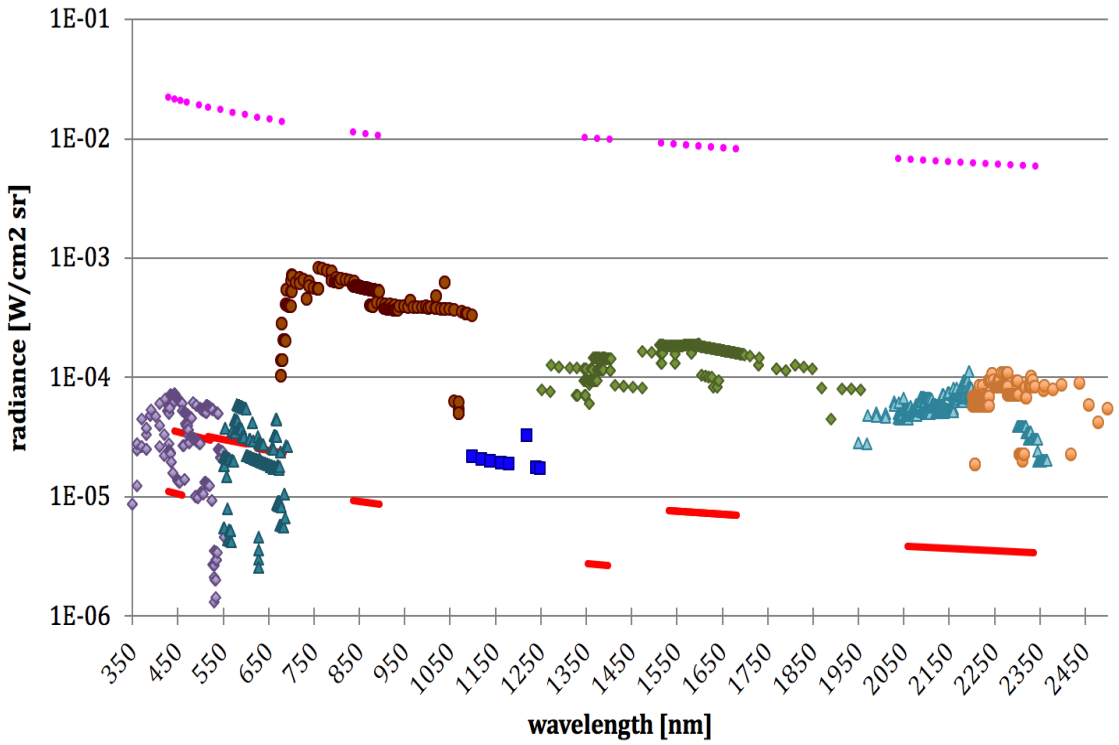
- **The GLAMR sphere illuminated approximately 5 modules at once.**
  - The sphere was centered on each module (14 images)
  - Captures within and between FPM crosstalk effects (if any)
- **Monochromator illuminated a small spot of about 60 detectors.**
  - The center of each module was illuminated, along with both of the focal plane edges (16 images).
- *Plot is only intended to illustrate the difference in the illumination pattern, not the absolute signal levels.*



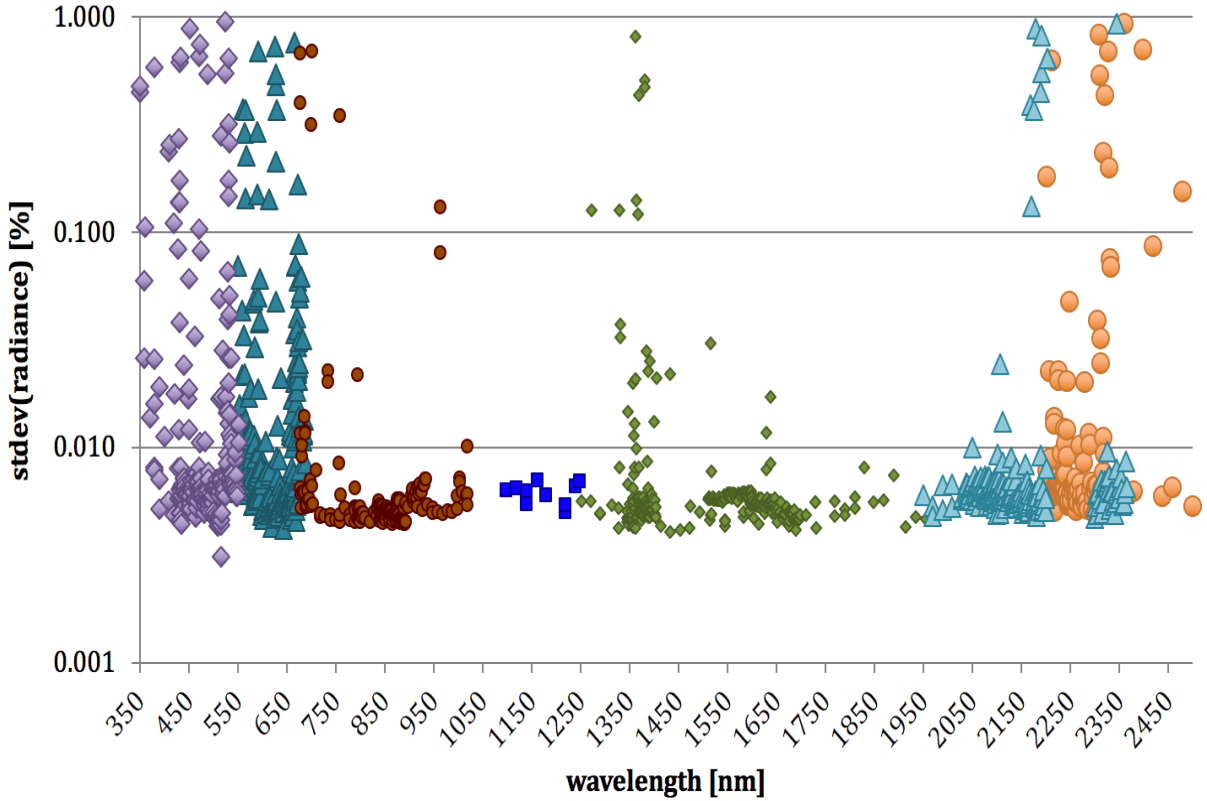


Radiance Levels and Stability for GLAMR testing of OLI-2

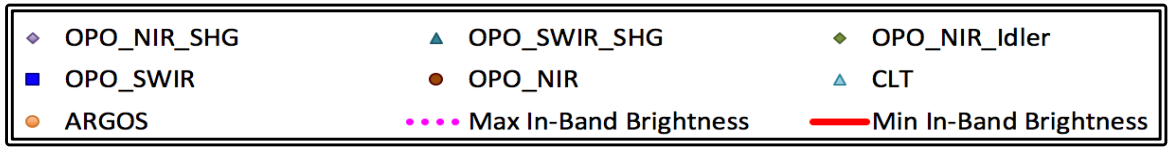
Radiance Levels



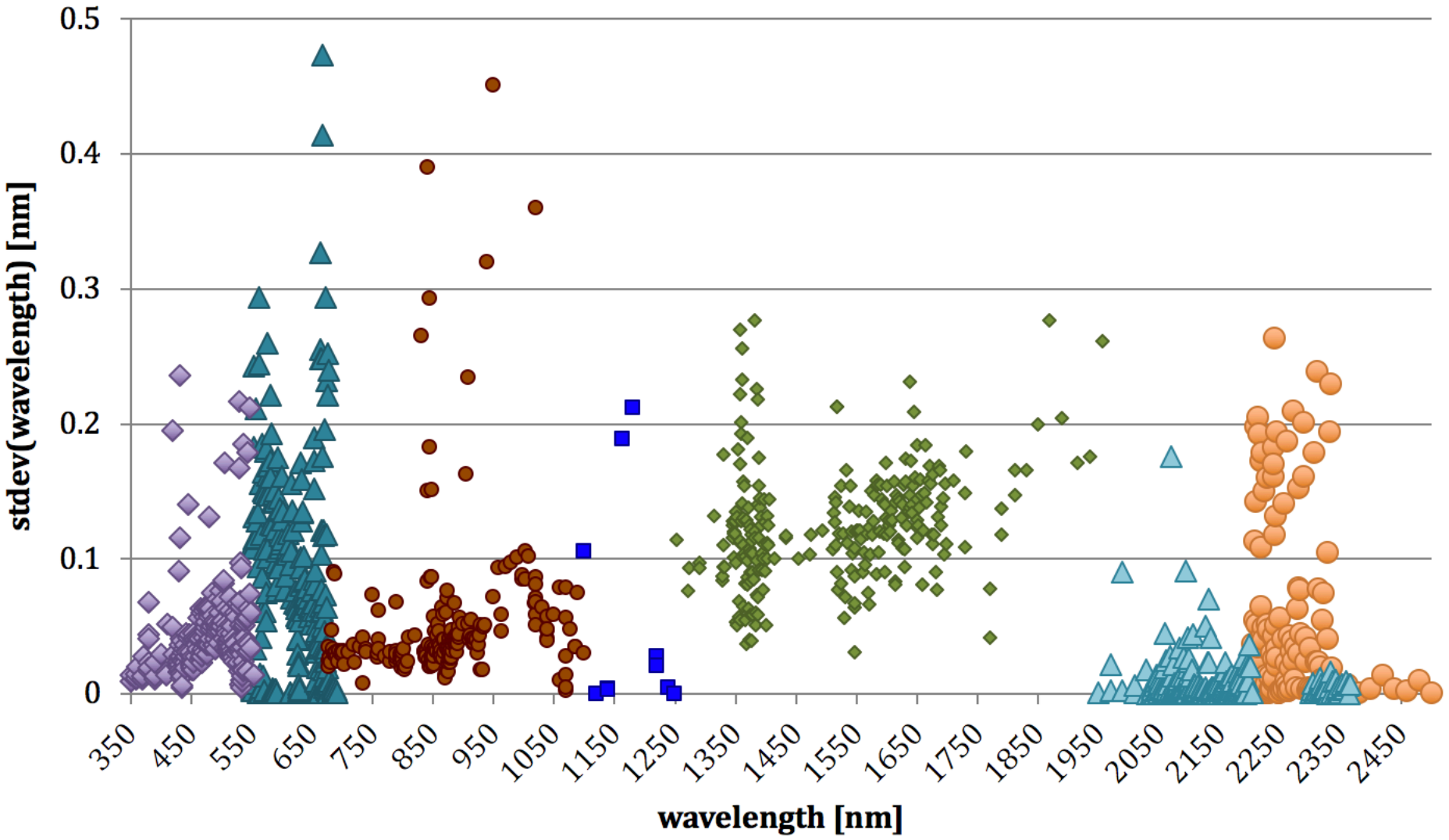
Radiance Stability – 2 minutes



Filtered to remove points > 1%



Wavelength Stability



Spectral Coverage

- **In-band characterization**
  - Spectral coverage was comparable between OLI and OLI-2 for instrument level testing

