The EO-1 Hyperion Imaging Spectrometer

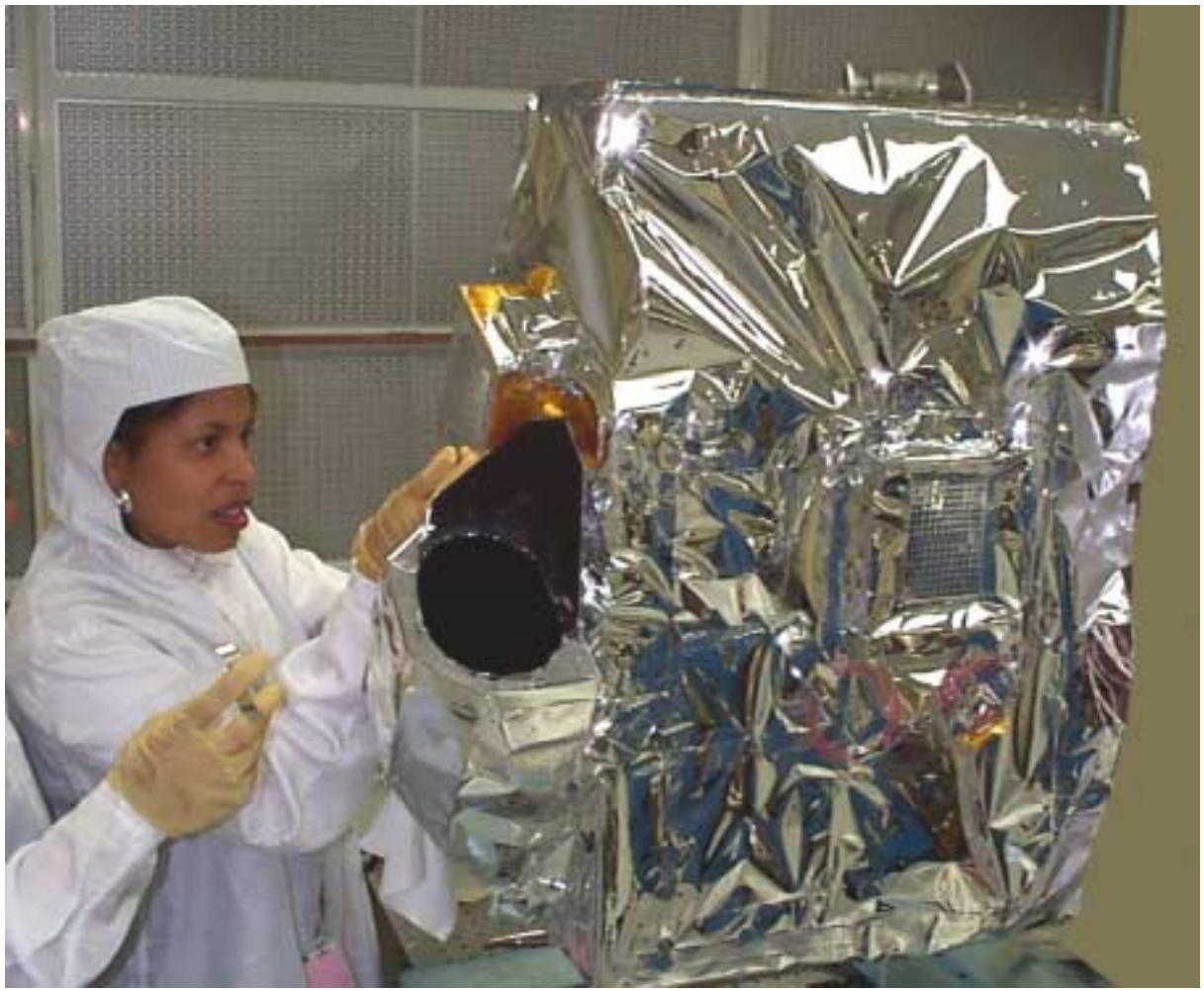
IEEE Aerospace Conference

Jay Pearlman, Carol Segal, Pamela Clancy, Neil Nelson, Peter Jarecke, Momi Ono, Debra Beiso, Lushalan Liao, Karen Yokoyama, and Steve Carman, TRW

And

Bill Browne, Lawrence Ong and Stephen Ungar, GSFC

Hyperion Hyperspectral Imager

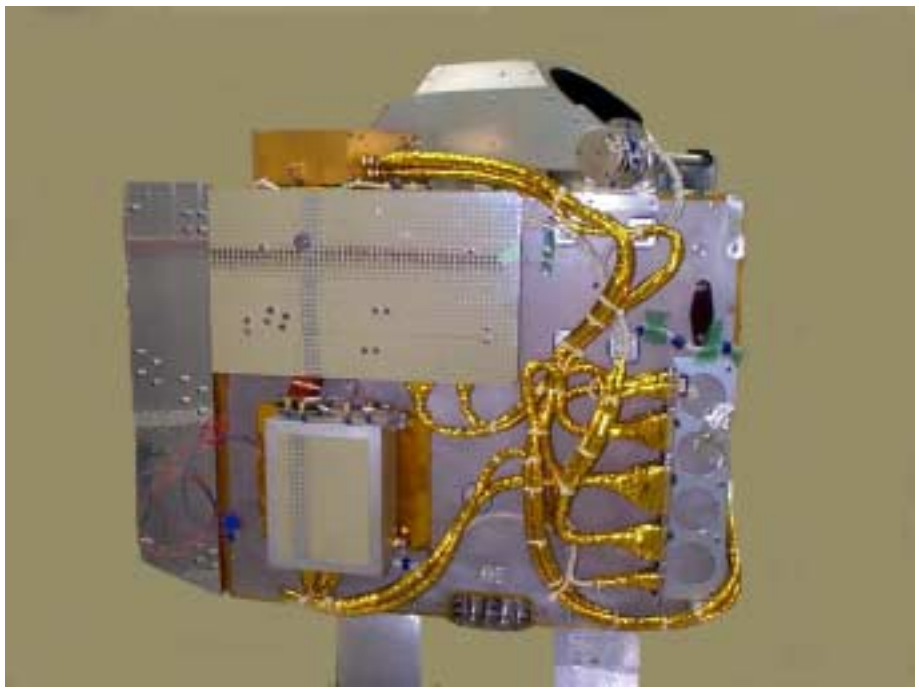


Earth Orbiter - 1 Mission

Three revolutionary land imaging instruments on EO-1 will collect multispectral and hyperspectral scenes over the course of the EO-1 mission in coordination with the Enhanced Thematic Mapper (ETM+) on Landsat-7. Detailed comparisons of the EO-1 and ETM+ images will be carried out to validate these instruments for follow-on missions.

Breakthrough technologies in lightweight materials, high performance integrated detector arrays and precision spectrometers will be demonstrated in these instruments.

Hyperion Imaging Spectrometer



Convex Grating spectrometers with CCD VNIR and HgCdTe SWIR detectors (60µm pixels)

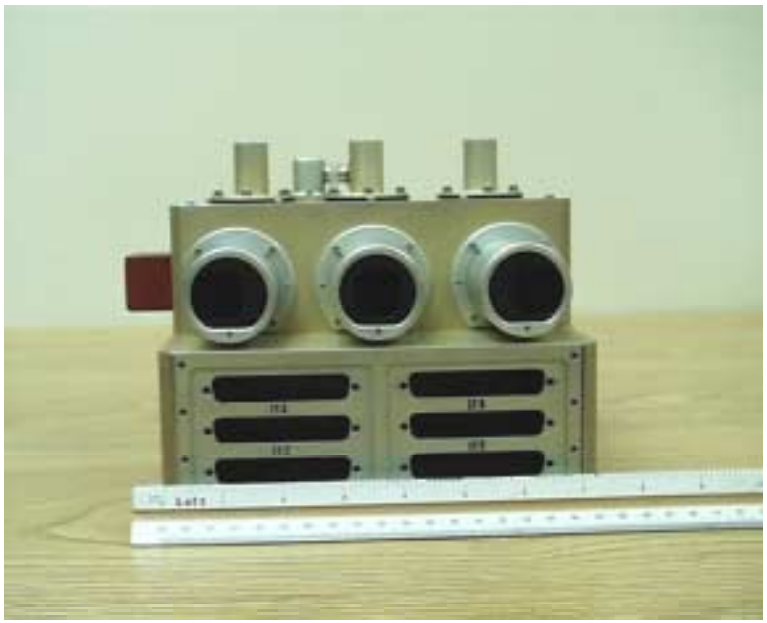
Multiple calibration options: lamps, lunar, solar, ground imaging and laboratory

Hyperspectral Imaging Capability to address technology and Earth Observation applications

Advanced Land Imager (ALI)

- **Objective is to validate pushbroom technologies for Landsat applications**
- **Pushbroom Multispectral Sensor - 9 multispectral (MS) channels and a pan channel**
- **Spectral coverage enhances Landsat ETM+ but excludes LWIR channel**
- **Swath width is 37km and MS ground resolution is 30m.**
- **S/N is 100 or better**

LEISA Atmospheric Corrector



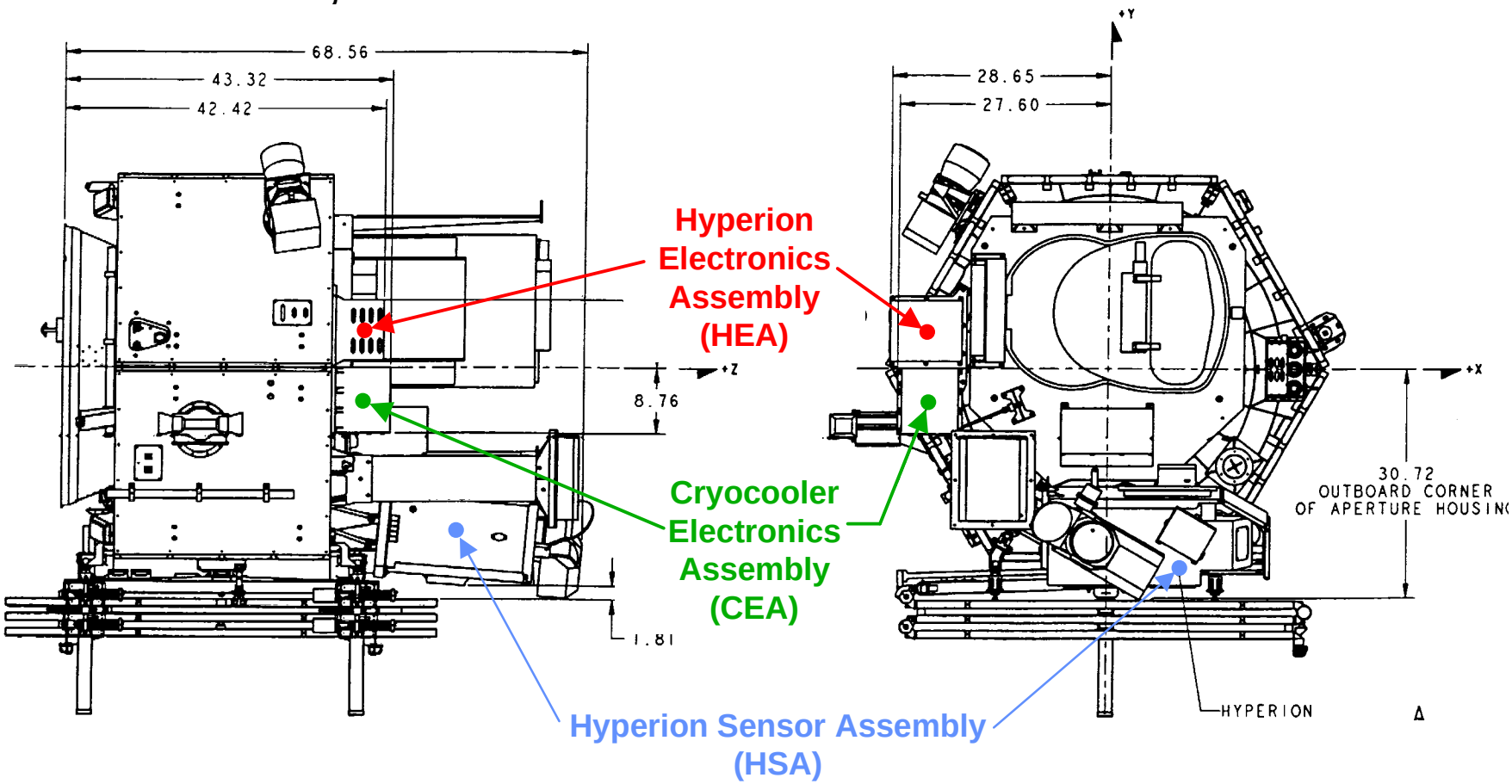
- **Correction of multispectral surface imagery for atmospheric variability (water and aerosols).**
- **High spectral, moderate spatial resolution (250m), large swath (180km) hyperspectral imager using wedge filter technology**
- **Spectral coverage of 0.89 - 1.6mm, bands selected for optimal correction of high spatial resolution images.**

