Characterization of the Airborne Compact Atmospheric Mapper During the Global Hawk Pacific Campaign

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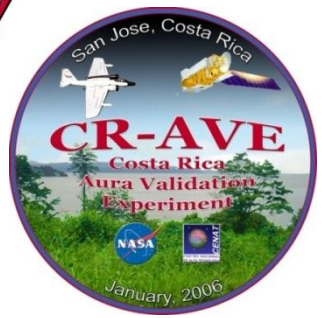


Outline

- Science Objectives
- Instrument Overview
- Characterization
  - Linearity
  - Stray light
  - Radiometry
- Conclusions

Science Objectives

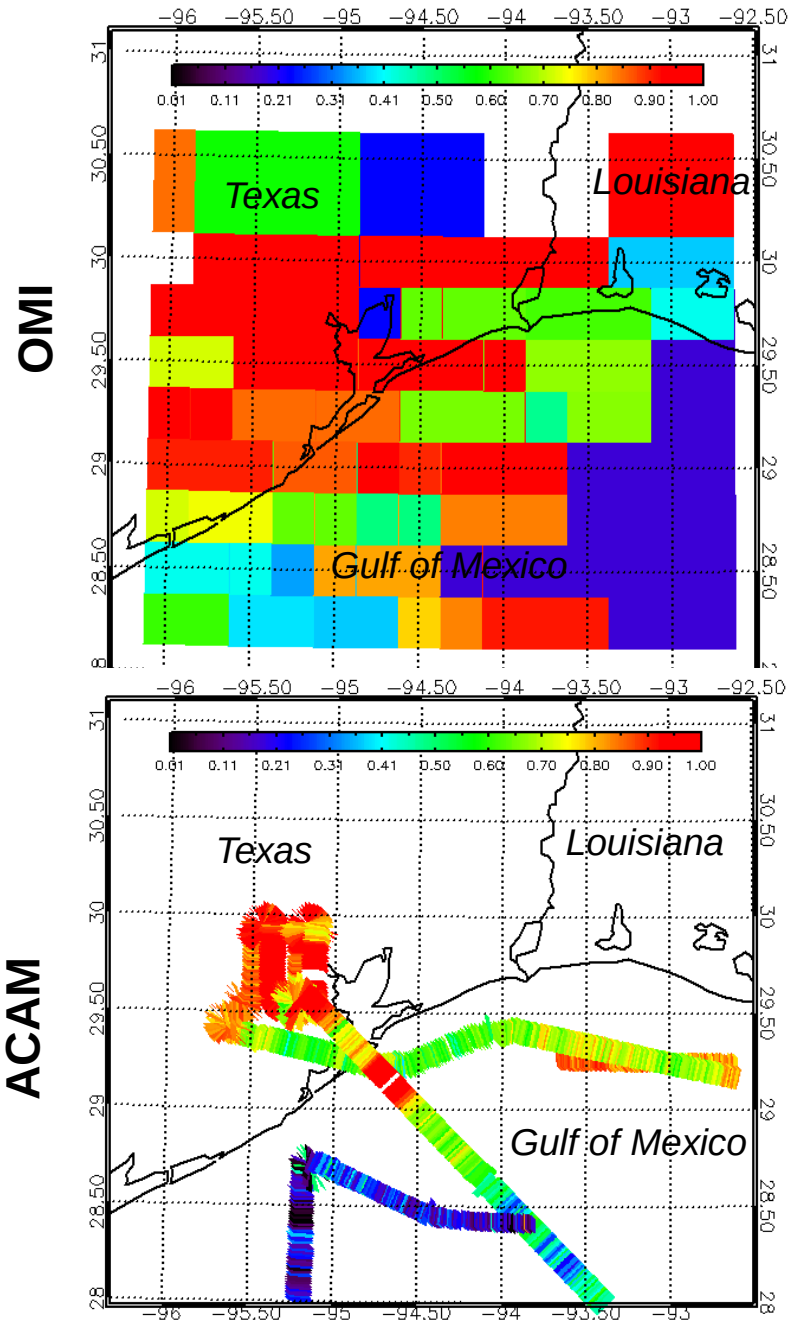
- Boundary layer NO_2 plume spatial scaling – OMI sub-pixel scaling errors and model studies for next-generation Geostationary sensors.

- NO_2 diurnal variability – model improvement for next-generation Geostationary sensors.

- Aerosol loading and distribution.

- Test sensitivity of Ocean Color spectrograph.

- Test radiometric calibration trending precision.



ACAM Integration Requirements

Instrument specifications:
Mechanical and Electrical

Size: 20"x16"x11"

Weight: 55 lbs

Power: 420 Watts DC (approx max)

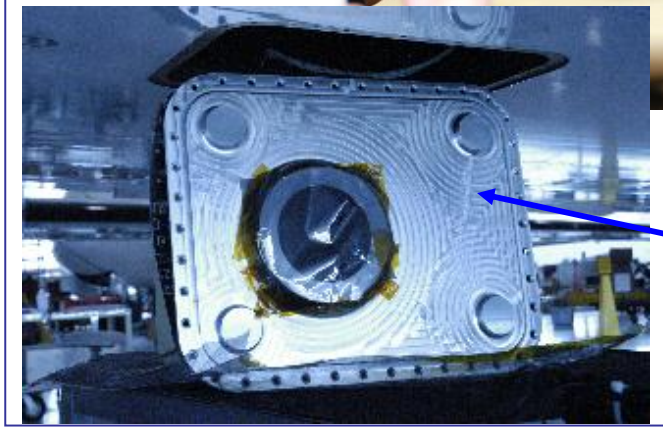
Inlet probe: NA

Exhaust port: NA

View ports/windows: (2) 4.9" Fused Silica, Zenith viewing fiber

Hazards (Lasers, Pressure vessels, Compressed Gases, Chemicals, Motors/Pumps, Batteries, etc.): none

Instrument Photo:



Instrument Requirements:
Control and Communication

 # Control Switches: (2) instrument power, survival heaters

Communications Bandwidth:

Required: Housekeeping 1Hz @ 750 bps

Desired : Video @ 1Mbs, Full frame ~70kbs,
QuickLook sub-sample spectral ROI's

Nav / Time inputs: Timesync & Nav via ethernet

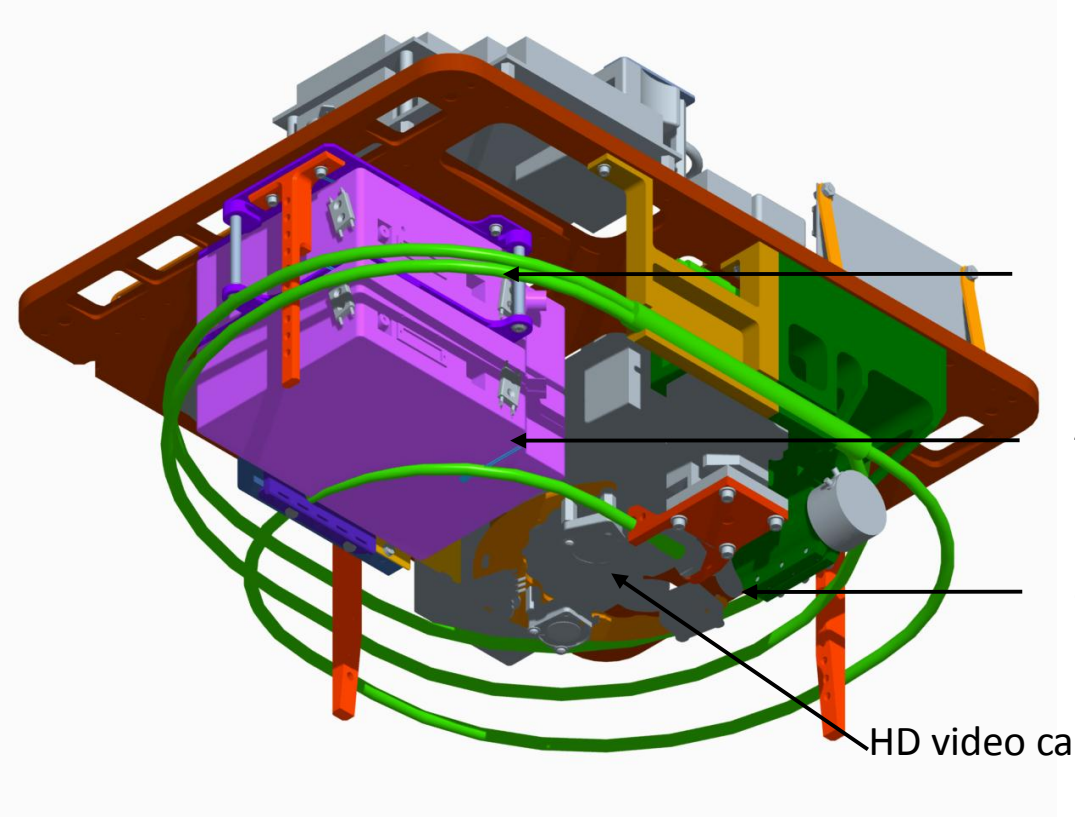
Instrument Modifications needed:

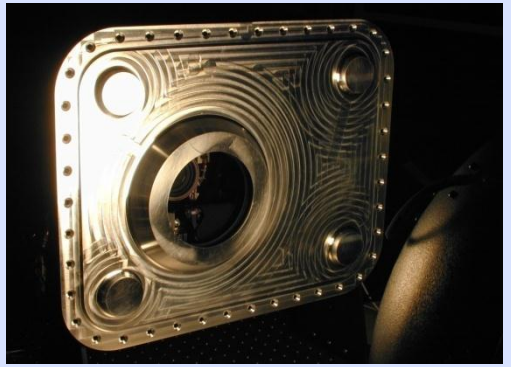
- **Hardware**
  - Zenith sky fiber feed through port.
  - Power and data connectors.
- **Software**
  - CMDH via ethernet
  - –Real-time science retrievals.

ACAM Optical Description

- **Two fiber coupled miniature spectrographs (nadir and zenith viewing)**
  - **Air Quality (AQ) 304:520nm @ 0.8nm resolution (NO2, O3, UV absorbing aerosols, *HCHO*)**
  - **Ocean Color (OC) 460:900nm @ 1.6nm resolution, GG475 long pass filter**

  (Aerosols, Ocean Color, water vapor)
- **HD video camera (2592 x 1936 pixels) – 3 pixel FWHM**





Optical bench and support electronics contained in pressure and temperature controlled enclosure

