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

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**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-$\sigma$ 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:

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

$$\text{dwell time} = 330 \text{ msec} / 390 \text{ rows}$$

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

# DARKCAL Algorithm (II)

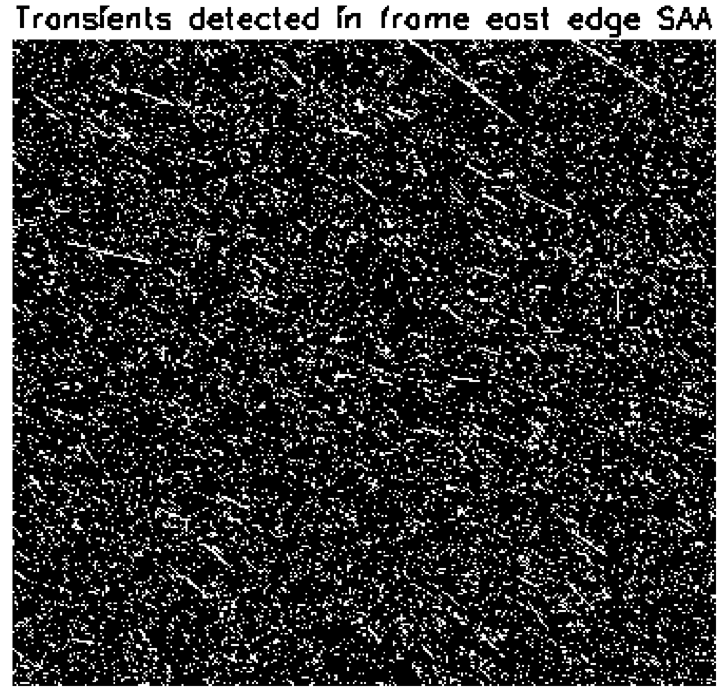
- **Corrections for arbitrary data are constructed as:**
  **DCC = Ncoadds x (Image Region Rates x Integration Time + Readout Counts)**
  **Smear columns in DCC: average of smear rows in Readout Counts**
- **The full-frame DCC is binned according to the EV or solar sample table**
- **For IDPS dark LUTs, 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**