EO-1 Instrument Overviews

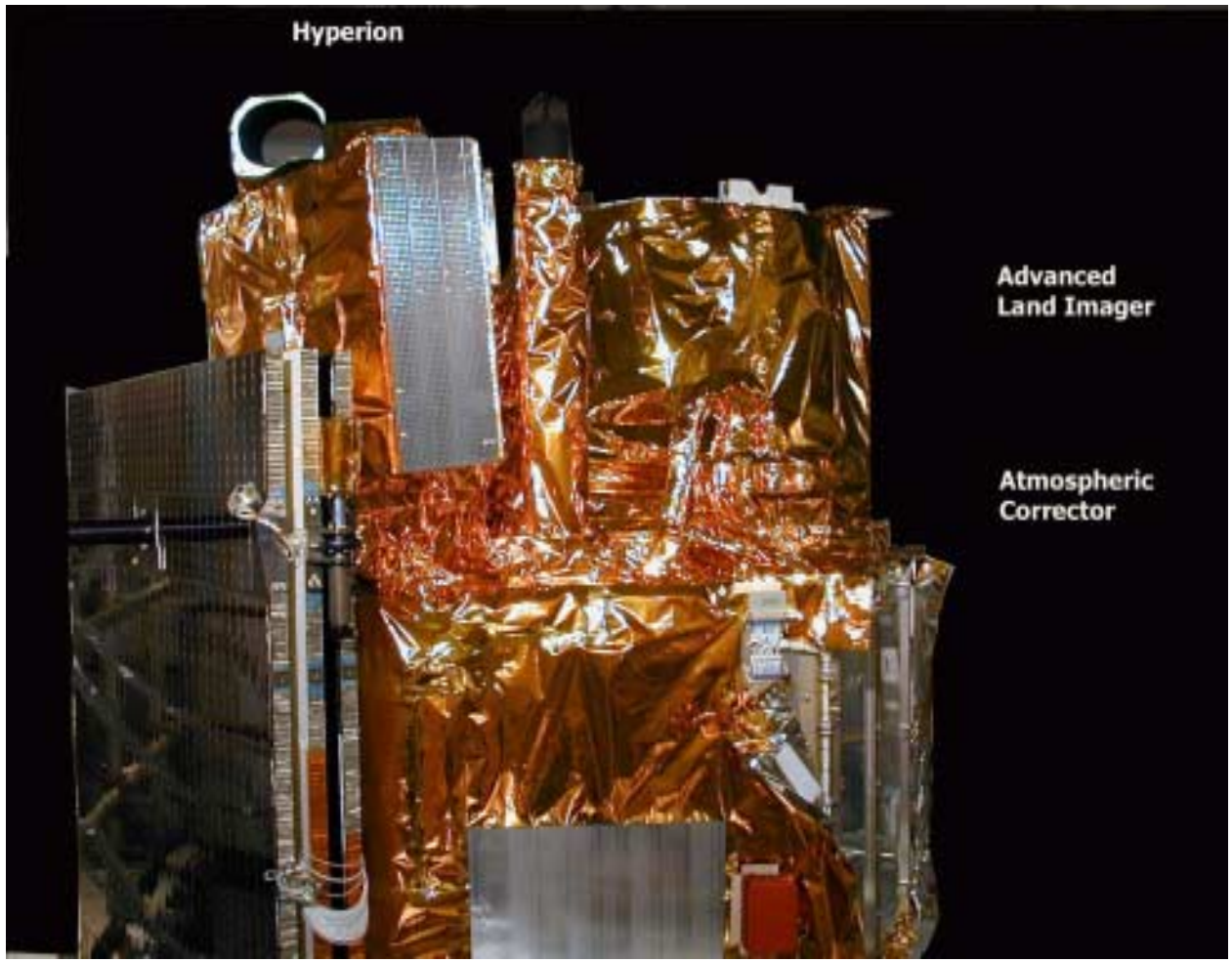
Parameters	EO-1		
	ALI	HYPERION	AC
Spectral Range	0.4 - 2.4 μm	0.4 - 2.5 μm	0.9 - 1.6 μm
Spatial Resolution	30 m	30 m	250 m
Swath Width	36 Km	7.5 Km	185 Km
Spectral Resolution	Variable	10 nm	6 nm
Spectral Coverage	Discrete	Continuous	Continuous
Pan Band Resolution	10 m	N/A	N/A
Total Number of Bands	10	220	256

Hyperion Spacecraft Accommodation

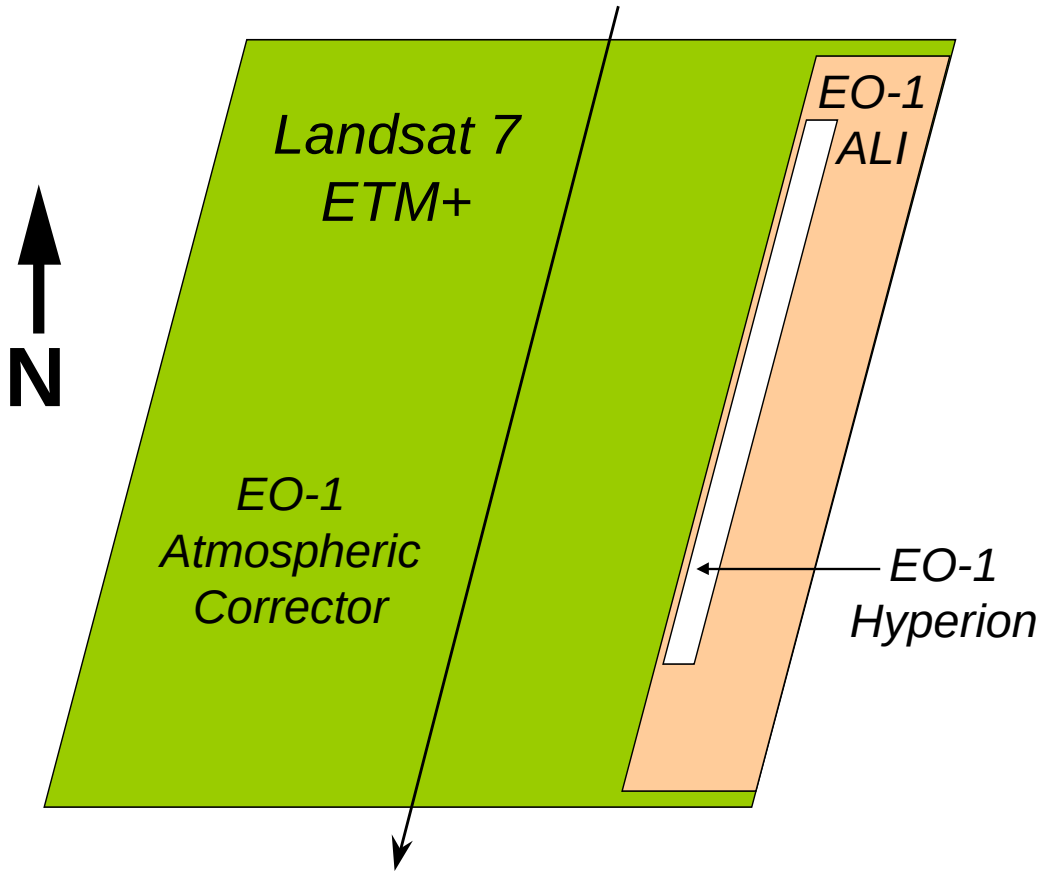
HSA, HEA and CEA locations on the EO-1 nadir deck



EO-1 Spacecraft Prepared for Launch



Hyperion Swath

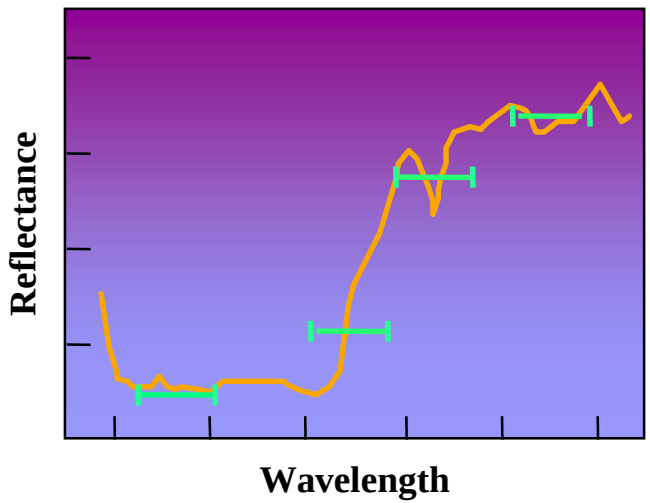


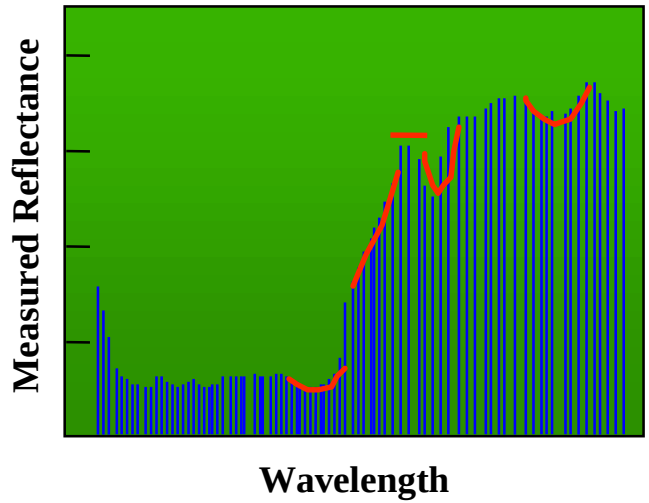
Swath is 7.5km wide; standard “image cube” is 20km long by 7.5km wide

Hyperspectral and Multispectral Scene Characterization

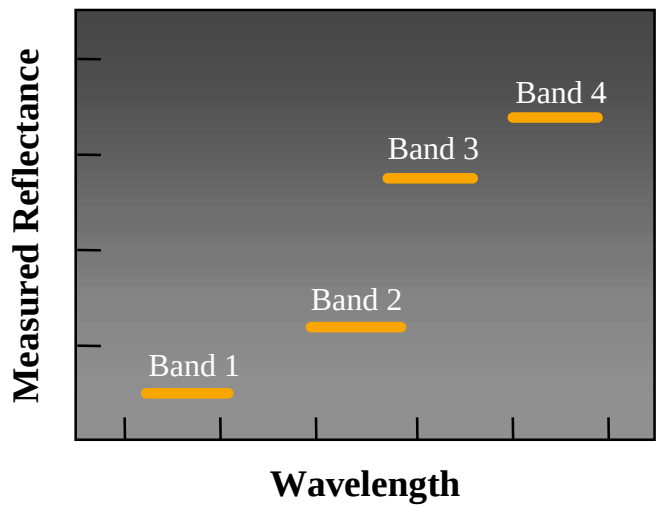
Hyperspectral Imaging
Hundreds of bands

Spectral characteristic of scene





Multispectral Imaging
Few bands



Hyperspectral Imaging Applications & Benefits

Application	Existing Satellite Capabilities (SPOT, LandSat)	Potential for HSI	Perceived Benefits
Mining/Geology mineral	Land cover classification	More Detailed mineral mapping	More Accurate remote exploration
Forestry	Land cover classification	Species ID Detail stand mapping Foliar chemistry Tree stress	Forest health/infestations Forest productivity/yield analysis Forest inventory/harvest planning
Agriculture	Land cover classification Limited crop mapping Soil mapping	Crop differentiation Crop stress	Yield prediction/commodities crop health/vigor
Environmental Management	Resource meeting Land use monitoring	Chemical/mineral mapping & analysis	Contaminant Mapping Vegetation Stress

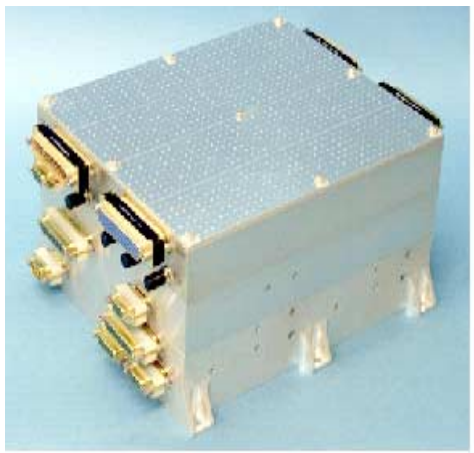
Hyperion Hyperspectral Imager

The Hyperion is a push-broom imager with:

- 220 10nm bands covering the spectrum from 400nm - 2500nm
- 6% absolute radiometric accuracy
- Image swath width of 7.5 km
- IFOV of 42.4 microradian
- GSD of 30 m at 705 km altitude
- 12-bit image data
- Power: 51W orbit avg., 126W peak
- Mass: 49kg
- On year Life (2 year Goal)

