Landsat-8 Operational Land Imager Spectral and Radiometric Characterization

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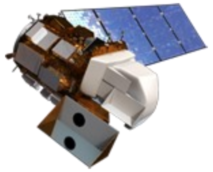


Topics

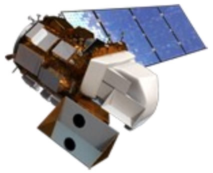
- OLI overview and definitions (if necessary)
- Spectral Characterization
- Radiometric Characterization
- Changes for Landsat-9 OLI-2
- Considerations to improve data harmonization
- Backup Slides

OLI Overview and Definitions

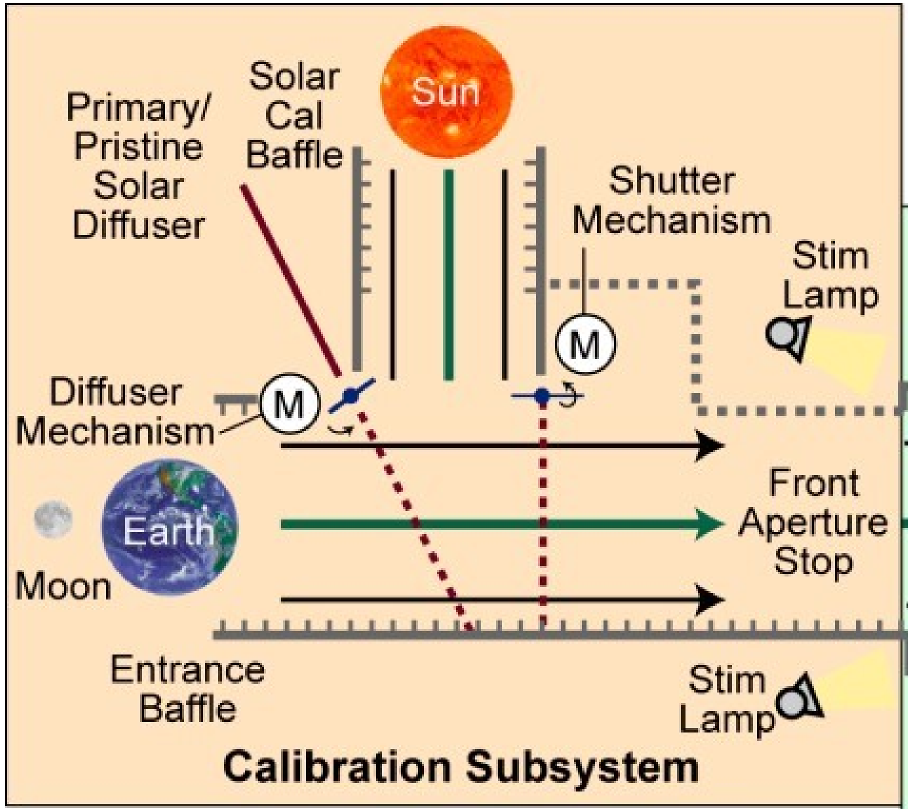
- OLI Salient Characteristics
- OLI Optical and Focal Plane Layout
- Definition
  - Uncertainty - parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (BIPM definition), a.k.a, a quantitative measure of the doubt of the validity of the result of a measurement
  - Begs the question of what quantity are we trying to measure
    - e.g., is it the reflectance or radiance at a specific wavelength, within a specific square-wave bandpass, or the spectrally weighted value defined by the instrument we are using.
    - Similarly, is it a reflectance or radiance at a specific point, within a defined, e.g., square wave response pixel, a specific ground target area or the spatially weighted value defined by the instrument we are using.
    - The answer to this question determines what error sources to include in an uncertainty analysis and how to reduce the errors

The Operational Land Imager (OLI) Salient Characteristics.

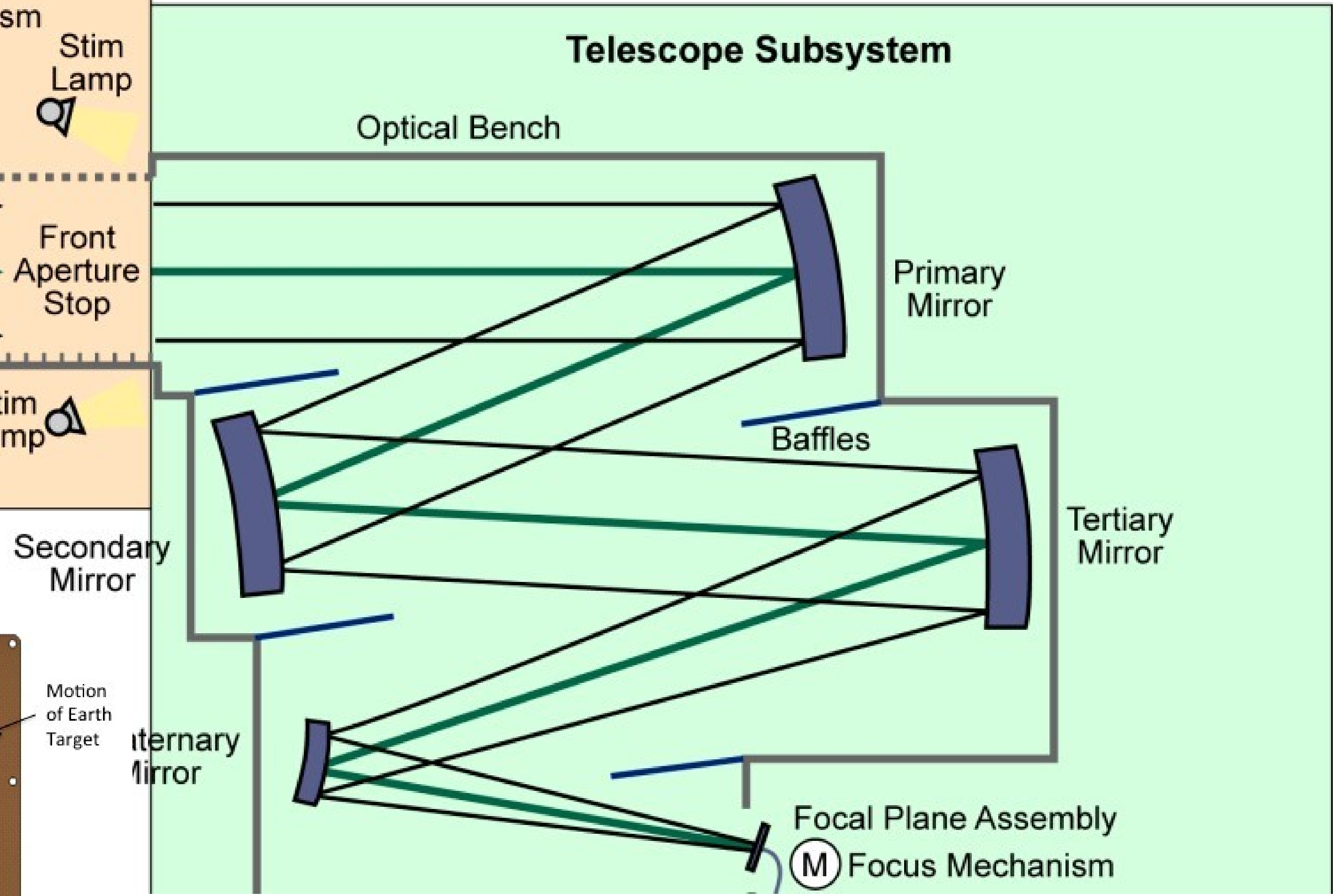
Band (#)	Band Name	Center Wavelength(nm)	Bandwidth (nm)	IFOV(m)	Active Detectors (#)
1	Coastal-Aerosol (CA)	443	16	30	6916 (14 × 494)
2	Blue	482	60	30	6916
3	Green	561	57	30	6916
4	Red	655	38	30	6916
5	Near-IR (NIR)	865	28	30	6916
6	Short Wave IR-1 (SWIR 1)	1609	85	30	6916
7	SWIR 2	2201	187	30	6916
8	Panchromatic (Pan)	590	172	15	13,832 (14 × 988)
9	Cirrus	1373	20	30	6916

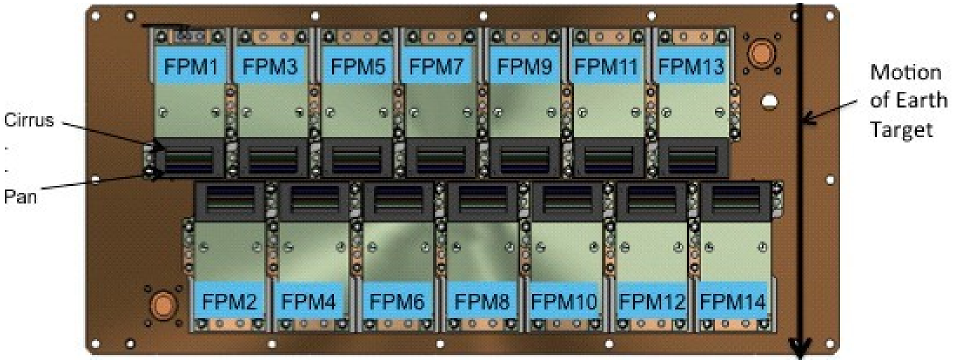


OLI Optical and Focal Plane Layout (Ball Aerospace)



