Toward an understanding of deferred signal as *instrument signature*: reconciling the available, contradictory sensor characterization data

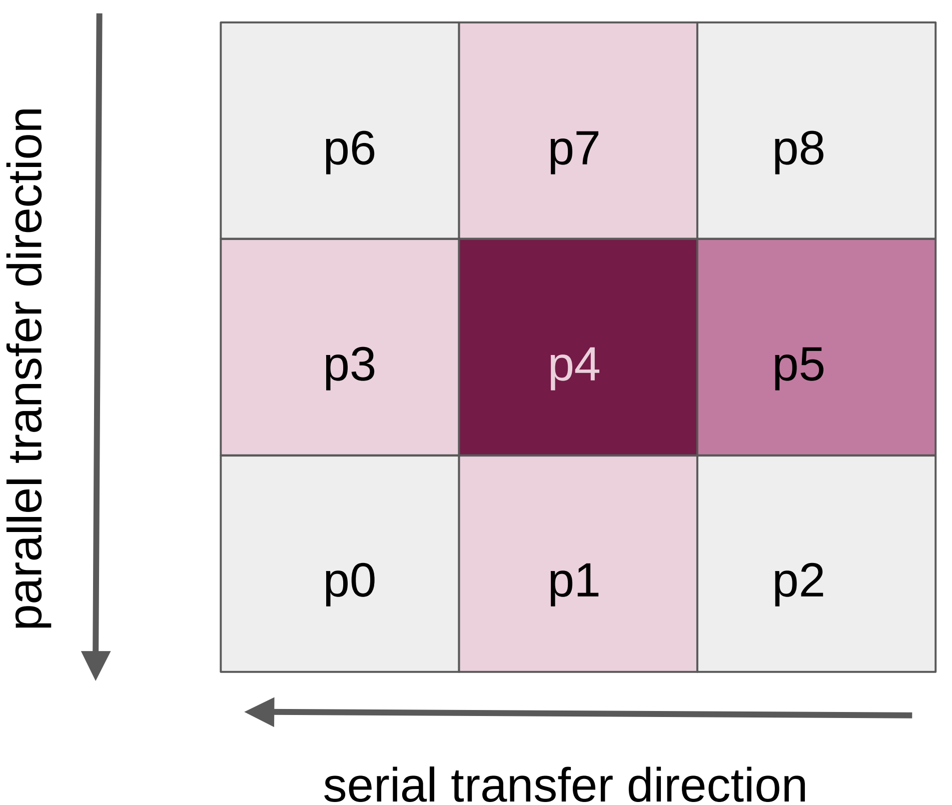
PACCD-2016 – 161202 – Andy Rasmussen

SLAC, LSST Camera

A multi-pronged attempt to reconcile some previously identified puzzles noticed in the Corr_{10} statistic arranged by flat field signal

Some background

- There are regular, amplifier dependent instances of deferred signal (perhaps charge) – displaced into the subsequent pixel directly following a major charge packet conversion → ^{55}*Fe X-ray shape analysis*.



- 3x3 pixel sub-image centered on X-ray event.
  - p4 is centroid
  - p0268 are corners
  - p17 are parallel neighbors
  - p35 are serial neighbors
  - (p5 sometimes referred to as “right neighbor”
- A major fraction of X-ray induced charge cloud (1610e-) is normally collected in the 3x3 sub-image, but rarely is most charge found in central pixel (p4).

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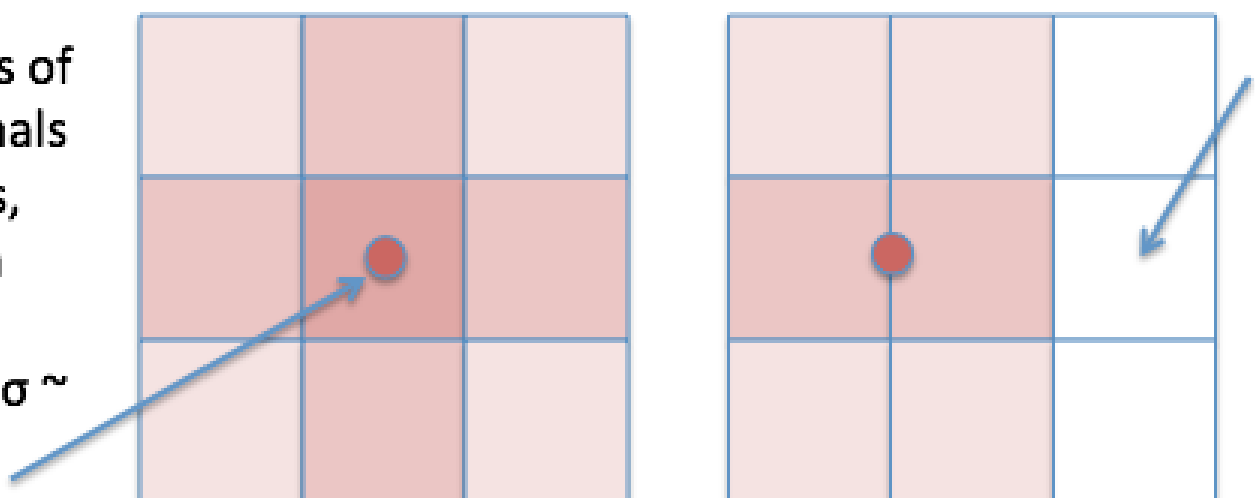
Cartoon examples of 3x3 recorded signals due to ^{55}Fe X-rays, each containing a total of ~1600 conversions, and σ ~ 4μm.



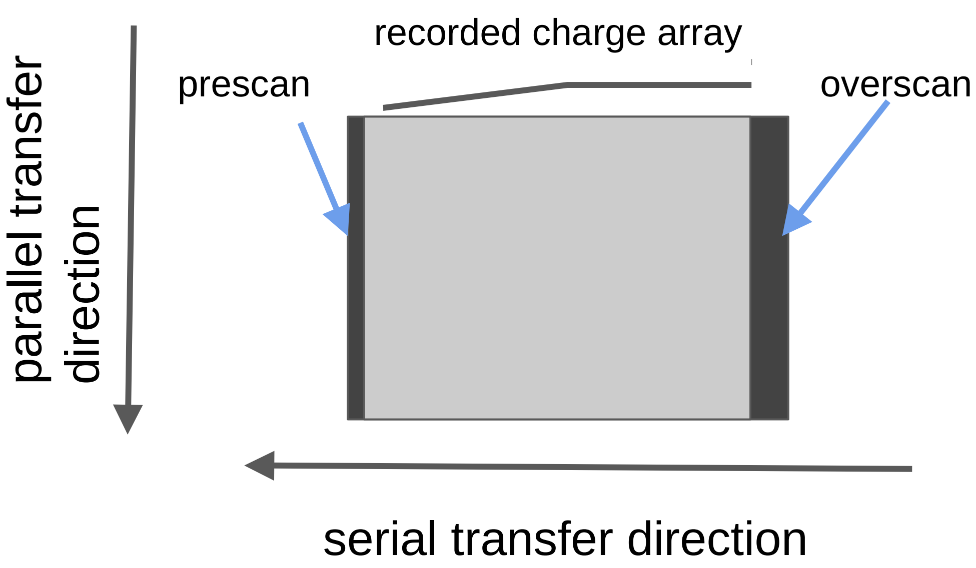
Event centroid

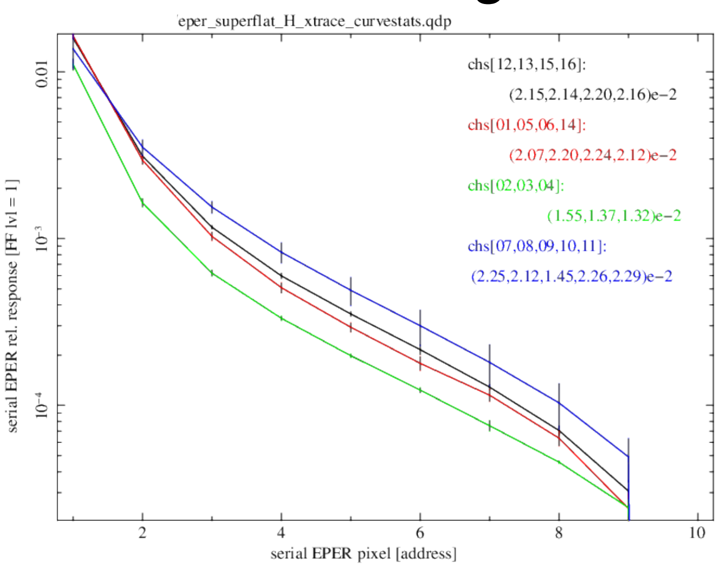
Neighboring pixel pulse heights should have a peak near the bias level

neighbor signal distributions turn out to be useful in quantifying any asymmetry in the average X-ray footprint unlikely to be present in the ***collected*** distribution, or unlikely to be detected in ***individual event fitting***.