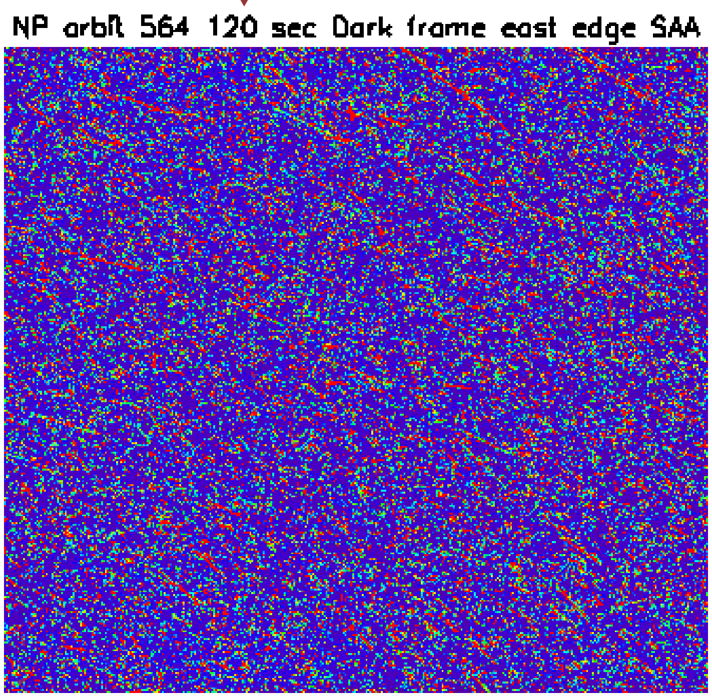
## DARKCAL Transient Filter

- **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)**

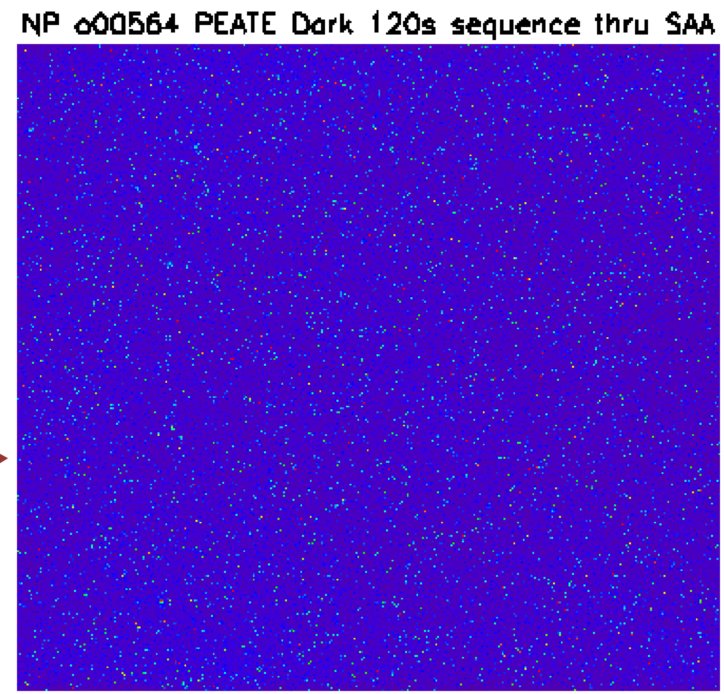



Frame in 22-frame sequence through SAA

Transients removed from frame

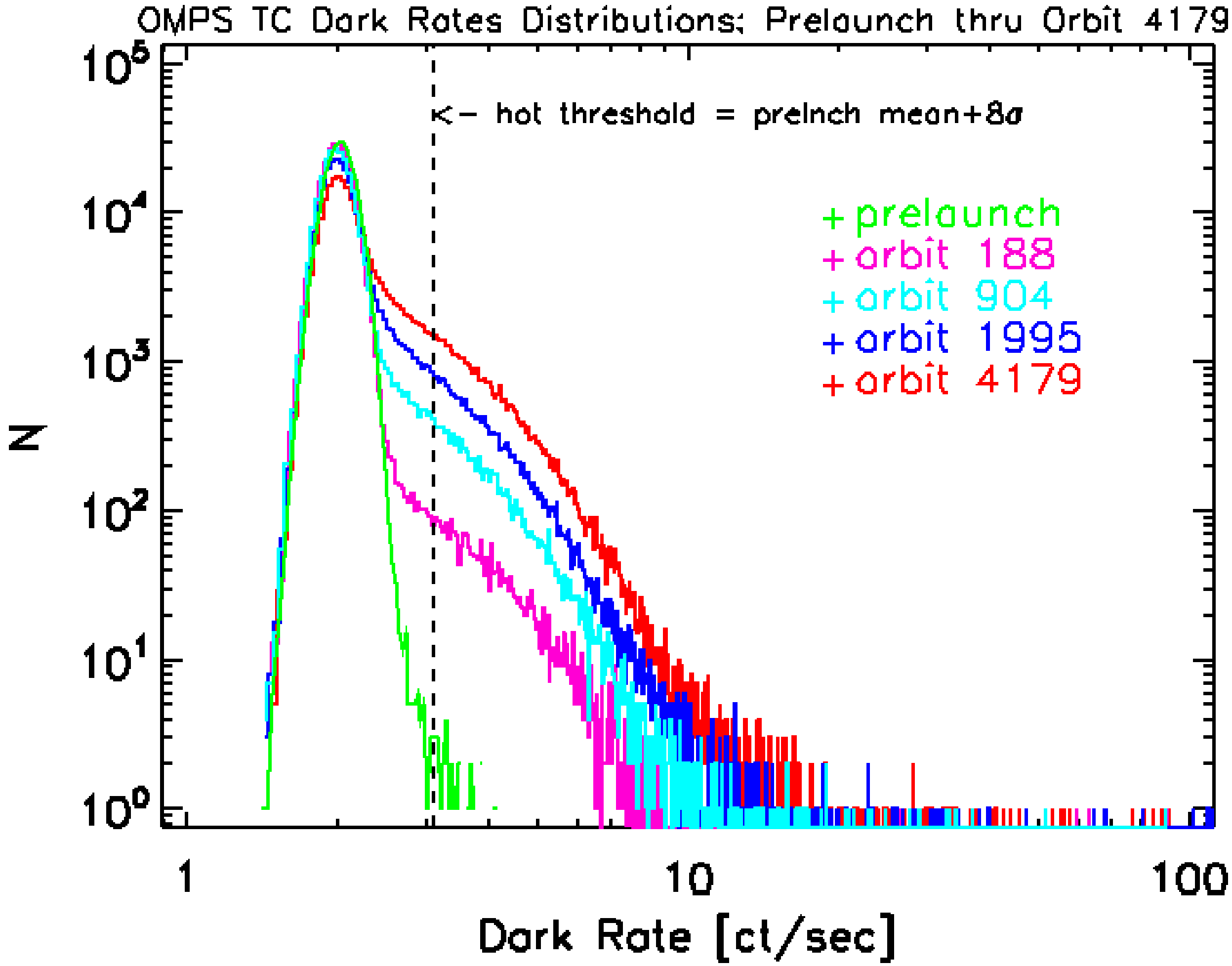



