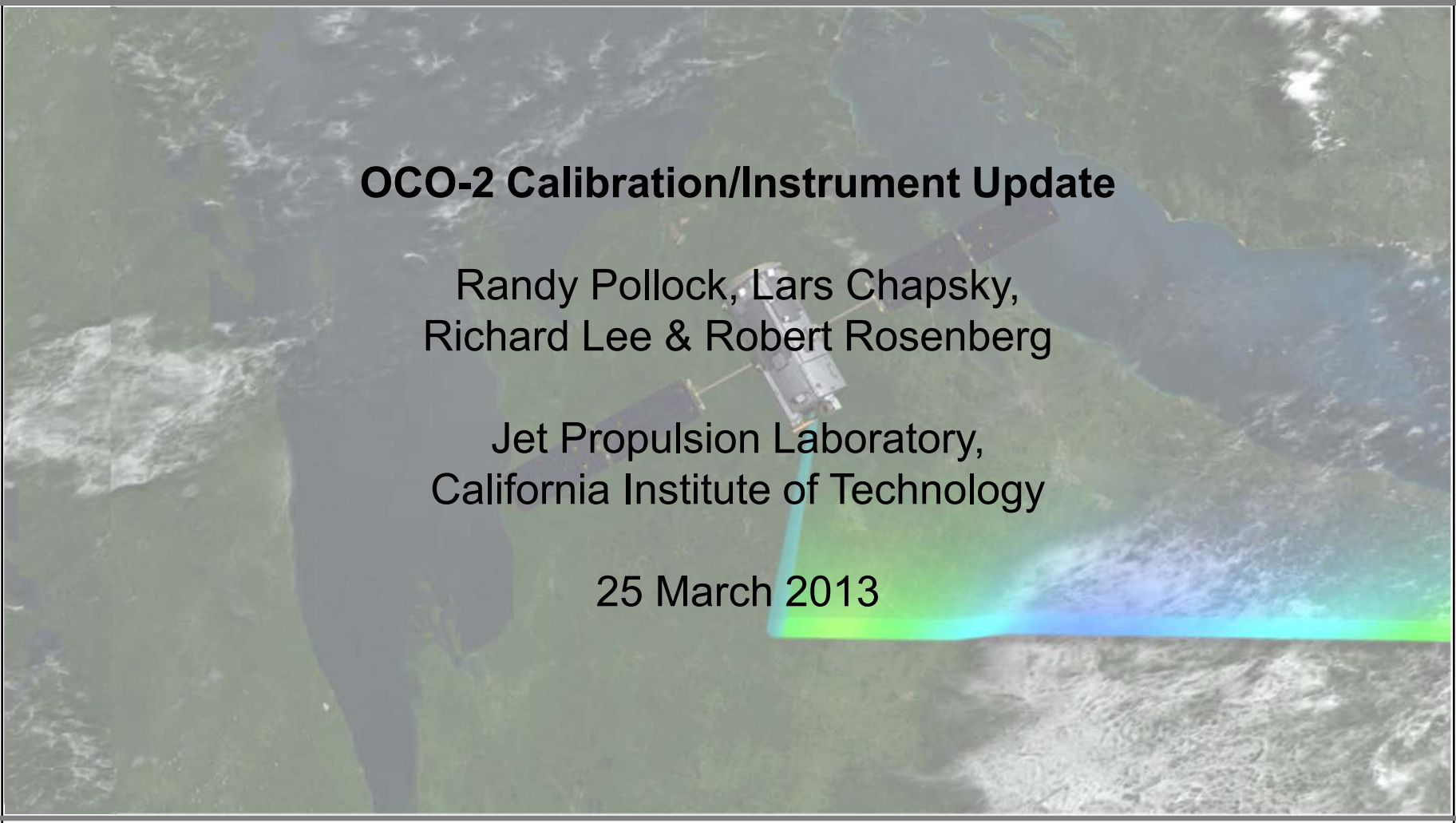


OCO-2 Calibration/Instrument Update

Randy Pollock, Lars Chapsky,
Richard Lee & Robert Rosenberg

Jet Propulsion Laboratory,
California Institute of Technology

25 March 2013

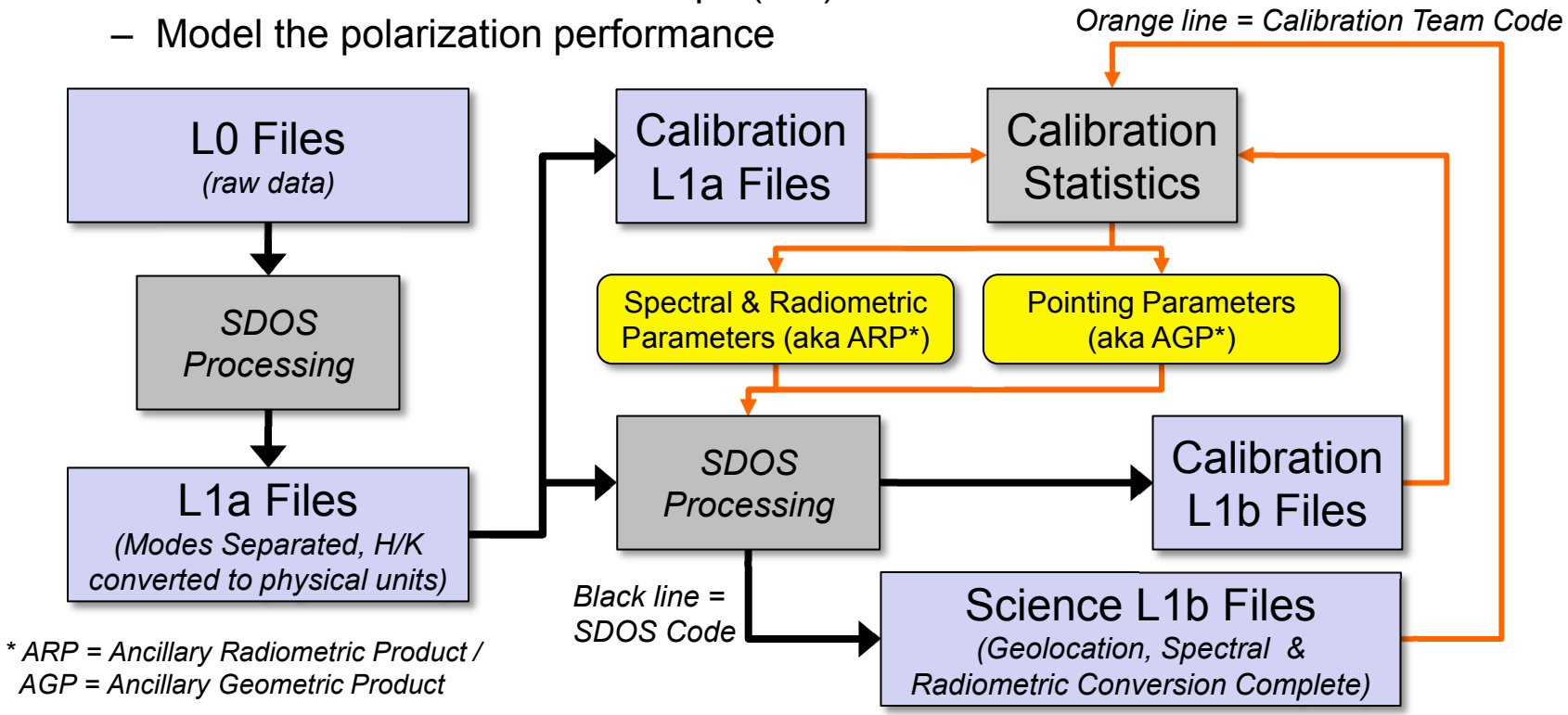
Instrument Update

- 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

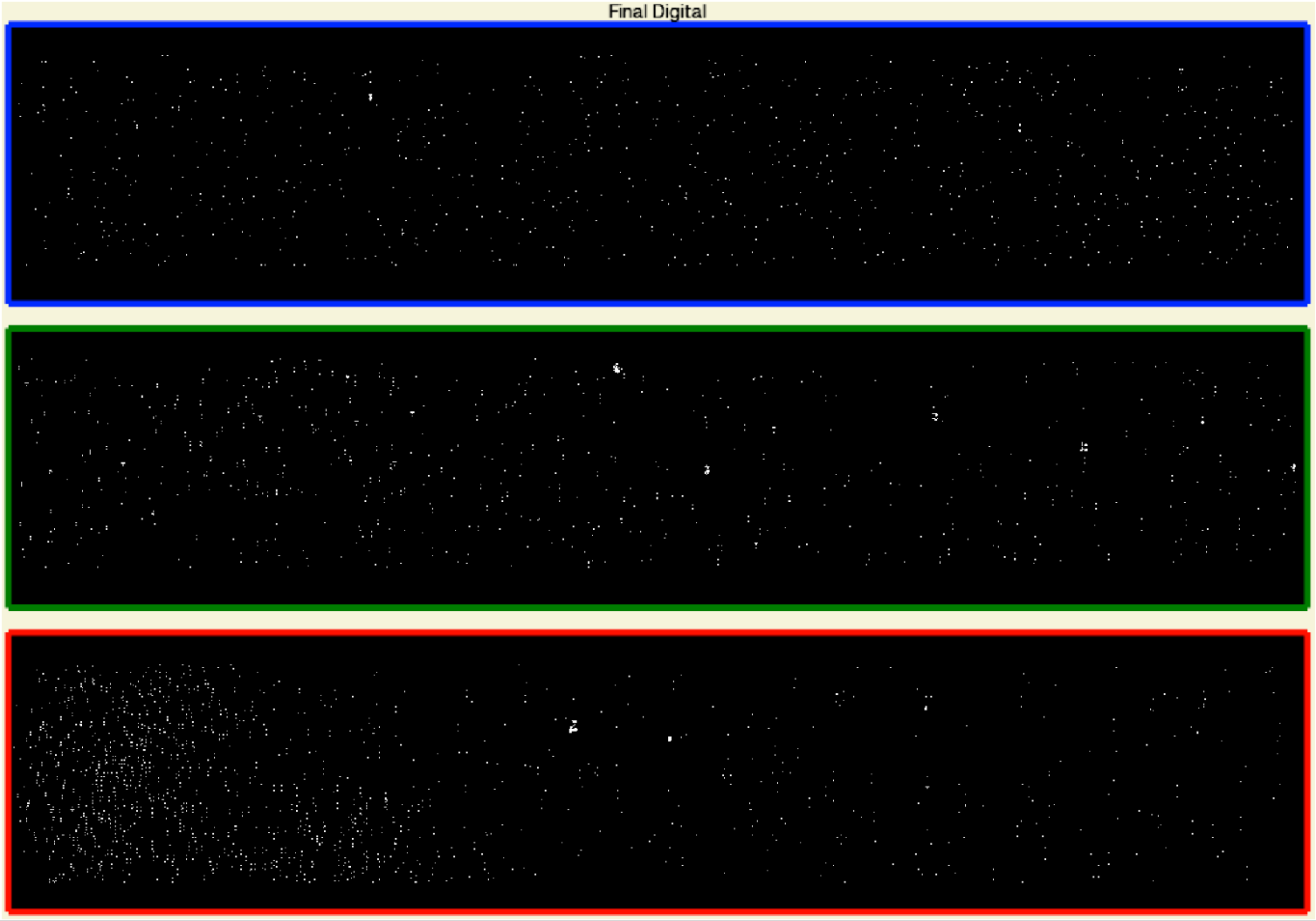
- Calibration Team provides instrument related parameters used to:
  - Convert spacecraft pointing/time data into geolocation information
  - Convert raw detector data into calibrated radiances including noise estimates
  - Convert FPA columns into wavelengths (non-Doppler corrected)
  - Model the Instrument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



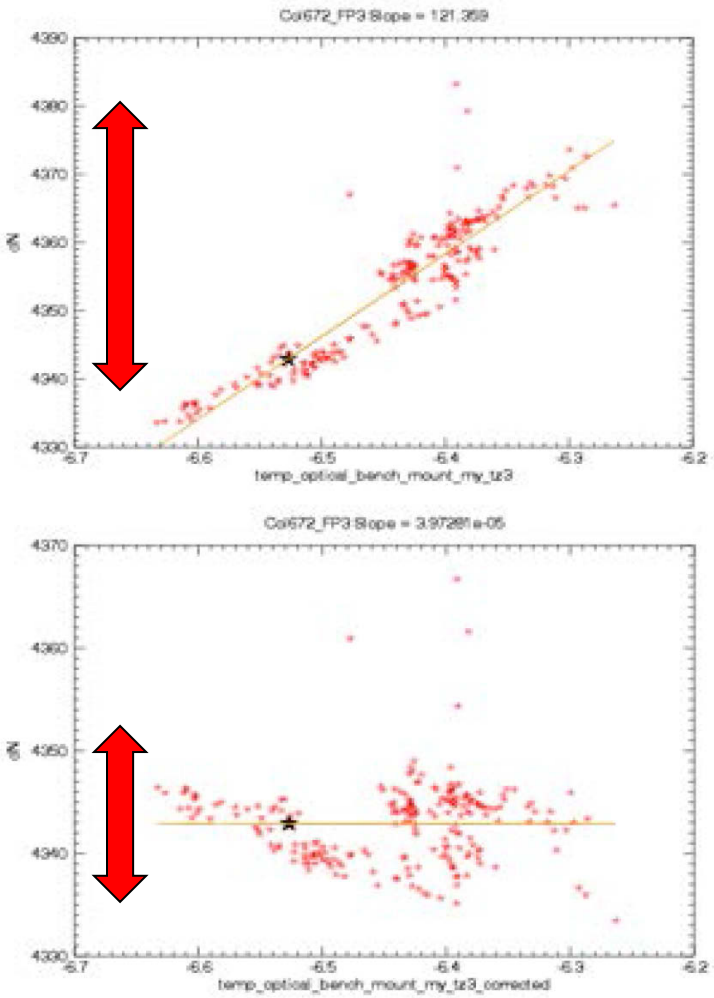
853/163840

1606/163840

1400/163840

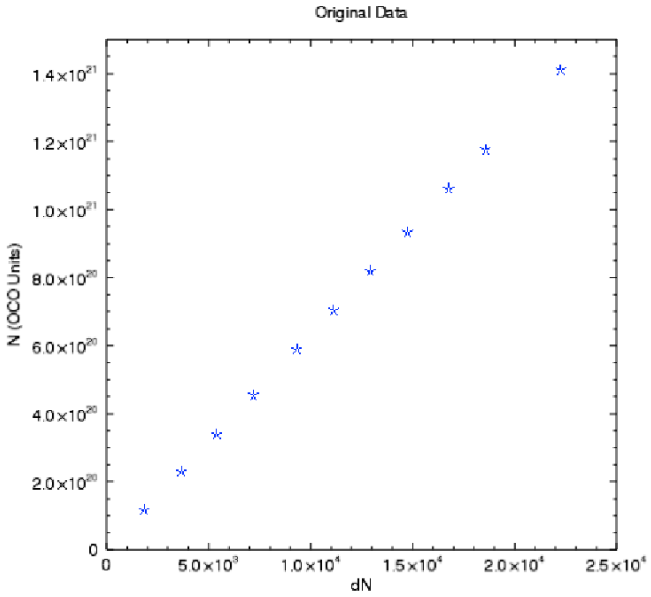
Dark Subtraction
First Step of Radiometric Calibration