Some background (2)

- Deferred signal was found to be connected to instances where serial EPER (relative) signal appeared to be inversely proportional to signal level → *EPER (1st oscan pix or integrated) vs. signal level*.
- Similar instances were also observed in prototype sensor sets, so the phenomenon appears to have survived any redesign attempts. We are faced with correcting, compensating, or otherwise mitigating this artifact as an *instrument signature*.





(EPER structure for 16 amplifiers, “high” signal superflat)

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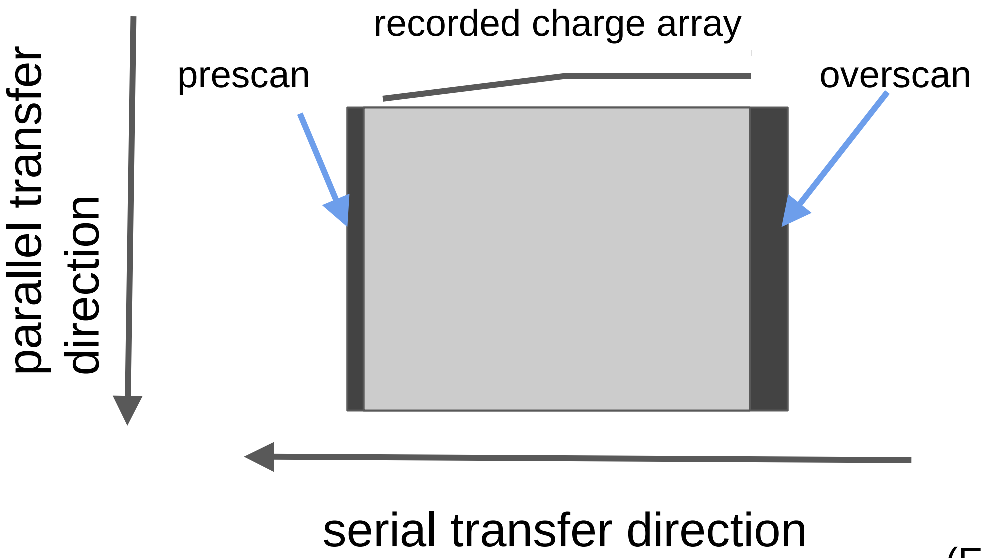
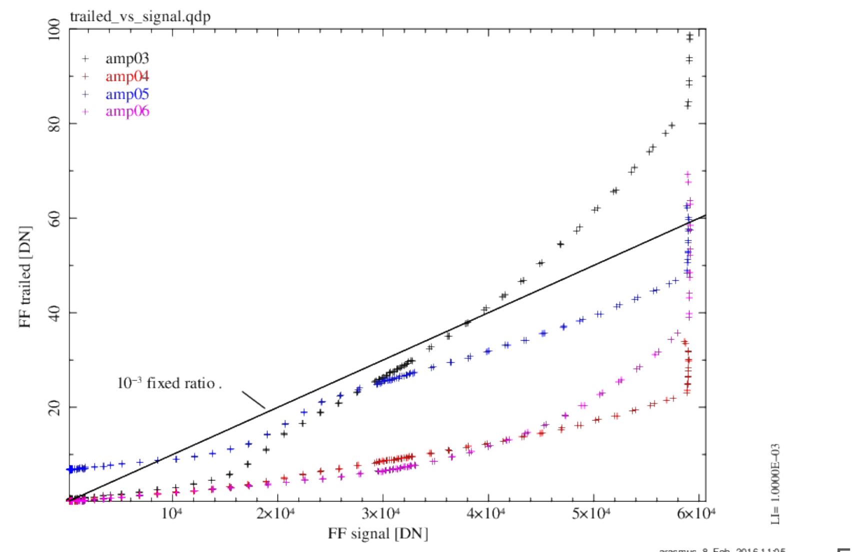
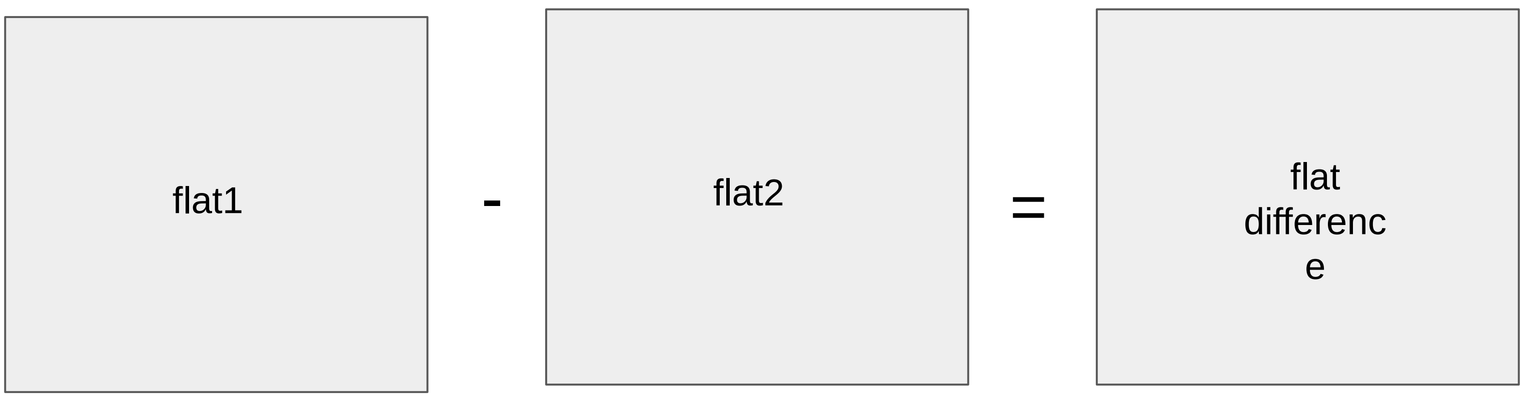


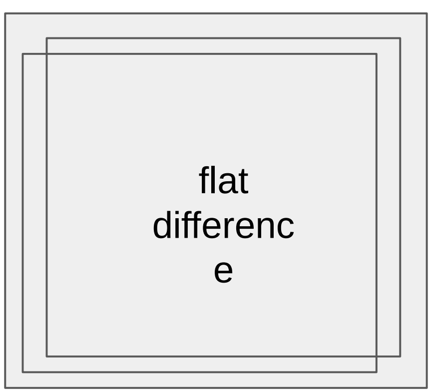


(EPER signal amplitude vs. FF signal level, for 4 channels)

Some background (3)

- Flat field correlations may be used to probe the interior of the imaging array using flat field exposures only - inaccessible to EPER for example.





- extract sub-images from the flat difference, separated by lag (Δser,Δpar)=(i,j).
- multiply sub-images.
- mean of product (minus product of sub-image means) yields Covariance(i,,j)
- Correlation(i,j) = Covariance(i,j)/Covariance(0,0)
- Incidentally, Correlation(i,j) wrt signal level is directly related to pixel boundary shift driven pixel area variations, AKA *brighter-fatter* mechanism.