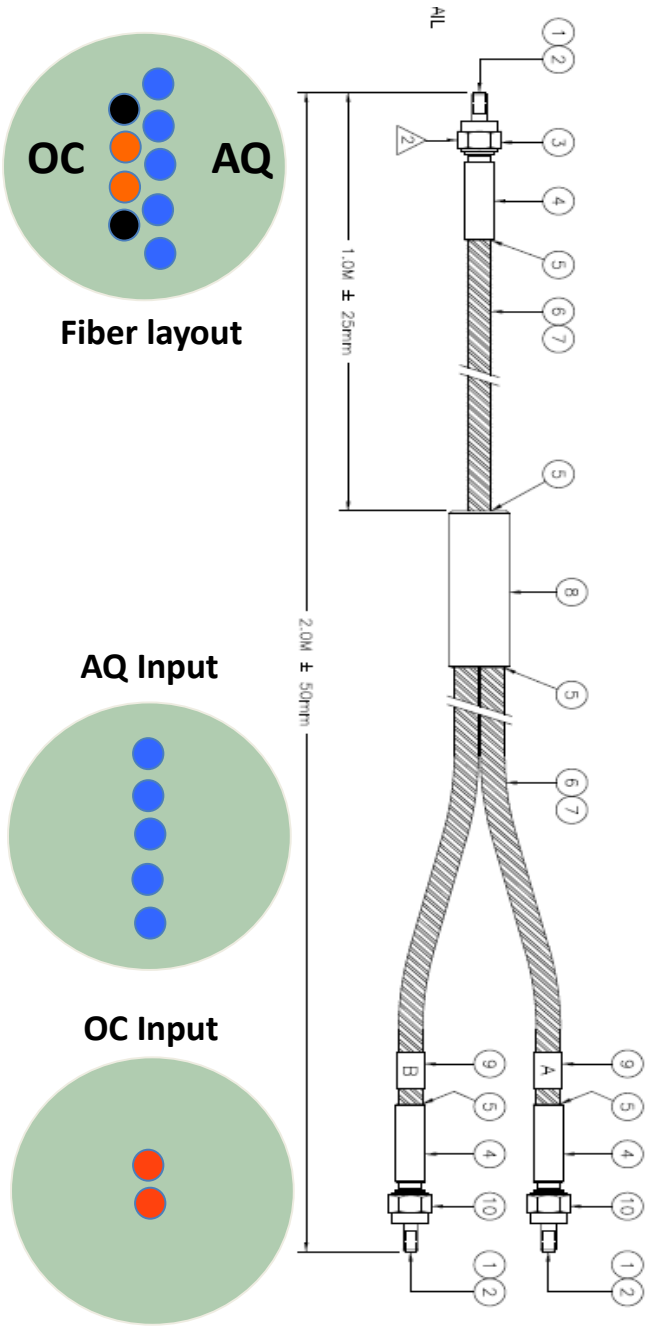
55 lbs total weight

250 watts avg. power

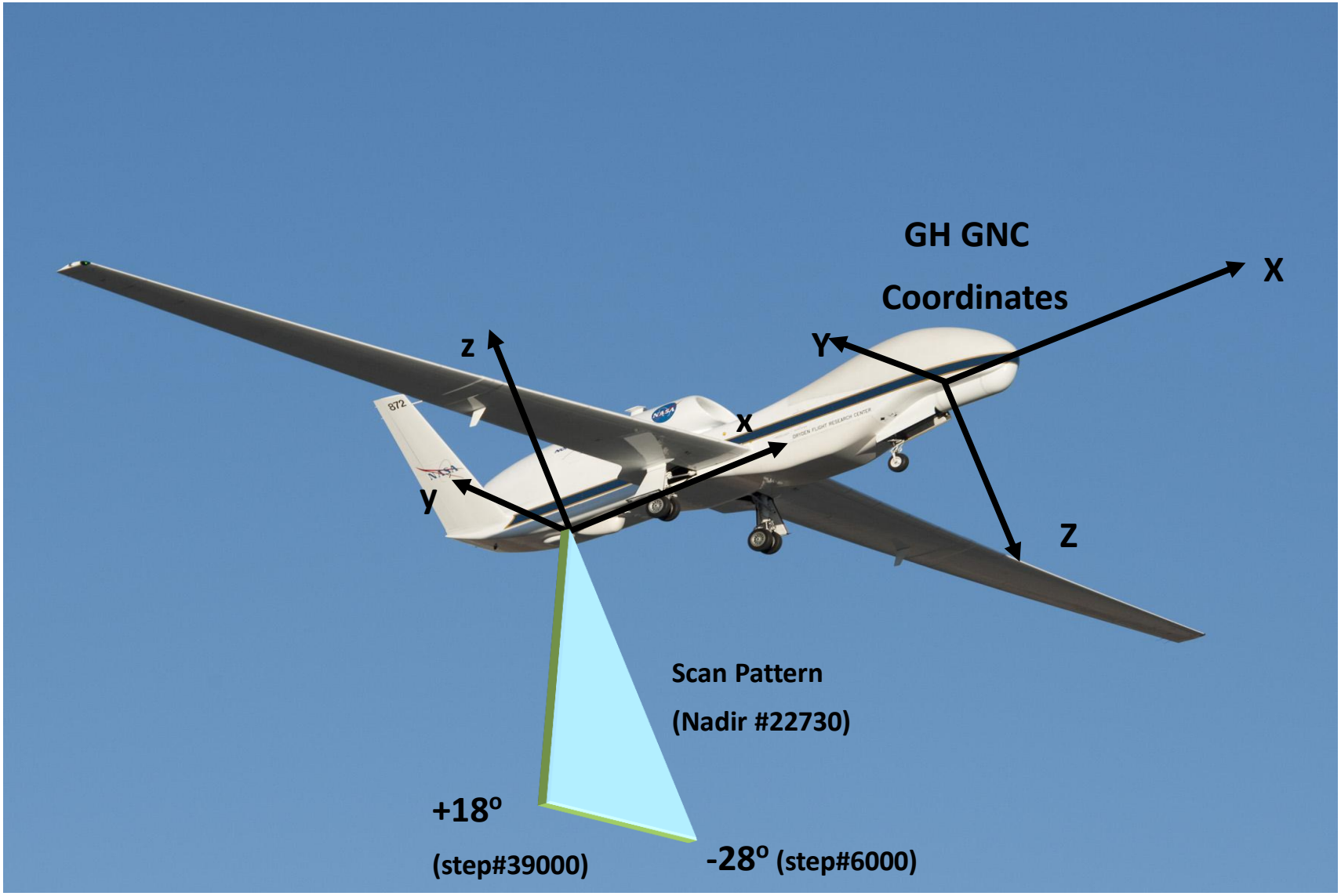
Fiber Optics

- **Nadir view**
  - Common fiber optic feed from collimator which images IFOV 800m x 800m (AQ), 375m x 800m (OC) from an 18 km altitude.
  - IFOV scanned via a small mirror mounted on a galvanometer up to angles of ±40º.
  - Fiber optically matched to spectrometers (F/4).

- **Zenith view**
  - 30' 19x220um bundle with collimator mounted on vertical fin feeds vacuum compatible bulkhead feed-through.
  - Fiber coupler and index matching optical couplant used to decrease transmission loss at fiber connection.
  - Feed-through extends inside housing to illuminate scan mirror.