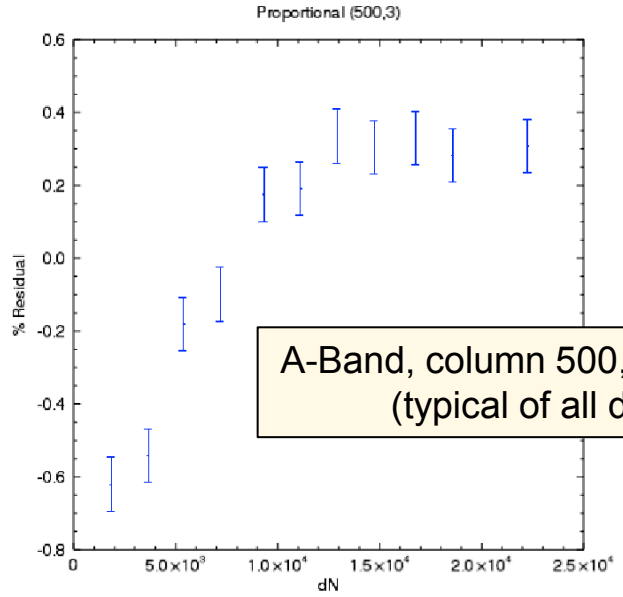
- Dark subtraction is critical to getting a good radiometric calibration
- Data taken in Tvac for the instrument provided the coefficients to correct for dark current drifts related to the optics and/or FPA temperature
- Simple linear corrections still leave a small residual – working to find ways to 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



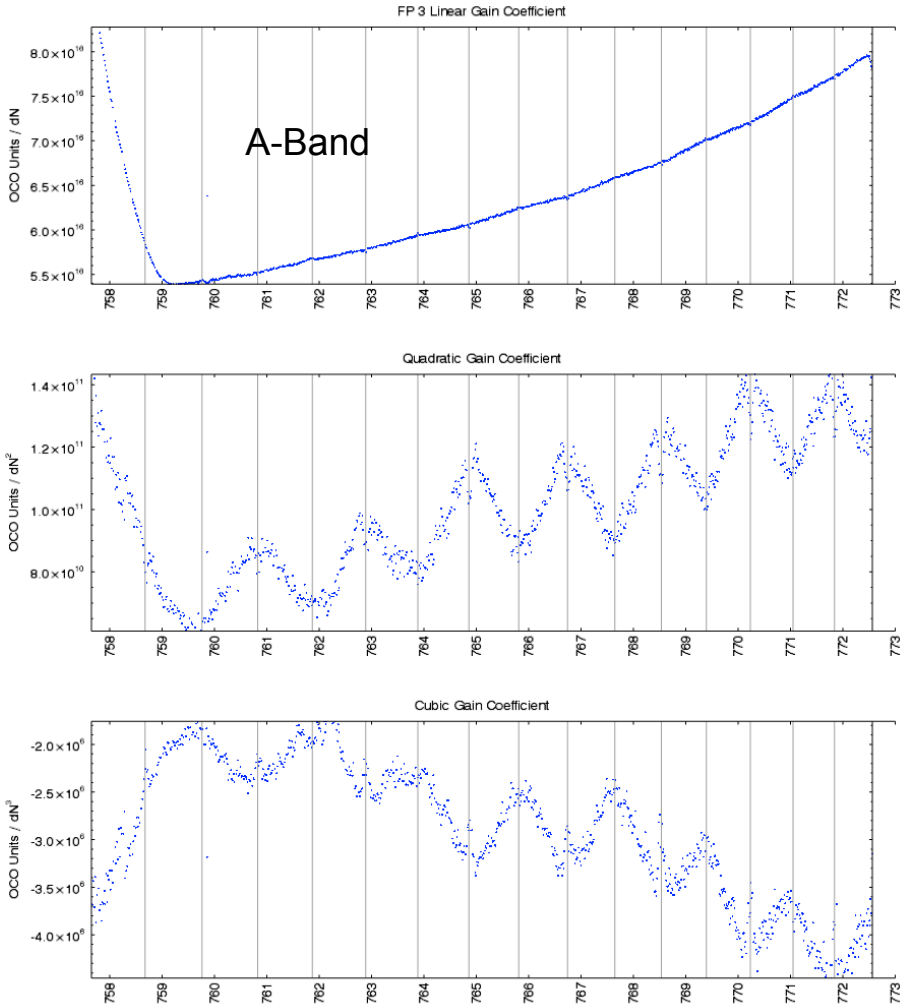


A-Band, column 500, footprint 4 (typical of all data)

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

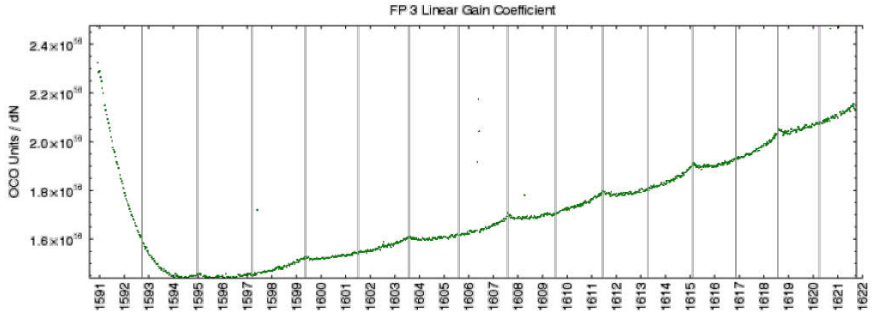
Non-linearity Varies across FPA

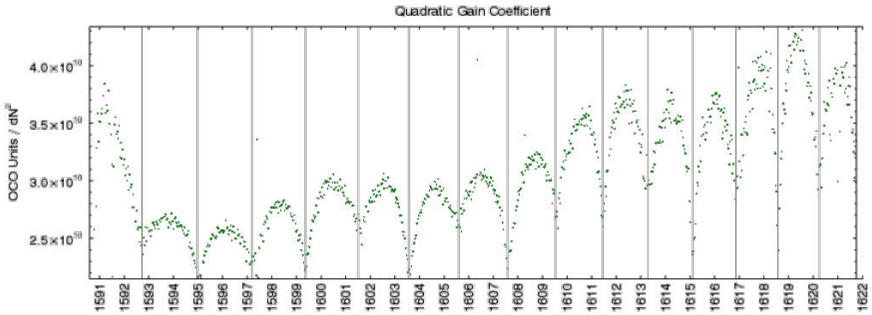
- **Linear** coefficients capture
  - Variability in transmission versus wavelength
  - Grating anamorphic magnification
- **Quadratic** coefficients capture
  - Non-linearity that varies with position in multiplexer grouping of 64 columns
- **Cubic** coefficients capture
  - Largely, but not entirely 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