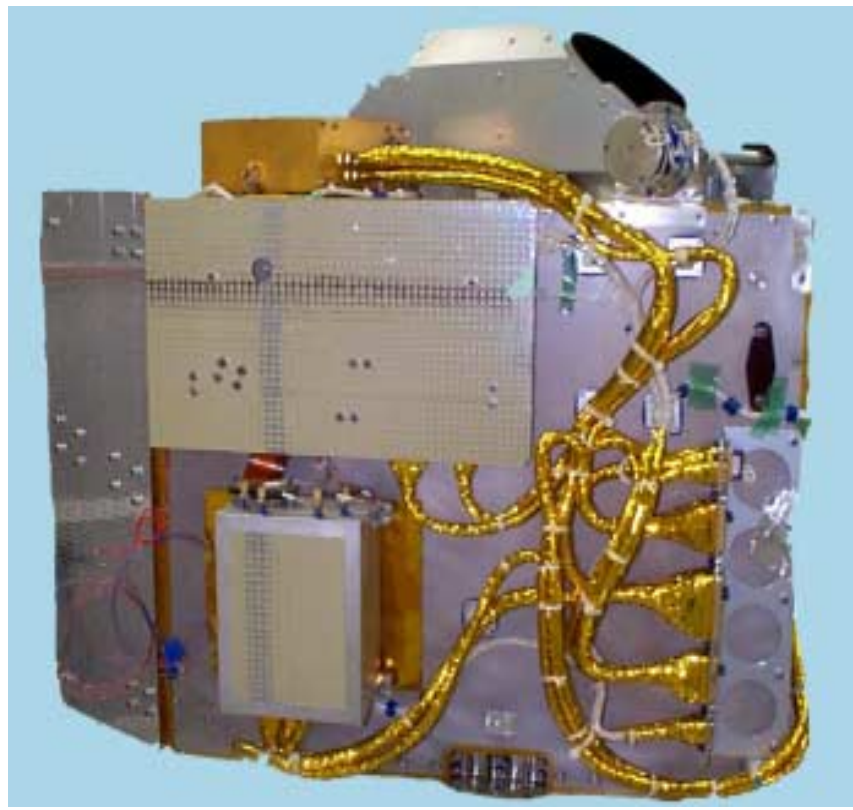
Hyperion
12 months from order to delivery

Hyperion Subassemblies



Hyperion Electronics Assembly (HEA)

Cryocooler Electronics Assembly (CEA)



Hyperion Sensor Assembly (HSA)

Hyperion Characteristics

Parameter	Hyperion
Volume (L x W x H, cm)	39x75x66
Weight (Kg)	49
Avg Power (W)	51
Peak Power (W)	126
Aperture (cm)	12
IFOV (mrad)	0.043
Crosstrack FOV (deg)	0.63
Wavelength Range (nm)	400 - 2500
Spectral Resolution (nm)	10
No. Spectral Bands	220
Digitization	12
Frame Rate (Hz)	225
Typical SNR	65 - 130

Performance Characterization – Pre-Launch

Properties Characterized

Radiometric Calibration

FPA Rectilinearity

- **Spatial Co-Registration of Spectral Channels**
- **Cross-Track Spectral Alignment**

Image Quality

- **Cross-track and Along-track MTF**
- **Spectral Slit Profile**

Spectral Response

Spectral Calibration

Scene Simulation

VNIR Noise Bifurcation

SWIR FPA Dark Field Stability

Echo Correction

Polarization

Hyperion Specifications (1)

Specification Item	Performance Measurements
GSD	29.88 m
Swath	7.5 km (0.61 degrees TFOV)
Spectral coverage	VNIR: 400 - 1000nm SWIR: 900 - 2500nm
Imaging aperture	12.4968 cm (4.92 in.)
VNIR SNR 550 - 700nm	144 - 161
SWIR SNR 1000 - 1050nm	90
SWIR SNR 1200 - 1250nm	110
SWIR SNR 1550 - 1600nm	89
SWIR SNR 2100 - 2150nm	40
On-Orbit life	1 year
IFOV	42.4μrad

Hyperion Specifications (2)

Specification Item	Performance Measurements
VNIR MTF @ 450nm	0.27 - 0.30
VNIR MTF @ 630nm	0.27 - 0.31
VNIR MTF @ 900nm	0.25 - 0.27
SWIR MTF @ 1050nm	0.25 - 0.29
SWIR MTF @ 1250nm	0.24 - 0.29
SWIR MTF @ 1650nm	0.23 - 0.27
SWIR MTF @ 2200nm	0.24 - 0.27
Number of spectral channels	220
SWIR spectral bandwidth	10.08 -10.09 nm
VNIR spectral bandwidth	10.11 - 10.13 nm
VNIR Cross-track spectral error	2.8 nm @ 655nm

Hyperion Specifications (3)

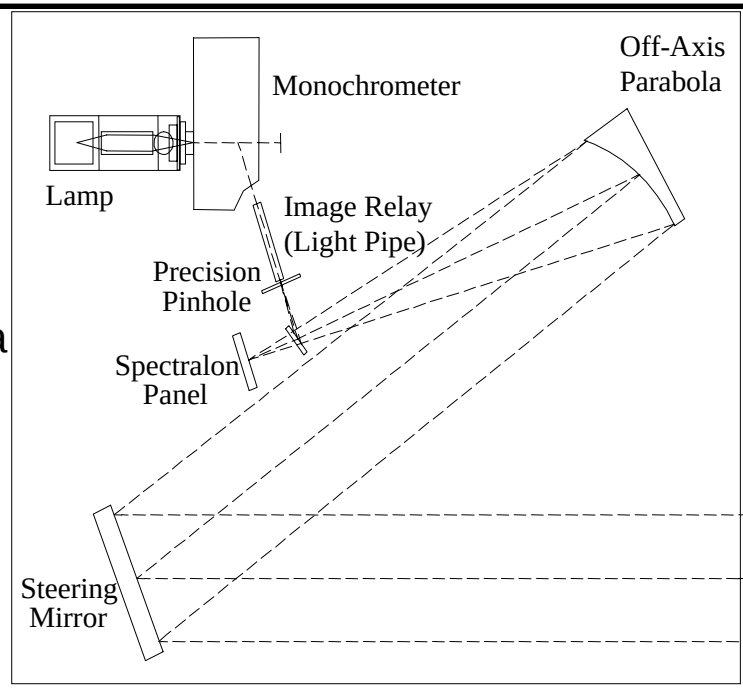
Specification Item	Performance Measurements
SWIR Cross-track spectral error (typical)	0.6 nm @ 1700nm
Spatial co-registration of pixel (typical)	VNIR 18% pix @ FOV Pix #126 SWIR 21% pix @ FOV Pix #131
Absolute radiometric accuracy (1 sigma)	<6%.
Data Quantization	12-bit

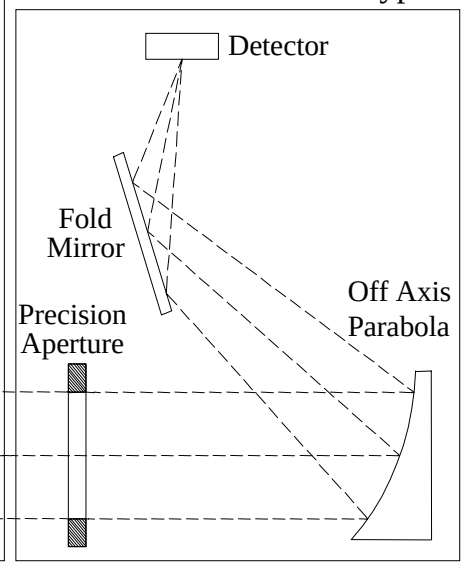
Hyperion Radiometric Characterization

Two modes of Operation:

1) Pinhole, slit and/or Knife Edge at end of light pipe put at focus of Off-axis Parabola (OAP)
2) End of light pipe is re-imaged onto Spectralon panel. Both are shown simultaneously in chart without re-imaging optics

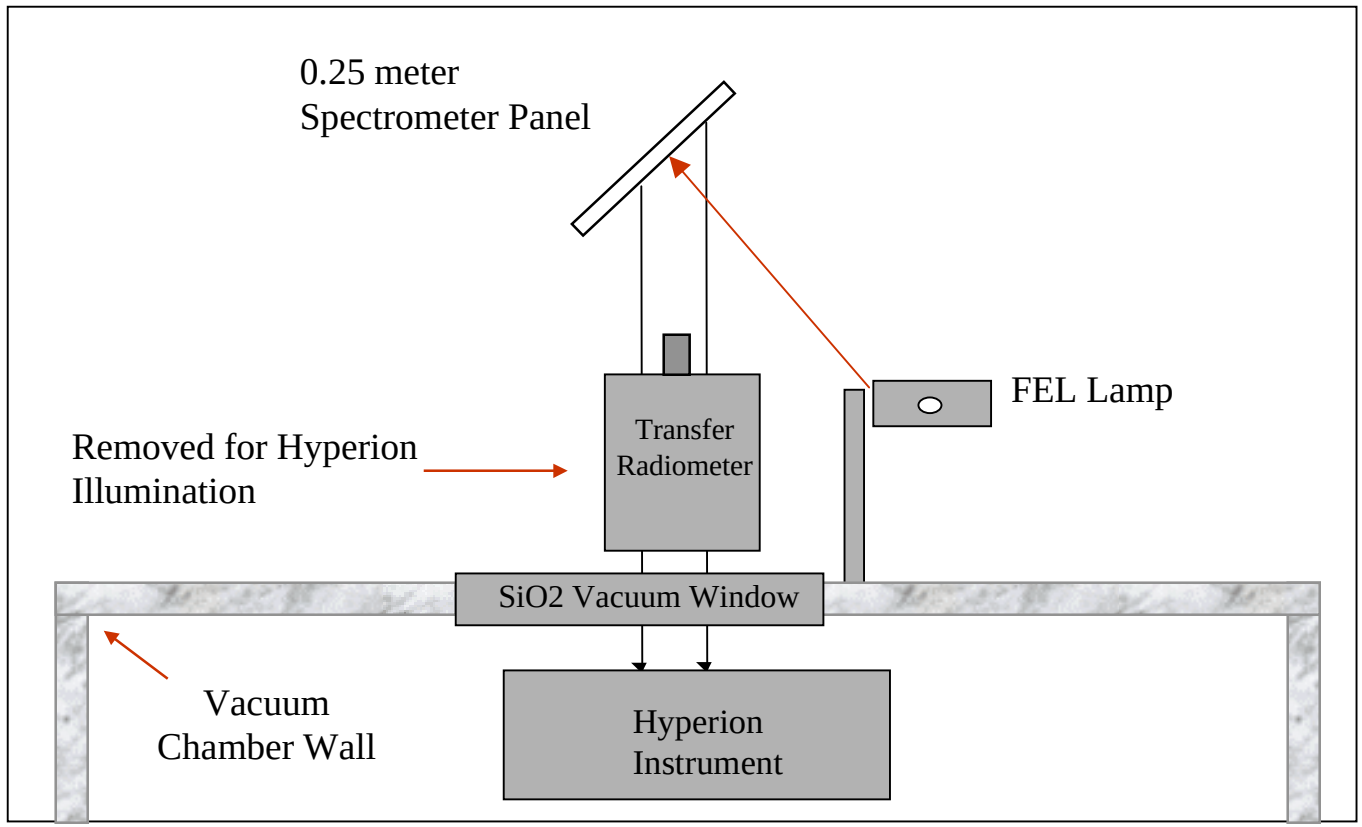
Steering mirror is a two axis, fine pointing mirror (± 1-2 mrad) for sub-pixel scanning in spatial dimensions