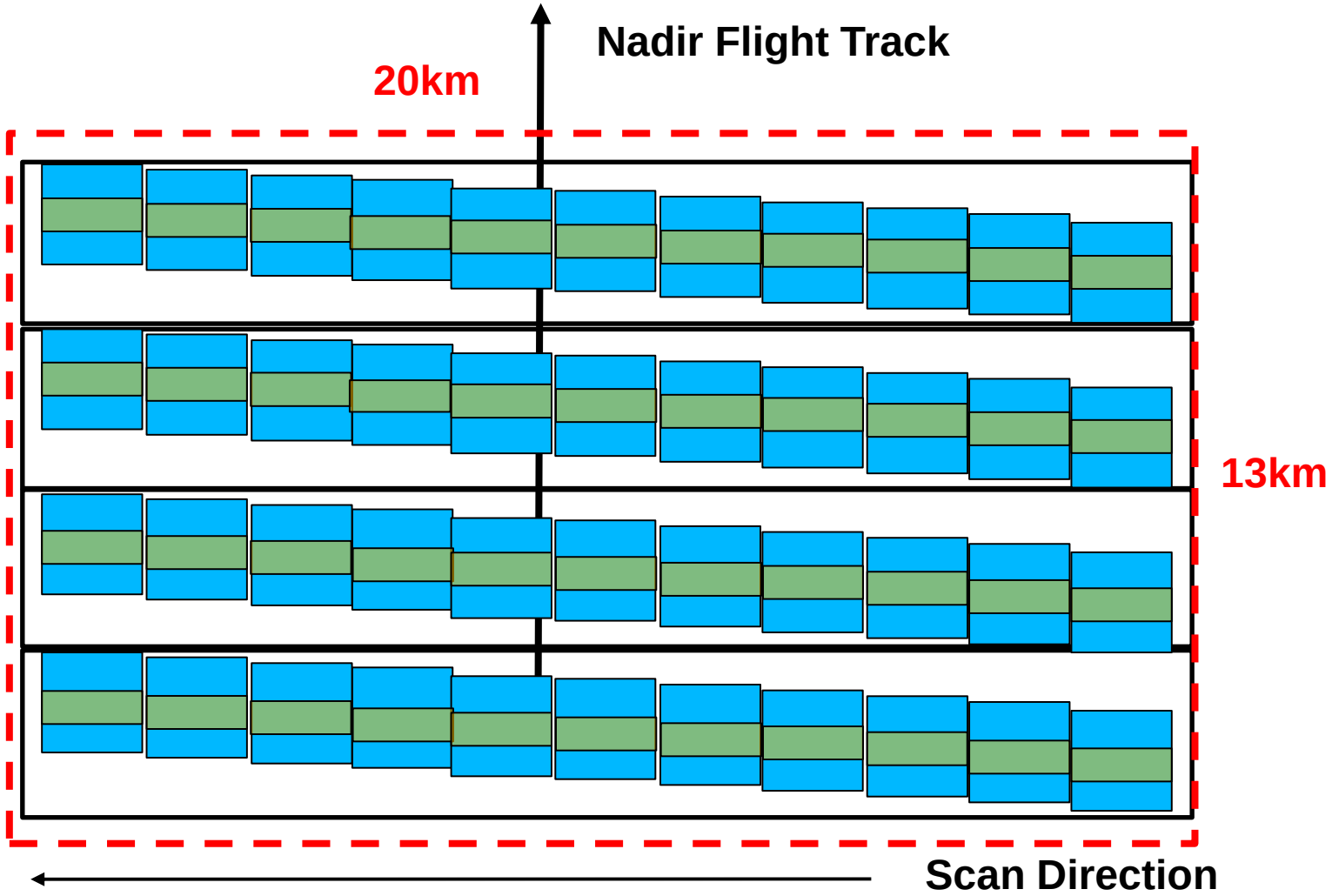
Global Hawk – ACAM Coordinate Frames



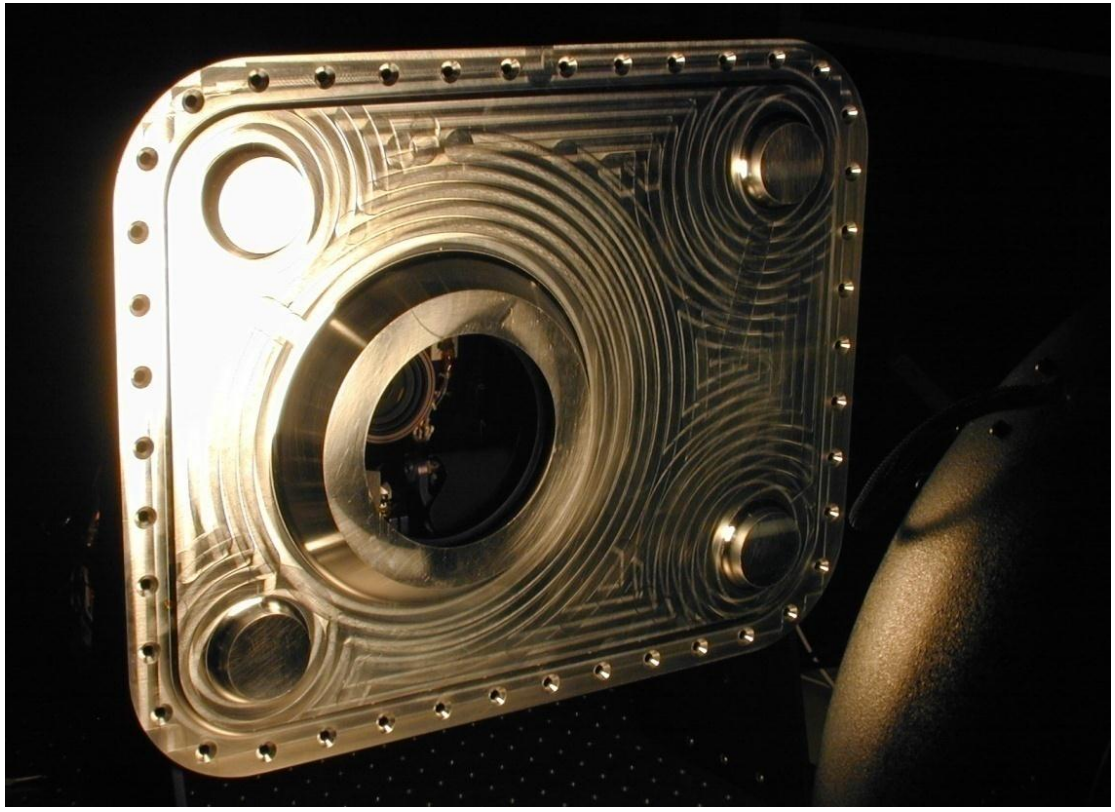
ACAM Operations

Scan Pattern

- Elphel 40º x 50º
- Video image rate 10Hz
- 11 steps per scan
- ~0.7sec/step



Characterization

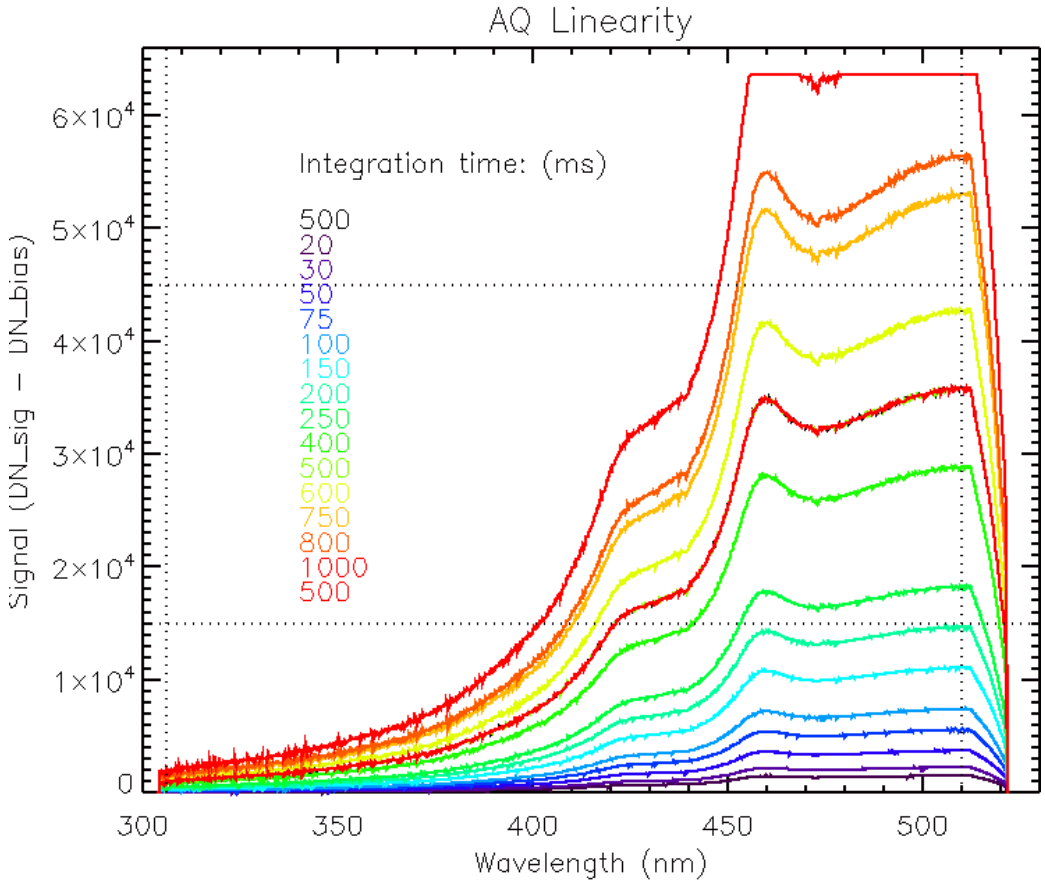


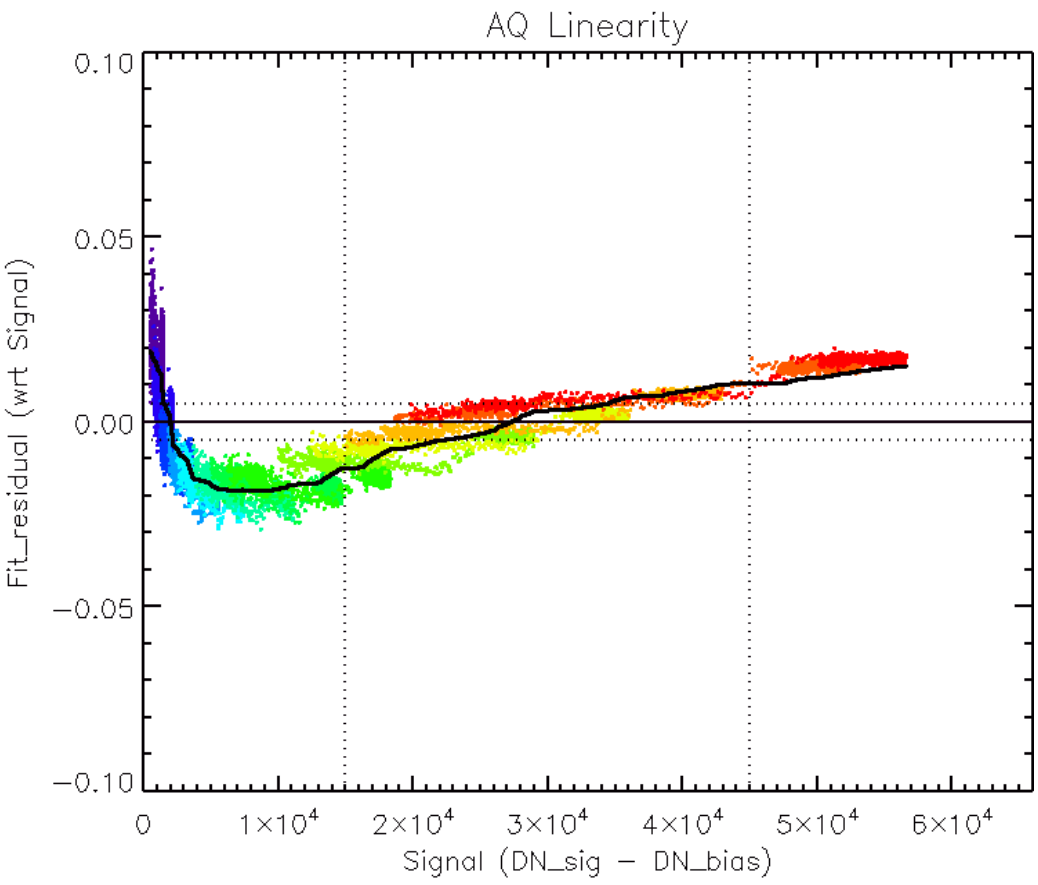
- Linearity
- Stray Light
  - Laser slit function
  - Broad band
- Radiometry
  - Scan angle dependence
  - Stability

Linearity

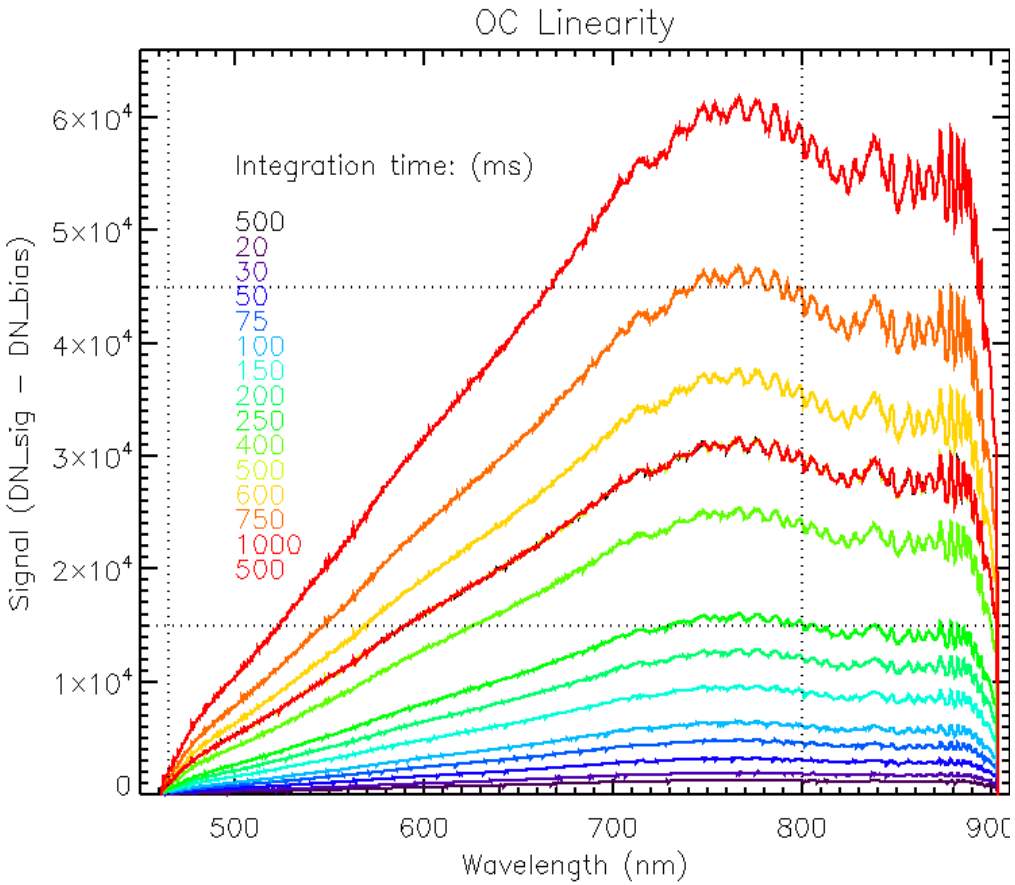
- Test Description
  - Field calibration source at constant output.
  - Multiple integration times to probe dynamic range.
  - Repeated integration times to monitor source changes.
- Data analysis
  - Each pixel's bias corrected signal linearly fit as function of integration time.
  - Fit residuals characterized as a function of signal level to determine non-linearity.

