PACE OCI Response Versus Scan Angle Measurement from Pre-launch Testing

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Overview

PACE OCI response versus scan angle (RVS) measurements

- Characterized at the NASA GSFC facility
  - Measured in 2022 for the flight unit (early 2022 and late 2022)
  - Tested under ambient conditions

Purpose

- To characterize the reflectance change with scan angle for OCI, which is necessary to correct the TOA radiance and reflectance products accurately

Test

- Observe an extended white light source at various scan angles and measure the OCI response

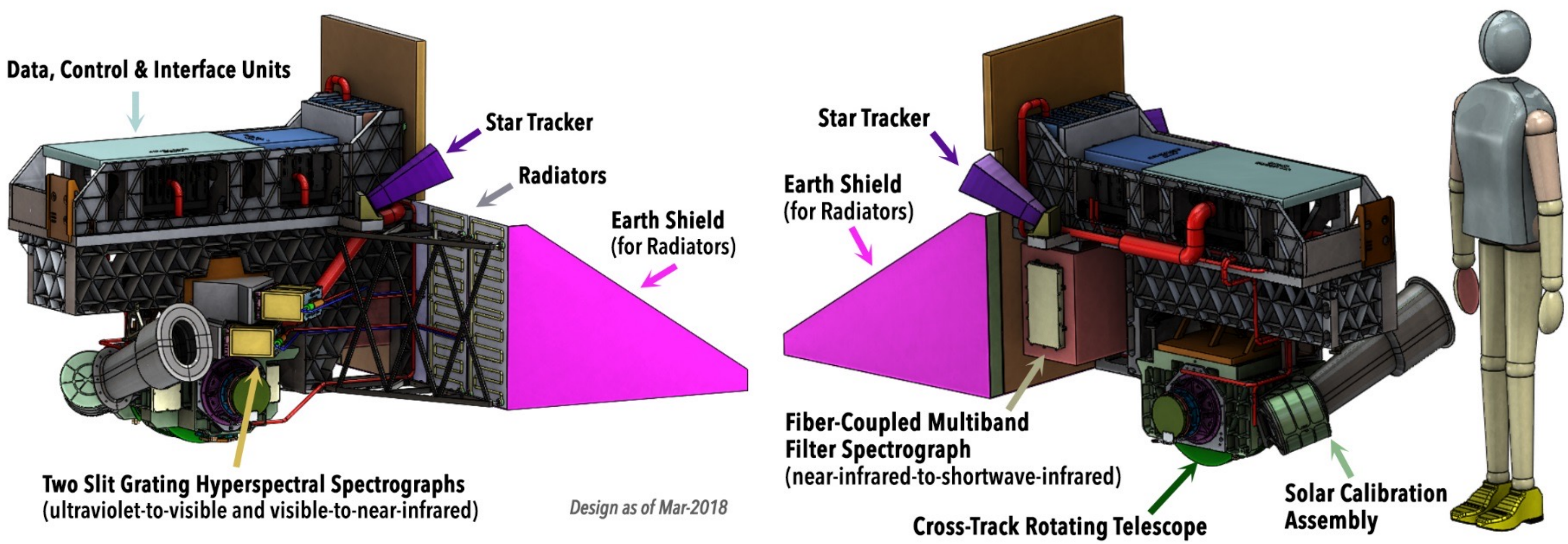
Analysis

- Perform data quality checks
- Determine the variation in reflectance with scan angle
- Determine the total uncertainty for the correction
- Compare to sensor design requirements

OCI Overview (I)

OCI Instrument Overview – Next Generation NASA Ocean Color Instrument

- **OCI is a grating spectrometer**
  - Hyperspectral coverage from ~315 nm to 895 nm with 5 nm bandwidth
    - Two gratings direct light onto two CCDs
  - Additional channels in the SWIR (InGaAs or HgCdTe)
    - 940, 1038, 1250, 1378, 1615, 2130, and 2260 nm
- **OCI has a rotating telescope to scan the Earth in the cross-track direction**
  - SeaWiFS and VIIRS heritage
  - Half Angle Mirror (HAM) rotates at half the speed of the telescope
  - Slit after the HAM is imaged onto the CCDs or SWIR detectors



OCI Overview (II)

CCDs have variable spatial and spectral aggregation schemes

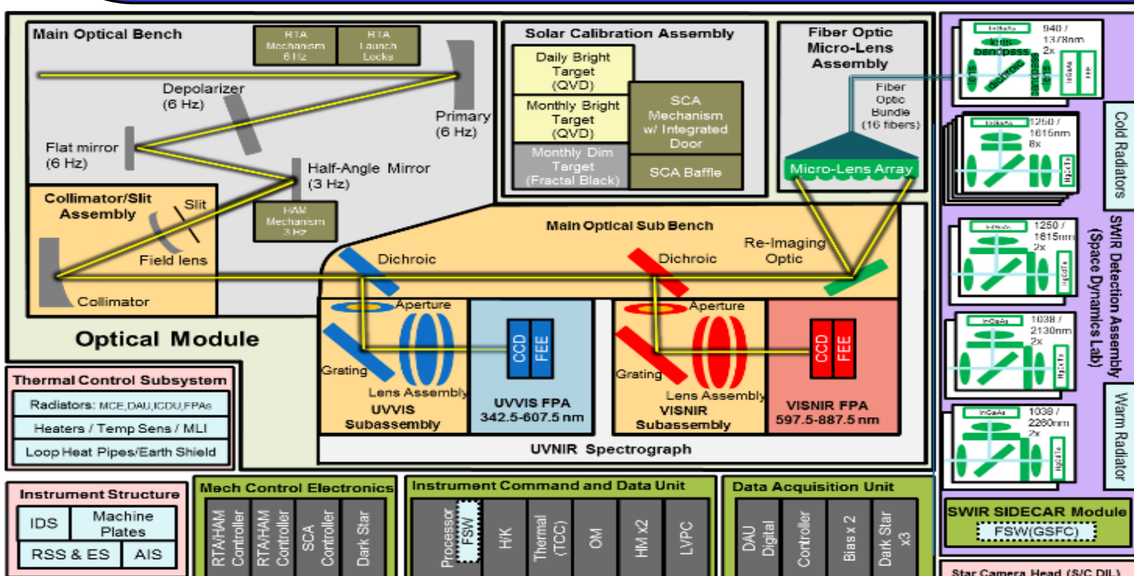
- An 8 x 8 array of physical pixels is combined into a science pixel
    - About 1050 meter square ground footprint at nadir
- TDI is used in the spatial direction to increase the signal to noise
    - 16 science pixels are summed as the image moves along the slit

OCI can operate in a number of different sensor modes

- Science, solar cal, lunar cal, Earth cal, engineering, and snapshot
- Science is the nominal mode measuring a ±56.5 degree off nadir swath
- Dark view is included in almost all modes

Solar cal view at -90 degrees off nadir

- Diffuser assembly has 3 diffusers (daily, monthly, and dim)