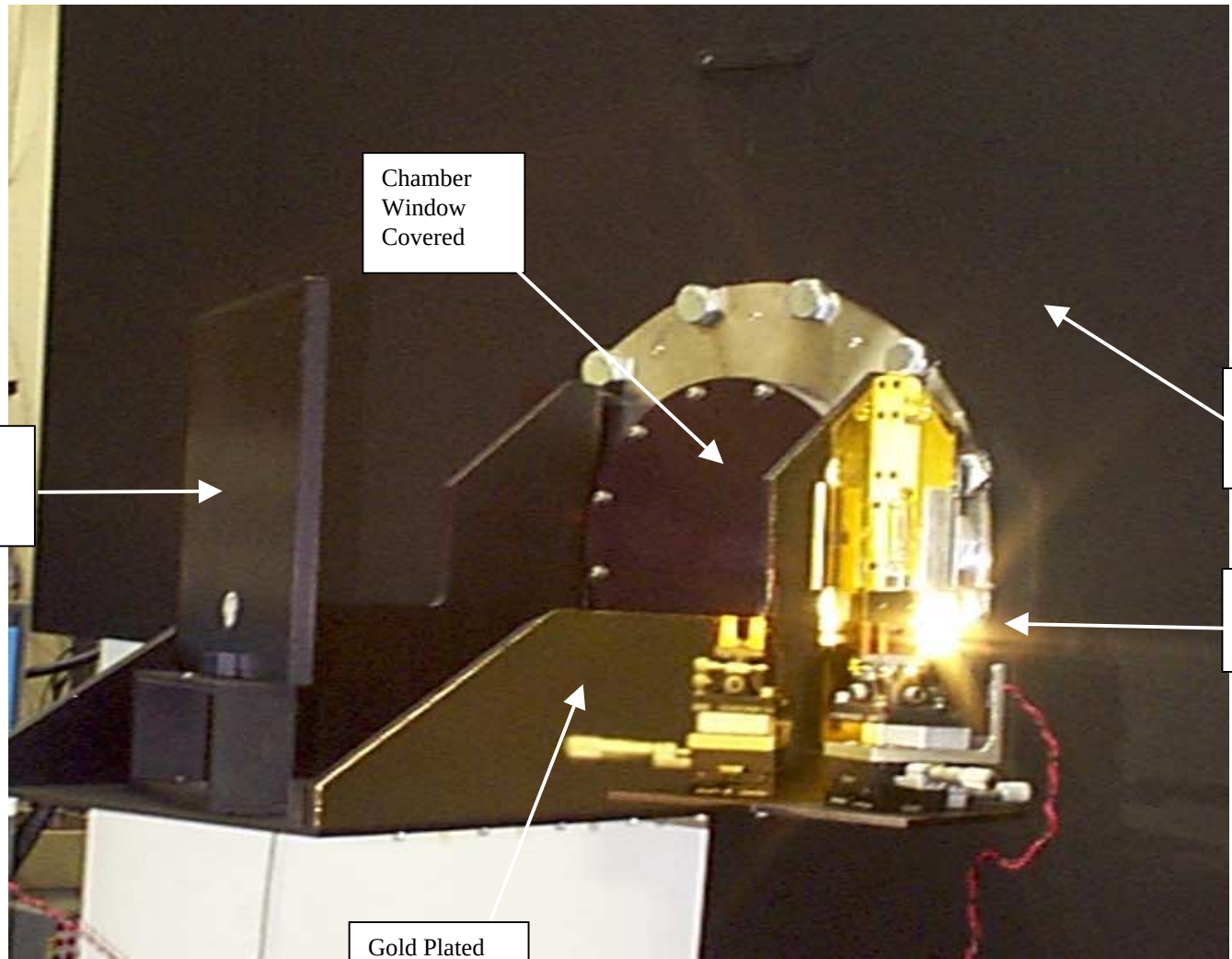
- Transfer radiometer is removable box for calibration of source
- Radiometer uses chopped pyroelectric detector
- Accurate AΩ is calculated from precision apertures and OAP focal length

Spectralon Panel Calibration

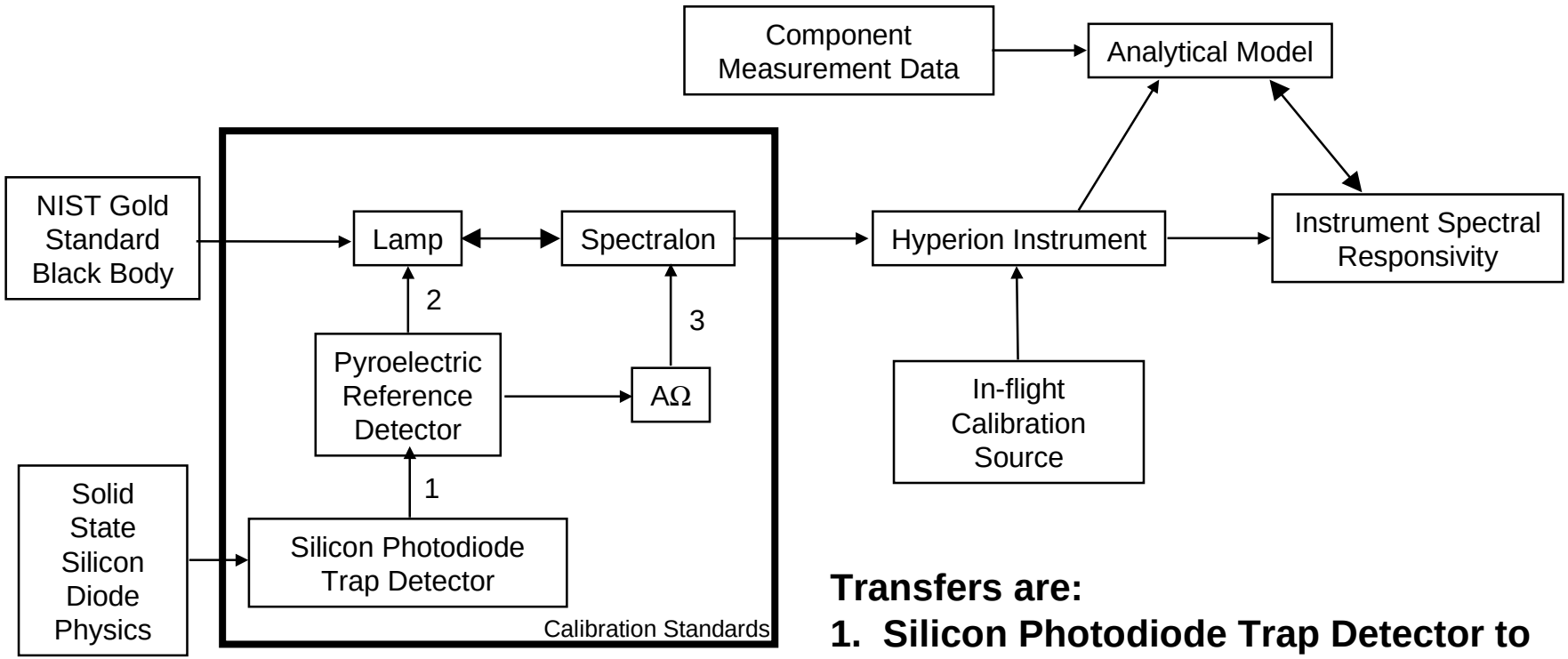


Spectralon Panel Assembly Installed

Spectralon Panel Assembly Installed



Calibration Flowchart



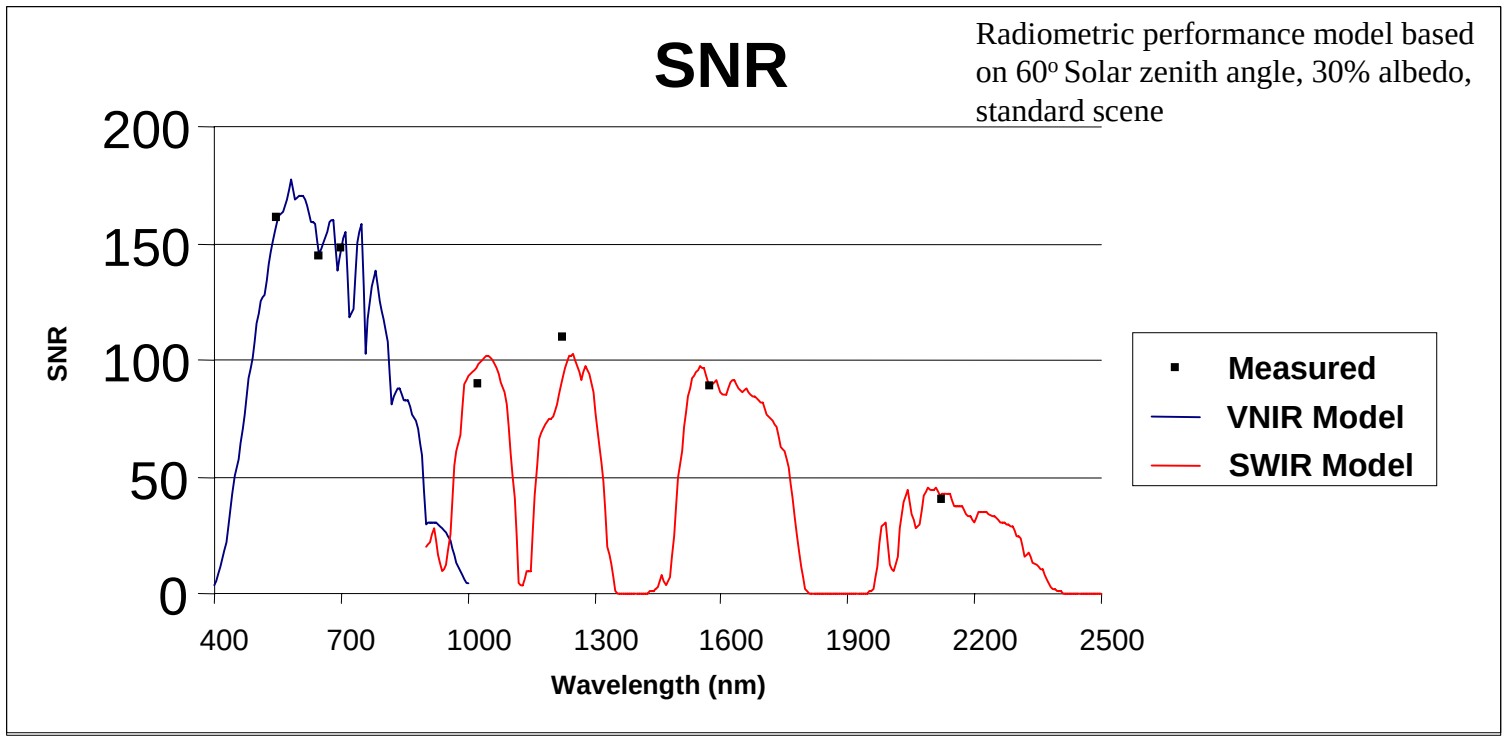
Transfers are:

1. **Silicon Photodiode Trap Detector to Pyroelectric Reference Detector (PRD) in Watts**

2. **PRD to Lamp in Irradiance**

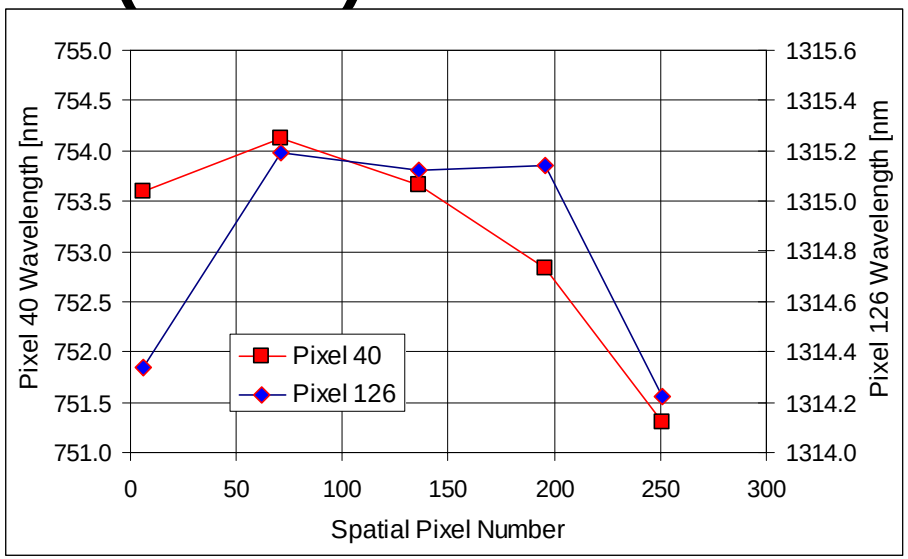
3. **PRD/ AΩ to Spectralon plate in Radiance**

Hyperion SNR



Hyperion Measured SNR						
550 nm	650 nm	700 nm	1025 nm	1225 nm	1575 nm	2125 nm
161	144	147	90	110	89	40

Cross Track Spectral Alignment (CTSA)



VNIR		SWIR	
Wavelength & (Pixel No)	Δλ* [nm]	Wavelength & (Pixel No.)	Δλ* [nm]
477nm (13)	3.5	2314nm (27)	0.45
655nm (31)	2.8	2012nm (57)	0.17
753nm (40)	2.9	1711nm (87)	0.57
834nm (48)	3.2	1315nm (126)	0.98
924nm (57)	2.7	1013nm (156)	0.45
* peak to peak value			