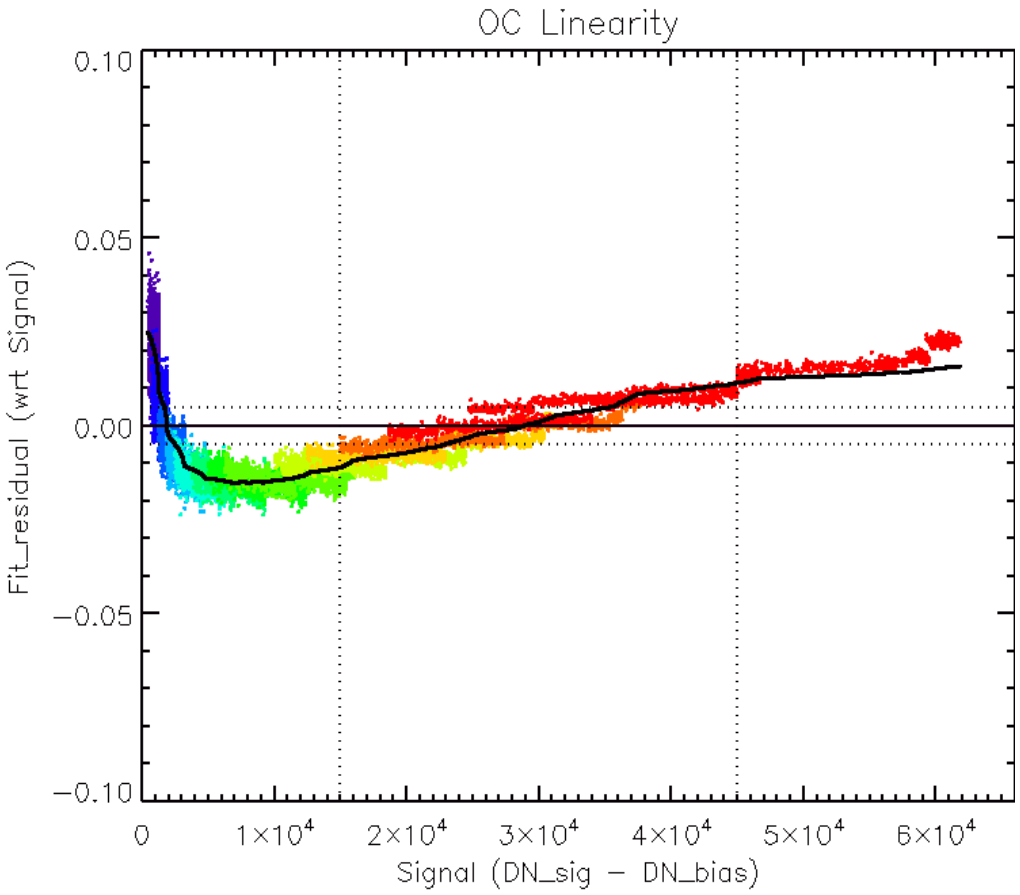
Linearity – AQ Results





Linearity – OC Results





Radiometric Calibration

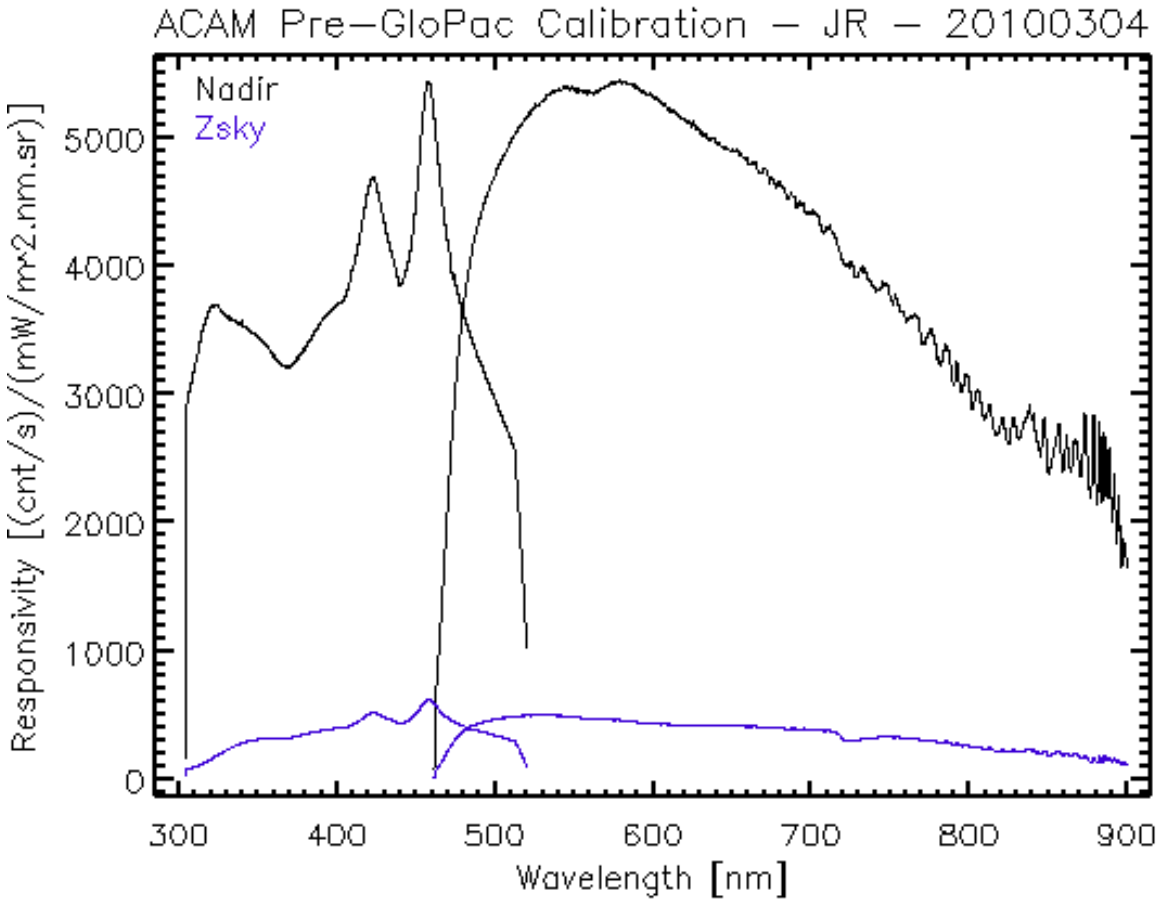
- Previous missions showed significant wavelength dependent sensitivity changes.

- Achieving sub-5% radiance transfers with satellite sensors requires in-field calibration monitoring.

- Calibration test plan
  - Pre- and Post-Mission laboratory tests include:
    - Calibration transfer of lab and field sphere sources.
    - ACAM calibration using both sources.
  - Field calibration before and/or after each flight.

Radiometric Results

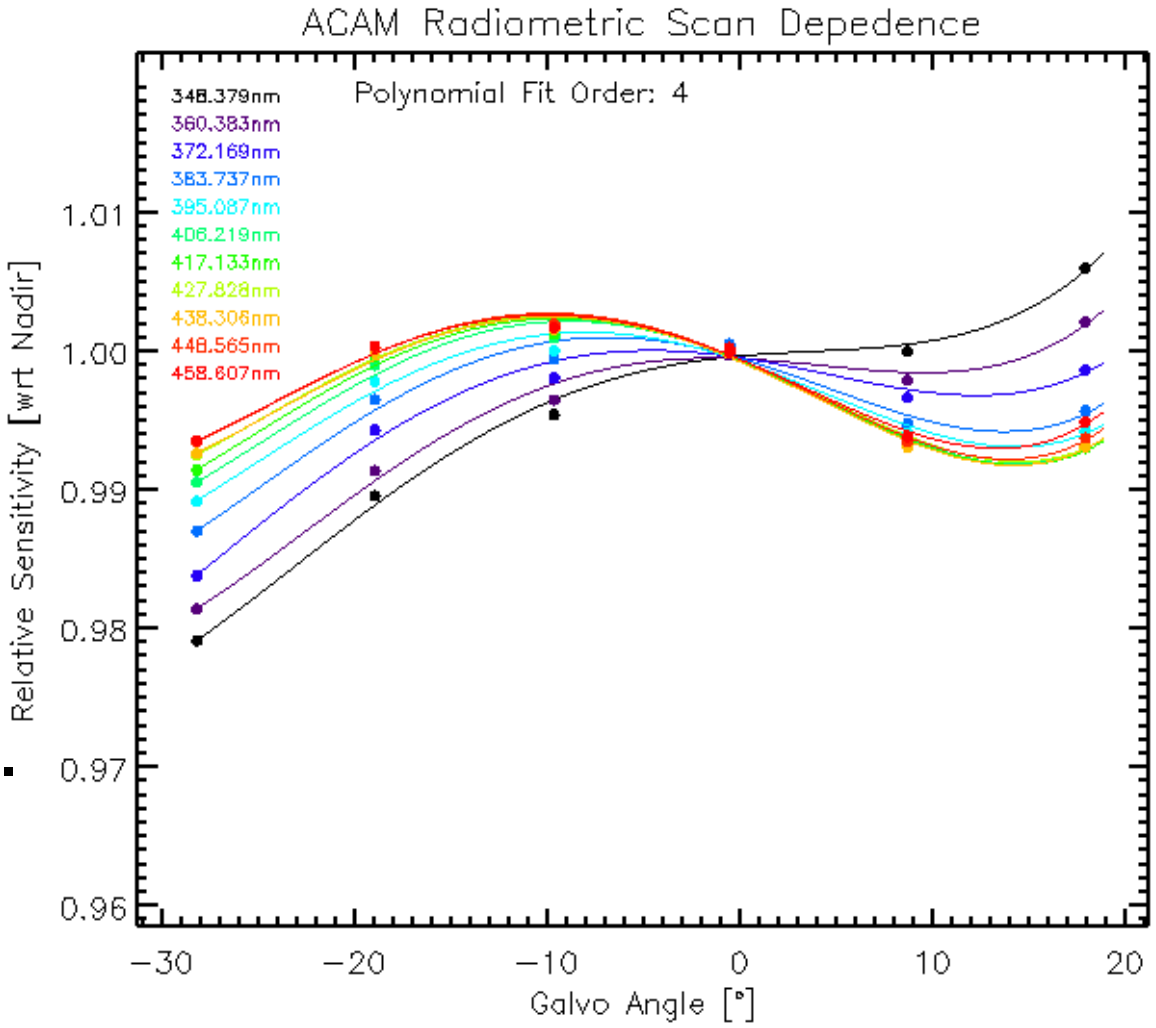
- **Laboratory integrating sphere calibrated against multiple NIST irradiance standards.**
- **Description:**
  - **20” internal diameter**
  - **8” exit port**
  - **PTFE linear**
  - **2 or 4 (configurable), 150W QTH internal bulbs**
  - **Single power supply monitored by shunt & meter**



- **Transfer uncertainty 1.5% [k=1] at 300nm**

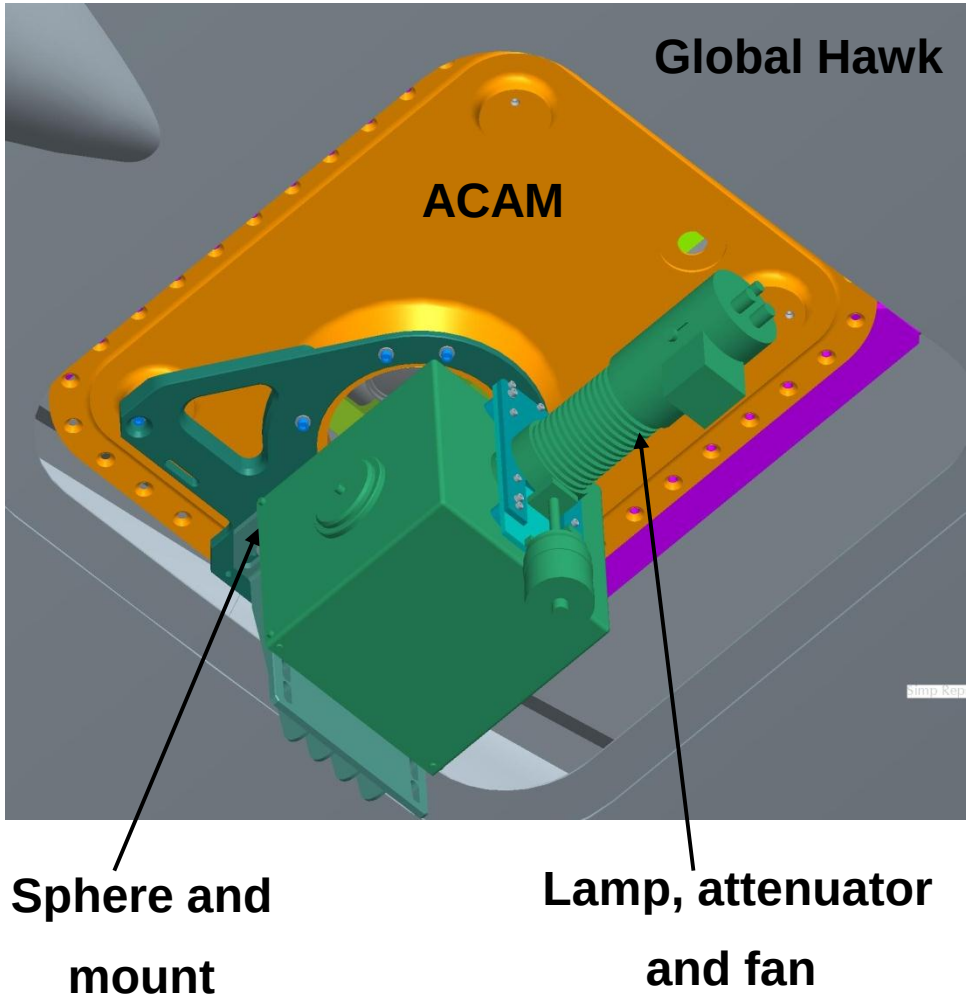
Radiometric Scan Dependence

- **Radiometric scan angle dependence measured by rotating ACAM about scan mirror while viewing sphere.**
- **Required for determining aerosol, ocean color, and radiance transfer comparisons.**
- **No internal scattering sources found.**

