OCO-2 Calibration/Instrument Update

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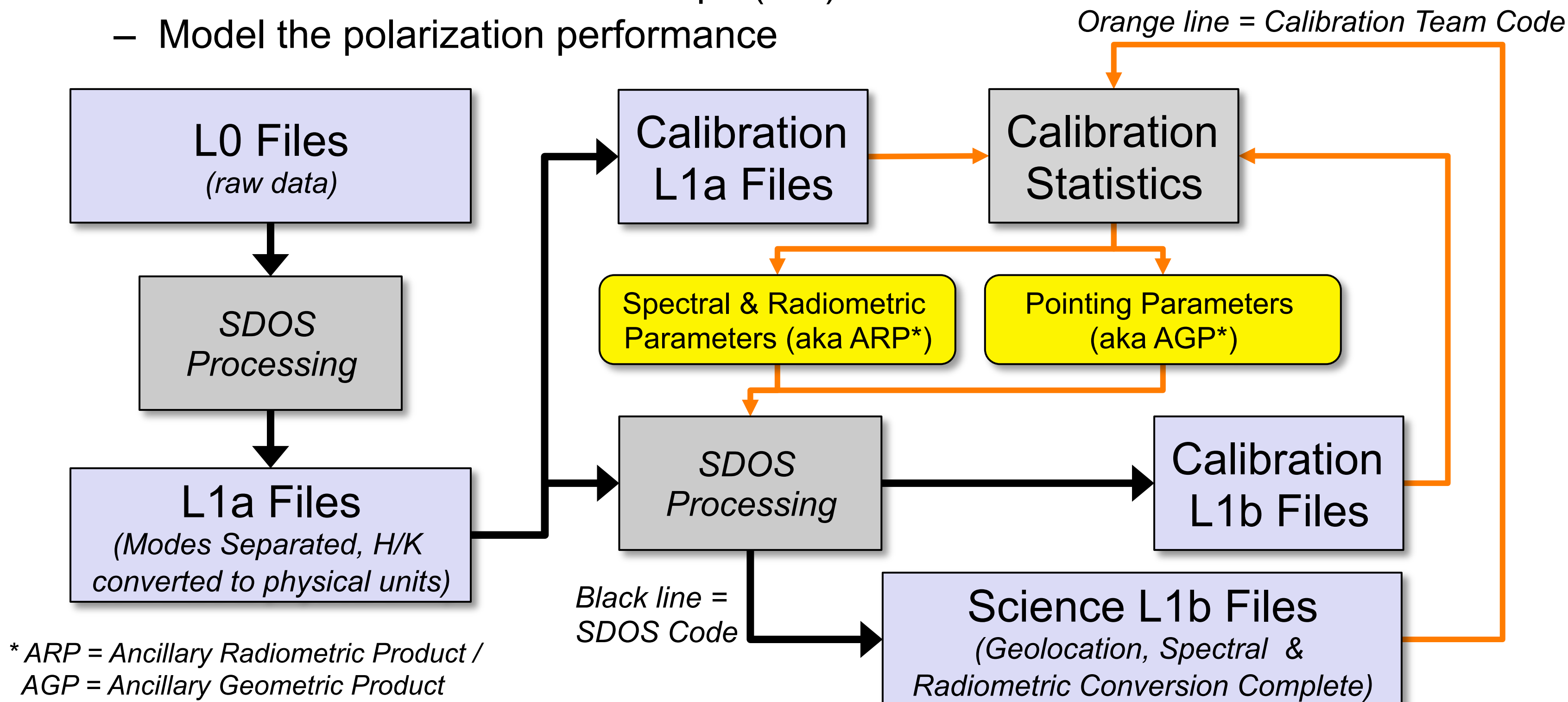
Instrument Update

- Flight Instrument
  - In storage at Orbital's facility in Gilbert, AZ
  - Currently removed from the spacecraft, will be reinstalled in June
  - Thermal Vacuum testing in December show no evidence of performance changes since the final instrument-level Tvac at JPL in April of 2012

- Spare Instrument
  - Largely assembled to start process of focusing the detectors next week
  - Should start the first characterization/calibration testing in May (once acceptable focus is achieved)
  - Testing should wrap up in June

Calibration And It's Role In Data Processing

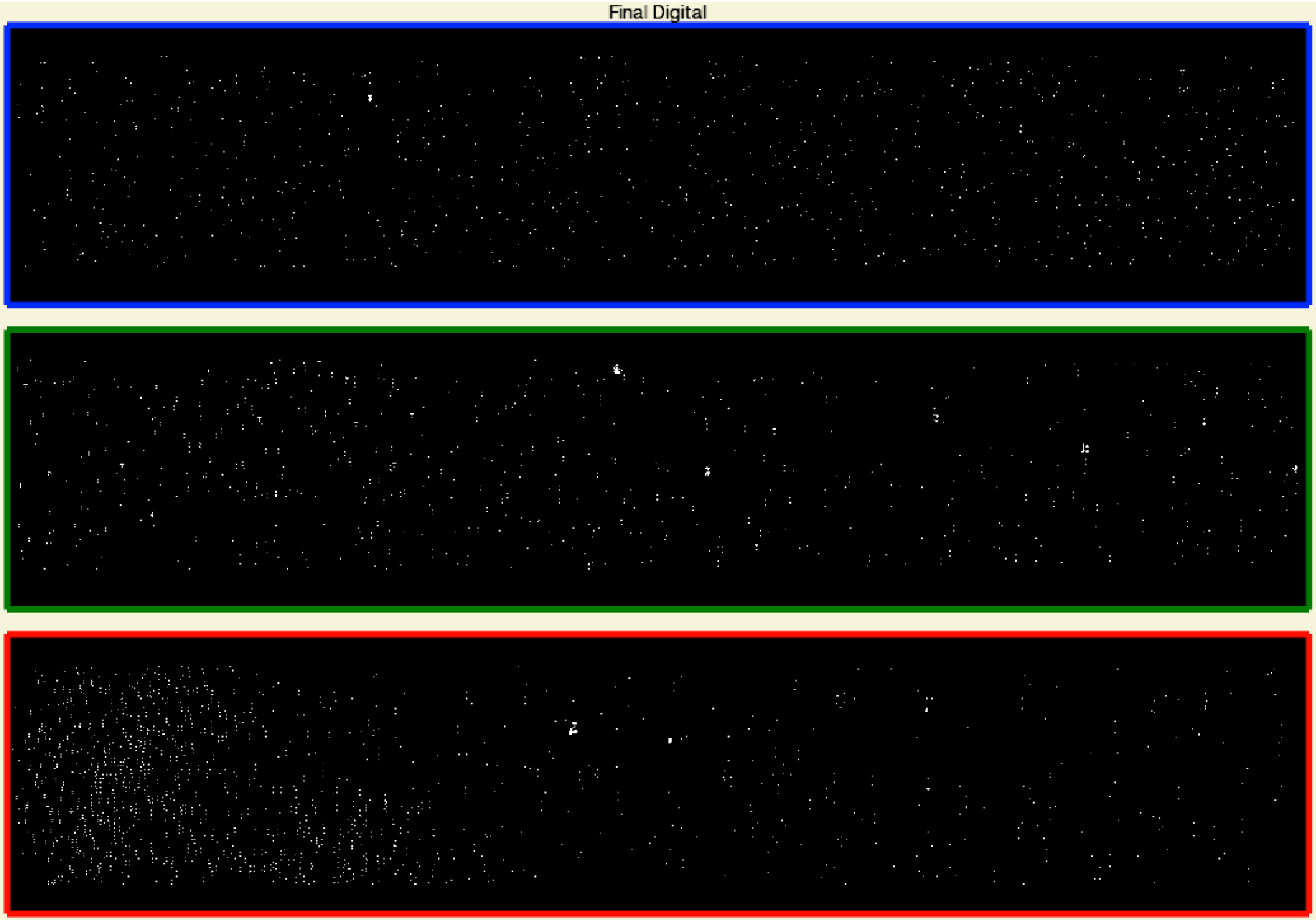
- Calibration Team provides instrument related parameters used to:
  - Convert spacecraft pointing/time data into geolocation information
  - Convert raw detector data into calibrated radiances including noise estimates
  - Convert FPA columns into wavelengths (non-Doppler corrected)
  - Model the Instrument Line Shape (ILS)
  - Model the polarization performance