Dark current image from all 22 filtered frames

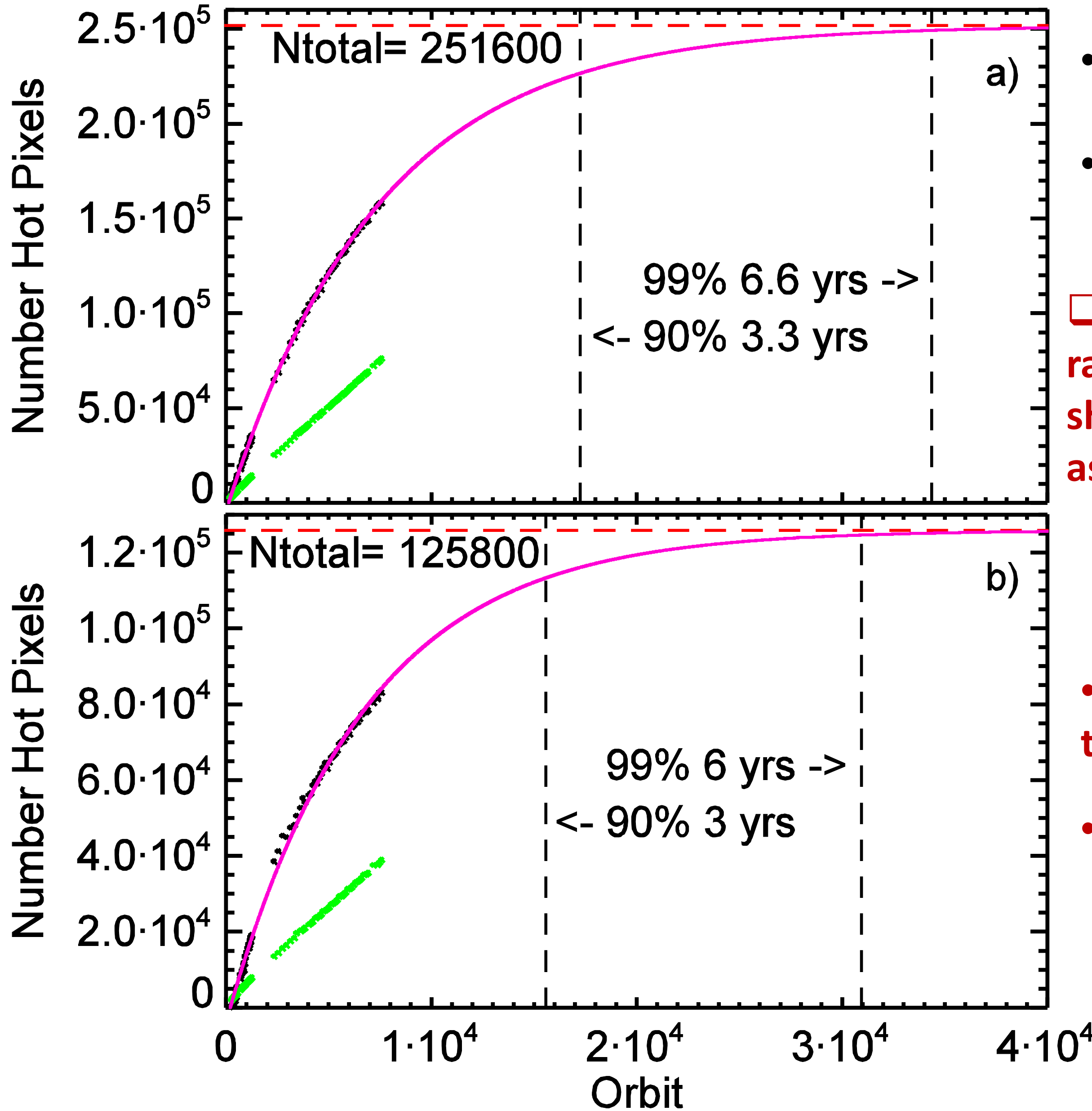


# Dark Current Histogram Evolution

- 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 $N_{tot}$ :

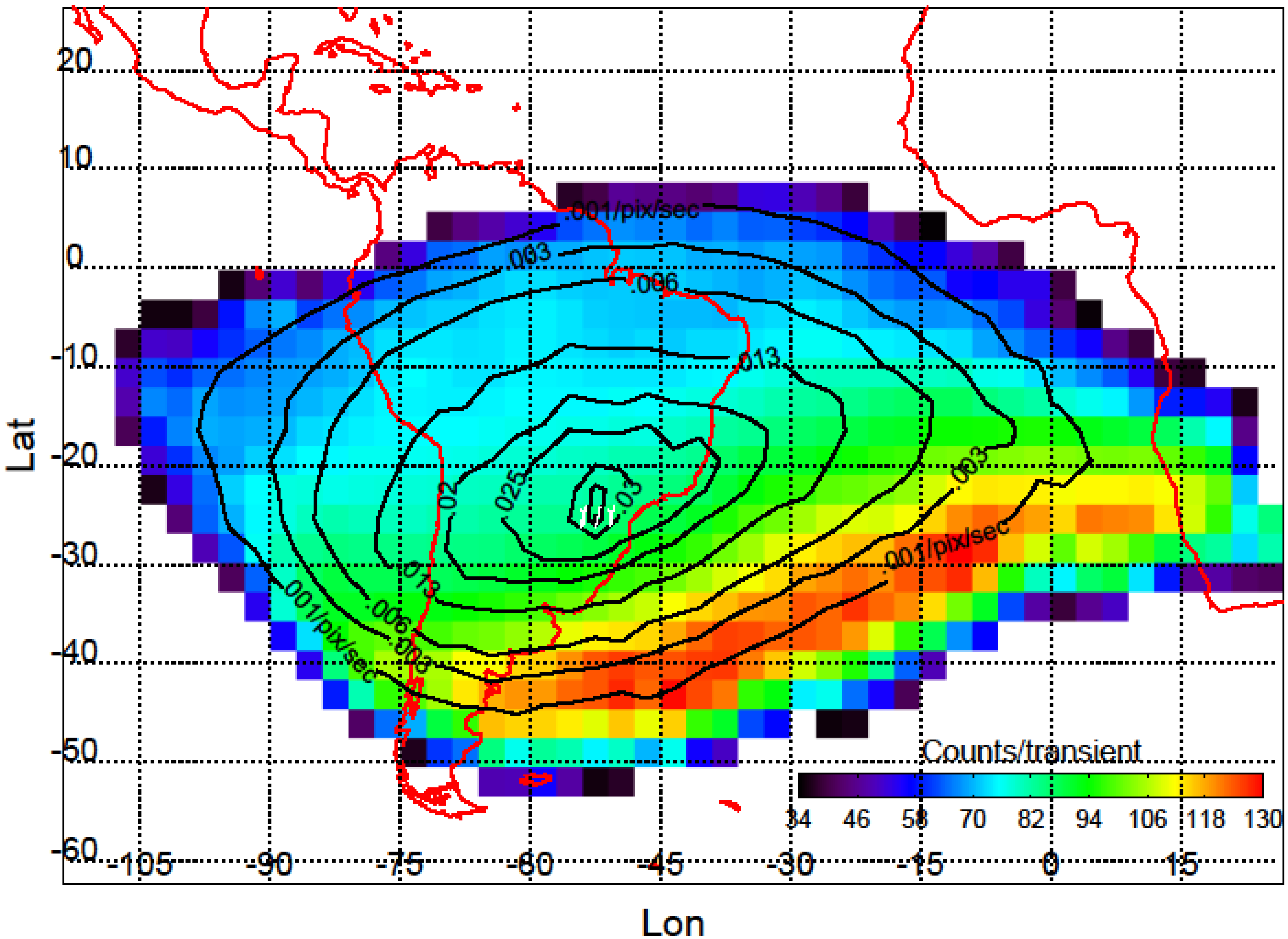
$$N_{damaged} = N_{tot}\,(1 - e^{-x/x_0})$$

