



# Overview of Hyperion On-Orbit Instrument Performance, Stability, and Artifacts

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## ***Topics***

***Summary of On-orbit Performance  
Assessment***

***Long-term Stability & Repeatability***

***Known instrument artifacts***



# ***On-Orbit Performance Assessment Strategy***



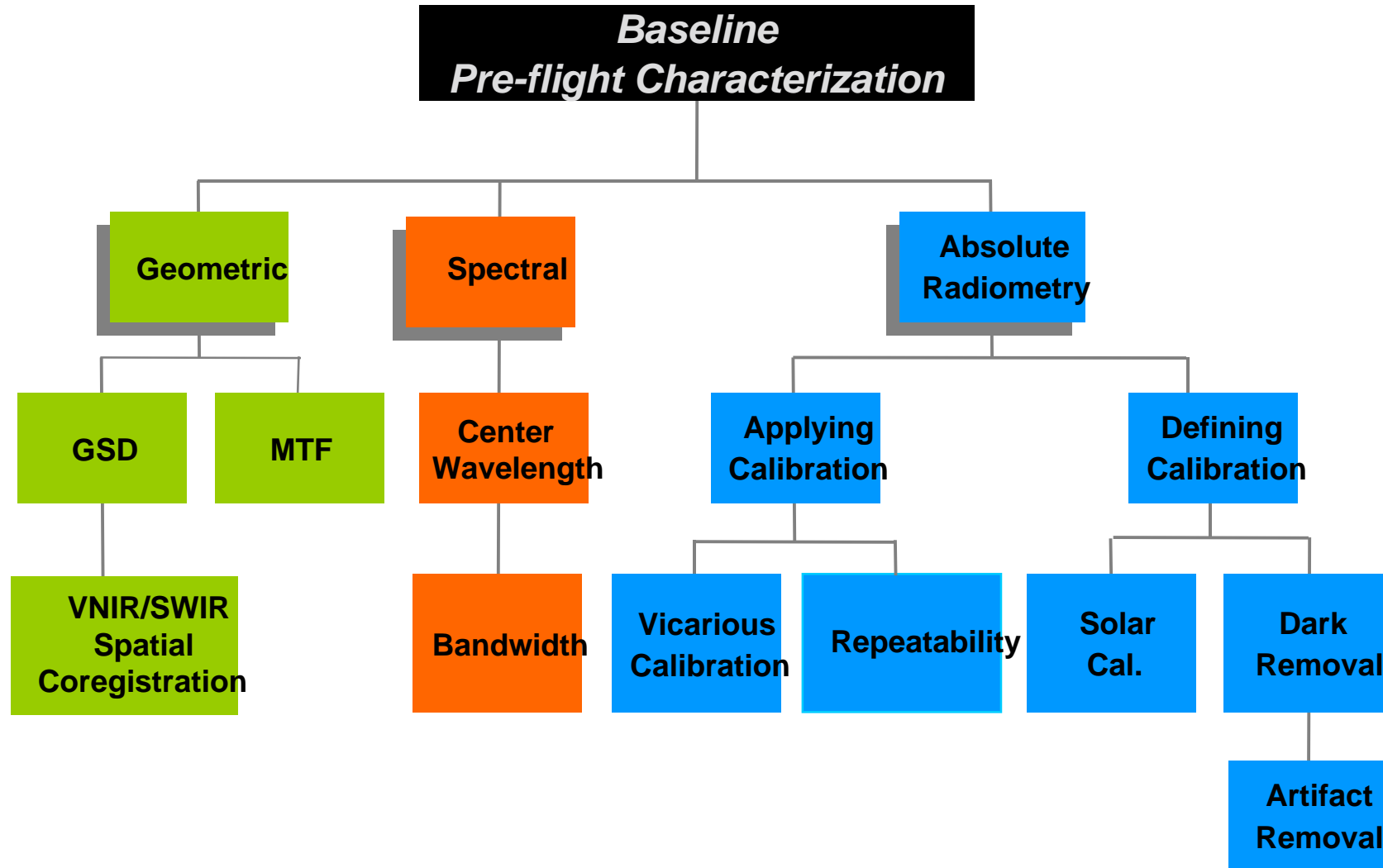
## ***Pre-Flight:***

- γ Establish instrument characteristics and assess requirement compliance
- γ Check performance through build, environmental test and spacecraft integration
- γ Provides solid foundation for on-orbit comparison
- γ Leveraged extensive TRW facilities and models specifically developed for hyperspectral characterization
- γ Cross calibrated with Landsat and ALI transfer radiometers

## ***On-orbit:***

- γ Determine on-orbit performance and compare with pre-flight performance
- γ Define data collects to assess performance of specific instrument parameters
- γ Analyze data to assess performance and determine accuracy

# On-Orbit End-to-End Performance Verification Process





# ***Absolute Radiometry: On-Orbit***

## ***Pre-flight Calibration transferred to On-Orbit Calibration***

### ***Solar Calibration***

- γ Absolute Comparison: VNIR within 2%, SWIR 5-8% low; SWIR has larger uncertainty due to solar model and BRDF model of diffuse surface
- γ Used to correct for pixel-to-pixel variations
- γ Included in repeatability assessment: 0.6% for VNIR, 1.6% for SWIR
- γ Used to define noise level as a function of signal level to determined SNR

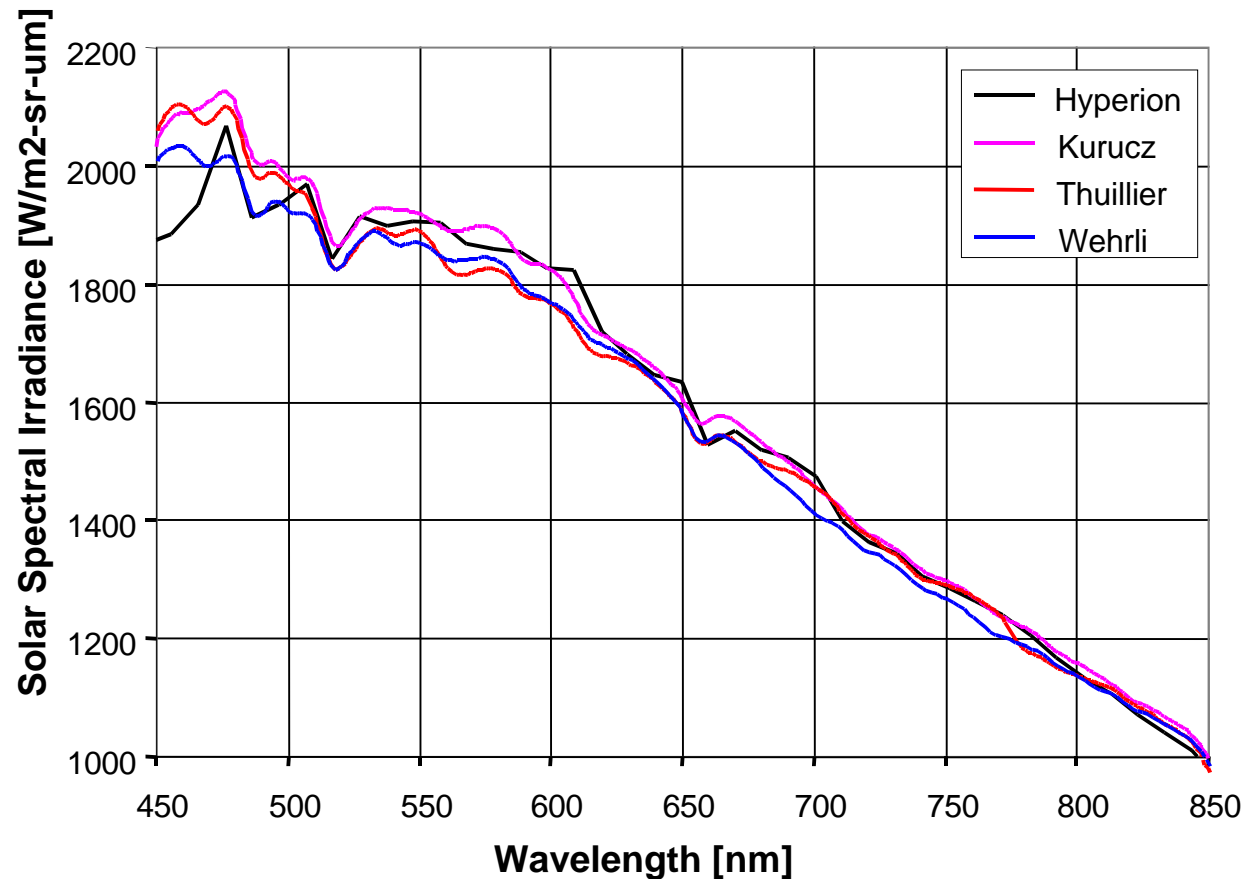
### ***Lunar Calibration***

- γ Used to reveal otherwise undetectable artifacts and verify proper artifact correction
- γ Used for repeatability assessment and cross comparisons