Notes about OCO-2 versus OCO Calibration

- General
  - Much better set of dark data interspersed in test data
- Radiometric Calibration
  - Added spectrometer to monitor sphere to *MEASURE* color temperature issues
  - Had NIST visit to calibration the sphere-chamber system
  - All three channels are measured simultaneously
- Spectral Calibration
  - Better job removing laser speckle
  - Lasers were running multimode during many tests (BAD)
    - Trying to fix for calibration of spare hardware
  - Took laser scans at far, far more wavelengths
- Heliostat Data
  - Learned that the heliostat is a little undersized
    - Small changes in alignment and/or uniformity of illumination create subtle (or sometimes not subtle) changes in the ILS and the radiometric calibration
    - This is greatly complicates the TCCON to OCO ILS comparisons and L2 code testing
    - Need to be vigilant against correcting for test equipment issues with flight calibration parameters

The OCO-2 Bad Pixel Map At Instrument Delivery



853/163840

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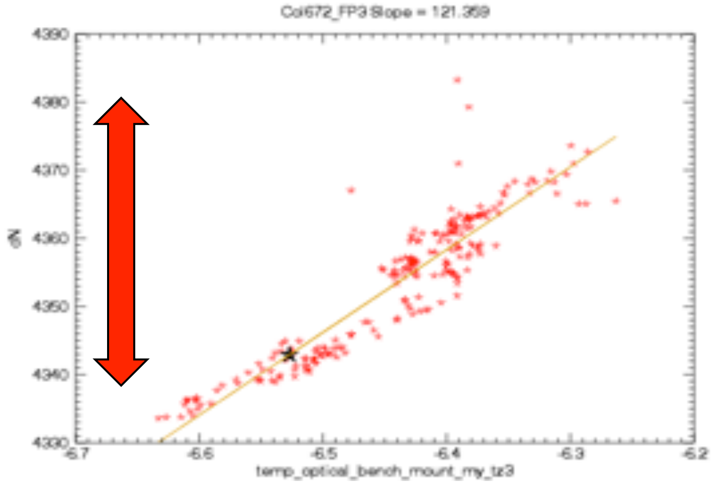
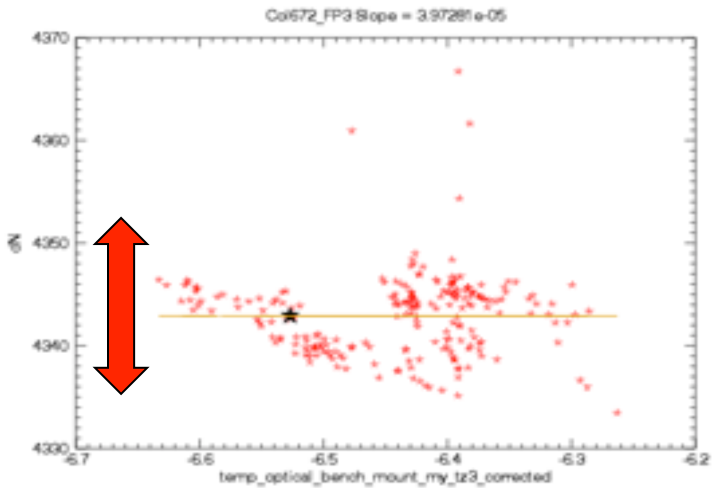
Dark Subtraction
First Step of Radiometric Calibration

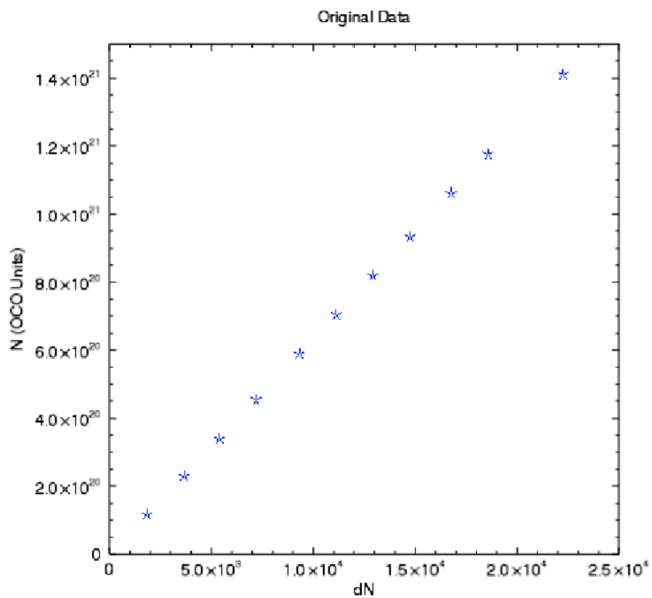
- Dark subtraction is critical to getting a good radiometric calibration
- Data taken in Tvac for the instrument provided the coefficients to correct for dark current drifts related to the optics and/or FPA temperature
- Simple linear corrections still leave a small residual – working to find ways to further correct this
- In flight, the instrument should be much more stable than on the ground and the dark subtraction should be good to a fraction of the noise level over a period of a week or two without significant correction
  - This will be one of the first things the calibration team will validate during early operations

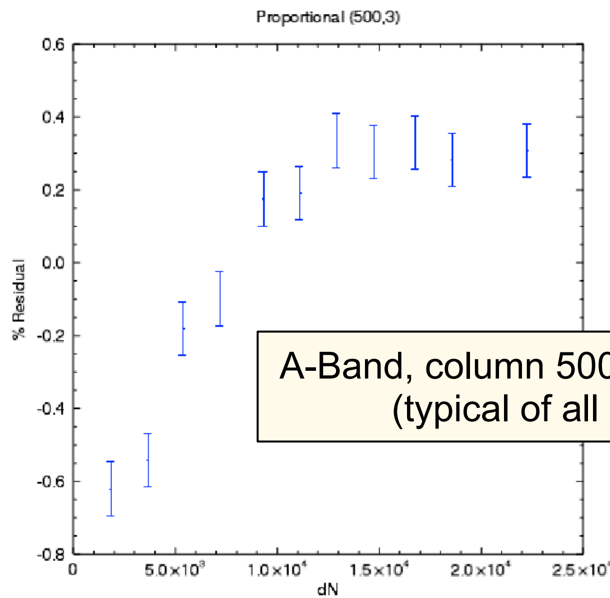




Radiometric Calibration Summary

- Absolute uncertainties are all probably in the 2-4% range
  - Still working on final error estimates
  - Several small terms remain to be captured, but we do not expect them to influence the results significantly
- Non-linearity is minimal – cubic function captures it well