Calibration Subsystem Includes Stim Lamp Assemblies



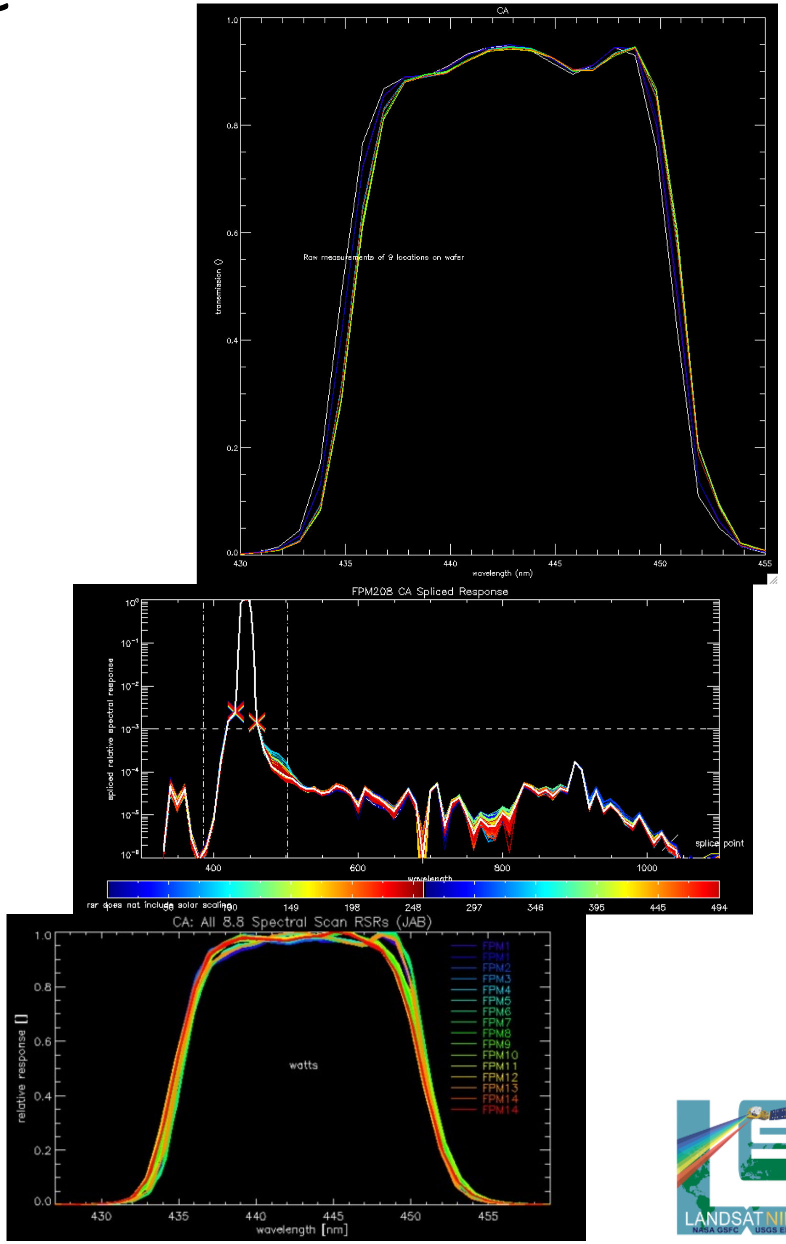


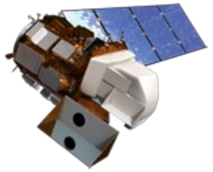
OLI Spectral Characterization

- Measurements
- Limitations/Uncertainties
- Contribution to Radiometric uncertainty

OLI Spectral Response Measurements

- Components
  - Detectors (35K Si - 30m, 21K HgCdTe, 14K Si-15m) Mirrors (4), Window(1), Filters (9x14)
  - Witness samples/flight parts (wafers prior to dicing for filters)
  - In-band and OOB
  - AOI and temperature effects modeled
- Focal Plane Module (combined detectors and filters)
  - Out-of-band primarily, though in-band coarsely measured
  - Operational temperature with AOI effects approximated
  - Flood illumination; all bands and all detectors
- Instrument (full system)
  - In-band only; partial aperture; partial field
  - ~10 % of detectors across focal plane
    - 16 locations on focal plane; ~50 detectors per location
  - Band averages are published spectral responses



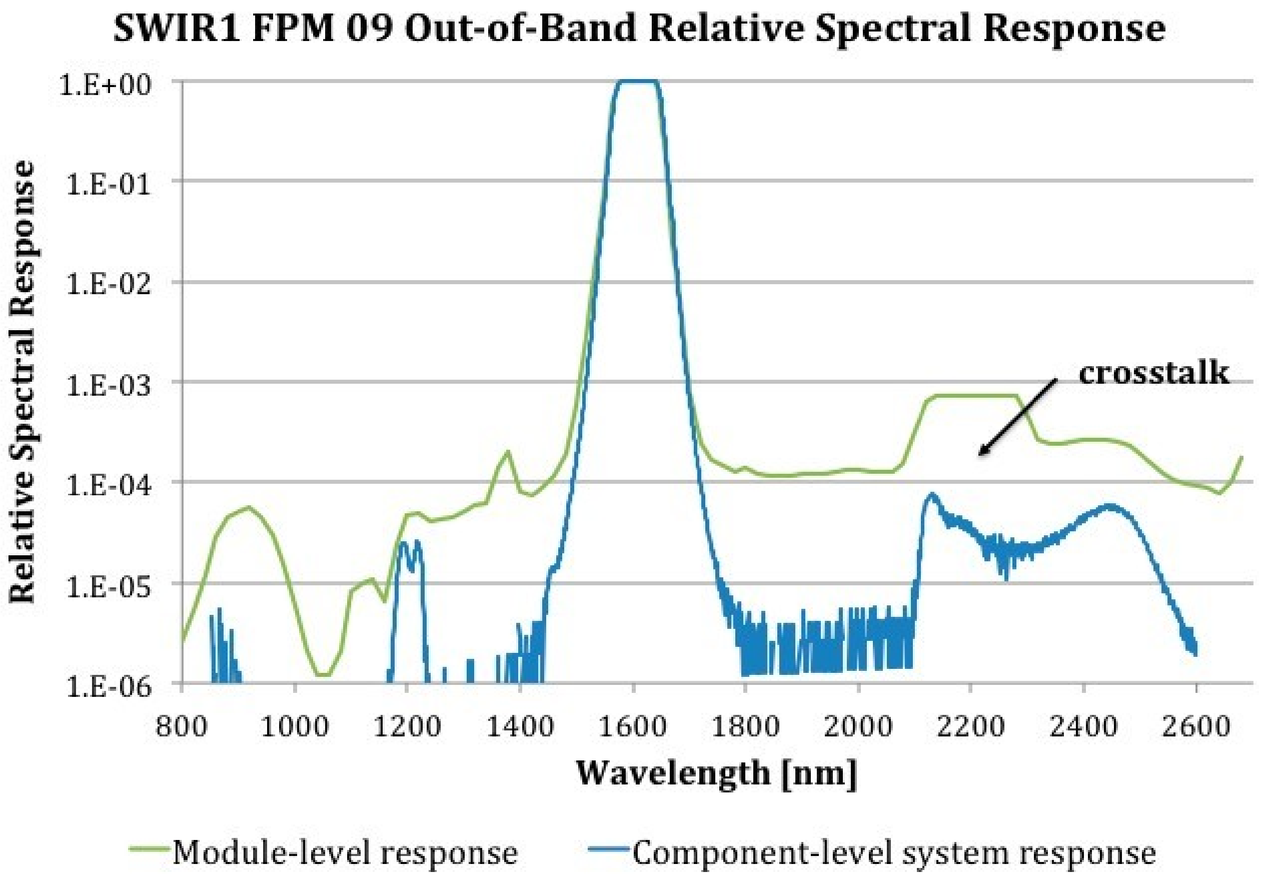


Spectral Response Uncertainties (OOB measurement)