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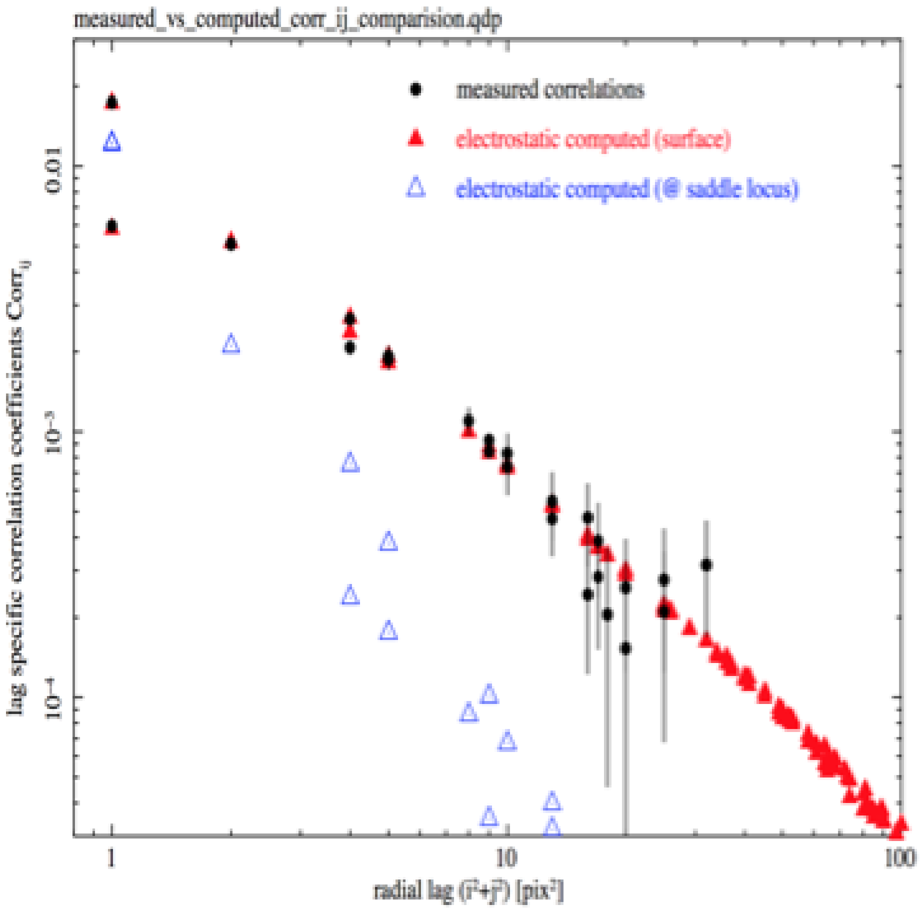

4-parameter fit to correlation values using area distortion correspondence

The best fit parameters that provide the comparison to the left, including all other dependencies (inputs & gain assumptions)

Table 1. Parameter list for the best-fit electrostatic drift model (for cold carriers)

parameter	value	units	comments
* N_a	1.11×10^{12}	cm^{-3}	acceptor density in depleted Si
t_{Si}	100	μm	sensor thickness (fixed)
BSS	-78	Volts	backside bias (fixed)[a]
* ξ_{cs}	12.407	ξ_0[b]	channel stop 2-D dipole moment
* ξ_{ck}	2.6425	ξ_0[b]	clock barrier 2-D dipole moment
* $\bar{p}$	0.0057208	p_0[c]	aggressor dipole moment[d]
μ	65230	e^-	mean signal level in flat
ζ^2	58429	$(e^-)^2$	variance in flat[d]

[a] constrained by measured X-ray diffusion variation with BSS on a similar device

[b] $\xi_0 \equiv 10^{-6}\,q_e$

[c] $p_0 \equiv 10^5\,\mu m\,q_e$

[d] exposure averaged, *rms* aggressor moment is $\bar{p} \equiv z_{chan}\,\zeta\,q_e$

$$z_{chan} = \bar{p}/(\zeta q_e) \approx 2.37 \mu m.$$

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- Flat field correlations may be used to probe the interior of the imaging array using flat field exposures only - inaccessible to EPER for example.

During a fruitful exchange of data & ideas with Augustin G., his correlation fit results file contained the following note:

```
i
j
mean
coeff
scoeff
offset : Il y a un residu de correlation a 0
khi2/ndf
variance@mu
ampli
bss
cv
#end
```

There's apparently more information in flat field correlations than lag specific pixel area distortion sensitivities..

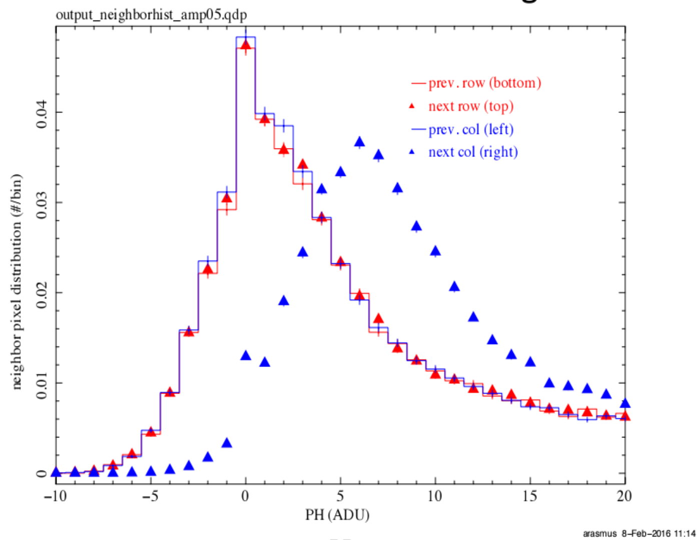
Some background (3)

- More recent work on flat field pixel statistics revealed some unexpected behavior specifically in the ij=10 lag correlation
  →*Flat field pairs vs. signal level.*
- Combining the 3 independent (maybe related) observables physically constrain the mechanism that impacts the data, so that instrument signature removal will be appropriate?

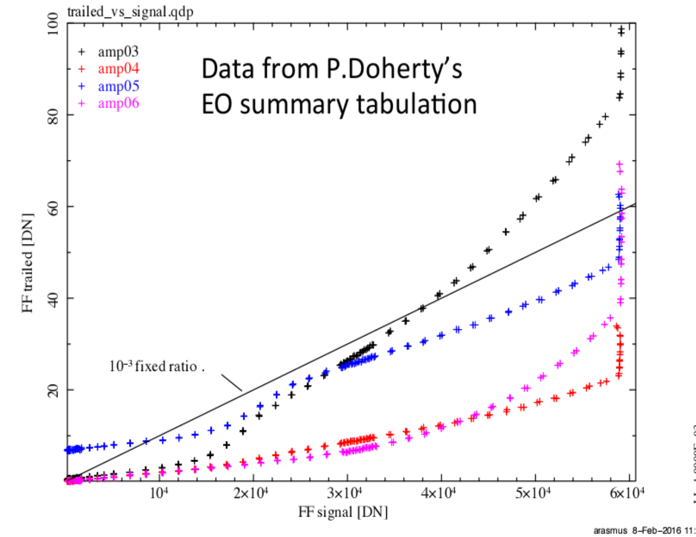
^{55}Fe X-ray neighbors & EPER vs. signal

- Feb & Mar '16
- Histograms show ~7DN *positive bias* in X-ray's right neighbor pixel value, *insensitive to position, and to central pixel value*.
- P.Doherty's absolute serial EPER signal vs. flat field signal shows arbitrarily large CTI at low signal.

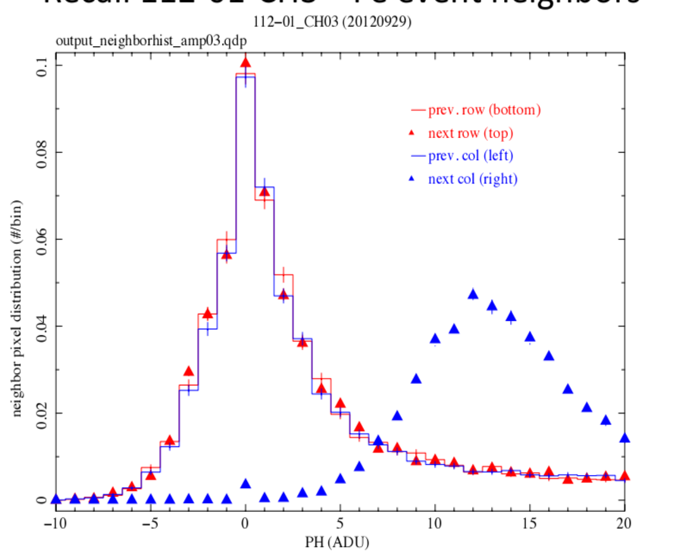
CH5 ^{55}Fe event neighbors



EPER "trailed charge" vs. FF level



Recall 112-01-CH3 ^{55}Fe event neighbors



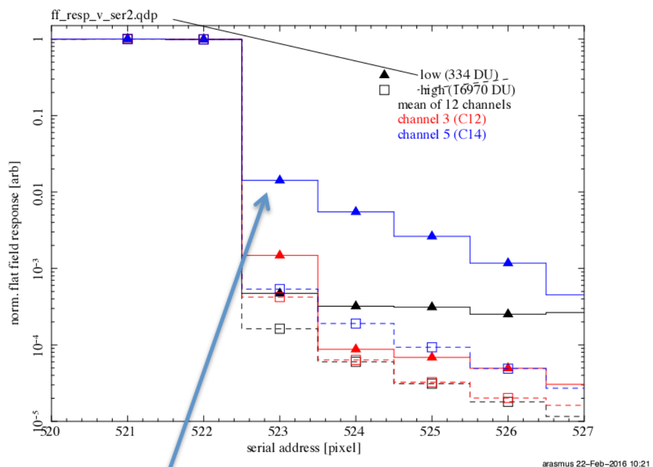
- Apparent bias (~7DN) in signal delivered immediately following major X-ray signal
- Neighbor pixel bias is consistent with low flux level trailed signal in EPER
- Similar properties seen in at least one other prototype device, 112-01.
- If CTI, position- and signal-dependence would be evident

Divergent EPER @ low signal & missing signal in first column of every row

- Signal deferred and released as serial (relative) EPER signal is large when flat field signal is low (*cf.* Last slide).
- Comparable signal level is **missing** from the expected pixel level *for each row*.
- This mechanism seems to vanish (perhaps too difficult to measure) as signal level increases.