### ***Vicarious Calibration and Cross Calibration***

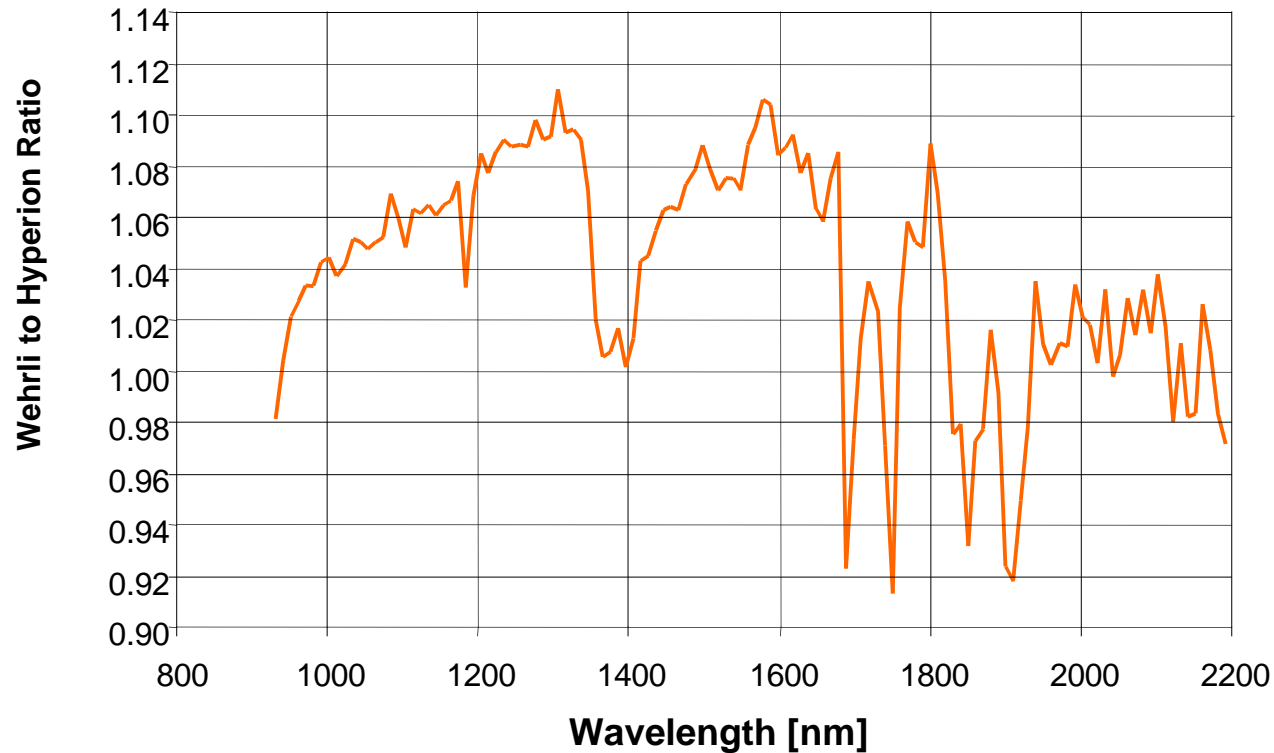
- γ Lake Frome: VNIR within 5%, SWIR 10-15% low – SWIR

# Hyperion Solar Calibration: VNIR



***Excellent agreement between Hyperion observations and solar models, within accuracy of paint reflectance and solar models, in VNIR region confirms ground calibration.***

# Hyperion Solar Calibration: SWIR



***Dominance of cover paint absorption lines from 1100 - 1900 and >2200 nm limits usefulness of solar calibration data in confirming ground calibration in these regions***

# Summary: Pre-flight Radiometric Performance Verified On-Orbit



Instrument Parameter	Spectral Range	Performance Requirement	Pre-Flight Measurement	On-Orbit Measurement
<b>Absolute Radiometry</b>	VNIR	< 6%	< 6%	Consistent with pre-flight
	SWIR	< 6%	< 6%	
<b>Signal to Noise</b>				
<b>VNIR</b>	550 nm	> 60	150	192
	650 nm	> 60	140	140
	700 nm	> 60	140	140
<b>SWIR</b>	1025 nm	> 60	90	65
	1225 nm	> 60	110	96
	1575 nm	> 60	89	64
	2125 nm	> 30	40	38

# ***Spectral Calibration: Pre-Flight***



## ***Center wavelength and Bandwidth***

- γ Measured at discrete locations - 20 VNIR, 25 SWIR
- γ Used to define center wavelength and bandwidth for every VNIR and SWIR pixel (256 spatial FOV X 242 spectral)
- γ Verified with spectralon and doped spectralon measurements and TRW patented spectral calibration algorithm

## ***Dispersion (nm/pixel)***

- γ Spacing of spectral channels ~10nm/pixel
- γ Closely matches the bandwidth (10 nm)

## ***Cross-track spectral error***

- γ Maximum wavelength difference across FOV for a single spectral channel

VNIR = 2.6-3.6 nm

SWIR = 0.40- 0.97 nm

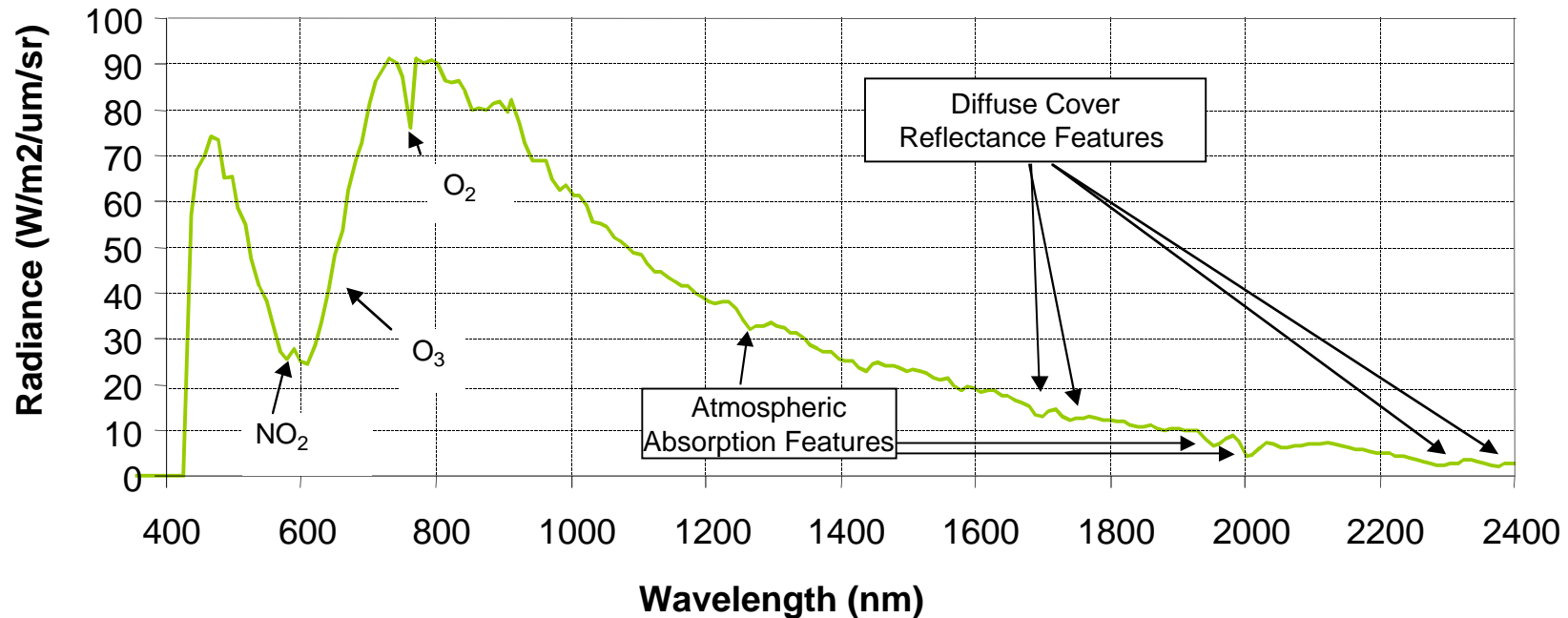
# Spectral Calibration: On-Orbit



## Atmospheric Limb Collect

### Atmospheric Limb Sample Spectra for the VNIR and SWIR

Approximate identification of features



***Hyperion views sun's reflection off telescope cover as sun rises through earth's limb and passes through atmosphere***