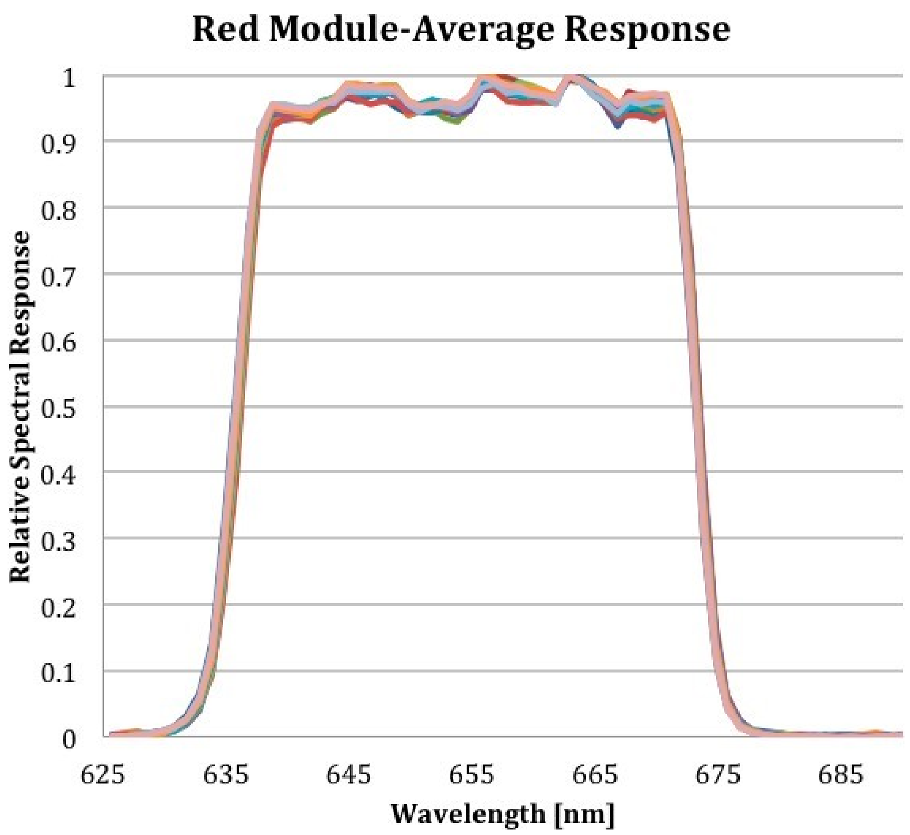
Though more precise, component level measurements do not capture all effects

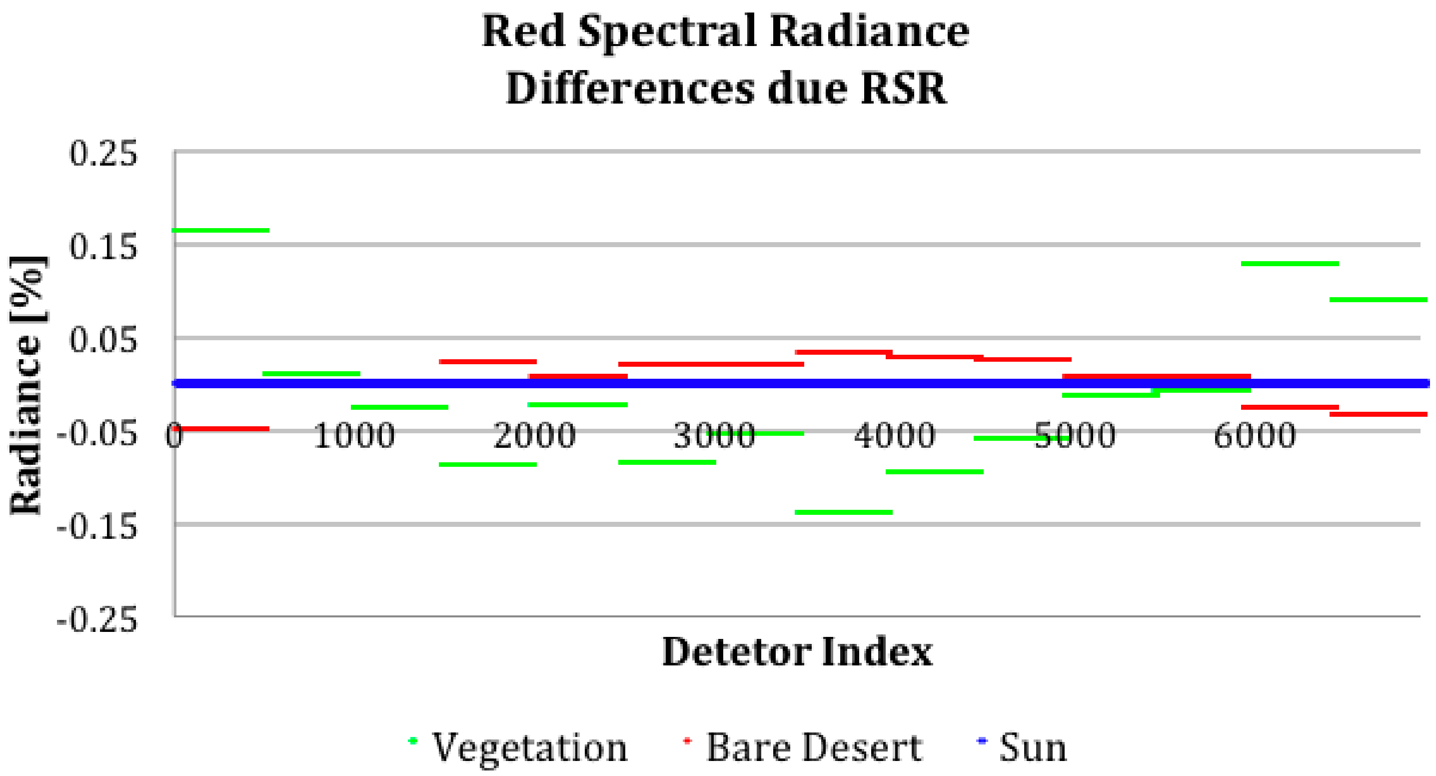
FPM Level measurements capture within FPM Crosstalk, though not between. Flood source Testir does not distinguish in-field from out-of-field Response

Instrument level OOB testing (not done on OLI), Planned for OLI-2 using tunable laser based system



Spectral Response Uncertainties (within band variability)





All OLI Red band filters were from the same wafer, though slight non-telecentricity of OLI results in band edges shifting towards the edges of the focal plane, resulting in target dependent response changes across the focal plane

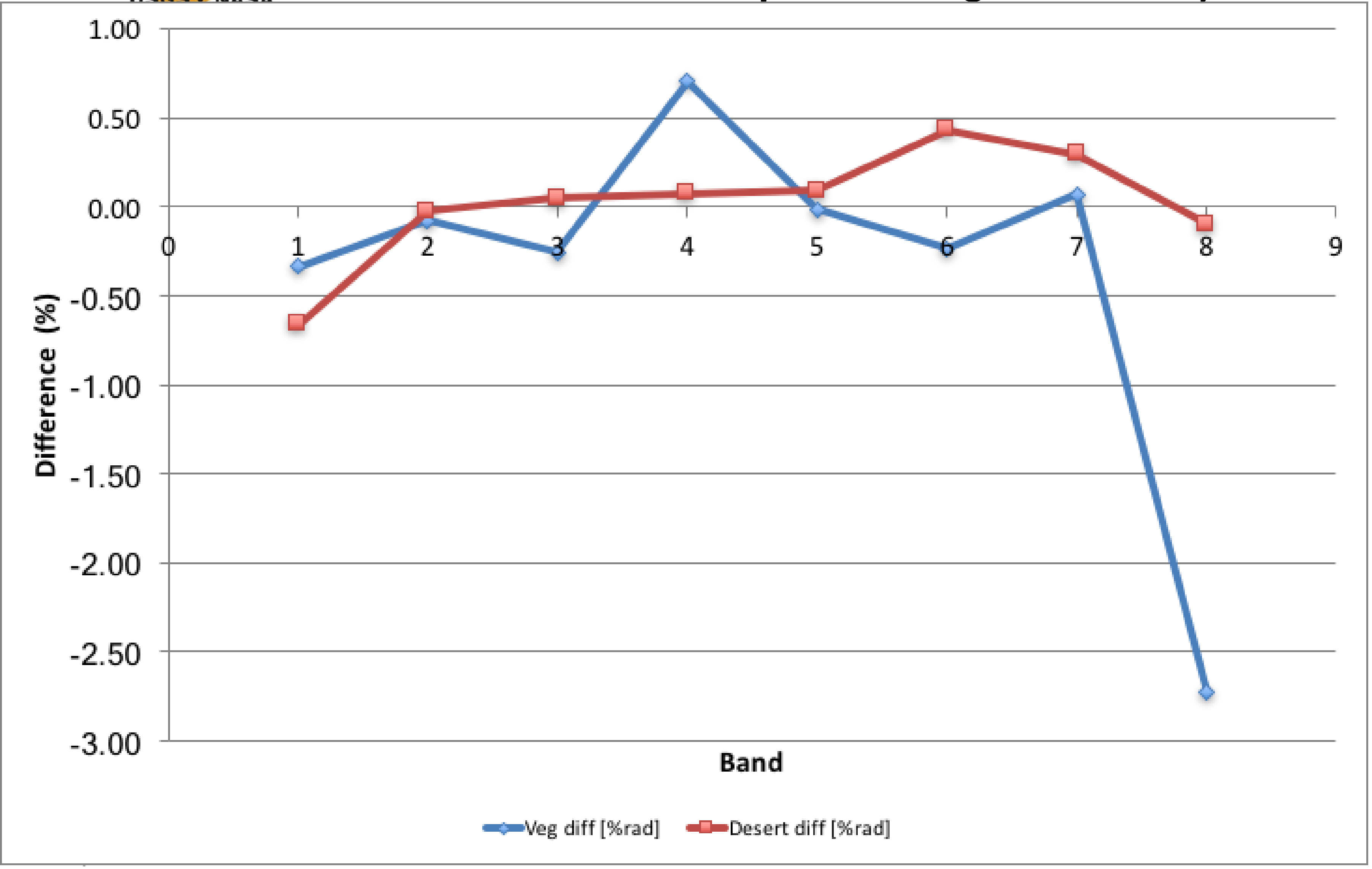
Spectral Response Uncertainties (within-band variability)