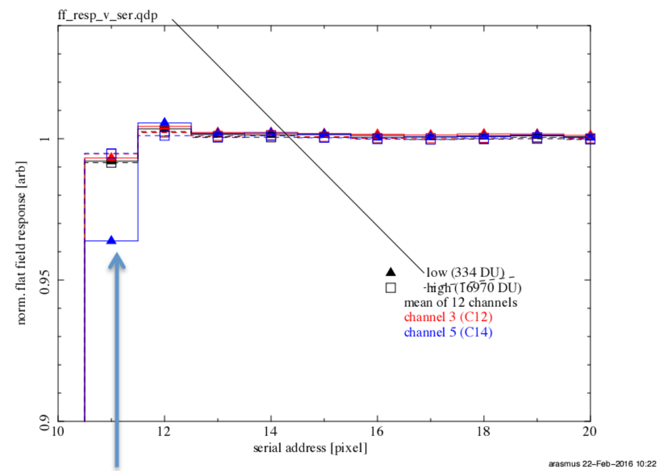
EPER release time profile & apparently related "leading charge loss" in first columns of each row

Last columns & EPER deferred charge release profile (log scale)



Integrated charge release 2.4% of flat field level p/p, ~1.1 pixel release/de-trapping time constant

Leading columns & "leading charge loss" (linear scale)



Leading signal loss is between 2.5 and 3.0% of flat field level p/p, trapping time appears to be shorter than de-trapping time

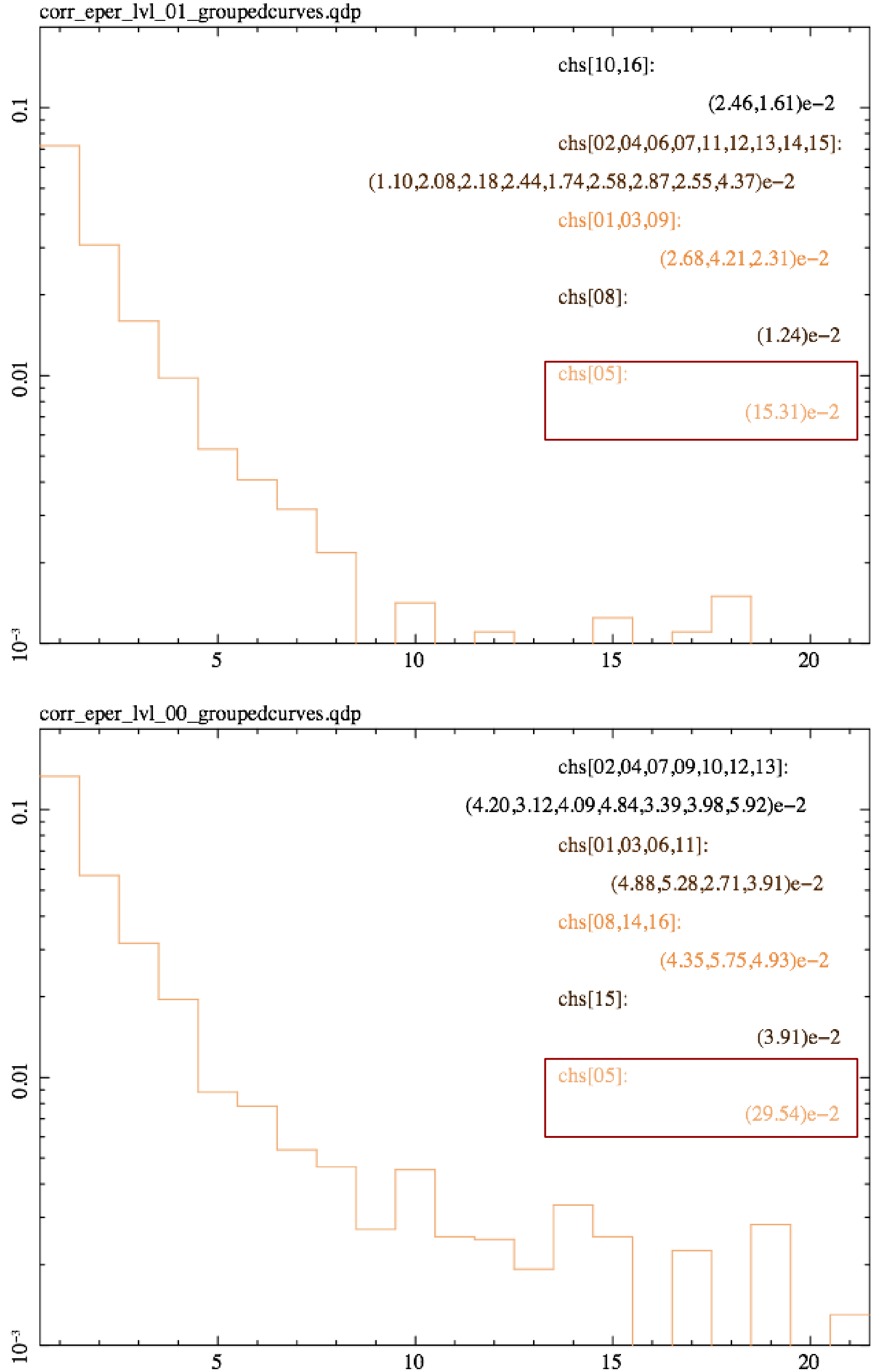
➔ CTI correction of science images should ***NOT*** take toy model CTI estimates directly from EPER signal and number of serial transfers!

➔ This CTI may vanish from instrument signature as soon as sky background provides an adequate ***fat zero (TBC).***

.. and fractional EPER continues to rise as signal level decreases.

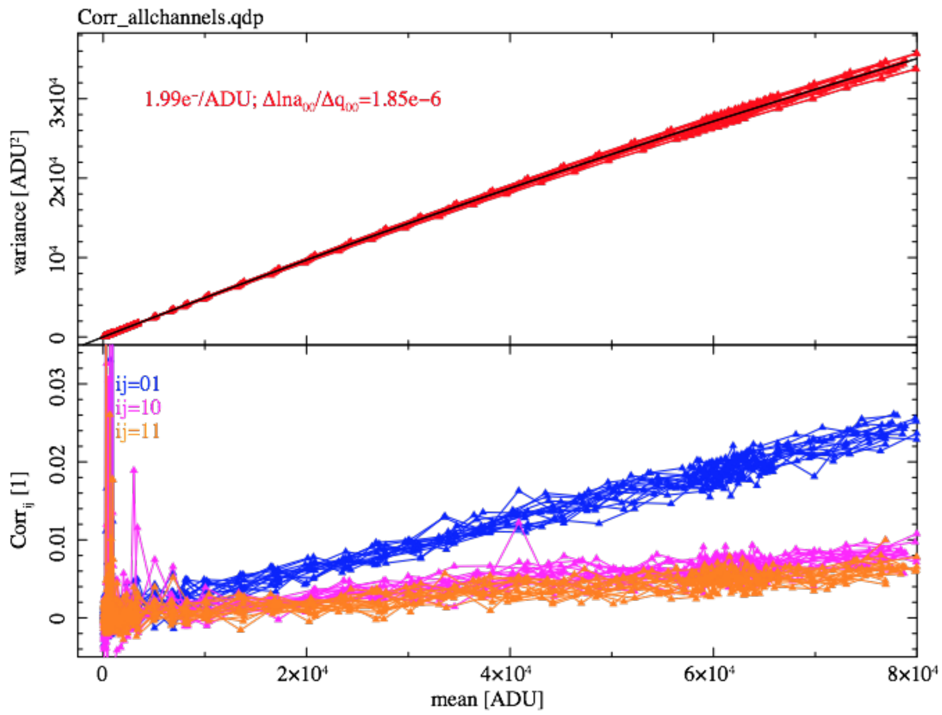
0.15 @ 65 ADU level,
0.295 @ 33 ADU level.. (!)
[gain ~ 2e-/ADU, 20e- trap]