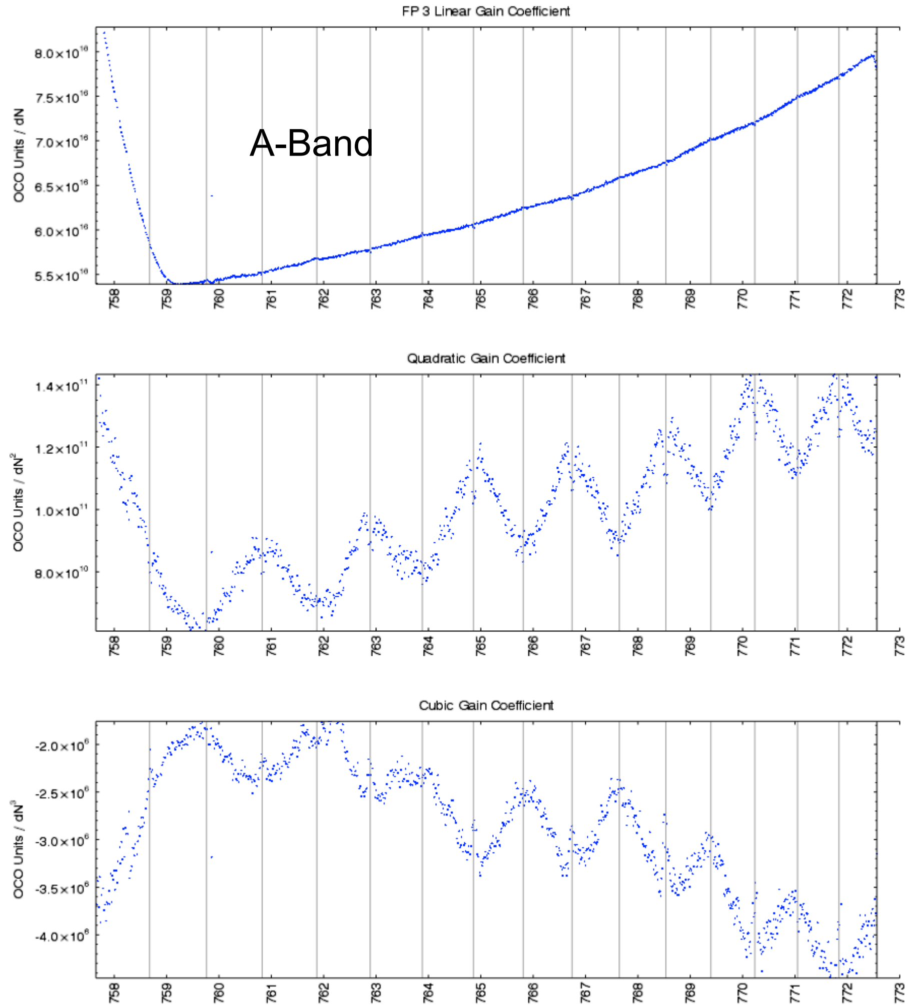


A-Band, column 500, footprint 4 (typical of all data)

A linear fit yields only a small residual due to non-linearity

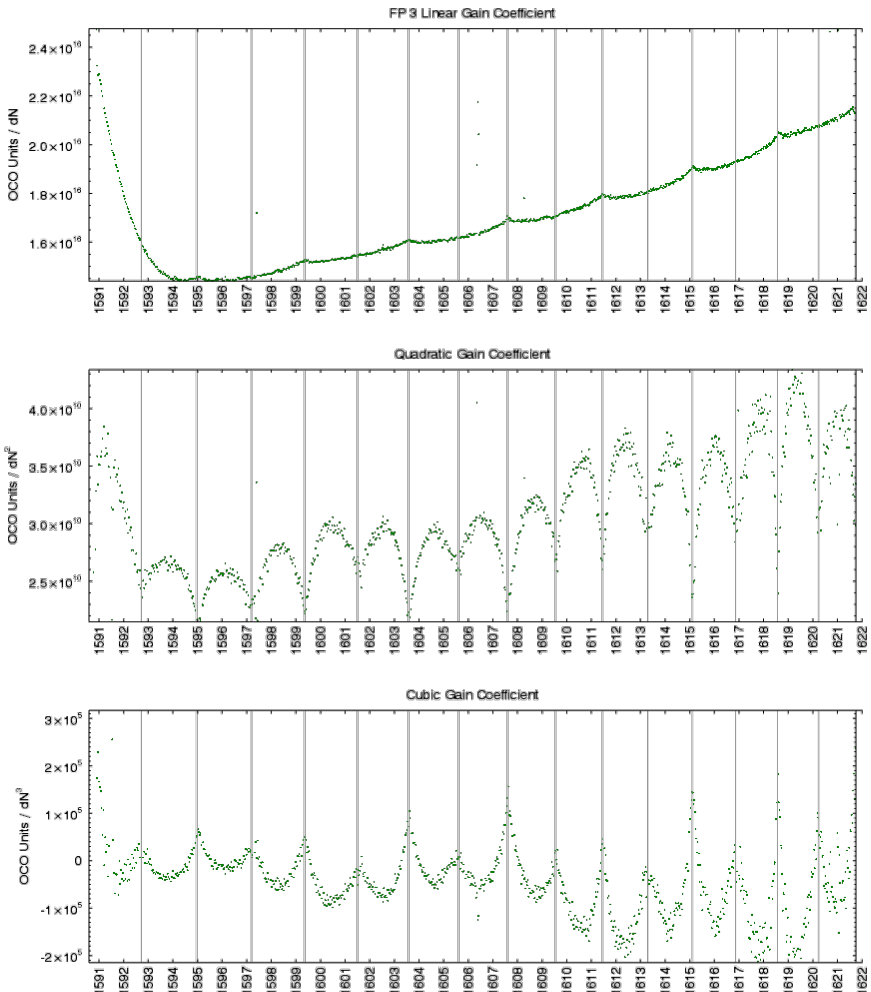
Non-linearity Varies across FPA

- **Linear** coefficients capture
  - Variability in transmission versus wavelength
  - Grating anamorphic magnification
- **Quadratic** coefficients capture
  - Non-linearity that varies with position in multiplexer grouping of 64 columns
- **Cubic** coefficients capture
  - Largely, but not entirely cancel the quadratic
  - Combination better captures the high dynamic range performance
- Quartic and high coefficients do not improve the fits in any meaningful way, so we are stopping at cubic
- Once again, all three channels look largely the same