- 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

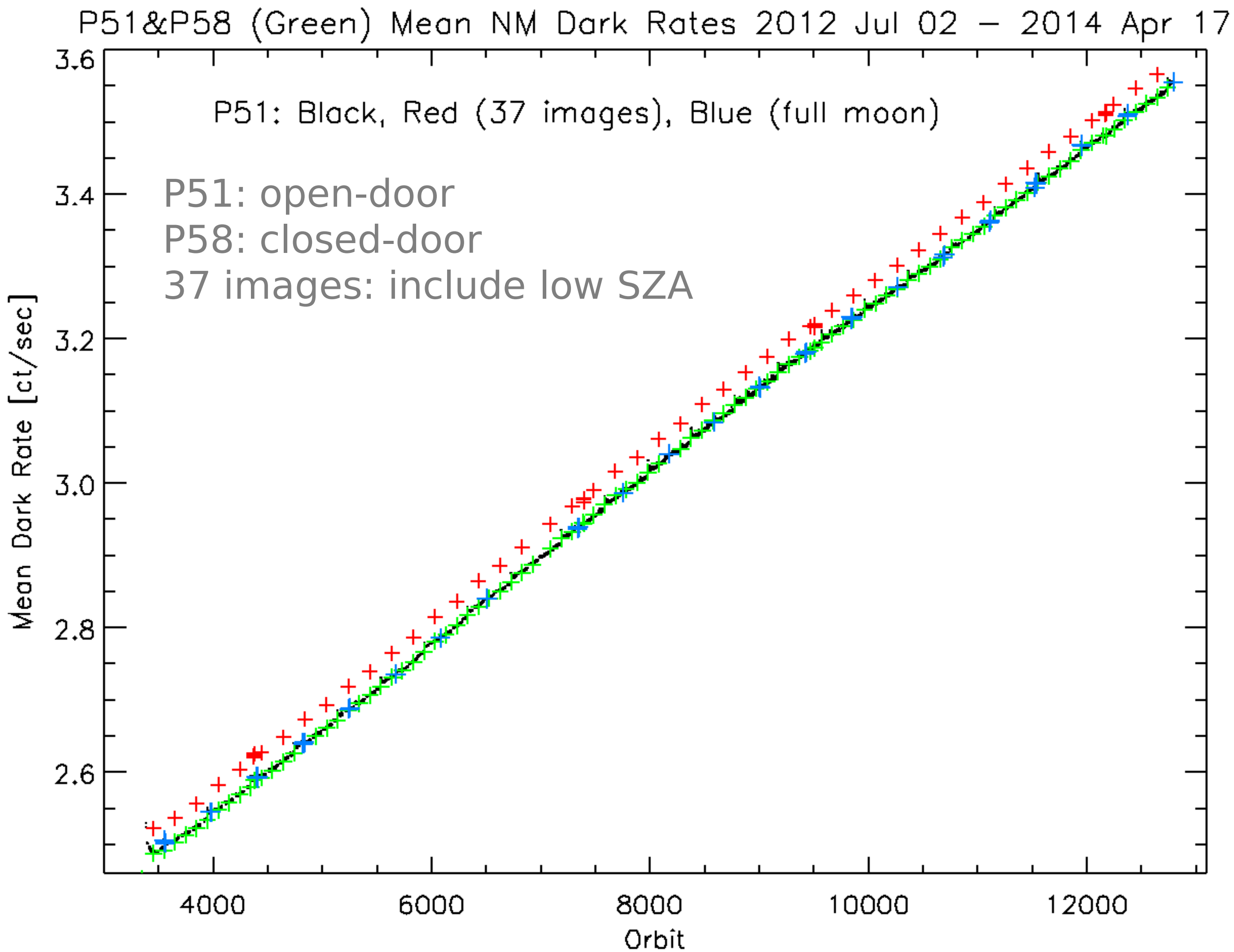
**Contours = particle density [pixel$^{-1}$ second$^{-1}$] – Expected**