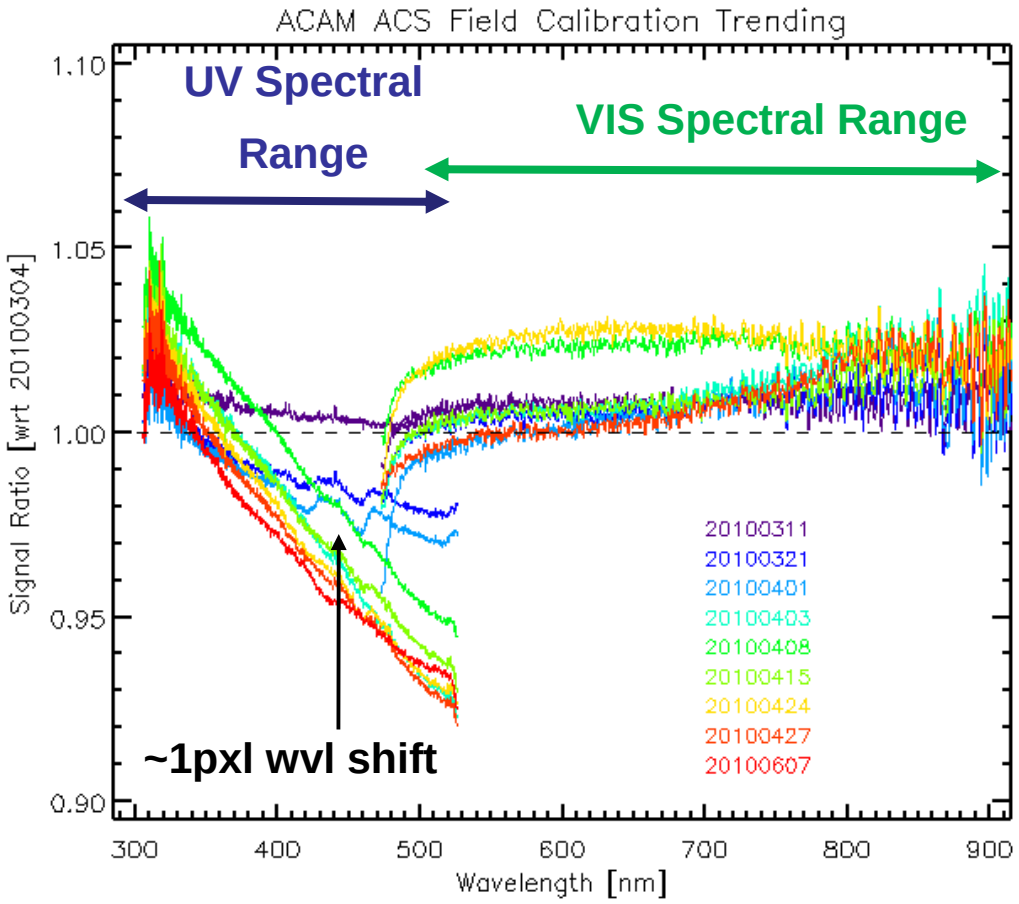


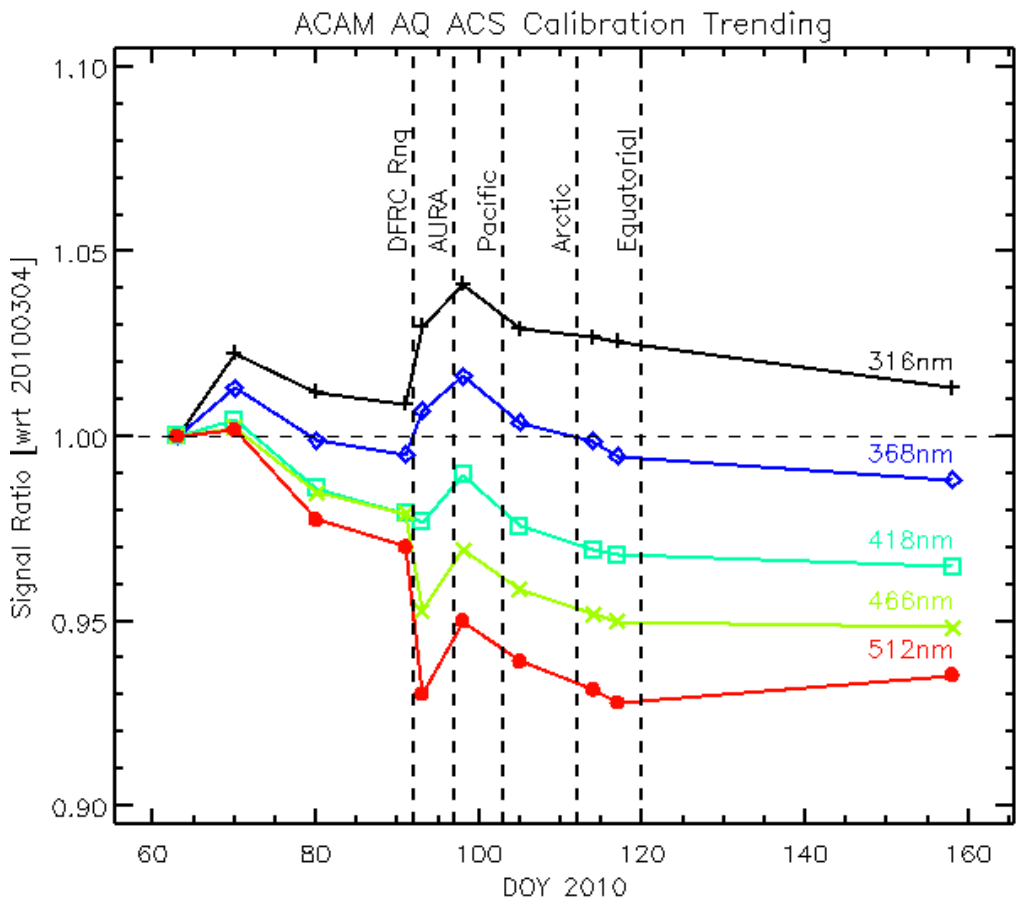
Field Calibration

- **Source description:**
  - **6” internal diameter PTFE liner**
  - **Single 150W QTH lamp**
  - **Micrometer driven attenuator**
- **Single power supply, current monitored with shunt and meter.**
- **Calibration performed prior to or after every flight.**
- **Spectrometers cooled to flight operating temperatures to ~1C.**



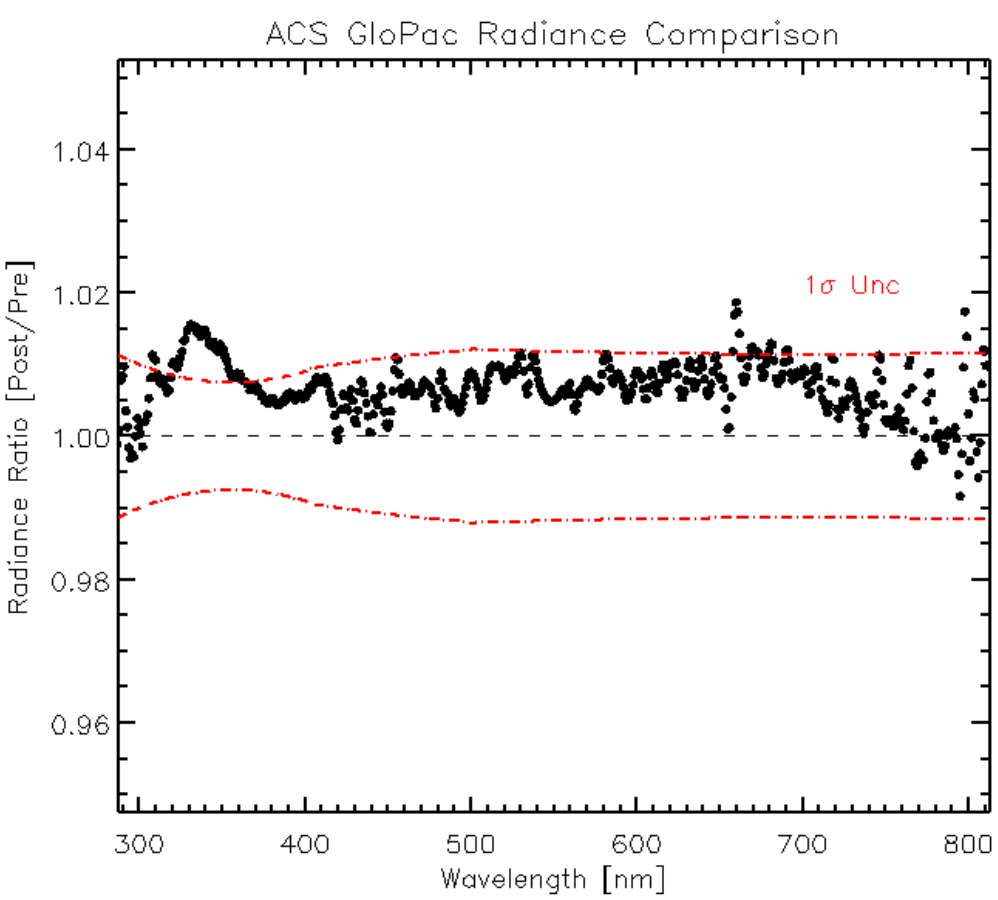
Radiometric Stability

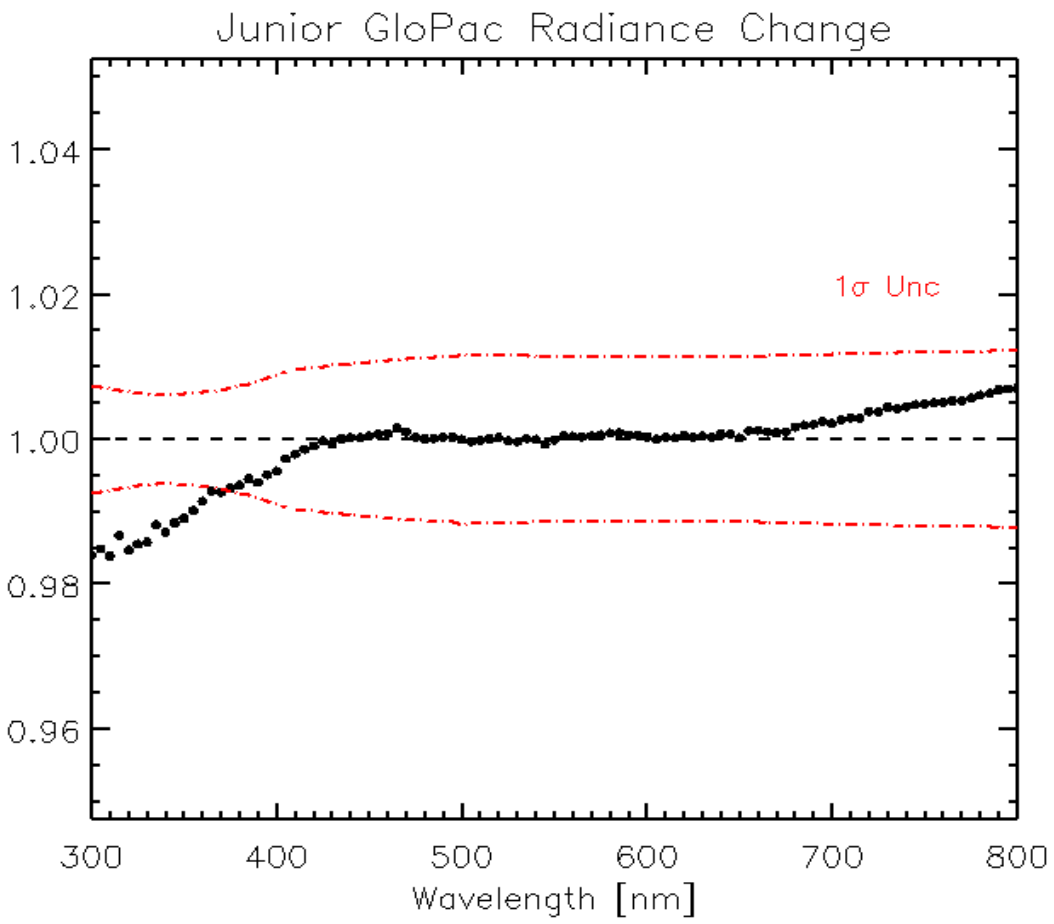




- 7% UV throughput change that started prior to first flight on April 1.
- Counter-intuitive spectral dependence for source or instrument degradation.
- Possible alignment change or contaminant on focus mirror or CCD window.
- Spectrometer temperatures changes caused AQ spectral features and OC etaloning features.