# VNIR Spectral Calibration

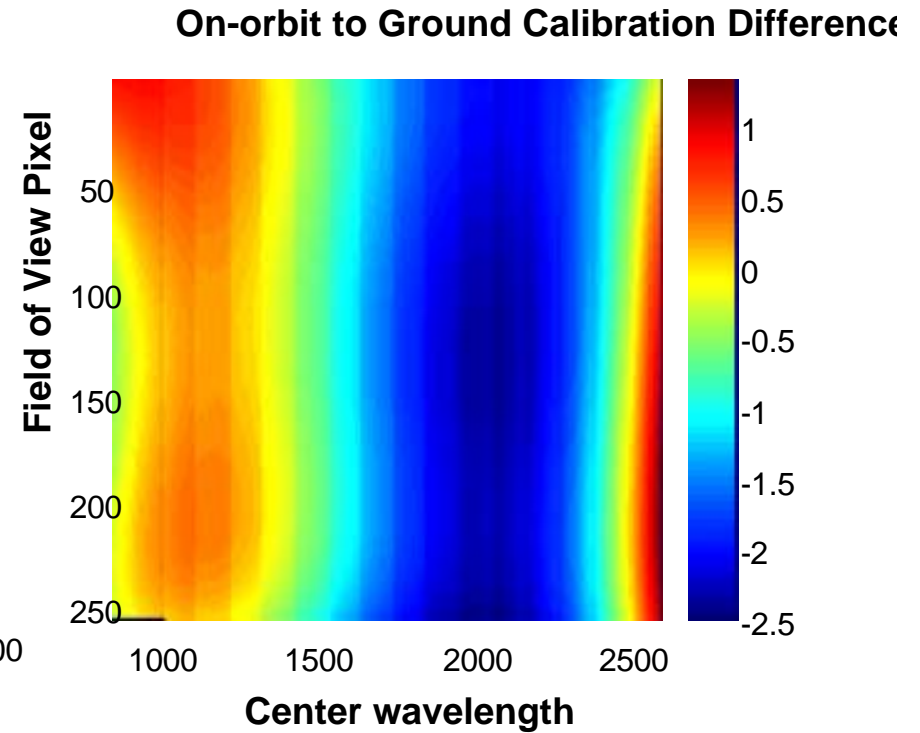
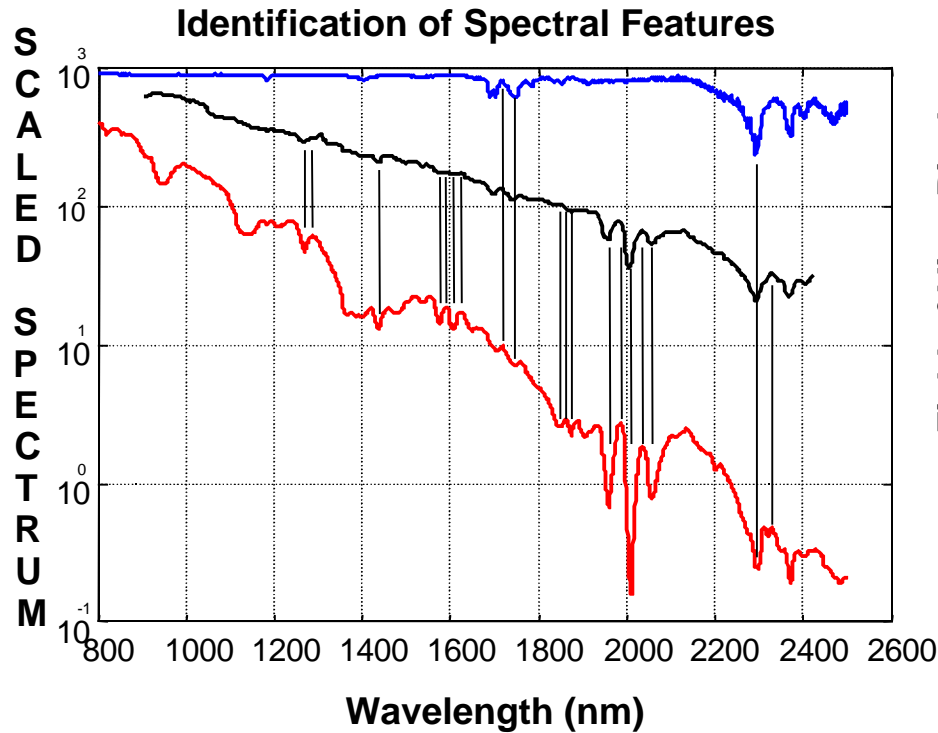
- γ **Spectral calibration based on solar line and the oxygen line**
- γ **Pre-flight calibration adjusted by an offset and rotation to match the solar and oxygen reference lines**
- γ **No change in calibration recommended based on on-orbit data**

**Comparison of Pre-flight and On-orbit Results for**

**FOV Pixel 136**

Spectral Pixel No.	Pre-flight [nm]	On-Orbit [nm]	Delta [nm]
13	478.32	478.29	-0.02
31	661.36	661.86	0.50
40	752.00	752.65	0.76

# SWIR Spectral Calibration Verified



***Peaks and troughs at 19 wavelengths are correlated from the MODTRAN Model (red) and White Paint spectrum (blue), to the Hyperion SWIR measurement (black).***

# Summary: Pre-flight Spectral Calibration Verified On-Orbit



Instrument Performance Parameter Requirement		Pre-Flight Measurement	On-Orbit Measurement
No. Spectral Channels VNIR/SWIR	220	comply	comply 200 selected for Level 1
Spectral Range	400 - 2500 nm	357 - 2576 nm Calibration $\pm$ 1 nm	357 - 2576 nm 436 - 2406 nm selected for Level 1 Analysis results $\pm$ 3 nm
Spectral Bandwidth	VNIR $\pm$ 0.1 nm SWIR $\pm$ 0.1 nm	10.08 – 10.09 10.11-10.13	Not measured Not measured
Cross Track Spectral Error	VNIR $\pm$ 1.5 SWIR $\pm$ 2.5	2.57 - 3.59 (waivered) .17 - .98	1.71 - 2.55 .40 - .97



## **Geometric Characterization: Pre-Flight**

### ***Modulation Transfer Function***

- γ Used knife edge and slit to measure Cross track direction, then Along-track was  $\text{Cross-Track} \times 2/\pi$

### ***VNIR and SWIR Co-registration***

- γ Used test bed to project a slit with a broad spectrum at multiple locations

### ***Ground Sample Distance***

- γ Measured IFOV using test bed





# ***Geometric Characterization: On-Orbit***

## ***Modulation Transfer Function***

- γ Used Ice Shelf & Lunar Limb (knife edge) and bridge (slit) to measure Cross-Track and Along-Track directly

## ***VNIR and SWIR Co-registration***

- γ Best result obtained during vicarious calibration by geo-locating Hyperion data to the ground features