**Colors = mean particle energy [counts] – Surprising!**

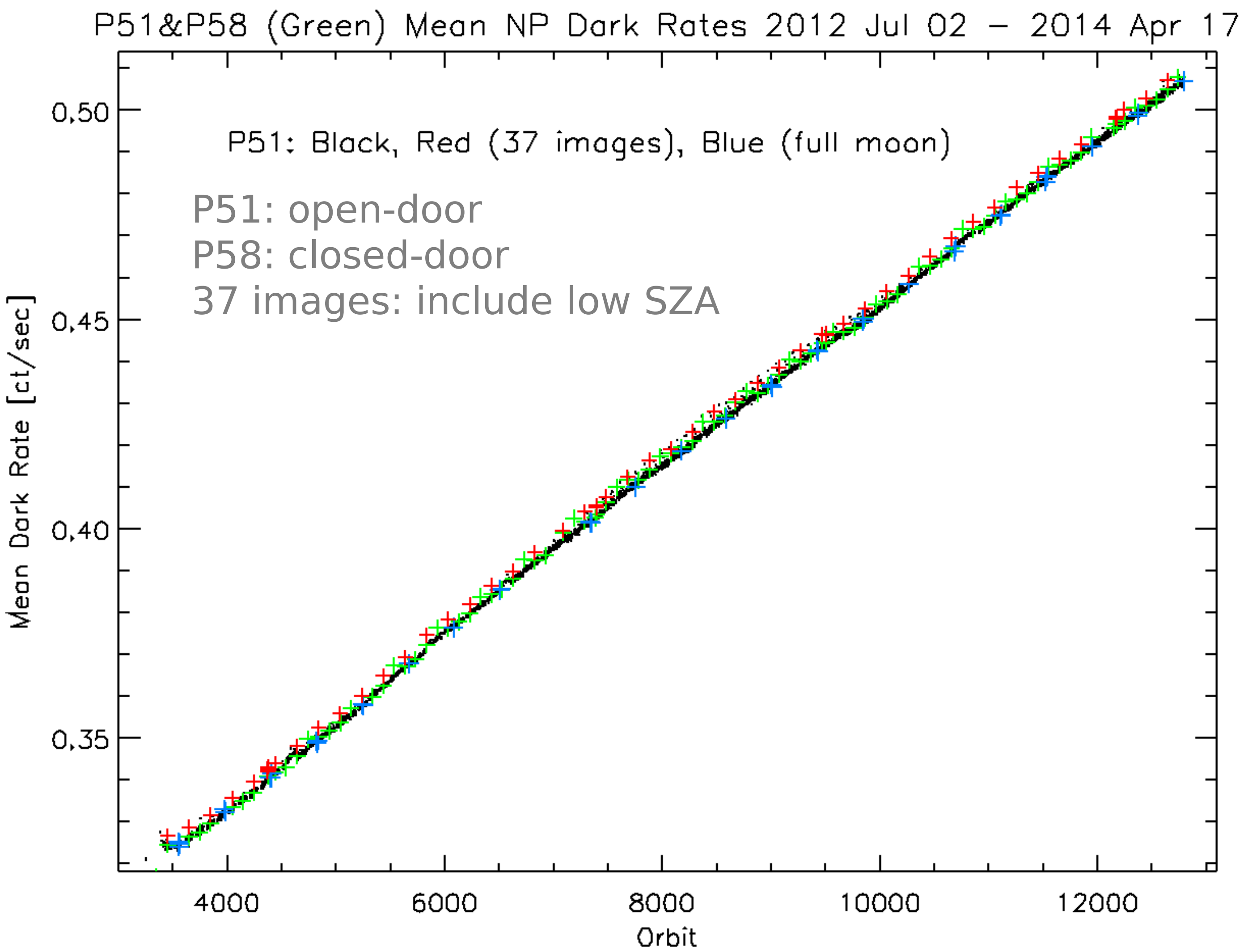


## Study to Qualify Open-Door Dark Data for Orbital Updates

- ➢ **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

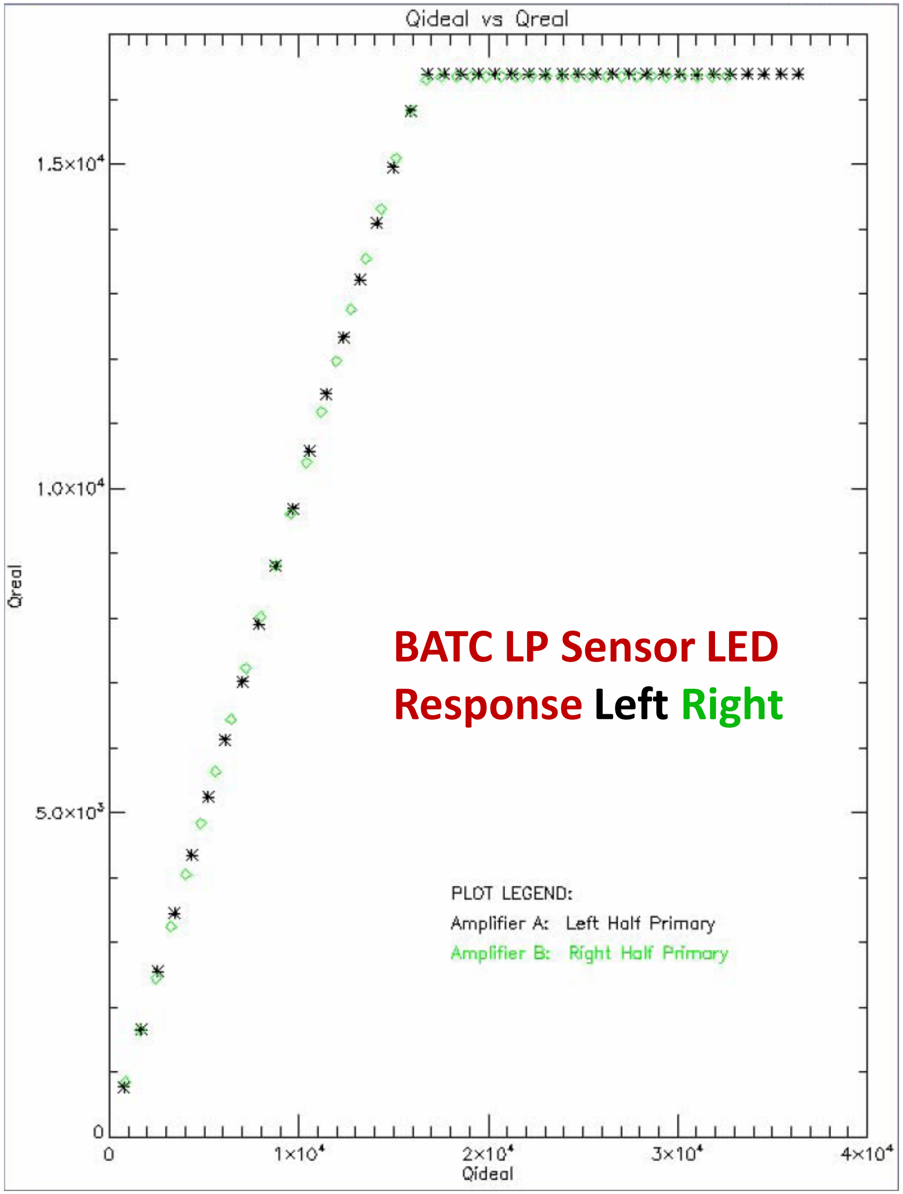
- Finds correction to convert measured counts ($C_{real}$) to linearized counts ($C_{ideal}$)
- Improved method fixes problems with original BATC approach
  - Allows sampling full dynamic range of pixel responses and assessing pixel full-well levels

