2014 STAR JPSS Science Team Annual Meeting

Derivation of solar irradiance for OMPS nadir instruments

2014-May-13

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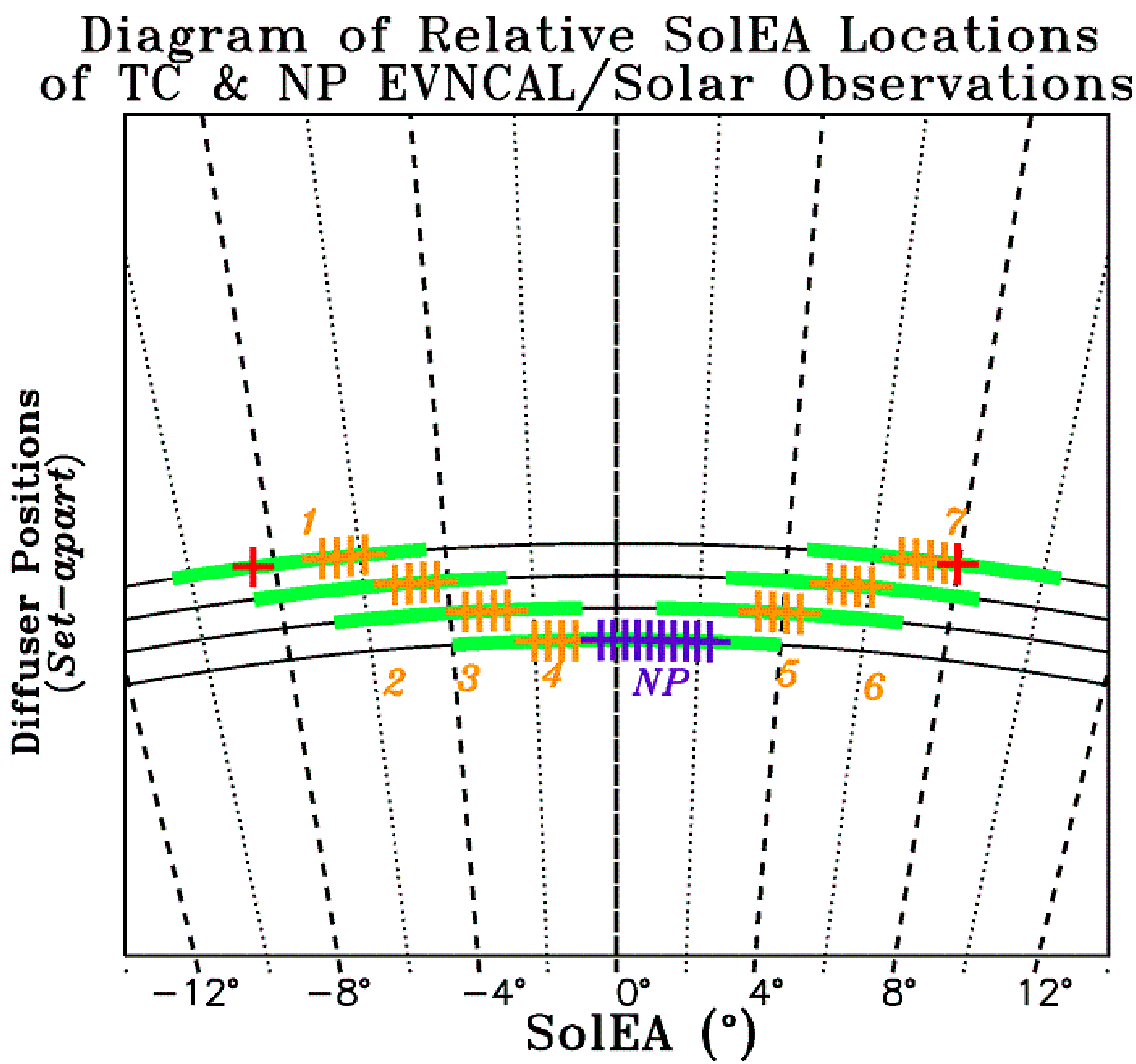
Solar Cal ConOps Changes

- Original: EVNCAL/EVNREF
  - Minimum number
    - 3 observations (obs.) at each NM DiffPos: IT=600 msec & 8 coadds
    - 9 obs. at NP DiffPos (#4): IT=332 msec & 15 coadds
- Current: 3orb_EV_Solar_N / 3orb_EV_RefSolar_N
  - Same ITs and numbers of coadds
  - 16 or 17 obs. at each NM DiffPos, & 23 for NM DiffPos nadir (#4)
  - 15 obs. for NP DiffPos
  - Observations span *most* of the goniometric range for each Diff Pos
    - Optimized number of images implemented
    - Provides better handling of diffuser features
    - Provides better statistics
    - 1st time for an *optimal approach;* prior approaches more *minimal*
    - *Bonus* of 9 additional observations for NM at DiffPos 1 & & on 3rd orbit
    - Compromise: To span entire goniometric ranges for all DiffPos, one would need 4-orbits, due to the overlap of DiffPos

Original Solar Calibration Layout



Diffuser Positions set-apart (fanned-out) to show goniometric Solar Elevation Angle Ranges vs Nadir Diffuser Positions

Green = Nadir Diffuser Goniometric Ranges

Orange = TC Observations Start &/or End Times, & DiffPos Numbers

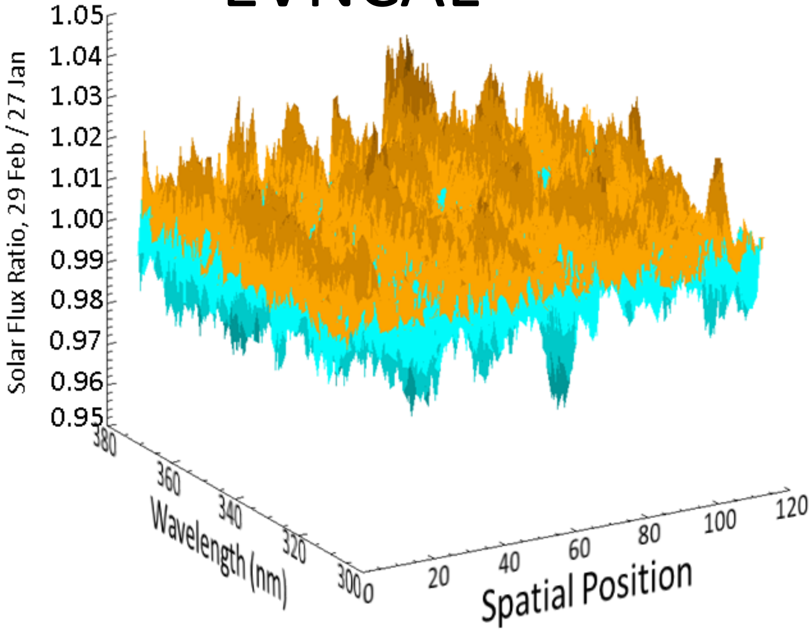
Purple = NP Observations Start &/or End Times

Red = Initial & Final Diffuser Movements for Solar Cal

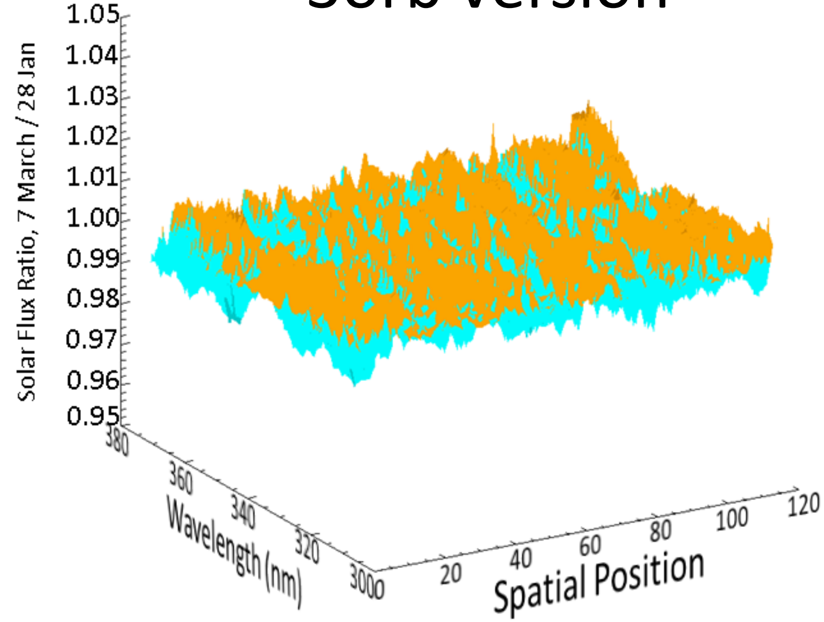
TC = NM

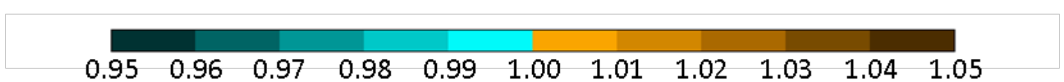
Solar Flux Ratio Comparisons: Working Solar Cal Options: TC4

EVNCAL



3orb version



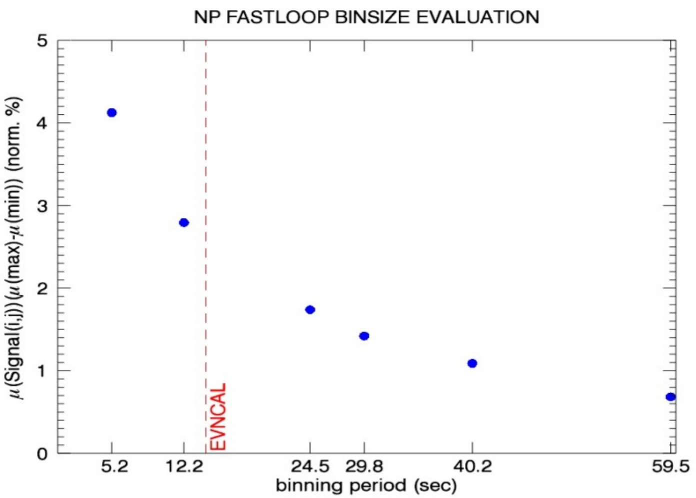


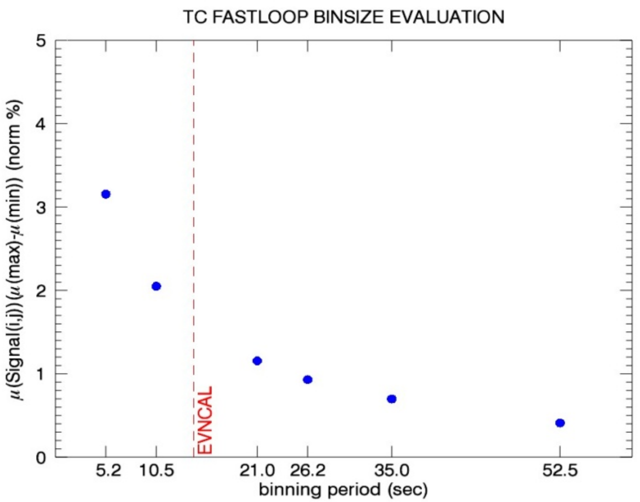
Gon. SolEA range ≈ 0.9° across 3 measurements

Gon. SolEA range ≈ 8°
Better statistics? Y.E.S.

Reduction of Solar Diffuser Features

Peak-to-Peak Variation / Mean Signal vs Binning Period

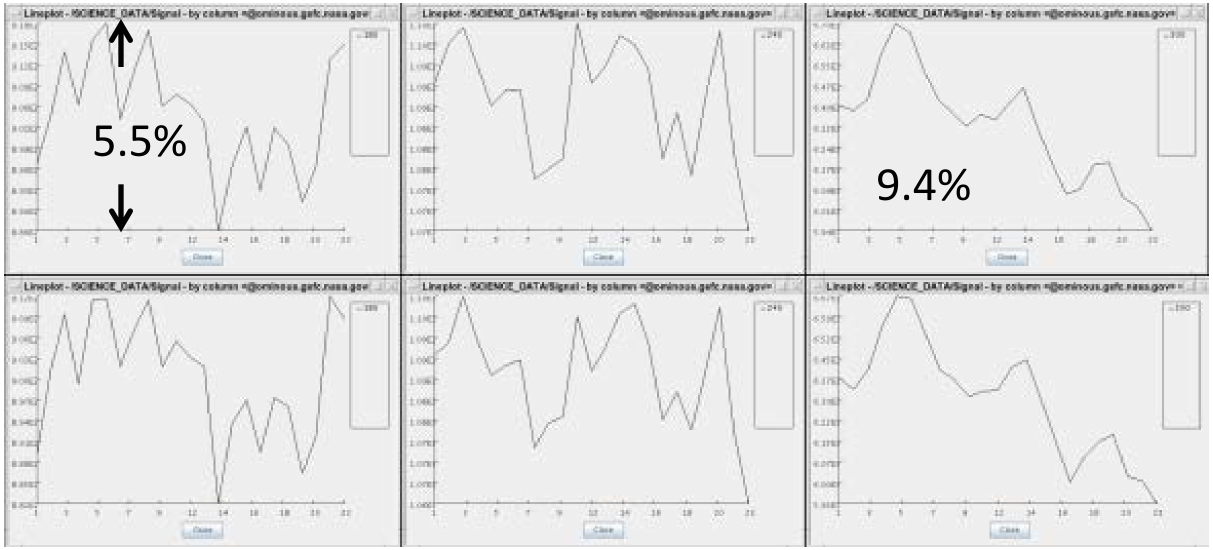




- NP Binning Period (sec)
- IDL> print,0.332d*15*[3, 16]
- 14.94 79.68
- 4X or 5X reduction

- TC Binning Period (sec)
- IDL> print,0.6d*8*[3, 16, 17, 23]
- 14.40 76.80 81.60 110.40
- Approximate 4X reduction

Solar Diffuser Features



Fluxes from WRK obs. Following 2nd & 4th Solar REFs

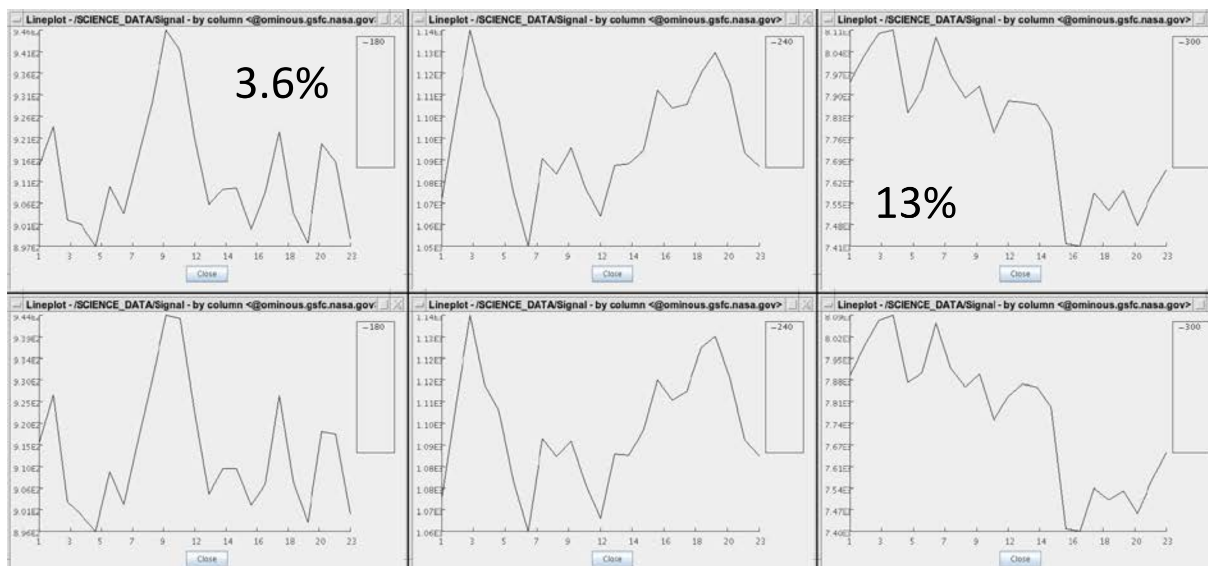
3orb, WRK Diff, TC4
3 Spectral Positions
Same Spatial Location

Not noise
Repeatable structure

3orb, REF Diff, TC4
Everything else same.

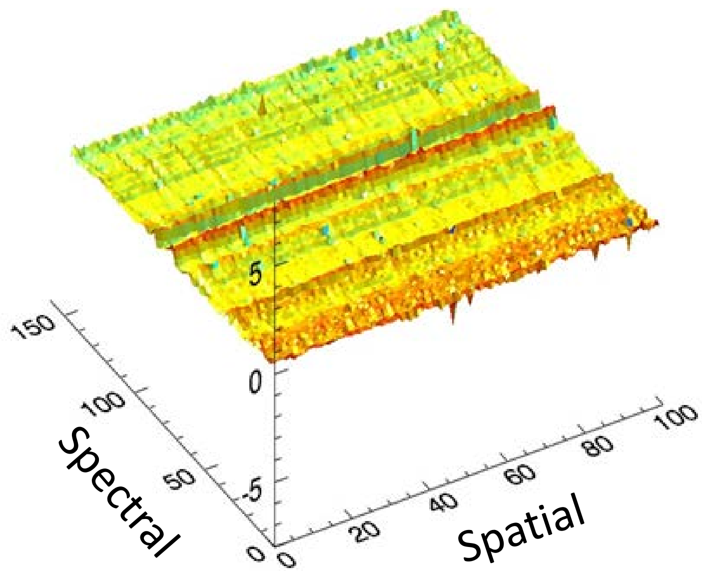
WRK & REF distinct & have unique features

Motion primarily in SolEA Angle, 8°

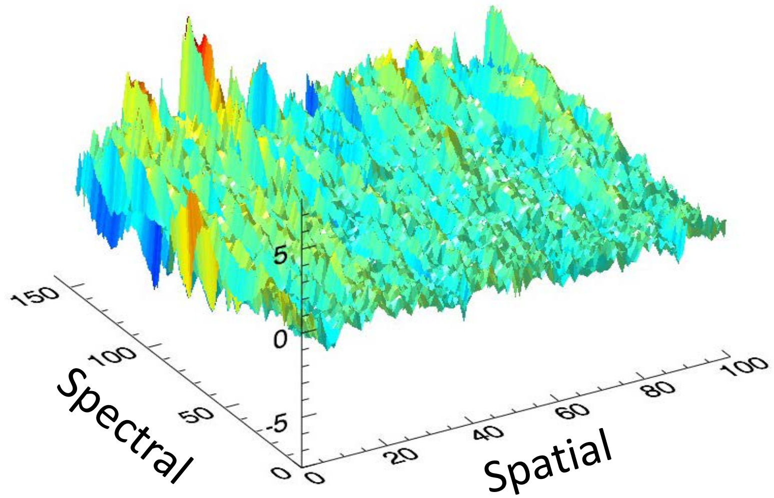


NP Solar Cal Diffuser-Feature Comparisons as Function of Solar Beta Angles

NP: Apr-4/Mar-21
β = 18.95°
σ = 0.189%



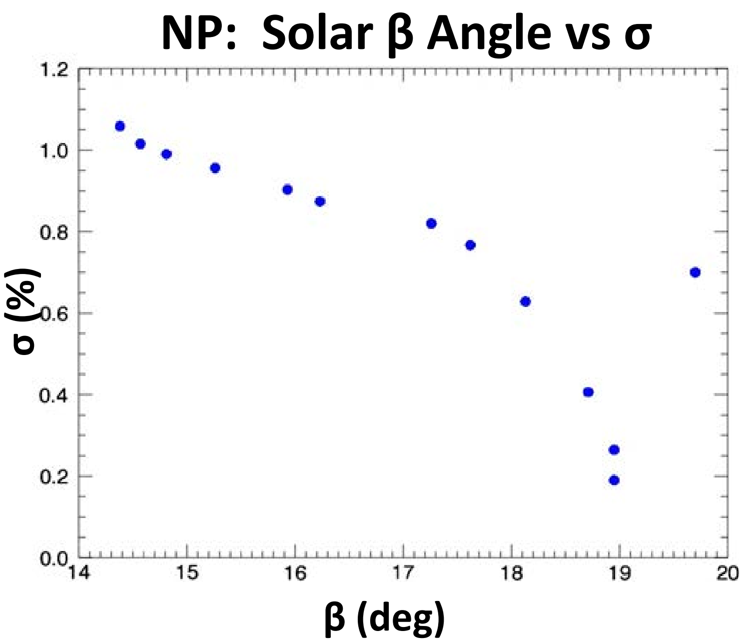
NP: Jun-27/Mar-21
β = 14.57°
σ = 1.015%

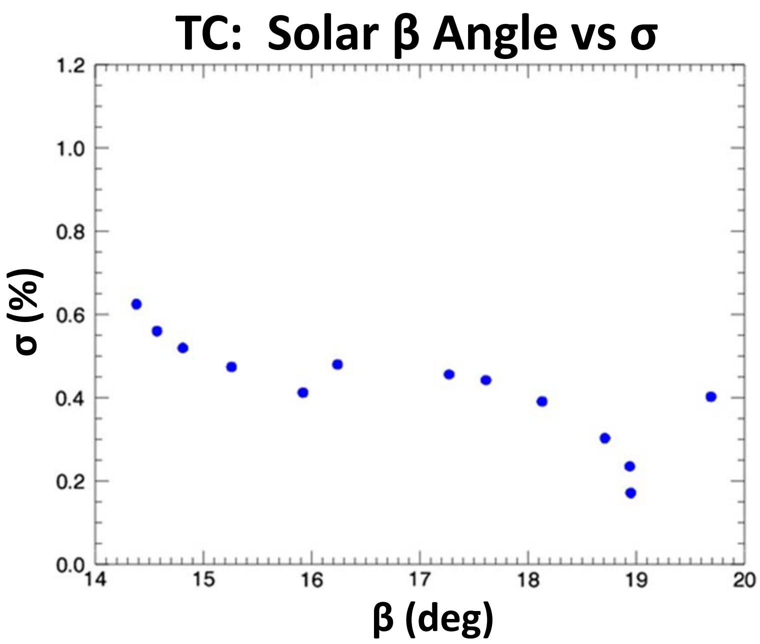


- Working Diff, 3orb observations
- Vertical (z) axes are Percent Difference
- 3 lines near 280 nm are ignored

- Differences in β significantly effect σ

Solar Cal Diffuser-Feature Comparisons as Function of Solar Beta Angle





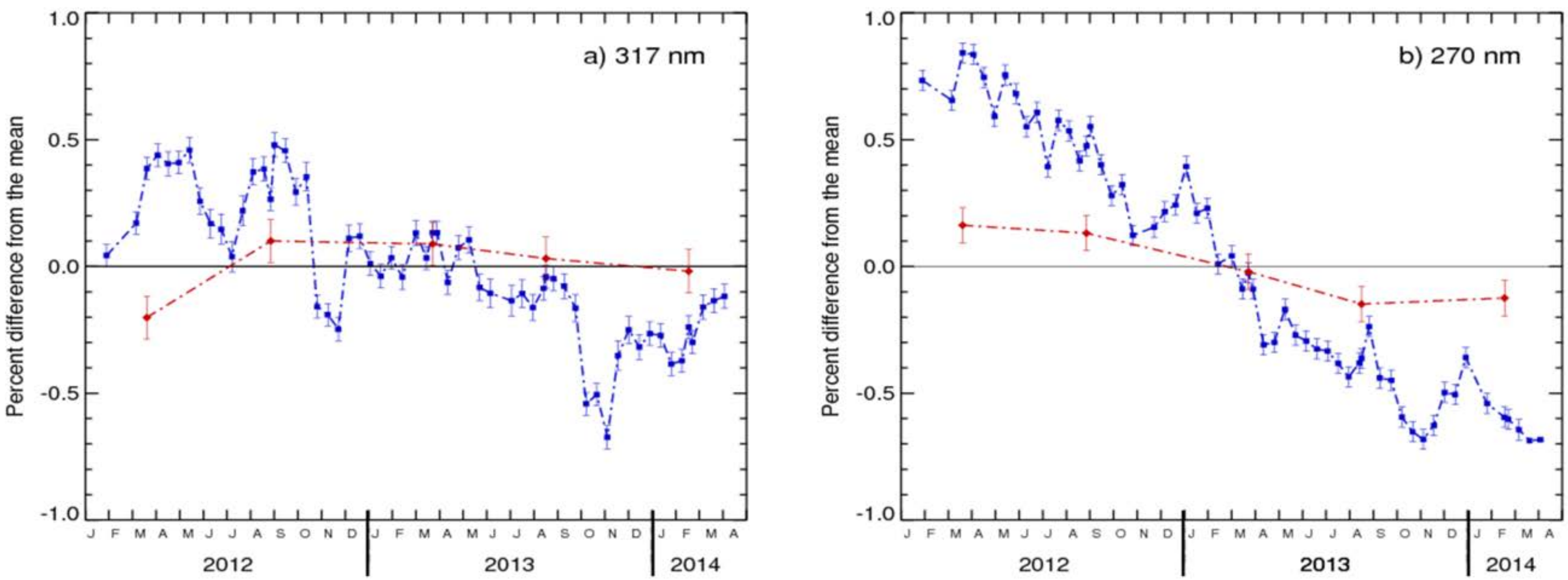
- Diffuser features minimized at same β
- **Infers repeating Solar Ref Cals at same β is advantageous**

- Similar results for NM Working Diff

Solar Cal ConOps Change Summary

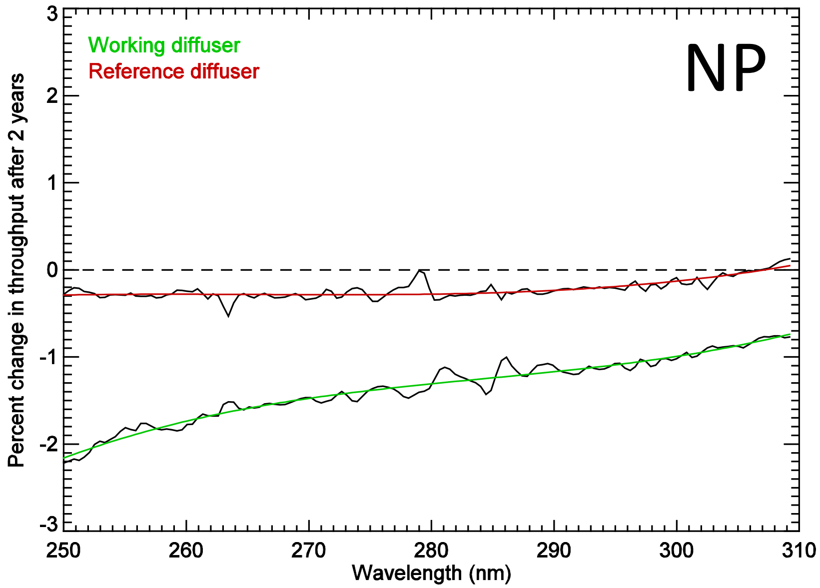
- 3orb vs Original Nadir Solar Cal Plan
  - Makes use of most of the goniometric ranges
    - Collects many more measurements
    - Different from most prior missions
    - Minimizes diffuser features
      - Most critical aspect
      - Significant improvement over original method
- Repeating Ref Cals at same Solar β Angle further lessens effect of diffuser features
  - Also different from prior missions