Presumably fractional charge missing from first column also diverges in low signal limit (TBC)

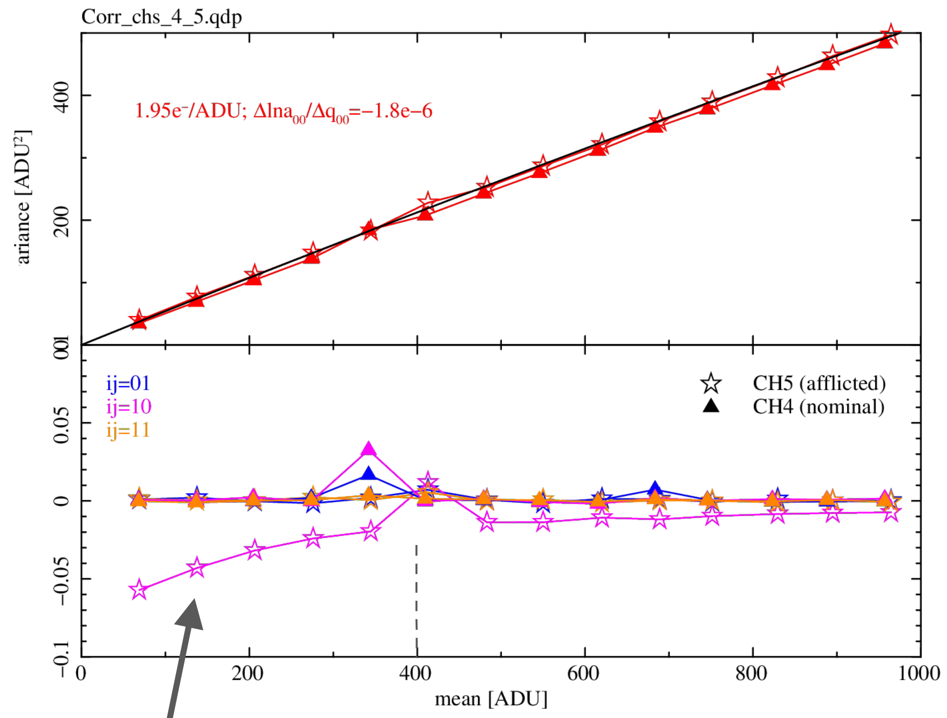


How is this expressed in the FF Correlations?

all 16 channels of this sensor



detail of the afflicted channel and comparison to a nominal channel



(σ ~ trap size near 400e- level)

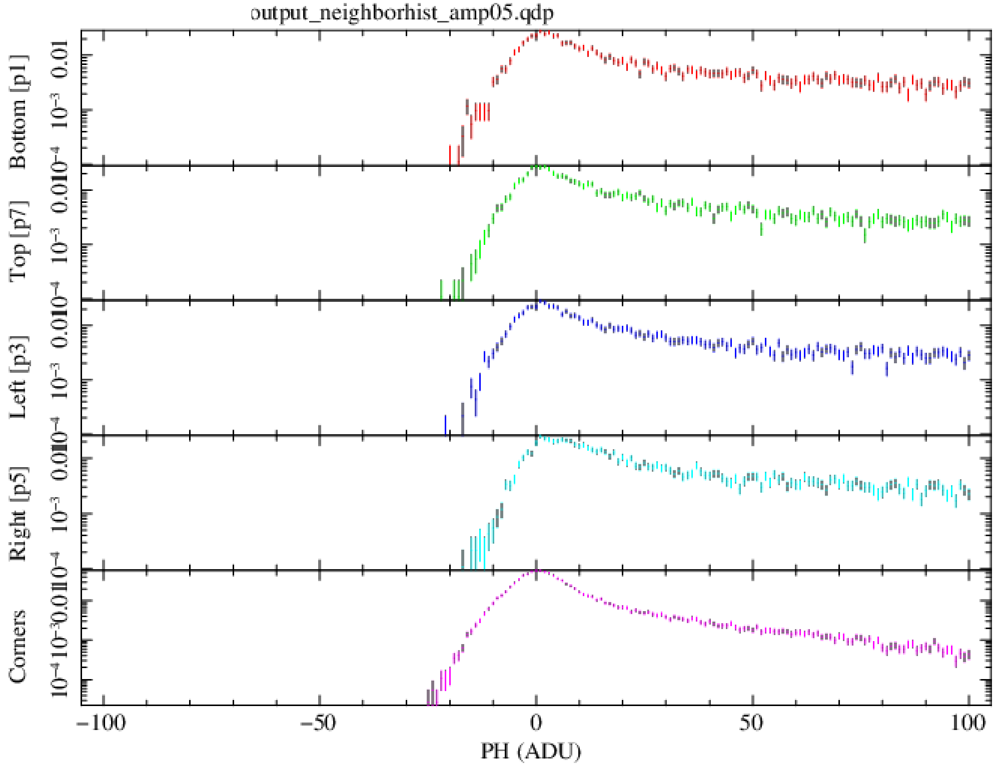
The negative correlations make sense if the likelihood of hi-fidelity transfer depends on traps filled by preceding charge packet
(or if an overzealous capture is reversed in the next pixel)

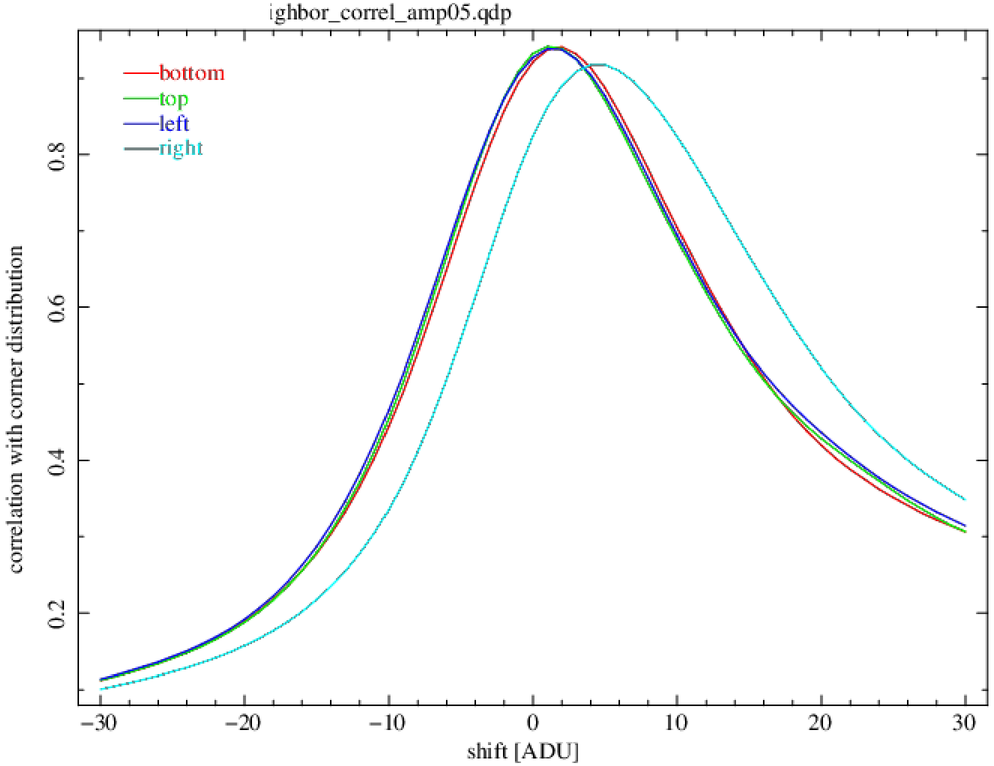
significant, negative correlations seen at low signal level (nominal channel [triangles] has nearly zero correlations for ij=10)

Previous slides were for a specific amplifier that showed interesting behavior.

What about for the devices being routinely churned out now?