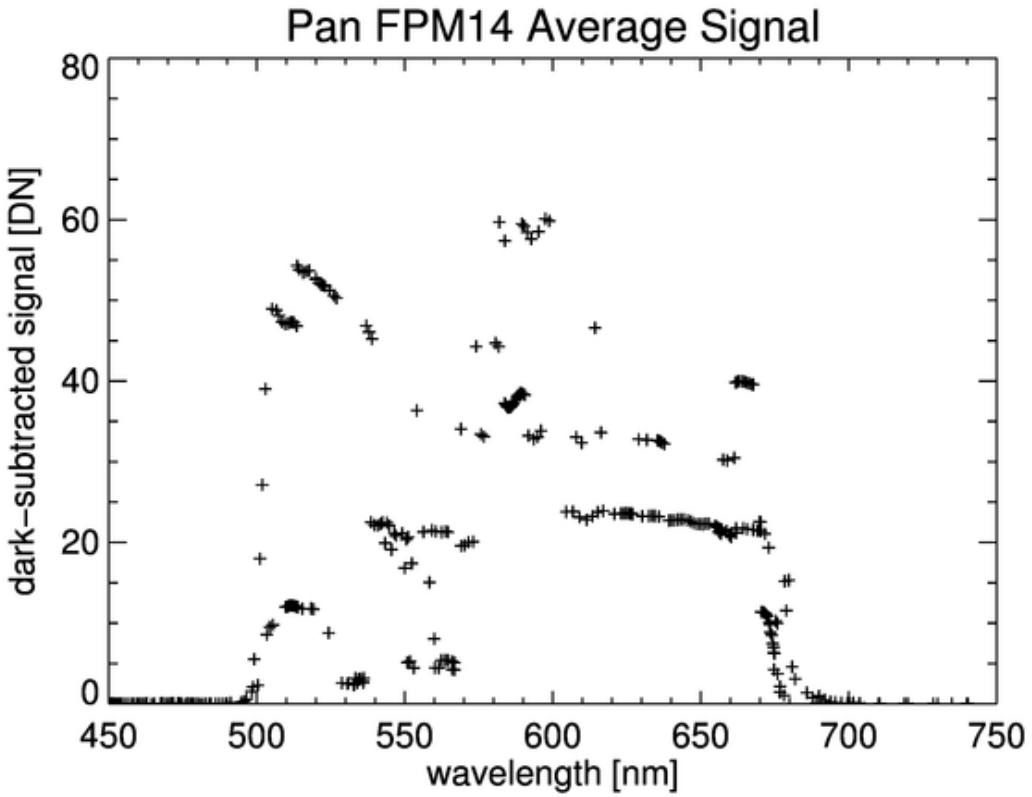
- **Out-of-band characterization**
  - L8 OLI out-of-band characterization was performed at the module level with course in-band spectral sampling.

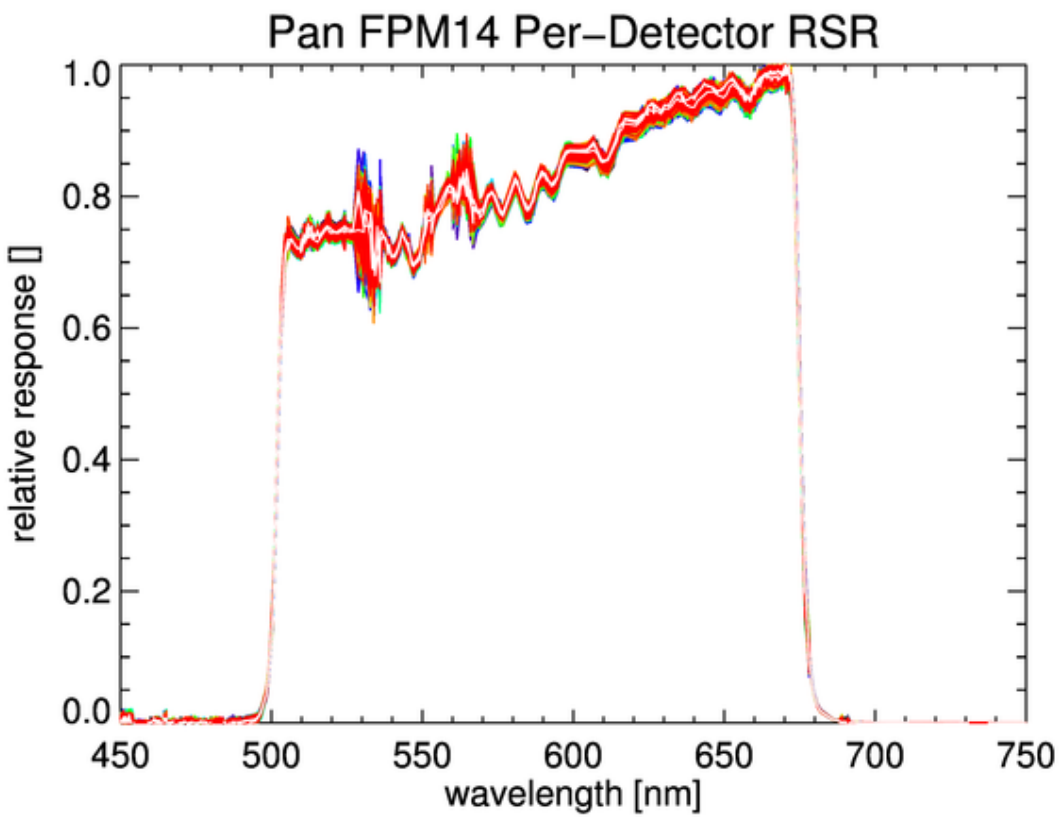
  - For L9 OLI-2, the GLAMR signal was strong enough in most of the wavelength region to provide adequate out-of-band characterization.
    - The signal below 700nm is marginal for out-of-band characterization (with the time allotted for measurement).
    - Module level data available as supplement

Issues/Challenges (1 of 2)

Challenging spectral regions (not unexpected)

- Pump laser wavelength/degeneracy – 532 nm
- 550-570 nm - fall off between NIR-SHG and SWIR_SHG





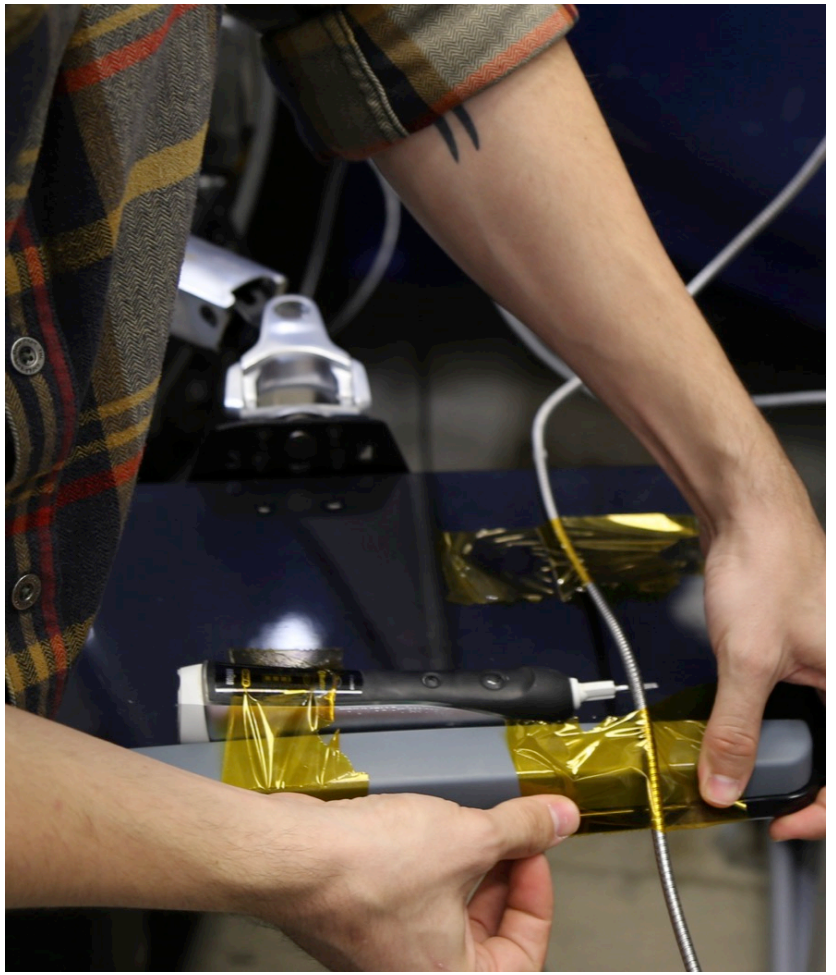
Issues/Challenges (2 of 2)