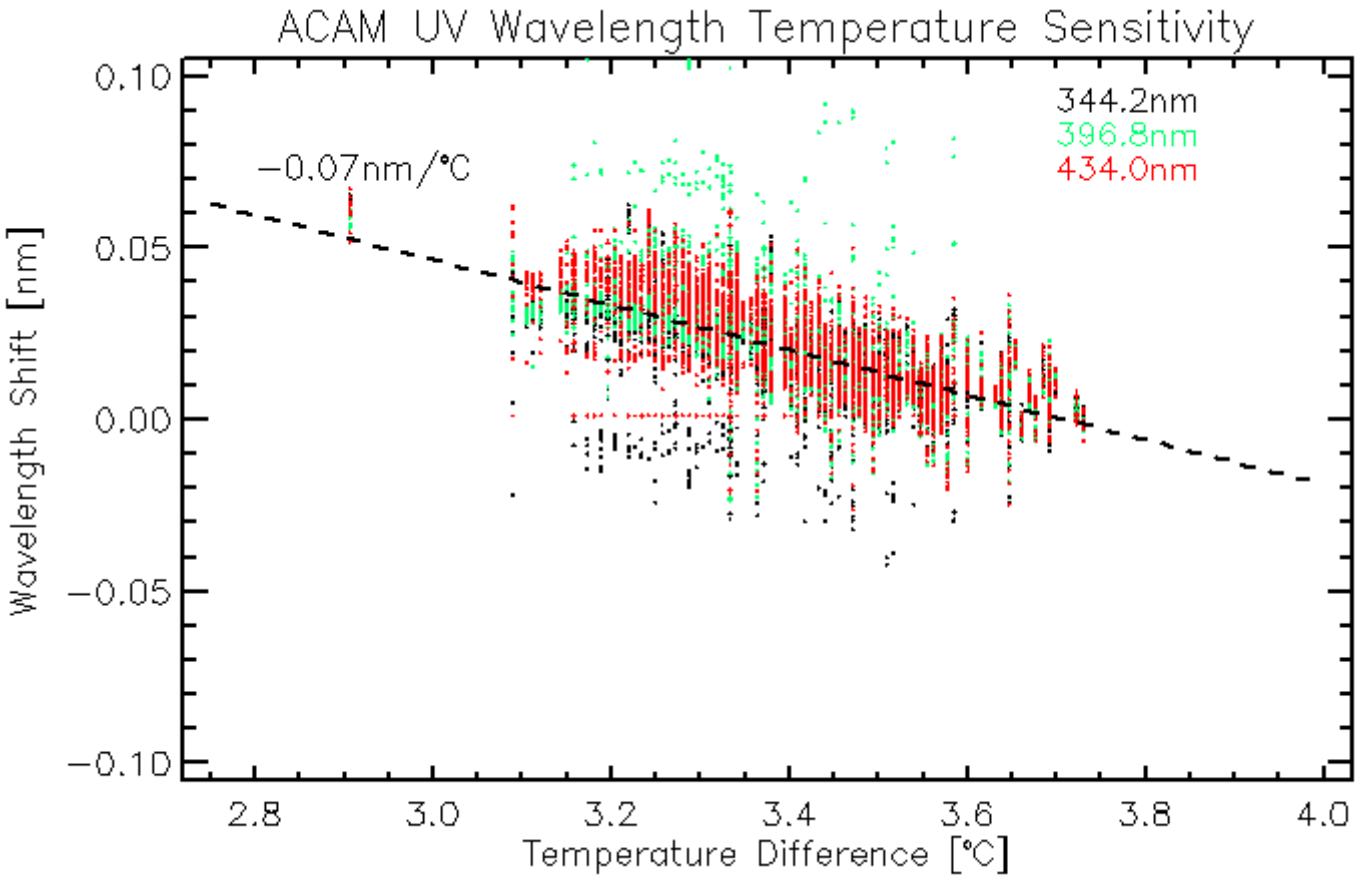
Radiometric Source Stability





- **Calibration sources fairly stable, with minor changes <350nm.**
- **Instrument changes not caused by source changes.**

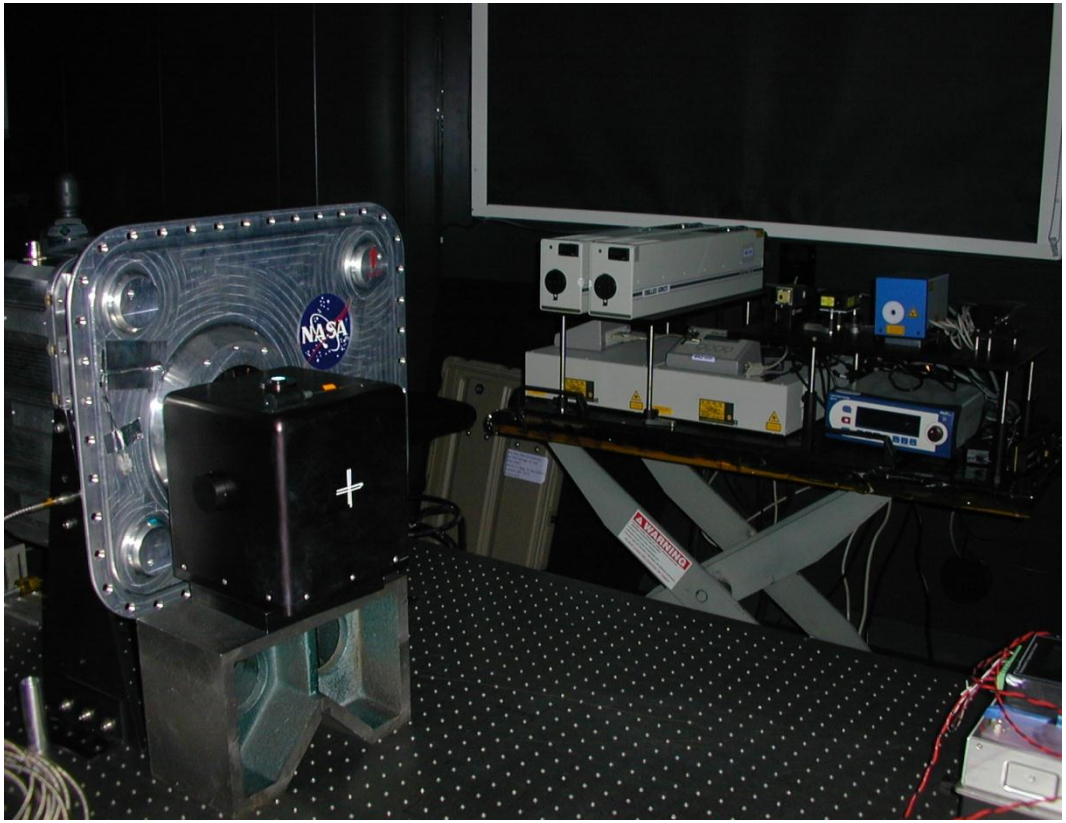
Spectral Stability



- Solar line fits to in-flight data used to characterize wavelength temperature dependence.
- Observed shift in AQ calibration trend (~1pxl) consistent with 1C temperature stability performance given spectrometer's 0.1nm/pxl sampling.

Slit Function

- Test Description
  - Discrete laser sources with line widths << spectral bandpass.
  - Lasers illuminated 6” integrating sphere which illuminated ACAM nadir scan mirror.
  - Multiple integration times to enhance characterization of wings.



- Data analysis
  - Bias correction & dark current corrections.
  - Integration time normalization.
  - Multiple integration times stitched together to create slit function.

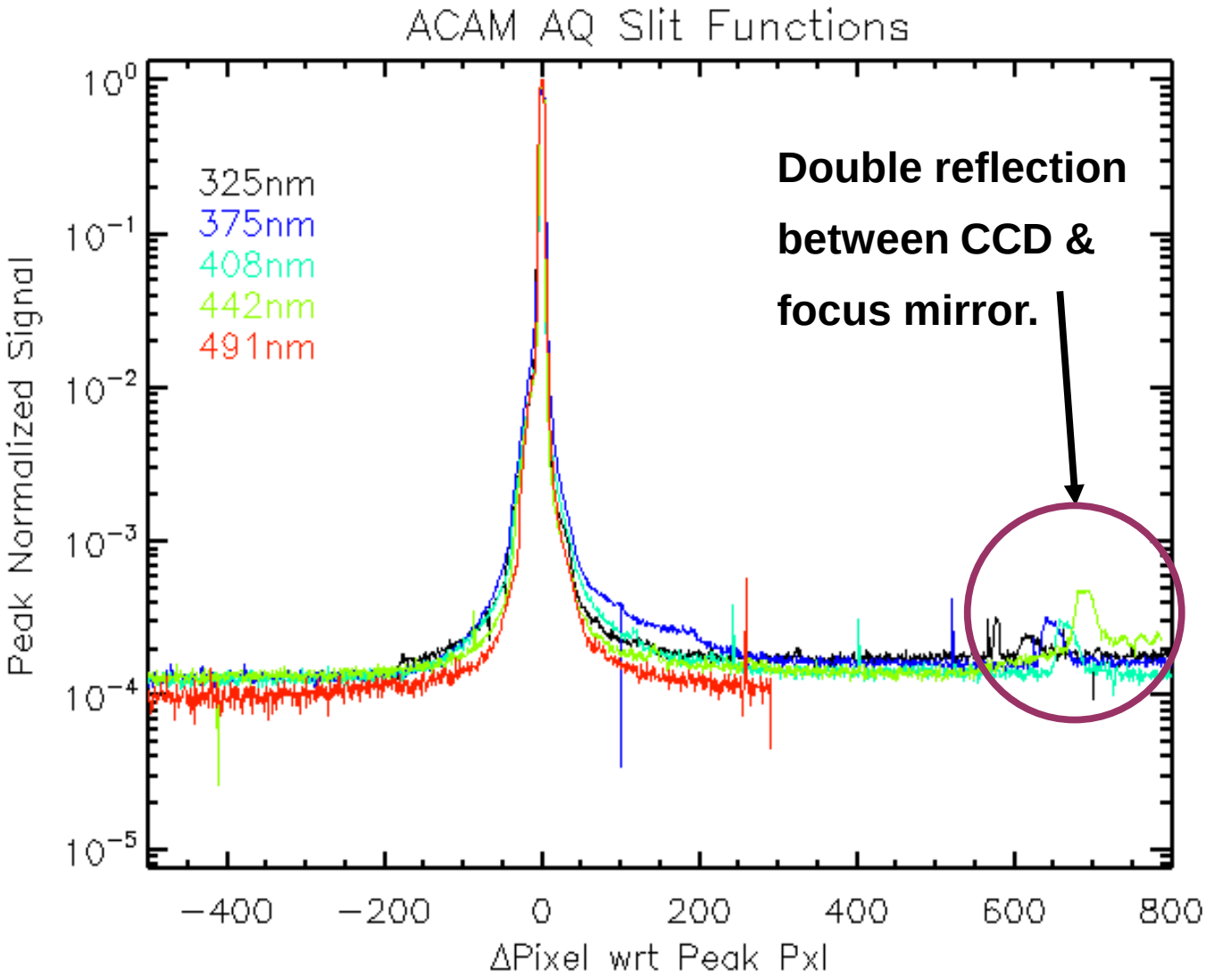
Slit Function - Results

- **Laser wavelength range limited slit function characterization to AQ spectrometer.**
- **Wavelength spacing too large for matrix correction.**

(Zong et al,. "Simple stray light correction method for array spectrometers", Applied Optics 2006).