	Maximum Discontinuity		Average Discontinuity		RMS Variability	
Band	Vegetation (%)	Soil (%)	Vegetation (%)	Soil	Vegetation (%)	Soil (%)
CA	0.19	0.08	0.12	0.05	0.09	0.04
Blue	0.16	0.03	0.05	0.01	0.07	0.02
Green	0.11	0.02	0.05	0.01	0.07	0.01
Red	0.15	0.05	0.06	0.01	0.09	0.02
NIR	0.11	0.02	0.05	0.01	0.04	0.01
SWIR1	0.16	0.03	0.10	0.08	0.09	0.01
SWIR2	0.07	0.35	0.03	0.08	0.03	0.08
Pan	0.19	0.05	0.08	0.02	0.05	0.02

Spectral Response Contributions to Radiometric Uncertainty

- Use of band-average RSR
  - Filters well matched; generally small effect ±0.1%
- Uncertainty in RSR
  - Differences between component and instrument give a measure of uncertainty; generally 0.5% or less
- Out-of-band contribution
  - Integrated OOB (beyond 1% response) – typically 0.5% or less of in-band for solar spectra (except Cirrus)
  - Crosstalk (out-of-field) contribution minor; except in Cirrus where there is often no in-band signal
- Difference from perfect square wave (not analyzed)

RSR Uncertainty Contribution to Radiometric Error (Difference between component and instrument level RSR's impact on Target Radiance)



Generally less than 0.5% ”uncertainty” in radiance induced by using component versus integrated instrument RSR’s (exception is Pan band)

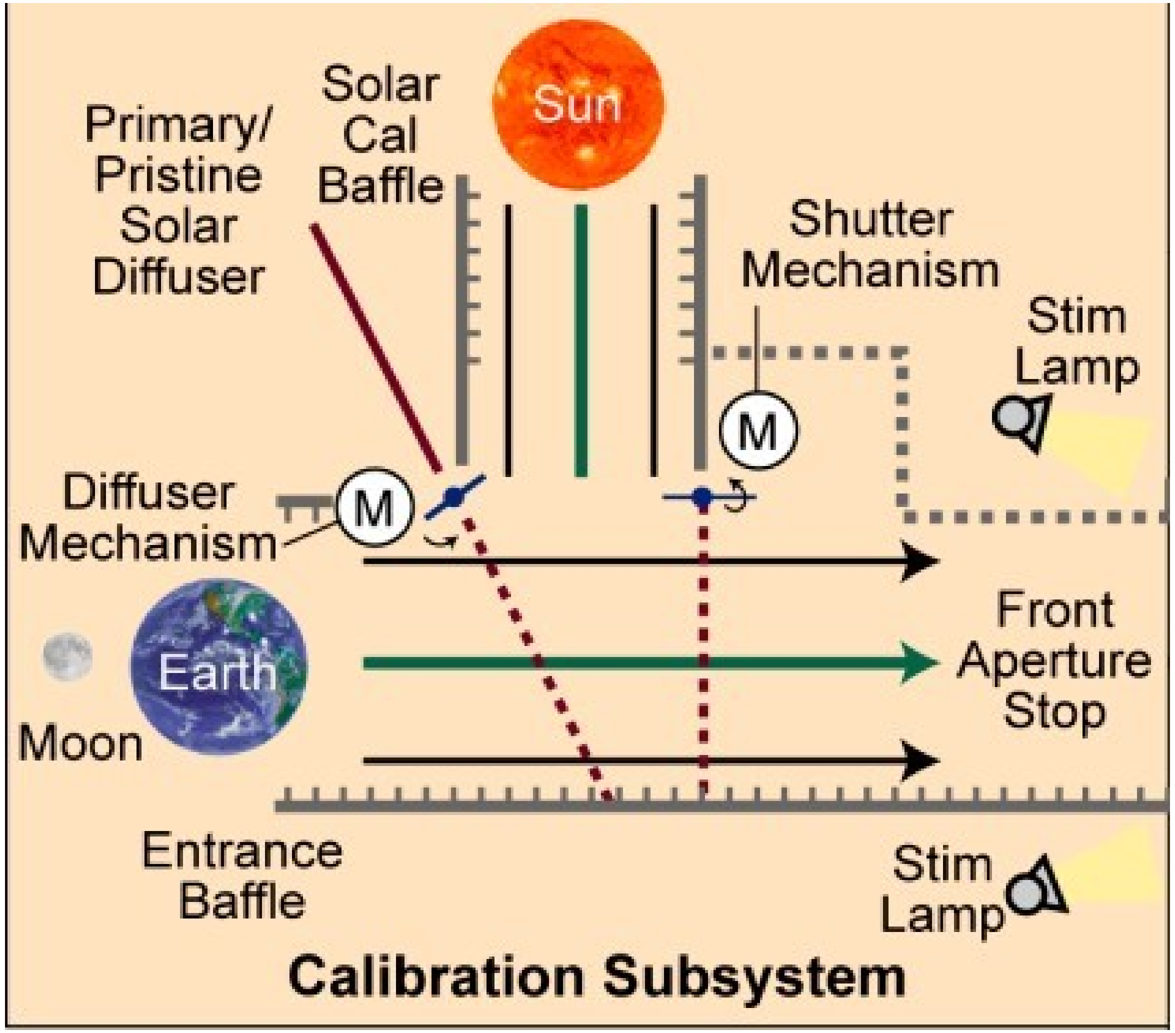
OLI Radiometric Characterization

- Radiance versus Reflectance Based Calibration Discussion/History
- OLI On-board Calibration Hardware
- Radiometric Characterization/contributors to uncertainty
- Reflectance Calibration Methodology, Traceability and Uncertainty
- Radiance Calibration Methodology, Traceability and Uncertainty
- Comparison of “Landsat solar irradiance” to solar irradiance models (as measure of OLI-2 radiometric uncertainty)

Radiance and Reflectance Calibration

- All Landsat sensors from MSS on Landsat-1 to ETM+ on Landsat-7 had strictly a radiance based radiometric calibration provided (tied to NIST standard of spectral irradiance through FASCAL calibrated FEL lamp transferred to integrating sphere)
  - Landsat-7 ETM+ had a diffuser, though reflectance-based calibration was not provided as part of data product (it could have been, but the diffuser was not well characterized in the SWIR bands)
- Landsat-8 OLI had both a radiance and a reflectance based calibration (ref cal tied to NIST through STARR calibrated reference diffuser)
  - Both provided to users, each separately traceable to standards
  - Similar to MODIS, though MODIS radiance was tied to reflectance call through a solar irradiance model
- Landsat-9 OLI-2 will be similar to Landsat-8 OLI (both calibrations provided)
- Current preference appears to be reflectance-based calibration due to lower uncertainty

OLI On-Board Radiometric Calibration Capabilities



Shutter
- once an orbit

Full aperture diffusers (2)
- used at different frequencies
- weekly, semi-annually