Eric T. Gorman, et al., "The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission: an emerging era of global, hyperspectral Earth system remote sensing," *Proc. SPIE 11151, Sensors, Systems, and Next-Generation Satellites XXIII, 111510G* (10 October 2019)

OCI Calibration

OCI Calibration Equation

Convert OCI digital counts to TOA radiance

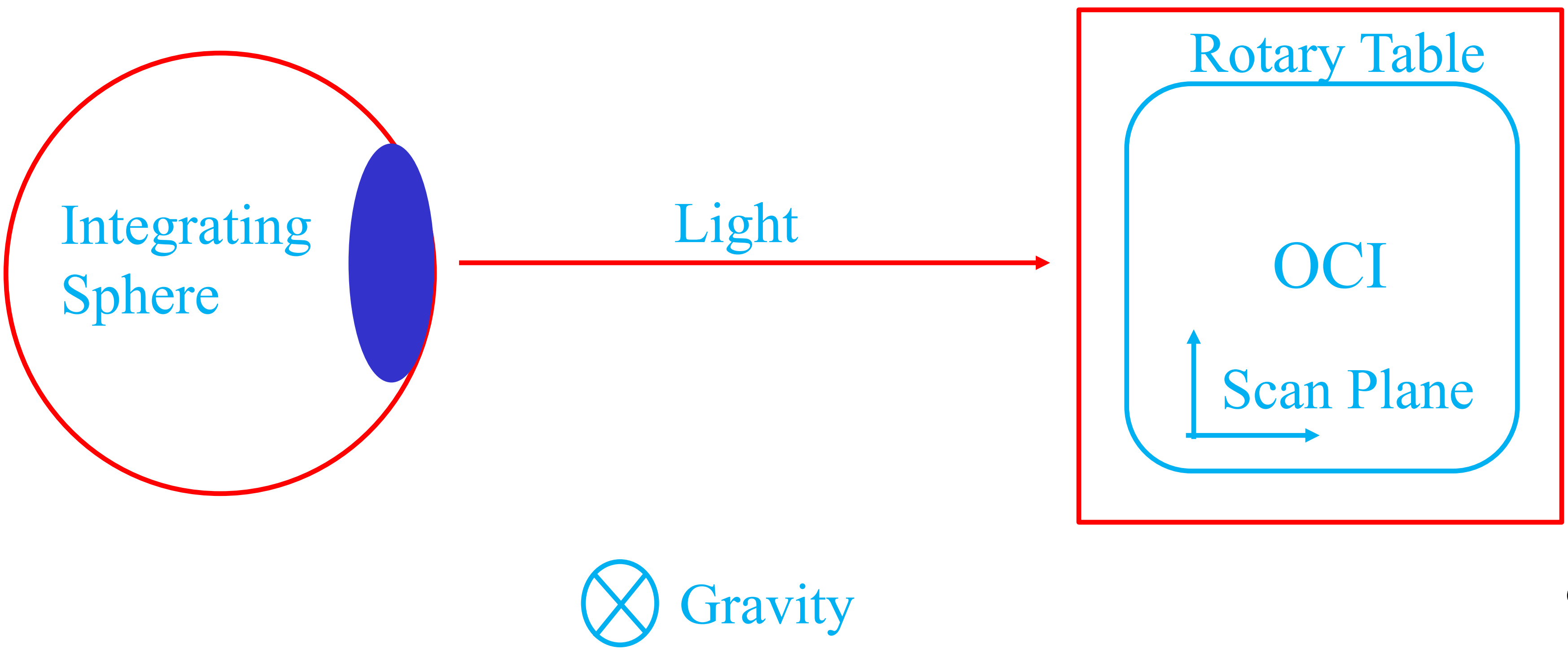
- K_1 is the radiometric gain
  - Measured pre-launch; updated on-orbit via vicarious calibration
- K_2 is the time dependent drift in the gain on-orbit
- K_3 is the temperature dependence of the gain; measured pre-launch
- K_4 is the RVS; measured pre-launch
- K_5 is the linearity correction; measured pre-launch
- K_p is the polarization correction; measured pre-launch
- dn is the offset corrected digital counts from OCI
- L is the TOA radiance