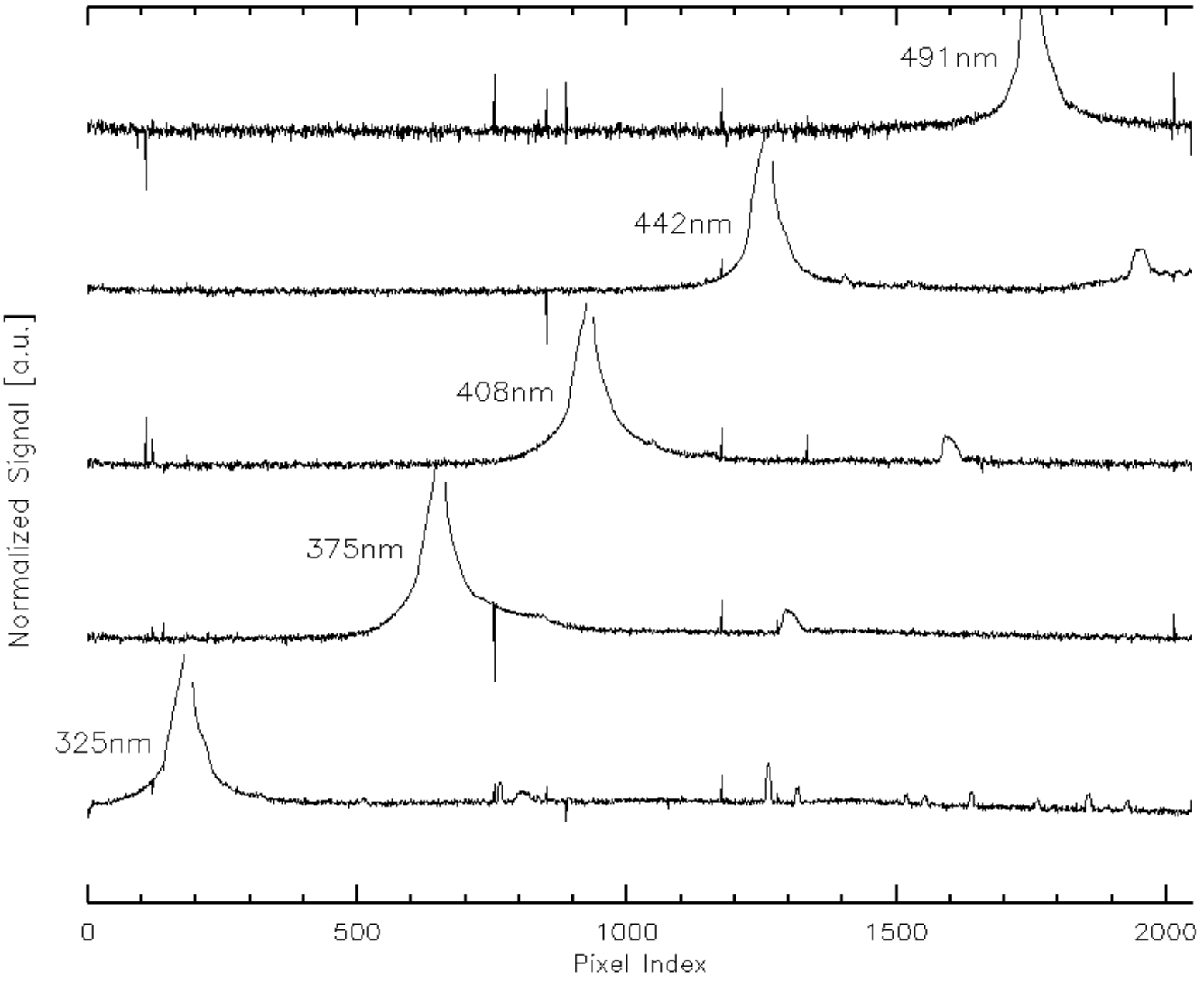
- **Spectral features seen in all slit functions (~5×10^{-5}).**
- **No sphere liner fluorescence observed.**

Slit Function – Results



14um pixel pitch

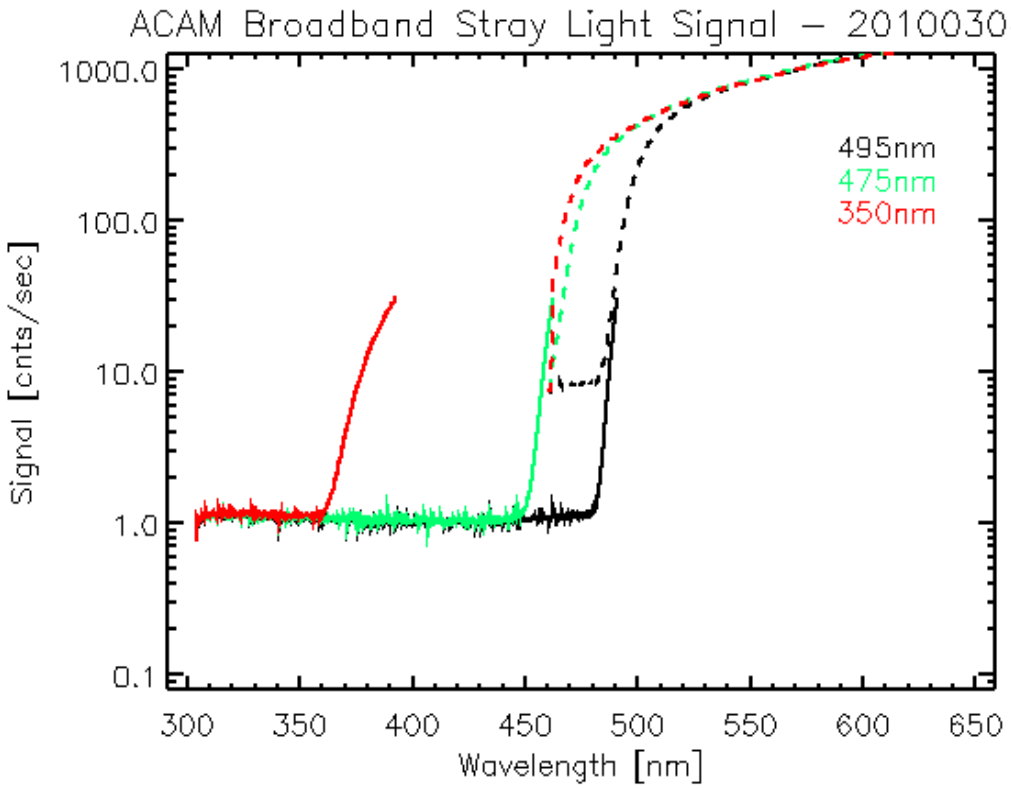
Slit Function - Results

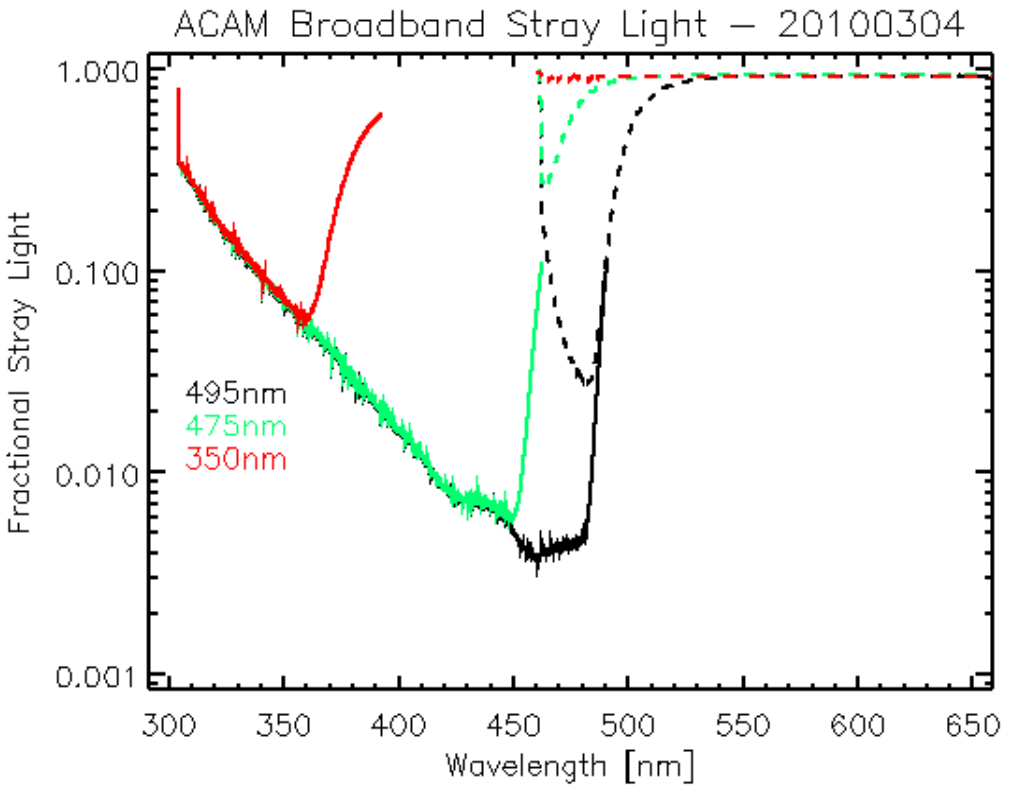


Broadband Stray Light

- Test Description
  - Field calibration source illuminates nadir viewing scan mirror.
  - Multiple cut-on filters used to isolate spectral source of scatter.
    - 350nm, 475nm, 495nm
    - All have blocking efficiencies better than 10^{-5}
- Data analysis
  - Bias correction & dark current corrections.
  - Integration time normalization.