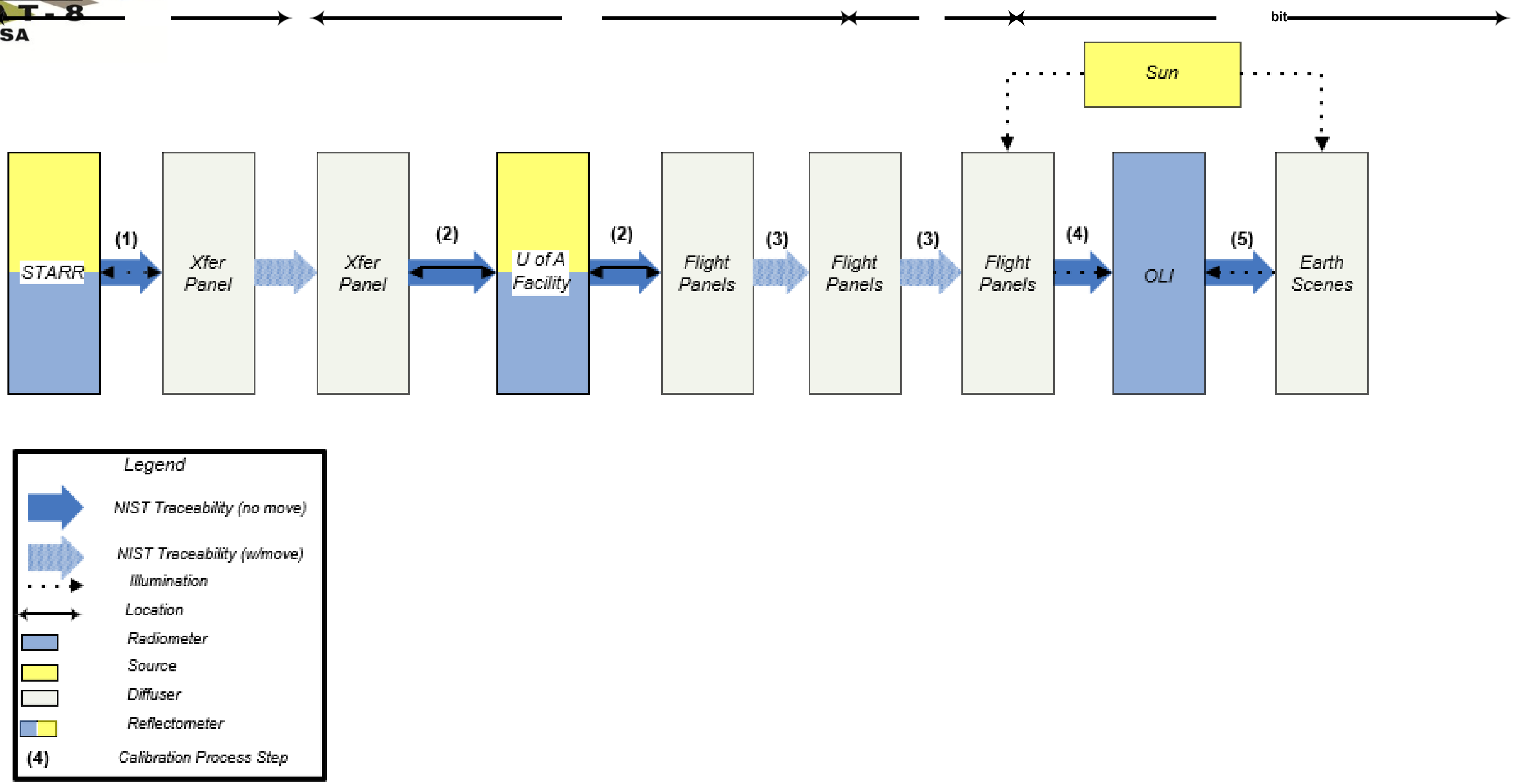
Stimulation lamps (3 pairs)
- used at different frequencies
- daily, bi-weekly, semi-annually

Moon
- once a lunar cycle
- all FPM’s

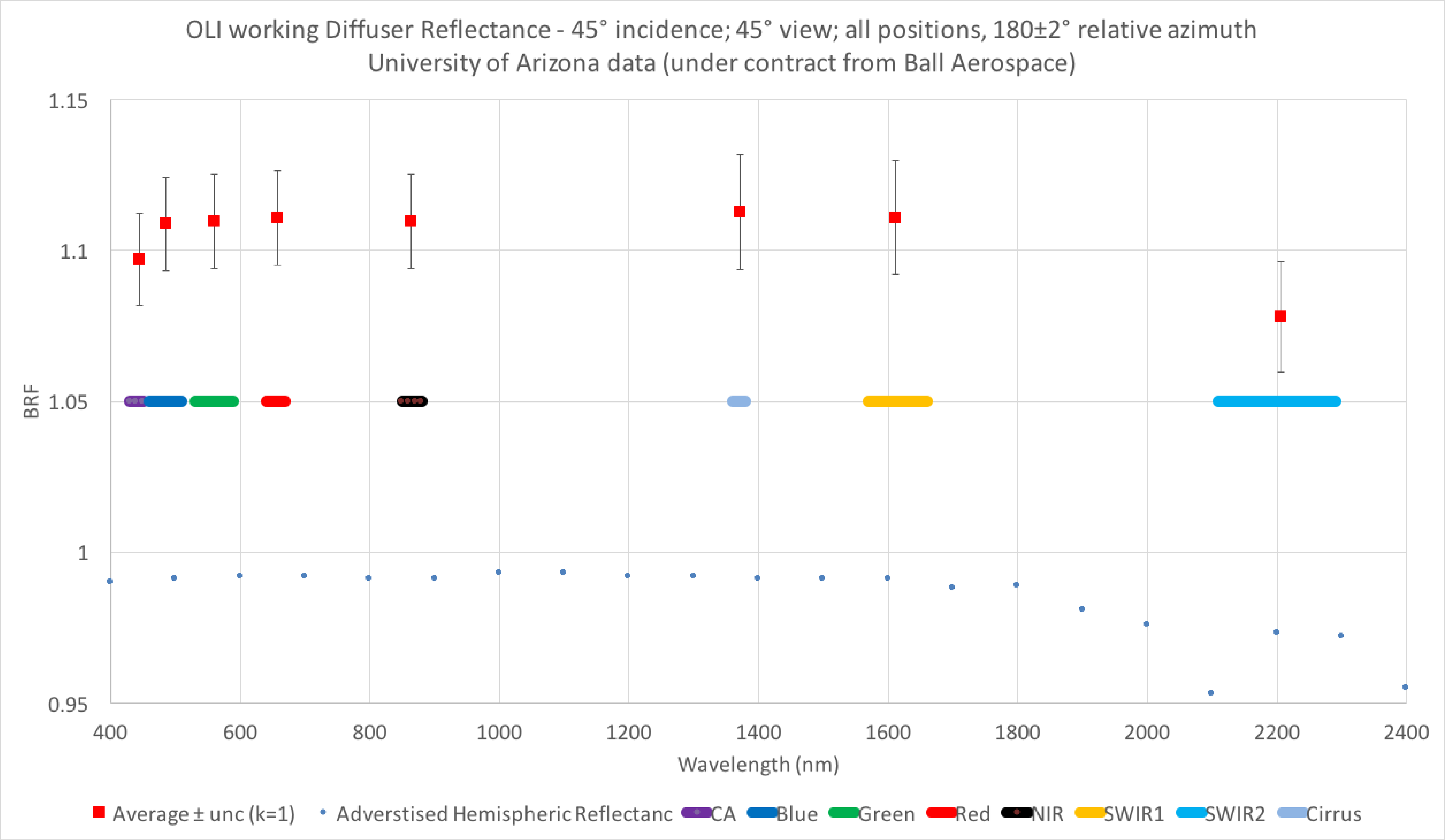
Radiometric Characterization/contributors to uncertainty

- Stability
  - Responsivity stability between solar calibrations
  - Dark level stability between shutter collects
- Linearity
  - Less well characterized than intended; radiance linearity testing uncertainty dominated by sphere radiance uncertainty in non-controlled bands in radiance feedback mode
  - Relied on reciprocity, using integration time tests where radiance linearity testing was missing
  - Imperfect understanding of reciprocity
- Uniformity
  - Requirement was 0.5% (1 sigma) across full field of view (FFOV) (plus some more localized requirements)
  - Extensive pre-launch analysis indicated FFOV requirement would be met
  - Contributors include spectral, diffuser characterization residual, non-linearity correction residual, noise, dark current residual
- Stray Light
  - Internal reflections in solar diffuser increase signal by ~1% based on modeling; testing results consistent, though with significant error bars