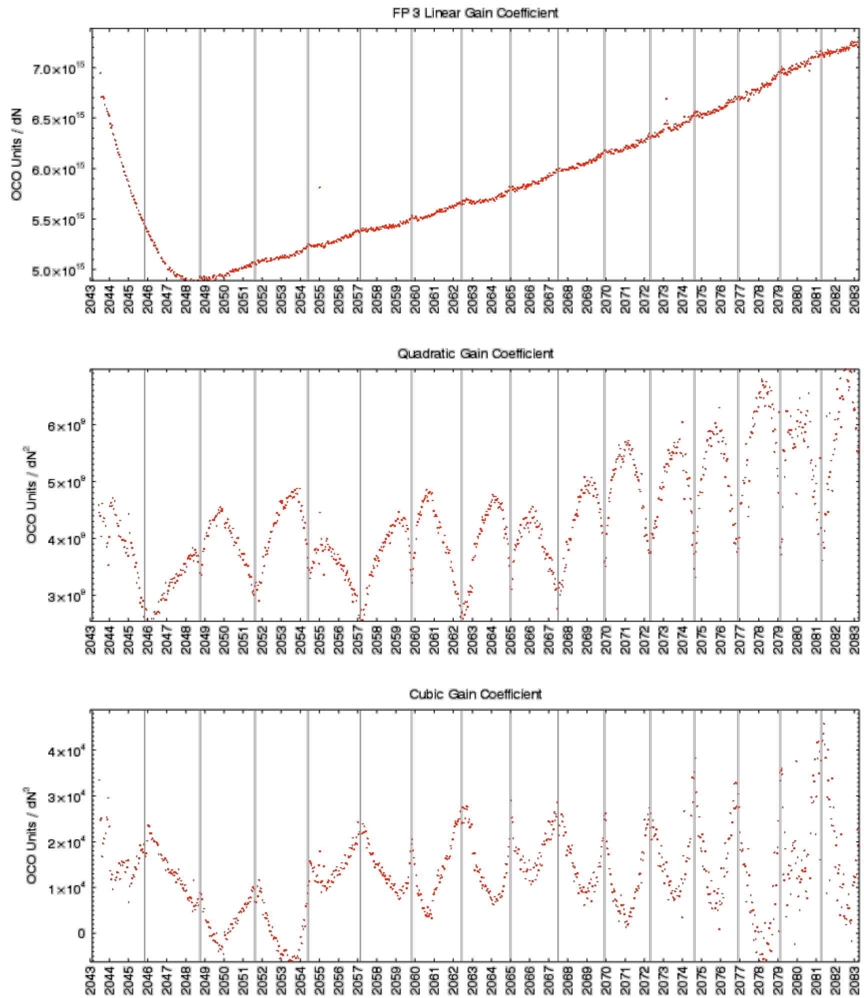


Non-linearity in CO2 Channels

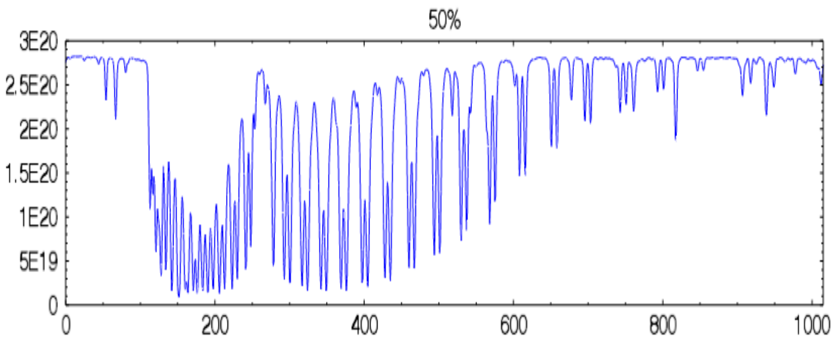
Weak CO_2

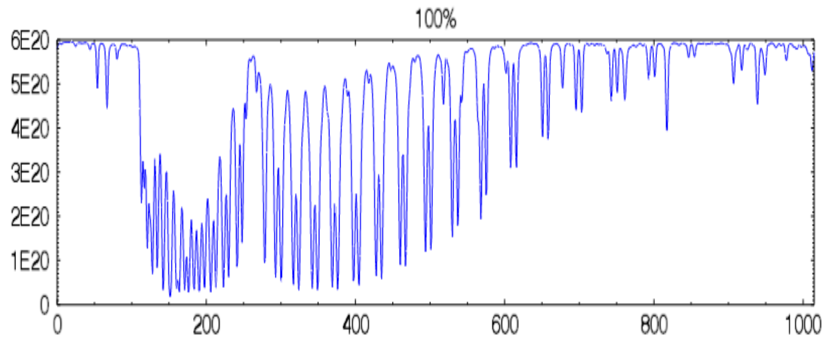


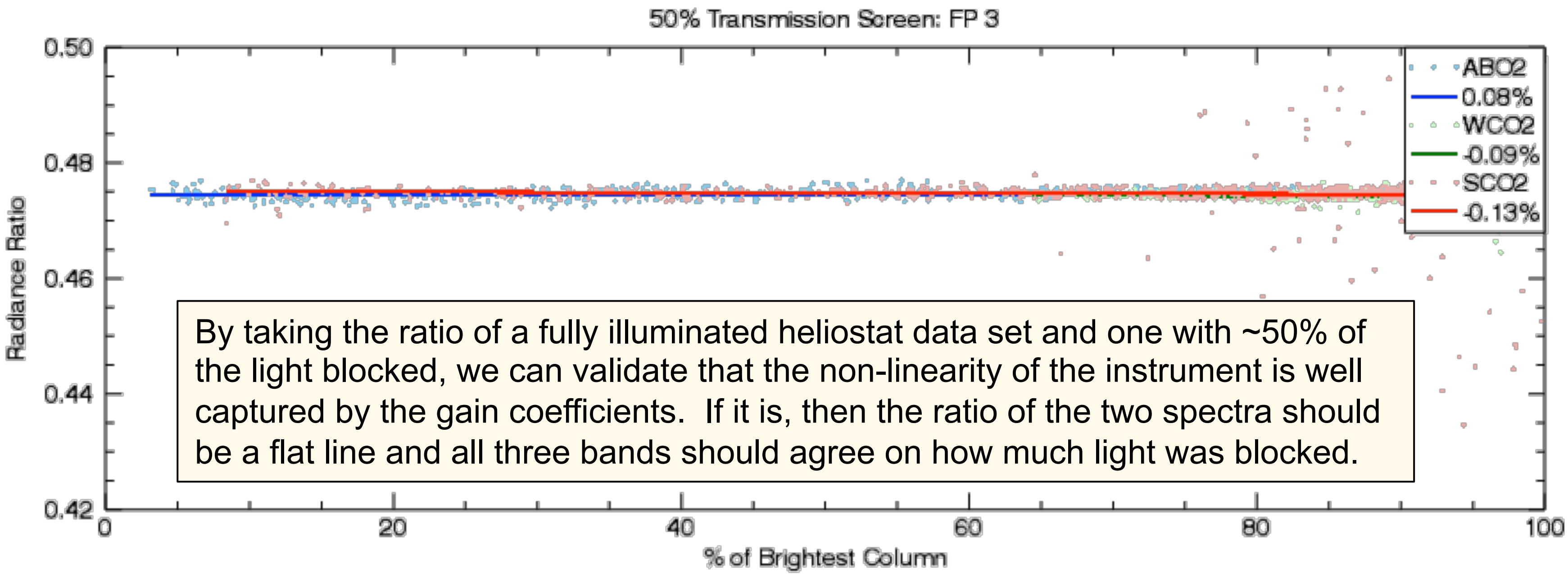
Strong CO_2



Validating Non-linearity

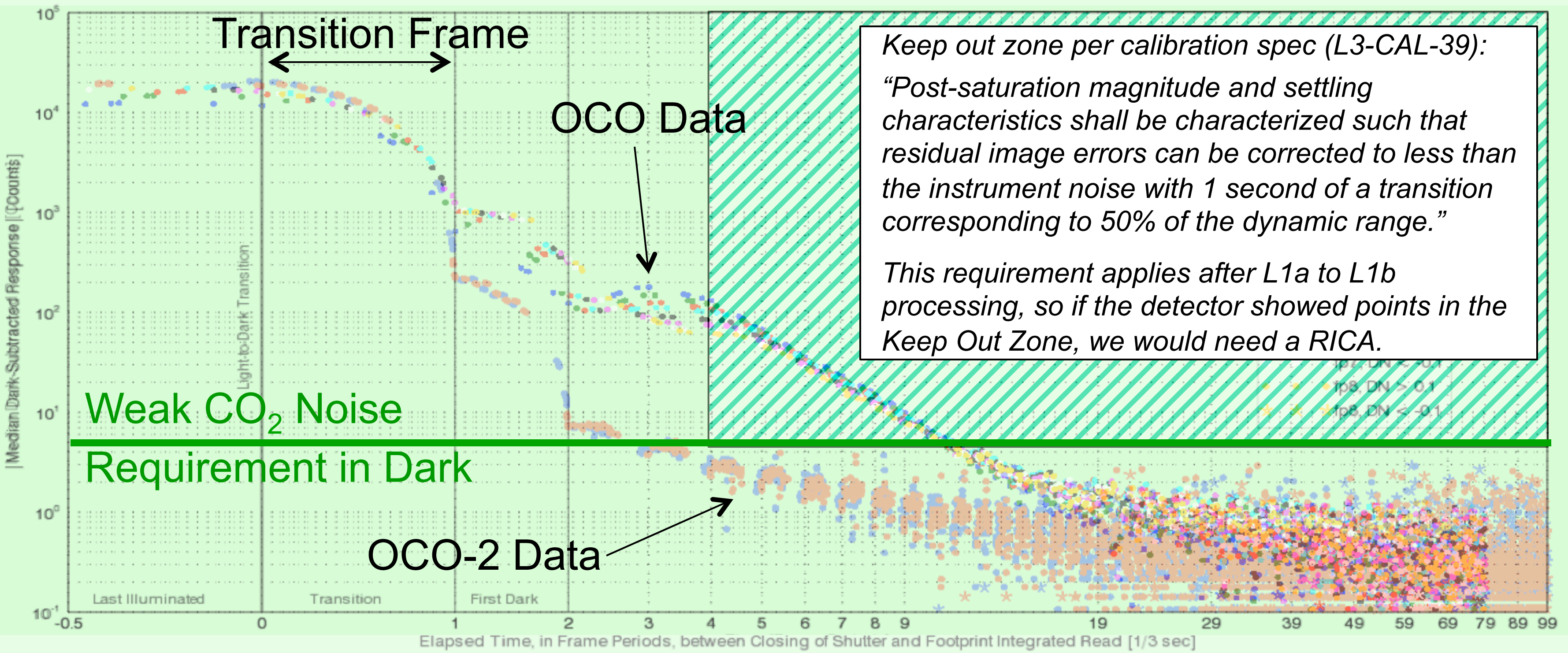






By taking the ratio of a fully illuminated heliostat data set and one with ~50% of the light blocked, we can validate that the non-linearity of the instrument is well captured by the gain coefficients. If it is, then the ratio of the two spectra should be a flat line and all three bands should agree on how much light was blocked.