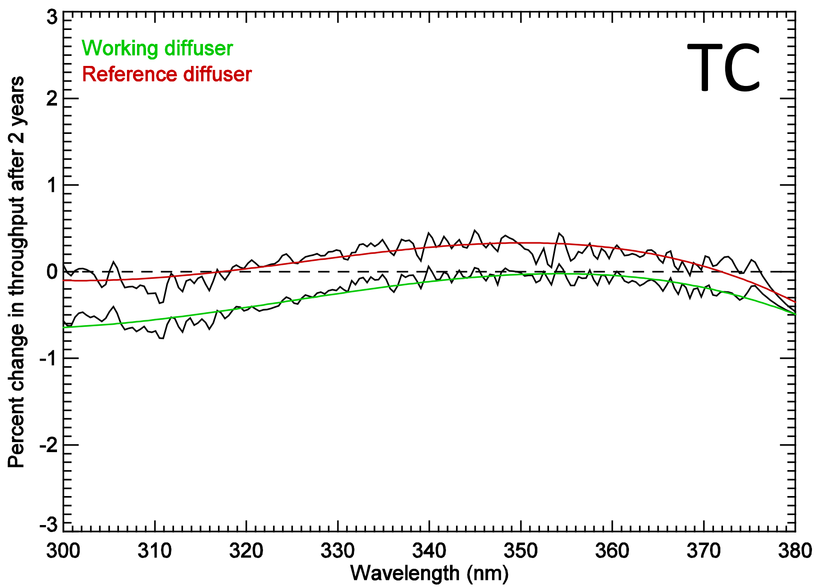
Nadir, Solar Cal, Throughput Time Series: NM & NP Sample



- NM Working Diff (on left) shows max, peak-to-peak, throughput variation of ~1.2 %
- NP (right) shows max, peak-to-peak variation of approx'ly 1¼ %
- Some systematic variations are evident
- Ref Diffuser obs. (in red) indicate little change in NM, and perhaps ¼ % change in NP
- Working Diff obs (blue) less than ½ % for NM, and approx'ly ½% per year for NP
- Not sensitive to solar activity

Net Throughput Changes after 2 Years





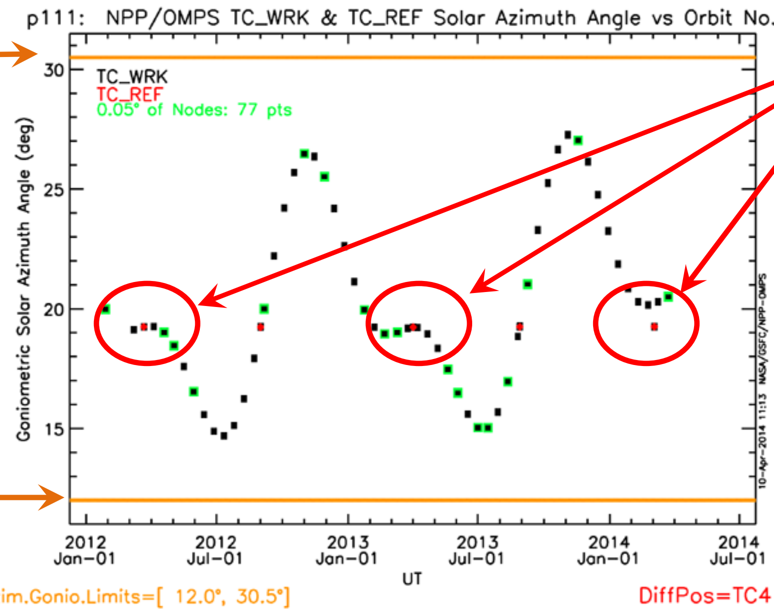
- Corrected for Solar Activity
- Small wavelength correction not applied (0.0x nm)

- No corrections for Solar Activity
- No wavelength corrections

Solar Ref Cals & Az.Angle Variation

Wrk
Ref

Gonio Limits



Saddle-points

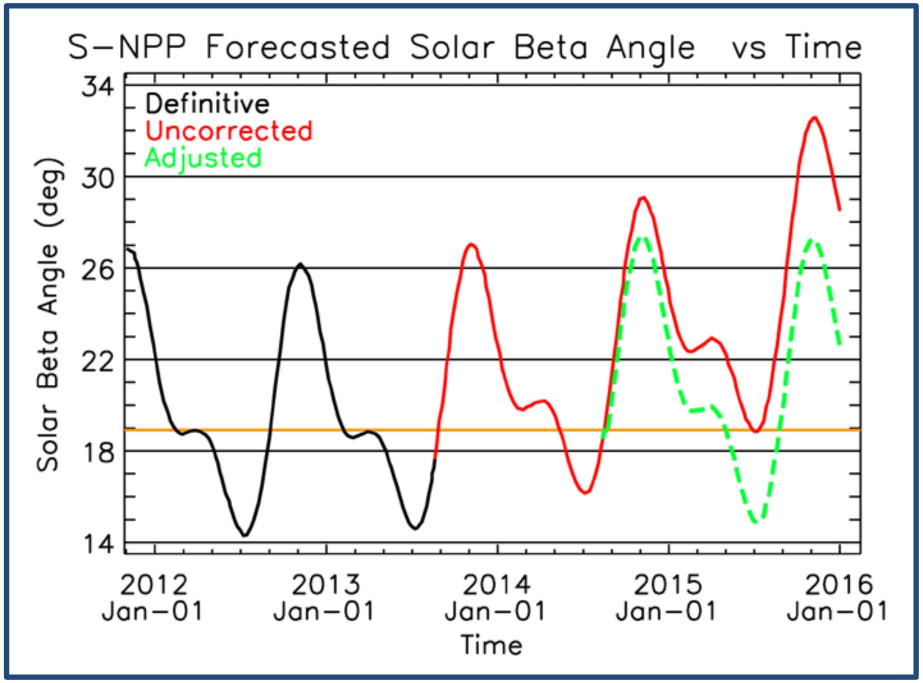
Solar Ref Cals:

- **Collect approx'ly semi-annually**
- **Maintain same Solar Azimuth Angle for all Ref Obs.**
- **Use saddle-point timeframe for 1st obs of year: Feb to late April**
- **2nd obs of year in late August**

- *Saddle-Points* occur due to elliptical Earth orbit and varying Sun-Earth distance
- *Saddle-Point* timeframe: Provides opportunity to re-run a Solar Ref Cal if needed (e.g., data was lost, unplanned spacecraft event, etc.)
- Late-August timeframe has fast rate-of-change: No second chances!
- However, one other significant challenge with this plan: Orbit Drift.

Solar Ref Cal Planning

- Challenges going forward
  - Changes in inclination are accelerating
  - Eastward drift in LTAN is also accelerating
  - Eventually drift beyond gonio. azimuthal range
- If not corrected, the Saddle-point
  - will move up by >1° per year
  - Will move later into July



Plans to begin orbital corrections in mid-2014:

- Involves both orbital inclination and LTAN
- Not a quick fix

Current Expected Schedule:

- 6th Solar Ref Cal in late July or early August
- Orbital adjustments should improve 7th Solar Ref Cal
- Sufficient improvements to obtain without requesting a 2nd yaw maneuver is TBD

Notes and Thoughts for OJ1

- Keep new approach of using same Beta Angles for Solar Ref Cals
  - Minimizes diffuser features
  - Needs to be somewhat adjustable in time
- Benefits of 3orb vs 3-observations Solar Cals
  - Better statistics (reduced diffuser features)
- Effects of orbit maintenance still TBD
  - Honing plans & skills at MOT during S-NPP mission
- Different diffuser material: QVD
  - Less diffuser features

S-NPP/OMPS Solar Measurements

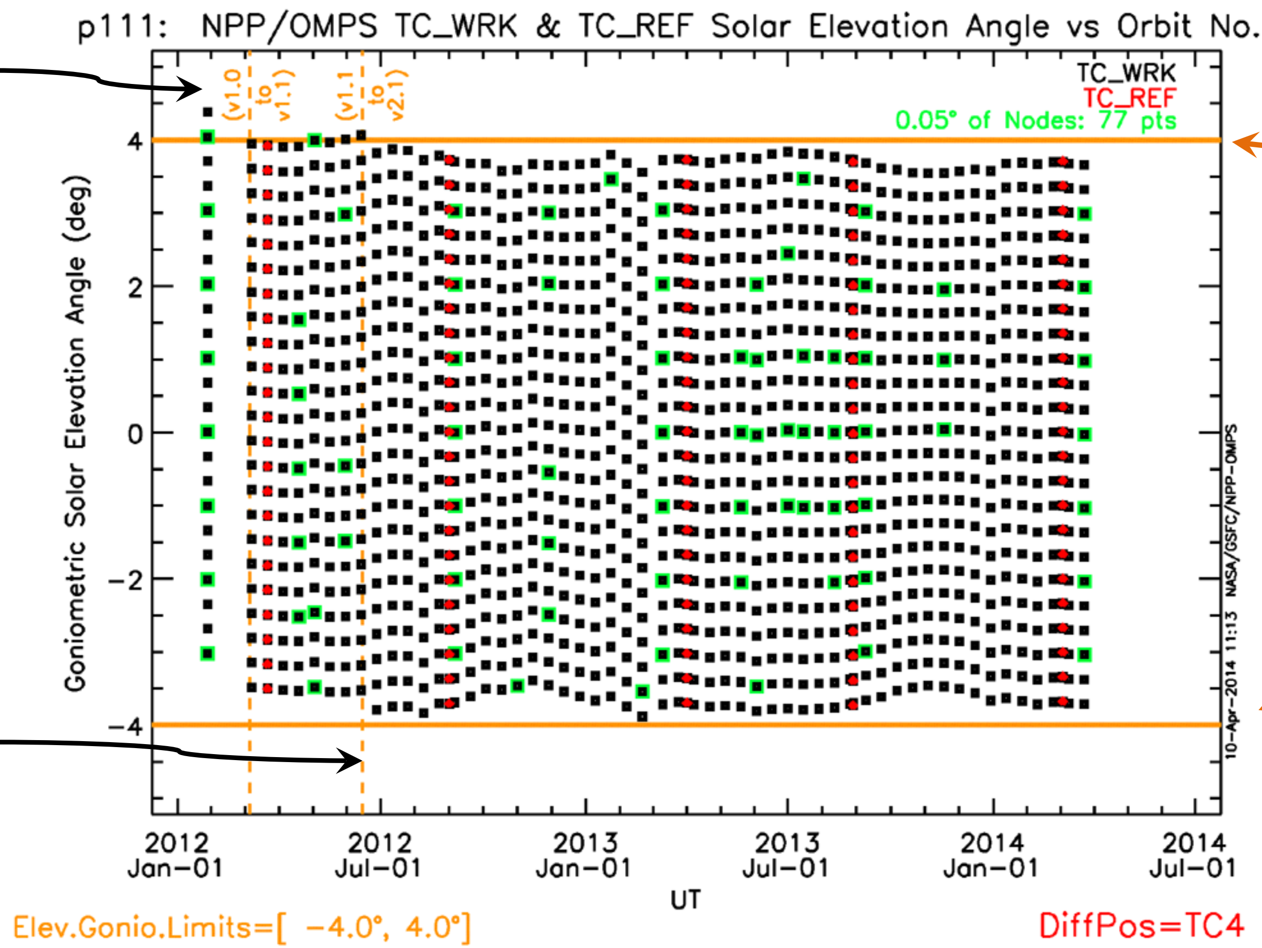
Back-Up Slides

3orb Solar Elevation Angle Goniometric Coverage: TC4

Initial Version updated from v1.0 to v1.1

Wrk
Ref

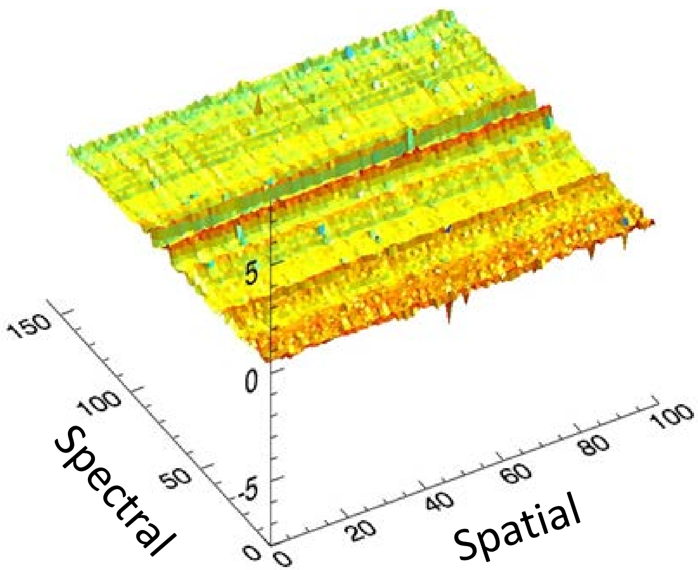
Version 1.1 updated to v2.1



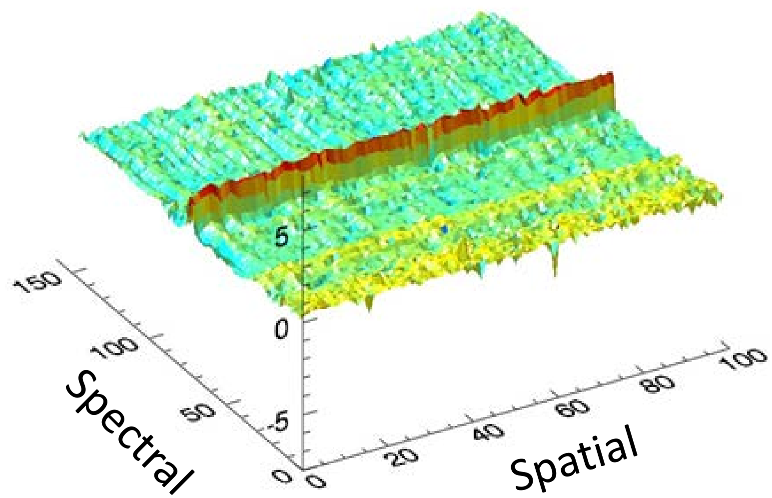
Gonio Limits

NP Solar Cal Diffuser-Feature Comparisons at Similar Solar Beta Angles

NP: Apr-4/Mar-21
β = 18.95°
σ = 0.189%



NP: Aug-31/Mar-21
β = 18.95°
σ = 0.264%



- Working Diff obs.
- Vertical (z) axes are Percent Difference
- 3 lines near 280 nm are ignored

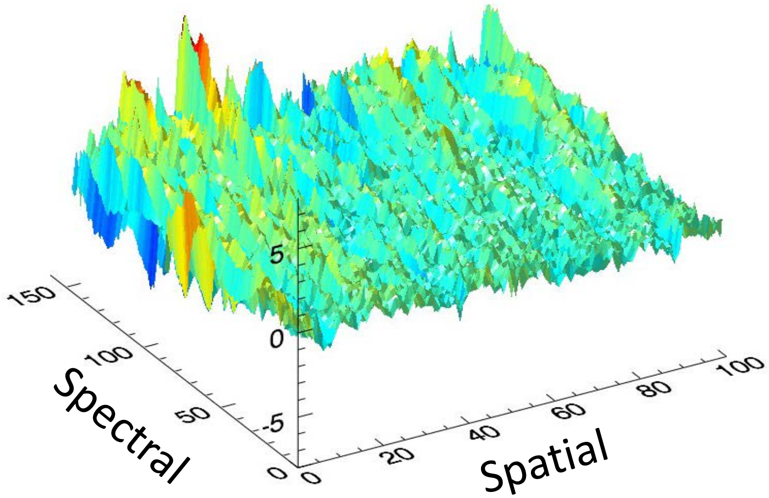
- Left: ~2 weeks apart
- Right: >5 months apart
- **σ for both examples ~ 0.25%**

NP Solar Cal Diffuser-Feature Comparisons at Different Solar Beta Angles

NP: Jun-27/Mar-21

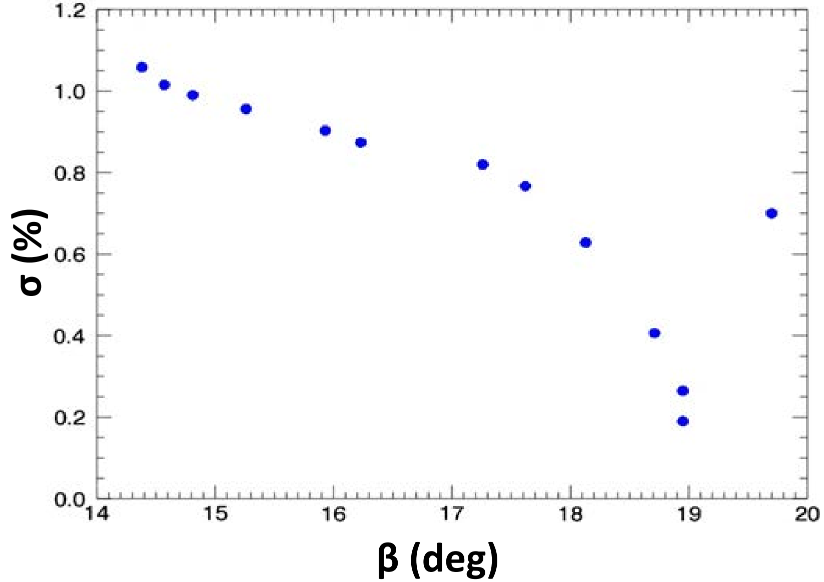
β = 14.57°

σ = 1.015%



- Working Diff obs.
- Vertical (z) axis is Percent Difference
- 3 lines near 280 nm are ignored

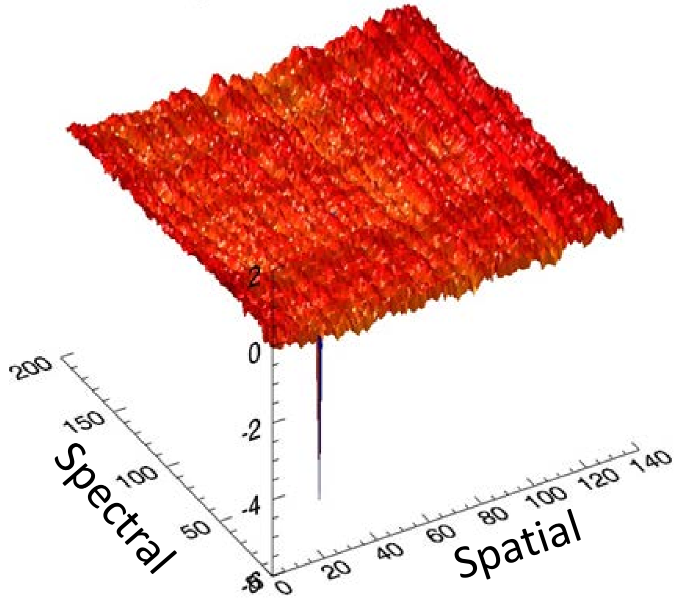
NP: Solar β Angle vs σ



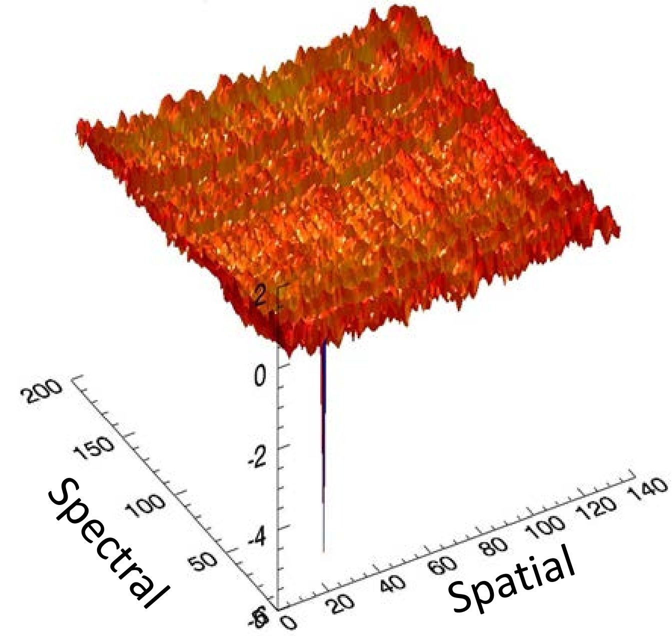
- From an early study with 13 obs.
- Differences in β significantly affect σ
- Diffuser features minimized at same β
- **Repeat Solar Ref Cals for NP at same β a good idea**
  - Need to compensate for orbit drift

TC Solar Cal Diffuser-Feature Comparisons at Similar Solar Beta Angles

TC: Apr-4/Mar-21
β = 18.95°
σ = 0.171%



TC: Aug-31/Mar-21
β = 18.94°
σ = 0.235%

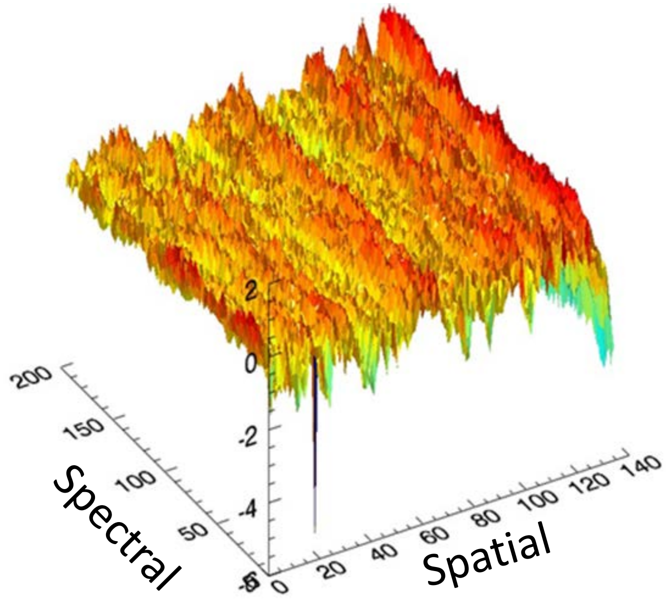


- Working Diff obs.
- Vertical (z) axes are Percent Difference

- Left: ~2 weeks apart
- Right: >5 months apart
- **σ for both examples ~ 0.25%**

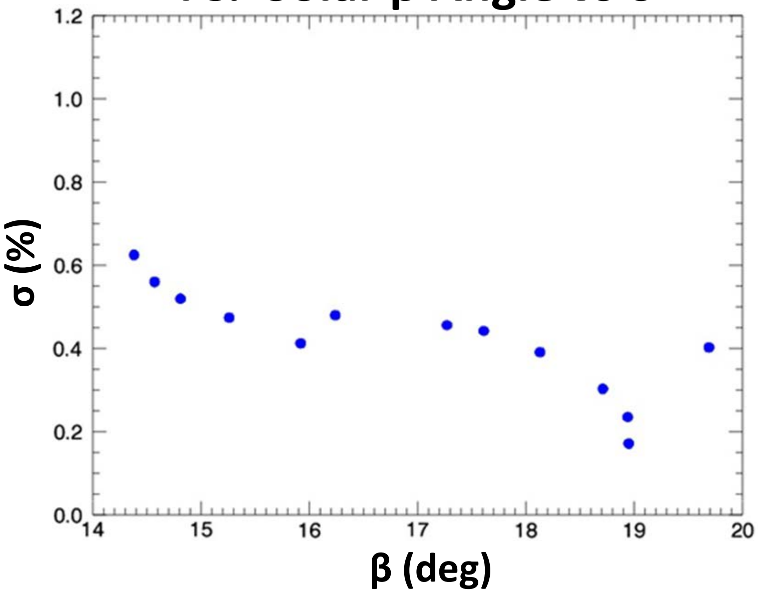
TC Solar Cal Diffuser-Feature Comparisons at Different Solar Beta Angles

TC: Jun-27/Mar-21
β = 14.57°
σ = 0.560%



- Working Diff obs.
- Vertical (z) axis is Percent Difference

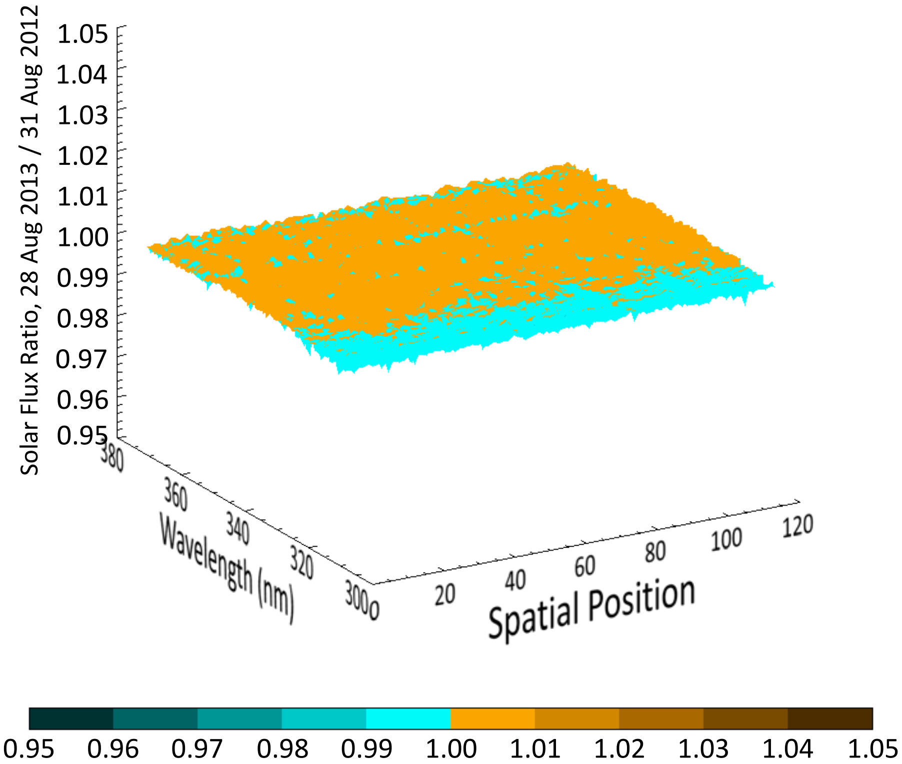
TC: Solar β Angle vs σ



- Early study with 13 obs.
- Differences in β significantly affect σ
- Diffuser features minimized at same β
- **Repeat Solar Ref Cals for TC at same β also a good idea**
    - Need to compensate for orbit drift

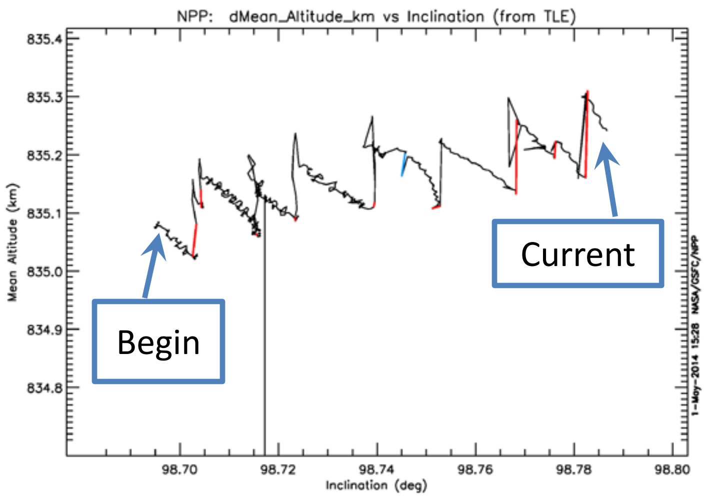
Comparisons at Similar Solar Beta Angles: 2^{nd} & 4^{th} Ref Cals

Ratio of 4^{th} to 2^{nd} NM Solar Ref Cal



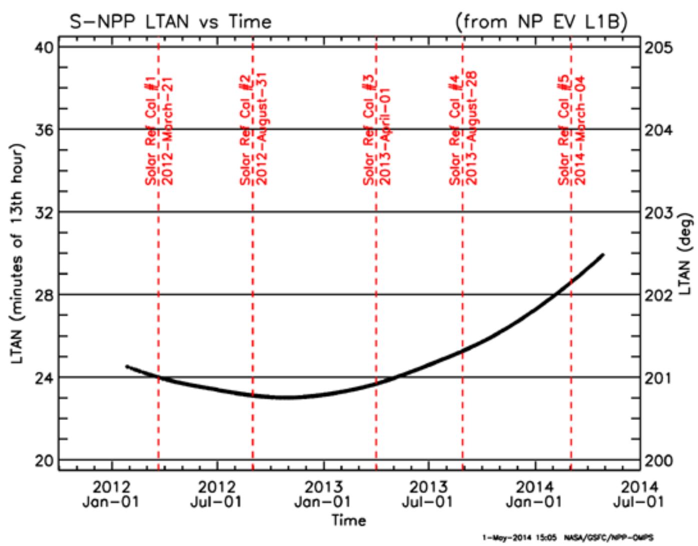
- August of 2012 & 2013 Ref Cals
- Diffuser features minimized
- Benefits Ref Cals
  - Minimizes 1 source of uncertainty: the goniometry corrections
- Not possible, in general, for Solar Working CALs
  - Solar Azimuth Angle varies throughout the year
  - Have many more to find similar β angle comparisons

S-NPP Orbit Drift vs Time



Info from TLE: Mean Altitude vs Inclination

- Inclination slowly increasing
- Net increase of ~0.09°
- Mean altitude has slight increase
- ➔ Rate of precession a little too large



Info from L1B: LTAN vs Time

- Minimum near end of 2012
- Accelerating rate to later LTAN since
- Began at 13:25 LT
- Now at 13:30 LT
- ➔ approx'ly 1.3° increase in Solar β

MOT to correct drifts

- Timeframe is this summer
- Slowly correct orbit

NASA Dark Current, Linearity, and Transients Calibration/Correction for OMPS Nadir Sensors

Michael Haken NASA/SSAI

2014 STAR JPSS Science Team Annual Meeting, 13 May 2014

Dark Current: Image and storage region rates derived from sequence of images, replaced original 100/10-coadd measurements. Transients detected, removed,recorded. Weekly doors-closed measurements, qualification of open-door data for change to orbital updates in progress

Linearity: Non-linearity correction derived from sequence of stepped exposures with LED illumination. Original BATC approach replaced by improved method: uses full dynamic range of response and accounts for pixel well-filling.