$$L = K_1 K_2 K_3 K_4 K_5 K_p dn$$

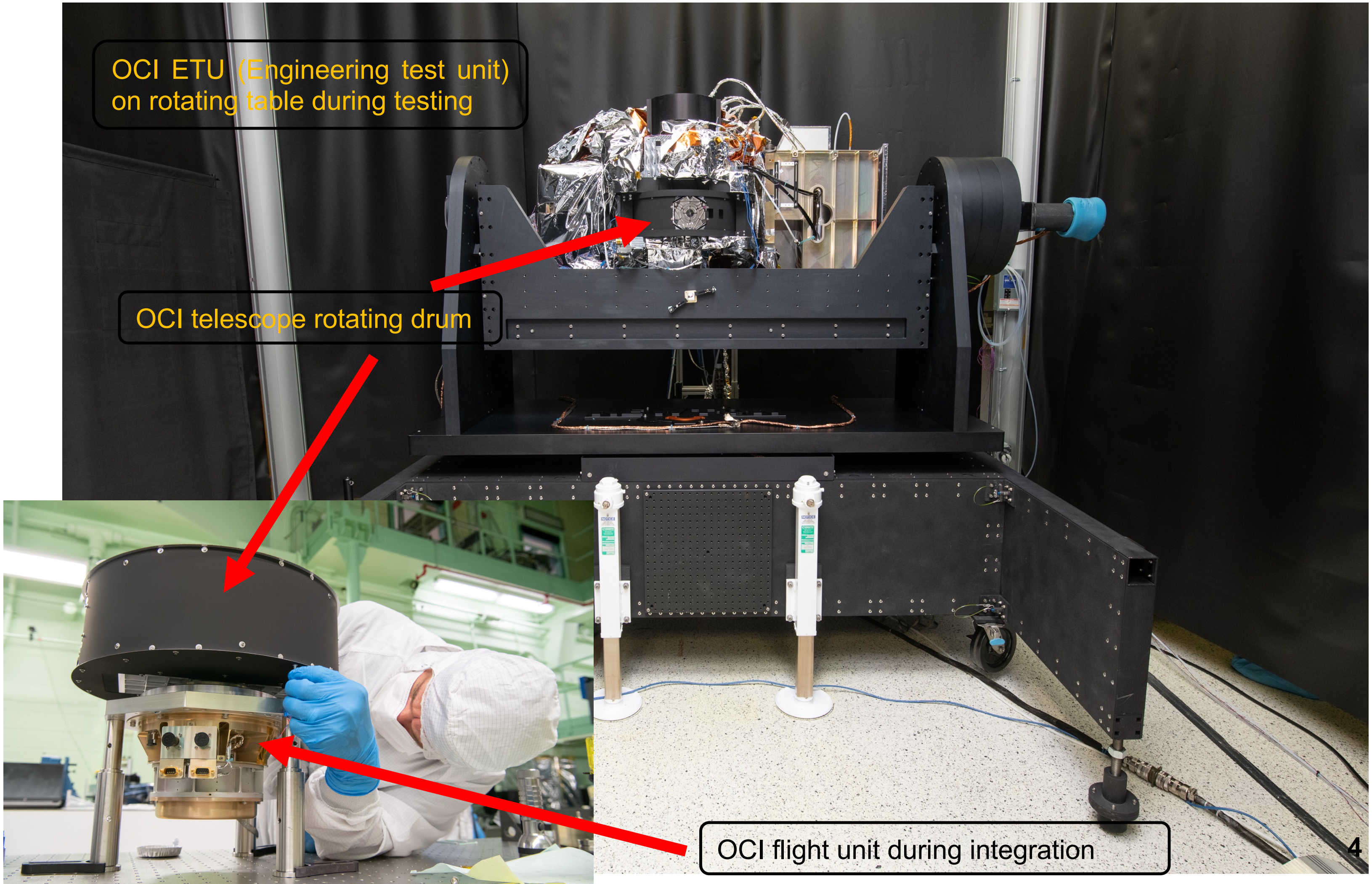
Test Setup

OCI Test Setup

- OCI was positioned on a rotary table with the scan plane perpendicular to gravity
- OCI was rotated such that it views an integrating sphere at a series of discrete scan angles
- Ground support equipment will provide source and environment information during the test
- Nominal OCI position on the rotating table obscures the solar calibration view
  - OCI was repositioned on the table to measure the solar calibration view



OCI Test Setup



Ground Support Equipment

Ground Support Equipment

Integrating sphere
- 20 inch integrating sphere with an 8 inch circular aperture
- Sources used to illuminate the sphere:
  - Energetiq EQ-400 source
  - 150 Watt halogen lamp at 50%
- Sphere aperture was 47 inches from the OCI telescope aperture in ambient
- A SR-4500 radiometer was used to measure the source radiance in real-time
- Temperature / Humidity monitors measured the laboratory conditions in real-time

Rotating table
- Rotated to view the sphere at different scan angles
- To view the solar calibration angle, OCI repositioned on the rotating table
  - A riser was installed between the table and OCI
  - The rotation axis of OCI was no longer coincident with the table rotation axis

Test

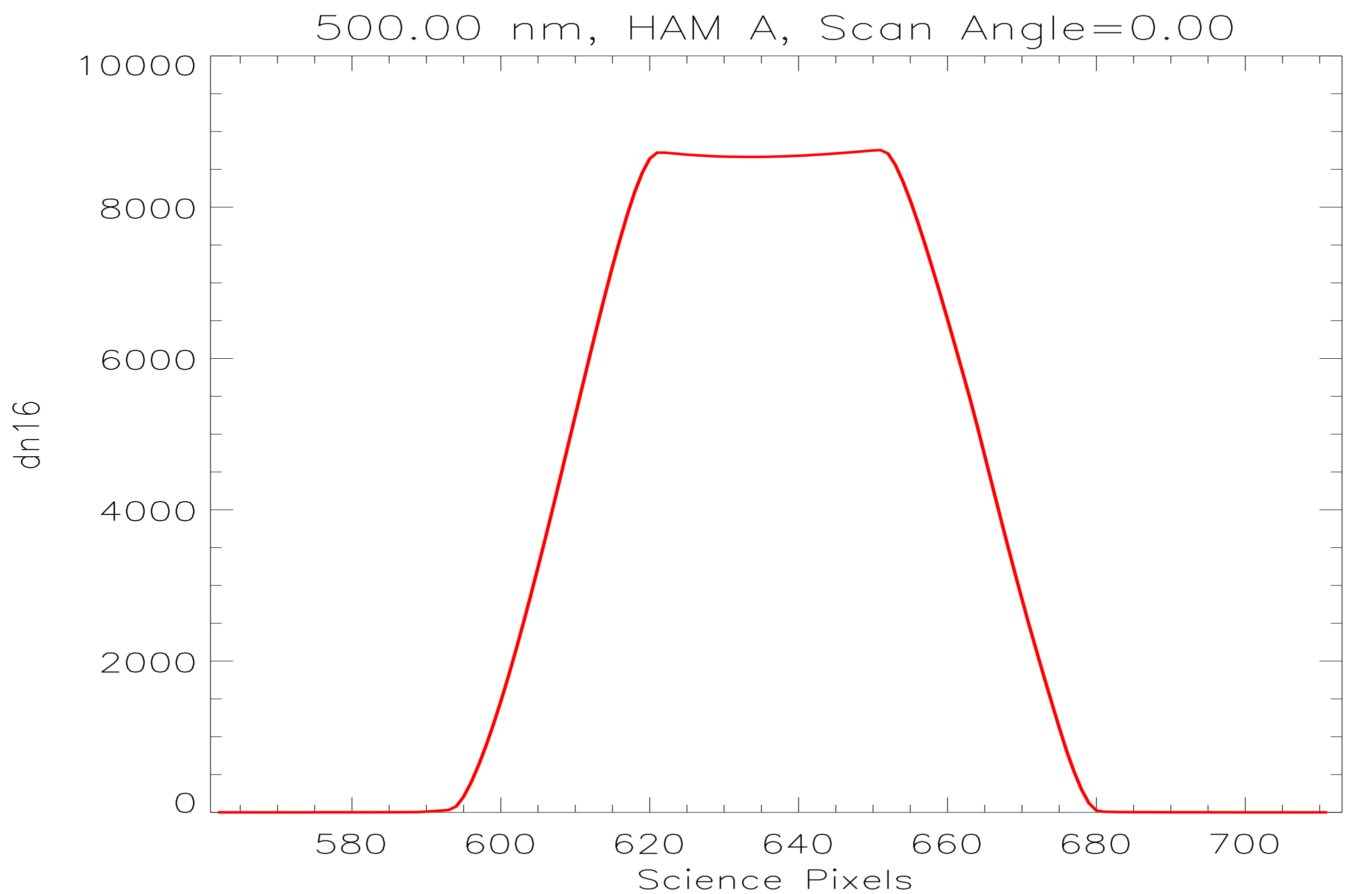
Test Description

- Data taken in 8x4 mode (full spatial aggregation and some spectral aggregation)
- Data was taken at a series of scan angles
  - 13 discrete scan angles in the science view (±56.5 degrees off nadir)
    - Each measurement was repeated 3 times (0 degrees 4 times)
  - Two scan angles measured in the solar cal configuration
    - -90 and -51 degrees off nadir
    - Solar diffuser assembly was not installed
- OCI took data for about 35 seconds for every measurement (~200 rotations of the telescope)
- Dark offset was measured inside the drum for rotating tests
- Early 2022 test measured under ambient conditions
  - HgCdTe bands were not cooled; measured on a single MCE side
  - SCA measurements were taken
  - Discovered that MCE side may influence path, especially for SWIR bands
- Late 2022 test measured under ambient conditions (retest)
  - HgCdTe bands were not cooled, measured on both MCE sides
  - No SCA measurement were taken
- Combine late 2022 test data with early 2022 SCA measurements to get final RVS
- HgCdTe bands RVS was modelled from InGaAs bands
  - Based on fiber position and component measurements