OCO Versus OCO-2 Residual Image



- Strong CO_2 shows similar performance, but the noise floor is higher => more margin
- A-band response falls off even faster than CO_2 channels – no 2nd derivative issues
- Residual image appears to be almost, but perhaps not completely, negligible
  - Working on how best to avoid XCO2 basis from this (ignore it? flag data? fix data?)

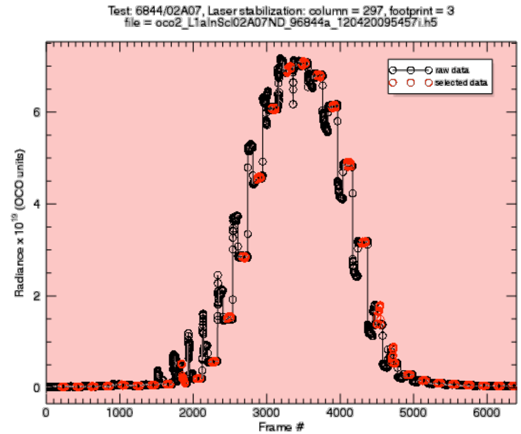
Spectral Calibration Overview

	Step #	Process	Response	Wavelength scale
same as OCO	1	TVac measurements	lasers using OCO-2 as power meter	laser wavemeters (problems)
same as OCO	2	Spectral Calibration	ILS relative response (+ ILS delta lambda)	dispersion relation (from lasers)
same as OCO	3	Spectral Verification	optimized ILS relative response (+ optimized ILS delta lambda)	optimized dispersion
new for OCO-2	4	Spectral Calibration	new ILS relative response using optimized dispersion	dispersion
new for OCO-2	5	Spectral Verification	new optimized ILS relative response (+ new optimized ILS delta lambda)	new optimized dispersion

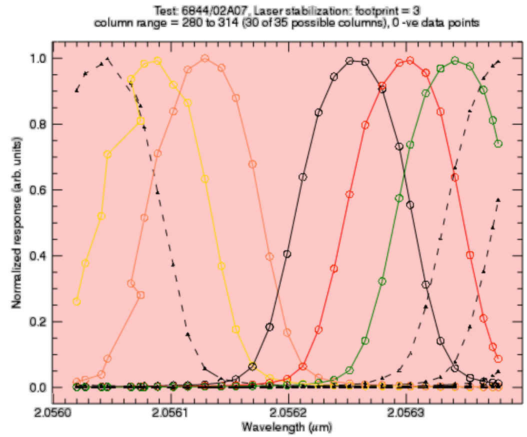
Exploring further optimization, but cautious of over fitting the data…

Spectral Calibration Process

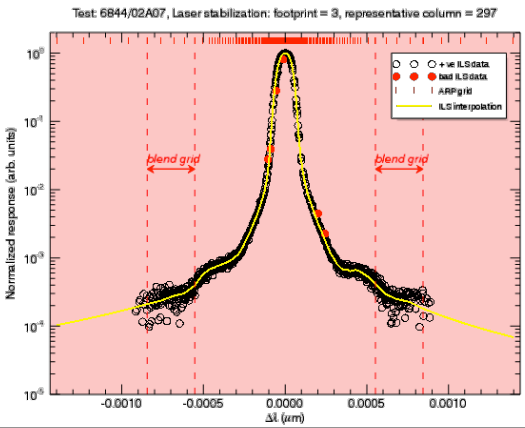
Step 1: Single laser fine-step scan as seen by a single sample



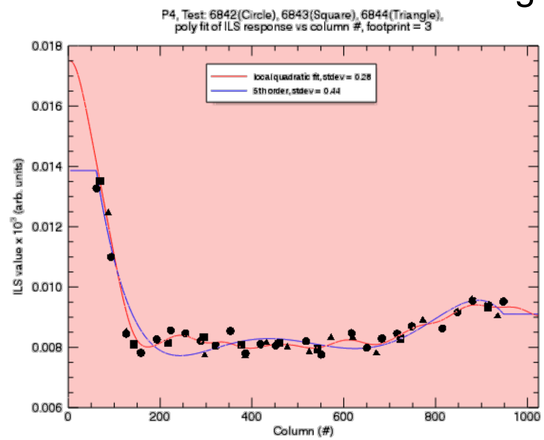
Step 2: Look at simultaneous data for stable laser periods as seen by neighboring samples



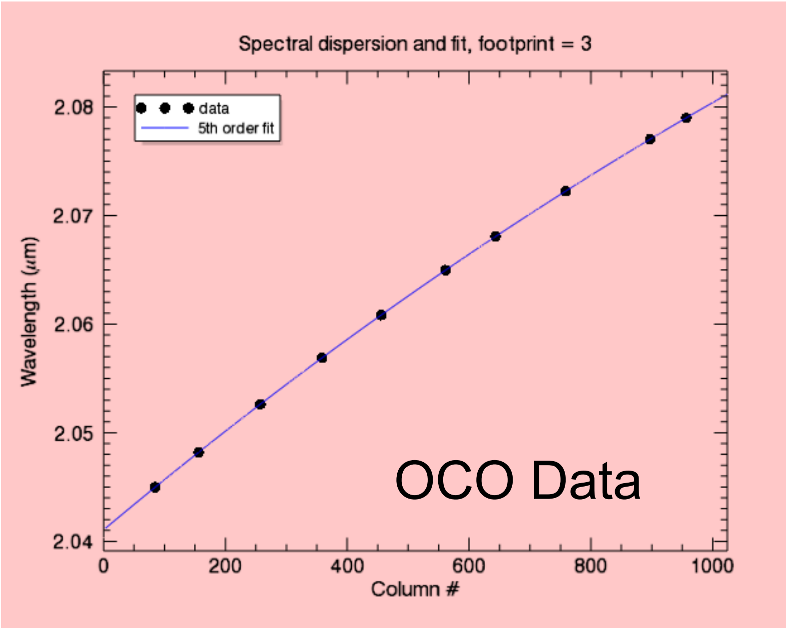
Step 3: Center all local data by subtracting center wavelength

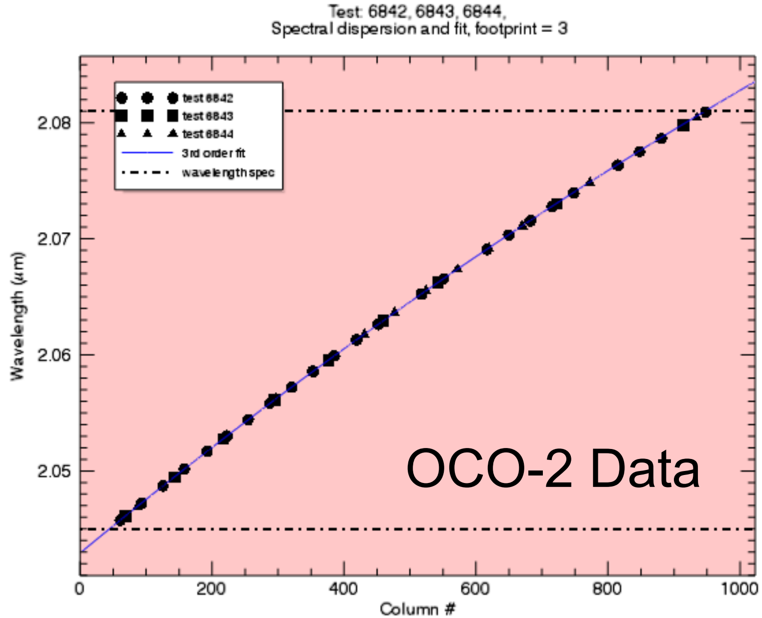


Step 4: Interpolate through all laser fine-step scans to estimate ILS at all wavelengths