## ***Ground Sample Distance***

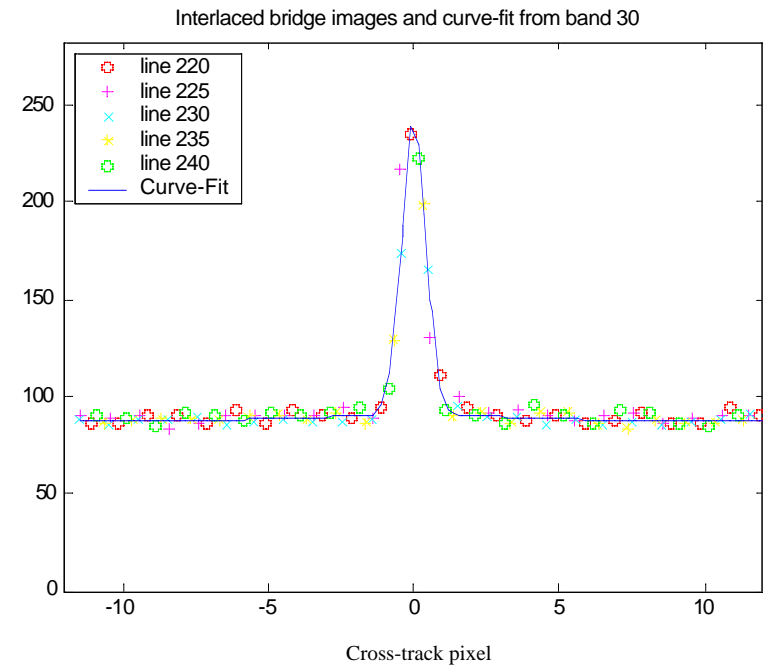
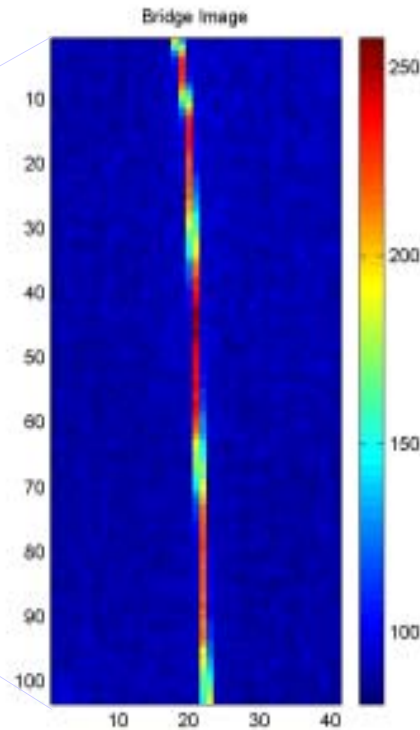
- γ Triangulated marked features in well mapped scene



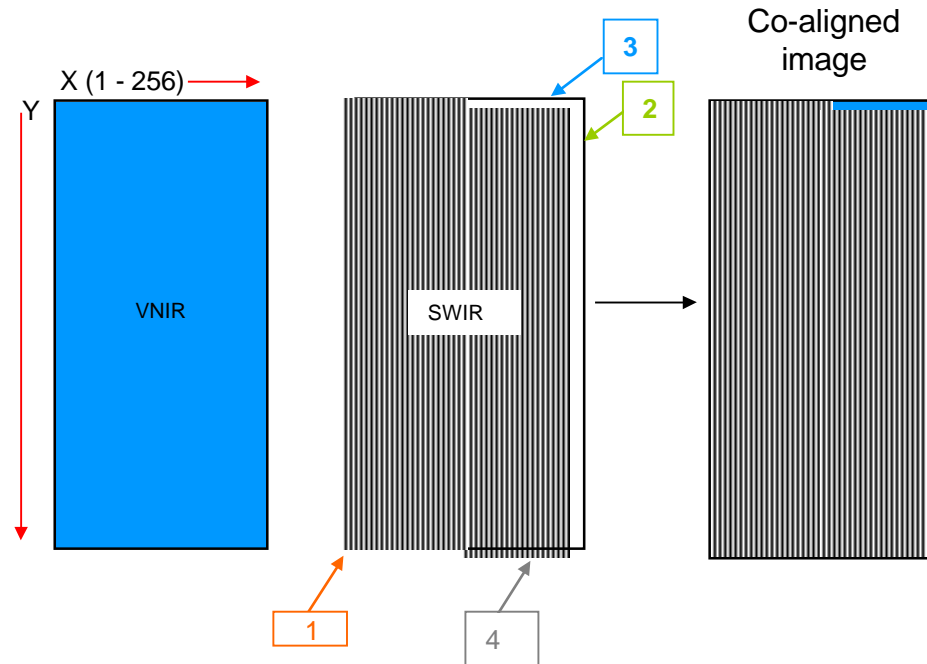
# Cross-Track MTF Example



- γ Mid-bay bridge near Destin, Florida.
- γ Bridge angle small, every 5th line used to develop high resolution bridge image.
- γ MTF result at Nyquist is between 0.39 to 0.42 while the pre-flight measurement was  $\sim 0.12$



# VNIR\_SWIR Spatial Co-alignment



*The co-alignment algorithm spatially co-registers the VNIR and SWIR data. Only SWIR data are shifted into alignment with the VNIR pixels. In the FC dimension (X), the SWIR pixels are shifted by -1. FOV pixel #1 is removed and pixel #256 is padded with zeros (2). In the along track dimension (Y), FOV pixels 129-256 are shifted by +1 pixel. For frame 1, FOV pixels 129- are padded with zeros (3) and the last frame is removed (4).*

# Summary. GEOMETRIC

## Characterization

### Pre-flight Performance Verified On-Orbit



Instrument Parameter	Spectral Range	Performance Requirement	Pre-Flight Measurement	On-Orbit Measurement
GSD	Entire Range	30 m +/- 1 m	29.88	30.38
Swath Width	Entire Range	> 7.5 km	7.75 km	7.75 km
MTF (In-Track)	450 nm	> 0.2	.22-.29 meas. @ 500nm	.23-.27 meas. @ 500nm
	630 nm	> 0.2	.22 - .27	.23 - .27
	900 nm	> 0.15	.22 - .24	.24 - .28
	1250 nm	> 0.14	.27 - .30	.20 - .25
	1650 nm	> 0.15	.25 - .27	.28
	2200 nm	> 0.15	.23 - .28	Not avail
Spatial Co-Registration				
VNIR	All	20% of Pixel	Waivered, 0.1-0.25	Consistent, 0.1 - 0.3
SWIR	All	20% of Pixel	Waivered, 0.18-0.28	Consistent, 0.1 - 0.4



## ***Long-term Stability & Repeatability***

### ***Post On-Orbit Performance Verification Monitoring***

***VNIR & SWIR focal plane stability and  
repeatability  
using Lunar and Solar Calibration Data***

***Internal cal lamp trending***

***Vicarious ground cals***

***Cross-comparisons with ALI and Landsat-7***



## ***VNIR/SWIR Repeatability***

### ***Solar Calibration data used to measure pixel-to-pixel repeatability***

- γ VNIR is highly repeatable with variations of <0.05% measured
- γ SWIR is repeatable with measured variations were <0.75%