Transients: Frequency, energies, and locations of transients recorded for trending and analysis. SAA particle density and energies mapped. Improvement of transient filters for smear signals in progress.

Dark Current

Replaced original dark measurement sequence of 100/10 coadds (NM/NP) 125 second total exposure, with sequence of single frames 72 seconds each

Original sequence was:

- Not designed for transient detection – effect of transients diluted but not removed
- Specialized to produce corrections only for standard Earth view measurements, different dark measurements would have to be taken to correct different types of data, e.g. solar calibration and special Earth view measurements

New sequence:

- Utilizes temporal transient filter – transients detected and eliminated from calculations
- Allows tracking/analysis of transient events.
- Consolidates all dark correction data in a single measurement activity
- Produces elemental output used to construct dark corrections for any type of measurement – e.g. High and Medium resolution Earth view, PRNU, Solar

Performance improvement from transient filter depends on magnitude and pixel location of random transient events which degrade coadded measurements but not new measurements:

Estimated potential impact of one transient saturating CCD in one coadded EV frame => 16383 counts/125 seconds = *130 counts/sec (65 x nominal rate NM, 525 x NP)*:

Resulting error in radiance depends on signal level of pixel hit:

Typical EV Signals: **NM up to 33% error , NP up to 20%**

Weak EV Signals: **NM signals 100% or greater error, NP 50% or greater**

DARKCAL Algorithm

- **Sequence of 72-second integration time images, shortest allowed by data rate for continuous operation**
  - 5, 17, 22, or 37 full-frameimages depending on other activities

- **Transients detected using median-based method**
  - Median of time series for each pixel calculated
  - Counts > median of time series + 3-σ of median image => transient
  - Mean of only non-transient values in time series used to calculate rates for image and storage region pixels

- **Image of storage region readout signal synthesized from storage region rates**
  - Dark current generated in CCD storage region during the 330 msec readout period: ramp shape increasing from first/last row read out
  - Ramp shape increasing from first/last row read out:

$$S_{ij} = \sum_{k=1}^{i} Rates_{kj} * \text{dwell time}$$

dwell time = 330 msec / 390 rows

- **Rates and readout signal stored as images in HDF 5 output file**

DARKCAL Algorithm (II)

- Corrections for arbitrary data are constructed as:
  DCC = Ncoadds x (Image Region Rates x Integration Time + Readout Counts)
  Smear columns in DCC: average of smear rows in Readout Counts
- The full-frame DCC is binned according to the EV or solar sample table
- For IDPS dark LUTs, the binned DCC is converted to IDPS format, and scaled to 100 coadds for NM and 10 coadds for NP to simulate original dark current measurements

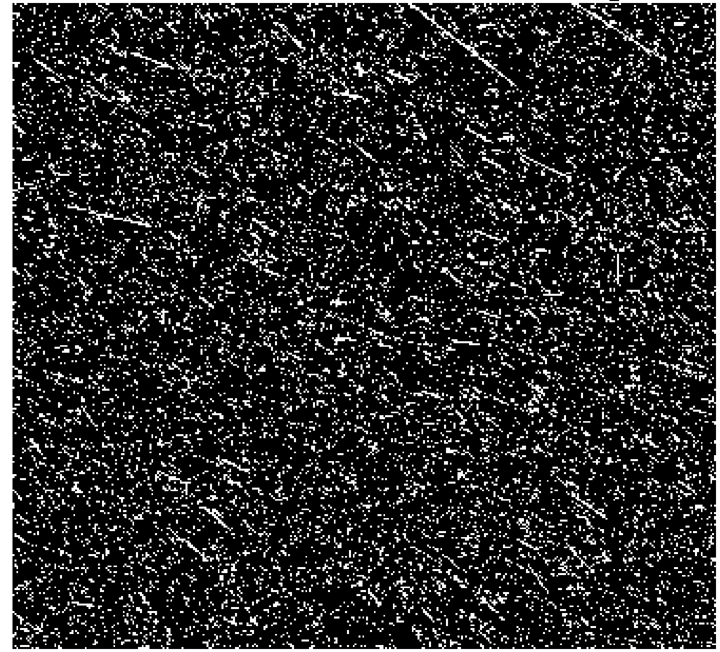
Original Dark Current Measurements

- Coadded full-frame measurements at standard Earth view integration time
- NM: 100 coadded frames 1.2471 seconds each
  NP: and 10 coadded frames 12.4792 seconds each

DARKCAL Transient Filter

- Detects transients in individual frames and records as images for tracking/analysis.
- Effective even within large part of SAA (demo only, images within SAA excluded from actual analysis)

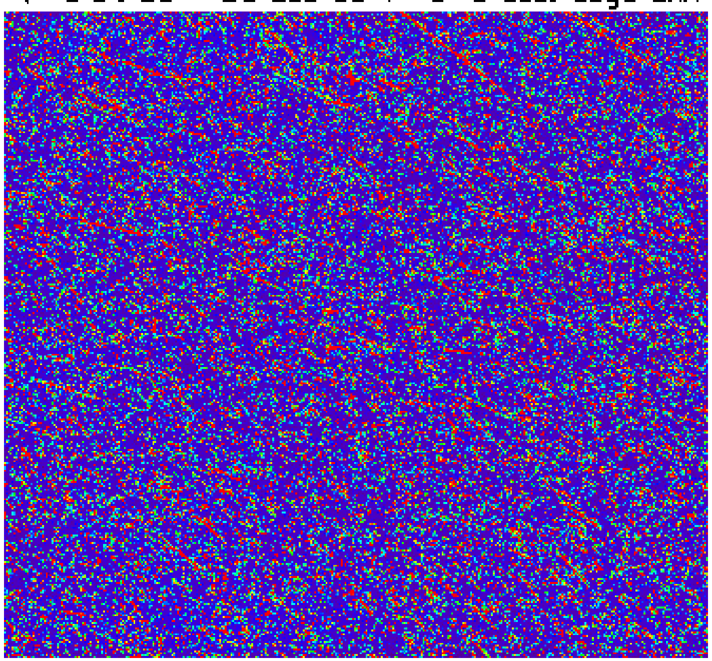
Transients detected in frame east edge SAA



Frame in 22-frame sequence through SAA

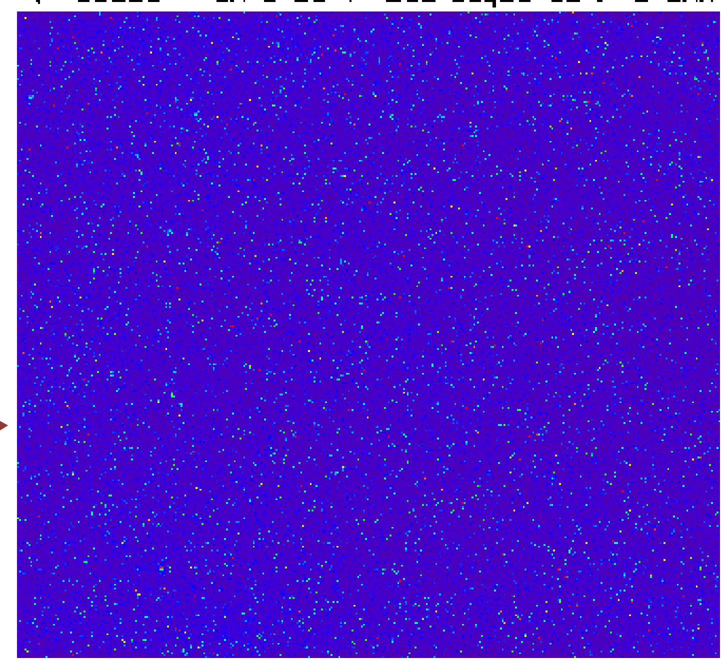
Transients removed from frame

NP orbit 564 120 sec Dark frame east edge SAA



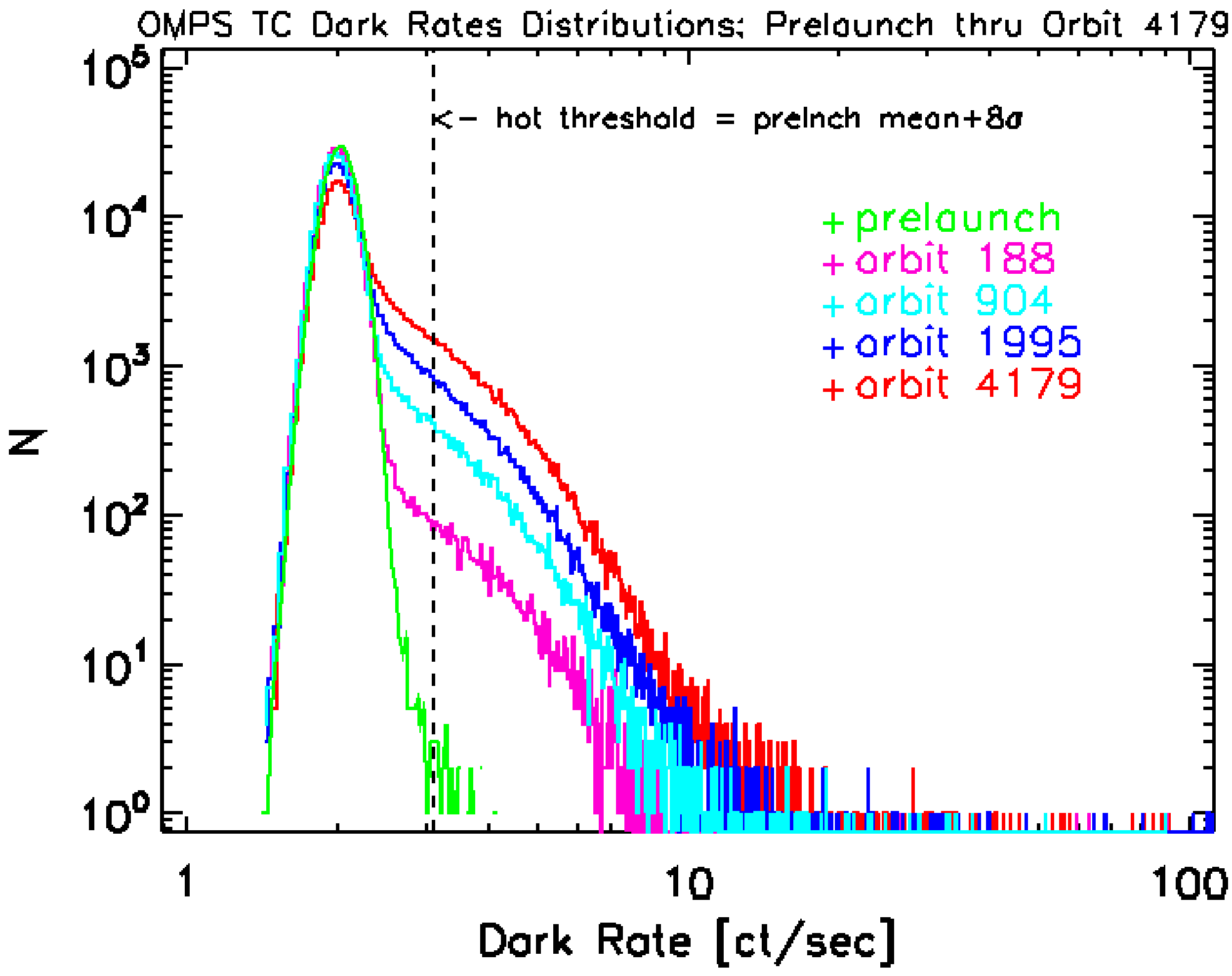
Dark current image from all 22 filtered frames

NP o00564 PEATE Dark 120s sequence thru SAA

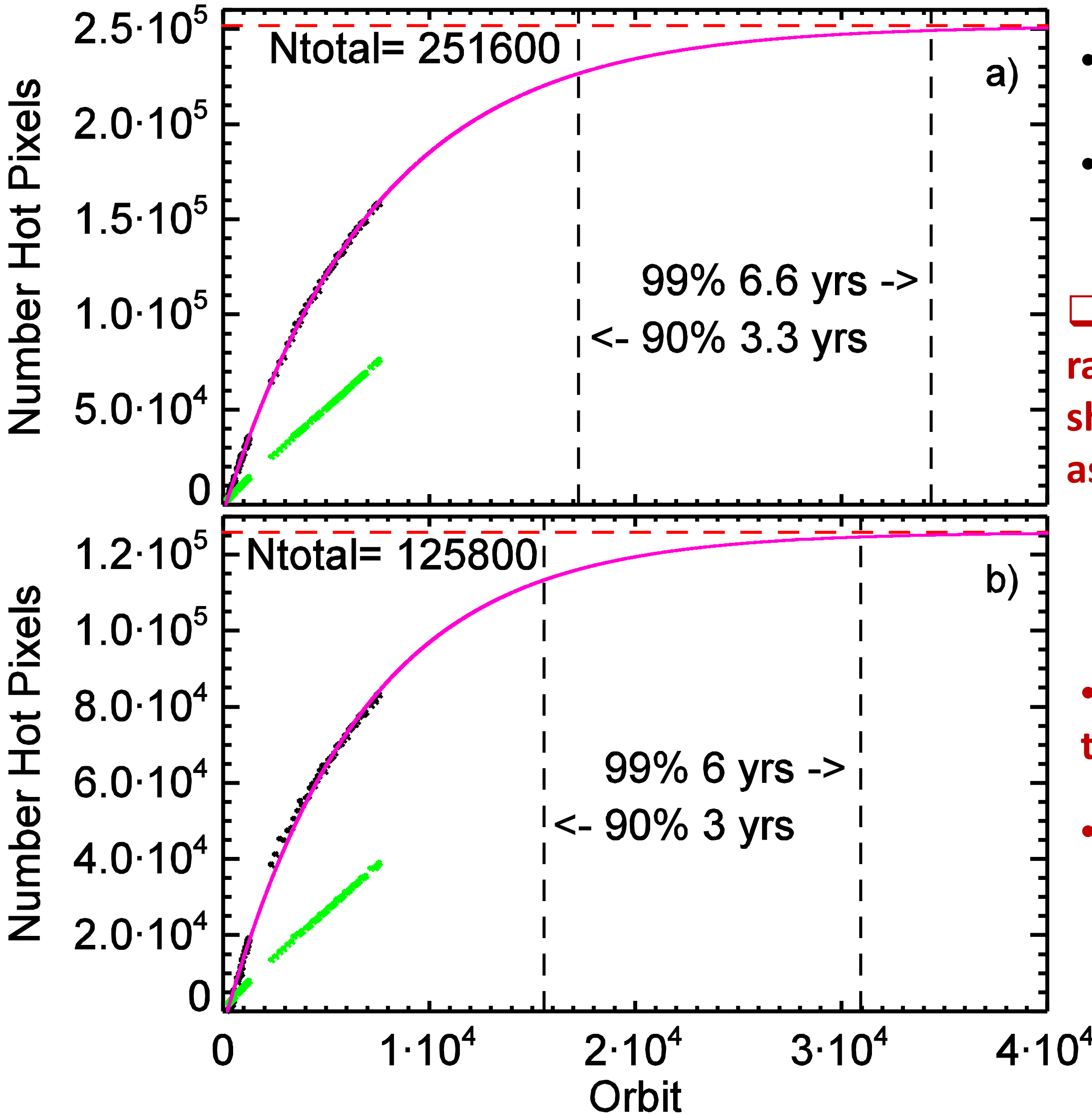


Dark Current Histogram Evolution

- Evolves on-orbit due to charged particle damage – some damaged pixels develop permanently elevated dark current rates
- Damaged pixels having rates > threshold (set from prelaunch distribution) designated “hot”
- Hot pixel number increasing ~linearly with time– underestimates number of damaged pixels
- Mode of distribution stable => way to estimate total number of damaged pixels



Histogram mode unchanged => undamaged fraction is represented by Gaussian with the peak height of histogram but mode and standard deviation of the prelaunch distribution



- $N_{damaged} = N_{tot}$ – (area under scaled prelaunch Gaussian)
- $N_{damaged}$ (black) more than twice N_{hot} given by threshold (green)

❑ Assuming a statistically constant rate of pixel damage, $N_{damaged}$ should be described by exponential asymptotically approaching N_{tot} :

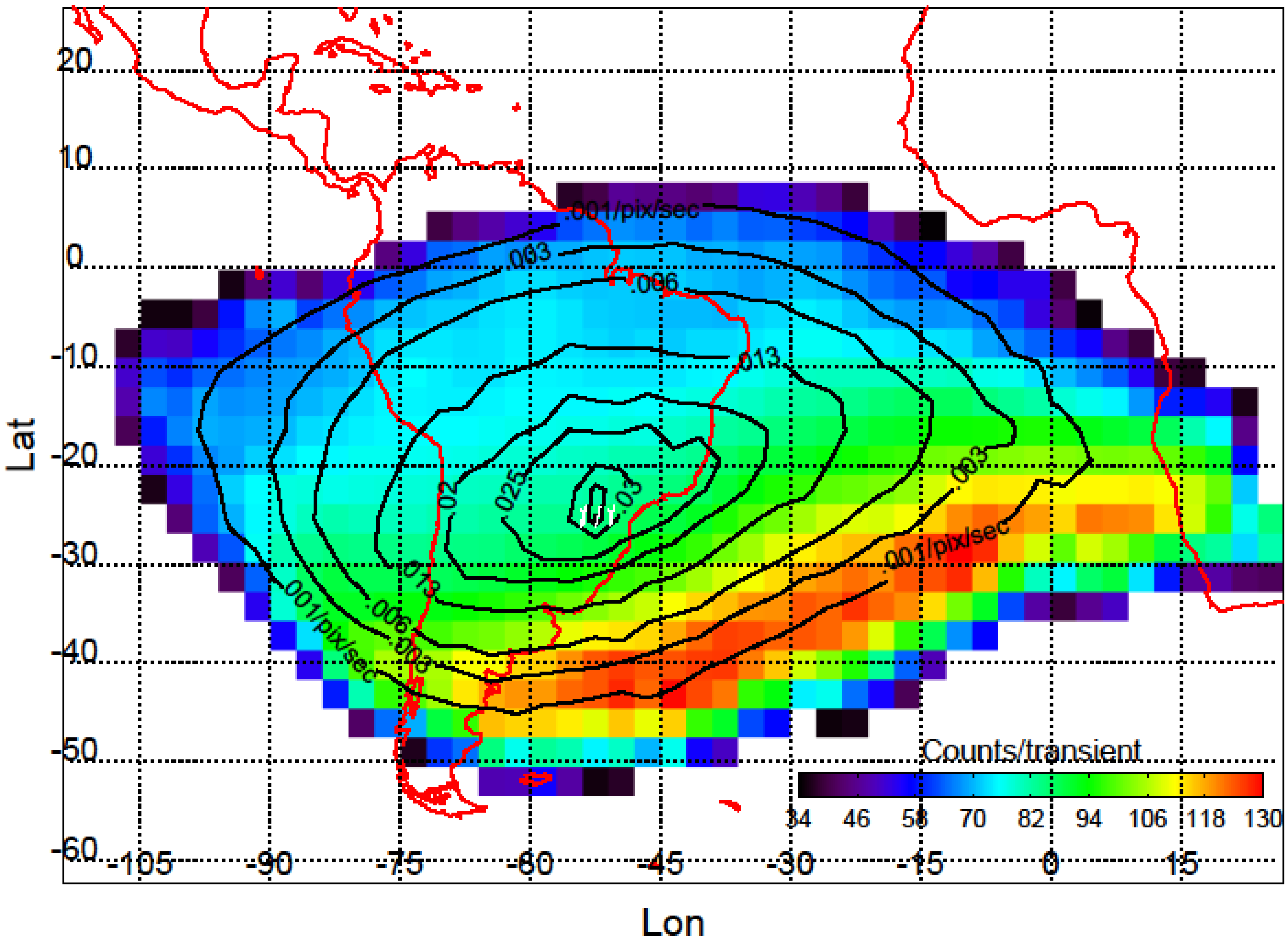
$$N_{damaged} = N_{tot}\,(1 - e^{-x/x_0})$$

- Above function good fit (purple) to calculated $N_{damaged}$
- Extrapolating fit predicts fraction of damaged pixels will reach 90% in 3–3.3 years and 99% in 6–6.6 years from launch.

SAA Mapped by OMPS LP Sensor from DARKCAL Detected Transients Analysis

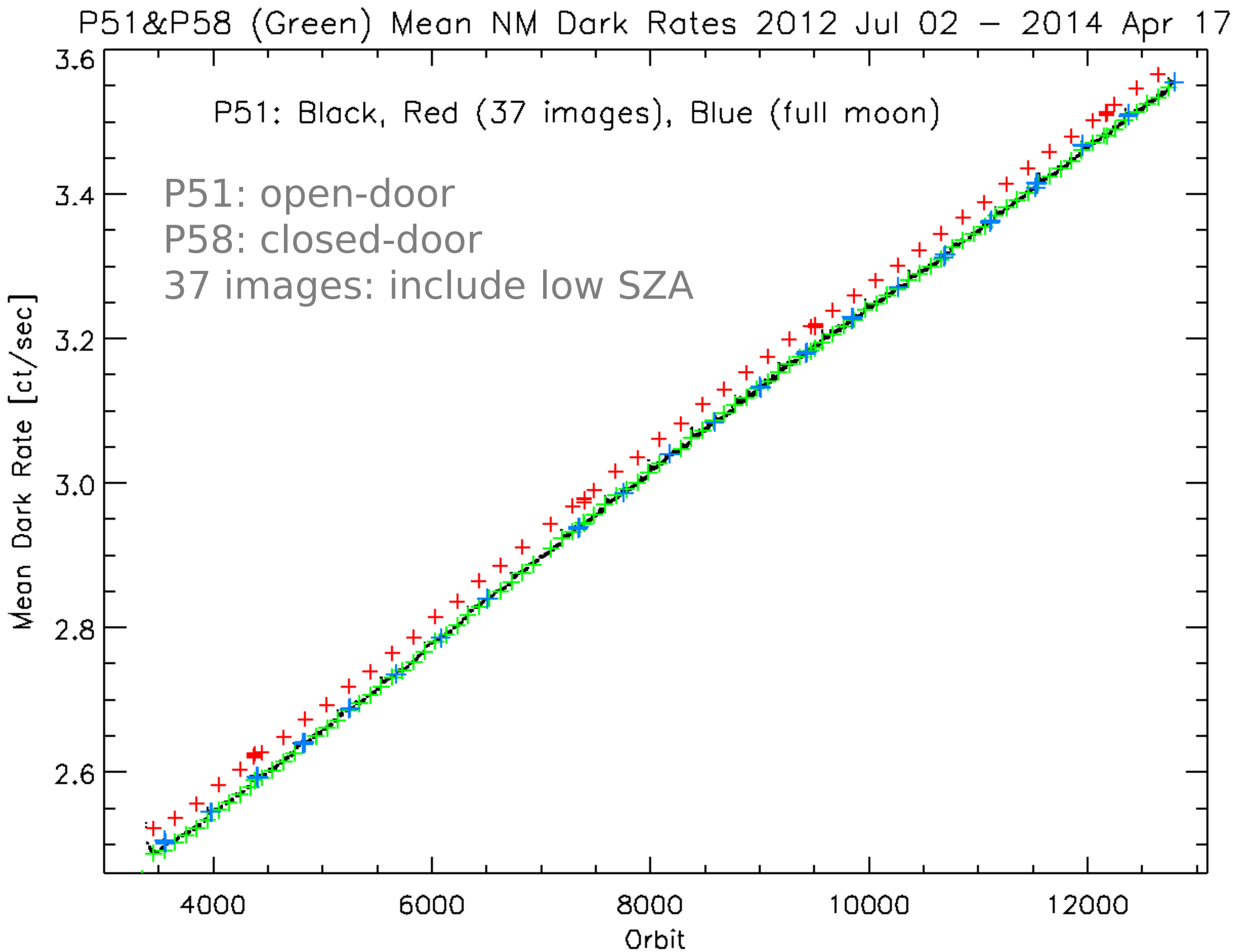
Contours = particle density [pixel^{-1} second^{-1}] – Expected

Colors = mean particle energy [counts] – Surprising!