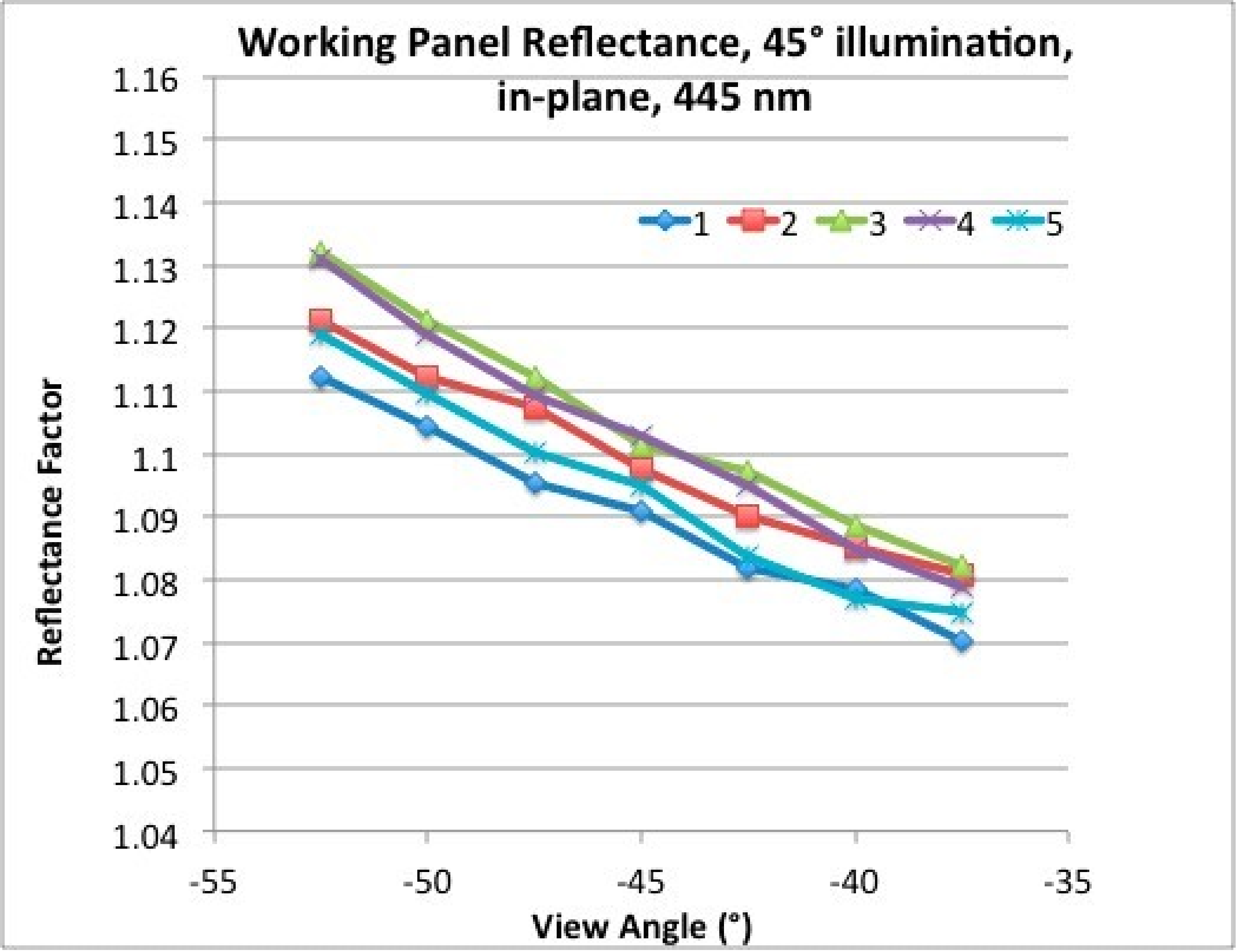
OLI Reflectance Calibration: Methodology, Traceability and Uncertainty



From Ball Aerospace Document



OLI working Diffuser Reflectance - 45° incidence; 45° view; all positions, 180±2° relative azimuth
University of Arizona data (under contract from Ball Aerospace)
1.15
1.1
1.05
1
0.95
BRF
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Average ± unc (k=1)
Adverstised Hemispheric Reflectanc
CA
Blue
Green
Red
NIR
SWIR1
SWIR2
Cirrus



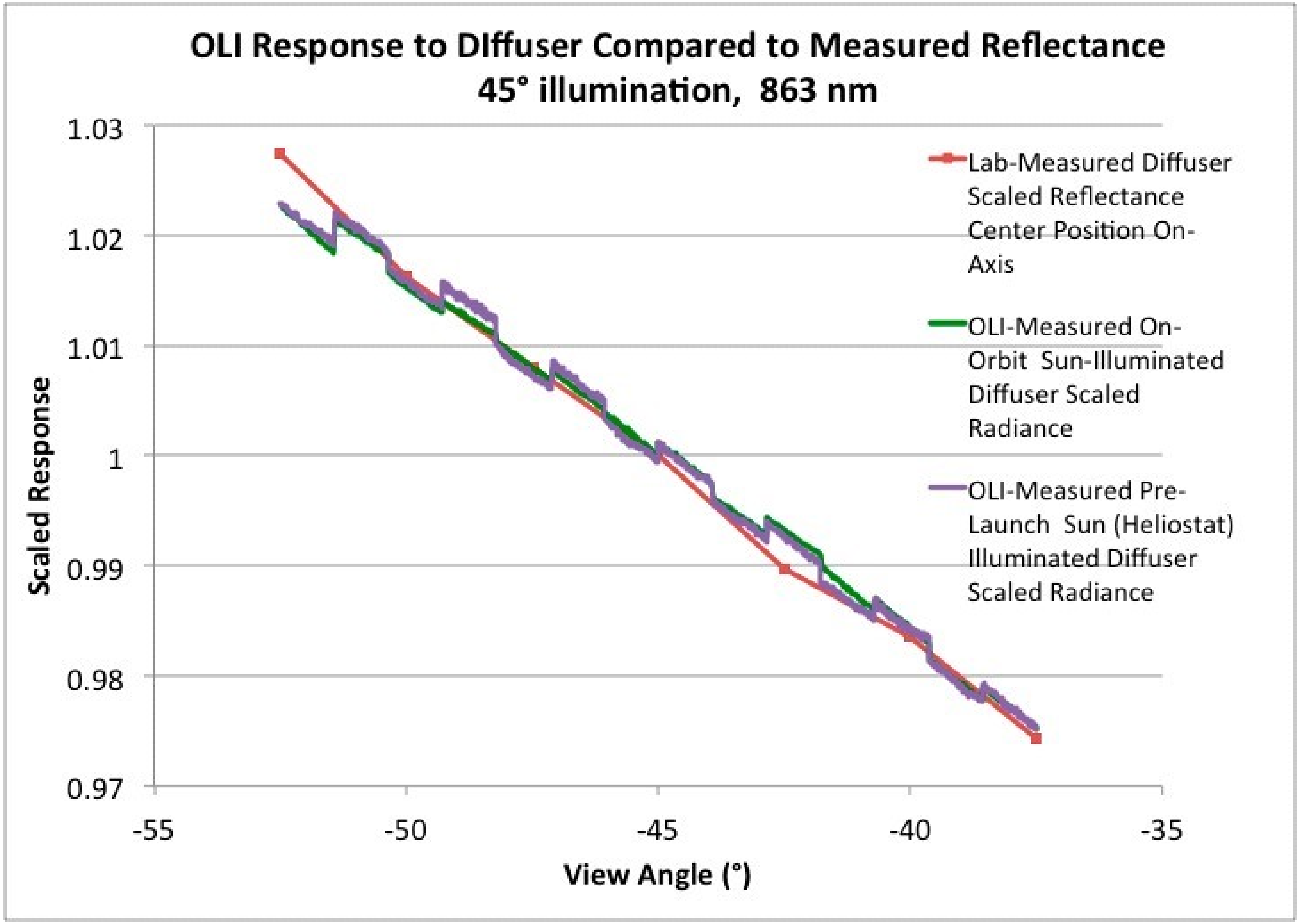
~5% reflectance change across OLI 15° FOV

Reflectance Calibration Uncertainty Estimates:

Radiances of $L_{typical}$ and above (pre-launch evaluation)

Term	Value								
	CA	Blue	Green	Red	NIR	SWIR1	SWIR2	Pan	Cirrus
Initial Diffuser BRDF	**1.4%**	**1.3%**	**1.1%**	**1.0%**	**1.0%**	**1.7%**	**1.4%**	**1.1%**	**1.7%**
Geom Unc	**0.9%**	**0.9%**	**0.9%**	**0.9%**	**0.9%**	**0.9%**	**0.9%**	**0.9%**	**0.9%**
Diffuser Light Shade Stray Light	**0.7%**	**0.7%**	**0.7%**	**0.7%**	**0.7%**	**0.7%**	**0.7%**	**0.7%**	**0.7%**
Stray Light	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Pristine -> Wkg	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Wkg -> Scene	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**
Non-Linearity	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
FFOV Non-Uniformity	**0.3%**	**0.2%**	**0.3%**	**0.3%**	**0.3%**	**0.3%**	**0.4%**	**0.3%**	**0.3%**
Long Term Stability 1σ	**0.1%**	**0.1%**	**0.1%**	**0.0%**	**0.0%**	**0.3%**	**0.2%**	**0.1%**	**0.6%**
Total Unc.	**2.1%**	**2.0%**	**1.9%**	**1.8%**	**1.8%**	**2.3%**	**2.1%**	**1.9%**	**2.4%**