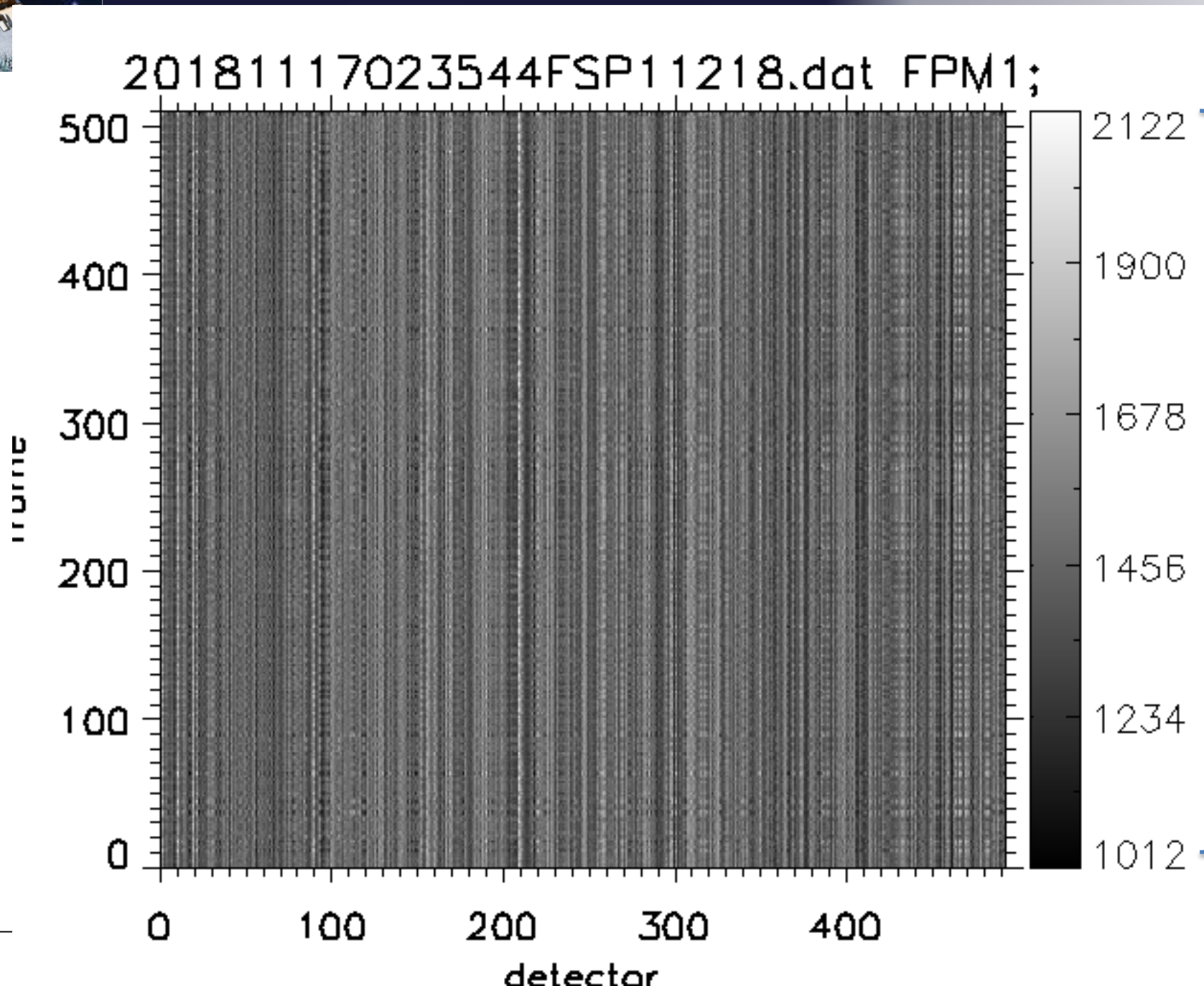
Speckle in SWIR (cw lasers) – (not unexpected)

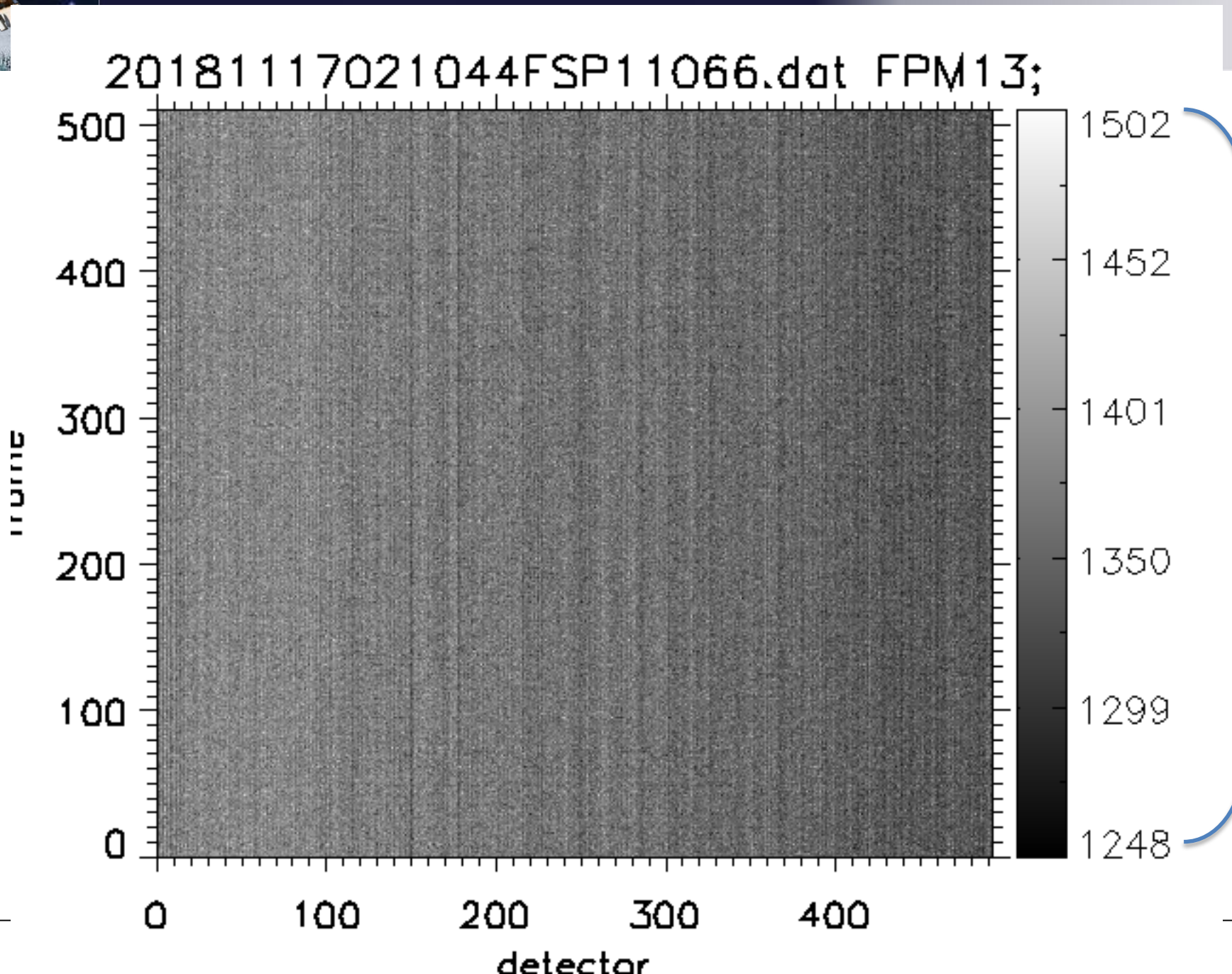
- SWIR coverage with CW lasers beyond 1600 nm new to GLAMR for this test
- Most apparent in CLT laser system (narrower bandwidth)
- Ameliorated with field fix

Maintaining laser stability for ~2 minutes

- Go backs as necessary



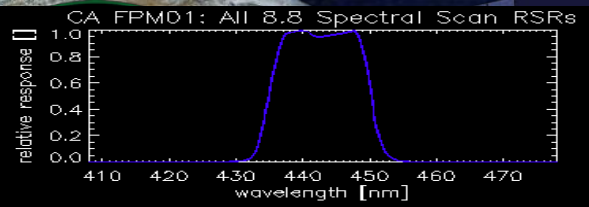

20181117023544FSP11218.dat FPM1;
500
400
300
200
100
0
0
100
200
300
400
detector
2122
1900
1678
1456
1234
1012
DN range
900-1200 DN