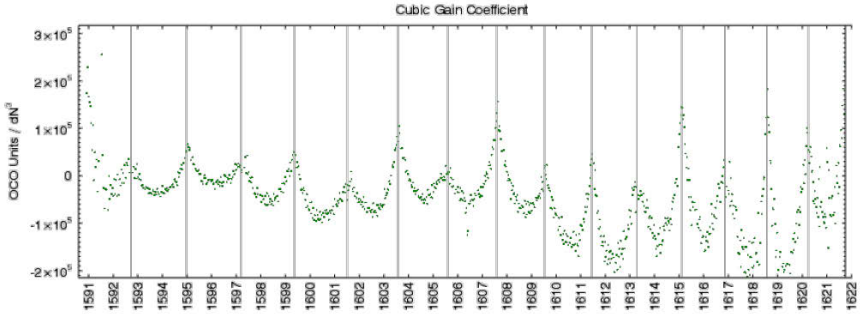


Non-linearity in CO2 Channels

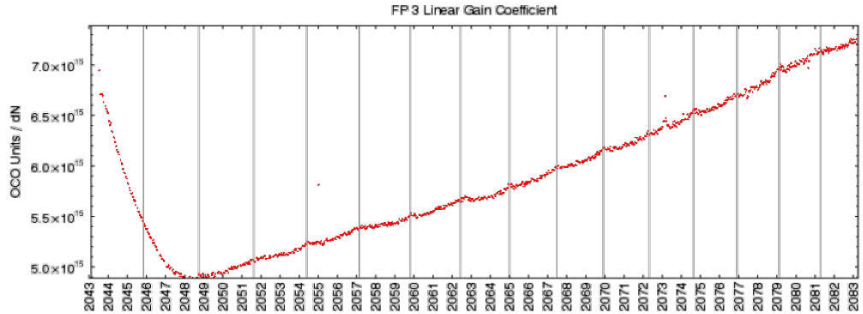
Weak CO_2

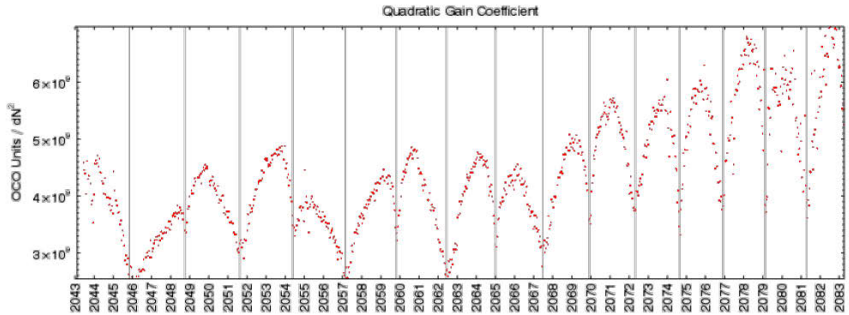


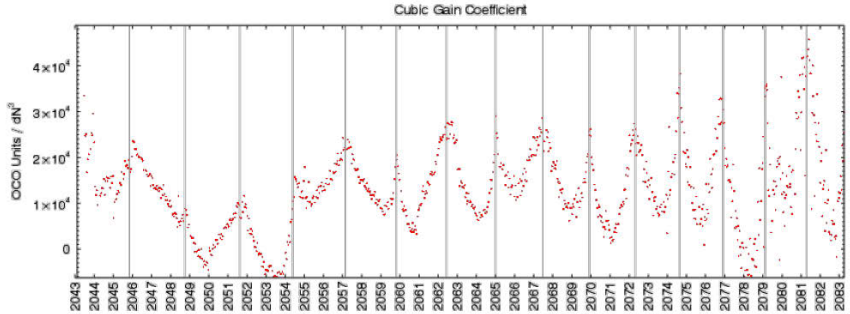




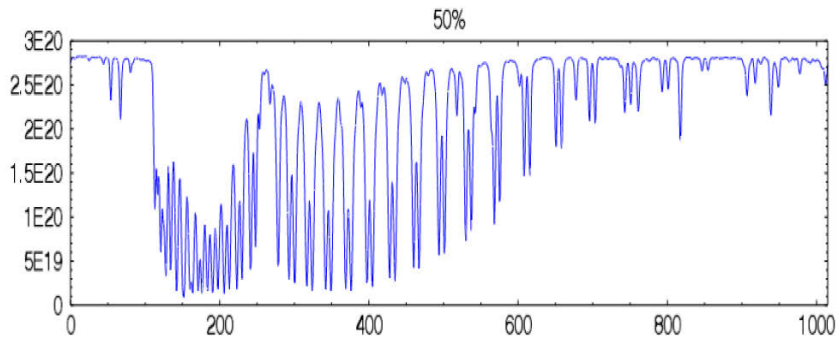
Strong CO_2

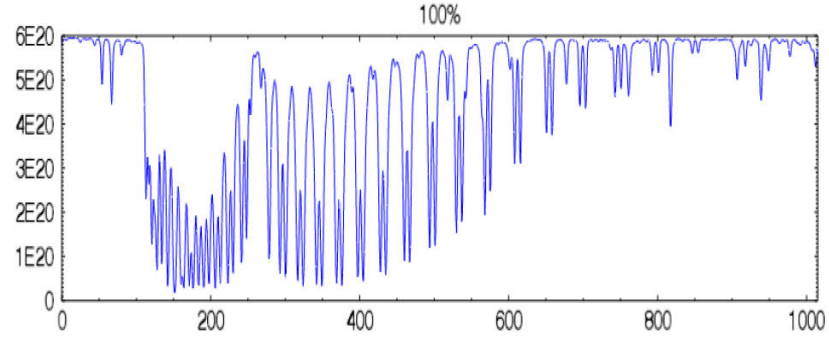


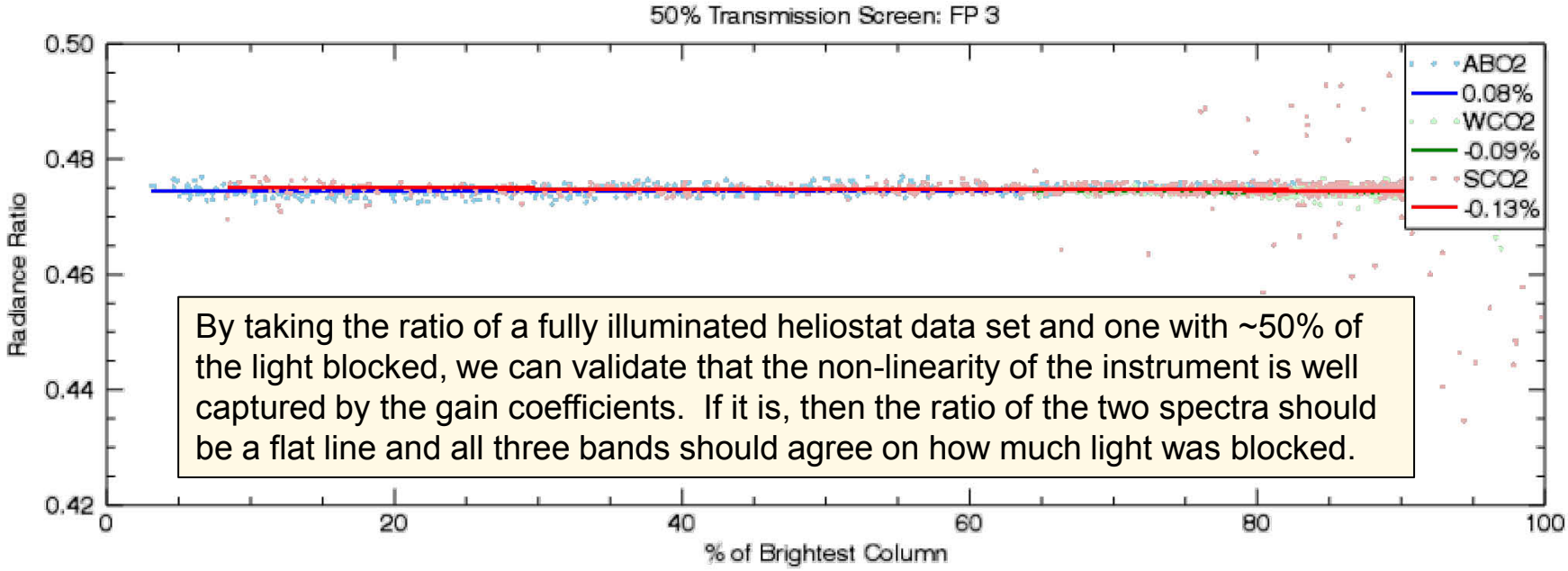




Validating Non-linearity

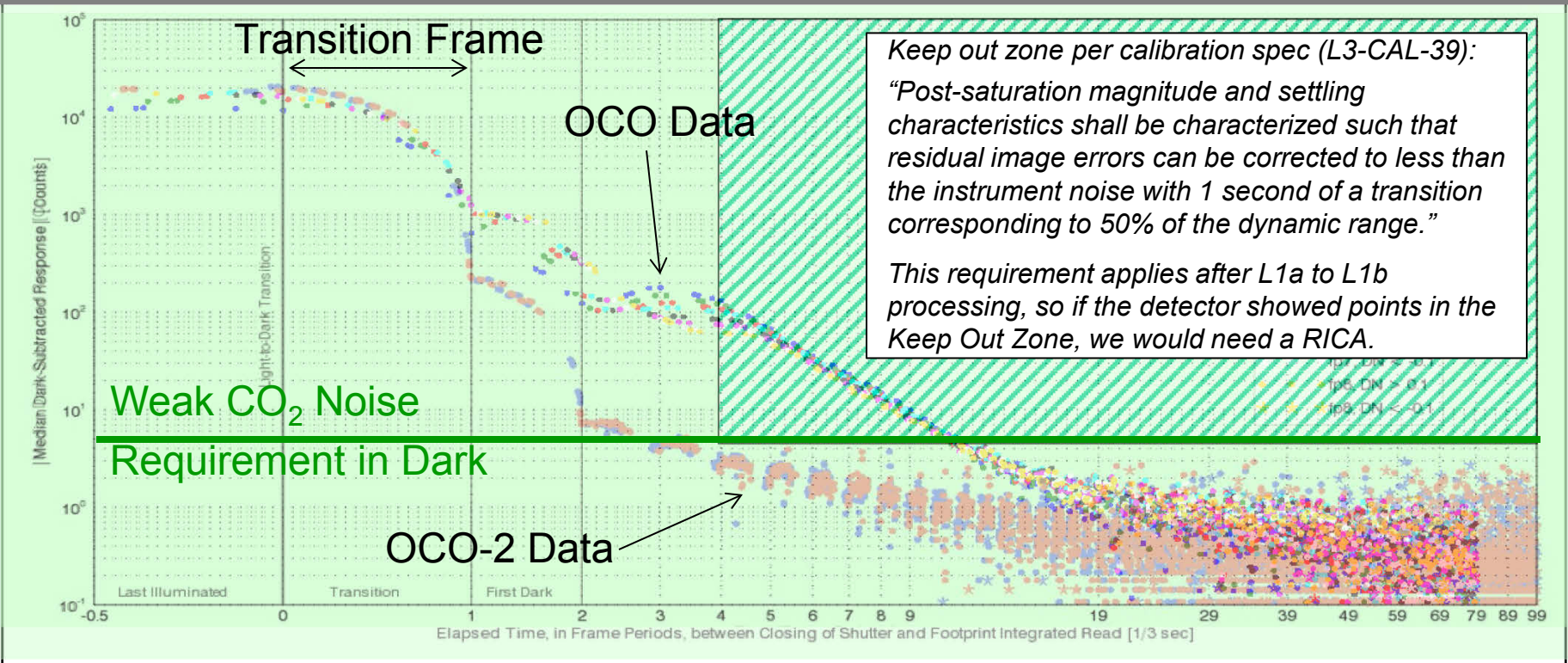






By taking the ratio of a fully illuminated heliostat data set and one with ~50% of the light blocked, we can validate that the non-linearity of the instrument is well captured by the gain coefficients. If it is, then