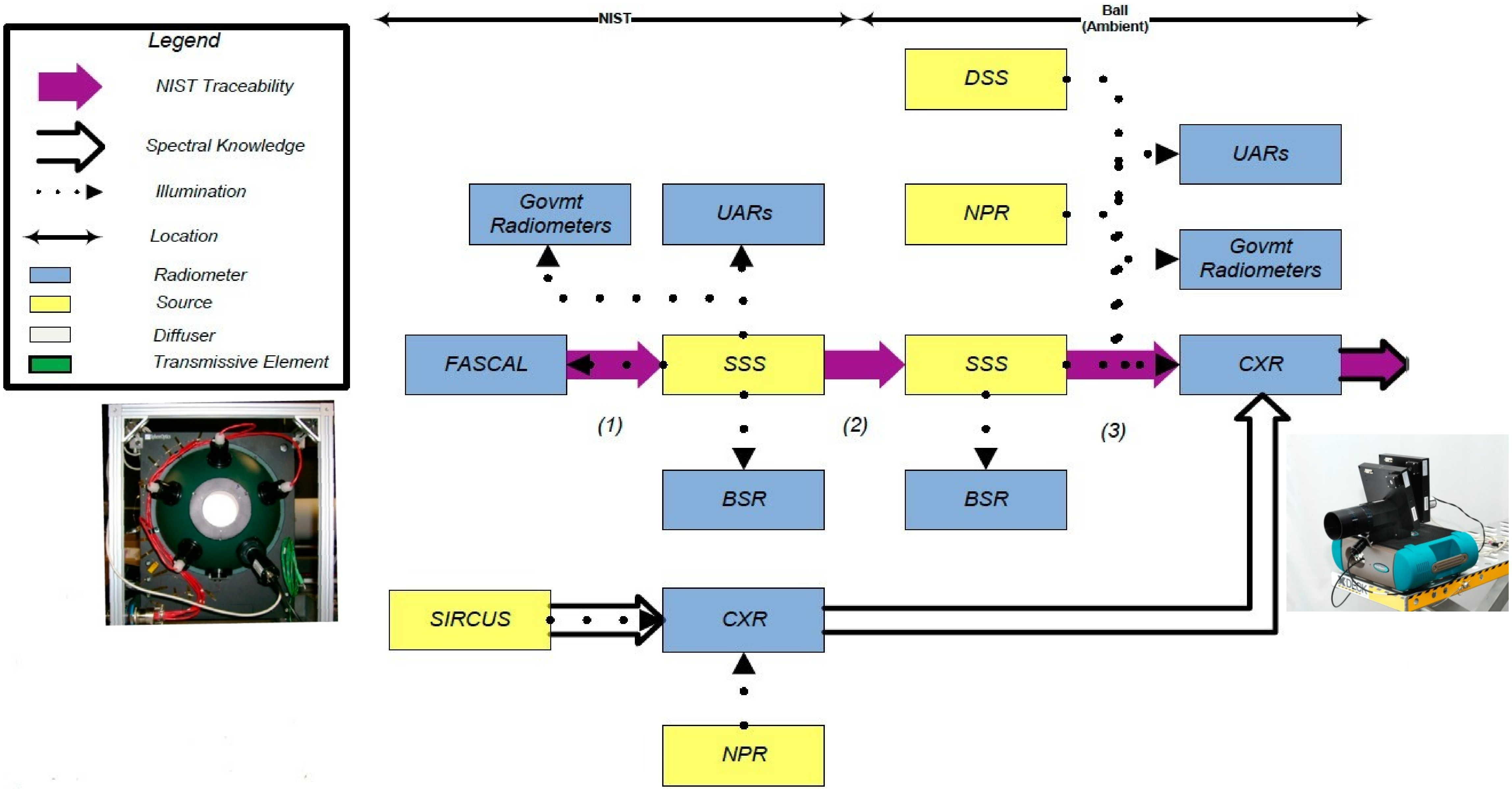
Slightly modified from Ball Aerospace document


OLI Response to DIffuser Compared to Measured Reflectance
45° illumination, 863 nm
Scaled Response
View Angle (°)
1.03
1.02
1.01
1
0.99
0.98
0.97
-55
-50
-45
-40
-35
Lab-Measured Diffuser Scaled Reflectance Center Position On-Axis
OLI-Measured On-Orbit Sun-Illuminated Diffuser Scaled Radiance
OLI-Measured Pre-Launch Sun (Heliostat) Illuminated Diffuser Scaled Radiance

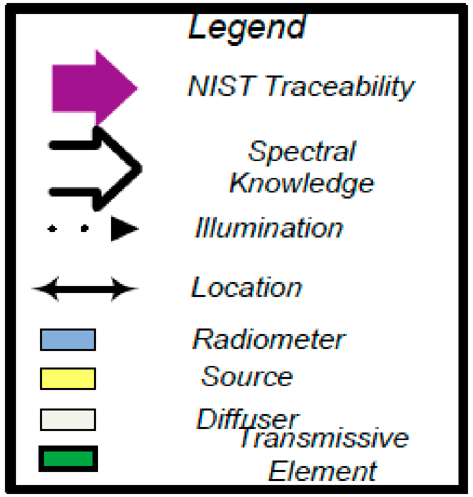
Radiance Calibration Methodology, Traceability and Uncertainty

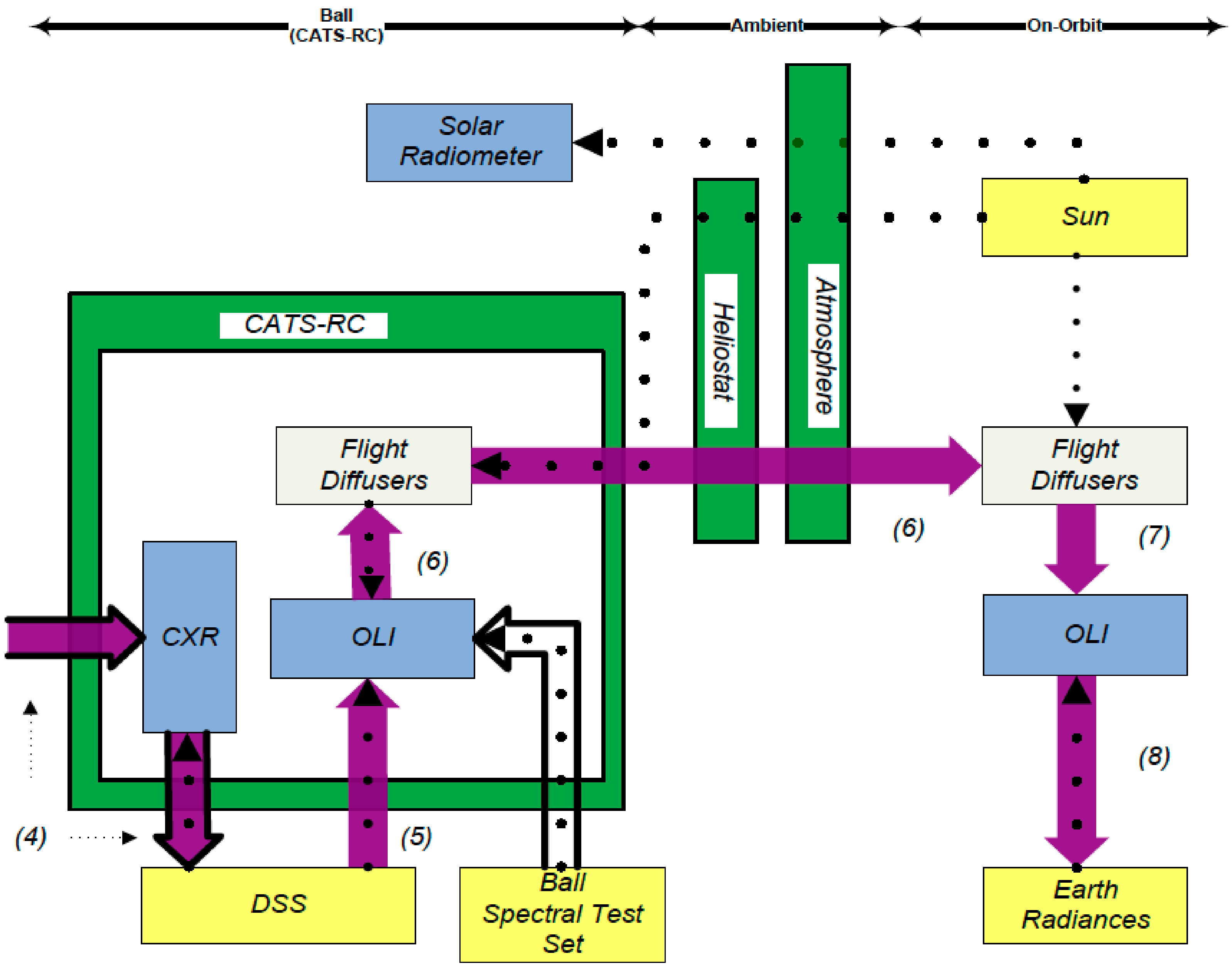
- Artifact Characterization and Validation (SSS, CXR, DSS)
- Transfer to Instrument
- Transfer to Orbit
- Uncertainty estimates