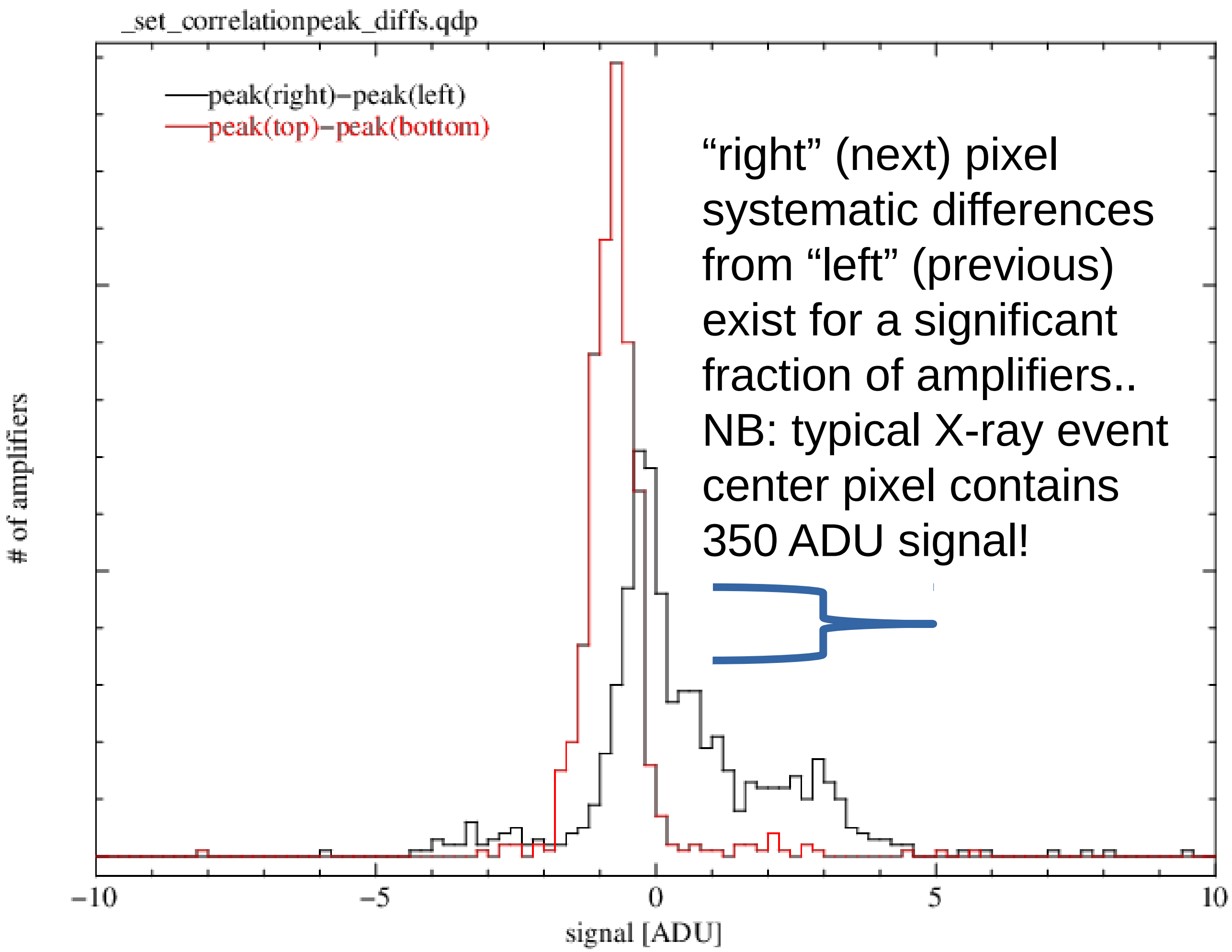
New methods: correlate X-ray neighbor signal distributions with corner pixel signal distributions





measure & record horizontal & vertical neighbor peak ***differences*** to isolate signal anisotropy (see next slide)

To partially decouple signal systematics from charge diffusion issues, retain correlation peak differences

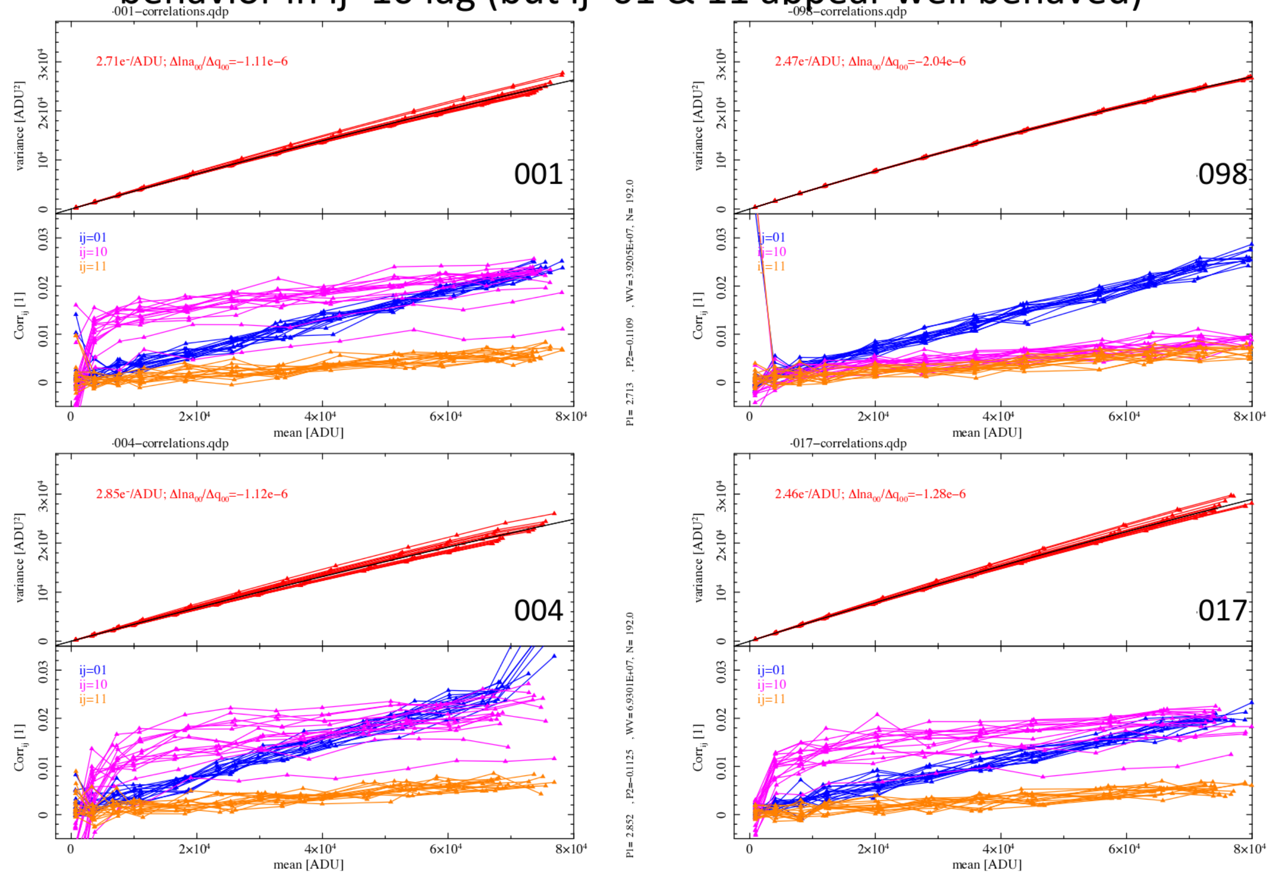


"right" (next) pixel systematic differences from "left" (previous) exist for a significant fraction of amplifiers.. NB: typical X-ray event center pixel contains 350 ADU signal!

we’ve lots of correlation trends to go through, too.