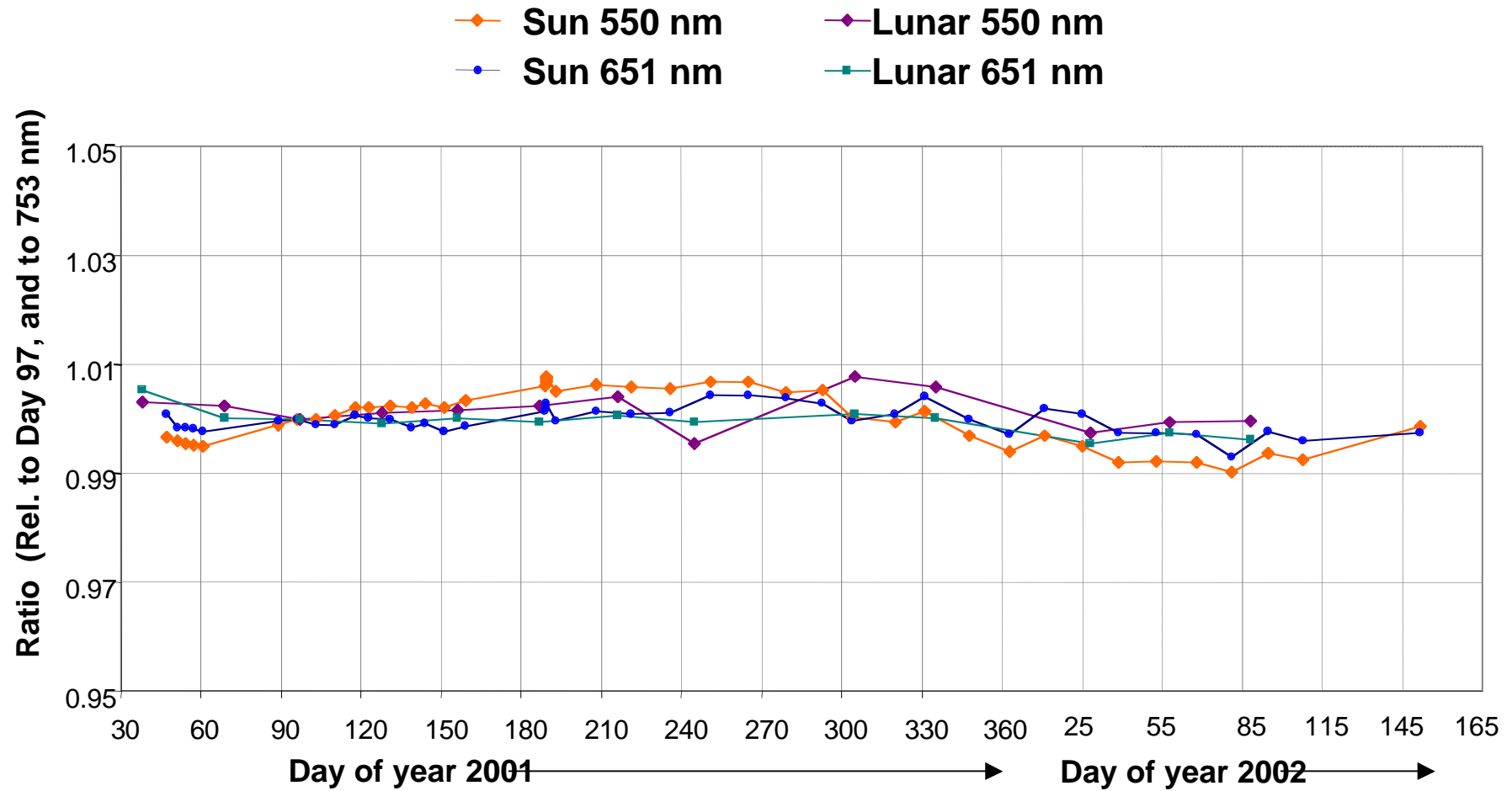
### ***Solar Calibration data also showed pixels that may be considered “outliers” to be watched or added to the bad pixel file***

- γ 17 VNIR pixels shown to have had responsivity changes of >5%
- γ 5 SWIR pixels have had responsivity changes of >5%
- γ No new dead pixels were identified in either the VNIR or the SWIR FPAs

20

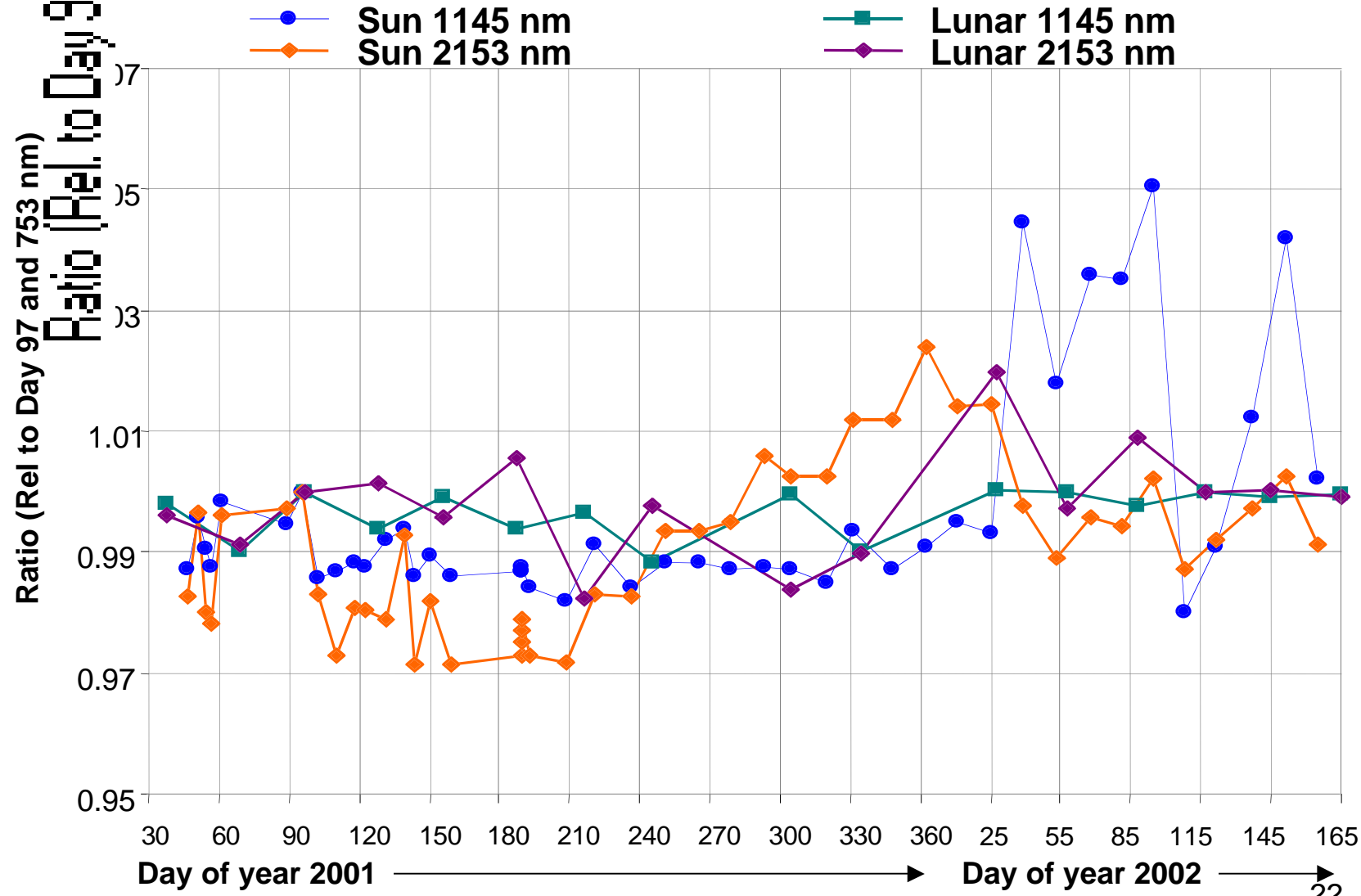


# VNIR Repeatability of Lunar and Solar Calibration Data



Ratio (Rel. to Day 97 and 753 nm)

# WIR Repeatability of Lunar and Solar Calibration Data



## ***Known Instrument Artifacts***

### ***VNIR***

***Dark Noise & Drift***

***Pattern Noise***

***Crosstalk***

***Banding***

### ***SWIR***

***Echo***

***Smear***

### ***Lunar Streak***





## **“Dark” Noise and Drift**

**Three dark scenes are taken over the course of a DCE:  
When compared with each other, the dark signal drifts over the course of a DCE**