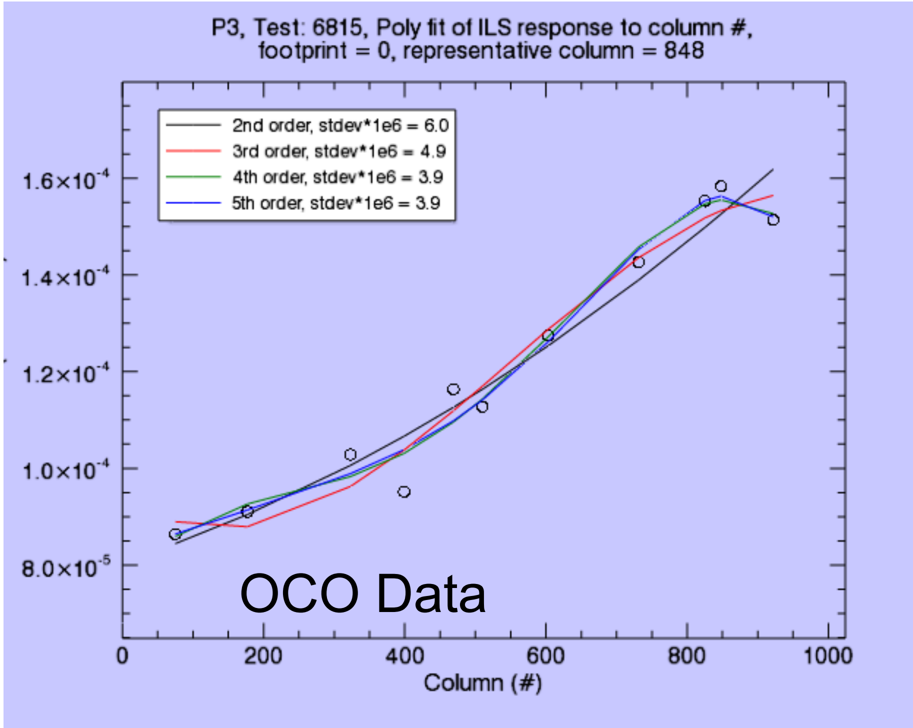
OCO-2 Collected Far More Spectral Calibration Data

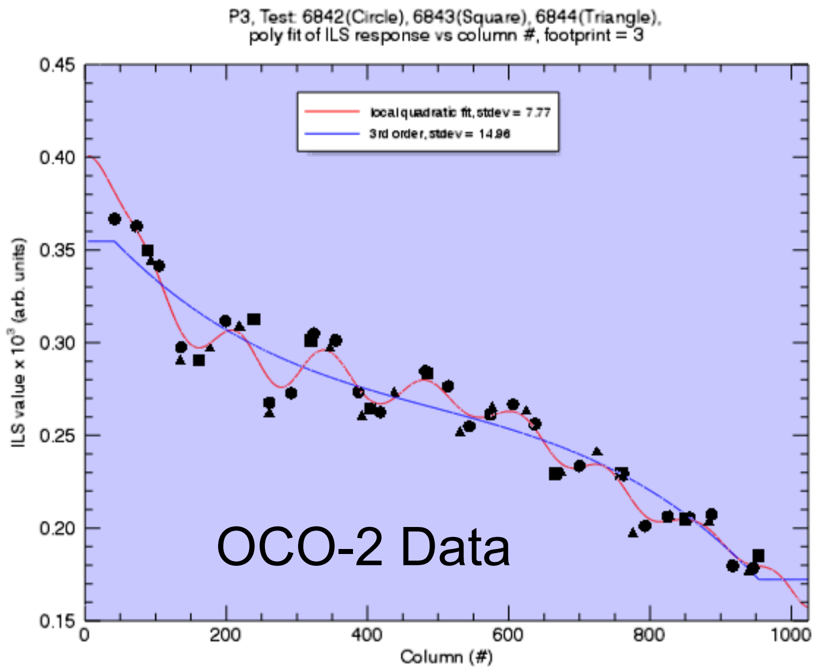




- Each symbol represents a position on the FPA where a fine laser scan was completed

OCO-2 Data Resolved Features Not Seen on OCO





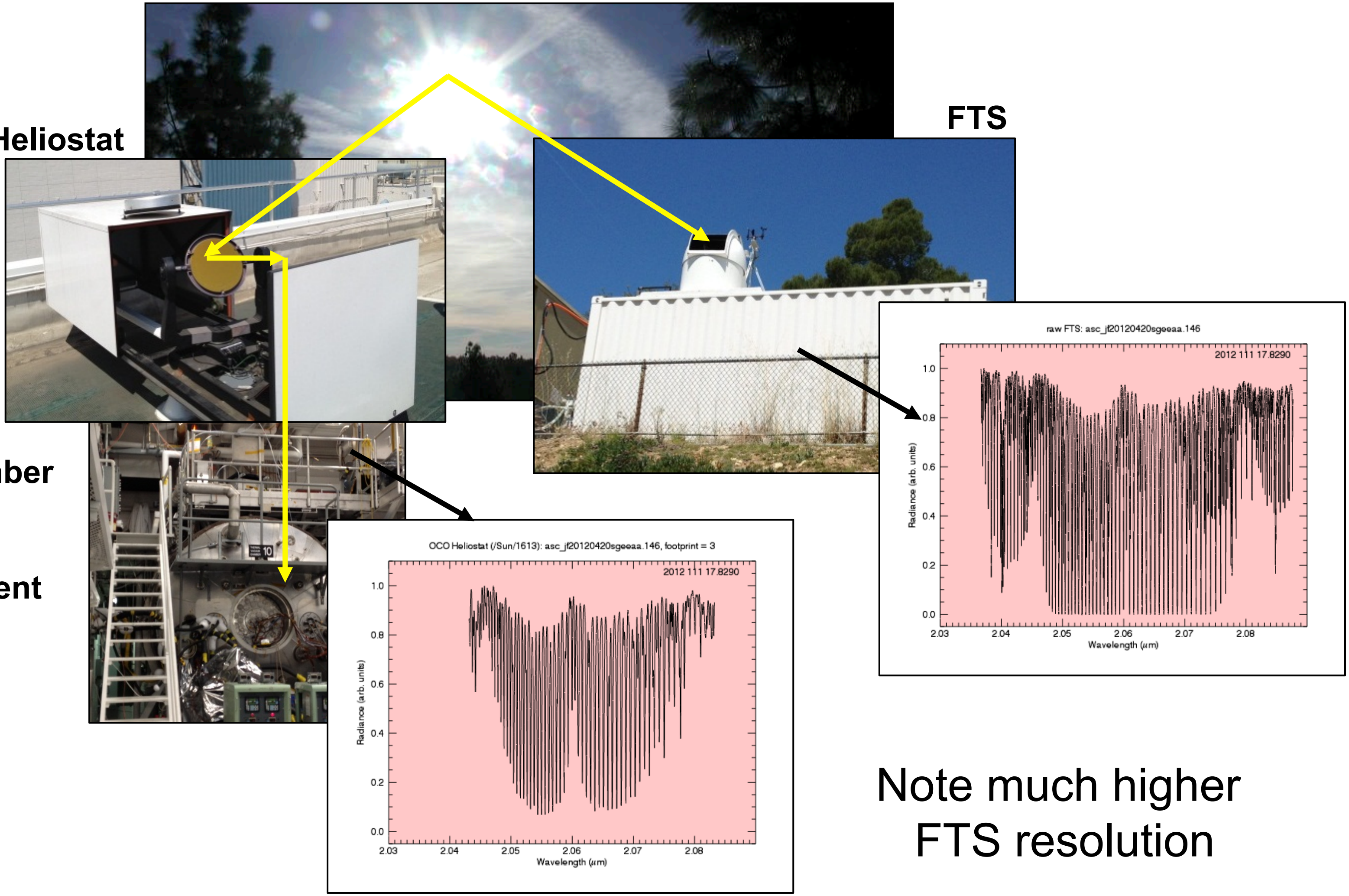
- Slopes differ to OCO being in slightly better focus than OCO-2 for the A-band
- Main point is that OCO-2's richer data set allows a mapping of high-frequency changes in the ILS that correspond to the W-patter.
  - If they were present in the OCO data, we could never have resolved them.