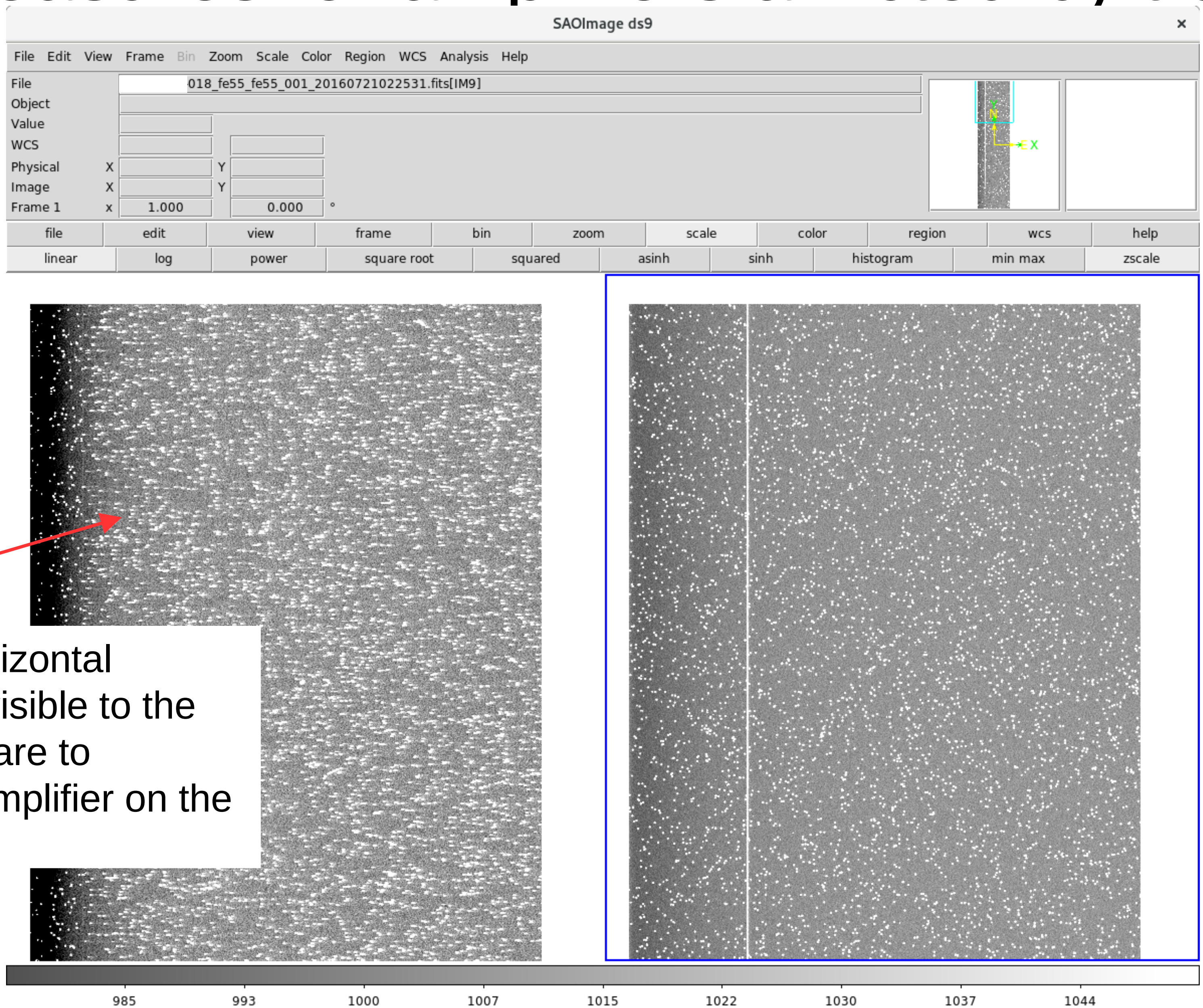
- Corr_{ij} vs. flat field signal sometimes show pecular behavior in the ij=10 lag particularly.
- Because our drift calculator appears to accurately reproduce the slopes of Corr_{ij} vs. signal, and there are no discernable distortions in adjacent lags, we believe the *offsets* and *onset* trends seen here (for ij=10) have to do with video chain signal fidelity and/or CTI.. ***not*** with pixel area distortion induced biases in neighboring pixel expectation values.

covariances drawn from vendor supplied data show puzzling behavior in ij=10 lag (but ij=01 & 11 appear well behaved)



➔ Curves are very amplifier specific.
➔ In some cases (cf. 098) behavior is very good for all 16 chs.
➔ These terms in Corr_{10} offsets can easily dominate over any B/F contribution

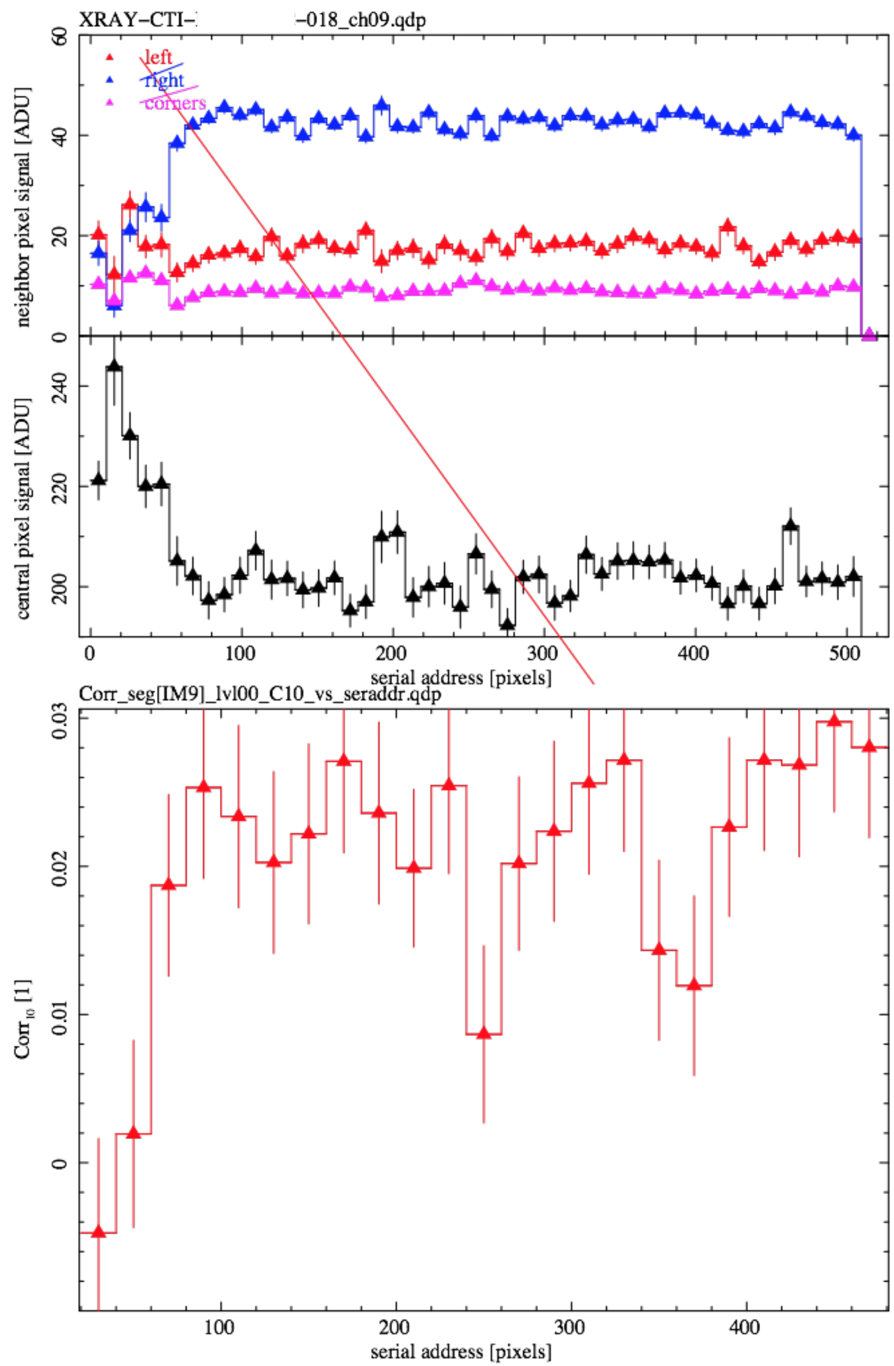
Compare derived $Corr_{ij=10}$ to serial EPER measures for amplifiers afflicted by traps



Severe horizontal smearing visible to the eye (compare to adjacent amplifier on the right)

.. a spatially resolved trap in the serial register

In the case of a significant trap near serial address=60, X-ray artifacts (upper left) are mirrored by structure seen in the lag-shifted difference image product (below, right). Better spatial resolution should be possible with >1 flat pair per signal level.