the ratio of the two spectra should be a flat line and all three bands should agree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

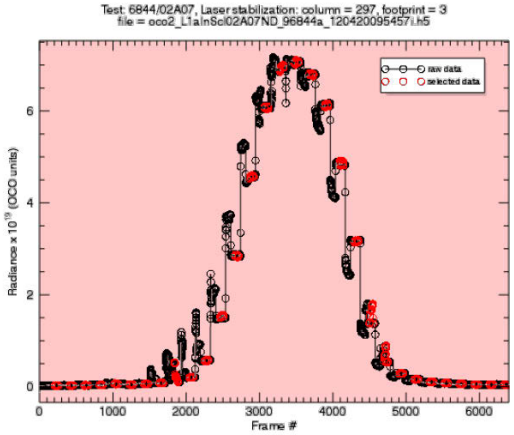
Spectral Calibration Overview

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

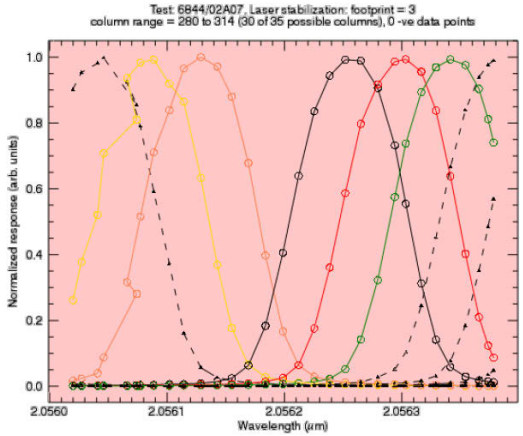
Exploring further optimization, but cautious of over fitting the data…

Spectral Calibration Process

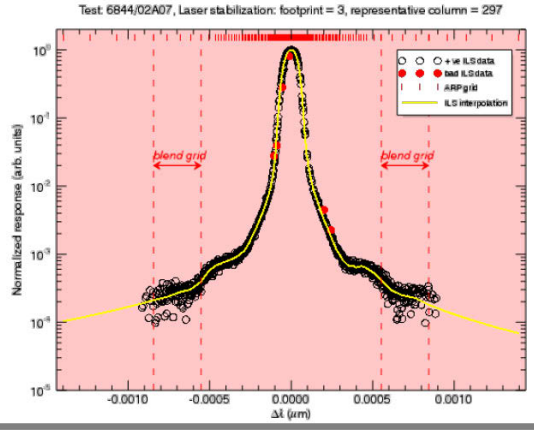
Step 1: Single laser fine-step scan as seen by a single sample



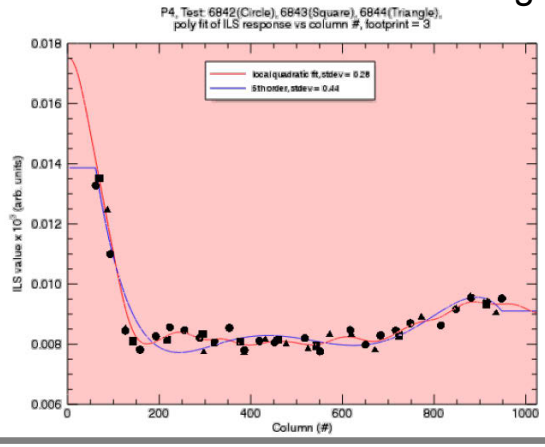
Step 2: Look at simultaneous data for stable laser periods as seen by neighboring samples