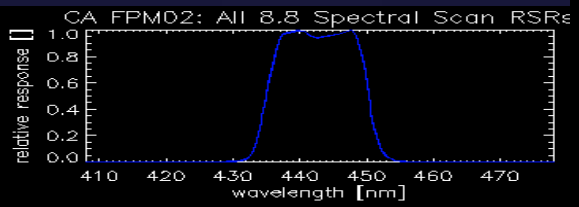


DN range
150-350 DN

Improvised speckle reduction – fiber vibrated with electric toothbrush

Sample Results


CA FPM01: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]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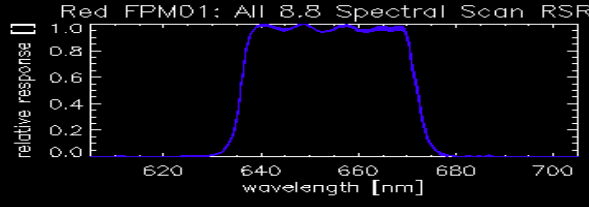
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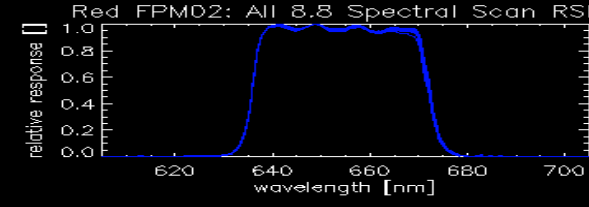
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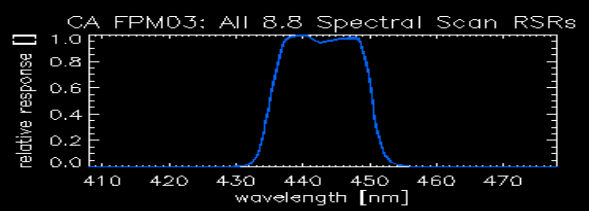
wavelength [nm]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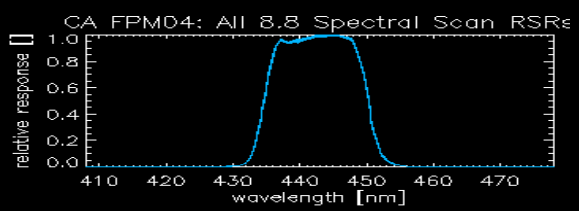
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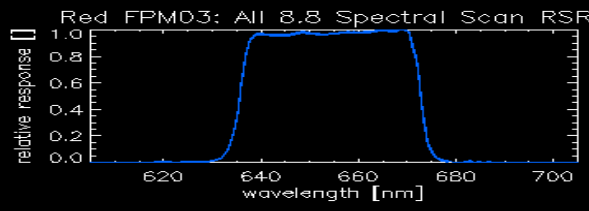
wavelength [nm]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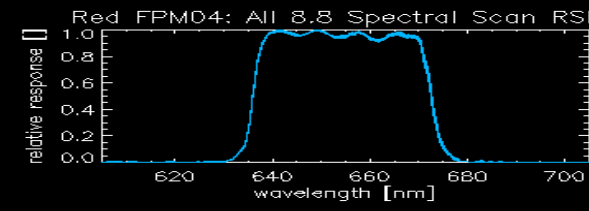
wavelength [nm]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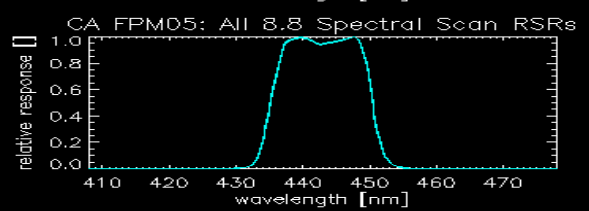
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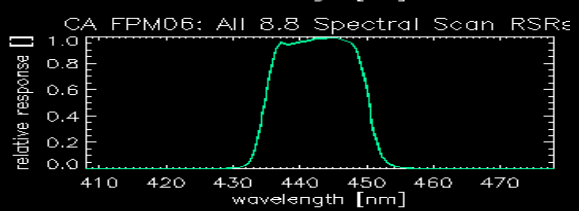
wavelength [nm]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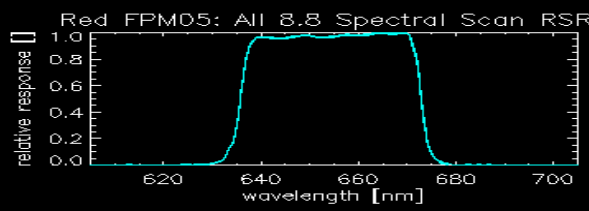
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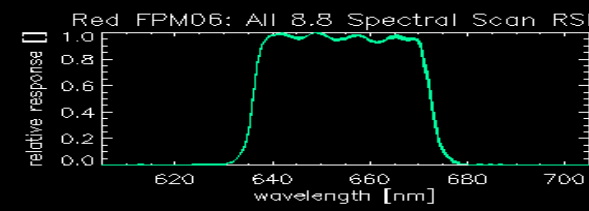
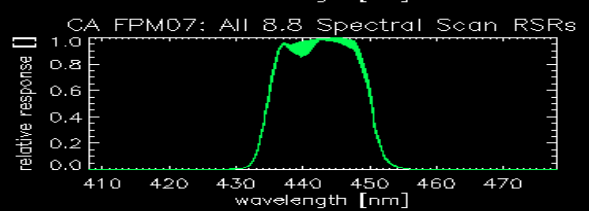
relative response []
wavelength [nm]


Red FPM06: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


CA FPM07: All 8.8 Spectral Scan RSRs
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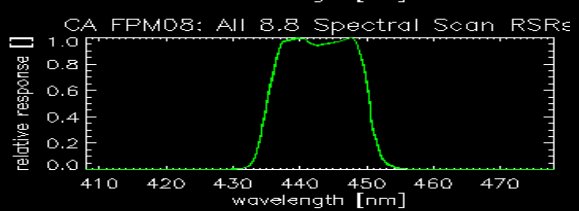
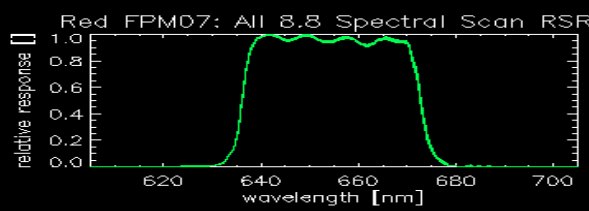
wavelength [nm]


CA FPM08: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Red FPM07: All 8.8 Spectral Scan RSRs
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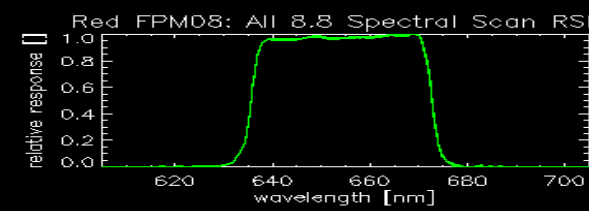
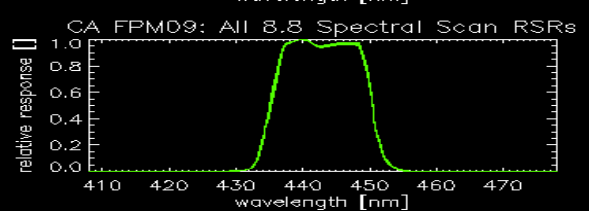
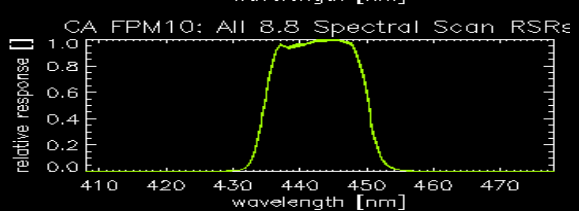
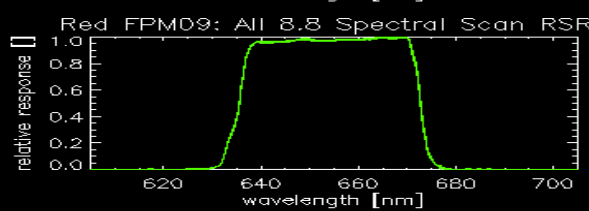
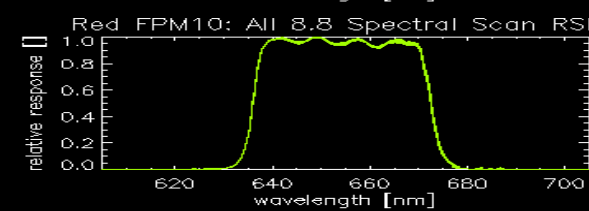
wavelength [nm]