ILS and Dispersion Verification Uses FTS Data

Heliostat

FTS

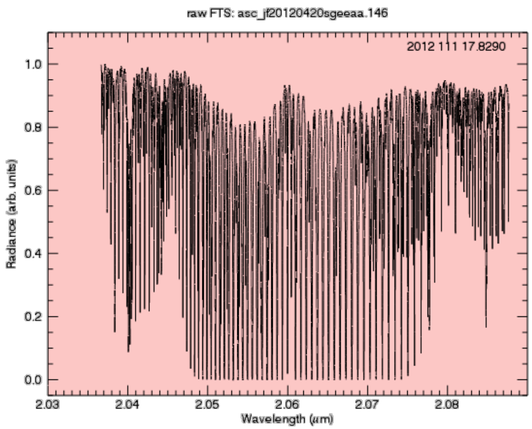
TV Chamber with Flight Instrument



Note much higher FTS resolution

Convolving FTS Data and Laser-Based ILS Provides Simulated OCO-2 Data

FTS spectrum



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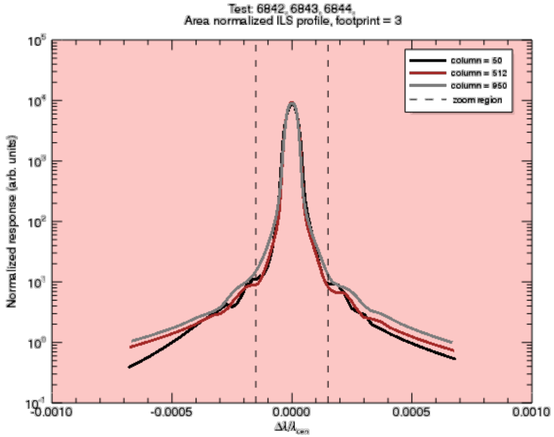
OCO-2 ILS



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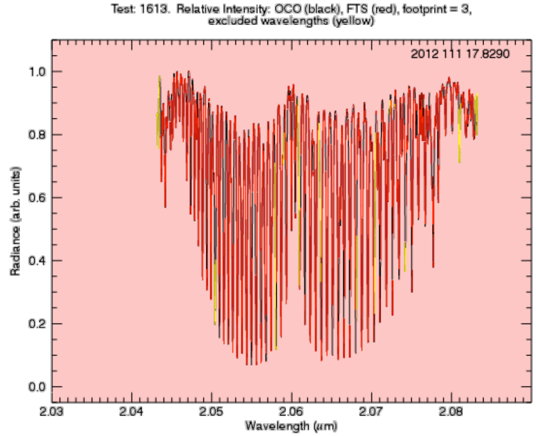
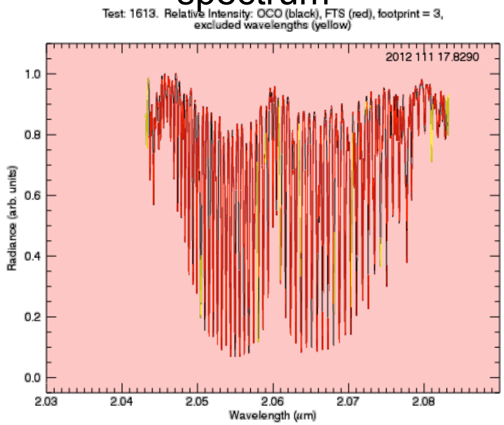
Simulated OCO-2 spectrum



Simulated OCO-2 spectrum



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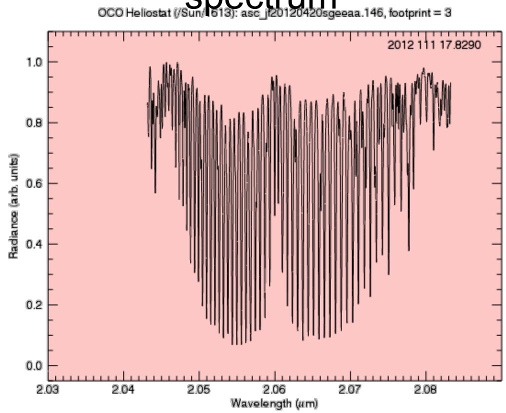
Measured OCO-2 spectrum



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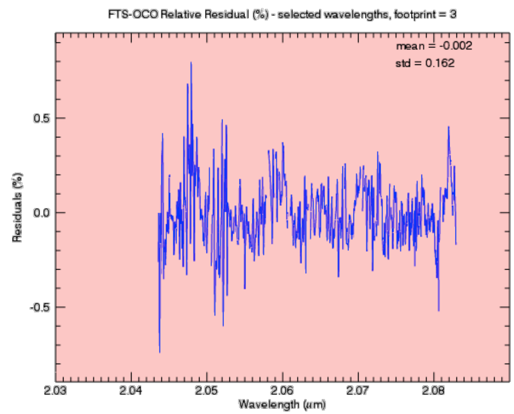
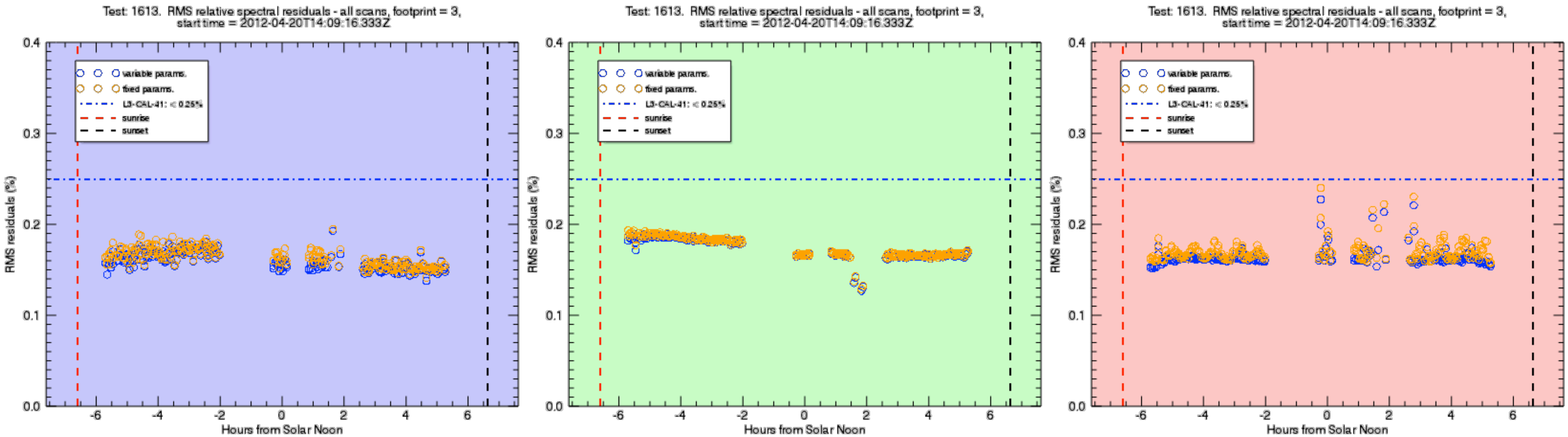
Spectral Residuals