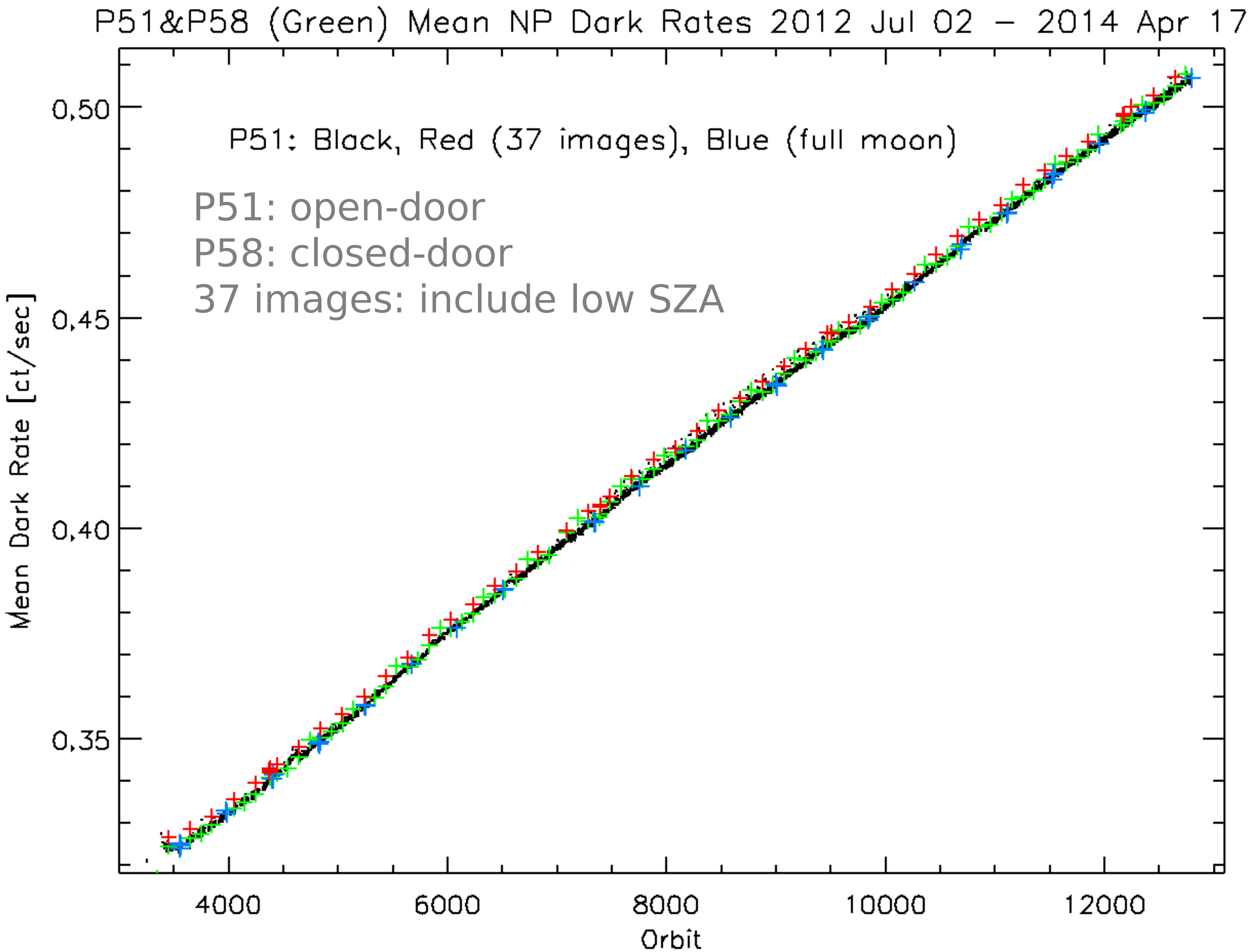


Study to Qualify Open-Door Dark Data for Orbital Updates

- ➢ **Generally no bias between weekly closed-door (green +s) and orbital open-door (black) dark rates, including at full moon (blue +s), except for bi-weekly measurements at low SZA (red +s)**
  - **Slight bias observed (imperceptible on plot) associated with LED activity every 28 days, not yet understood**



- DARKCAL update will have low-SZA filter to allow use of 37-images activity data
- Small 28-day bias to be quantified, quality of affected data assessed



Open/Closed-Door Dark Summary Statistics

Average % differences open/closed-doors Darks separated by 1 orbit*
(p51-p58)/p58 for Normal, 37 images (low SZA), Full Moon measurements
***except for full moon, normal separated by 2 orbits shown for comparison**

NM

Type [Δ orb]	Mean % Δ	StdDev % Δ**
Normal [1]	0.070	1.710
Low SZA orbits [1]	1.320	2.940
Full Moon [2,3]	0.330	3.015
Normal [2]	0.320	2.424

NP

Type [Δ orb]	Mean % Δ	StdDev % Δ**
Normal [1]	-0.202145	3.09634
Low SZA orbits [1]	0.659423	3.50797
Full Moon [3]	-0.206063	3.11968
Normal [2]	0.0895352	4.90505

*****Compare to prelaunch distribution StDev ~7% and shot noise ~1.3% NM, 3.5% NP***

NASA Non-Linearity Correction Algorithm

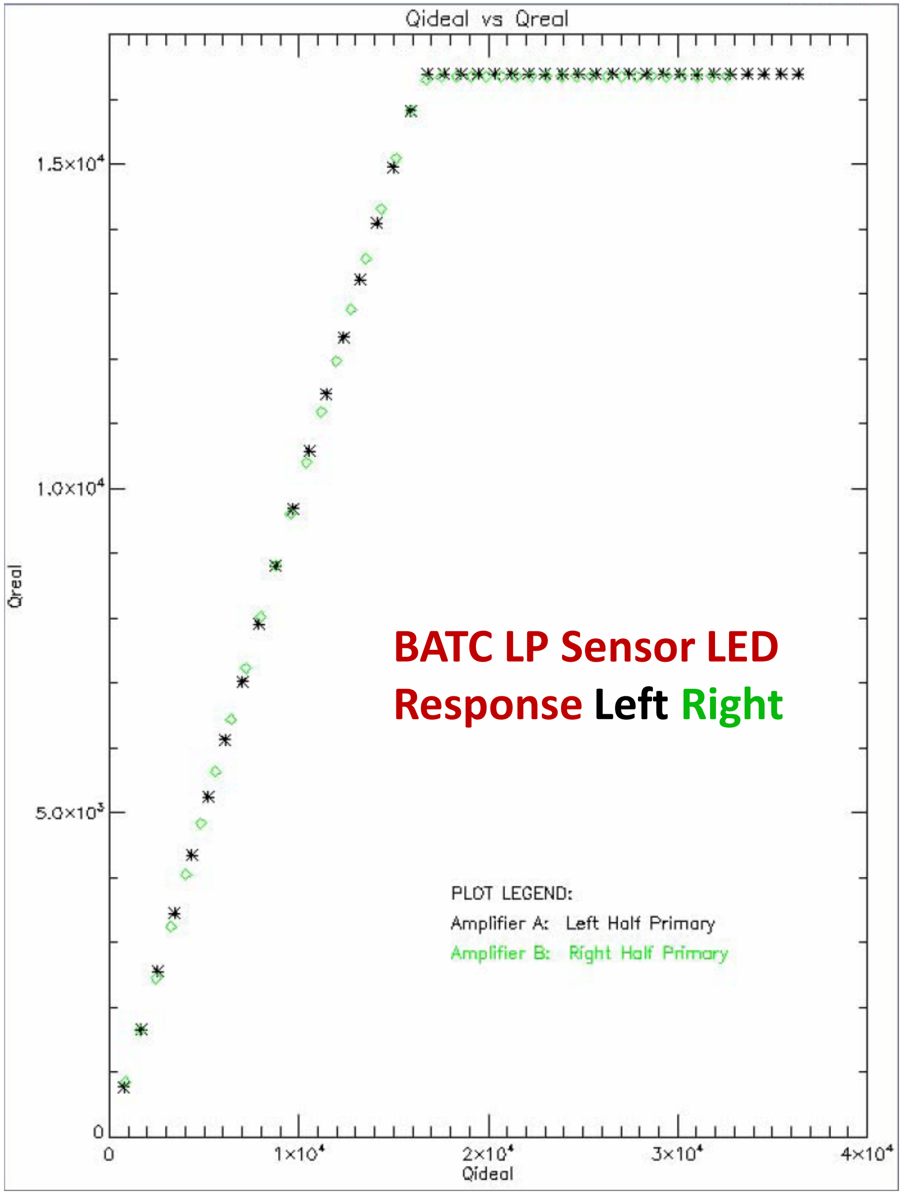
- Finds correction to convert measured counts (C_{real}) to linearized counts (C_{ideal})
- Improved method fixes problems with original BATC approach
  - Allows sampling full dynamic range of pixel responses and assessing pixel full-well levels

- Sequence of frames with integration times in 60 msec steps from 0 to 2.4 seconds
  - Response should be linear with integration time, assuming constant LED illumination
  - Slight LED drift does occur, interleaved 500 ms reference frames used to compensate by adjusting integration times
- Ideal linearity defined as straight line between two tie points C_{up} and C_{low} (set prelaunch)
  - Tie point C_{low} = bias level, tie point C_{up} = 12000 counts (~75% ADC saturation)
  - Response for each pixel is converted from C_{real} to C_{ideal} by scaling the effective exposure times with the slope between the two tie points

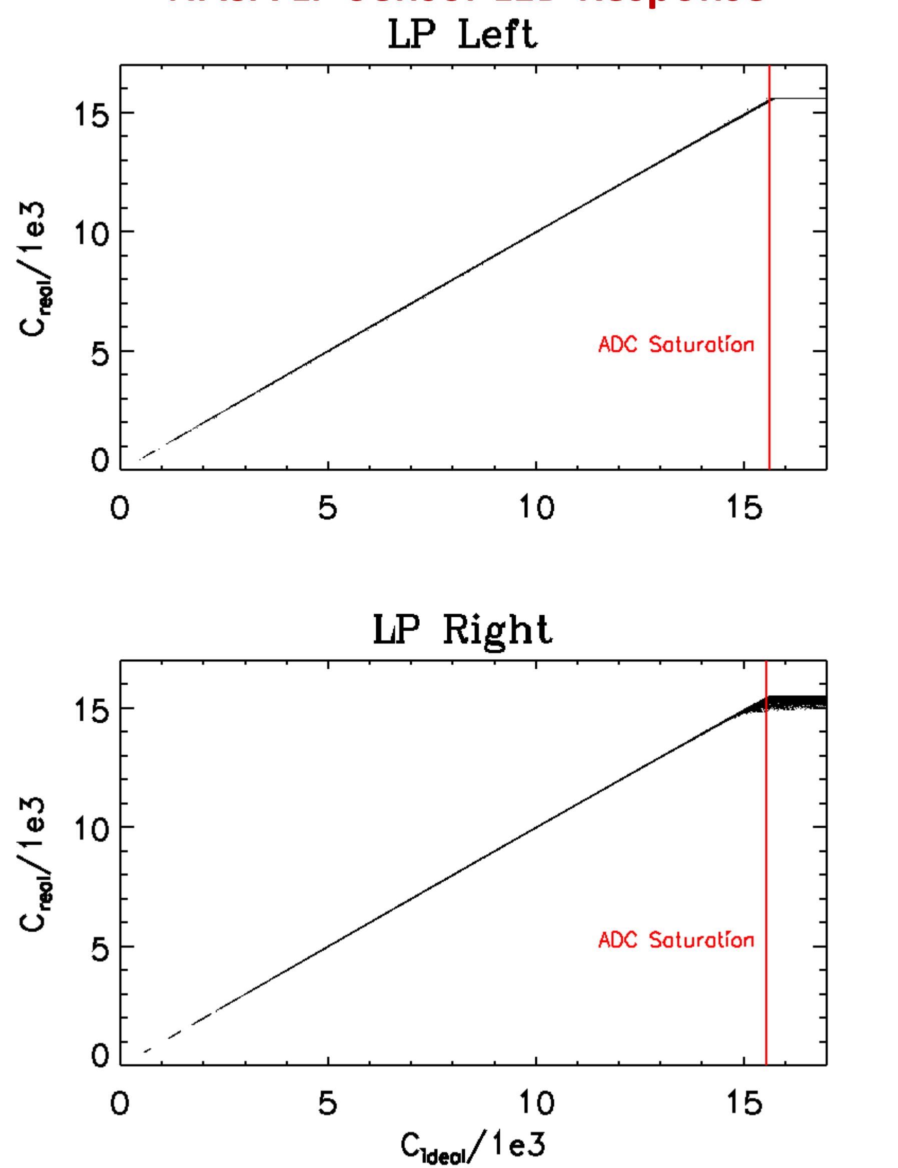
- **NASA Improvement:** convert from C_{real} to C_{ideal} at pixel level, use all pixels (BATC averaged small group of pixels at each integration time step before converting), then . . .
- Linearity correction determined by fitting a 5th-degree polynomial to the difference $C_{ideal} - C_{real}$
  - Pixel full-well levels are first computed => level where pixel response non-linearity exceeds the uncorrected instrument requirement of 2% (if any – with proper gain calibration all pixels should reach ADC saturation before full-well)
  - Points with C_{real} greater than the minimum pixel full-well level are excluded from the fit.

BATC approach failed to account for premature well filling on OMPS LP right side CCD

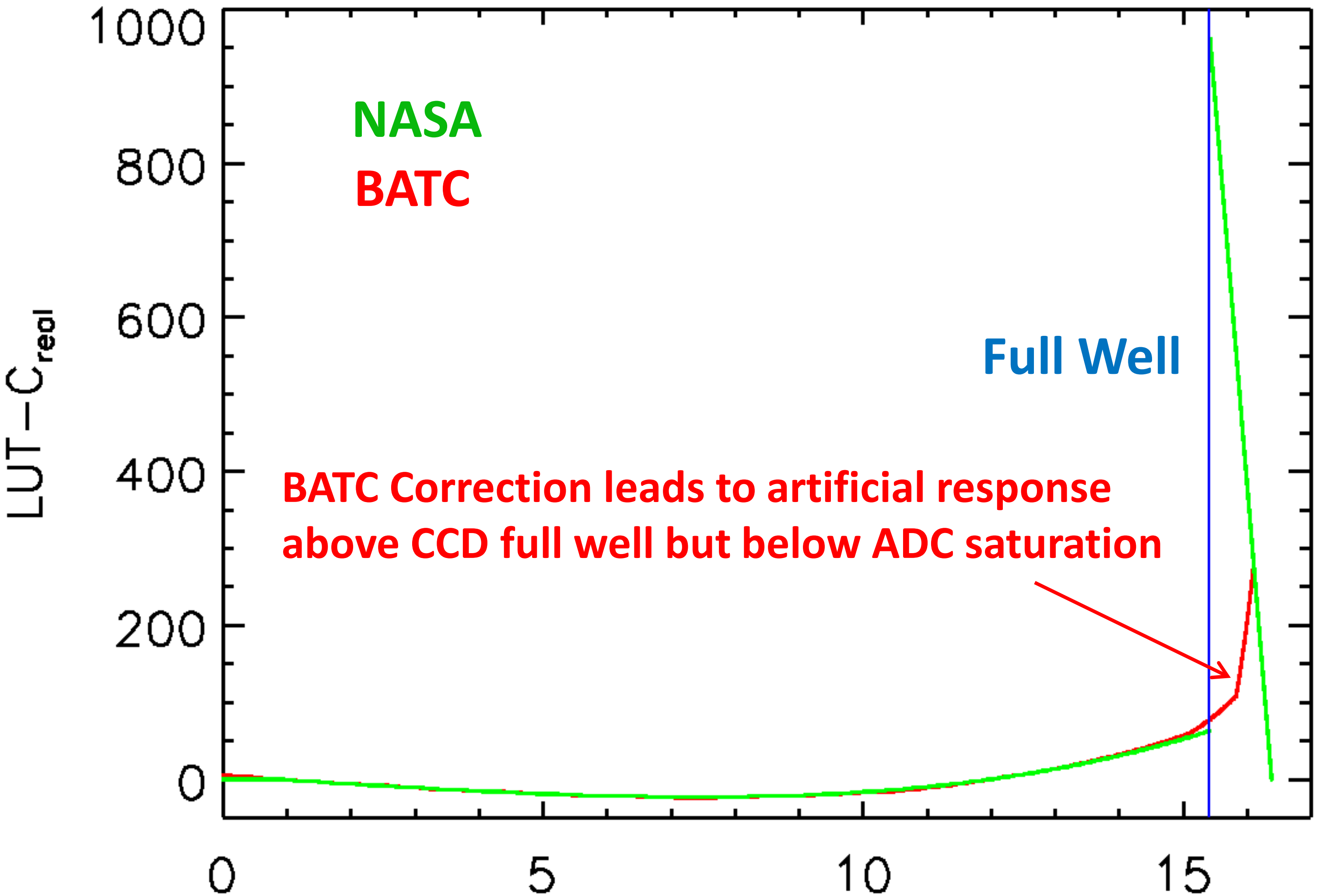
- Averaging pixels at each IT time step before converting to C_{ideal} masks full well behavior



NASA LP Sensor LED Response



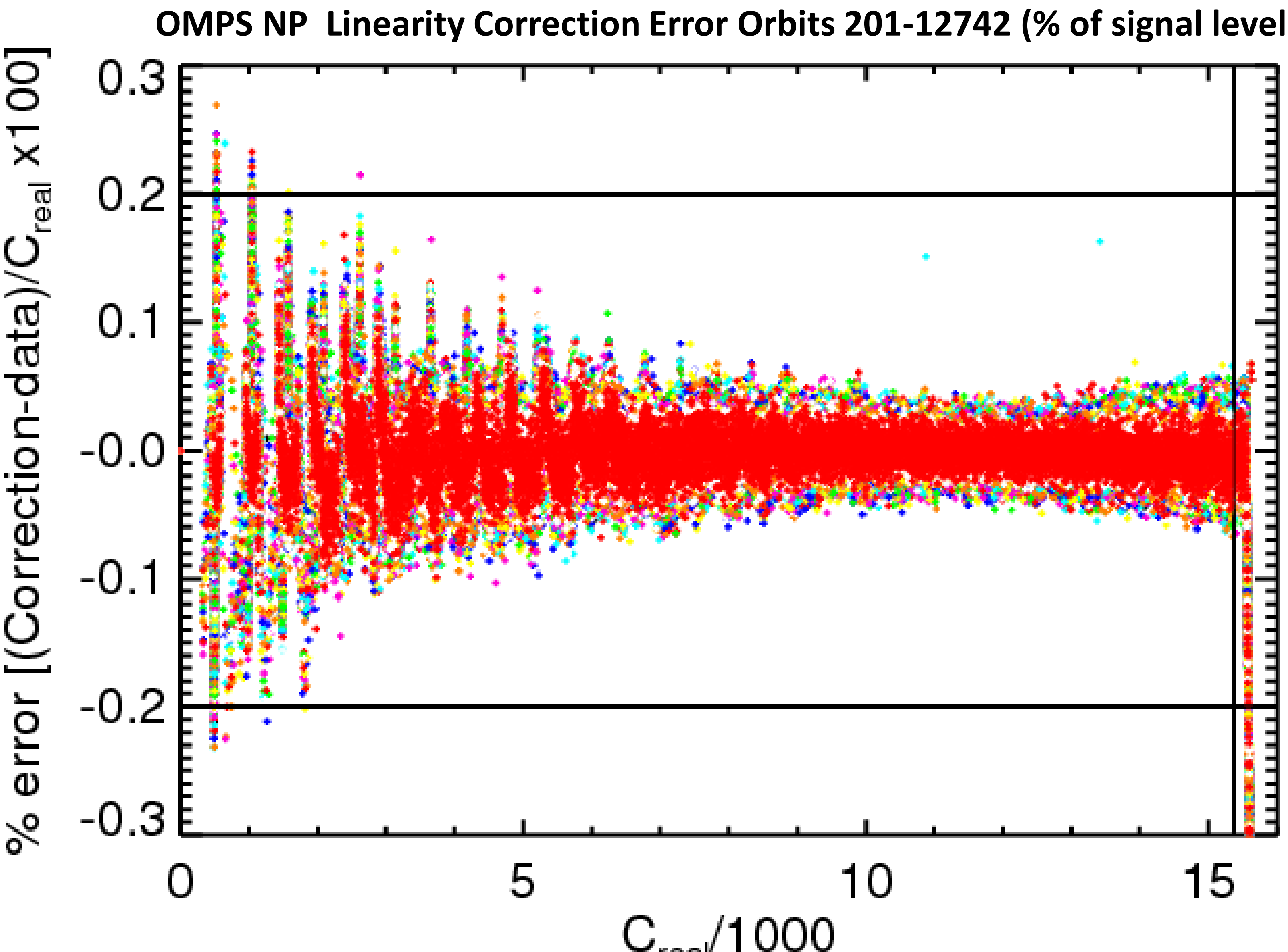
NASA and BATC LP Sensor Right Side Linearity Correction



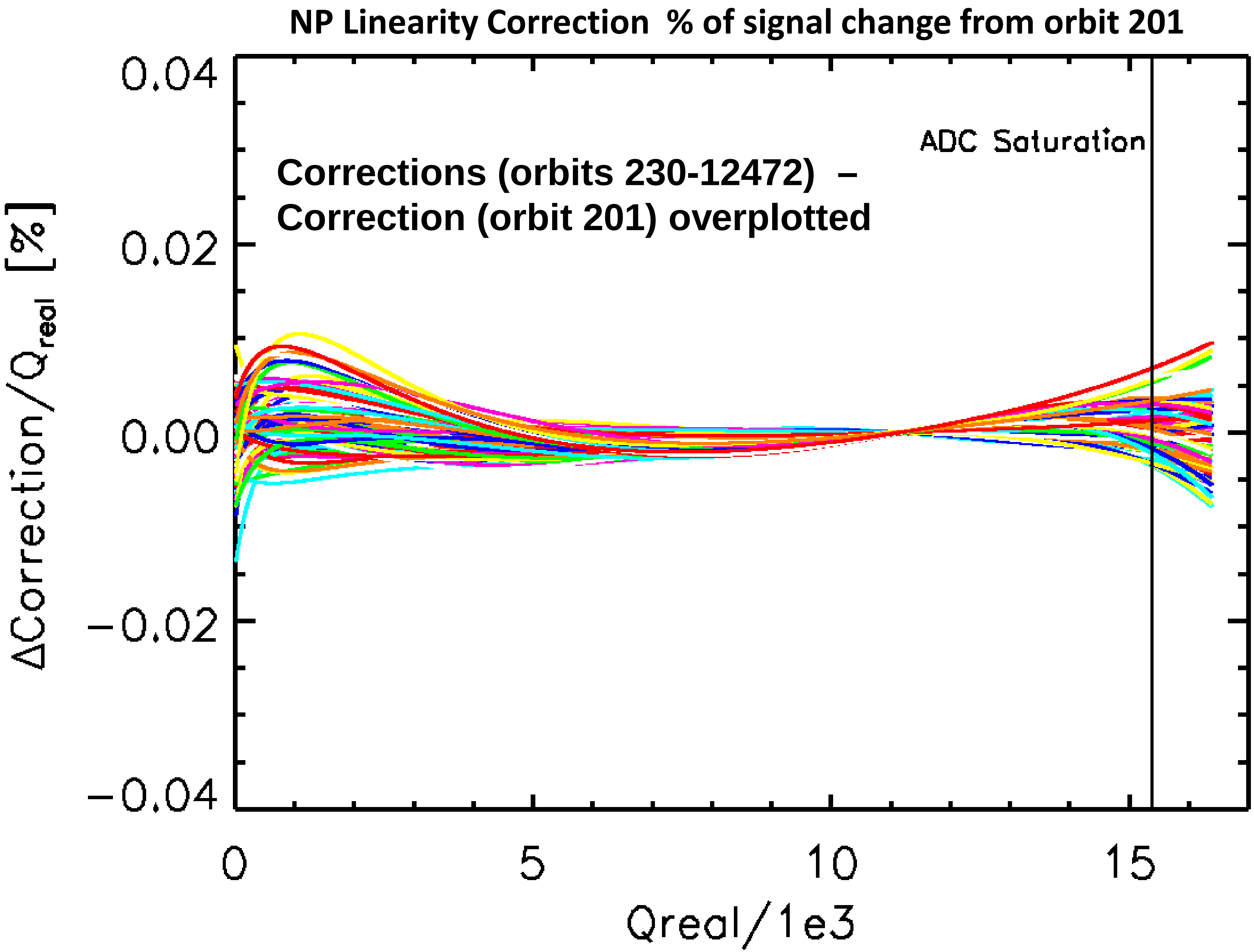
NASA sets LUT = ADC saturation for input > full well

BATC LUT interpolates across interval (full well – ADC saturation)

OMPS Linearity Correction is stable and meets ±0.2% knowledge requirement over virtually the full dynamic range



Linearity Correction Stability: varies less than ±0.01% of signal over 12472 Orbits



Summary

- **Original coadded dark measurement sequence replaced with sequence of single frames with temporal transient filtering**
  - Original measurement specialized to correct standard Earth view measurements only, susceptible to degradation from transients
  - New measurement flexible- provides correction elements for arbitrary application, eliminates potential for dark current error due to transient contamination (potential error over 100% NM, 50% NP)

- **Open/Closed-Door Dark Comparison to Enable Orbital Updates**
  - No statistically significant difference between open/closed door darks except on orbits with 37-image sequence, SZA below 118°, filter to be implemented
  - Small bias with 28-day period has yet to be explained, associated with LED activity

- **NASA Non-Linearity Correction Algorithm Fixed BATC Problem**
  - Well filling analysis and use of full dynamic range of pixel responses enabled detection/correction of artifact in BATC linearity LUT
  - Non-linearity Correction stable to ±0.01% through 12472 orbits, easily meets 0.2% of level knowledge requirement over full dynamic range

Work In Progress

- **Improvement of transient filters for smear signals**
  - **Missed detections have occurred due to design flaw in current filters**
  - **Transients in smear much easier to detect than transients in image since smear signal is so low, because transfer time of frame from image to storage region is only 0.936 msec:**

$$\boldsymbol{smear = \frac{frame\ xfr\ time}{integration\ time} \text{ X } signal}$$

NP Earth View:

NP Earth view signal is very low, maximum signal ~6000 counts/pixel/coadd, integration time 12.5 seconds => maximum smear ~0.5 count => content of smear rows almost entirely bias (~750 counts) => just a small fixed threshold above median smear should work

- **Threshold 1-2 counts above NP Earth view smear median / image has worked well in trials**

Work In Progress (II)

➢ **Improvement of transient filters for smear signals (contd)**

Solar and NM:

Stronger signal and shorter integration times for solar and NM Earth view => non-negligible smear, varies with spectral index

- **Non-negligible spectral gradients in solar and NM smear require more sophisticated approach. Approaches under study are fixed threshold above a piecewise median in spectral space and temporal filtering.**

Post-launch Wavelength Registration of OMPS Nadir Sensors

Mark Kowitt, PhD – NASA/SSAI

13 May 2014

Prelaunch Calibration

- Ball Aerospace (BATC) designed, built, and calibrated all three OMPS sensor, including –
  - Nadir Mapper (NM), sometimes called Total Column (TC) after its principal product
  - Nadir Profiler (NP)
  - Limb Profiler (LP); not discussed in this report
- For all 3 sensors, BATC provided preflight Channel Band Center (CBC) and Bandpass (BPS) tables based on lab measurements; estimated thermal and atmospheric shifts from ground to orbit were applied to the band passes (slit functions).

NASA Wavelength Registration Algorithm

- A high-res solar spectrum (sampled at 0.01 nm) developed by KNMI for OMI is convolved with the preflight bandpasses centered in turn at each band center to form a synthetic solar spectrum
- For OMPS NP, solar activity corrections are applied to the synthetic spectrum
- A polynomial scaling function (essential for EV) morphs synthetic irradiance into synthetic radiance
- An implementation of the Levenberg-Marquardt nonlinear least squares algorithm used to minimize the difference between synthetic and measured irradiance or radiance
- The final optimizing CBC and the spectral calibration coefficients used to constitute it at each spatial index are the principal products.

Dispersion Relation

- For both nadir sensors, each spatial index has an independent band center solution whose coefficients are applied as follows:

  CBC(iSpat,iSpec) = a0(iSpat) + a1(iSpat)*(iSpec-iSpec0) + a2(iSpat)*(iSpec-iSpec0)^2 + a3(iSpat)*(iSpec-iSpec0)^3

  where iSpat is the spatial pixel index, iSpec the spectral pixel index, and iSpec0 is the spectral pixel index of the fitting window lower bound.