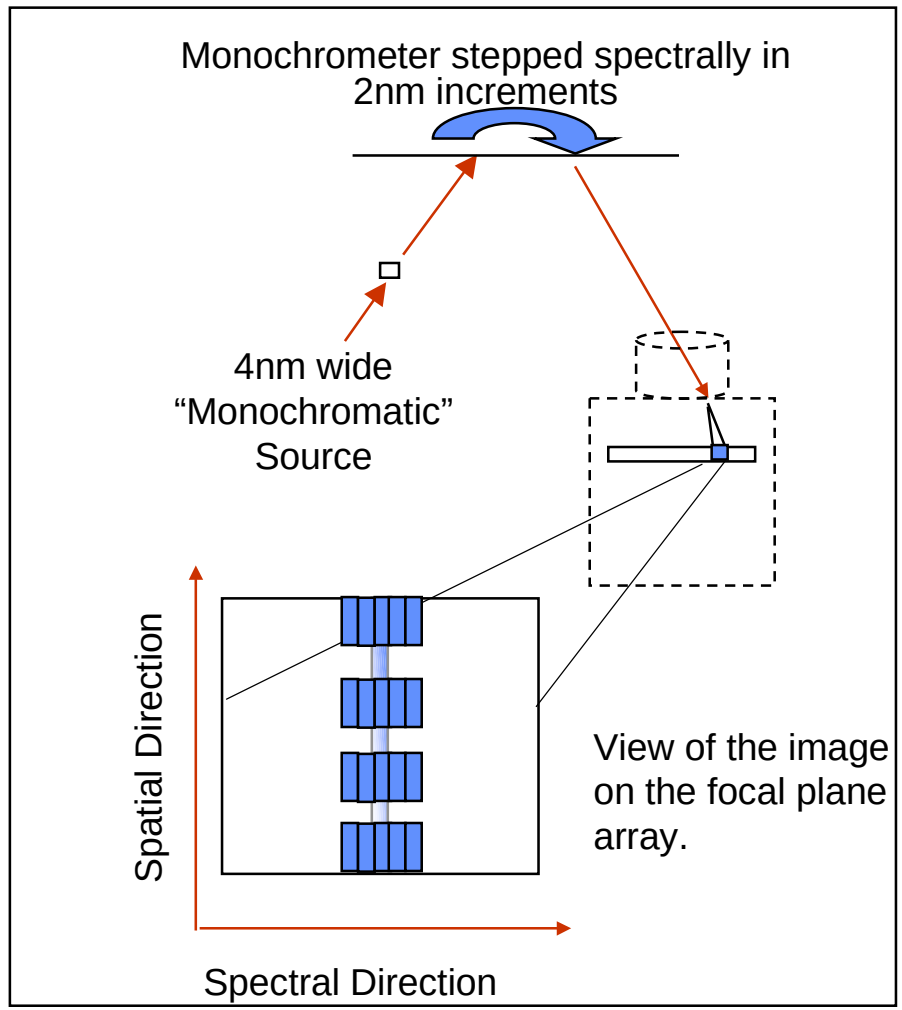
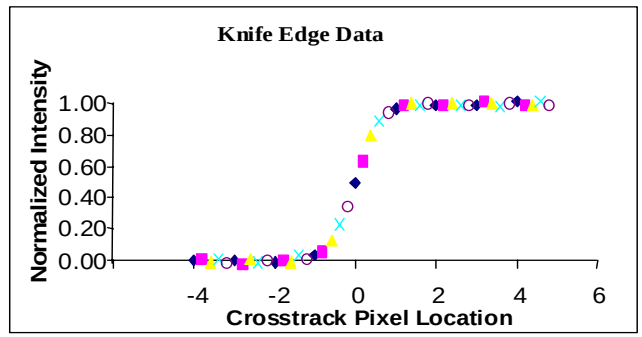
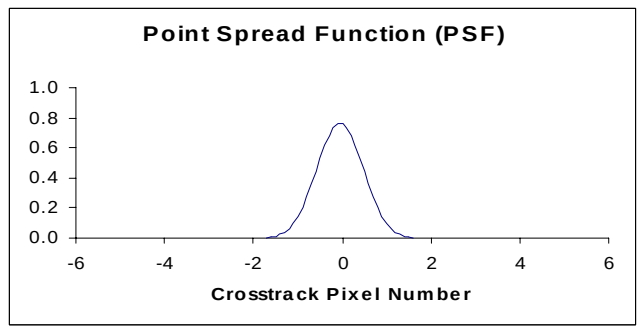


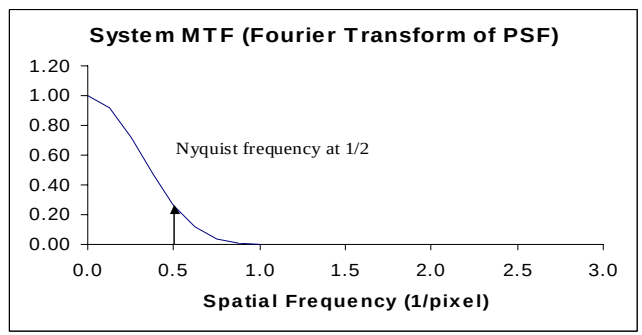
Image Quality - MTF

Measured using knife-edge MTF technique:

- **Knife-edge positioned at image relay focus with edge perpendicular to the slit of spectrometer**
- **Knife-edge illuminated with broadband light source**
- **Over-sampling by tilting steering mirror in fractional-pixel steps**
- **Fourier transform of the Point Spread Function (PSF) produces Cross-track MTF (CT-MTF)**
- **Along-track direction MTF equals $\frac{2}{\pi}$ of the cross track value**



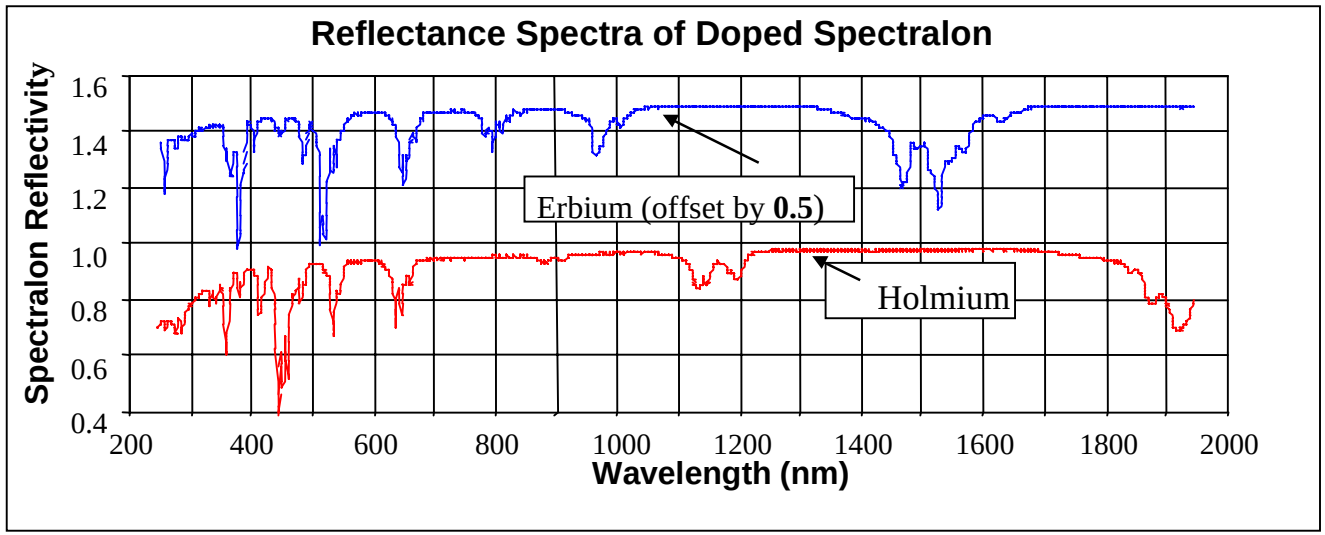


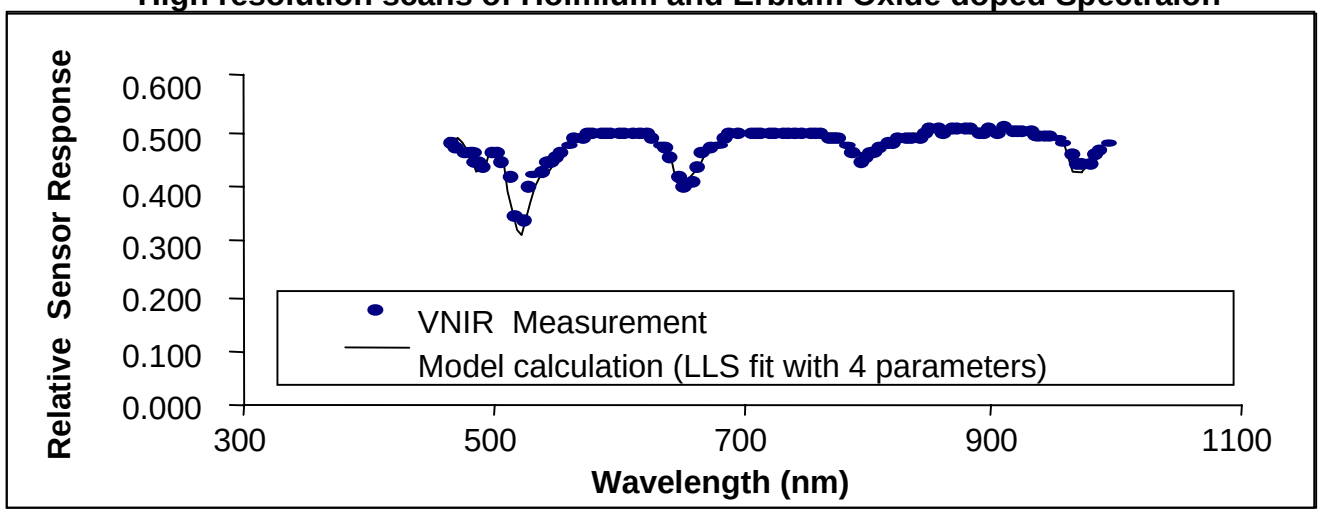


Spectral Wavelength Calibration

Process:

1. Two data frames taken:
   - Doped Spectralon
   - Un-doped Spectralon
2. Ratio of frames removes lamp source wavelength and sensor response variations
3. High resolution scans are convolved with sensor spectral response function
4. Linear least squares regression using second order fit in λ versus pixel number determines sensor wavelength calibration (accuracy ~ 0.02 pixels)





VNIR Spectral Response

VNIR Channel Center Wavelengths (nm, accuracy +/- 0.5 nm)					
Spectral Channel / FOV #	13	31	40	48	57
6	477.4	656.5	753.6	834.3	925.4
71	478.5	657.5	754.1	834.9	925.1
136	478.0	656.8	753.7	834.4	925.3
196	476.8	655.7	752.8	833.4	924.4
251	475.2	654.6	751.3	831.9	922.8

VNIR FWHM of Spectral Response Functions (nm)					
Spectral Channel / FOV #	13	31	40	48	57
6	11.2	10.5	10.6	11.1	11.1
71	11.6	10.4	10.9	11.3	11.3
136	11.3	10.3	10.7	11.3	11.3
196	11.4	10.2	10.7	11.4	11.3
251	11.3	10.2	10.6	11.3	11.2

SWIR Spectral Response

SWIR channel Center Wavelengths (nm +/- 0.5 nm)					
Specral Channel / FOV #	27	57	87	126	156
6	2314.1	2012.2	1711.2	1314.3	1013.3
71	2314.2	2012.1	1711.4	1315.2	1013.2
136	2314.0	2012.2	1711.6	1315.1	1013.2
196	2313.9	2012.1	1711.6	1315.1	1013.2
251	2313.7		1711.1	1314.2	1012.9

SWIR FWHM of Spectral Response Function (nm)					
Special Channel / FOV #	27	57	87	126	156
6	10.4	10.6	11.6	10.6	10.7
71	10.5	10.8	11.4	10.6	11.1
136	10.4	10.9	11.8	10.8	11.2
196	10.5	11.1	11.6	10.8	11.2
251	10.2		11.3	10.6	11.1