γ The drift in all four quadrants of the VNIR is less than 1.5 counts

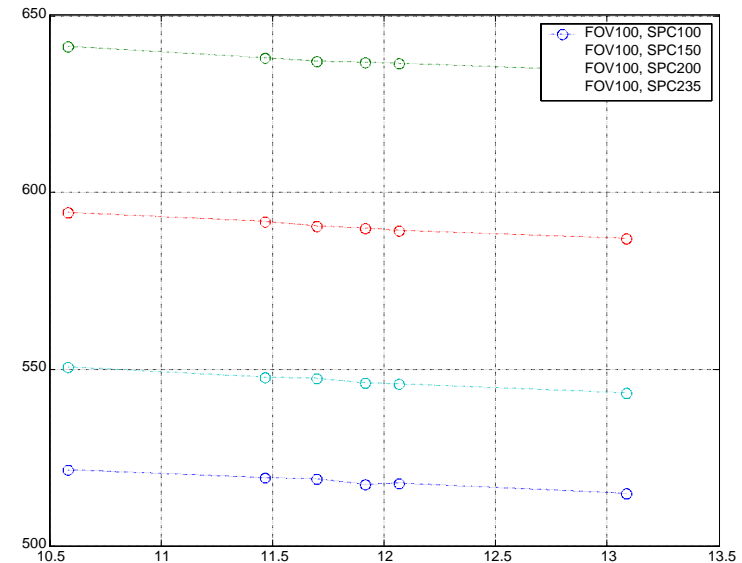
γ The drift in the SWIR is

γ approximately 4 counts in each readout channel  
The drift is linear and is removed to better than 0.05% when using linear interpolation

**The measured noise in the dark frames includes both readout and dark current noise**

γ Typical noise in a VNIR dark frame is 1.5 DN

γ Typical noise in a SWIR dark frame is 4 DN



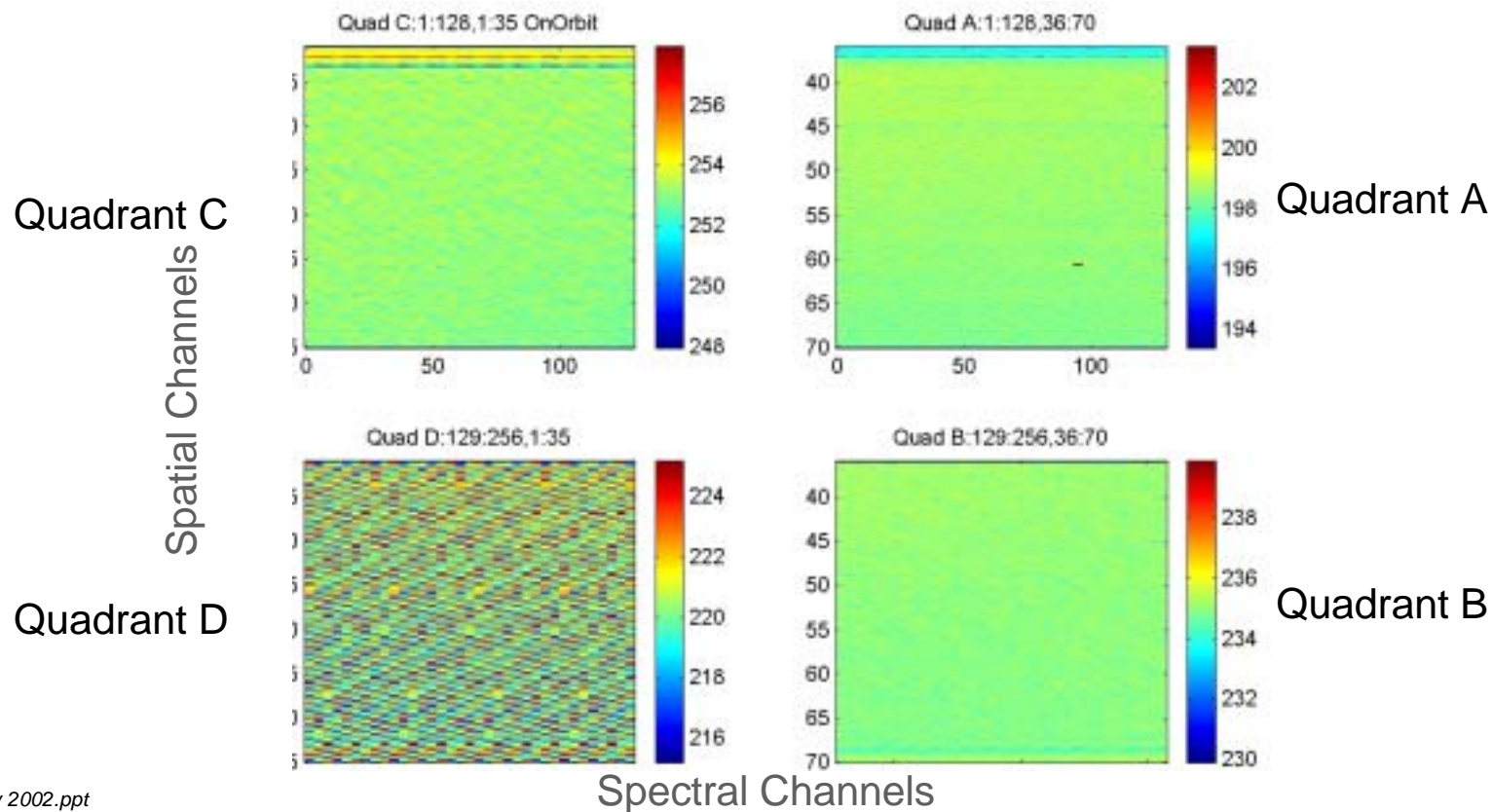
Lunar Calibration data from 01-010



# VNIR Artifacts: Dark Pattern

**A pattern in the dark images is seen in Quadrant D and is referred to as the “Dark Pattern”**

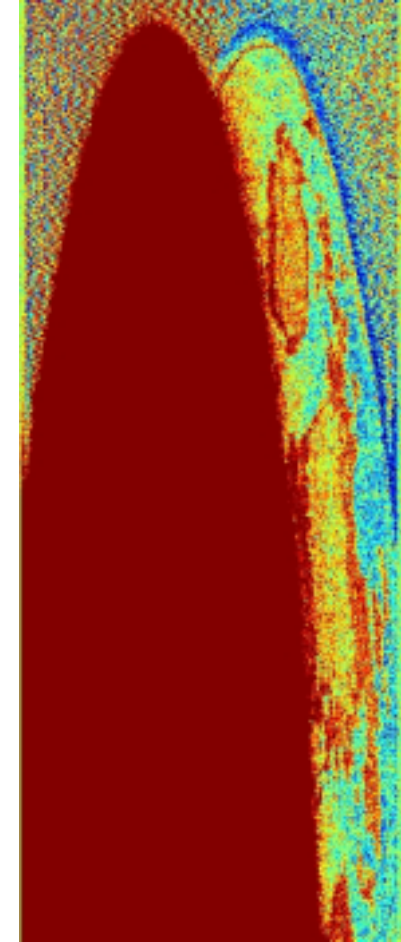
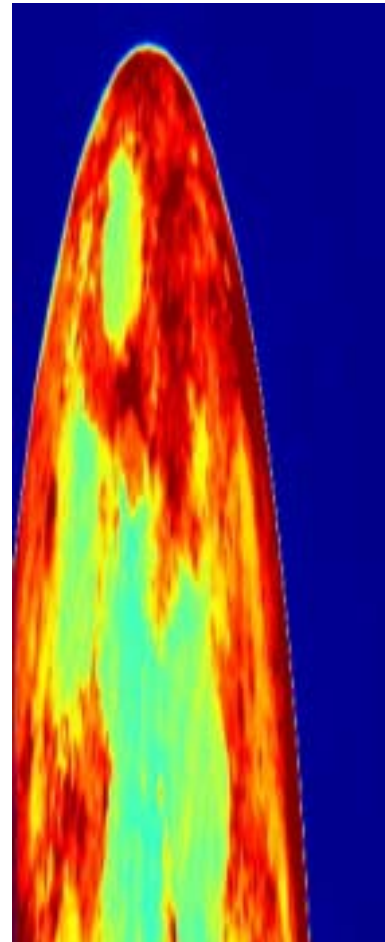
- γ Though it is not consistent between DCEs, it is very repeatable within a DCE
- γ Completely removed with dark subtraction