Test Data

Test Data

- Plot: scan profile -- OCI's footprint moves across the source
    - "Flat top" when footprint is fully within the source aperture
- Determine centroid of scan profile, select pixel range around centroid for processing
    - Average over selected pixels, then drift correct for lamp drift



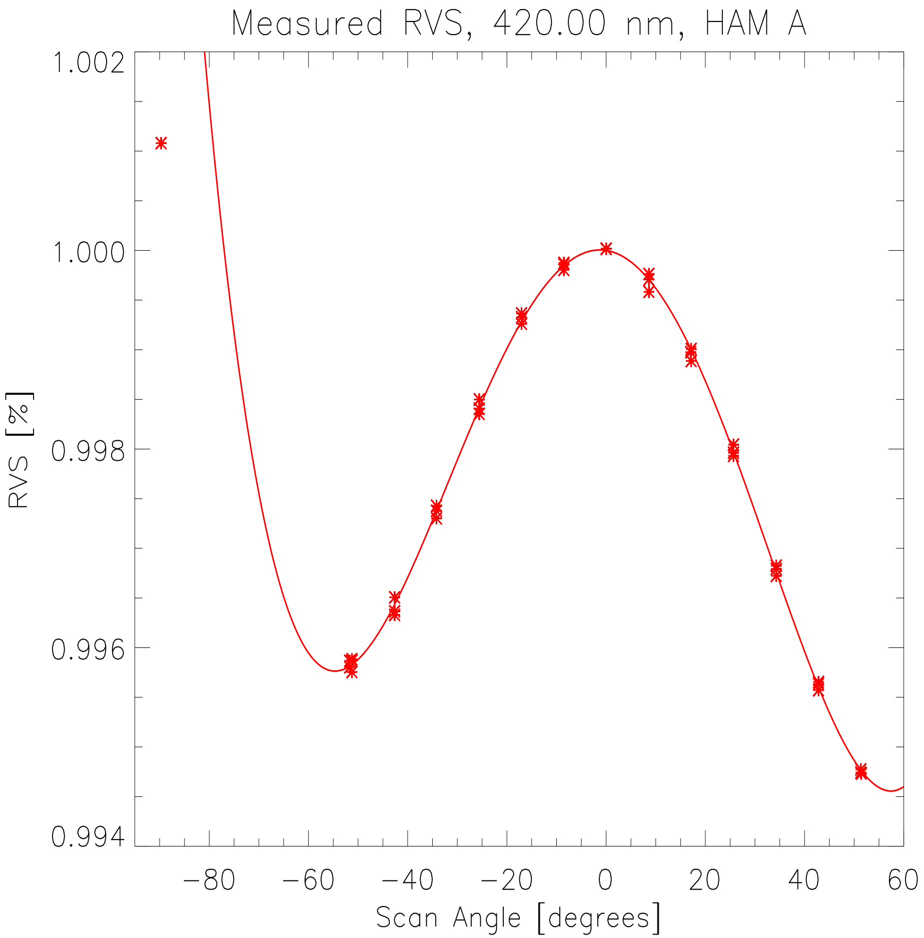
RVS Fitting

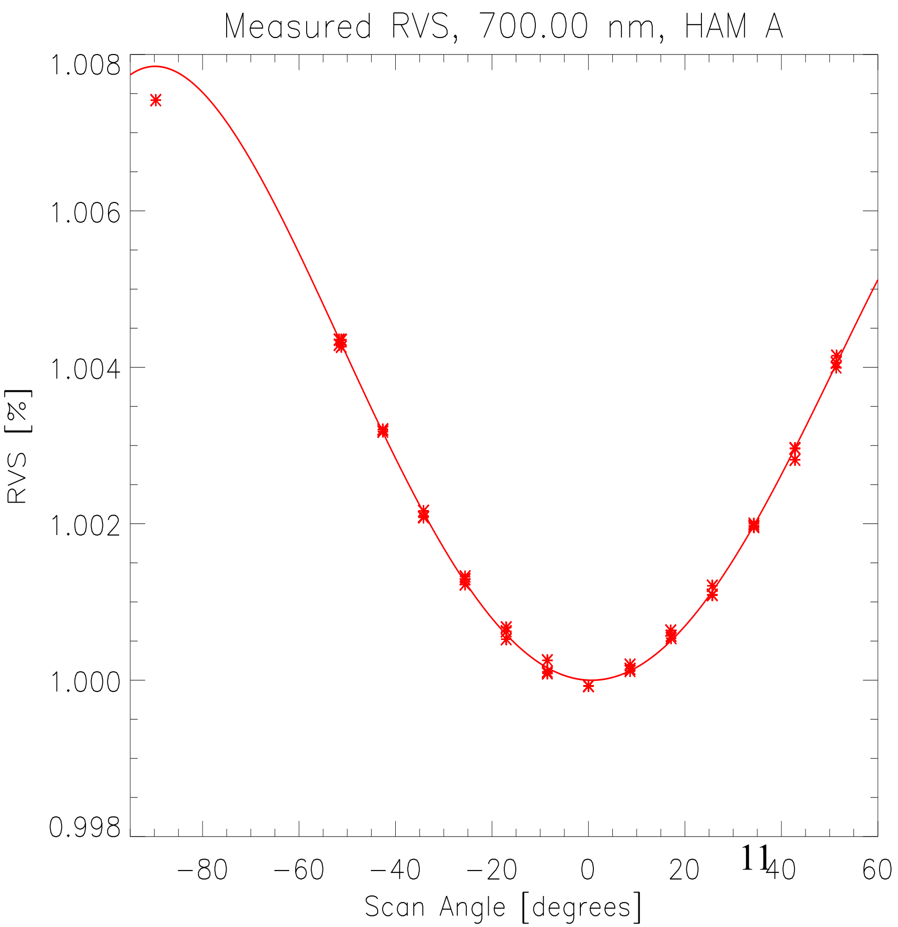
RVS Fitting

OCI data plotted (symbols) with fits (lines)

Fourth order polynomial fits the data pretty well (SCA angle not always consistent)