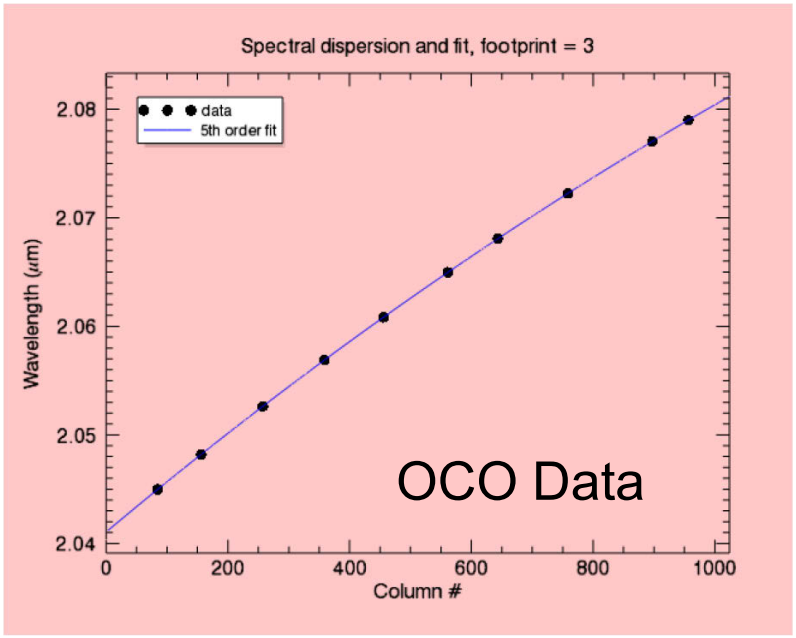
Step 3: Center all local data by subtracting center wavelength

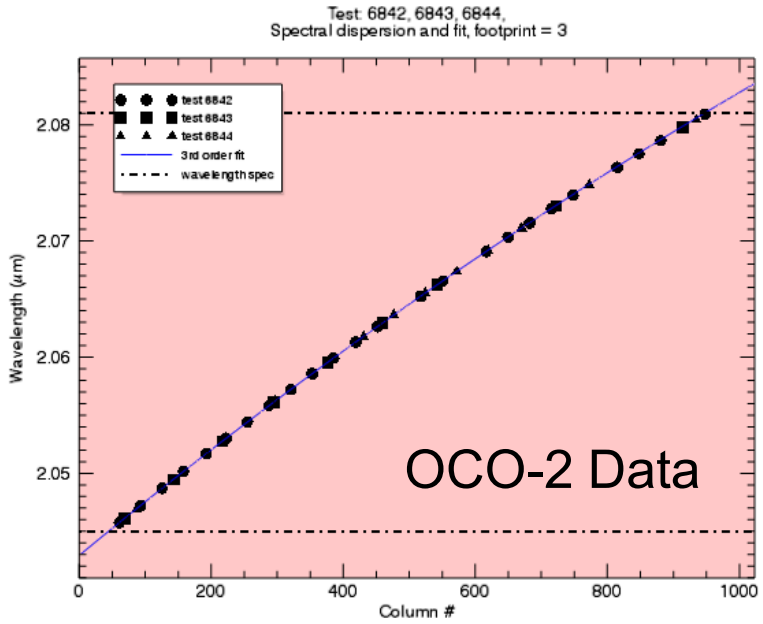


Step 4: Interpolate through all laser fine-step scans to estimate ILS at all wavelengths



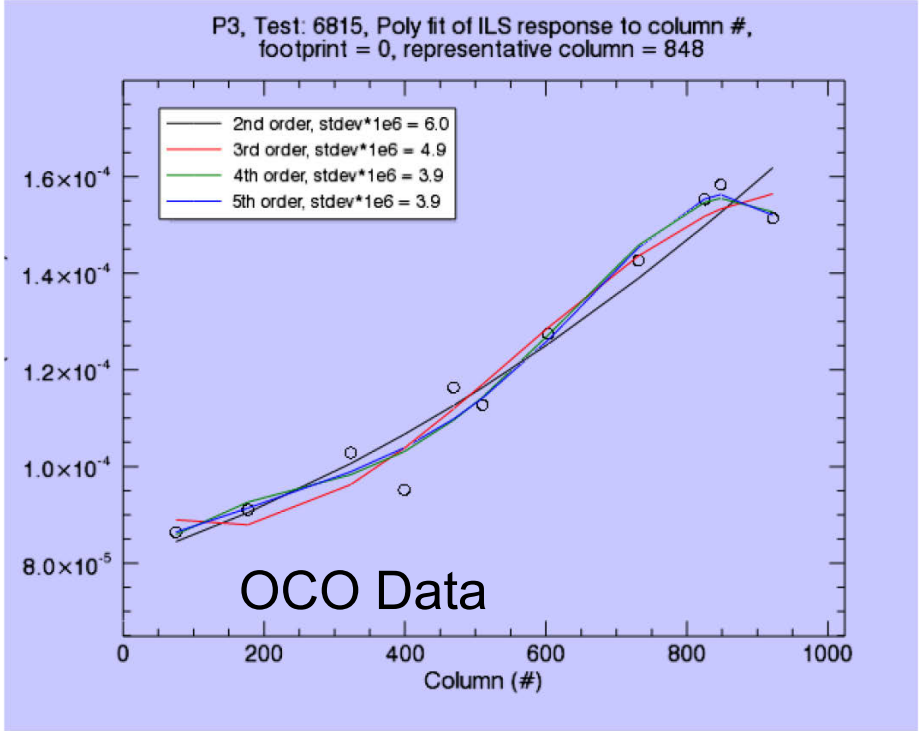
OCO-2 Collected Far More Spectral Calibration Data

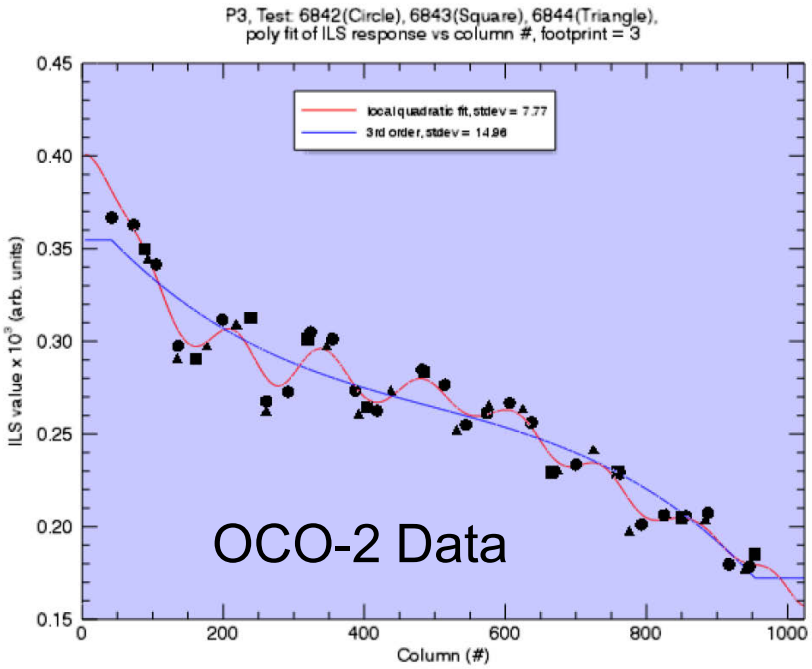




- Each symbol represents a position on the FPA where a fine laser scan was completed