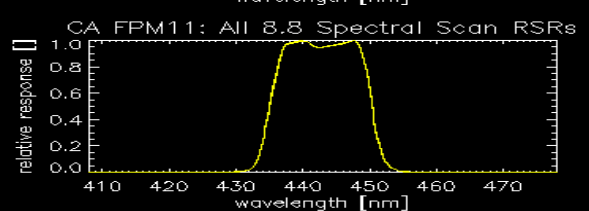

Red FPM08: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

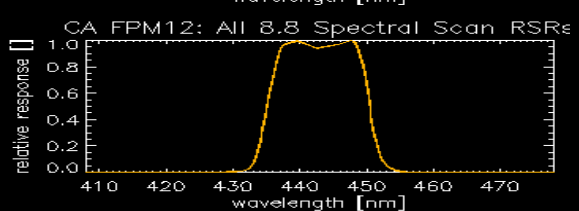

CA FPM09: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

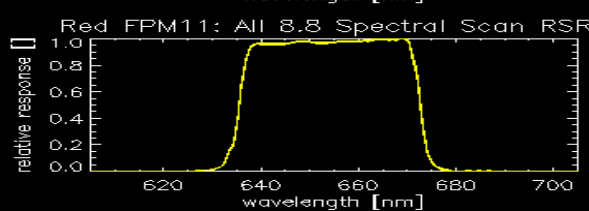

CA FPM10: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

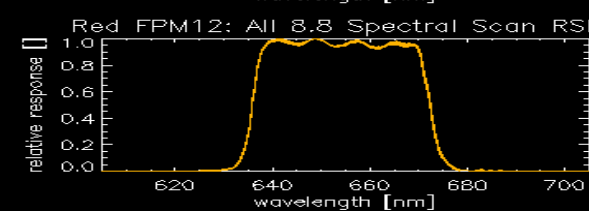

Red FPM09: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

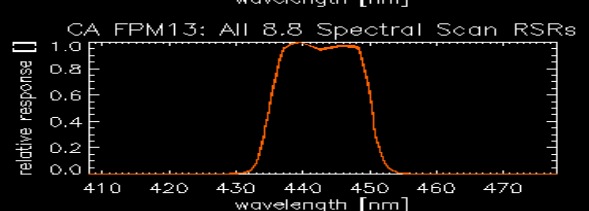

Red FPM10: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

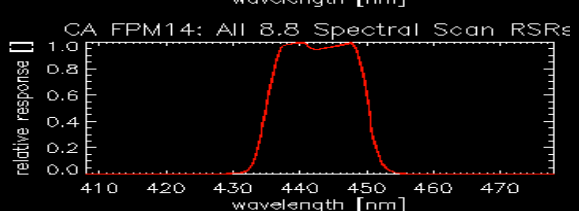

CA FPM11: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

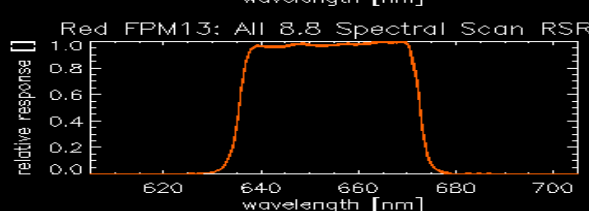

CA FPM12: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

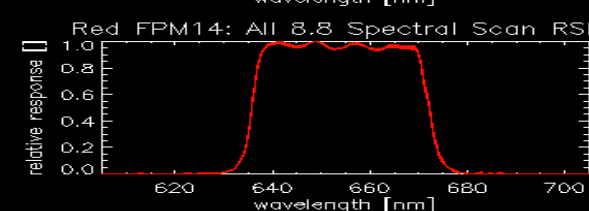

Red FPM11: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

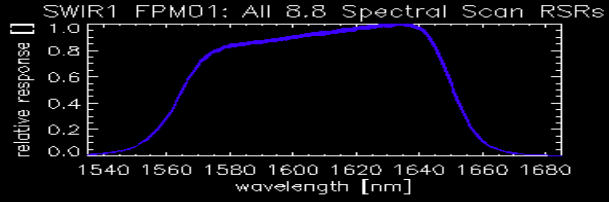

Red FPM12: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

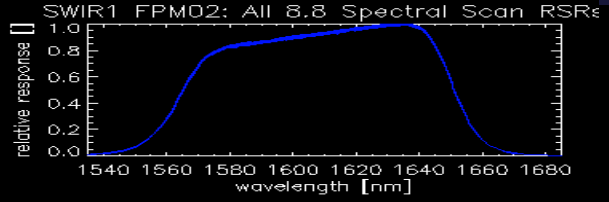

CA FPM13: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

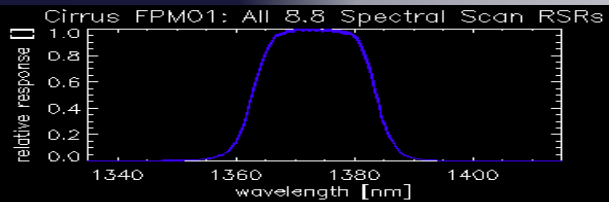

CA FPM14: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

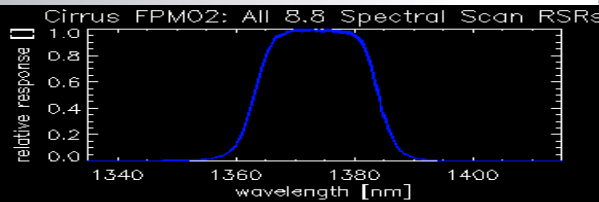

Red FPM13: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Red FPM14: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


SWIR1 FPM01: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

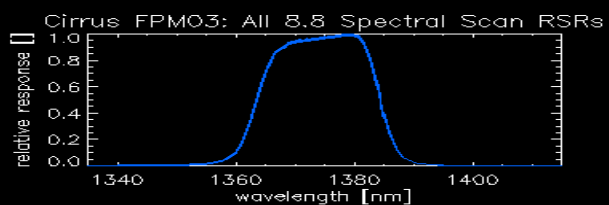

SWIR1 FPM02: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

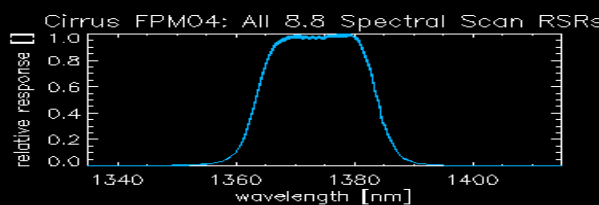

Cirrus FPM01: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

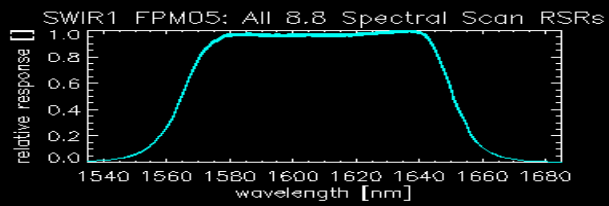

Cirrus FPM02: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

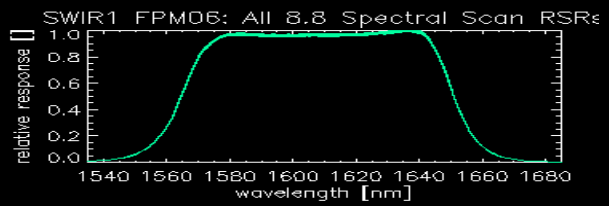

SWIR1 FPM03: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

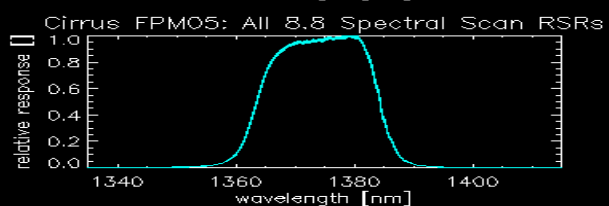

SWIR1 FPM04: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

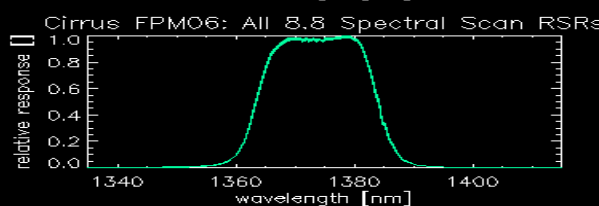

Cirrus FPM03: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

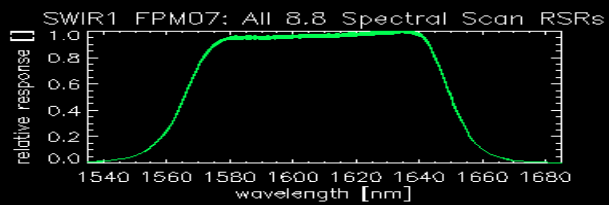

Cirrus FPM04: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

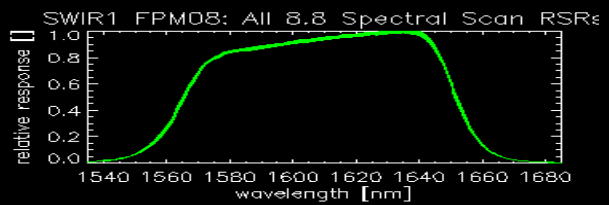

SWIR1 FPM05: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

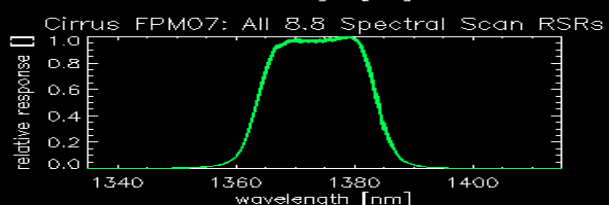

SWIR1 FPM06: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

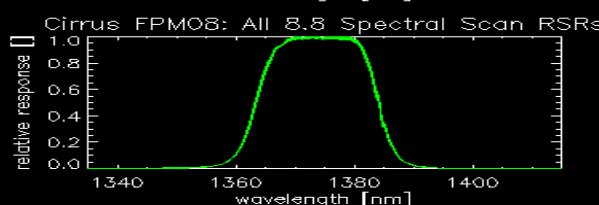

Cirrus FPM05: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Cirrus FPM06: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


SWIR1 FPM07: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

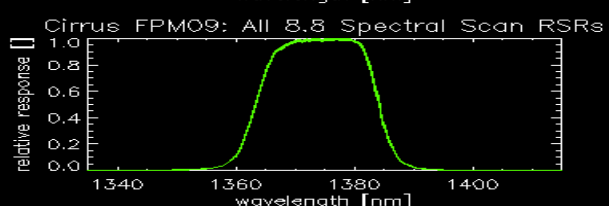

SWIR1 FPM08: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

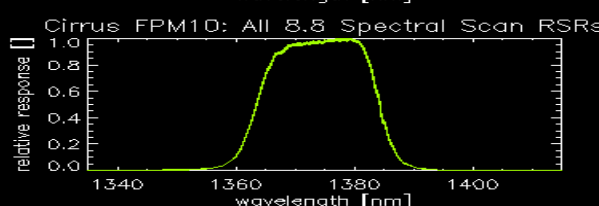

Cirrus FPM07: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Cirrus FPM08: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

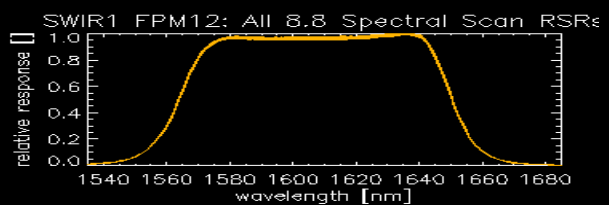

SWIR1 FPM09: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

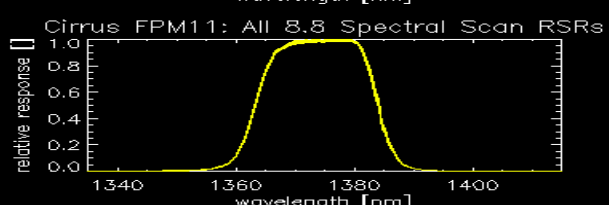

SWIR1 FPM10: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

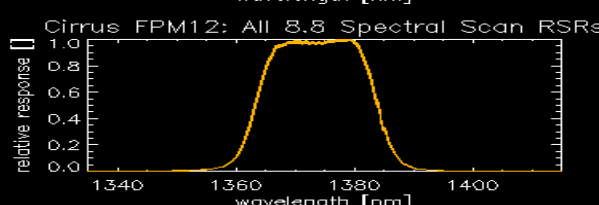

Cirrus FPM09: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

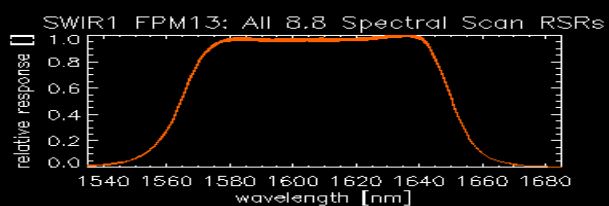

Cirrus FPM10: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

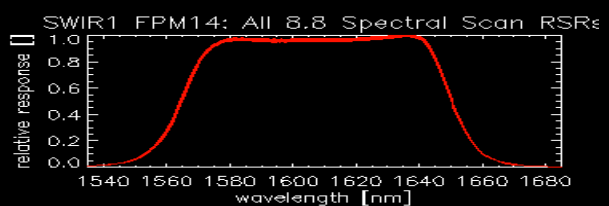

SWIR1 FPM11: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

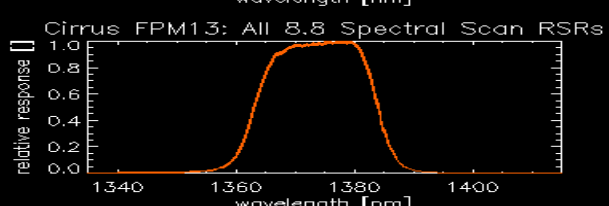

SWIR1 FPM12: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

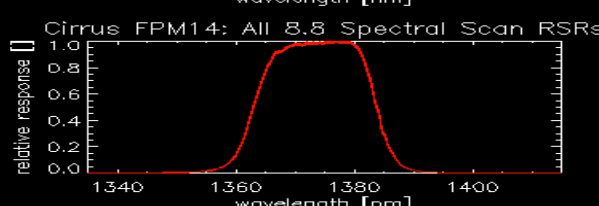

Cirrus FPM11: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Cirrus FPM12: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