# VNIR Artifacts: Crosstalk

## Quadrants C and D suffer from Crosstalk

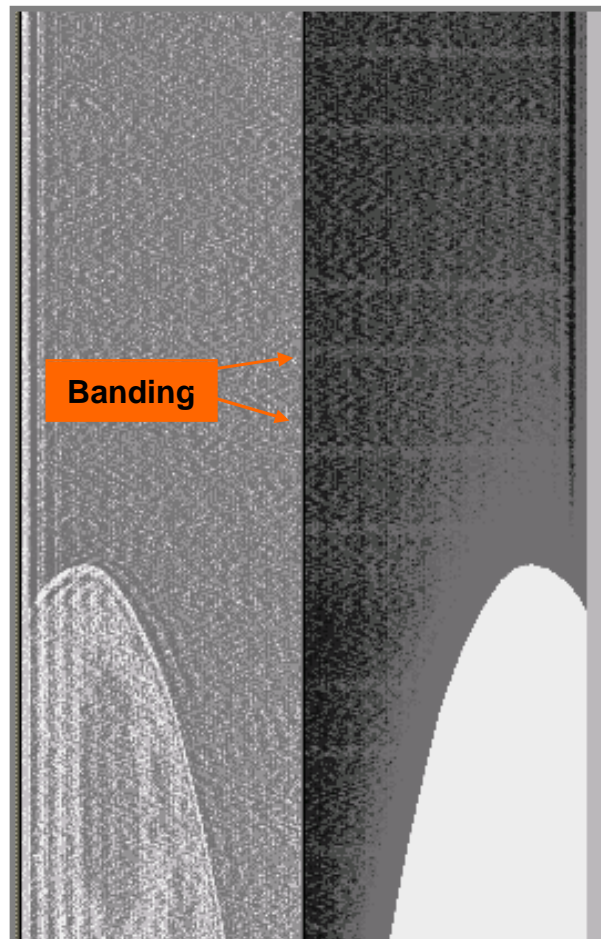
- γ Few examples have been seen of this as it is only seen when there are very bright areas next to very dark areas.
- γ Effect due to crosstalk during readout
- γ The lunar image shows the normal scale and a very stretched scale to show the mirror image effect. The “ghost” is approximately 0.9% of the image signal level.
- γ Other images with non-zero backgrounds show less than 0.5% induced signal



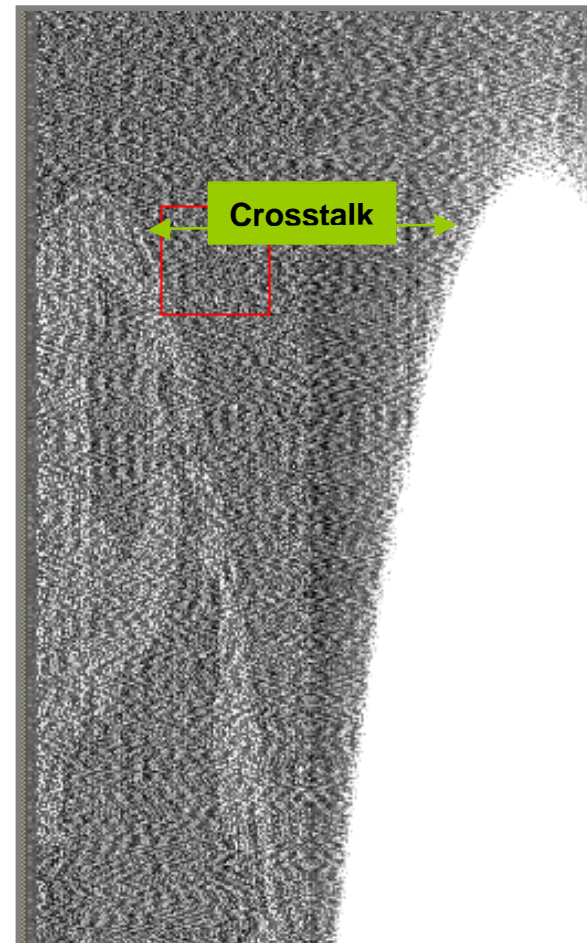
# VNIR Artifacts: Banding



Lunar Cal Day 028 (2002)  
Level 0  
PC Bands 8-34  
(Quad C&D)



Lunar Cal Day 028 (2002)  
Level 1\_B1  
Bands 30



# SWIR Artifacts and Data Impacts



## “Smear”

Significant signal persists into the next pixel that is read out in that output channel

Shows up two spectral pixels to shorter wavelengths because of the readout scheme

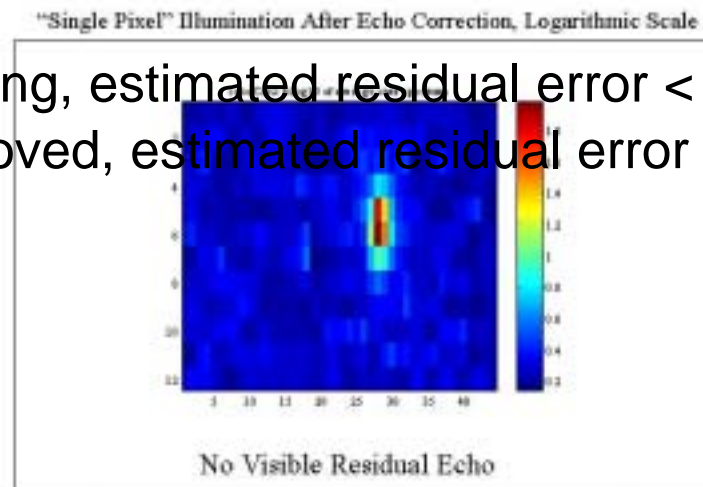
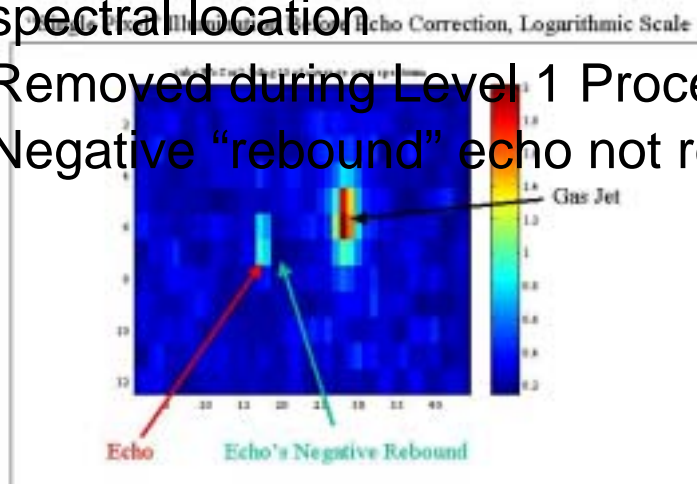
Removed during Level 1 Processing, estimated residual error < 0.5%

## “Echo”

Signal crosstalks into a pixel 249 spatial channels later at the same spectral location