- 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

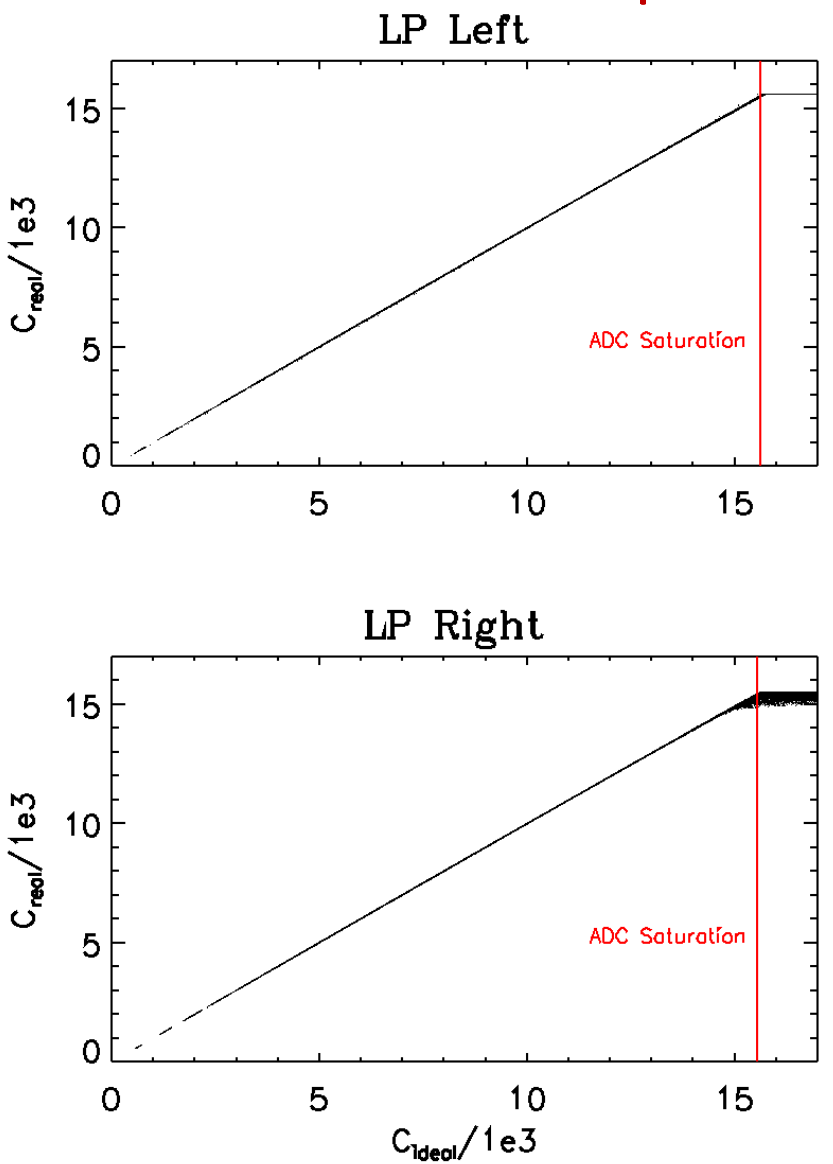
- **NASA Improvement:** convert from $C_{real}$ to $C_{ideal}$ at pixel level, use all pixels (BATC averaged small group of pixels at each integration time step before converting), then . . .
- Linearity correction determined by fitting a 5th-degree polynomial to the difference $C_{ideal} - C_{real}$
  - 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