SWIR1 FPM13: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

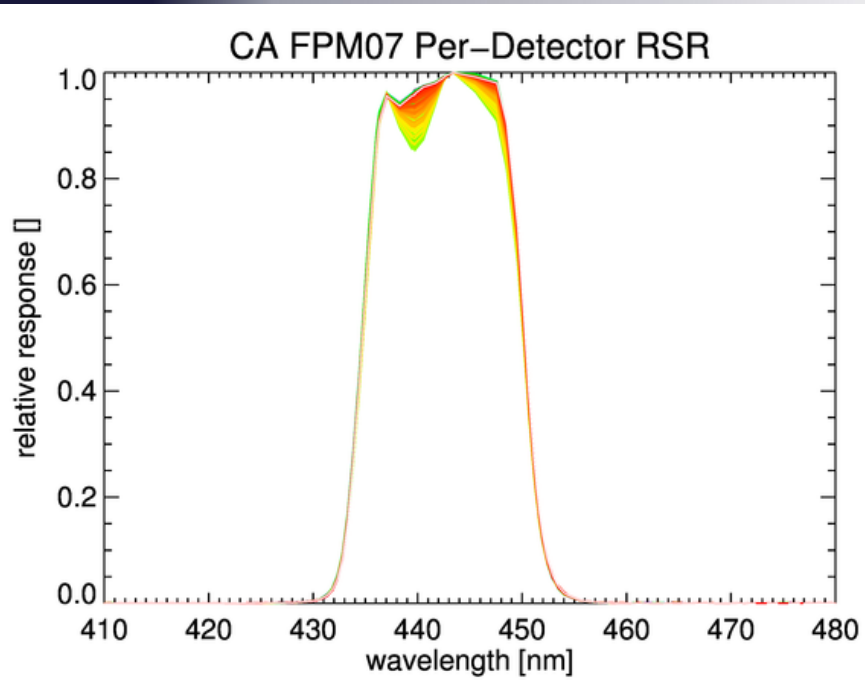

SWIR1 FPM14: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

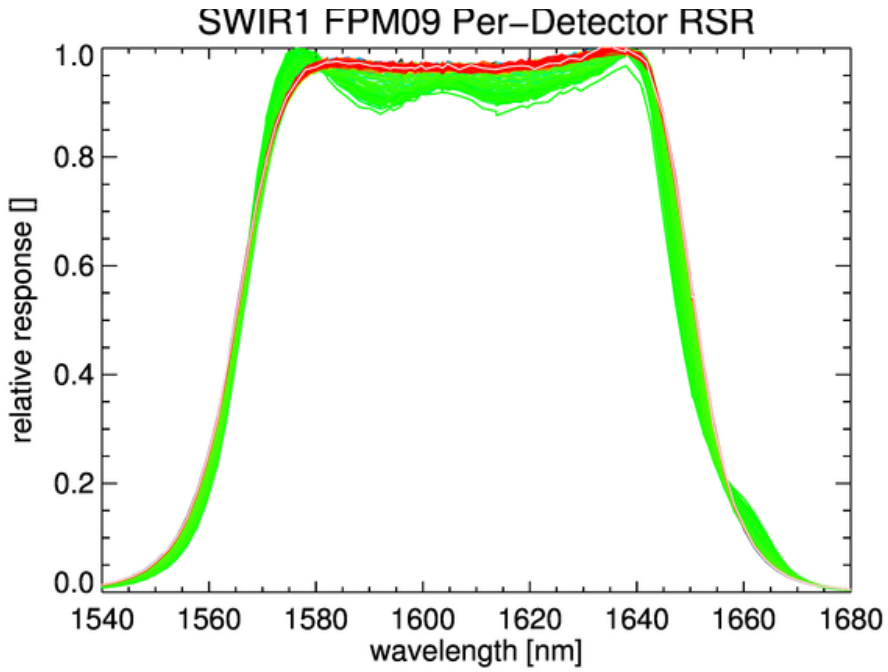

Cirrus FPM13: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]


Cirrus FPM14: All 8.8 Spectral Scan RSRs
relative response []
wavelength [nm]