Initially quadratic polynomial was used, but asymmetry was observed

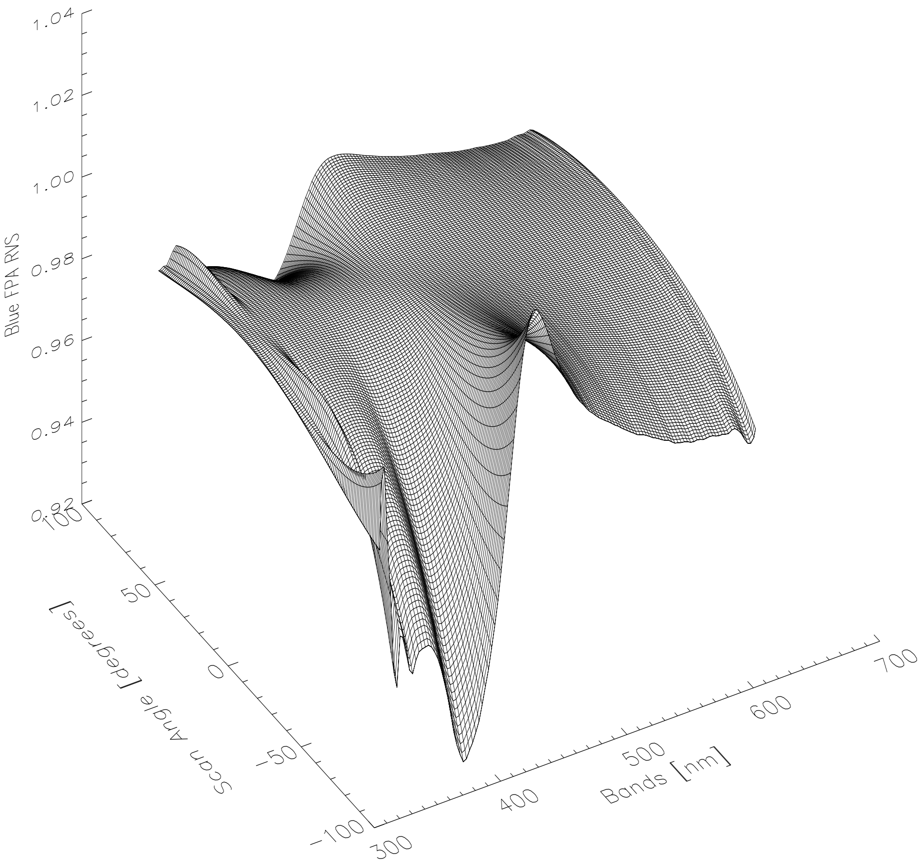


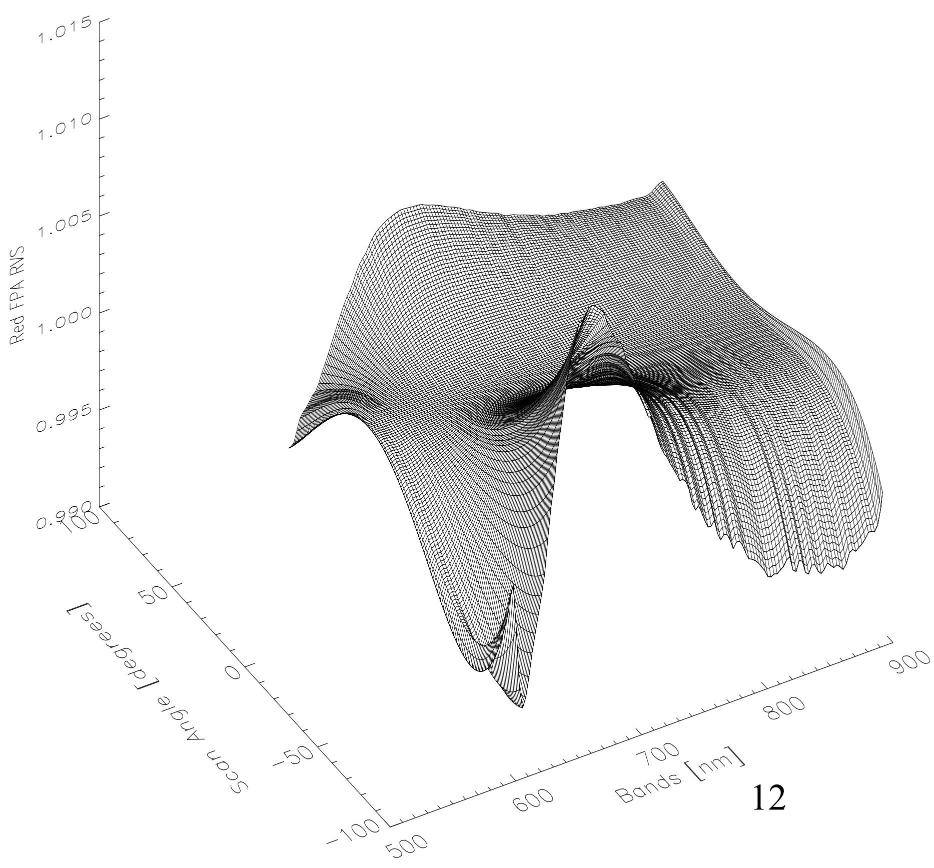


RVS Fitting

RVS Fitting –- Hyperspectral Bands

- Left plot: blue FPA RVS; right plot: red FPA RVS
- Plots show change in RVS with wavelength
  - RVS is generally small (less than 1%), but can be as high as 2.5%