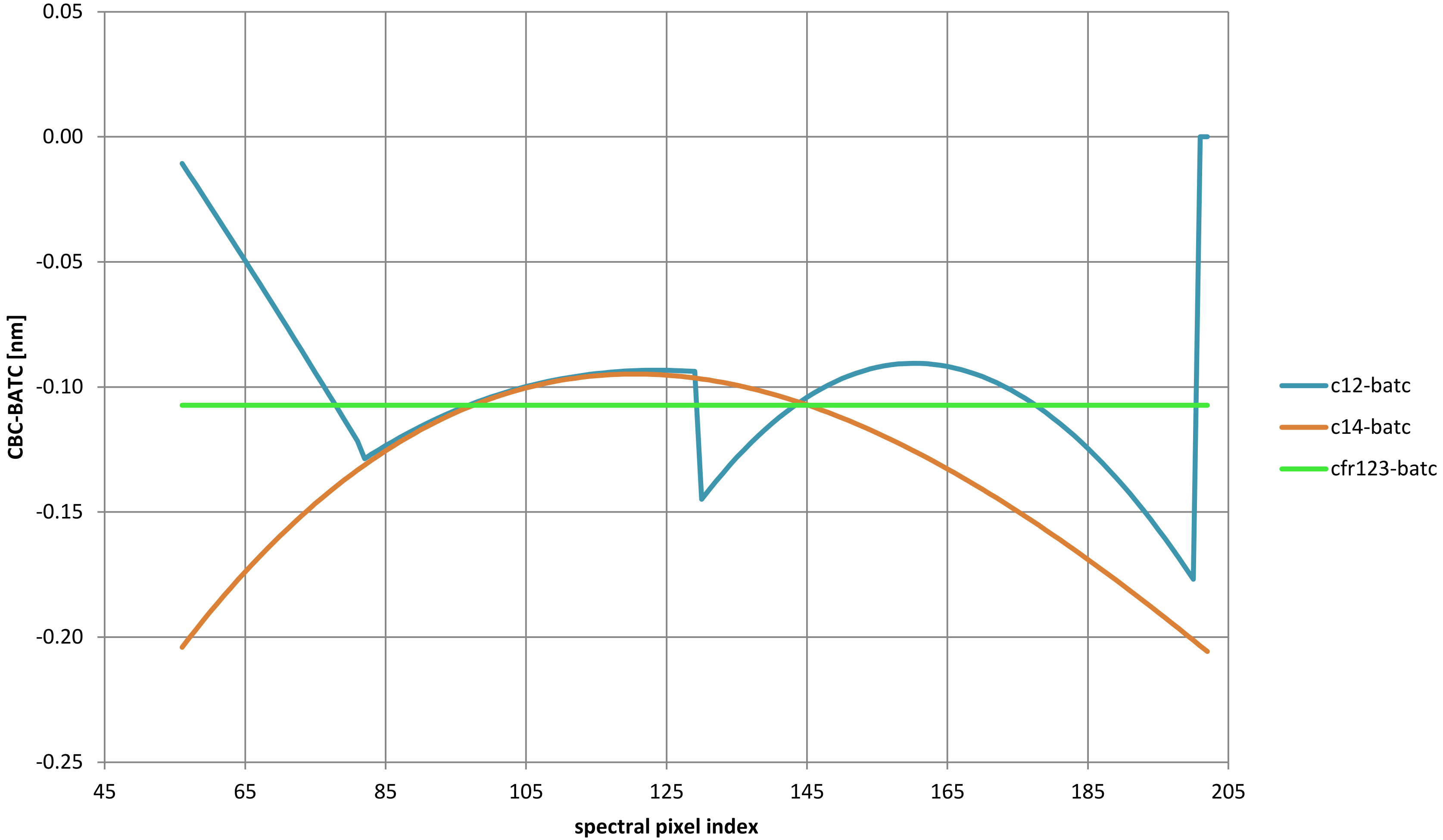
Some Results To Date

- Updated CBC tables for solar calibration for NP and NM
- New mid-EV CBC for NM
- Extended tabulation of NP seasonal/annual shifts vs. nadir telescope temperature

NP Solar CBC Evolution

- In the newest parametrization of the CBC for both NP and NM, only a0 is varied (independently for each spatial index); a1, a2, and a3 are frozen (hence, fr123)
- The next chart shows the difference (near nadir, for example) between various incarnations of the NP CBC and the preflight CBC derived by BATC; note that for the newest version, the plot is constant as a function of wavelength
- [reminder: a0(x,t) plots, residuals]

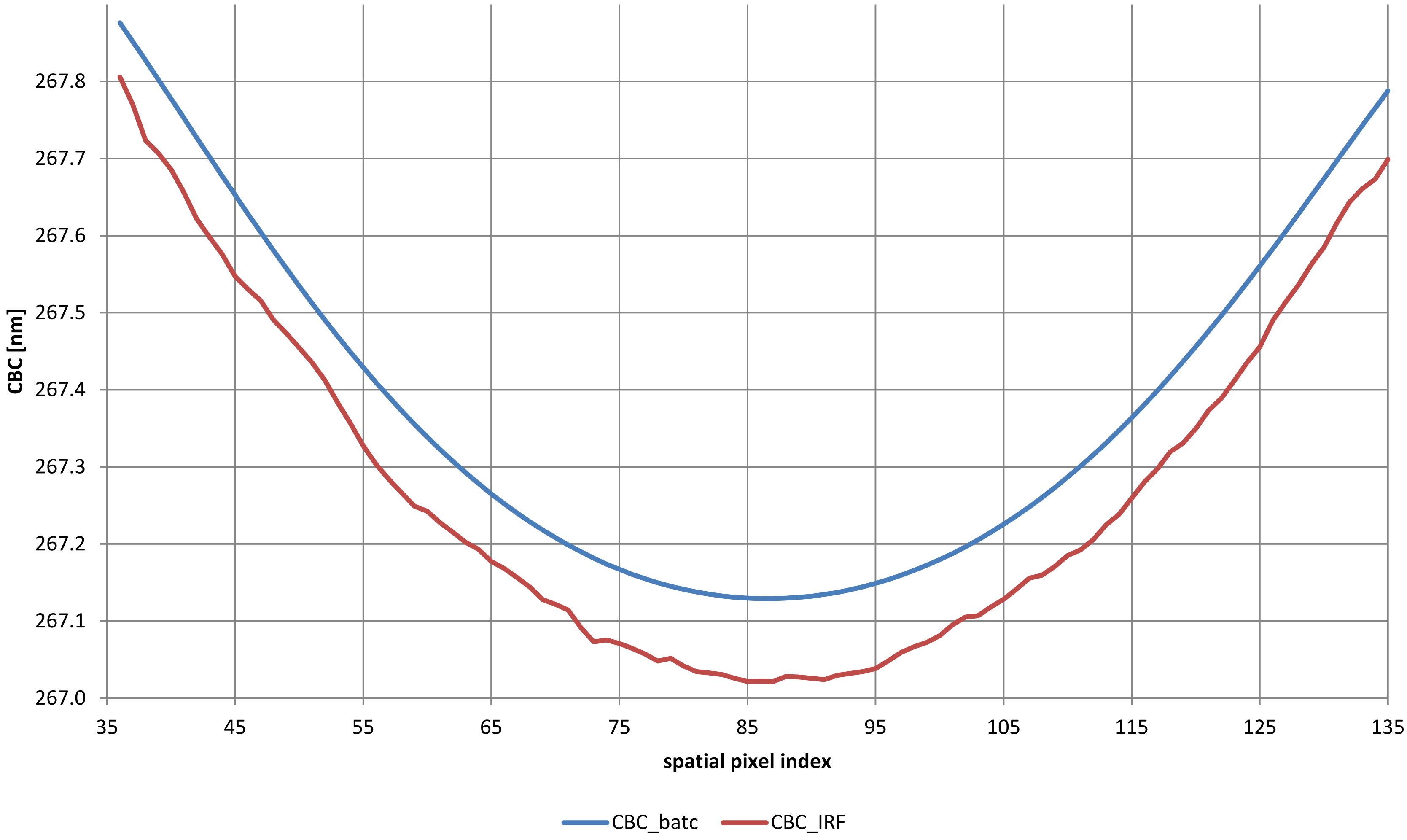
NP postlaunch CBC - preflight BATC CBC near nadir (spatial index 86)



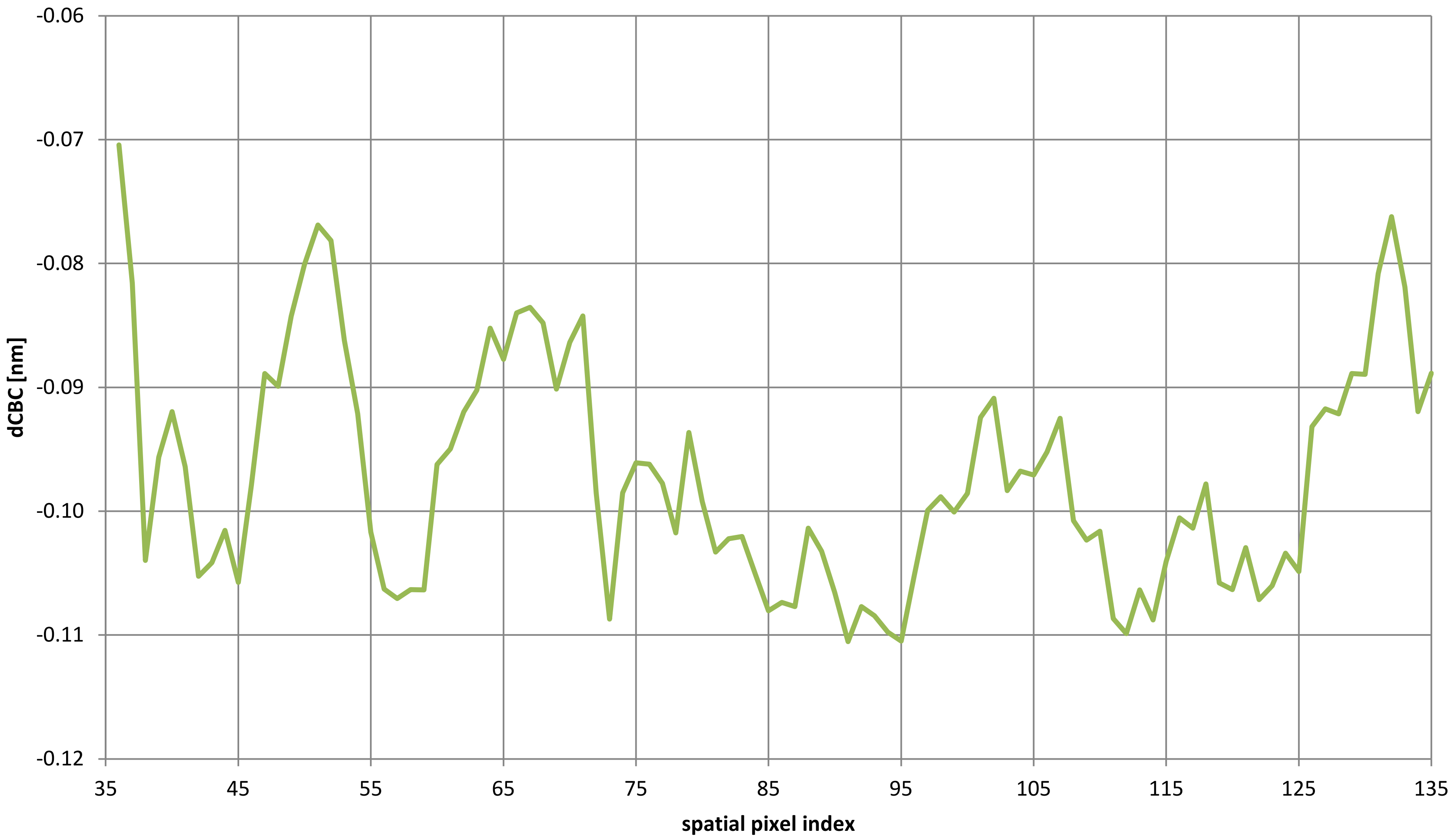
NP Slit Edge Features

- The next 2 slides show slit edge irregularities that appear in post-launch analysis that were smoothed in the preflight BATC CBC

NP Spectral Smile at spectral index 100 for preflight (BATC) and IRF CBCs



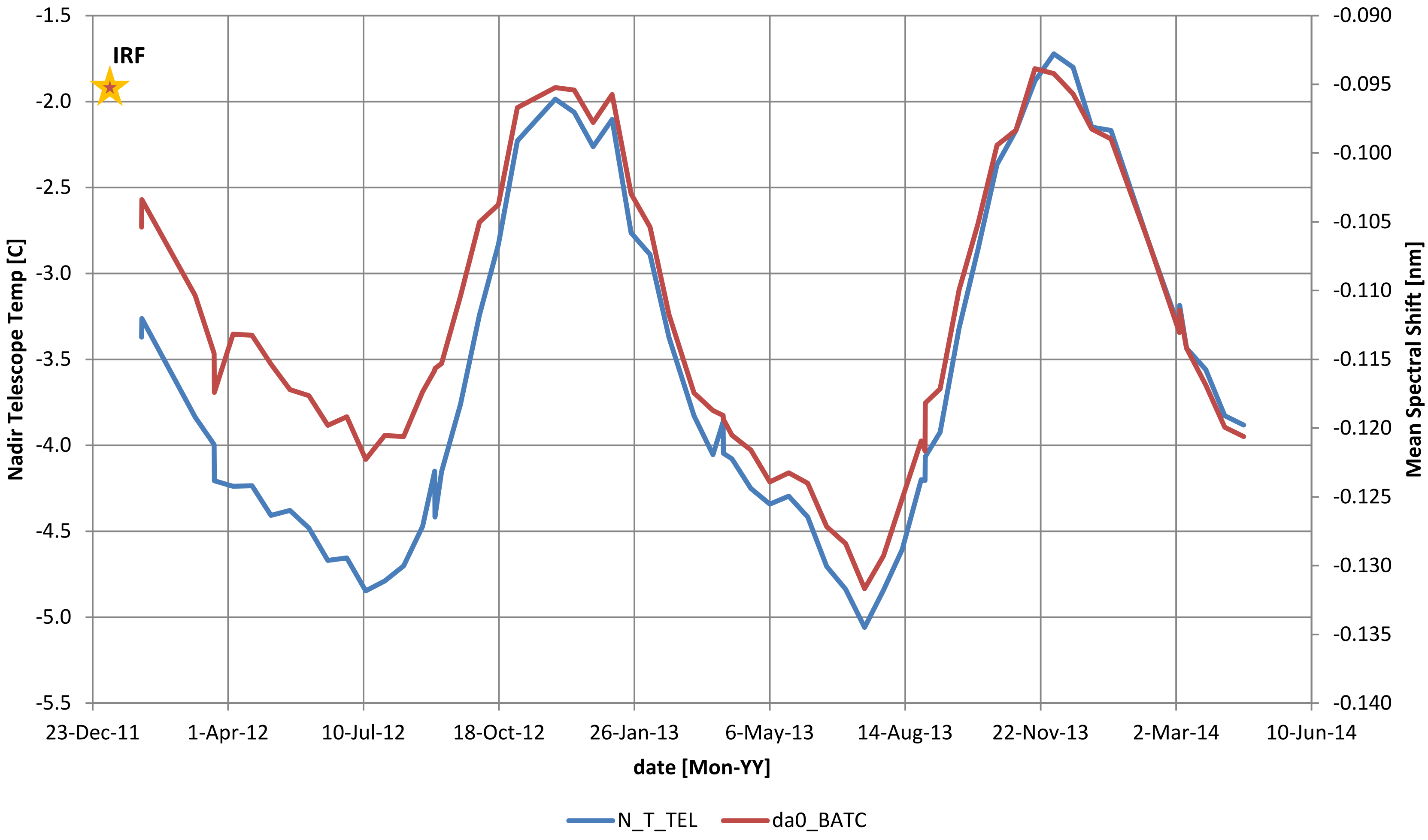
NP CBC for IRF - preflight CBC (BATC) at spatial index 100



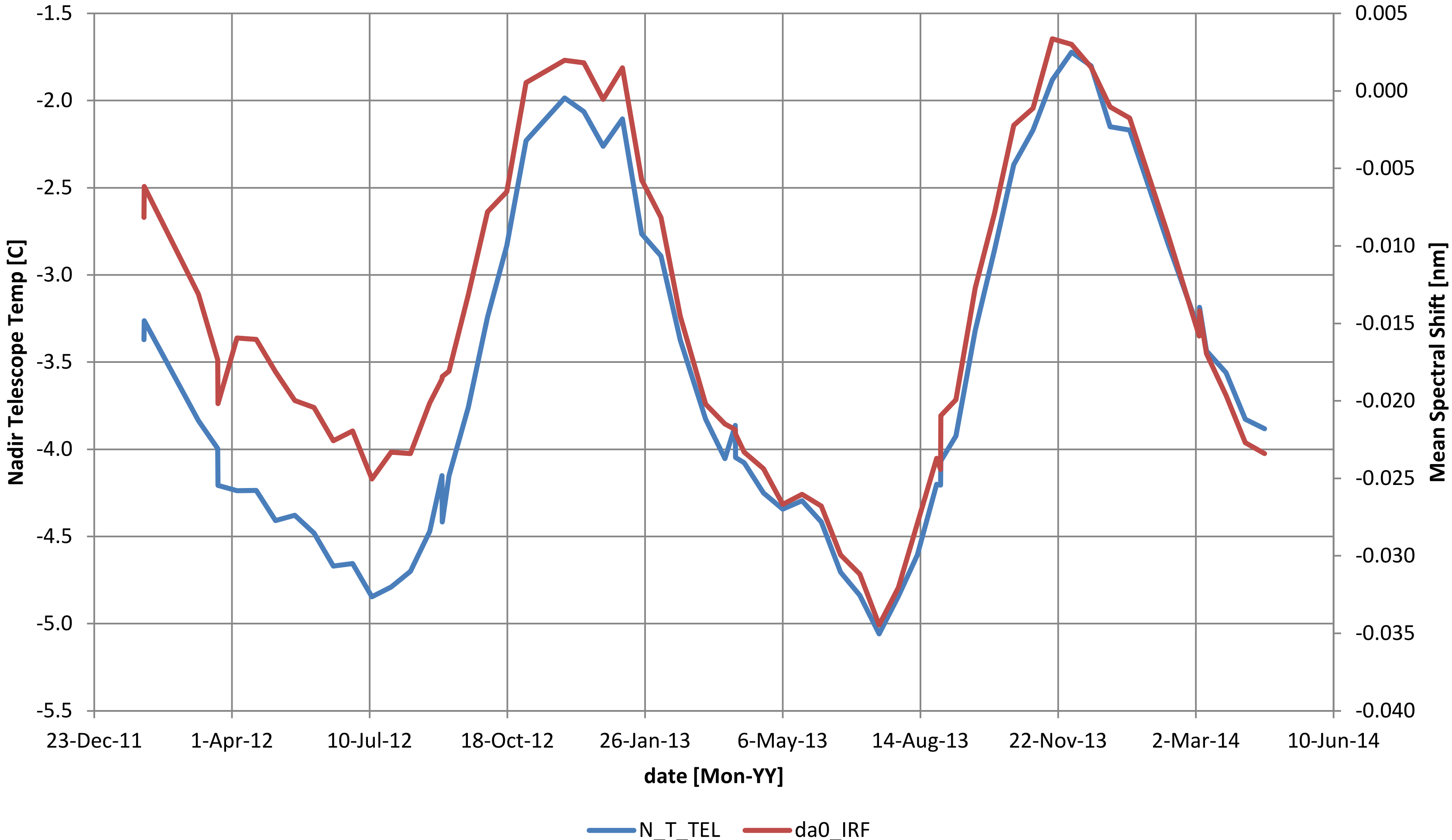
NP "Seasonal" Spectral Shift

- The following charts illustrate the correlation between annual ("seasonal") variation cycles of Nadir Telescope Temperature (during solar calibration) and wavelength (a0 in the current model)
- A star toward the upper left of the first chart indicates the approximate date and wavelength of the initial reference solar flux (IRF), the measurement baseline for the second chart.

Mean Nadir Telescope Temperature vs Spectral Shift [rel. to BATC]



Mean Nadir Telescope Temperature vs Spectral Shift [rel. to IRF]



NM (TC) Solar CBC Evolution

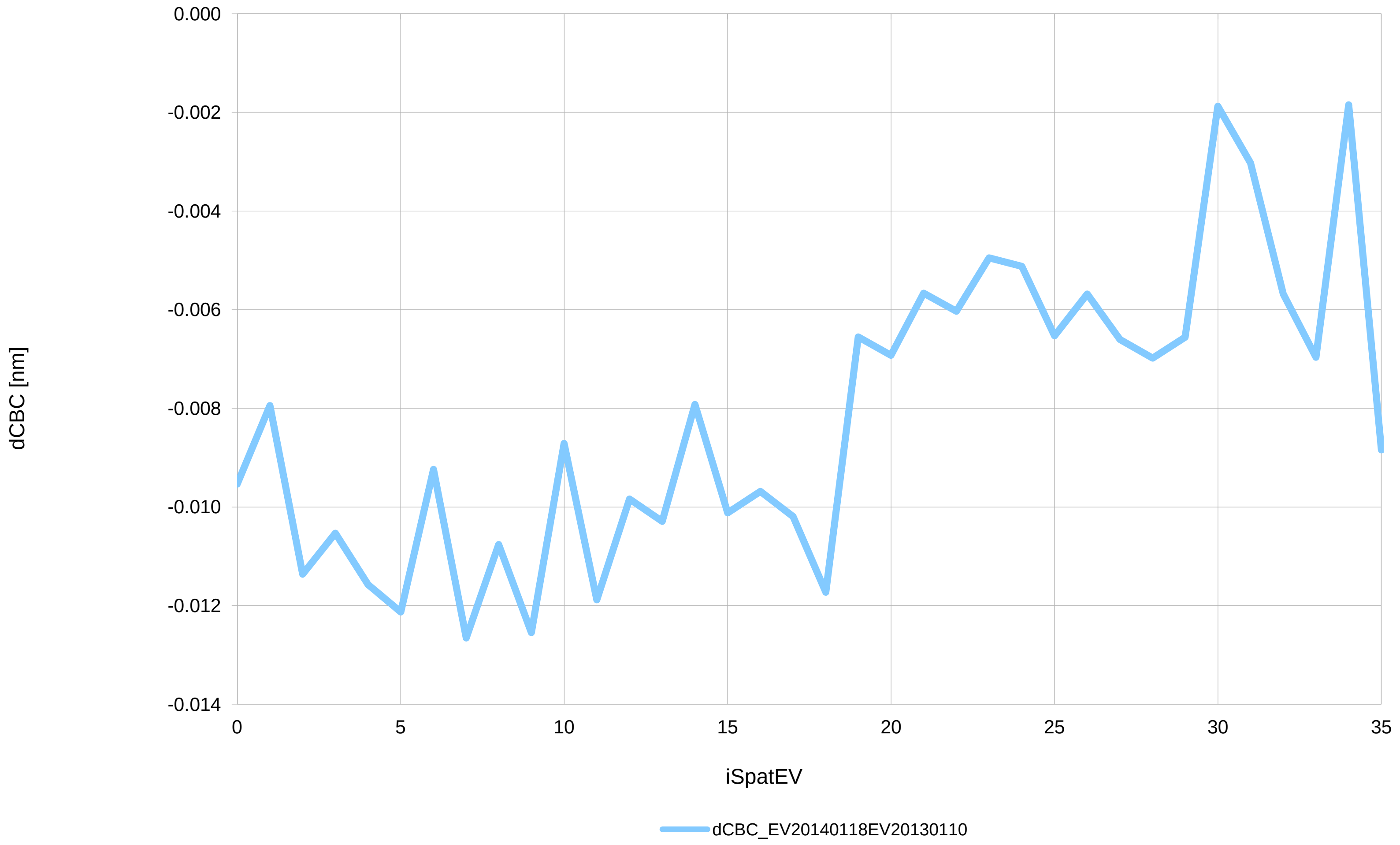
- CBC, dCBC, a0(x,t) plots, residuals

NM mid-EarthView CBC

- Cross-track differences between solar and mid-EV CBCs
- EV intraorbital spectral shifts

TC cross-track offset -- mid-EV - IRF at EV resolution, EV orbits 6238, 11531

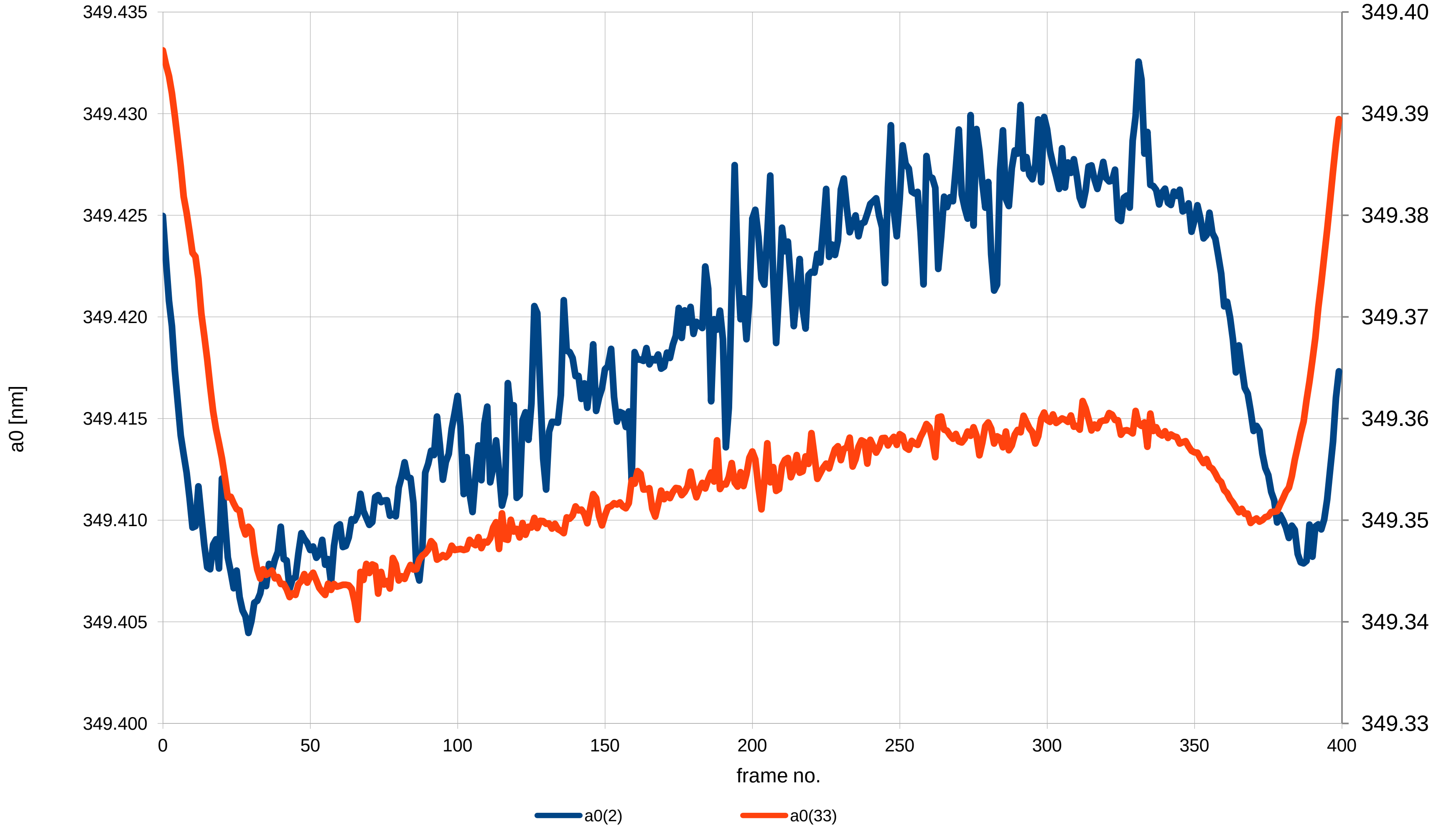
dCBC for TC: mid-EV, 1/14 - 1/13 orbits 6238,11531