Removed during Level 1 Processing, estimated residual error < 0.8%

Negative “rebound” echo not removed, estimated residual error < 0.7%

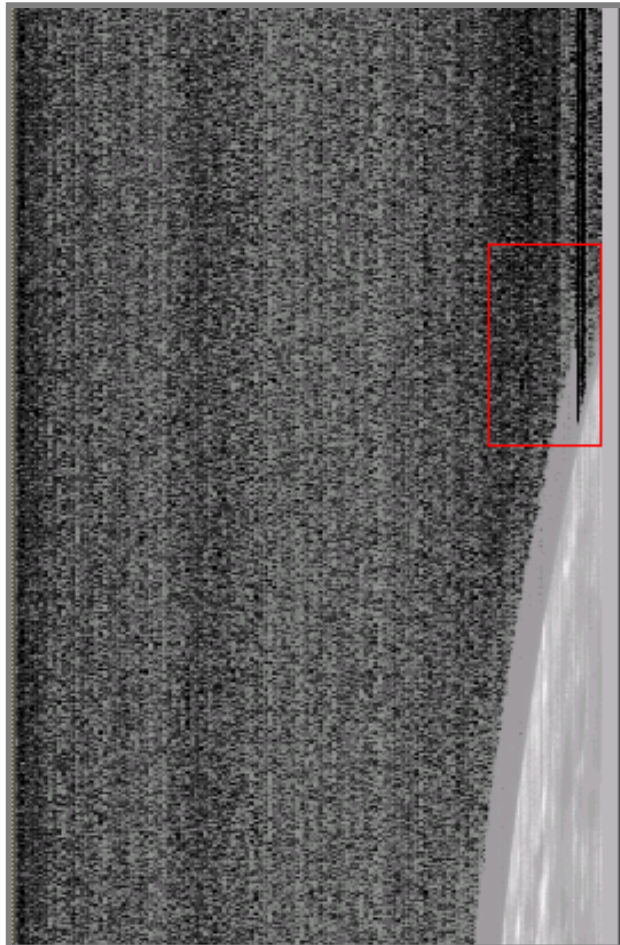


Moomba Gas Flare Scene, Before and After Echo Correction

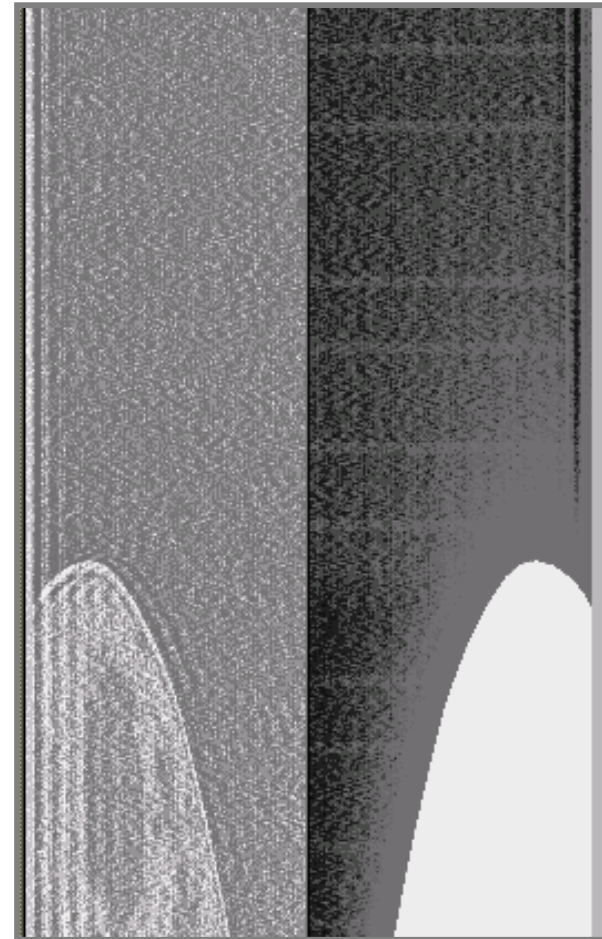
# Edge Echo in VNIR Data



Lunar Cal Day 001 (2002)  
Level 0  
SWIR dark subtracted

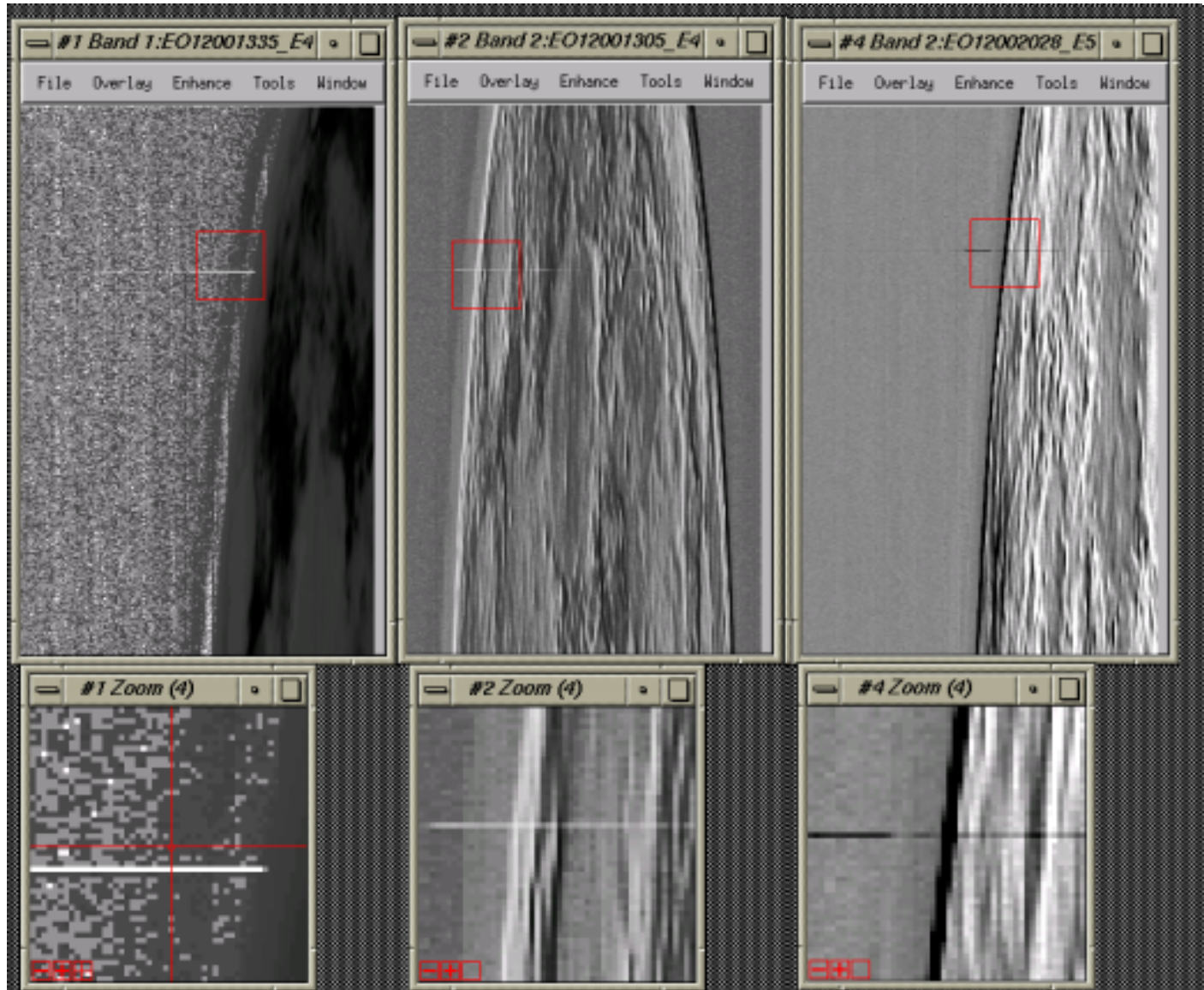


Lunar Cal Day 028 (2002)  
Level 0  
PC Bands 8-34  
(Quad C&D)



# ***Lunar “Streak”***

***Observed in MNF bands of multiple lunar calibration files***



# Hyperion Level 1 Processing History



Level 1 version	.cal	.L1	.L1_A	.L1_A1	.L1_A2	.L1_A3	.L1_B	.L1_B1
Effective date	pre-flight	4/1/2001	7/1/2001	10/12/2001	10/16/2001	10/23/2001	11/15/2001	1/29/2002
<b>Level 1 parameters mods</b>								
Ratio file	ratio.txt	ratio.txt	ratio_revA.txt	ratio_revB.txt	ratio_revB.txt	ratio_revB.txt	ratio_revB.txt	ratio_revB.txt
Gain file	PriRadL0	hypgain	HypGain_revA	HypGain_revA	HypGain_revB	HypGain_revB	HypGain_revB	HypGain_revC
Data type	uint16	uint16	int16	int16	int16	int16	int16	int16
Cal multiplier VNIR	100	100	40	40	40	40	40	40
Cal multiplier SWIR	100	100	80	80	80	80	80	80
Cal Min	0	0	-32768	-32768	-32768	-32768	-32768	-32768
Cal Max		40000	32768	32768	32767	32767	32767	32767
Bad pixel file	badpix	badpix2	badpix2	badpix3	badpix3	badpix3	badpix3	badpix3
<b>Level 1 algorithm mods</b>								
Bad pixel repair	yes	yes	yes	yes (update)	yes	yes	yes	yes
Saturated pixel report	no	no	yes	yes (update)	yes (update)	yes (update)	yes (update)	yes
Offset removal	nearest in time	nearest in time	interpolated in time	interpolated in time	interpolated in time	interpolated in time	interpolated in time (update)	interpolated in time
IR/SWIR co-alignment	no	no	no	no	no	no	yes	yes

change from previous version    yes=included in level 1 version    no=not included in level 1 version