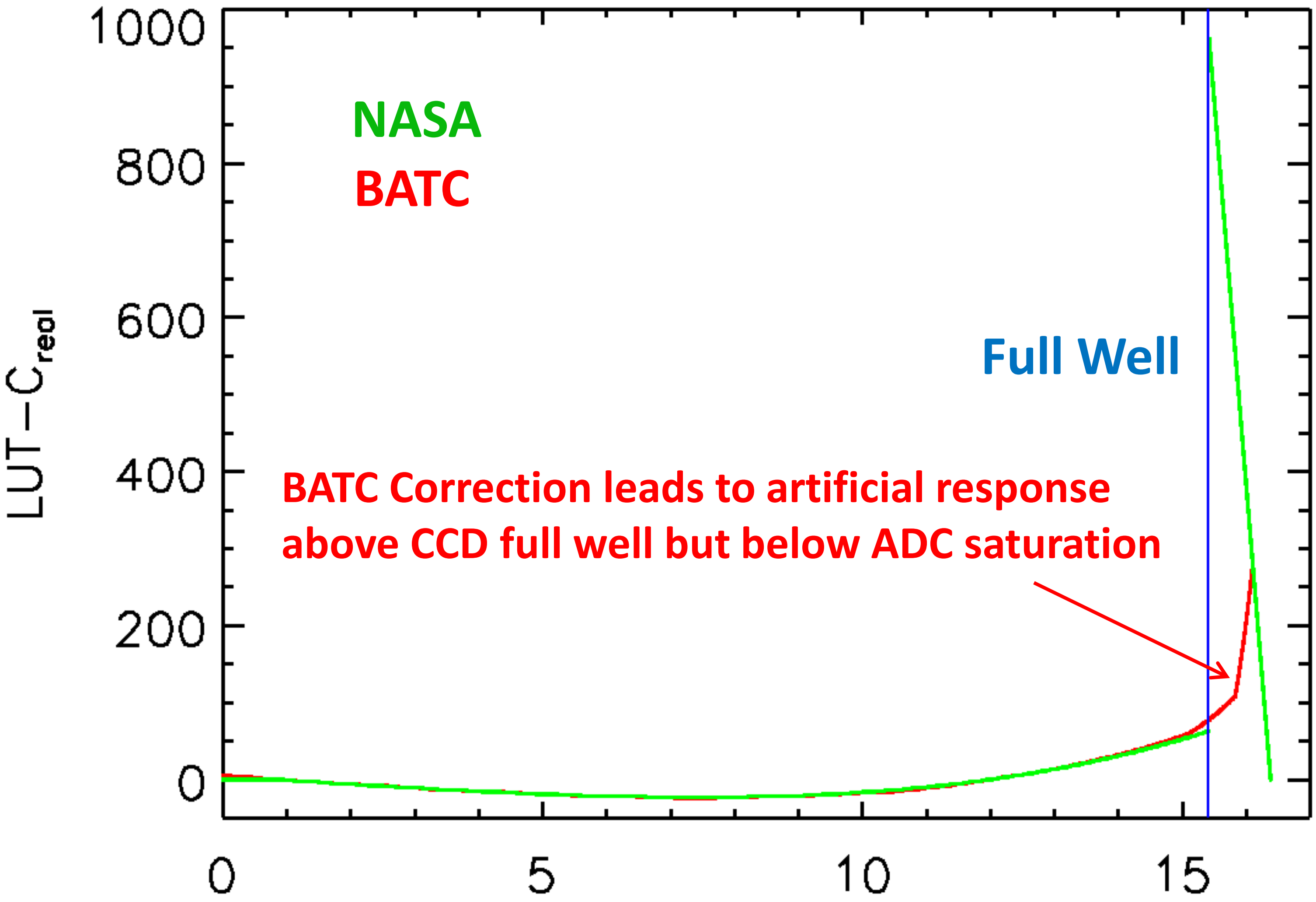
- Averaging pixels at each IT time step before converting to $C_{ideal}$ masks full well behavior




NASA LP Sensor LED Response



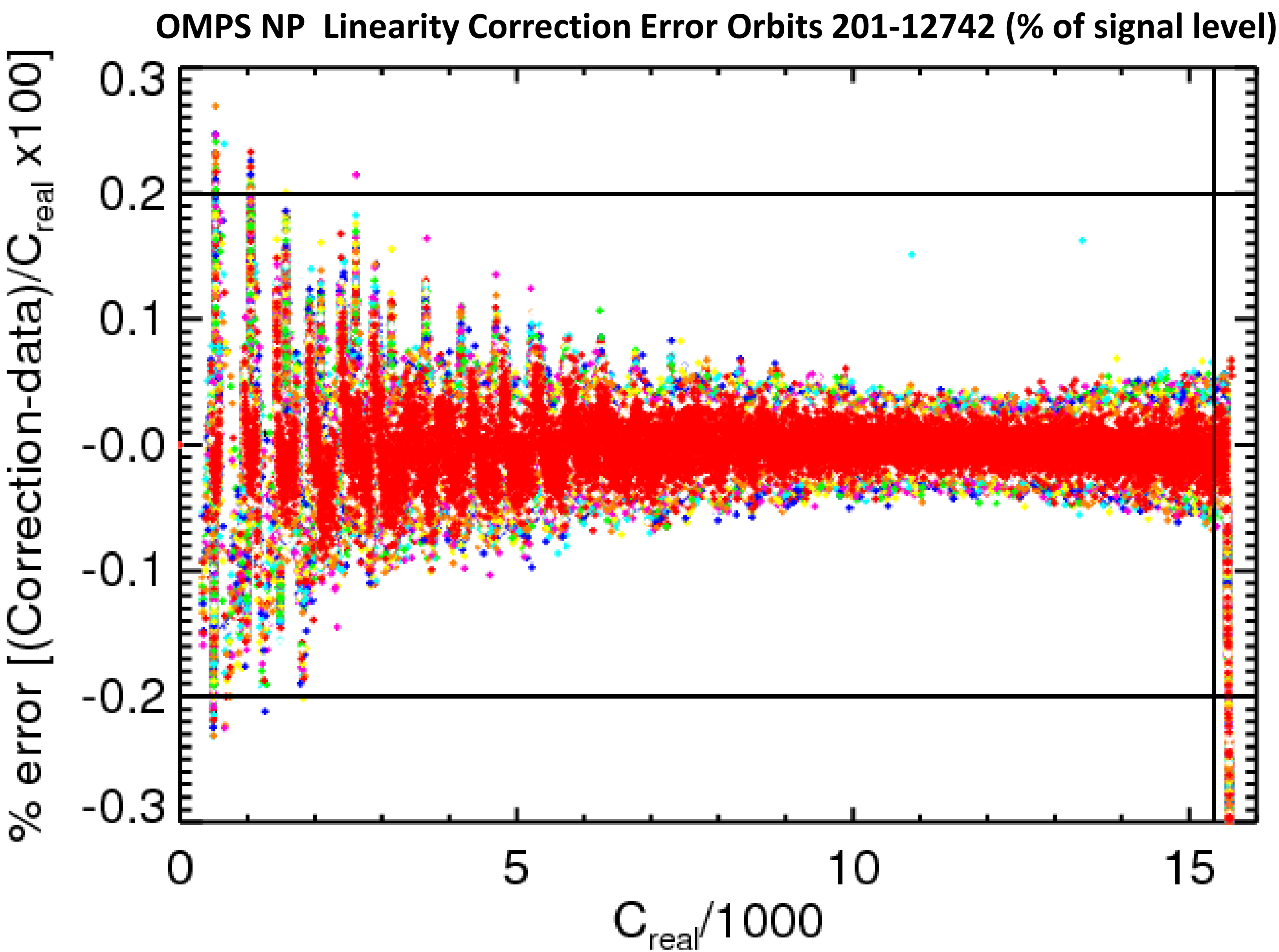
# NASA and BATC LP Sensor Right Side Linearity Correction