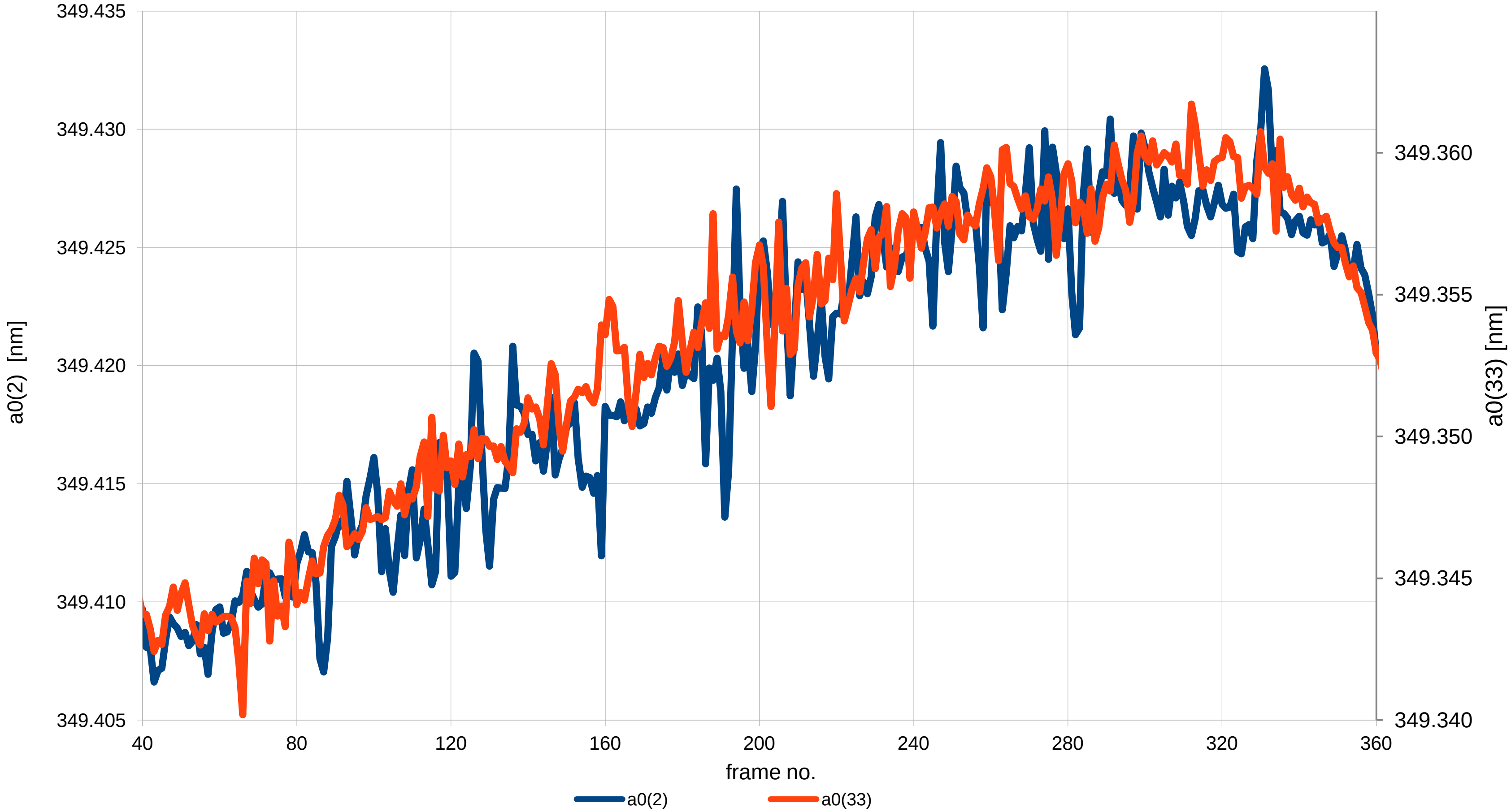
TC Intraorbital Wavelength Shift

- First slide includes distorted wavelength registration in the earliest and latest frames; on the right, in particular, mainly because of very high SZA (exceeding 90 degrees near the beginning and toward the end of EV), and weak radiance (~1% of baseline at mid-EV), long optical path, etc.
- Second slide clips the first and last 40 frames (about 5 minutes each) – note the similarity of the shifts for far left and far right macropixels (the 3rd and 34th, respectively, of 36).

TC intraorbital shift (full EV)



TC intraorbital shift (clipped)



What’s Next?

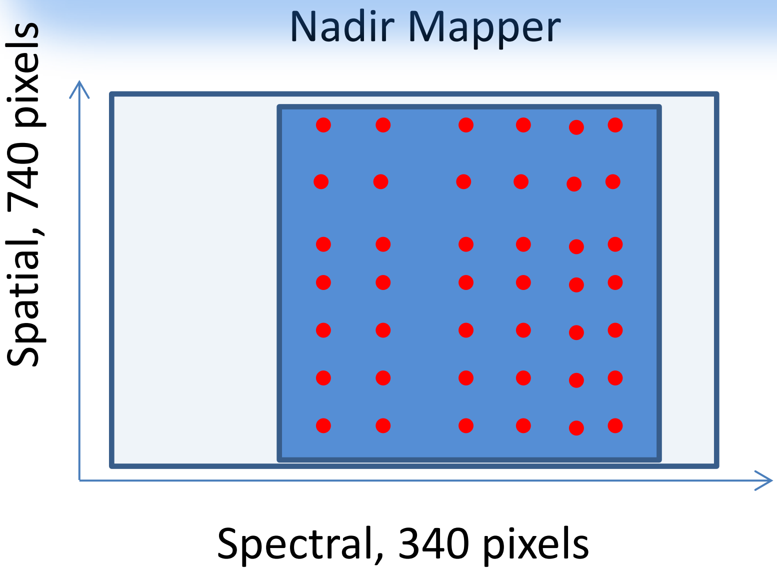
- NASA Operationalization & Testing
- Ring Effect correction for EV analysis

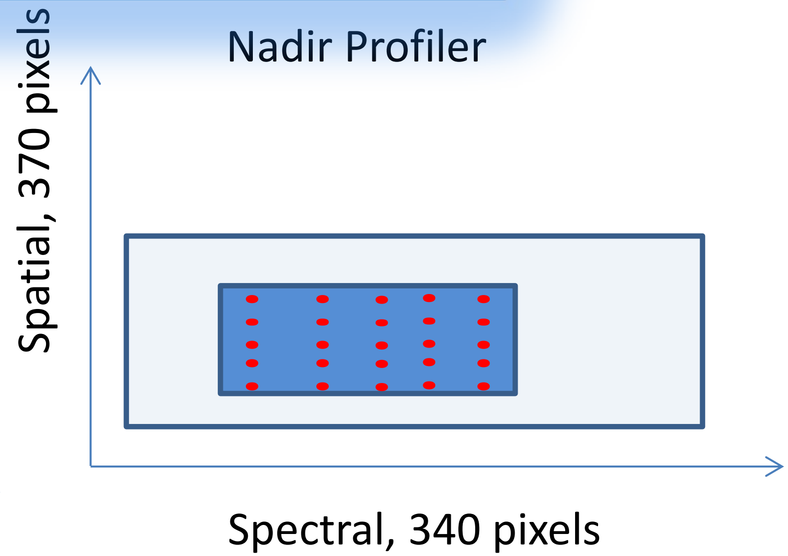
SNPP OMPS Nadir Instruments Stray Light Corrections

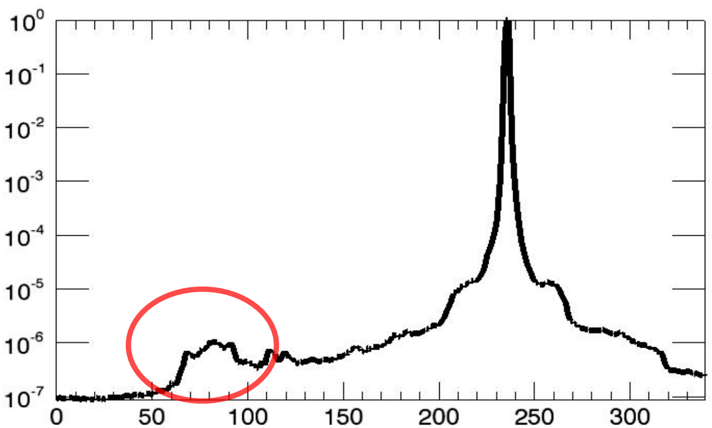
Hong Grace Chen, SSAI/GSFC/NASA
Glen Jaross, GSFC/NASA

- **Stray Light Characterizations**
- **Stray Light Correction Approach in PEATE's APP**
- **Updates Have Been Done since Launch**
- **Validation Results and Future Plans for PEATE's Work**

Instrument Stray Light Characterization in Pre-Launch Tests







Stray Light Correction Approach in PEATE's APP

Simulation Method

Stray Light Accuracy

$$C_{stray}(i_t, j_t) = \sum_{i_s}\sum_{j_s} C_{in}(i_s, j_s) PSF(i_s, j_s, i_t, j_t) + \sum_{i_s}\sum_{j_s} C_{in}(i_s, j_s) GHOST(i_s, j_s, i_t, j_t)$$

1. Ground Test Measurements Accuracy

||

NM

$$C_{stray}(i_t, j_t) = \sum_{i_{s,spec}=1}^{500}\sum_{j_{s,spat}=1}^{740} C_{in}(i_{s,spec}, j_{s,spat}) Jacobian\_FullSize(i_{s,spec}, j_{s,spat}, i_t, j_t,)$$

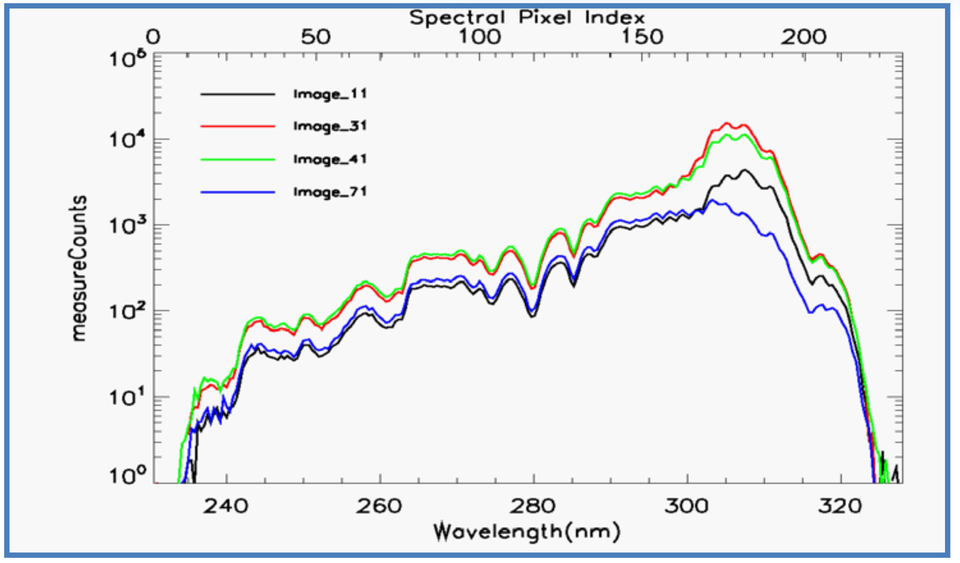
2. Source Binning Accuracy

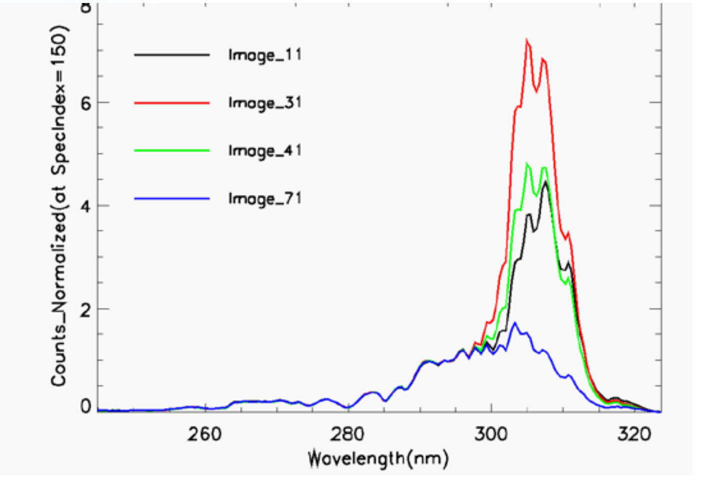
Applied in App for NM

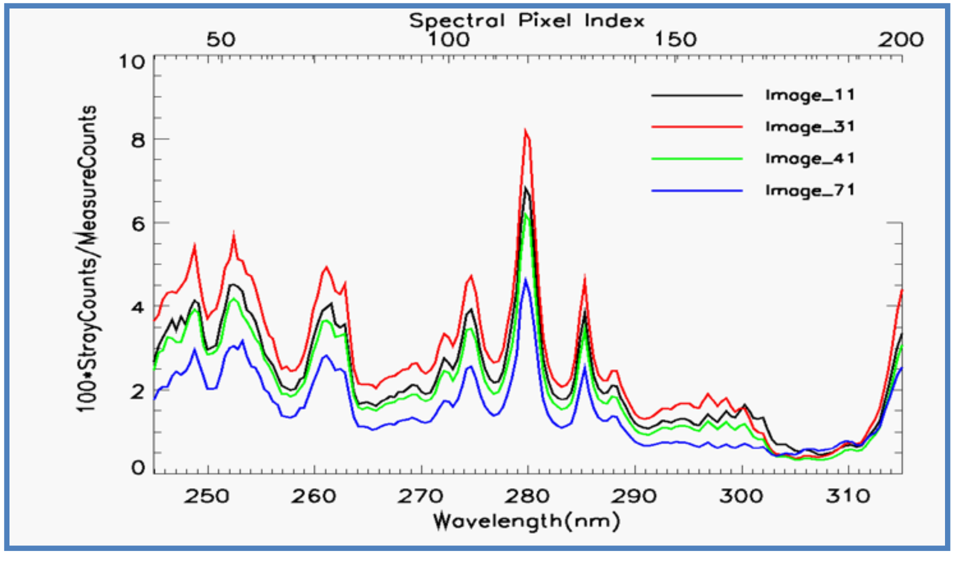
$$C_{stray}(i_t, j_t) = \sum_{kspec=1,}^{21}\sum_{lspat=1}^{36} C_{in}(k,l) Jacobian(kspec, lspat, i_t, j_t,)$$

$$C_{in}(k,l) = \sum_{m\in(k),}\sum_{n\in(l)} C_{in}(i_s, j_s)$$

Validation Results for Nadir Profiler





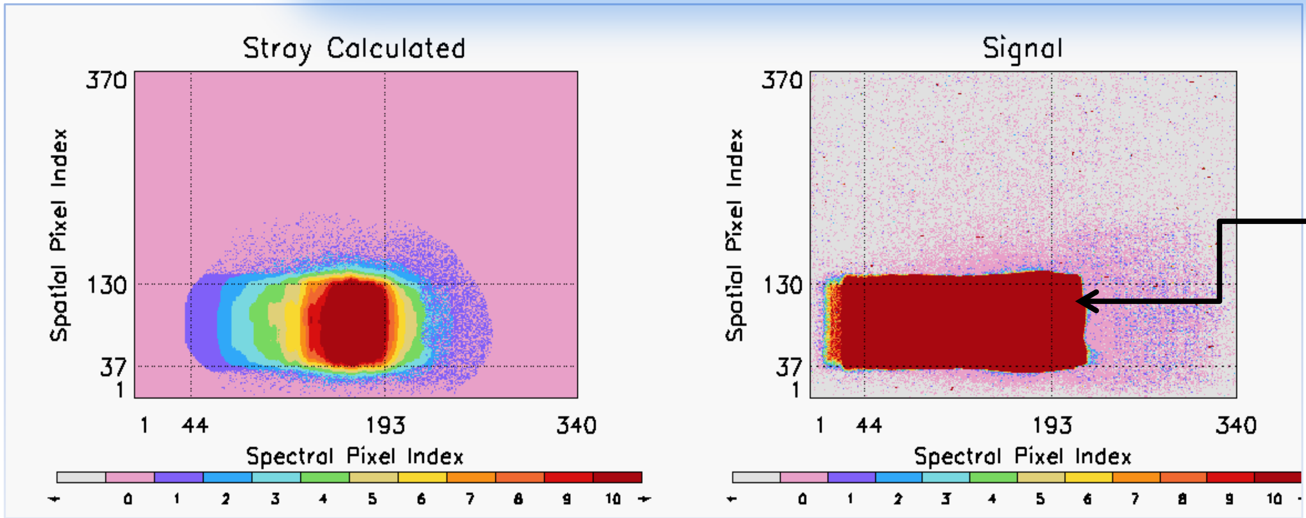


NP full-frame Earth View Measurement: there are total 80 frames in this orbit.

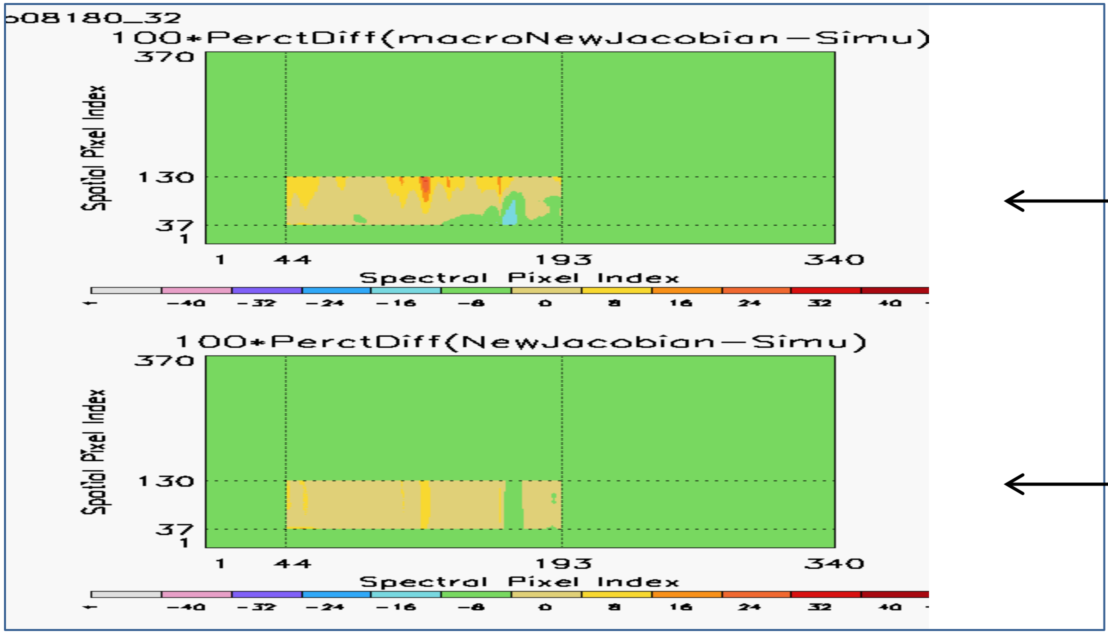
Top Left panel: Measured counts (with dark and smear cleaned)

Lower Panel: Stray light percentage vs wavelength.

Updates since Launch and Residual for Nadir Profiler



Updates at dichroic filter transition area



IDPS Jacobian
(SL_COR_COEFF
(1,147,1,14))

PEATE Jacobian
(370,340,14,7)

Updates since Launch for Nadir Mapper(NM)

- **In-band, in-field PSF Stray Light**
- **In-band, in-field Ghosts**

-----------First delivery to IDPS

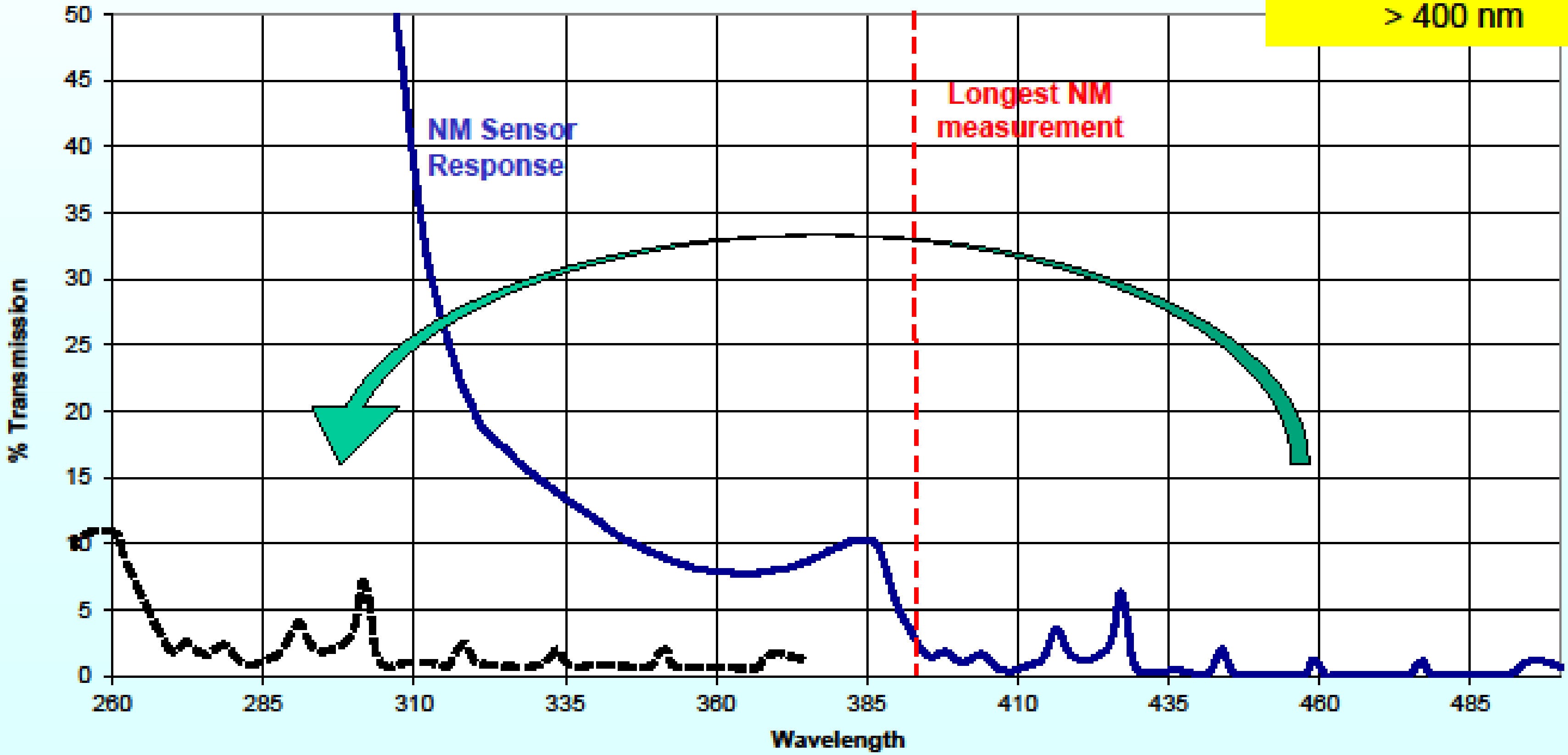
- **Out-of-band PSF Stray Light**
- **Out-of-band Ghost (was not fully characterized during pre-launch tests)**

-------Second delivery to IDPS

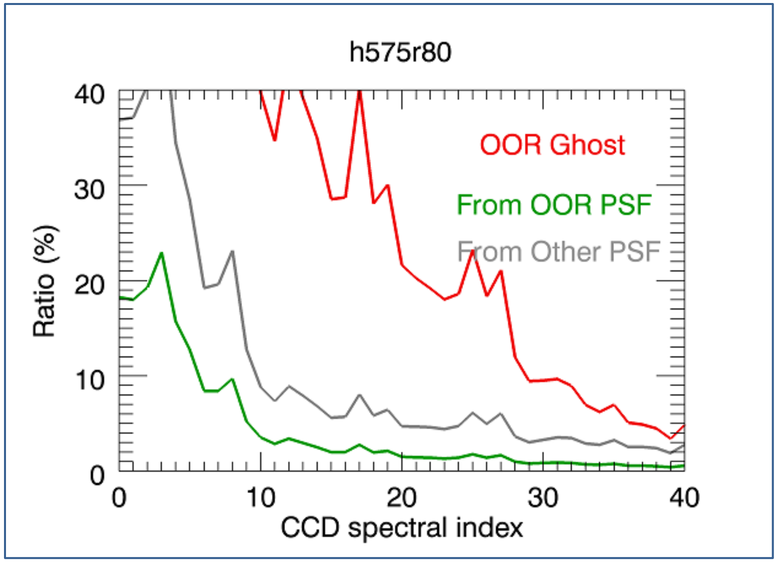
NM ghost is a significant error source at $\lambda < 310$ nm

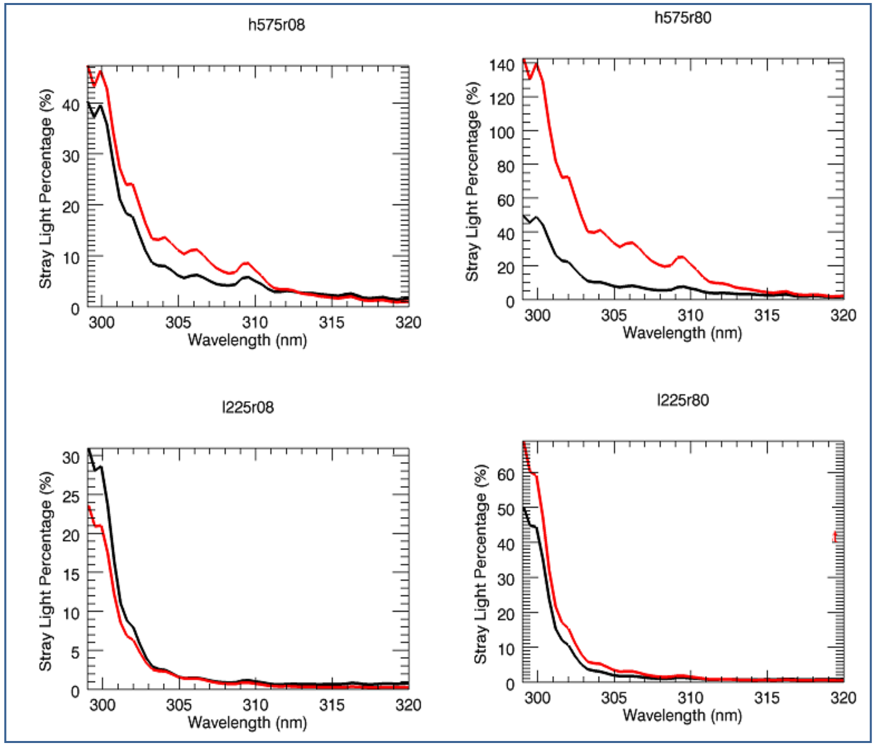
Reflection within NM spectrometer creates "ghost" spectrum at shorter wavelengths