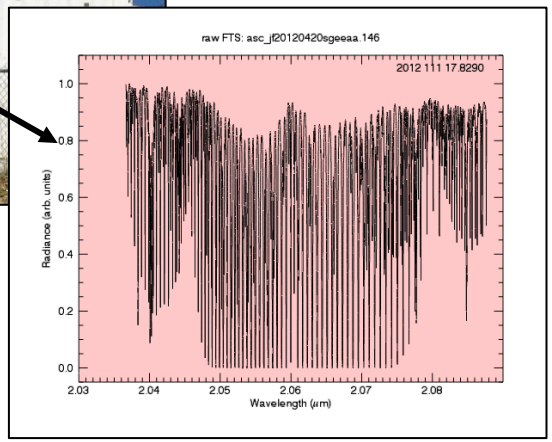
OCO-2 Data Resolved Features Not Seen on OCO

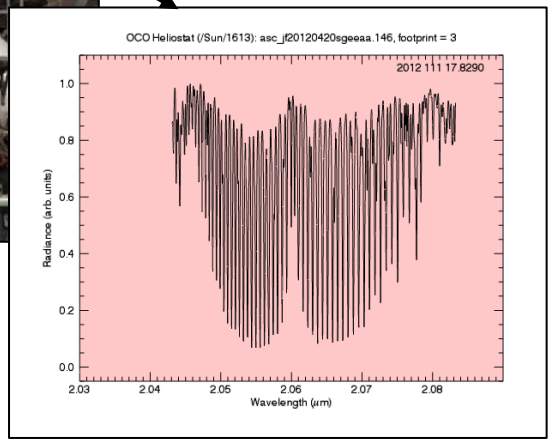




- Slopes differ to OCO being in slightly better focus than OCO-2 for the A-band
- Main point is that OCO-2's richer data set allows a mapping of high-frequency changes in the ILS that correspond to the W-patter.
  - If they were present in the OCO data, we could never have resolved them.

ILS and Dispersion Verification Uses FTS Data

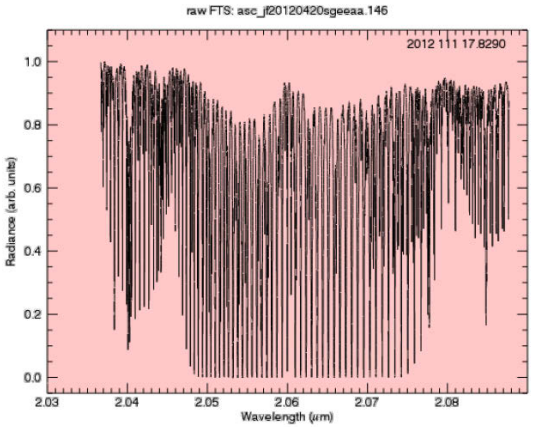




Note much higher FTS resolution

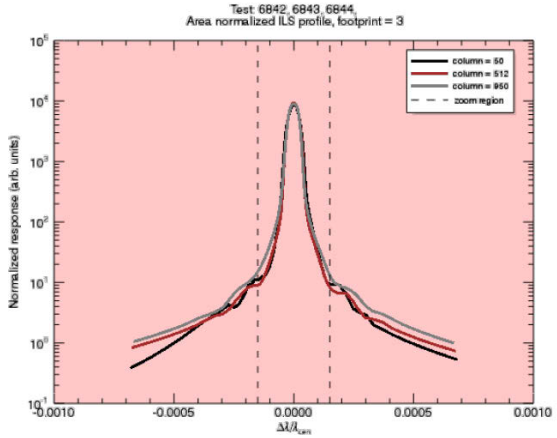
Convolving FTS Data and Laser-Based ILS Provides Simulated OCO-2 Data