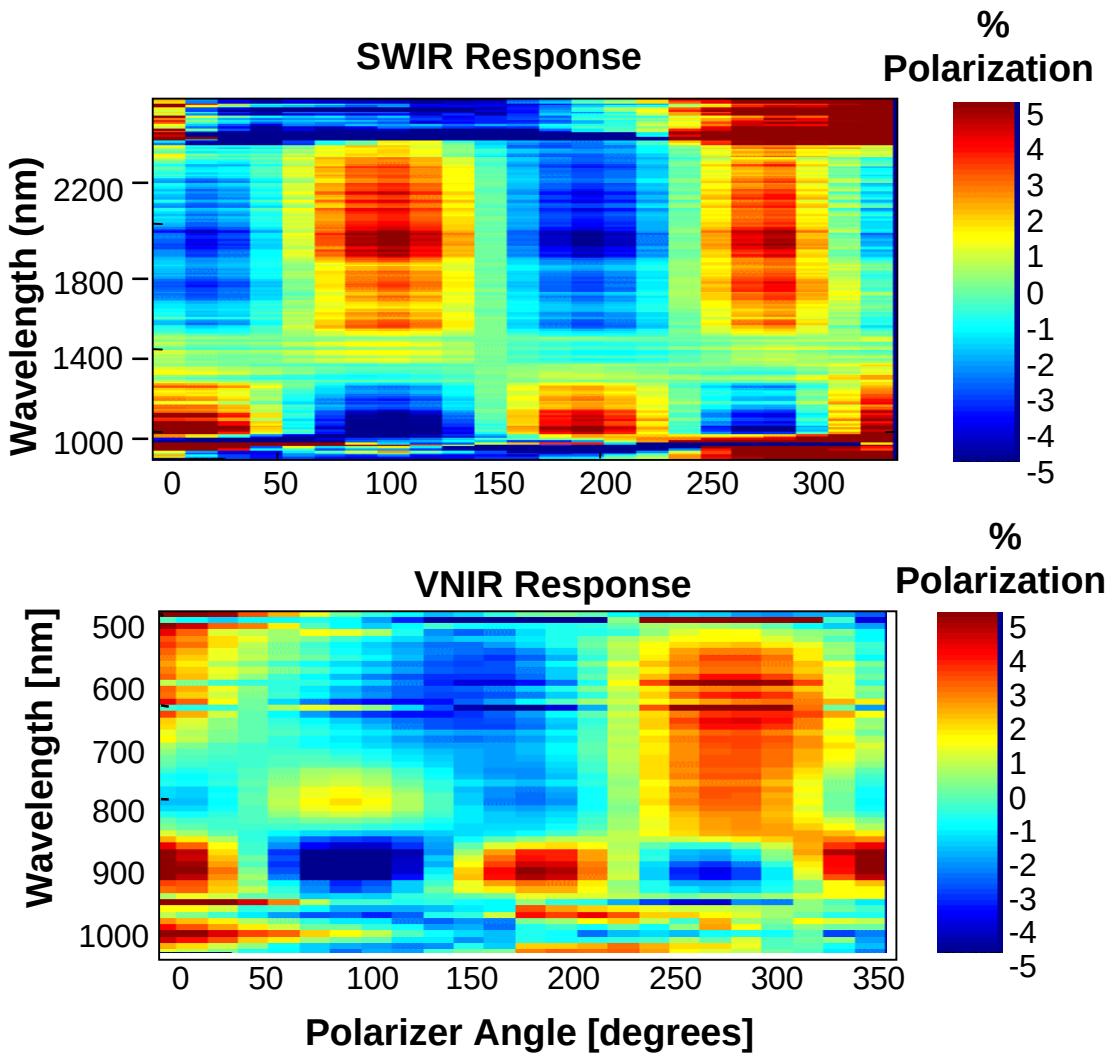
Polarization

Polarizer located just outside of the vacuum window

Data taken at 15 degree steps in polarization angle

Scene response averaged over spatial channels 171-256 for each spectral channel

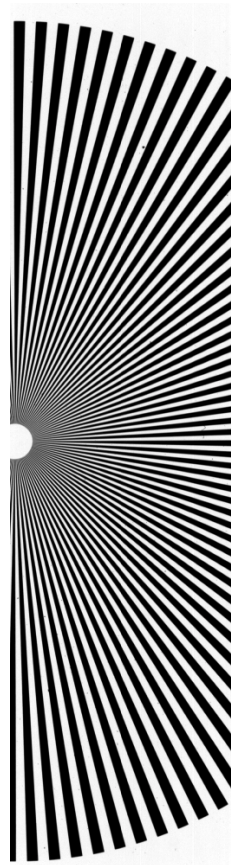
Results are in Percent Polarization



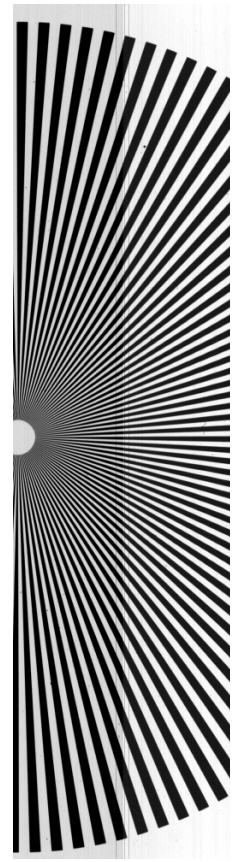
Starburst Image (from End to End Test)

Image is created by translating a "starburst" pattern across the Hyperion slit simulating satellite motion.

Starburst pattern used as an alternative technique to assess MTF characteristics



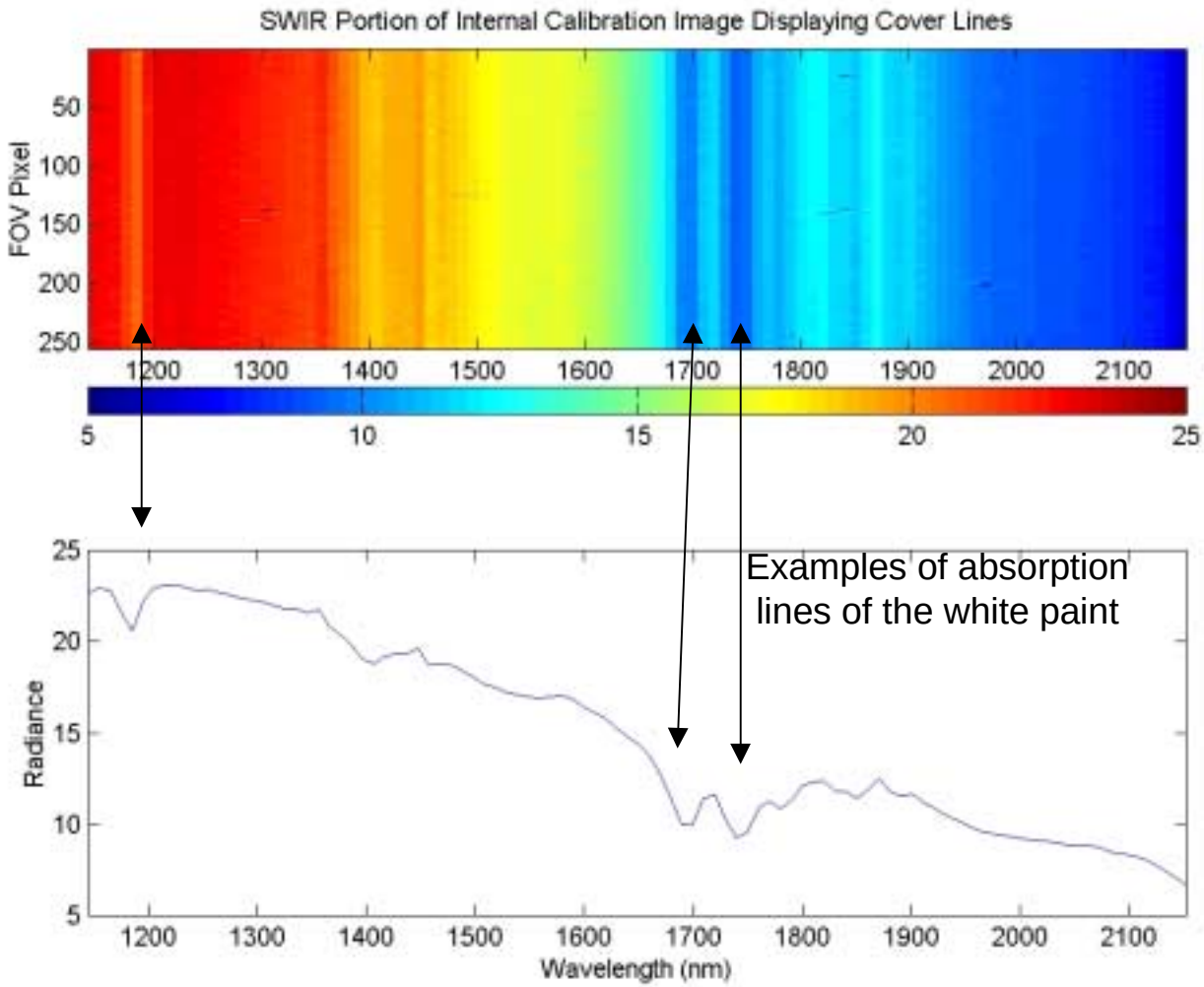
Radiometrically corrected



Uncorrected Data

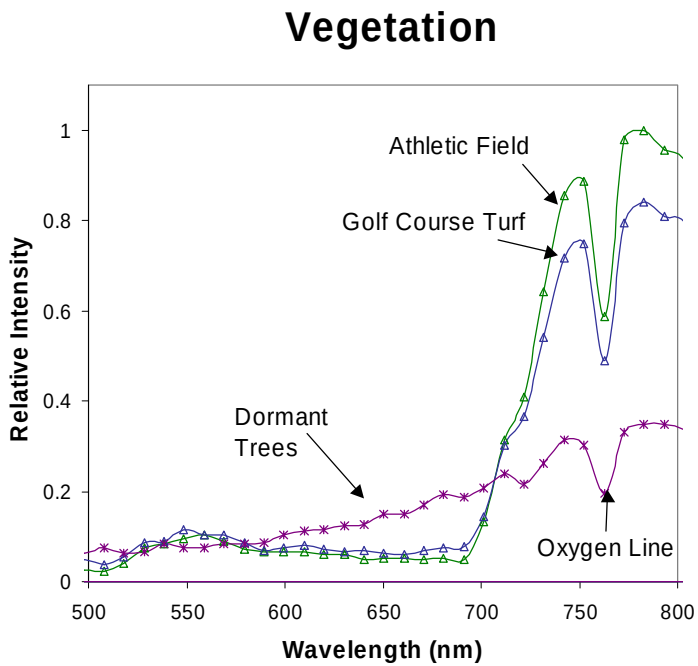
Performance Characterization – On-Orbit -- Preliminary Results

Spectral Calibration using Internal Calibration System



Hyperion Image of Fairfax, VA December 2000

Image taken by Hyperion shows the relative chlorophyll content of vegetation in Fairfax County. The spectral profiles indicate healthy grass in the athletic field and golf course. The spectral profile of the trees indicates dormant vegetation.

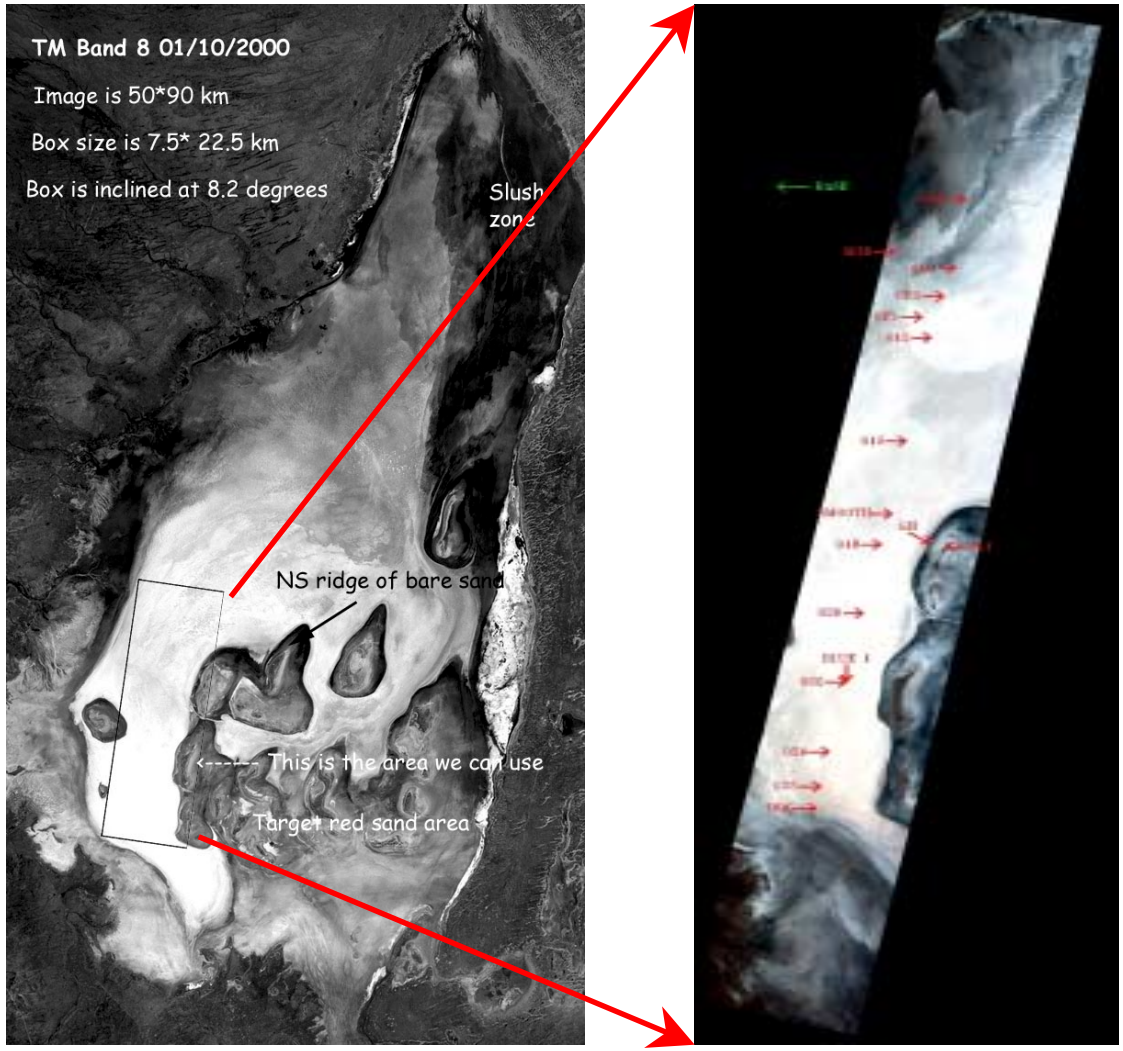


Oxygen in the atmosphere is detected by the spectral profiles in the near infrared wavelength.