Correction requires an estimate of radiances > 400 nm



Before Launch Simulation for NM





Stray Light Percentage

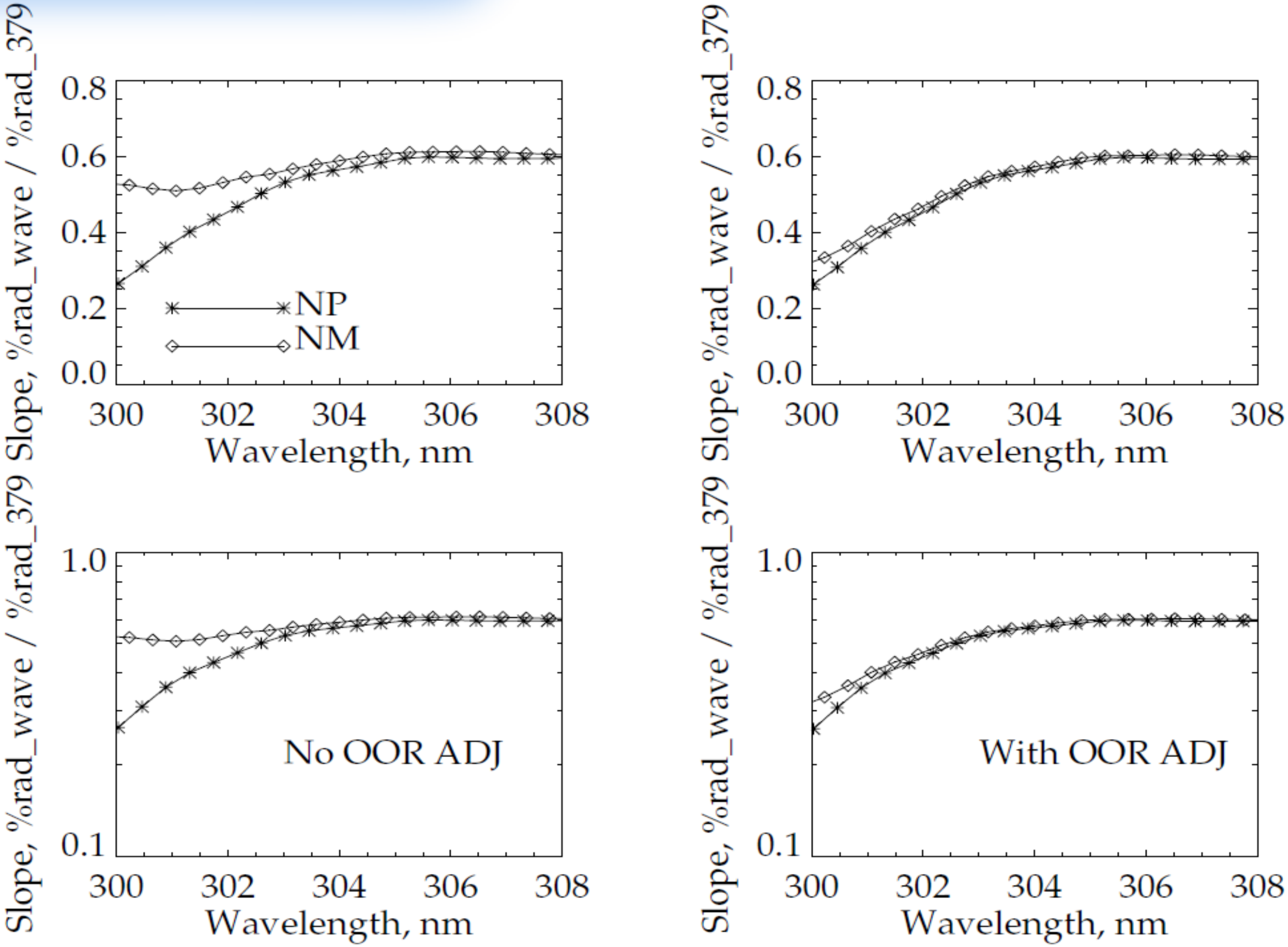
Gray: All in-band contributions
Green: OOR PSF contribution
Red : OOR ghost contribution

Stray light Percentage

Black color: all in-band contributions
Red color : OOR contributions

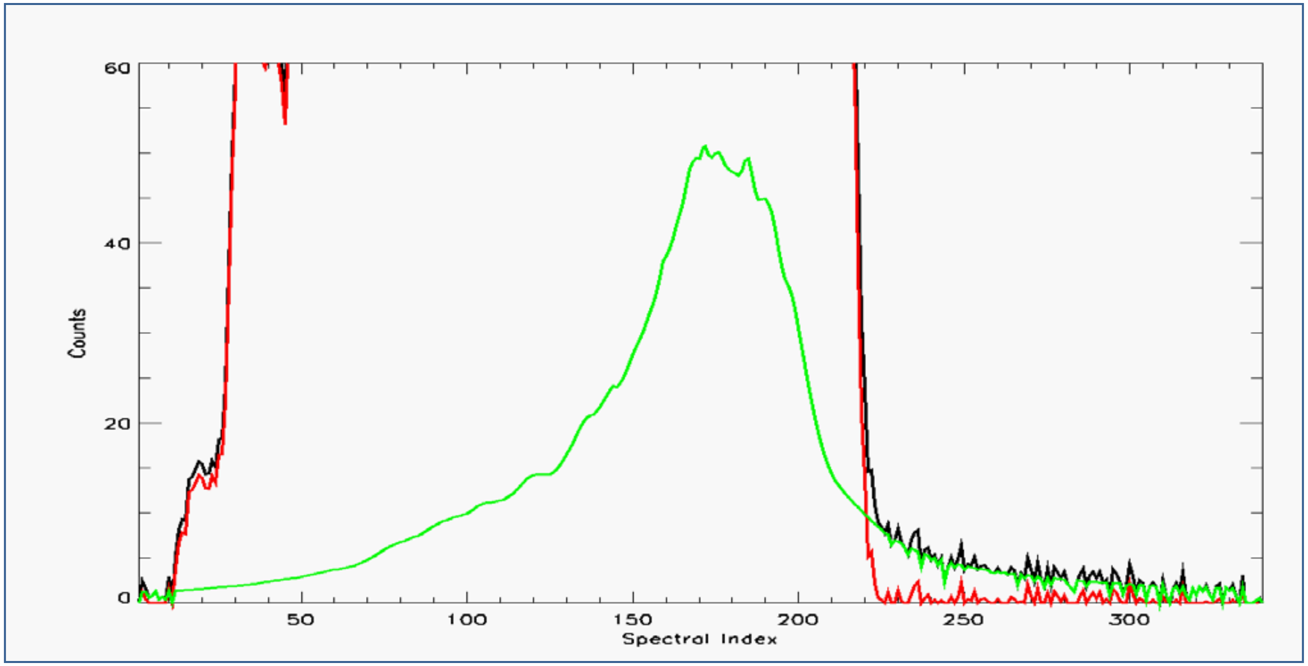
Validation Results for NM

Larry F., NOAA, DR7387…



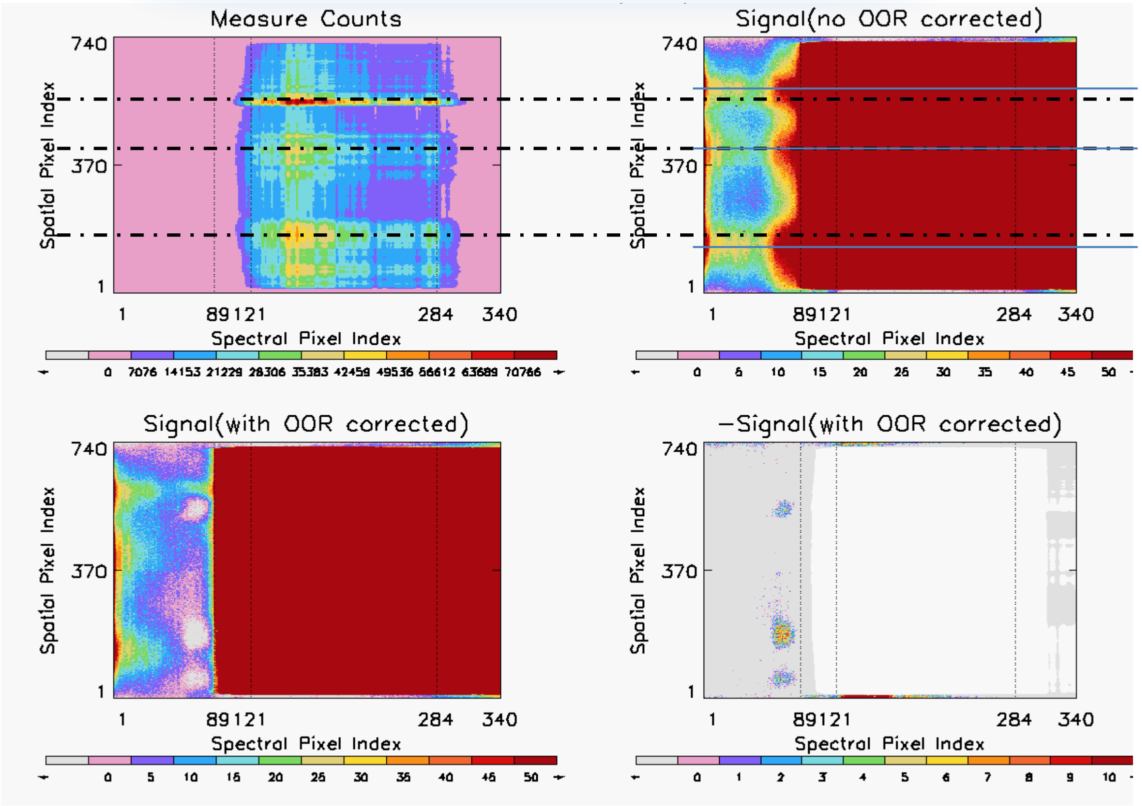
Residual analysis: Nadir Profiler

MeasuredCounts=SignalCounts +StrayCounts
? ?



The measured counts (Black), calculated stray light counts (Green) and the signal counts (Red) vs CCD spectral index. At the longer wavelength end, the remaining signal counts are near zero; this suggests no (very few) residual stray light.

Residual Analysis: Nadir Mapper



NM full frame measurement before and after stray light is removed

The black-dot lines show the OOR Ghost source spatial locations; the blue thin lines show the OOR Ghost spatial locations. Clearly there are offsets….

On-Going and Future Work for NM and NP

NM

Working on OOR ghost

*Spatial dependence

*OOR source signal estimation

NP

More   Need your inputs!

Q: What the instrument imaging prosperities changes since launch?

Q: What pre-launch tests missed ?

OMPS NM & NP measurements in the 300 – 310 nm range

G. Jaross (with help from)
J. Li, G. Chen, L-K. Huang, M. Kowitt, C. Seftor

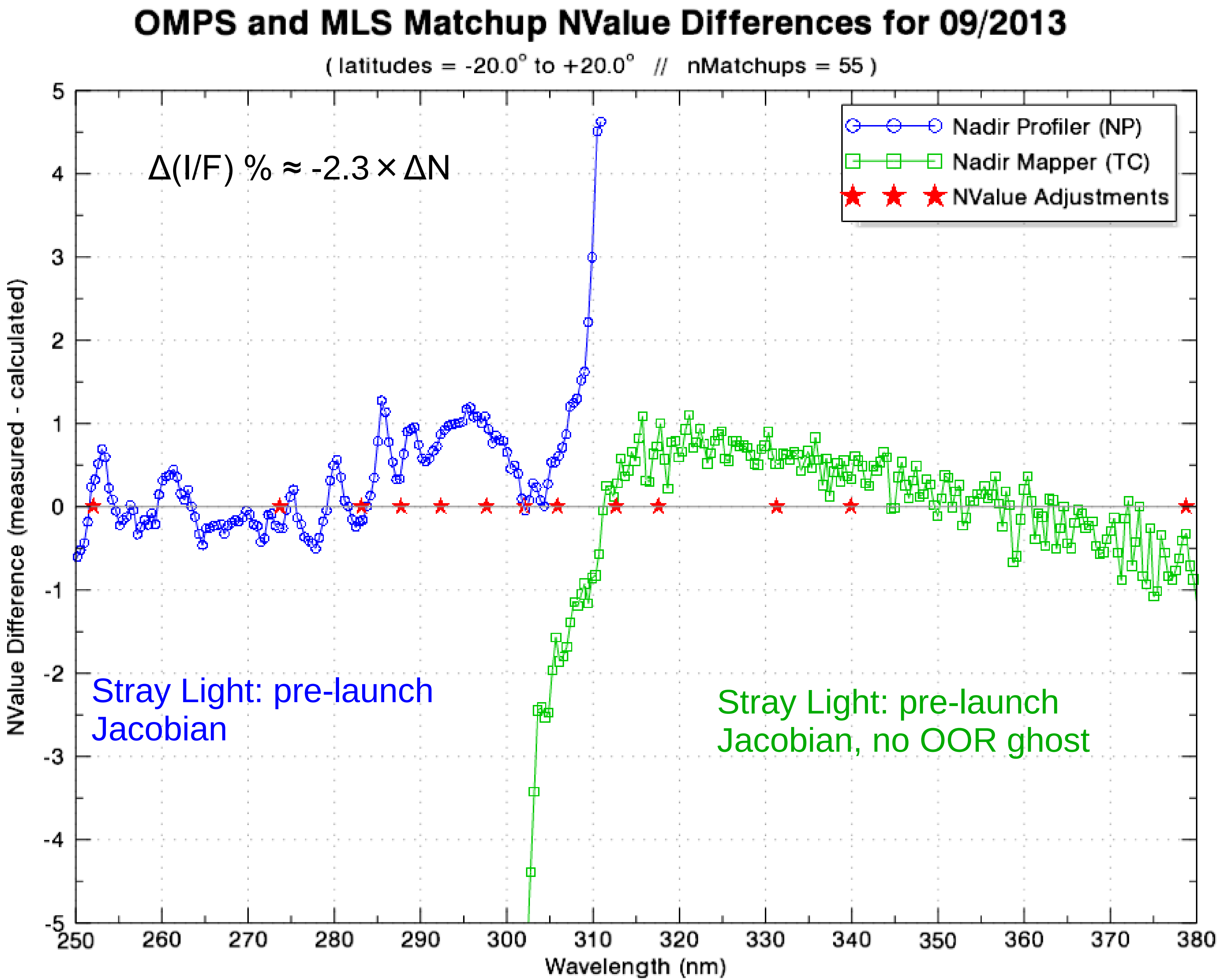
The NM and NP measured TOA reflectances should agree in the overlapping wavelength range. They do not.

- **FOVs are well matched**
- **Simultaneously calibrated sensors (< 2% albedo cal. errors)**
- **Radiances and irradiances have larger calibration errors, but should also agree.**

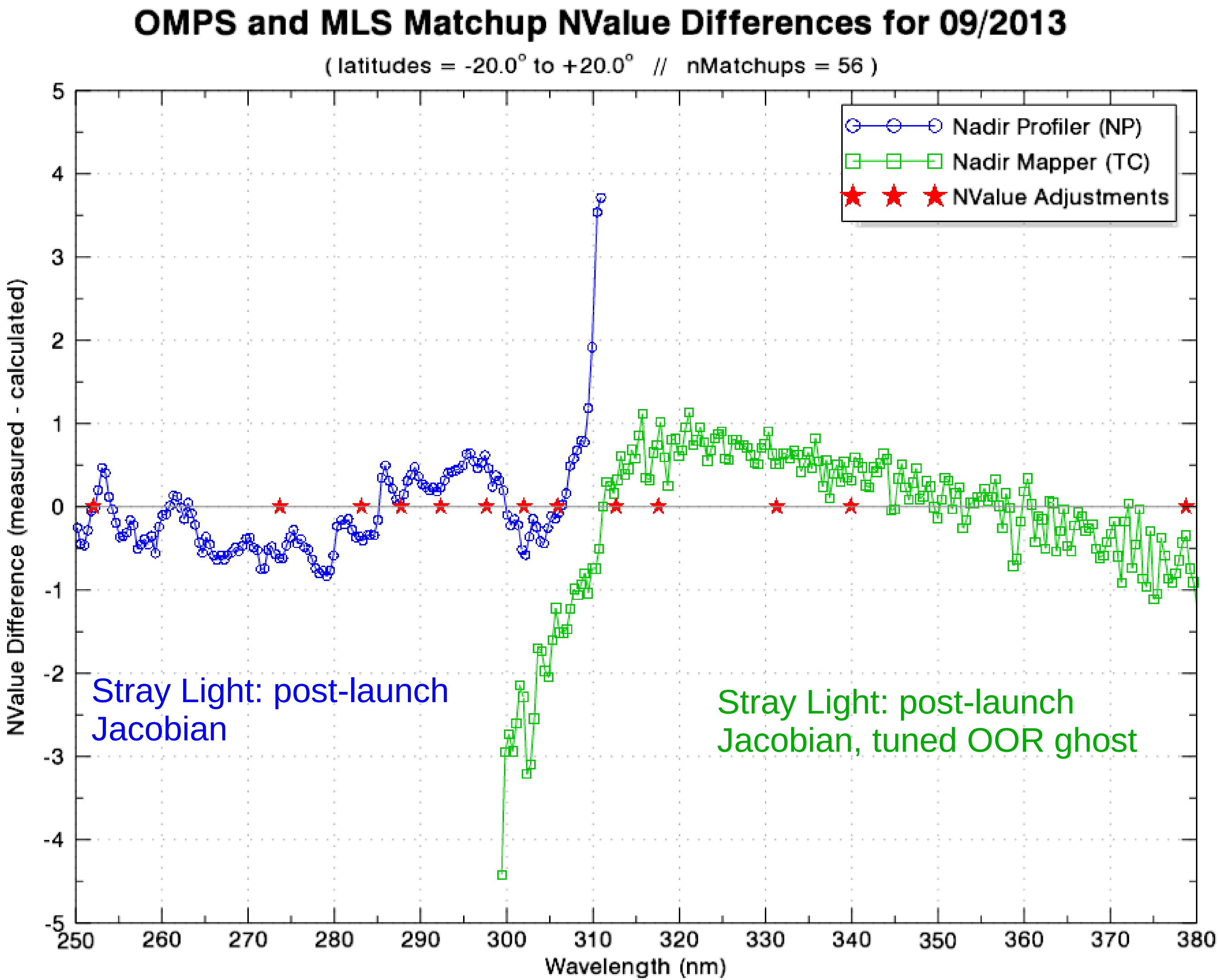
Conclusion: Underlying cause of difference most likely NOT radiometric calibration

Scene content, instrument (or both) have changed from ground to orbit

Goal: Find the underlying causes for mismatch. Correct those errors before applying empirical adjustments.

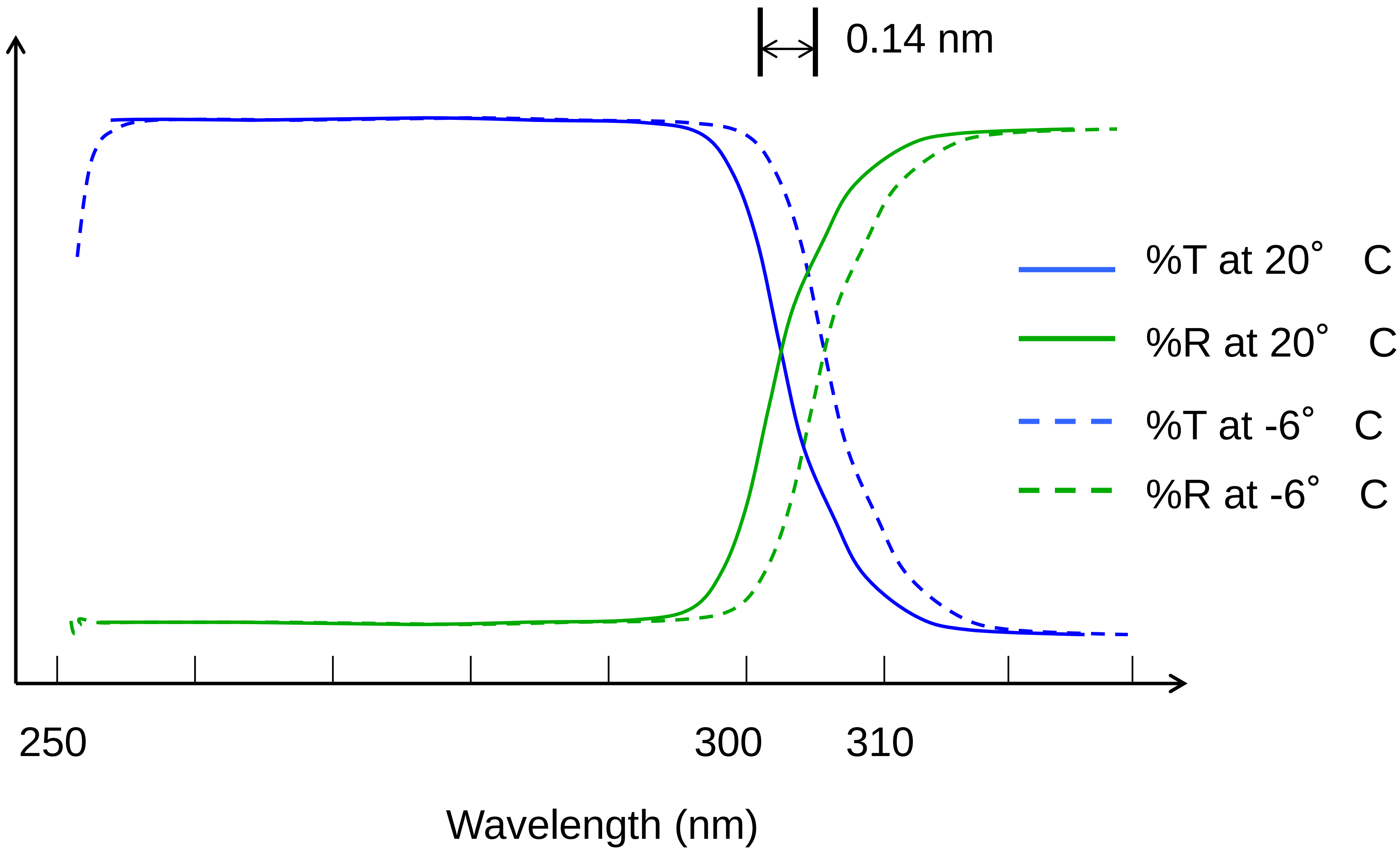


NP_SLT_V001, TC_SLT_V001



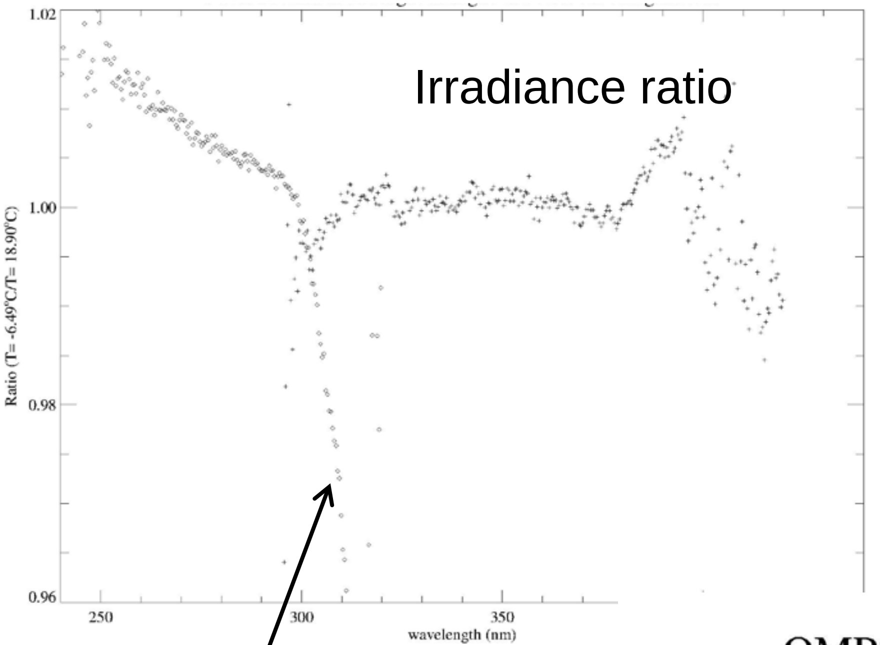
NP_SLT_V003, TC_SLT_V005

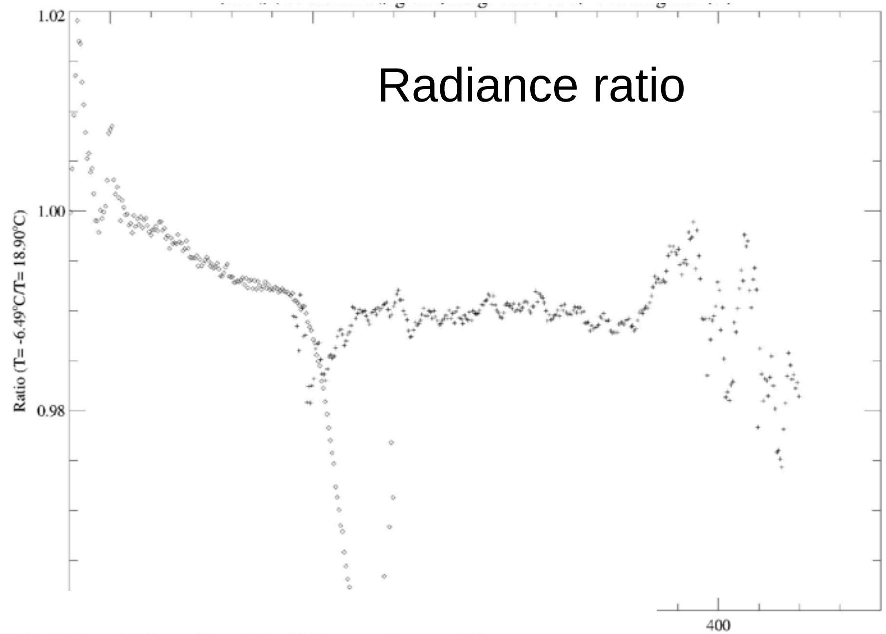
Dichroic filter Trans/Refl curves shift longer at flight temperatures