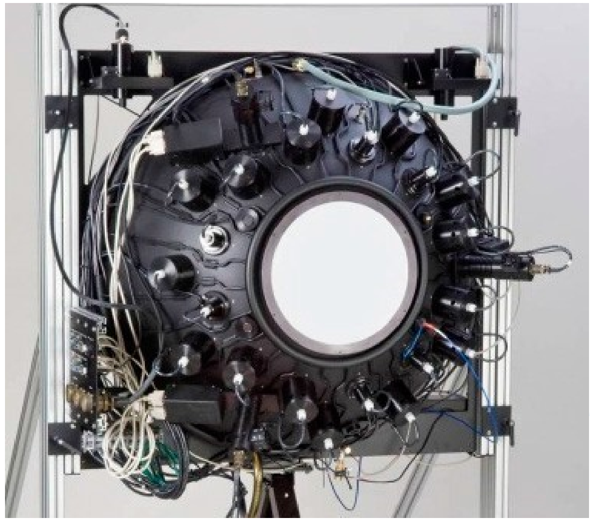
Radiance Calibration Methodology and Traceability (1 of 2)



Radiance Calibration Methodology and Traceability (2 of 2)

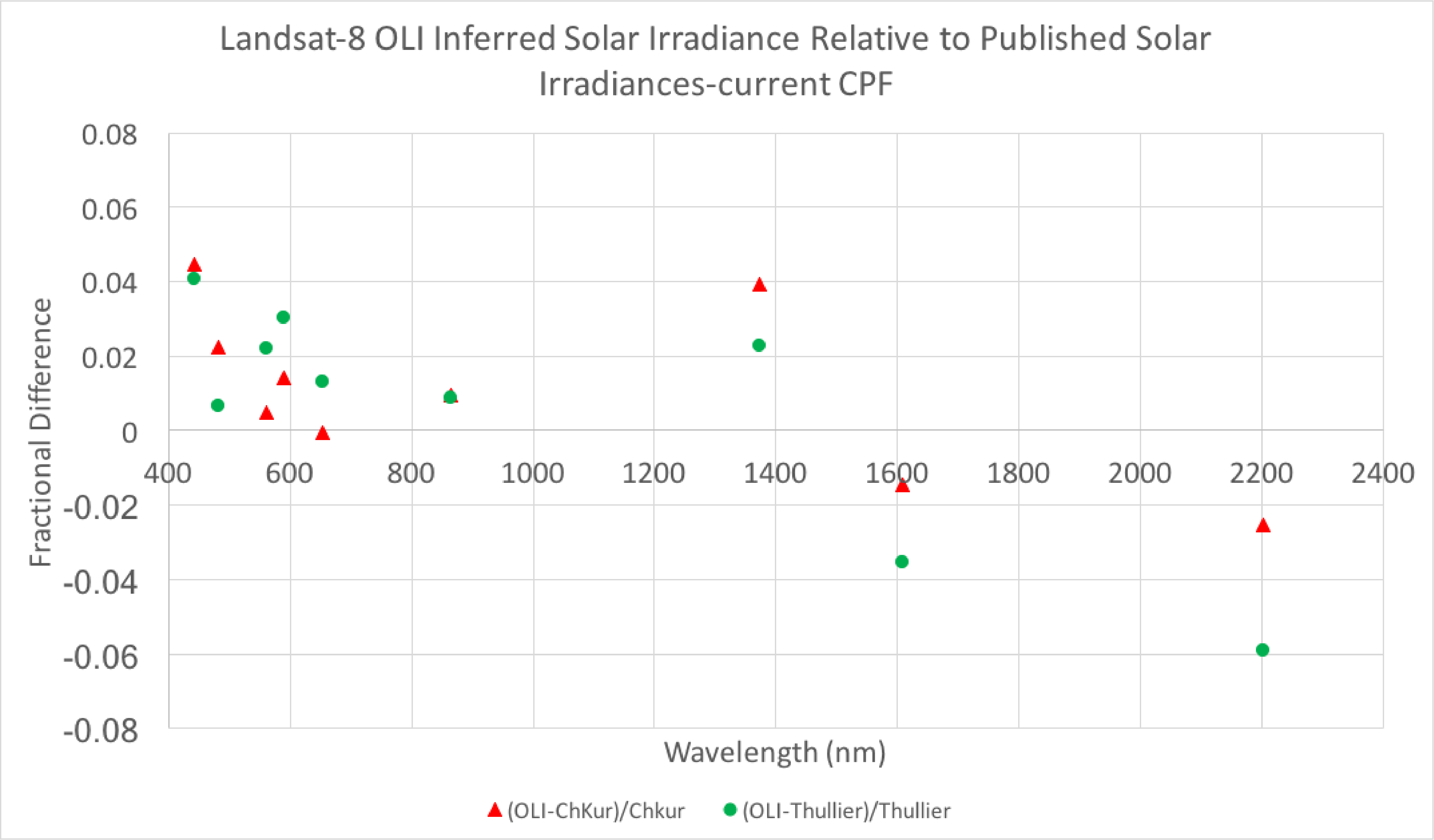






Radiance Calibration Uncertainty Estimates (with TTO uncertainty included): Radiances of $L_{typical}$ and above (pre-launch evaluation)

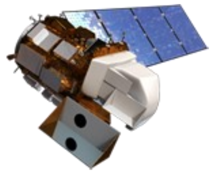
Term	Value								
	CA	Blue	Green	Red	NIR	SWIR1	SWIR2	Pan	Cirrus
Initial DSS	**2.2%**	**1.9%**	**1.8%**	**1.8%**	**1.8%**	**2.4%**	**2.3%**	**2.0%**	**2.4%**
DSS -> SD	**1.1%**	**1.1%**	**1.1%**	**1.1%**	**1.1%**	**1.1%**	**1.1%**	**1.8%**	**0.0%**
Spectral (DSS -> Solar)	-0.2%	0.2%	-0.3%	0.2%	0.0%	0.2%	0.0%	-1.4%	
Stray Light	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	
Source Stab.	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	
Non-Linearity	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	
TTO	**2.1%**	**1.9%**	**1.8%**	**1.6%**	**1.9%**	**1.7%**	**1.7%**	**1.7%**	**3.0%**
Atm. Trans	1.4%	1.2%	1.0%	0.8%	0.7%	0.5%	0.5%	0.9%	
Helio Trans	1.2%	1.1%	1.1%	1.0%	1.5%	1.3%	1.3%	1.1%	
Non-Linearity	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	
Pristine -> Wkg	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**
Wkg -> Scene	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.0%**	**1.1%**	**1.0%**	**1.2%**	**1.0%**
Spectral (Solar -> Scene)	0.1%	0.0%	-0.2%	0.1%	0.0%	-0.4%	-0.2%	-0.6%	0.0%
Non-Linearity	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
FFOV Non-Uniformity	**0.3%**	**0.2%**	**0.3%**	**0.3%**	**0.3%**	**0.3%**	**0.4%**	**0.3%**	**0.3%**
Long Term Stability 1σ	**0.1%**	**0.1%**	**0.1%**	**0.0%**	**0.0%**	**0.3%**	**0.2%**	**0.1%**	**1.1%**
Total Unc.	**3.4%**	**3.1%**	**3.0%**	**2.9%**	**3.0%**	**3.3%**	**3.2%**	**3.4%**	**4.1%**
Rqmt.	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**	**5.0%**
Margin	**46.9%**	**62.9%**	**68.0%**	**75.0%**	**65.7%**	**49.9%**	**54.5%**	**47.6%**	**21.1%**



Landsat-8 OLI Inferred Solar Irradiance Relative to Published Solar Irradiances-current CPF
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Fractional Difference
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
(OLI-ChKur)/Chkur
(OLI-Thullier)/Thullier

Characterization Changes for Landsat-9 OLI-2

- GLAMR
  - Spectral - all bands all detectors at instrument level
  - Some OOB/crosstalk coverage at instrument level
  - Absolute Calibration Validation
  - Linearity validation [TBD]
- 14-bit
- Linearity testing
  - FPE
  - Instrument
- Somewhat reduced sphere based radiometric scale realization efforts (fewer participants)



Thoughts on Harmonization

- Make instruments the best they can be:
  - Stability is the key
  - Adequate on-board capabilities to track
  - Uniformity in response across focal plane, e.g., spectral: telecentricity, filter uniformity
- Characterize response sufficiently
  - Flat fielding/diffuser BRDF
  - Linearity
  - Spectral
- Commonality of Designs
  - Spectral filter specifications, i.e., same bands to extent possible
  - Angular coverage, GSD, PSF, etc.