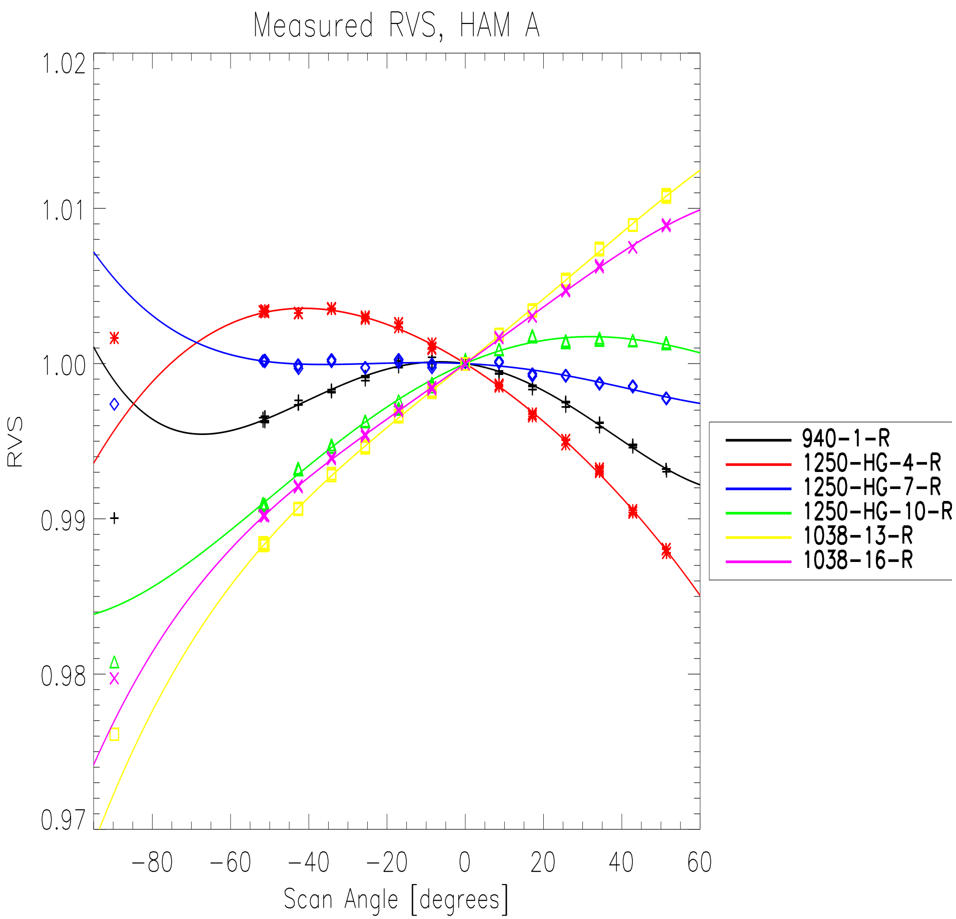


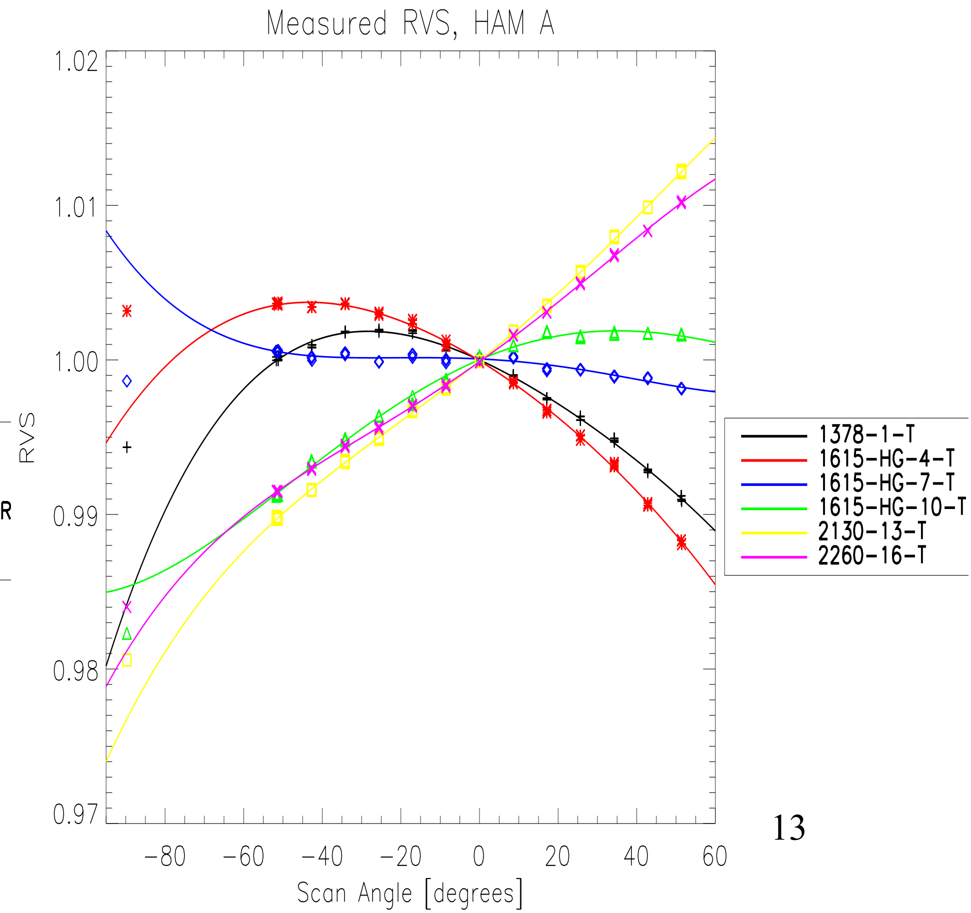


RVS Fitting

RVS Fitting –- SWIR Bands

- Left plot: InGaAs RVS; right plot: HgCdTe RVS
- Plots show change in RVS with wavelength
  - RVS varies with position on MLA; can be small or up to 3%
  - HgCdTe RVS modelled from component RVS and InGaAs RVS