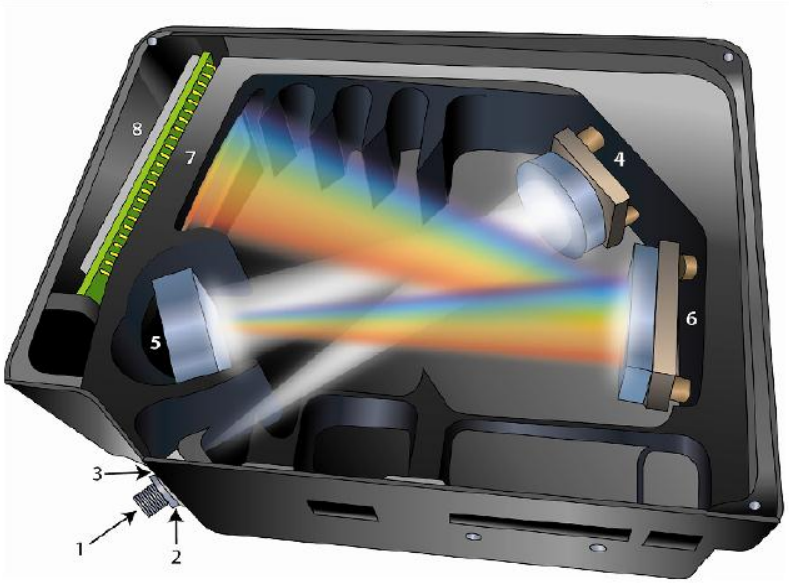
Broadband Stray Light



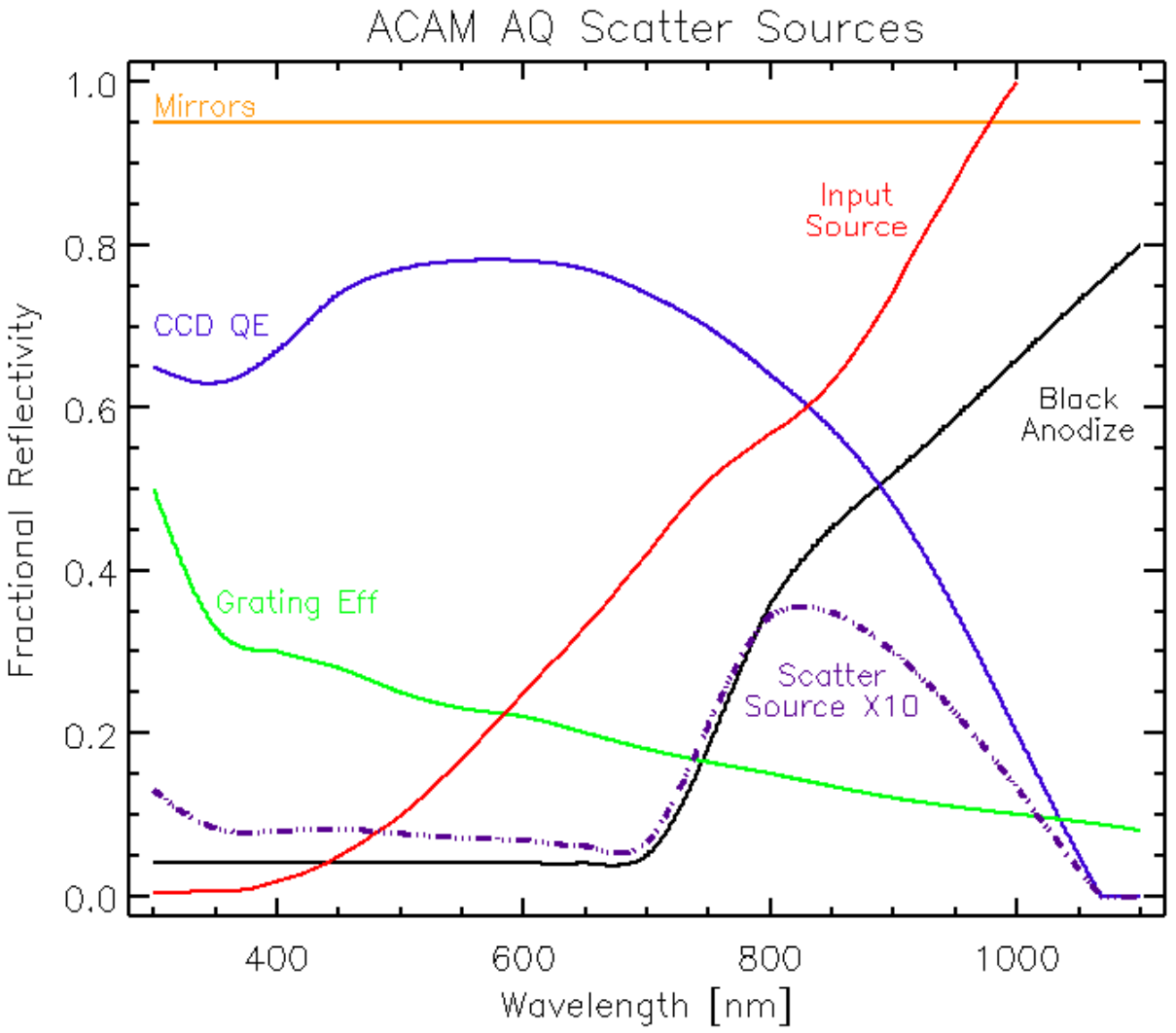


- Different filters yield similar scatter levels below cut-on wavelength.
- More recent tests using OG590 cut-on filter yields similar results.
- Nearly 30% of observed calibration signal at 300nm due to scatter.

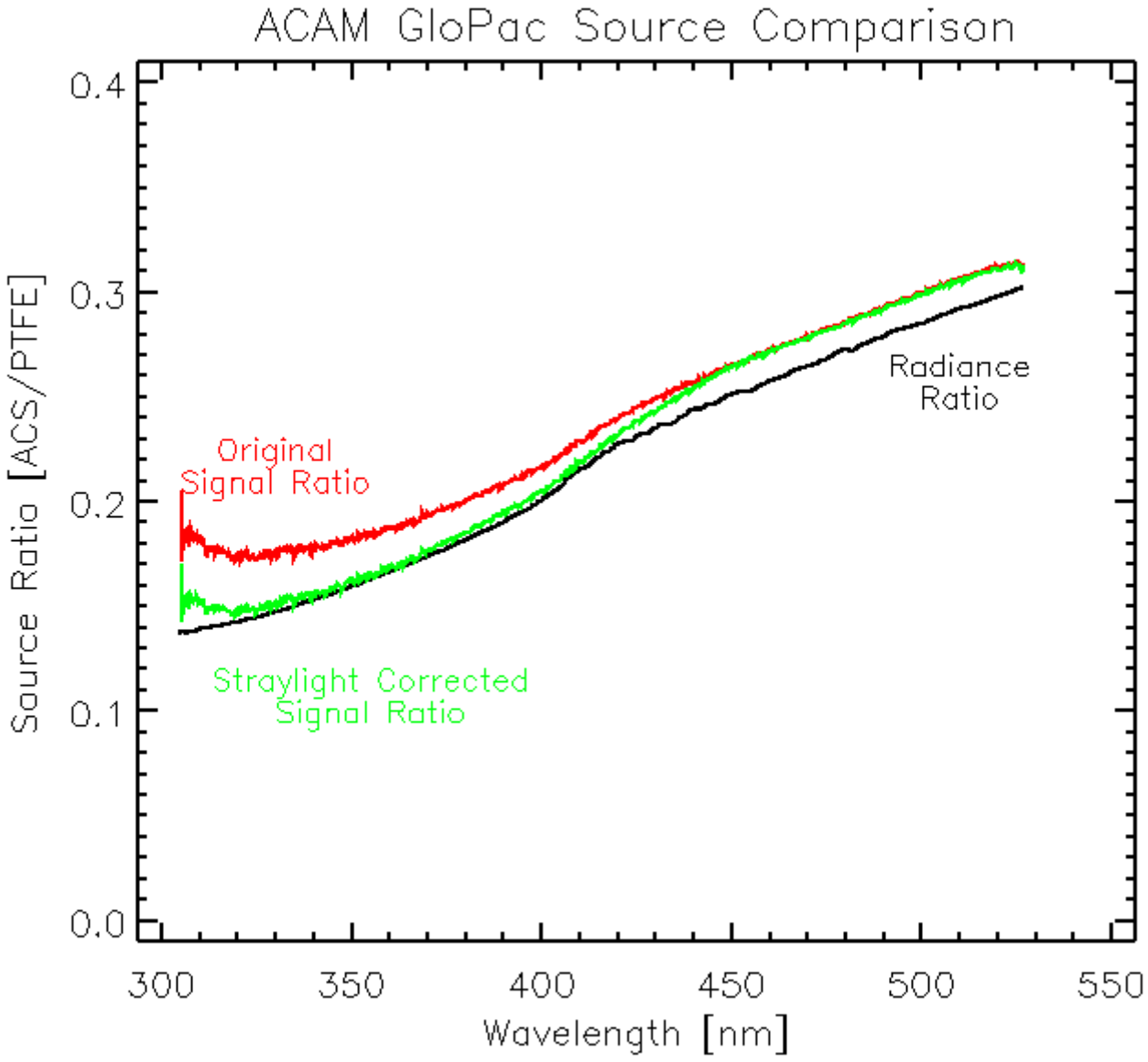
Scattering Sources



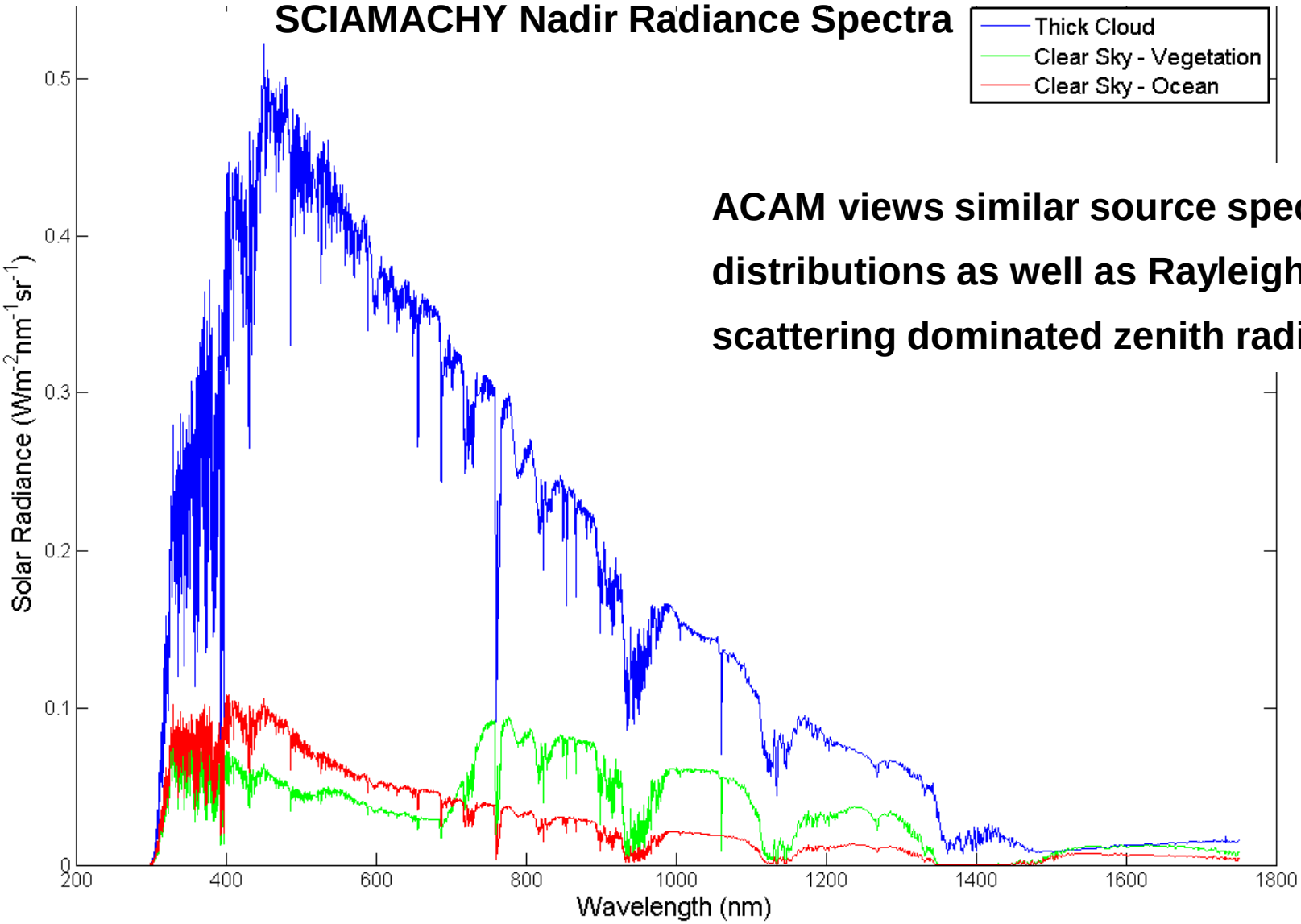
*www.OceanOptics.com



Broadband Correction



ACAM Terrestrial Sources



ACAM views similar source spectral distributions as well as Rayleigh scattering dominated zenith radiances.

Pilewskie et al,, “CLARREO Visible and Near-Infrared Studies”, LASP U. Colorado.

clarreo.larc.nasa.gov/docs/III.6_LASP_Solar_Studies_Oct_workshop.ppt

Conclusions

- Non-linearity characterized to within 0.5%.
- Field calibration trending precision ~2%.
  - AQ experienced time and spectrally dependent change during mission.
  - OC stable to within trending uncertainty (2%). No significant spectral dependence aside from etaloning.
  - Spectrometer temperature repeatability/stability critical to accurate trending.
- Spectrometers' slit function characterizations require higher wavelength fidelity.
- Broadband stray light indicates AQ scattering source from out from out of range wavelengths (700-1000nm).
- OC exhibits some short wavelength scatter. Requires more testing.


Thank you for your attention