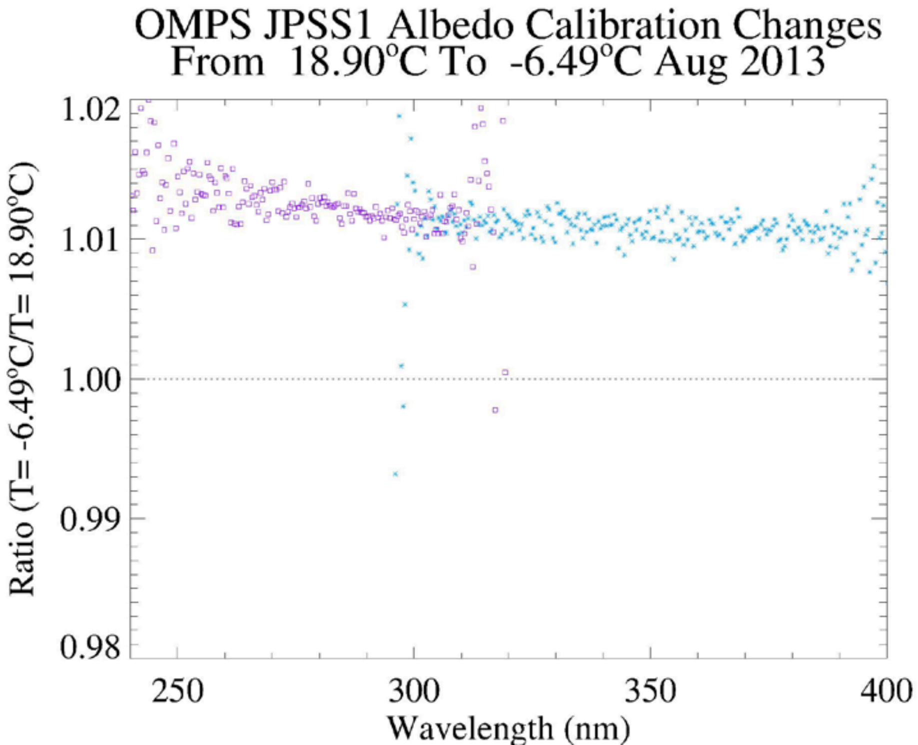
Effect on coefficients is same for Radiance and Irradiance
(no significant on-orbit temperature differential)

J1 OMPS test confirms cancellation of shift effects in Albedo ratio





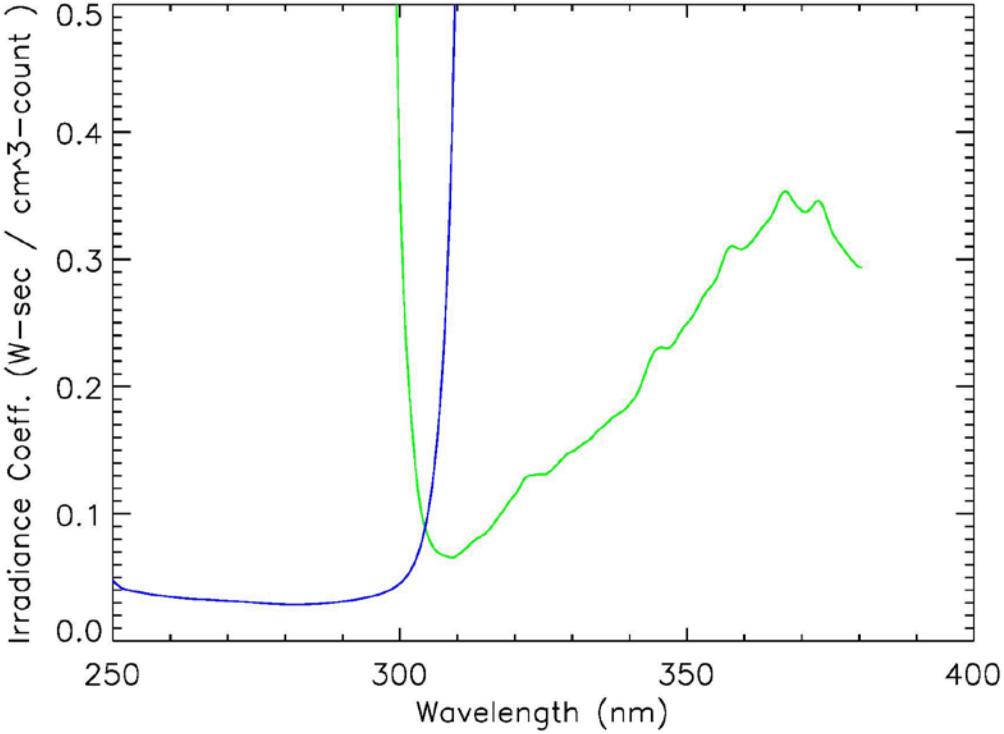
Result is opposite that seen on NPP (see solar irradiance slide)



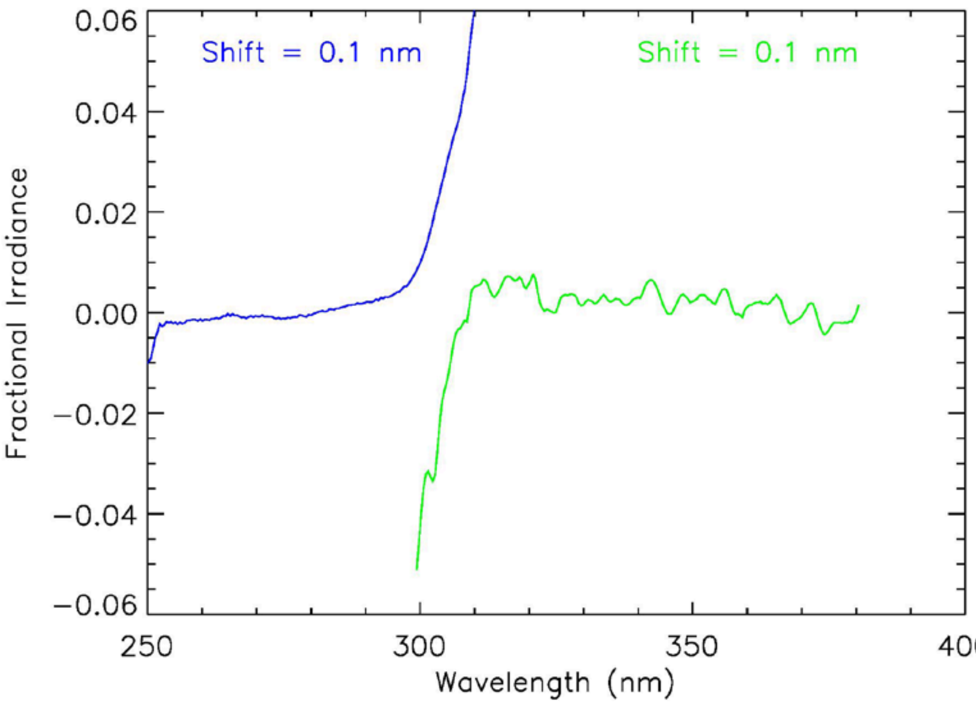
Ground-to-orbit λ shift causes radiometric calibration error

- Error largest where sensitivity gradients are high
- NP shift: -0.1 to -0.13 nm (seasonally variant)
- NM shift: solar -0.1 nm, EV -.07 to -.04 nm (cross-track variations)

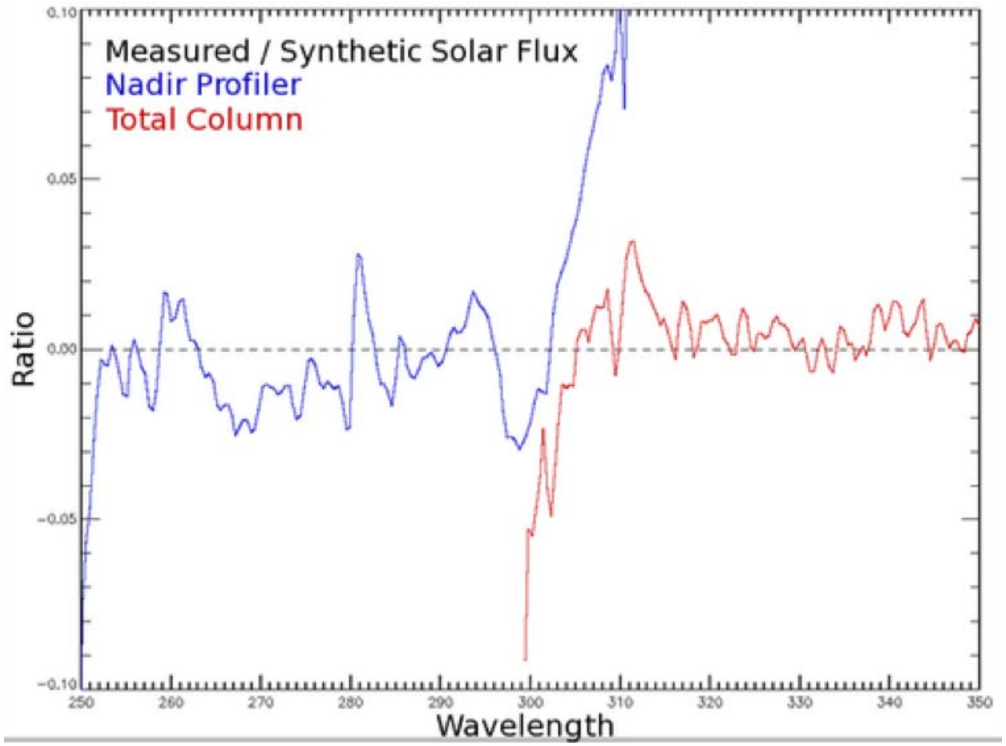
Irradiance Calibration Coefficients

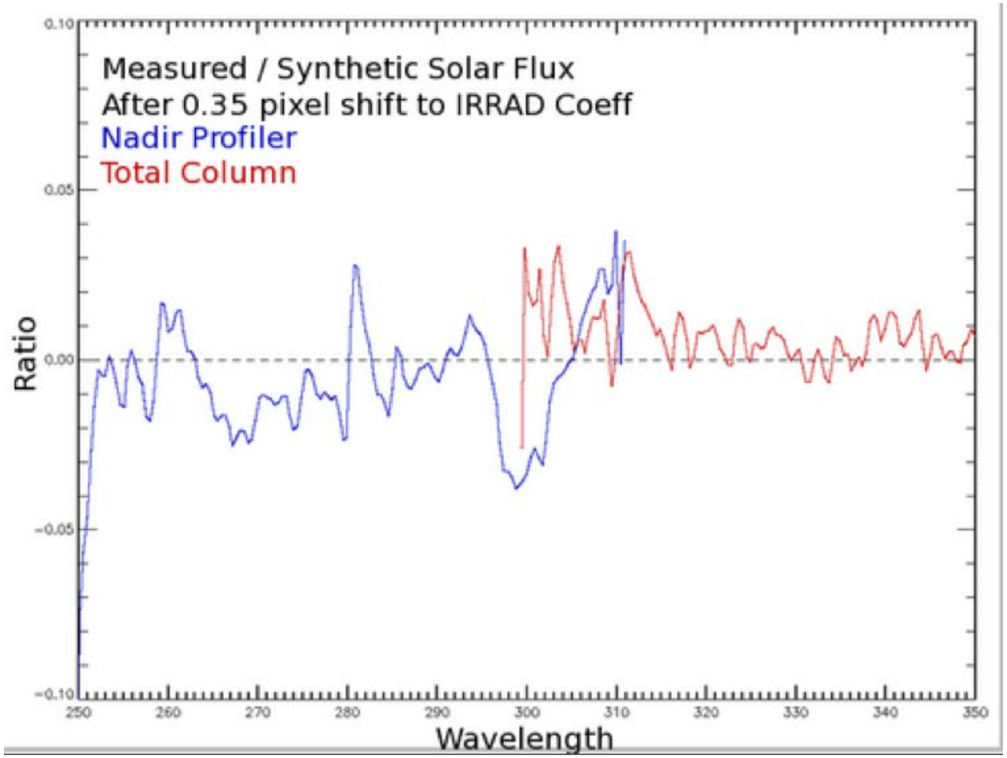


Estimated Calibration Error

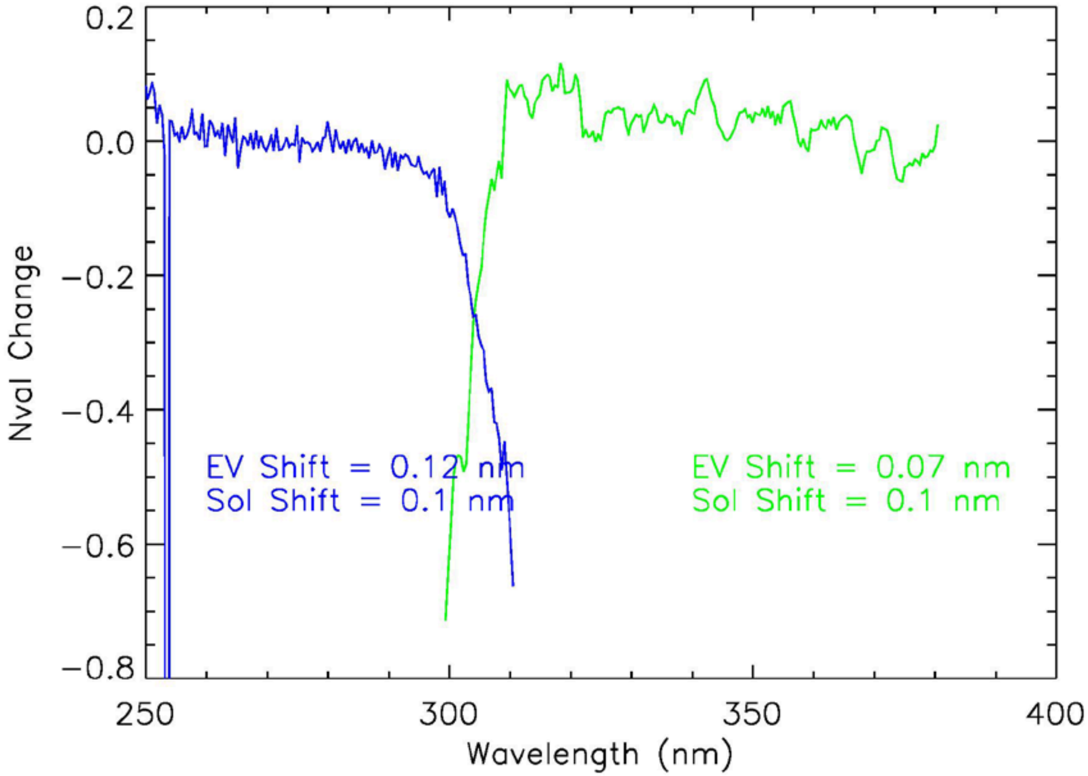


By adjusting the irradiance coefficients for a λ shift, we demonstrate that such a correction will result in accurate solar irradiance measurements

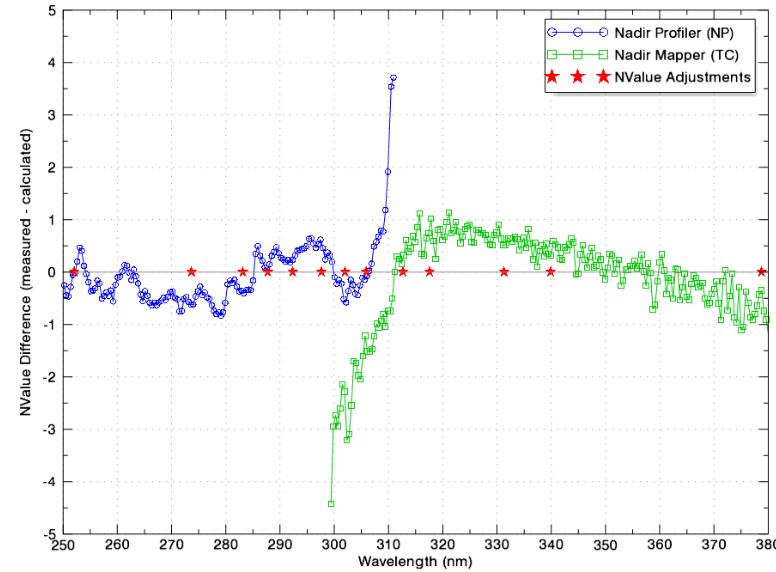




Predicted error in TOA reflectance based on ground-to-orbit wavelength shift



Observed

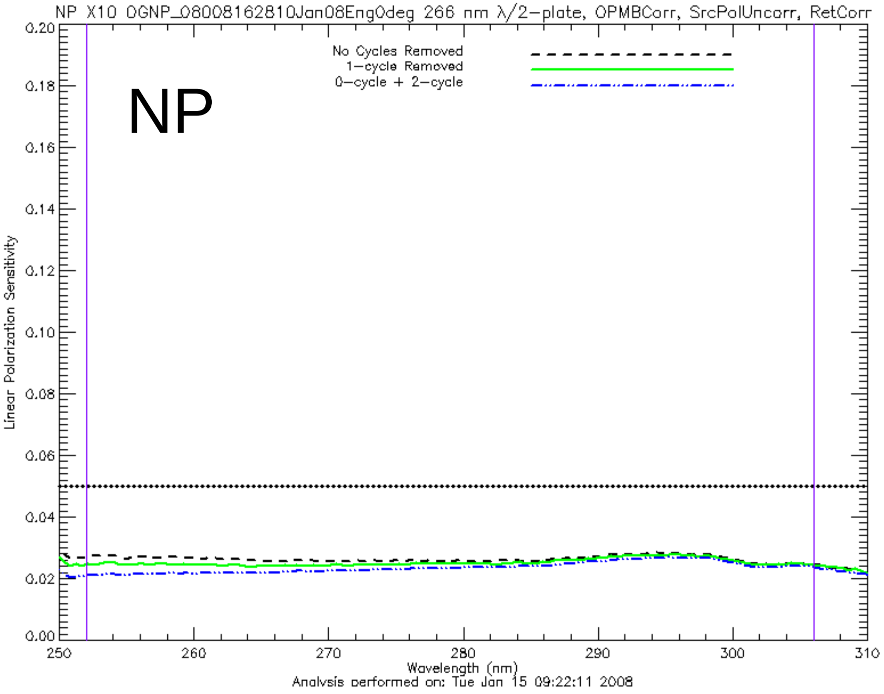


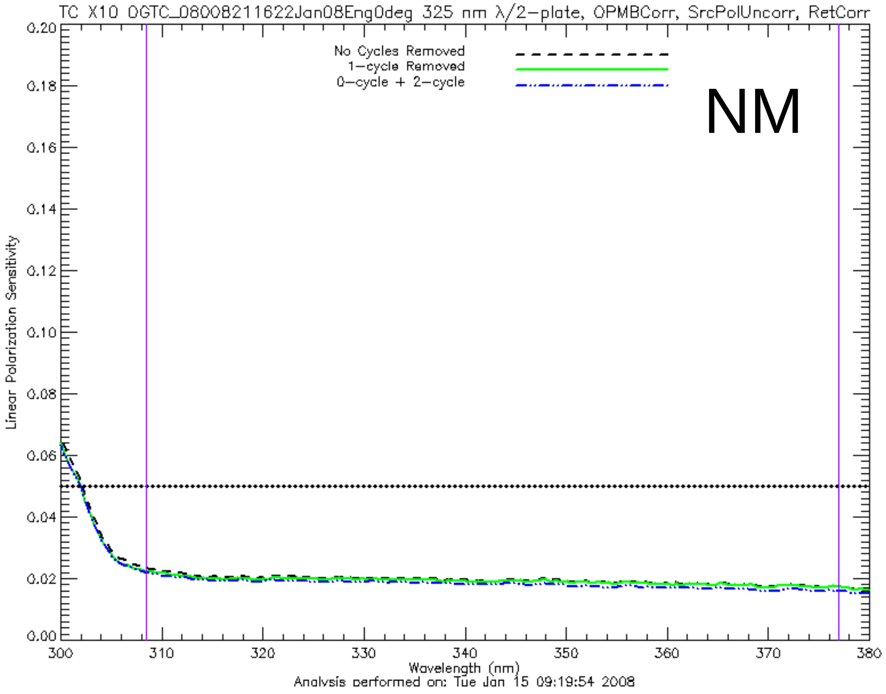
Not nearly enough differential shift to explain observation (NP prediction is opposite)

Polarization sensitivity could explain NM behavior, but not NP

- Polarization sensitivity to solar irradiance is calibrated, but not Earth radiance
- Multiple scattering decreases as O_3 absorption increases
- Dichroic filters are highly polarizing and polarization sensitive

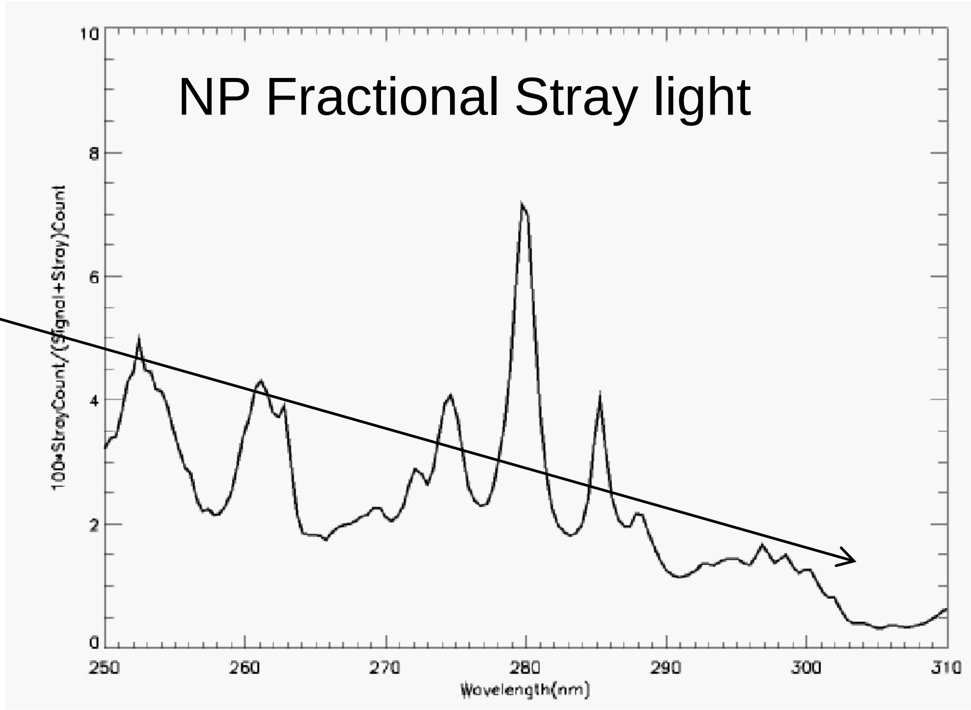
Linear Polarization Sensitivity



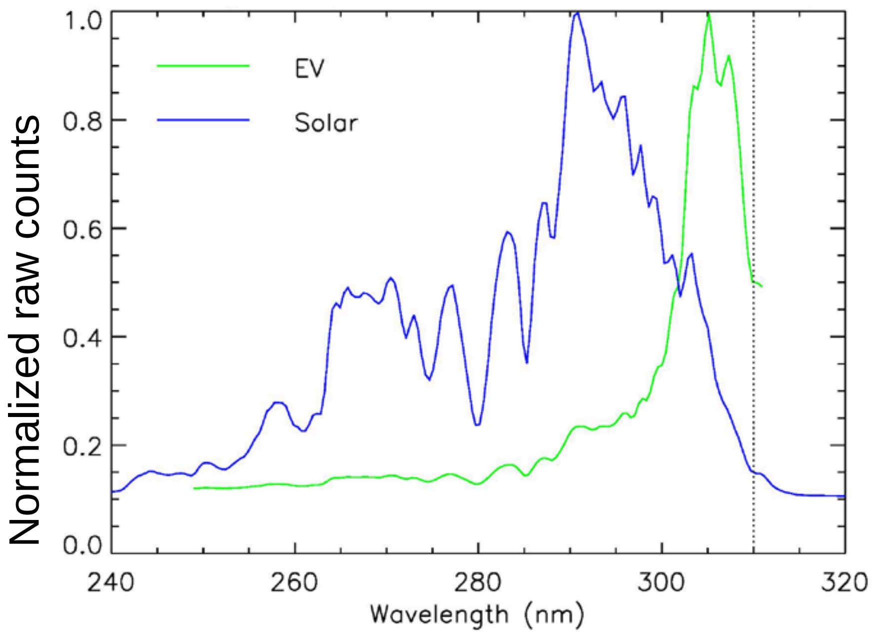


Easiest to focus on NP: Why does it measure TOA reflectance too low ?

- 8 – 9% error at 310 nm
- EV / Sol λ-shift differential results in < 2% error
- EV Stray light content is < 1% at 310 nm
- Correction for Solar S.L. will provide additional reduction (how much ?)

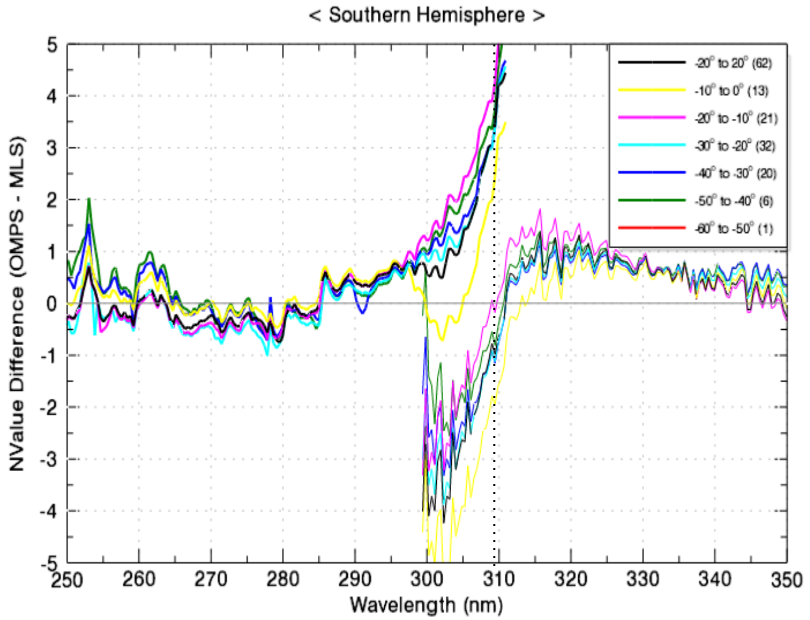


Raw NP Signal



Next Steps

- Focus on explaining NP reflectance errors 300 – 310 nm
  - NM stray light is complicated in this range; intraorbital λ shifts
  - BATC did not adequately correct cal. coefficients for OOR ghost
- After all known NP and NM corrections have been applied …
  - Normalize NP to NM at 310 nm (NM error < 1 Nval)
  - Apply decreasing NP adjustments down to 290 nm
  - Normalize NM (λ < 310 nm) to NP



- Reprocess select data for soft calibration analysis
  - Avoid normalization to MLS
  - D pair may not work well
  - Ascending-descending may not help much
  - Residual analysis

JPSS STAR Science Team Annual Meeting
OMPS SDR Team Discussions

Xiangqian Wu
OMSP SDR Lead

May. 13, 2014

Outlines

- History
- Future
- Lessons learned
- New challenges for J1

History

- STAR needs to understand UV instruments and SDR/L1B process similar to those for the imaging and sounding instruments, in the VIS, IR, and MW spectra, and on GOES and POES.
- Flynn has been the most knowledgeable, but he has also been increasingly needed for EDR and ozone science in general.
- Wu was assigned to lead the OMPS SDR Team and started to ask the meaning of every acronym.

Future

- Partly because of that history, our roles have often been that STAR makes decision, NASA calibrates instruments, NGAS adapts for IDPS, Raytheon implements, and Aerospace coordinates.
- It has been necessary and served us well in the past, but in future STAR expects to
  - Perform cal/val and adapt for IDPS.
  - Collaborate with NASA broadly and indefinitely.
  - Get advice from NGAS for as long as possible.
  - Work with Raytheon and Aerospace as has been.

Lessons learned from S-NPP

- Inflexible code, esp. CAL SDR
- Update the DARK sooner
- Evaluate stray light and update the correction sooner.
- Wavelength registration may depend on temperature.
- Dichroic transmittance may change after orbit.
- Need offline science code.
- Need tools to interrogate the RDR / SRD
- Need tools and data to compare (GOME-2, SBUV/2, OMI, CRTM, MLS, …)
- Need to access BATC documents

New challenges of J1

- Pre-processor
- Spectral gaps
- CAL RDR collection
- CAL SDR improvements