RVS Fitting

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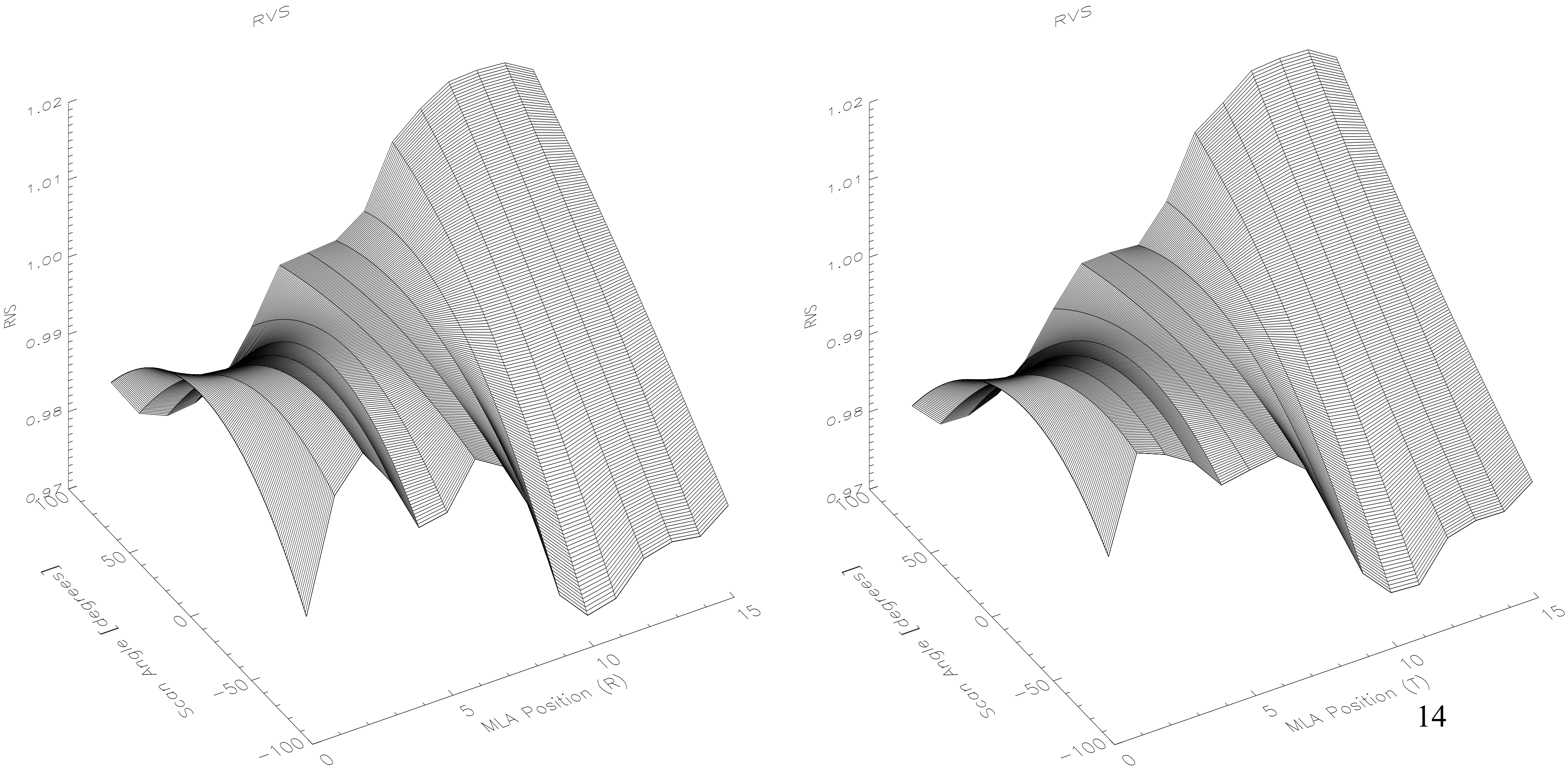
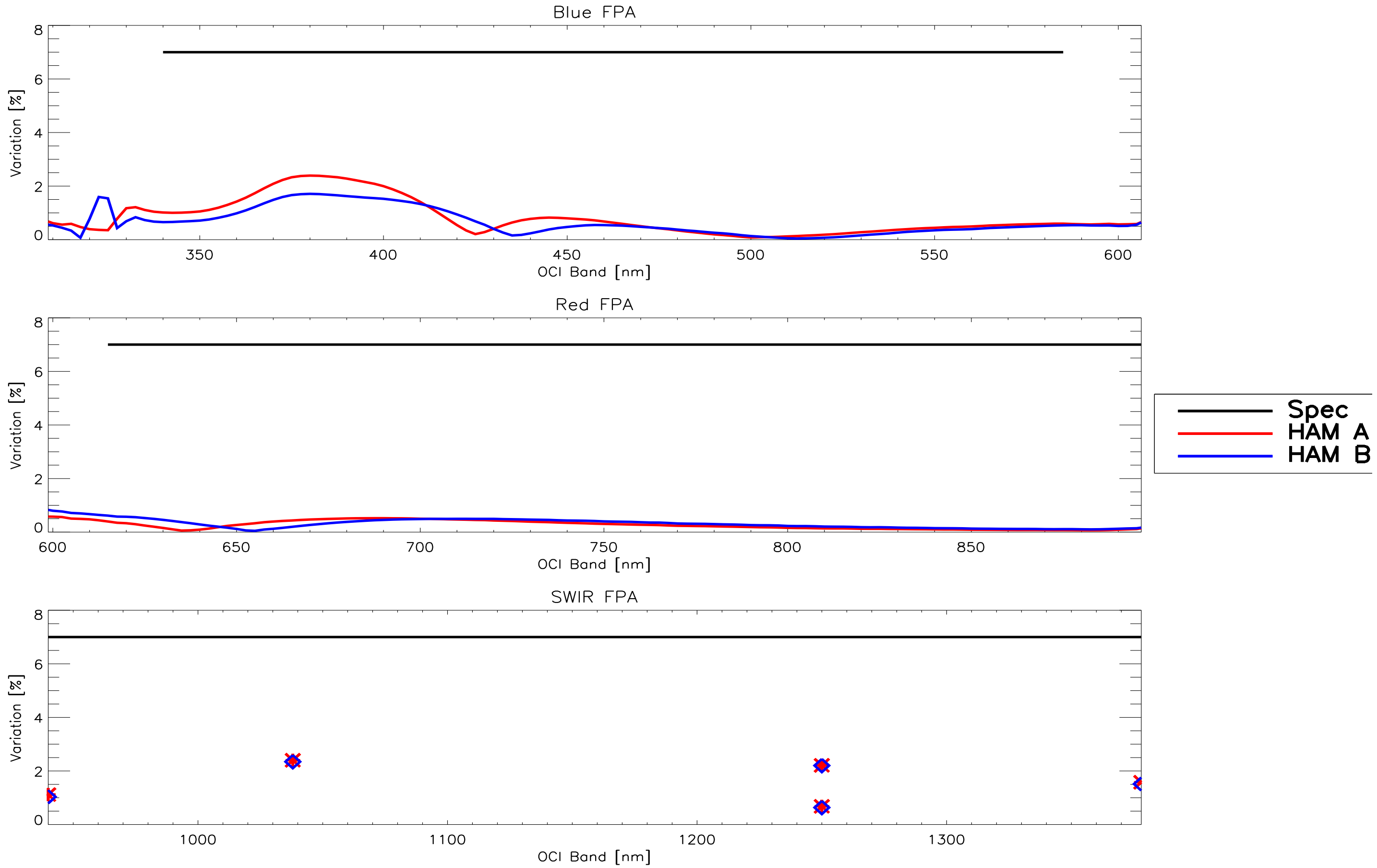


Maximum RVS Variation

Maximum RVS Variation over Scan Range

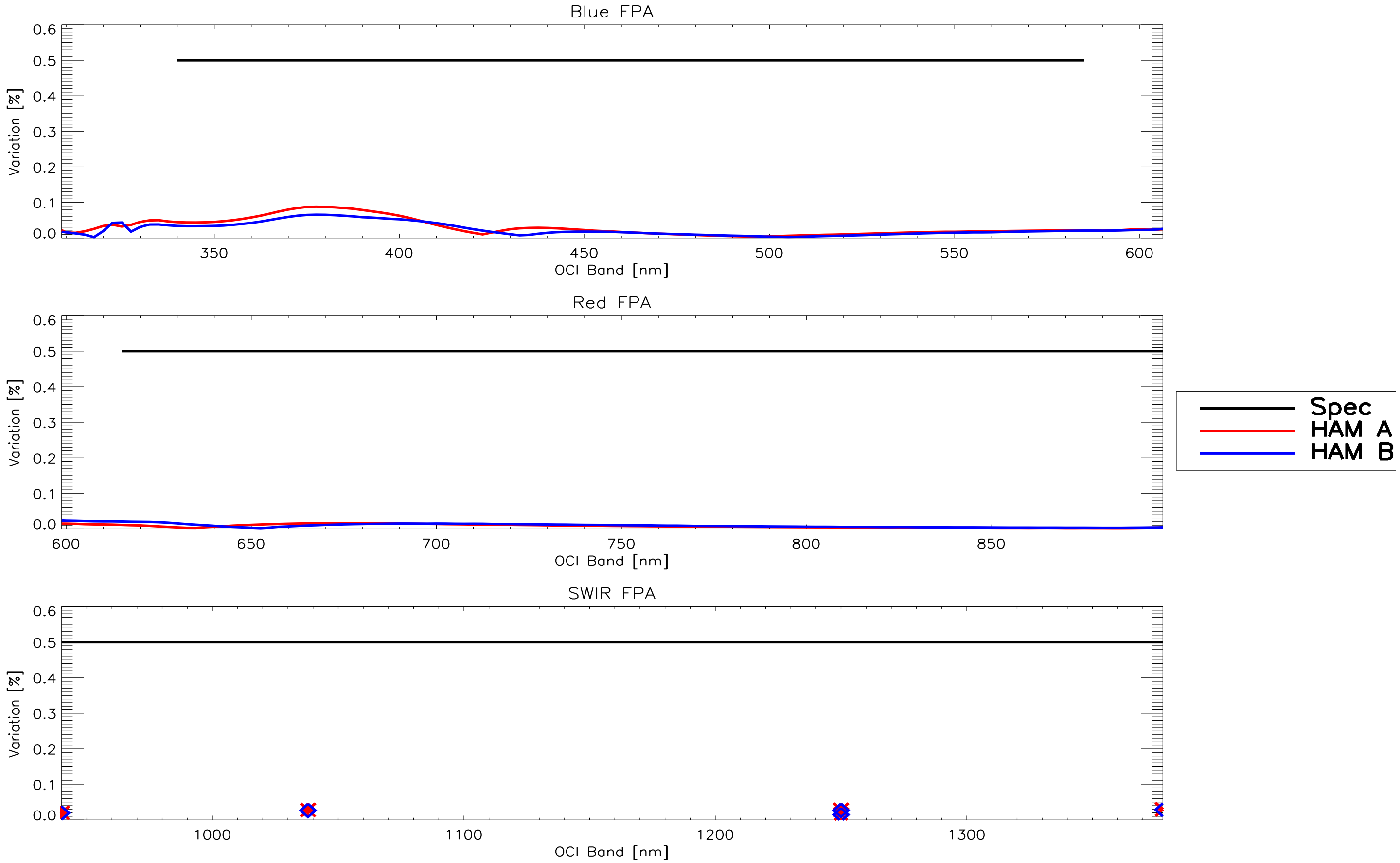
- Upper plot: blue FPA; Middle plot: red FPA; Lower plot: SWIR FPA (InGaAs only)
  - Black line – design requirement (5%)
- Variation larger in blue (350 – 450 nm) with up to 2.5%; SWIR bands also as high as 2%
- Most bands are below 1%