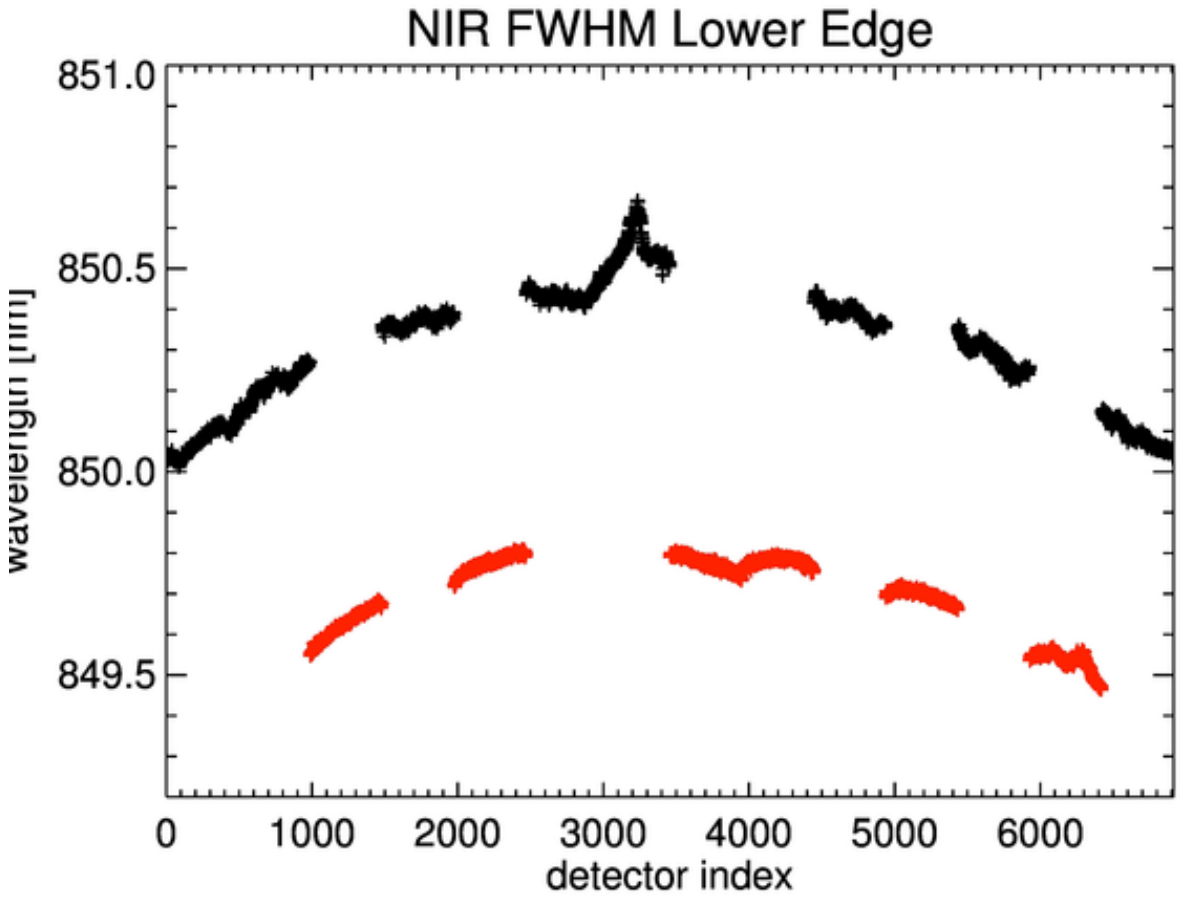
Within-module variation

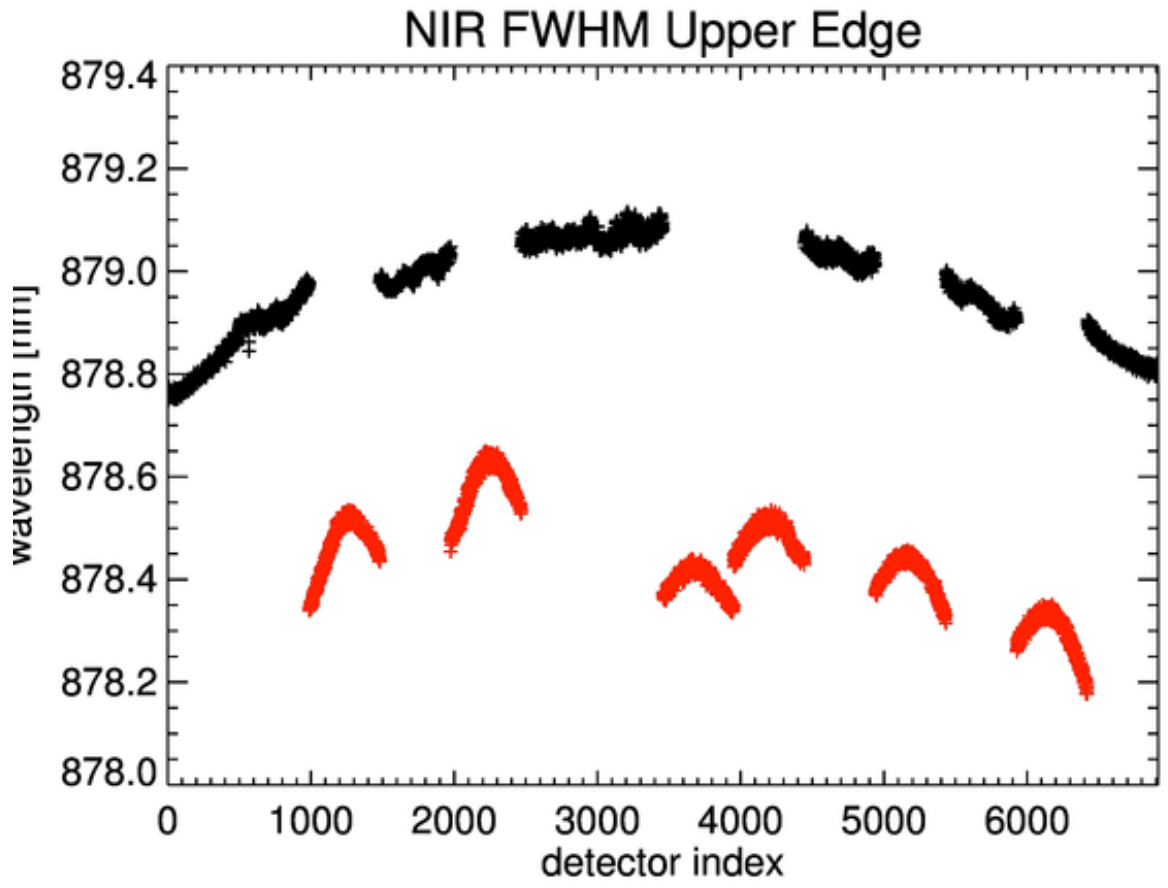
- **Variation within a module was not detected for OLI.**
- **Two modules appear to have small "features" in the filters**
  - CA FPM07
  - SWIR1 FPM09
- *Plots include RSRs for every detector on each module. The variation in the color shows that the RSRs don't all overlap.*





Variation in Spectral Response Across Focal Plane - example



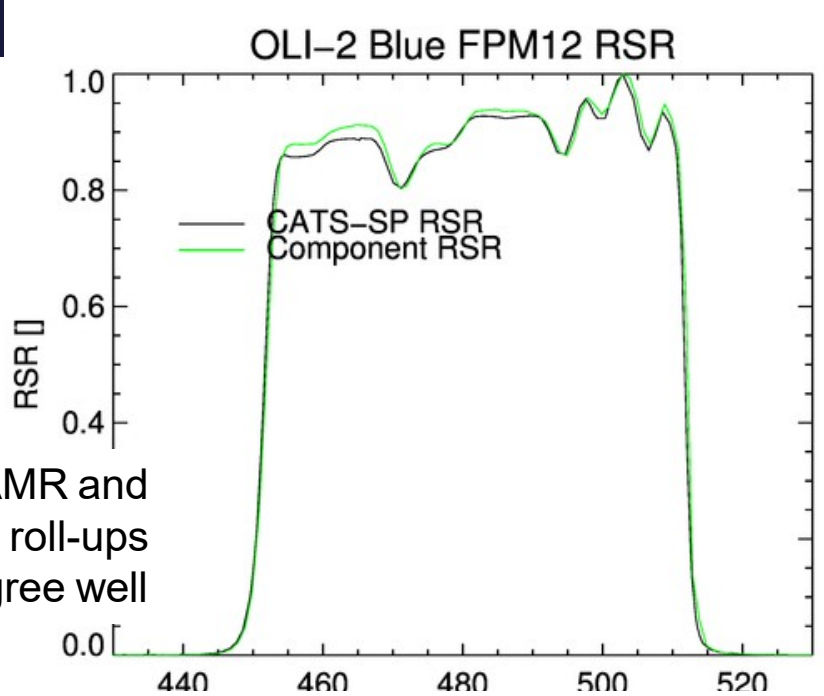


Band edges vary as expected with filter wafer source for filters (red and black colors) and with Angle of Incidence (AOI) variation across focal plane (variability all within requirements)

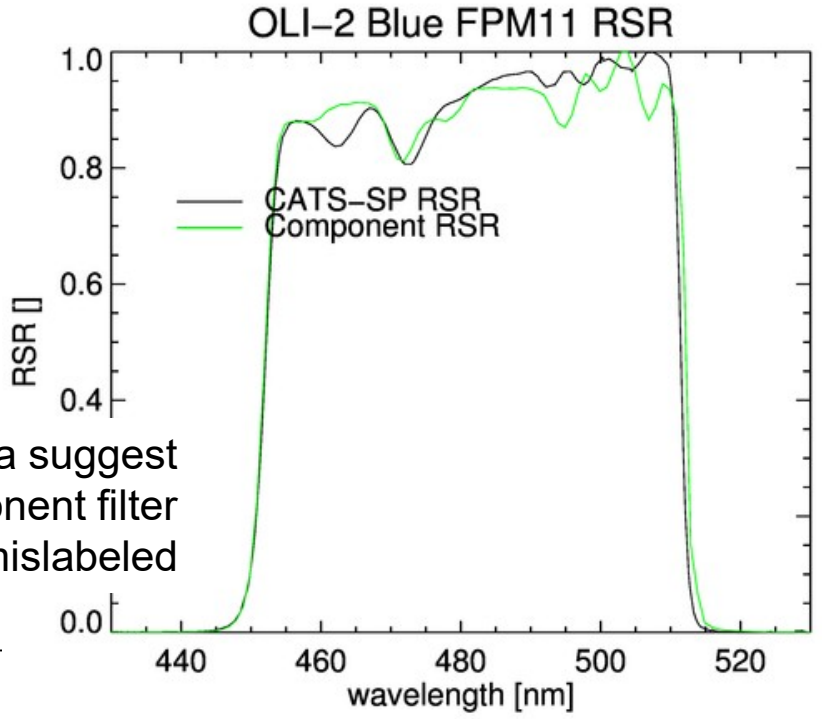
Filter Stick Identification

- Throughout the test, the CATS-SP results was compared to the roll-up of the individual component spectral responses (filter, detectors, optics)

- CATS-SP had enough resolution to detect that the wafer source of some of the filter sticks had likely been mislabeled