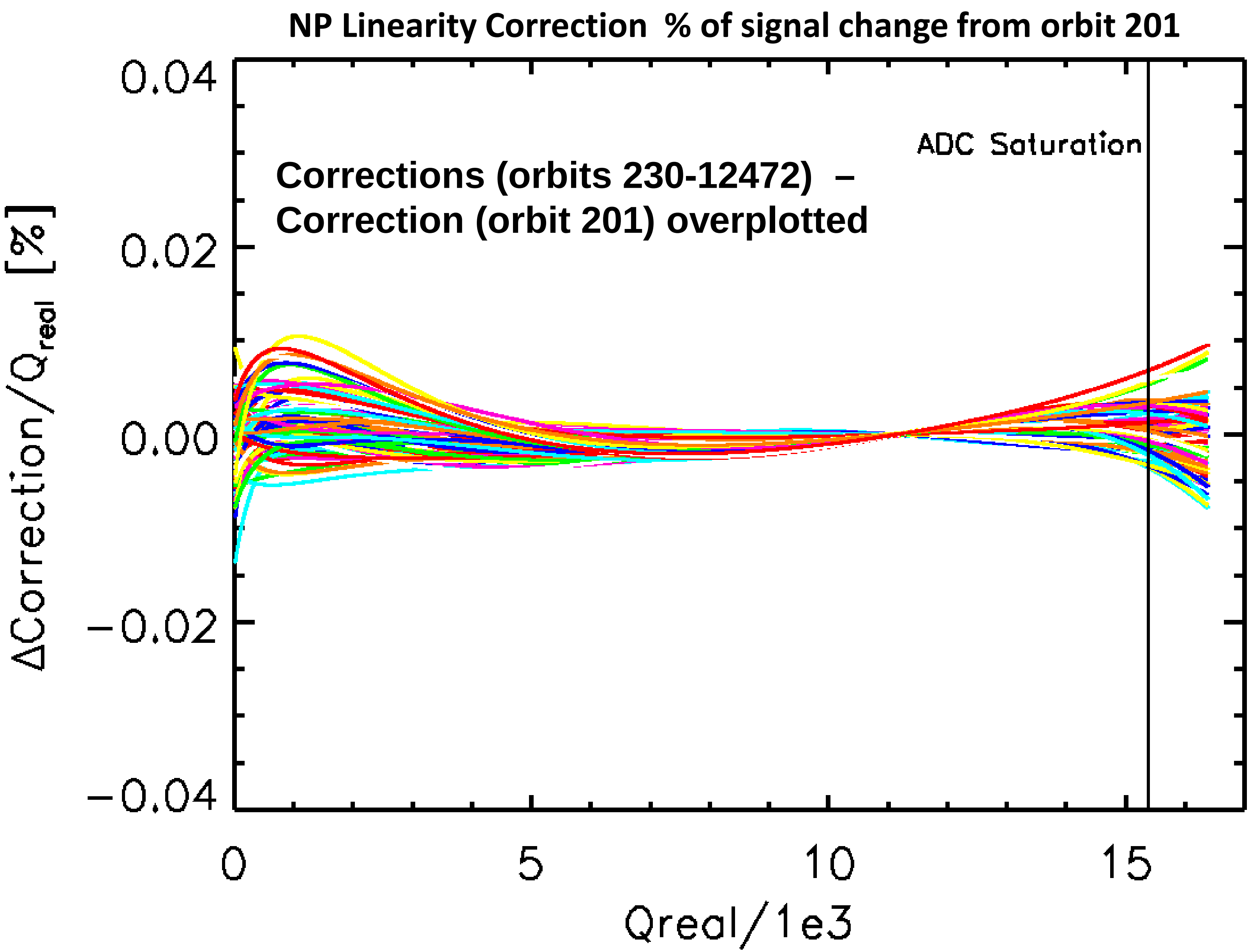

**NASA sets LUT = ADC saturation for input > full well**

**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$^{o}$, 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:**

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

## 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.**