Maximum RVS Variation

Maximum RVS Variation per Degree Scan Angle

- Upper plot: blue FPA; Middle plot: red FPA; Lower plot: SWIR FPA (InGaAs only)
  - Black line – design requirement (0.5%)
- Variation larger in blue (350 – 450 nm) with up to 0.1%
- Most bands showed very low variation per degree scan angle



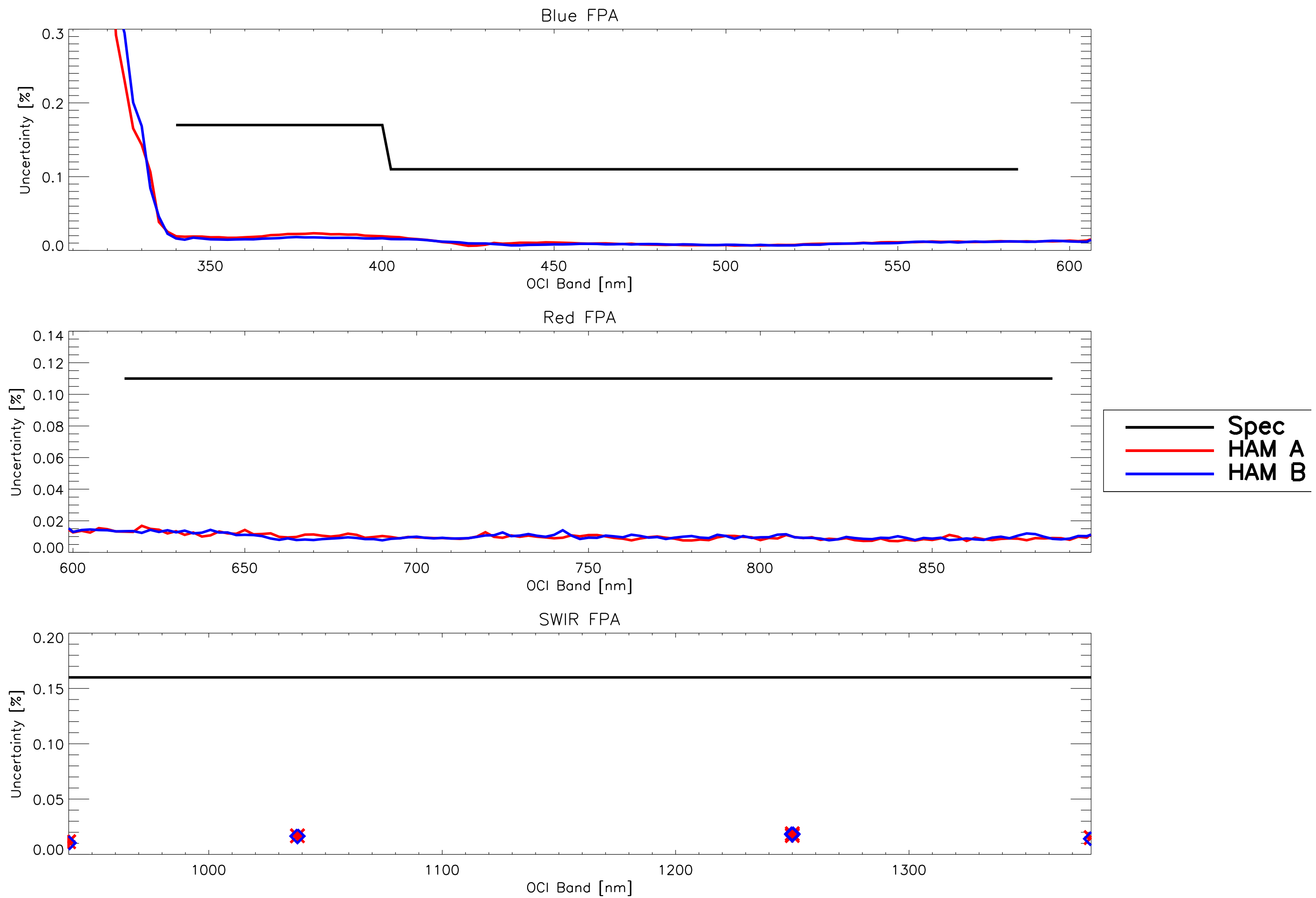
RVS Uncertainty

Maximum RVS Uncertainty

Upper plot: blue FPA; Middle plot: red FPA; Lower plot: SWIR FPA (InGaAs only)

Black line – design requirement (0.11% above 400 nm; 0.17 below 400 nm)

Uncertainties usually in the 0.02 % range, except below 340 nm



RVS Uncertainty

Maximum RVS Uncertainty – HgCdTe Bands

Table shows the uncertainties in the optical model, maximum uncertainty in the InGaAs bands, and prediction error for the 1378nm from the 940nm measurements. The Total uncertainty is the RSS of the three contributors.

	1615 nm	2130 nm	2260 nm
Model	0.6%	0.75%	0.92%
InGaAs	0.058%	0.058%	0.058%
940 / 1378	0.4%	0.4%	0.4%
Total	0.72%	0.85%	1.00%

	940 nm	1038 nm	1250 nm SG	1250 nm HG	1378 nm
Total	0.01%	0.02%	0.02%	0.02%	0.02%

Conclusions

OCI RVS testing was completed and was successful

RVS and uncertainty were measured

- Included all bands over a range of scan angles
- Tables were delivered for use in on-orbit corrections
- Design requirements were met, indicating expected on-orbit performance will be good

Acknowledgements:

- OCI Calibration Working Group
- OCI Test Team