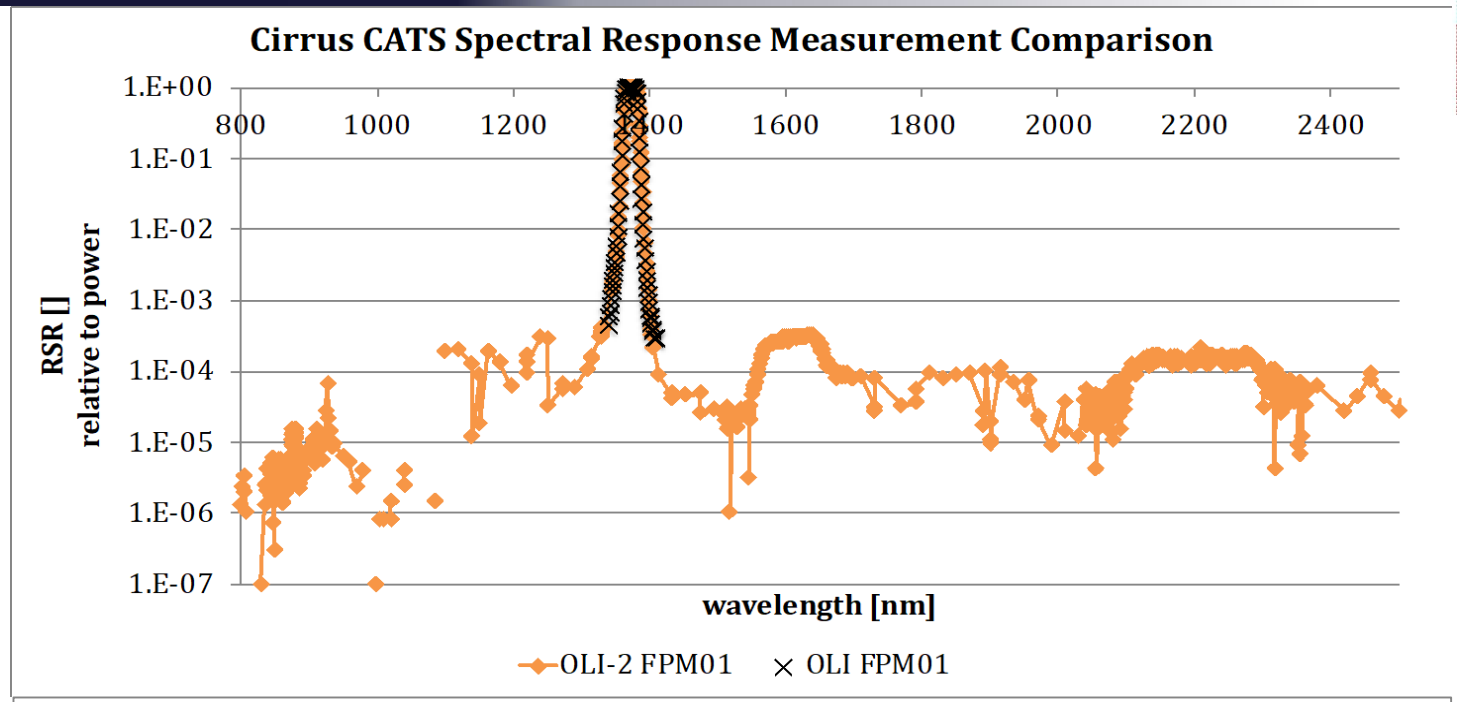
GLAMR and subsystem roll-ups agree well

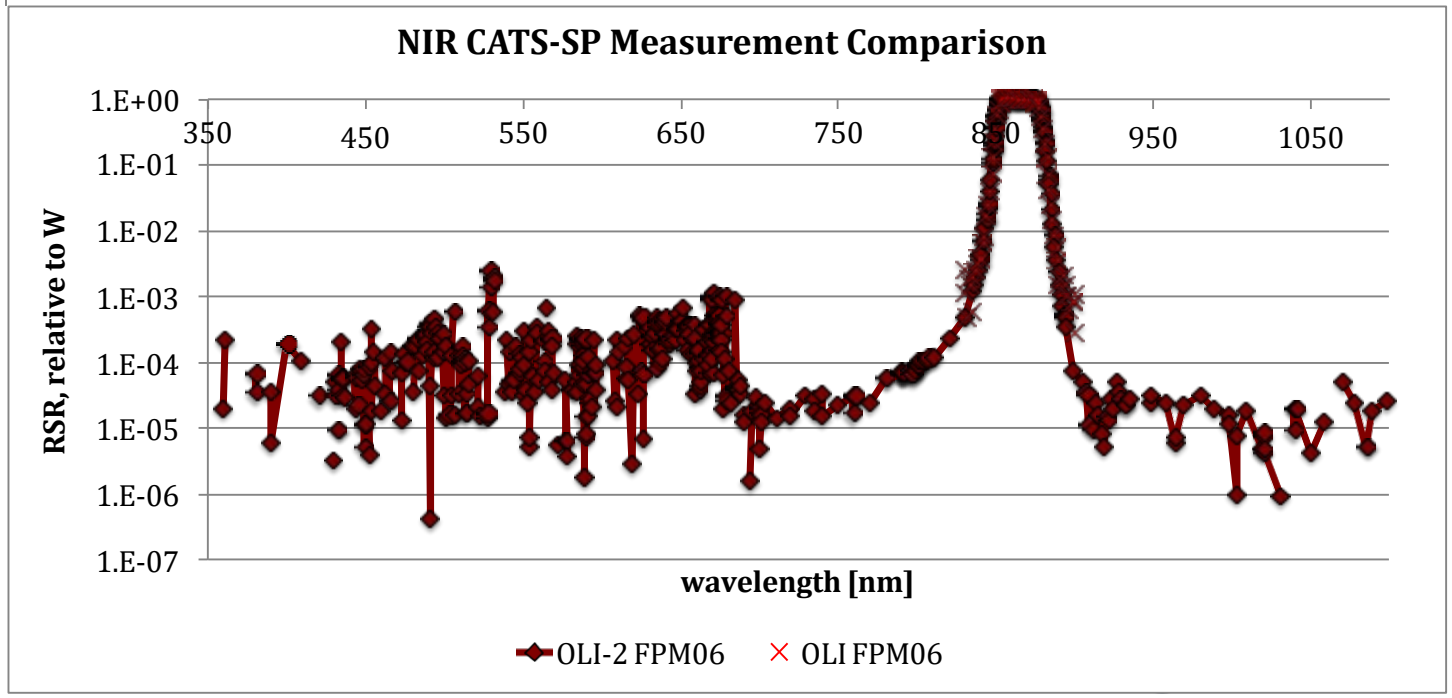


GLAMR data suggest that component filter was mislabeled

Out-of-band characterization

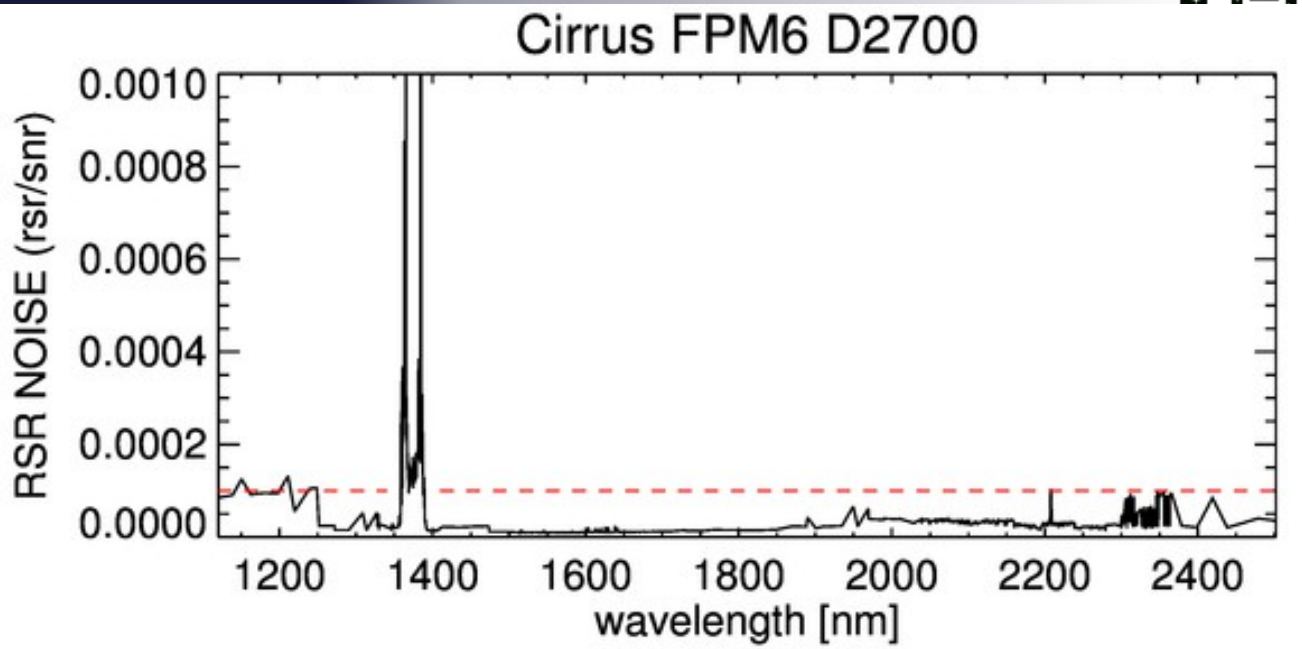
- GLAMR provided enough signal for out-of-band characterization across much of the spectral range
- The SWIR1 and Cirrus cross talk features are apparent
- The signal below 700nm is marginal for out-of-band assessment in the configuration used

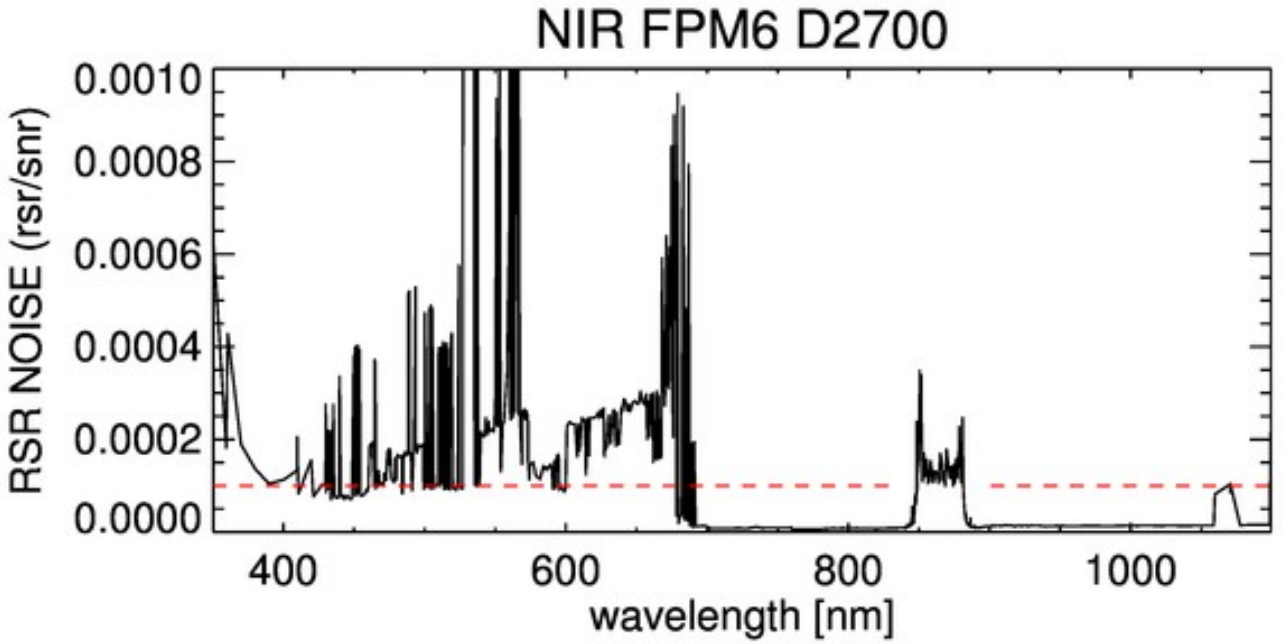




Out-of-band characterization

- OOB requirement: noise should be less than 1e-4 in the out-of-band regions
- Easily met across most of the spectral region
- Below 700nm where the signals get weaker, the OOB noise is generally within a factor of 3 of the requirement, though there are larger excursions in more challenging spectral regions.





Additional GLAMR testing results

- Comparison of absolute calibration between GLAMR and Broad-band QTH source
  - Ongoing
- Non-linearity radiometric response characterization
  - Two wavelengths – one in NIR band and one in SWIR-1 band – 13 levels of radiance across ~4 orders of magnitude – to be compared to other linearity measurements
  - Awaiting linearity characterization of transfer radiometers

Summary

- **Revised OLI spectral response characterization gains**
  - Closer to test as you fly configuration
    - Near full field illumination – captures most crosstalk possibilities
    - Full aperture illumination
  - More complete characterization
    - All detectors measured (versus ~10%) in less time (including OOB characterization)
      - Capture within focal plane module variation
    - Out of band characterization
      - Good signal levels above ~700 nm
- **Impacts**
  - Reduced RSR uncertainty; also validation of absolute radiometric uncertainty
  - Will publish FPM average RSR's and individual RSR's for FPM's with within band variation
    - Particular value to demanding science communities, e.g. water color