FTS spectrum



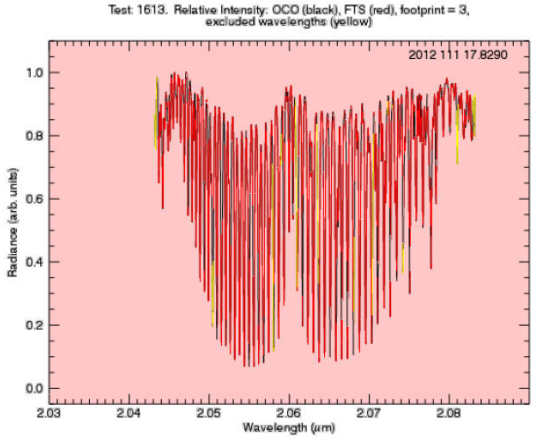
*

OCO-2 ILS

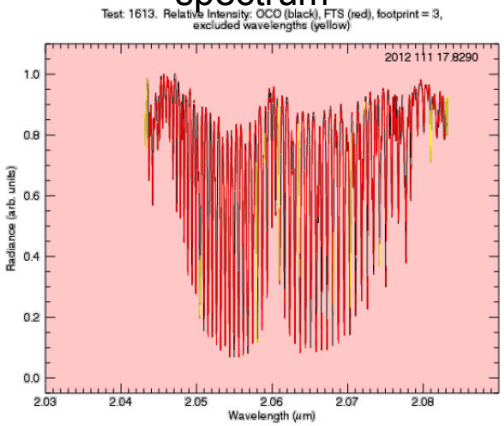


=

Simulated OCO-2 spectrum

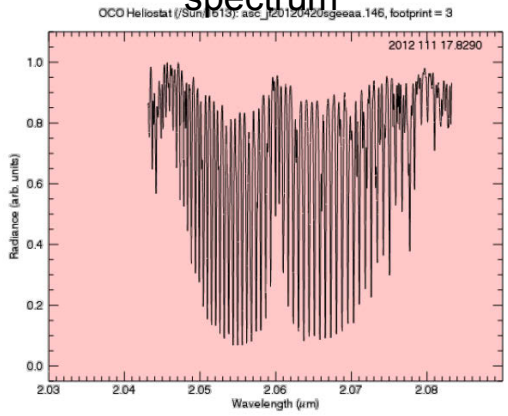


Simulated OCO-2 spectrum



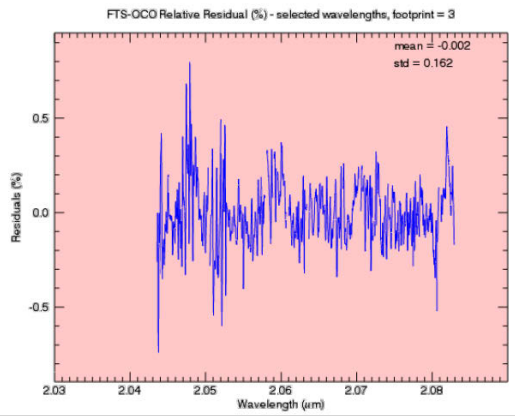
-

Measured OCO-2 spectrum

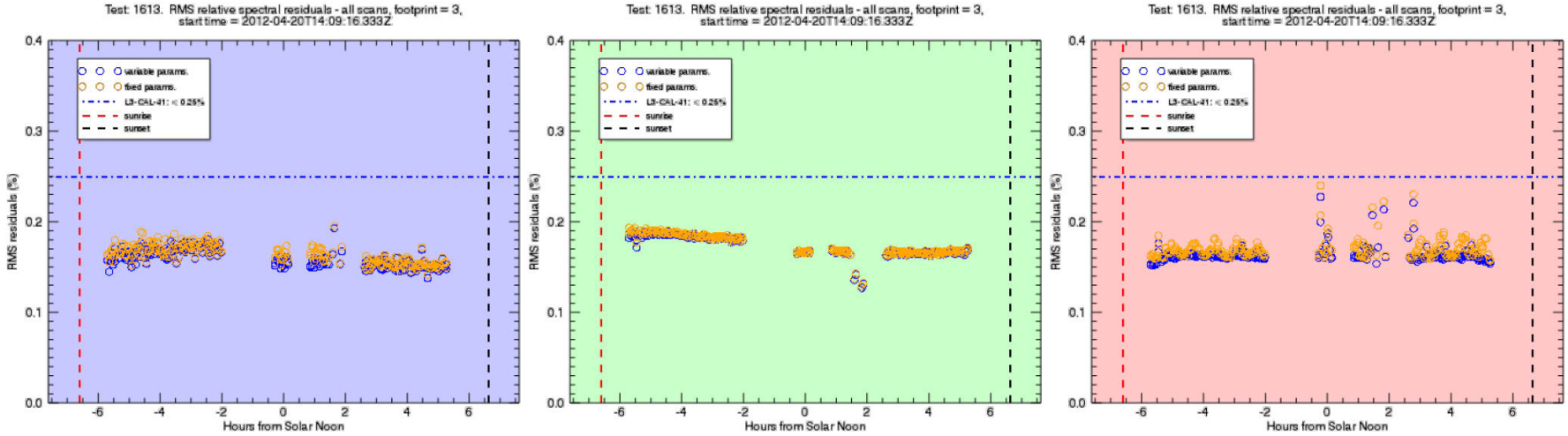


=

Spectral Residuals



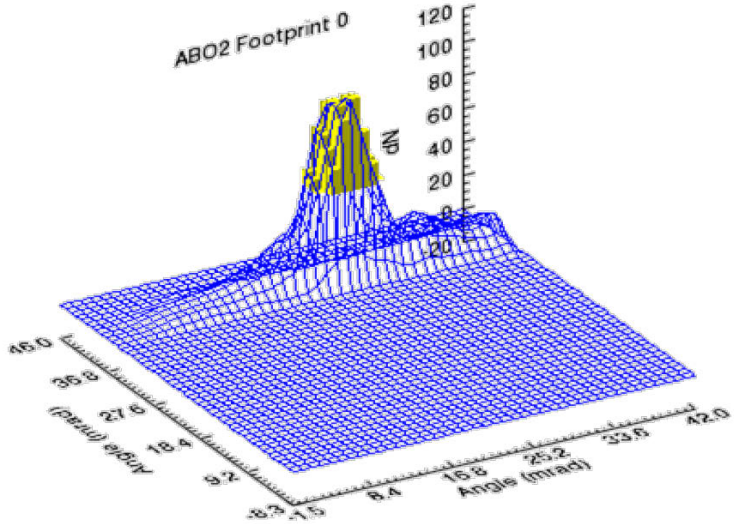
RMS of Residuals Validates ILS & Dispersion

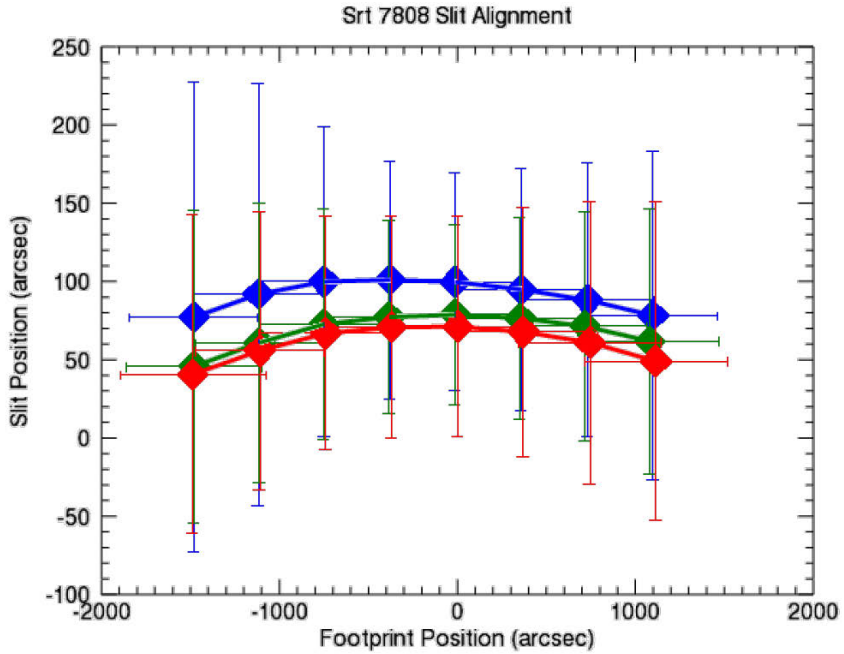


- Residuals look small and constant over the entire range of atmospheric paths

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

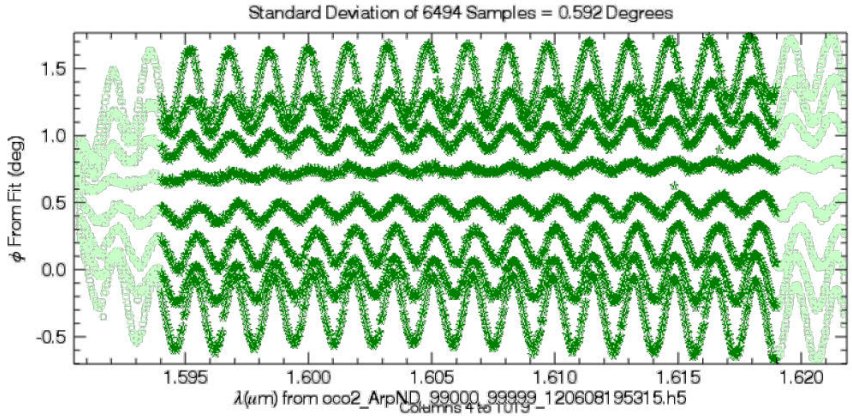


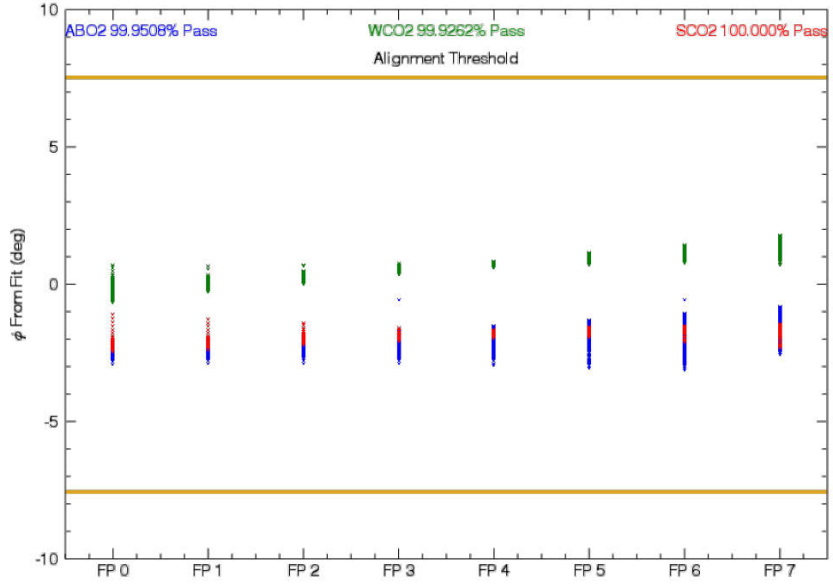


FP #	xmax (arcsec)	ymax (arcsec)	Δx (arcsec)	Δy (arcsec)
0	78.2	1100.6	105.3	358.8
1	88.0	733.9	87.6	374.6
2	94.9	358.3	77.3	376.0
3	99.7	-13.8	69.5	373.2
4	101.0	-379.4	76.2	366.3
5	99.9	-746.9	98.8	363.8
6	91.9	-1118.4	135.1	369.9
7	77.1	-1481.4	150.2	361.8

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