Verrazano-Narrows Bridge, New York

Note clearly defined shadow of bridge

Lake Frome Calibration Site



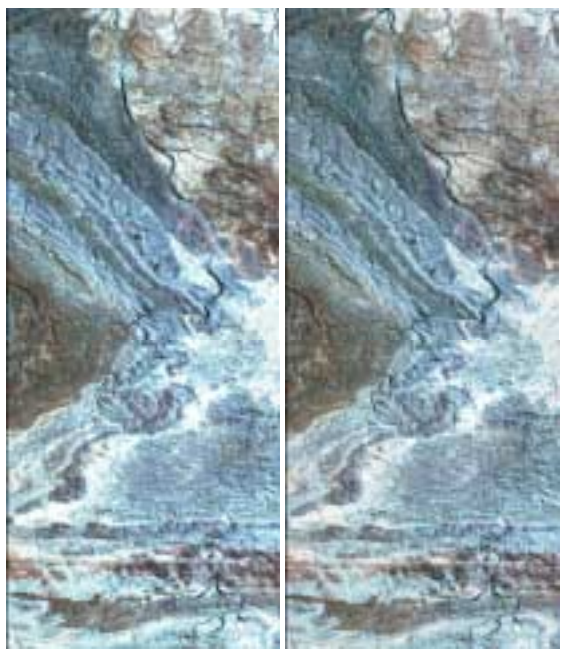
Applying Calibration: Repeatability

50 % Complete

Solar Calibration DCEs indicate instrument repeatability

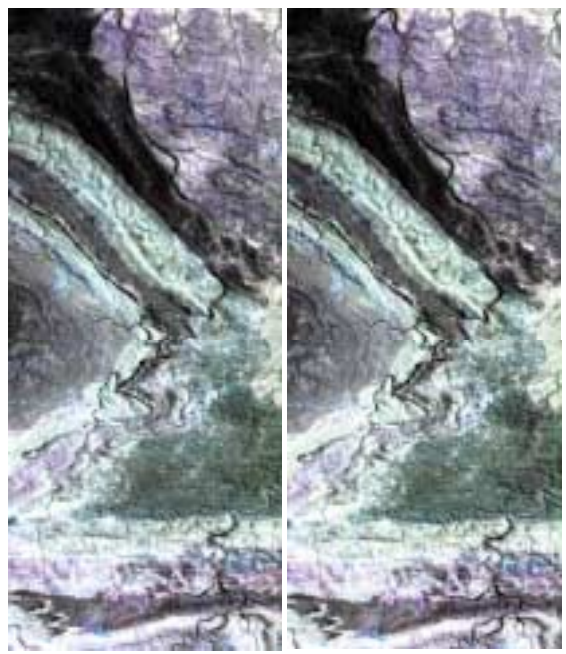
Duplicate ground images may also be used to verify repeatability based on Top of Atmosphere Radiance, EX: Mt. Fitton, Saharan

VNIR: 630 nm 549 nm 487 nm



Day 362 *Day 012*

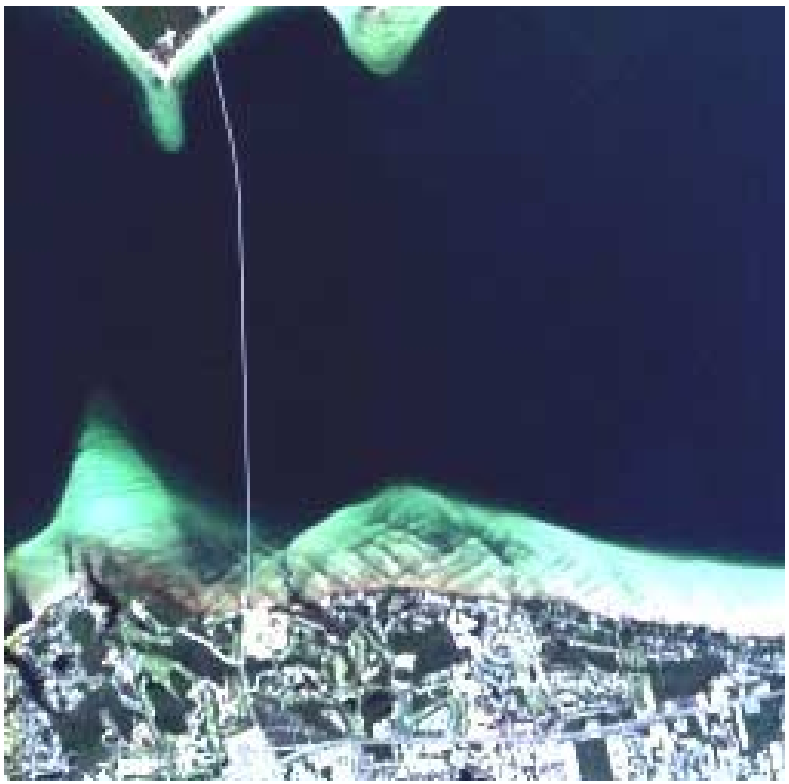
SWIR: 2358 nm 2327 nm 2206 nm



Day 362 *Day 012*

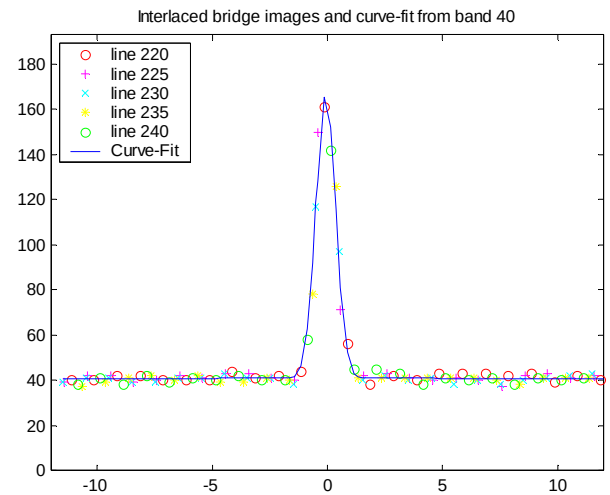
MTF Examples

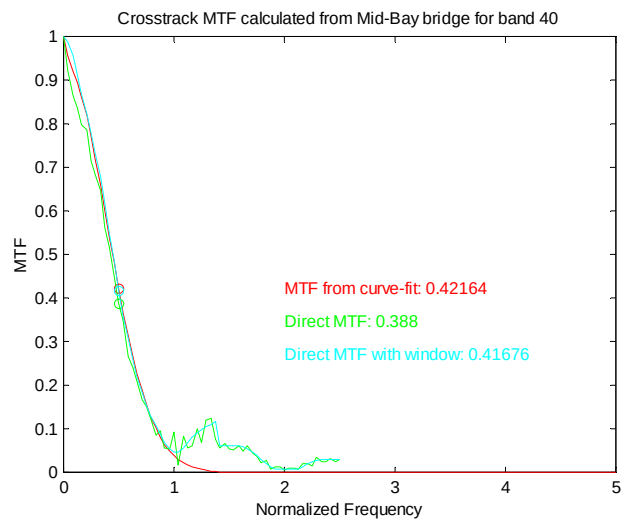
Port Eglin Day 359



Scene crosstrack MTF: 0.41

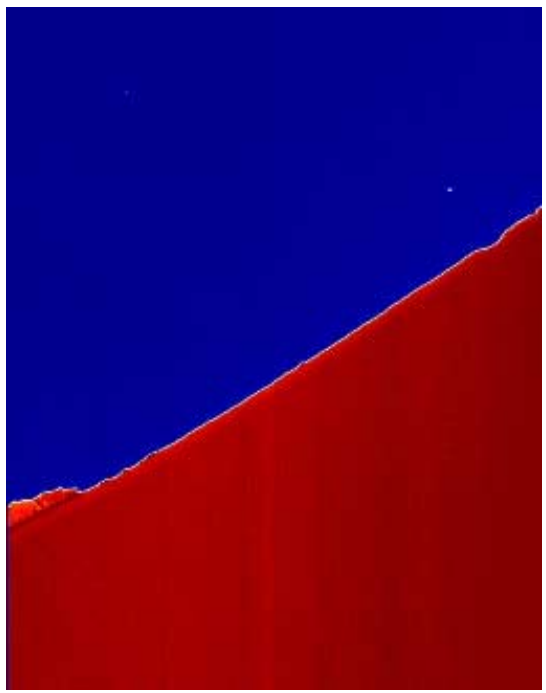
Ground measurement: 0.34 - 0.44

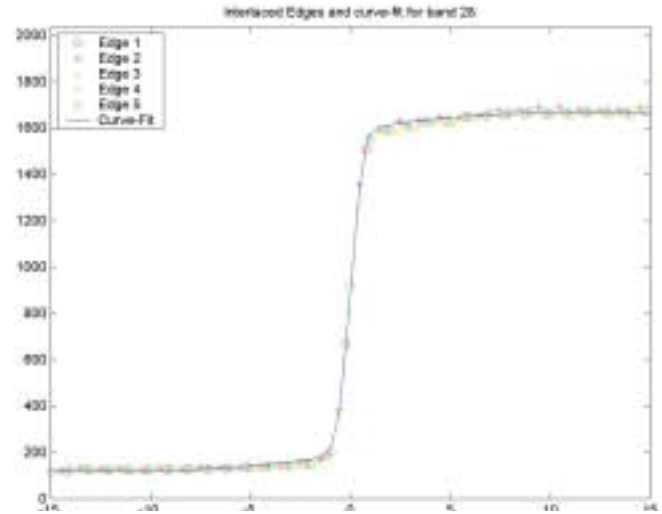


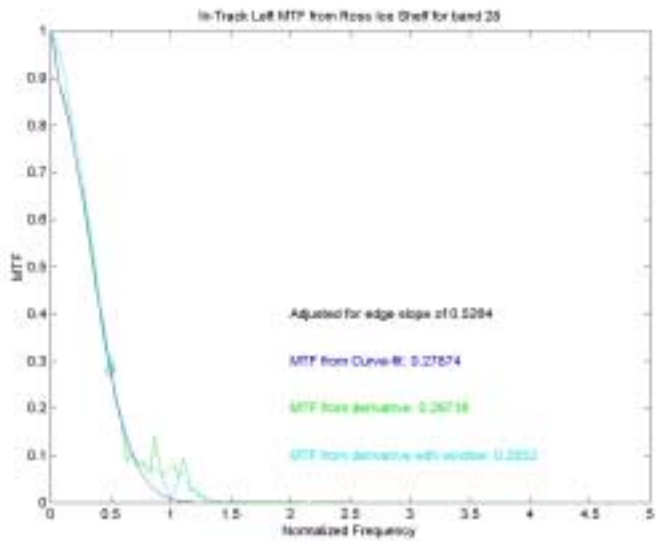


MTF Examples

Ross Ice Shelf Day 16, Band 28







Scene In-track MTF: 0.28

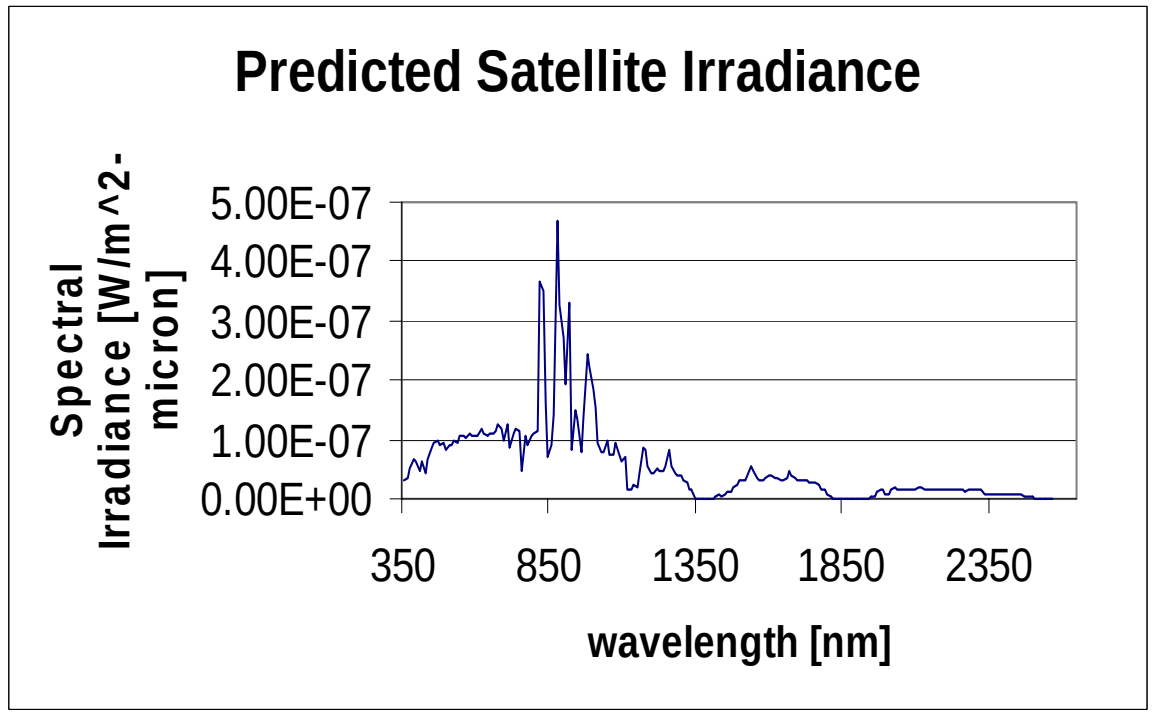
Ground measurement: 0.22 - 0.27

Active Illumination with 3 Lamps

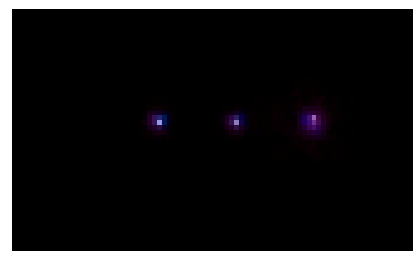
On the night of December 10, 2000 three Xenon lamps spaced linearly 160 meters apart were directed at EO-1 from Edwards AFB. High clouds were present during the test.