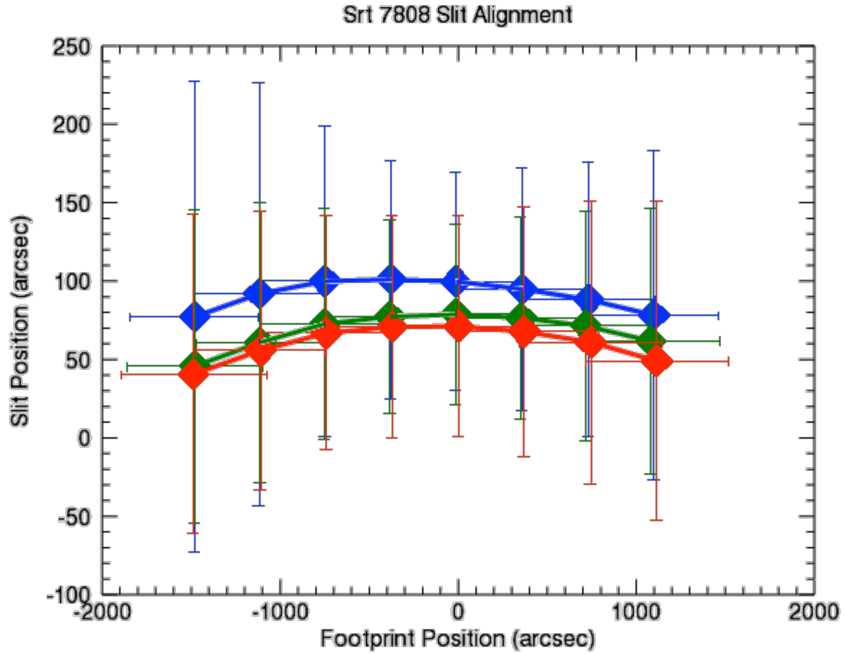
RMS of Residuals Validates ILS & Dispersion

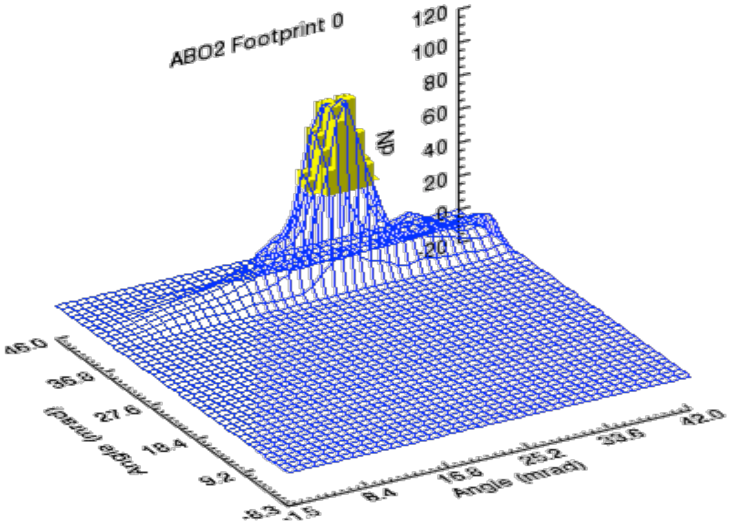


- Residuals look small and constant over the entire range of atmospheric paths

Instrument Level Geolocation Data

- Measured with a pin-hole used on a raster scan (see below)
- SDOS gets a table of data with the center and width in the cross-slit and along-slit directions
  - For geolocation data, the footprint is represented as a parallelogram based on the IFOV FWHM points combined with the spacecraft motion

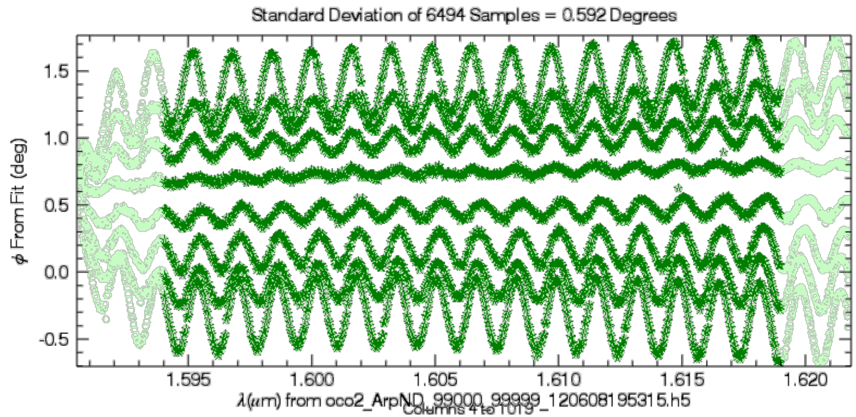


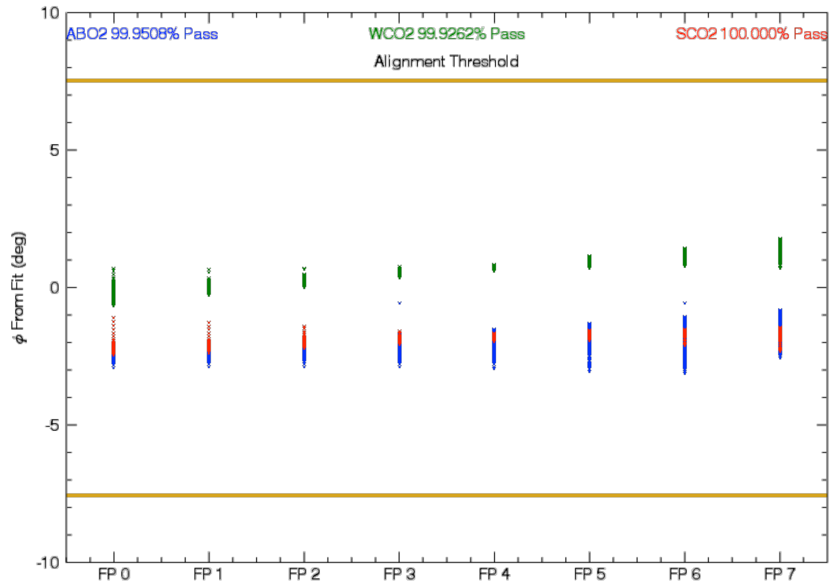


FP #	xmax (arcsec)	ymax (arcsec)	Δx (arcsec)	Δy (arcsec)
0	78.2	1100.6	105.3	358.8
1	88.0	733.9	87.6	374.6
2	94.9	358.3	77.3	376.0
3	99.7	-13.8	69.5	373.2
4	101.0	-379.4	76.2	366.3
5	99.9	-746.9	98.8	363.8
6	91.9	-1118.4	135.1	369.9
7	77.1	-1481.4	150.2	361.8

Polarization

- The ripples seen here are due to stress-induced birefringence in the chamber window (expected)
- The footprint-to-footprint offsets are probably real
  - Will be adding the median value to ARP in a 3 x 8 array
  - This will slightly tweak the Muller Matrices in the L1b files





Conclusions

- Radiometric Calibration
  - Largely complete
  - Finishing write-up on requirements
  - Still making the call on the need for a tiny residual image correction
- Spectral Calibration
  - Largely complete
  - Moving from FTS-based validation to looking at L2 residuals
- Spatial Calibration
  - Complete until first lunar calibration in orbit
- Polarization Calibration
  - Complete

- After the spare instrument Tvac is complete, the calibration team will be moving on to developing and/or validating the tools to maintain the calibration in flight