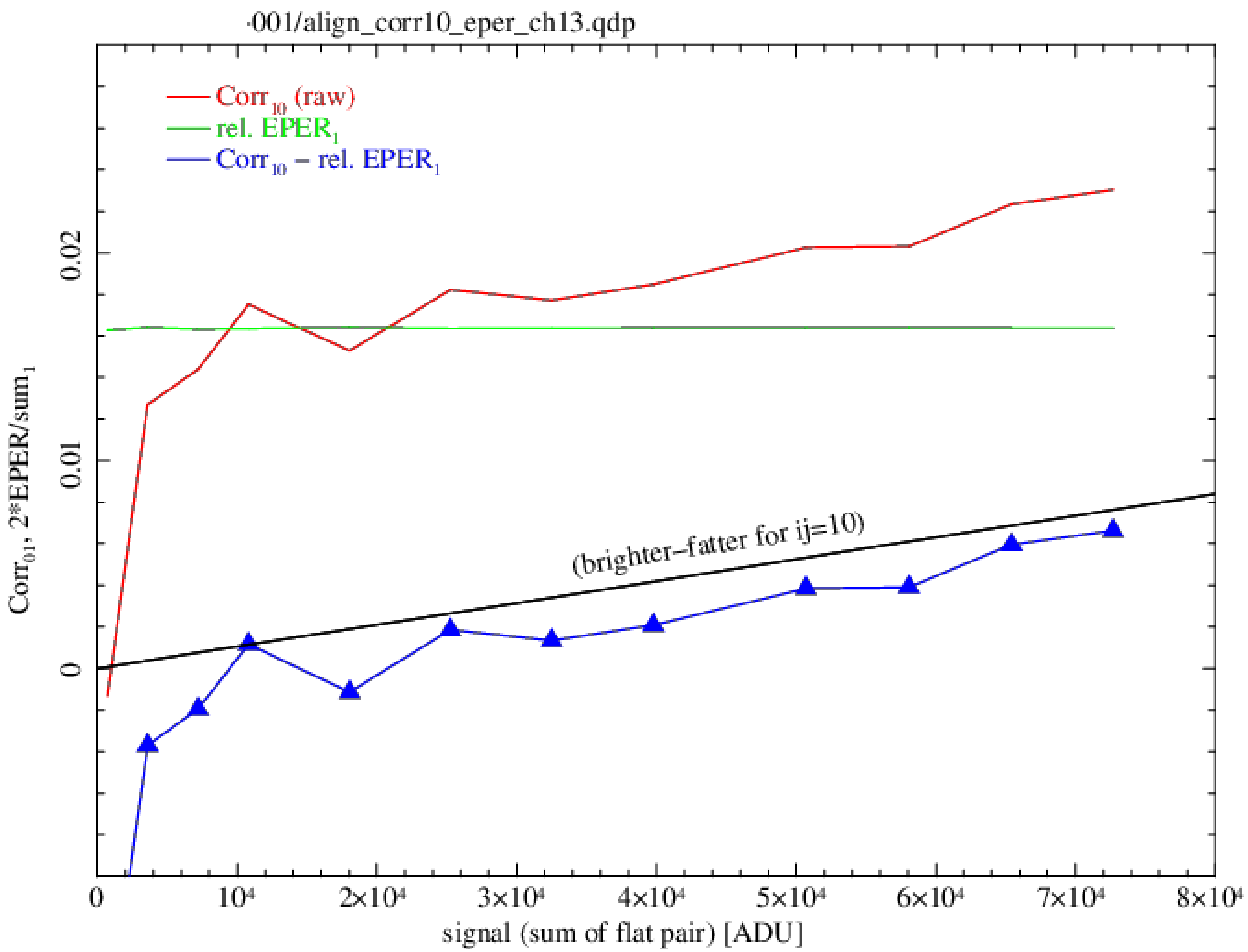


Summary

- We've begun combining complementary observables to help constrain a working model that connects “real” CTI and EPER deferred signal, where ^{55}Fe X-ray charge cloud asymmetries provided badly needed detail as to the nature of the CTI mechanism.
- A proper breakdown of electronic slew limitations at the CDS and true CTI may drop out from careful examination of the EPER time dependence of decay, together with modeling the $EPER_1$ vs. signal in a way that isolates the true brighter-fatter signal from the $Corr_{10}$ statistics.
- Need more flat pairs at low flux!
- Need more flat pairs in general to provide spatial resolution in the correlations
- Need to come up with a direction sensitive correlation calculation or data object that can distinguish isotropic effects from settling effects (as ^{55}Fe neighbors already provide)

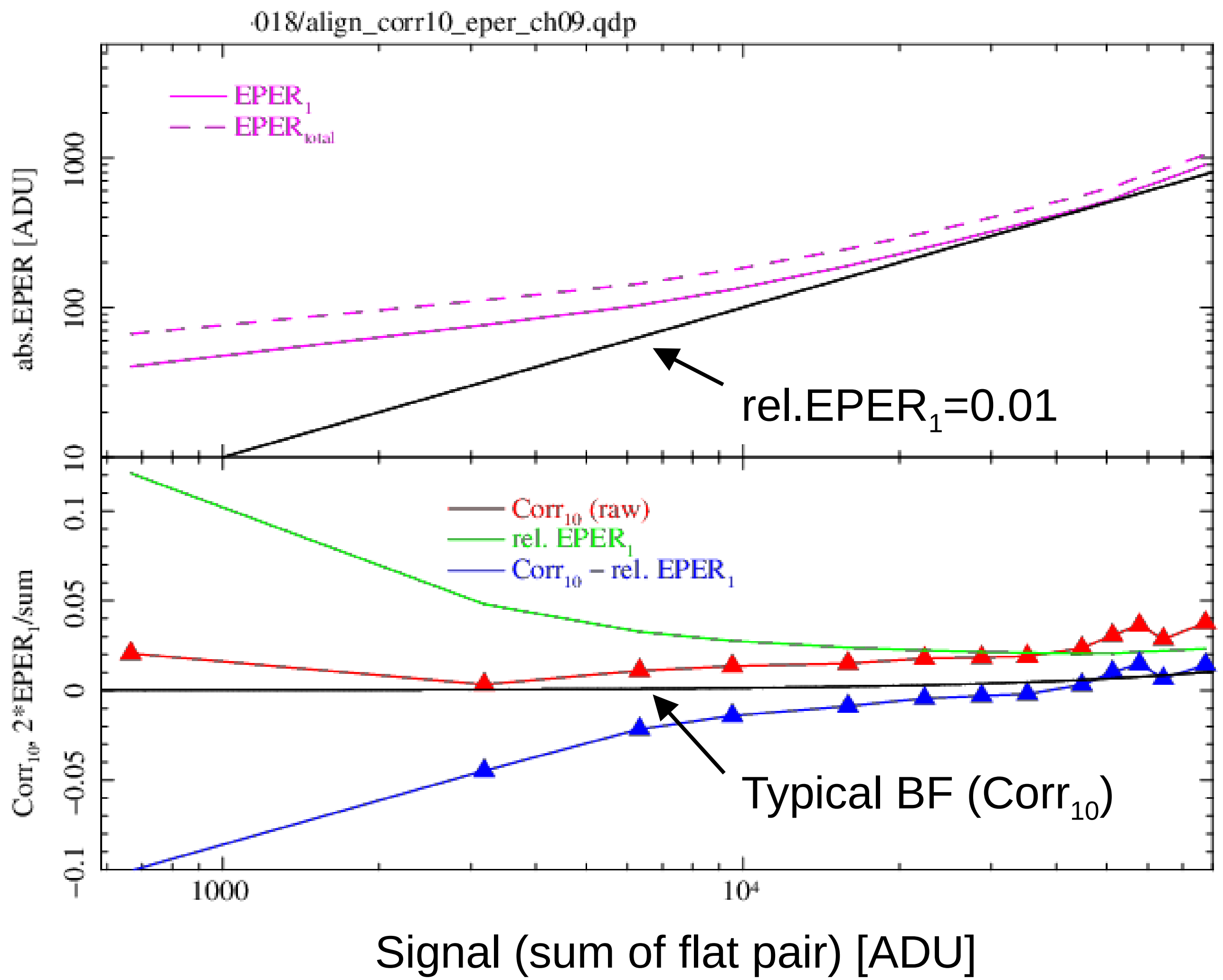
Compare derived $Corr_{ij=10}$ to serial EPER measures for relatively "healthy" amplifiers

"correcting" the $Corr_{10}$ by subtracting off the single pixel EPER value appears to overcorrect the correlation to so that it no longer appears to scale linearly with signal. This may be due to presence of real traps (in addition to electronic systematics) that contribute to the EPER signal – which may not be in affect the image at until carriers in the channel undergo depopulation (e.g., overscan).



Compare derived $Corr_{ij=10}$ to serial EPER measures for amplifiers afflicted by traps (2)

The much larger trap (150e$^-$?) located in the serial register of this amplifier causes a similar ***overcorrection*** when I naively correct $Corr_{10}$ using the measured $EPER_1$. I believe this is an indication that the peculiar shapes to $Corr_{10}$(signal) shown above, may be due primarily to electronic slew limitations at the CDS. A corollary to this would be that a significant fraction of the measured $EPER_1$ may not be related to CTI at all, in some amplifiers.



New methods: categorize shape of EPER release curve into one of several self-similar families