The spotlight spectrum has sharp lines for spectral calibration and a broad spectrum for spatial coregistration.

This was very early in the EO-1 mission while pointing was being established. Spotlights were seen by Landsat-7 and ALI.

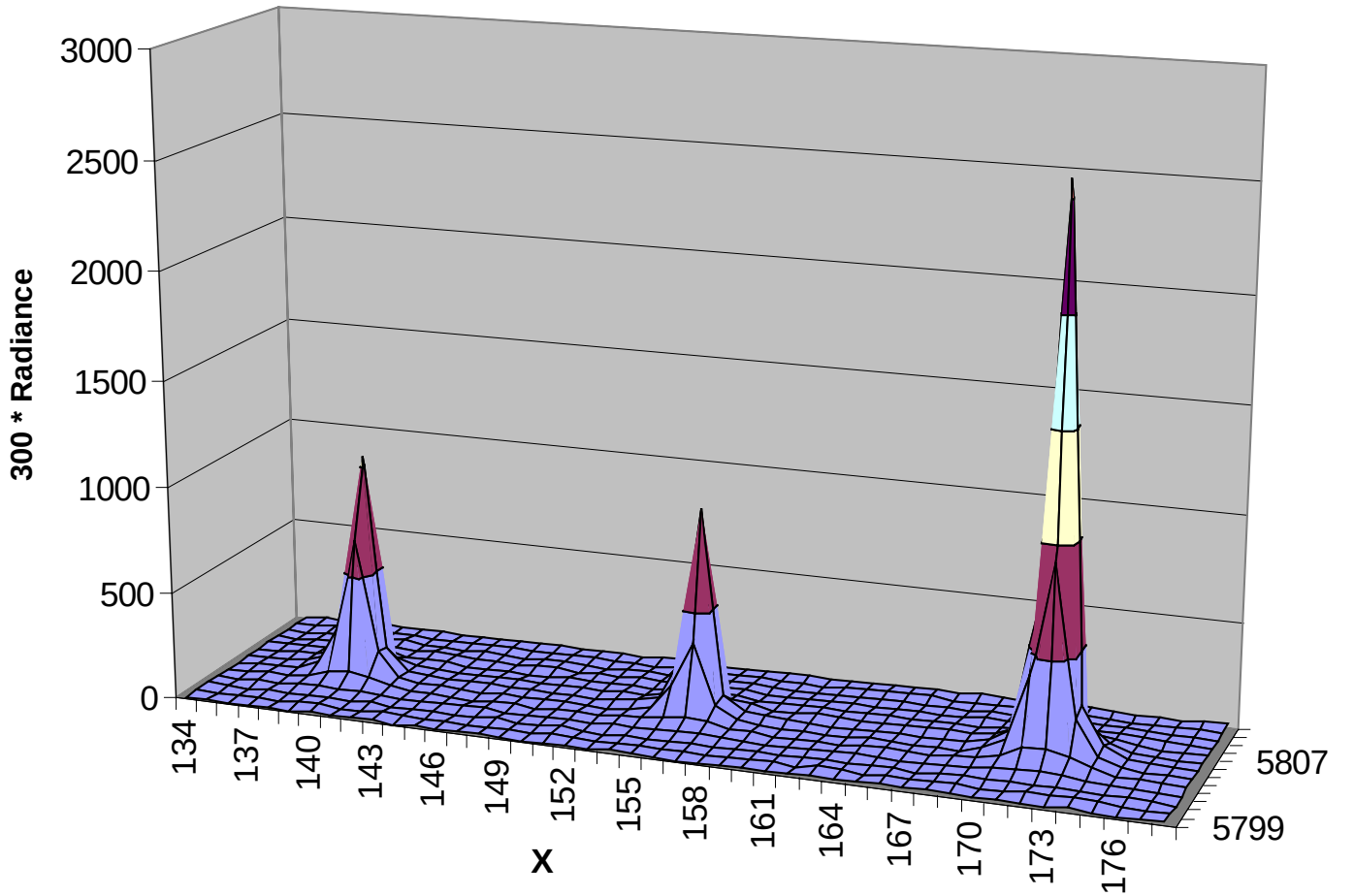


Landsat-7 PAN image

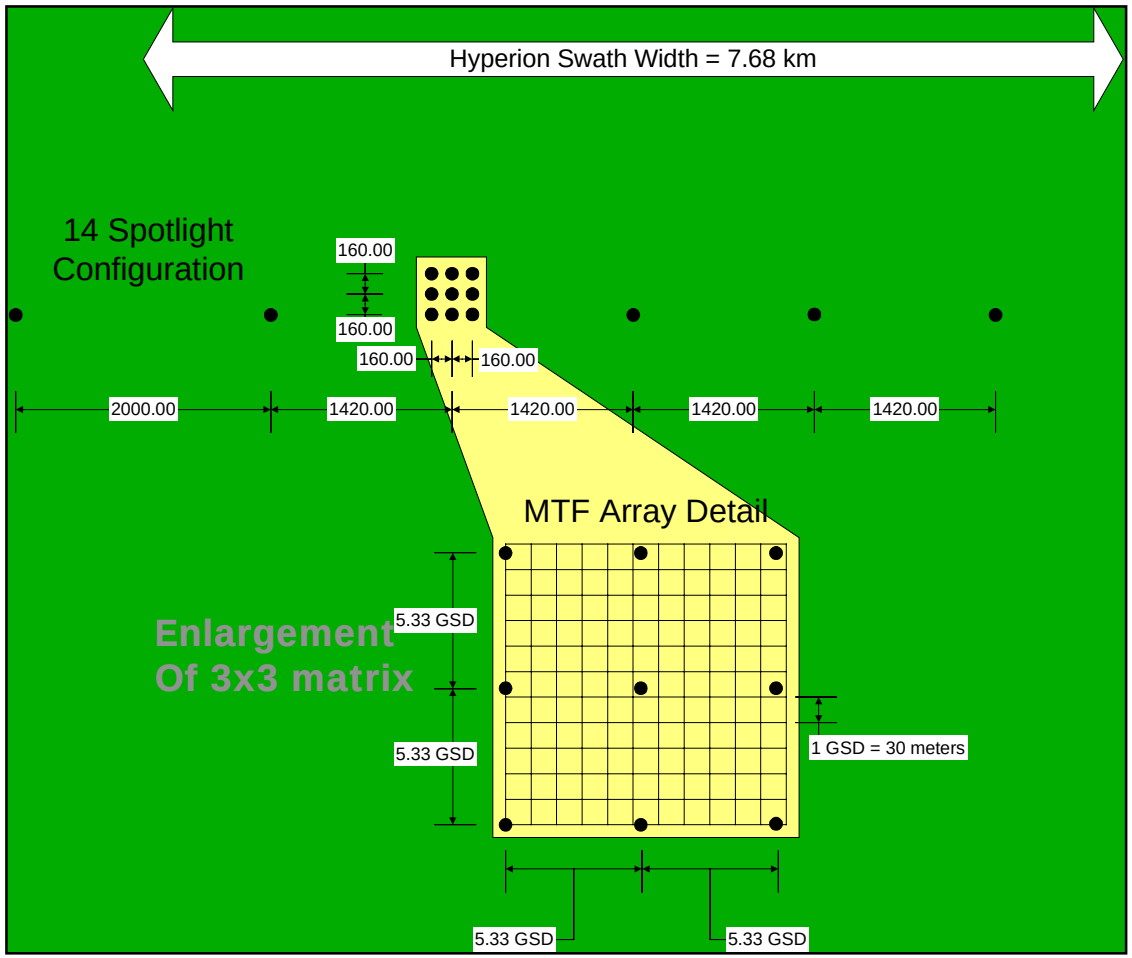


ALI PAN image

Expanded View of ALI data



14 Lamp Active Illumination Configuration



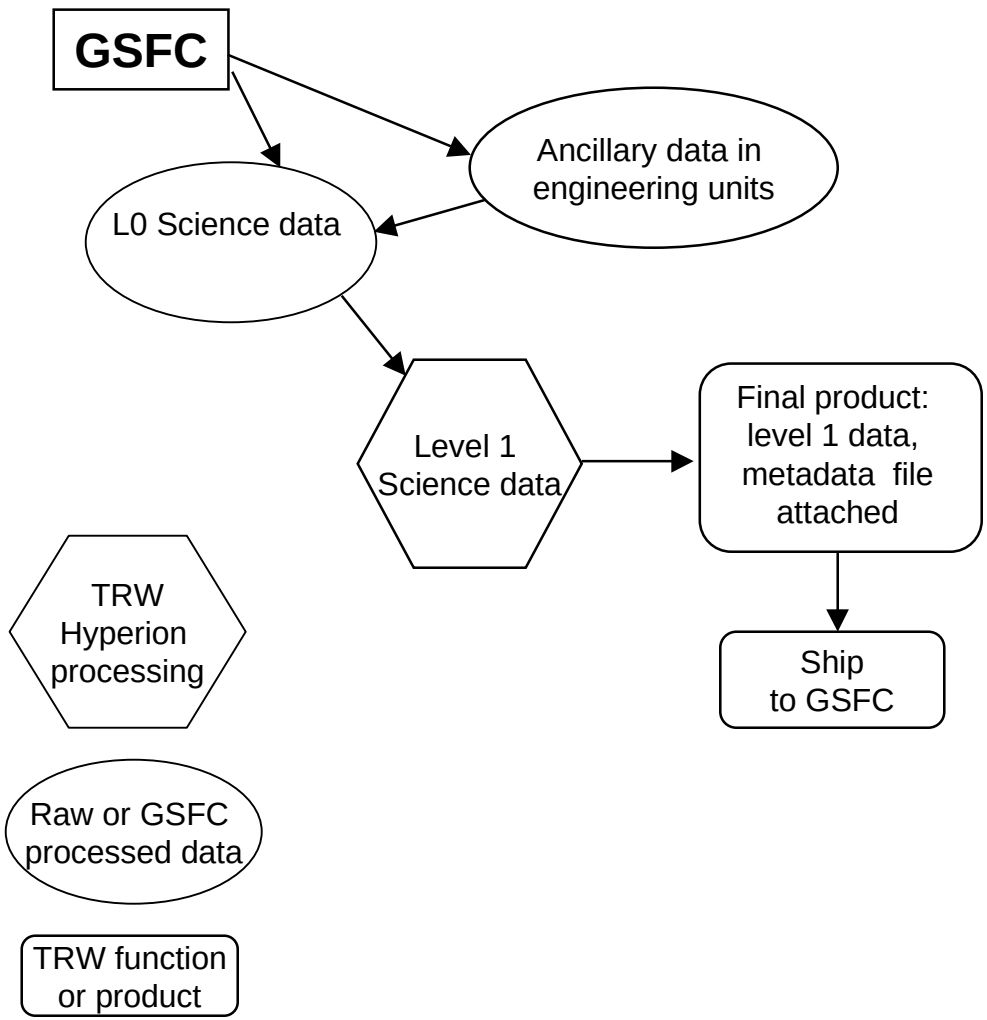
The expanded configuration allows testing of MTF, spatial coregistration, spectral accuracy, GSD and artifact correction.

Experiment was scheduled for Jan 10, 2000 but had to be rescheduled due to weather and pointing uncertainty.

- Results should be available by May 2001

Hyperion Data Processing

Overview: Hyperion Data Flow



Science Data: Level 0 or Level 1 (radiometrically corrected) data products with VNIR and SWIR data frames combined. Includes solar, lunar calibrations, earth images, dark and light calibrations

Metadata: Data about the science data. Information to support higher level processing, e.g., pre-flight characterization data

Ancillary Data: Supporting data derived from spacecraft telemetry during image collection

Hyperion Data Flow