Investigation of Deferred Charge Effects in LSST CCD Sensors

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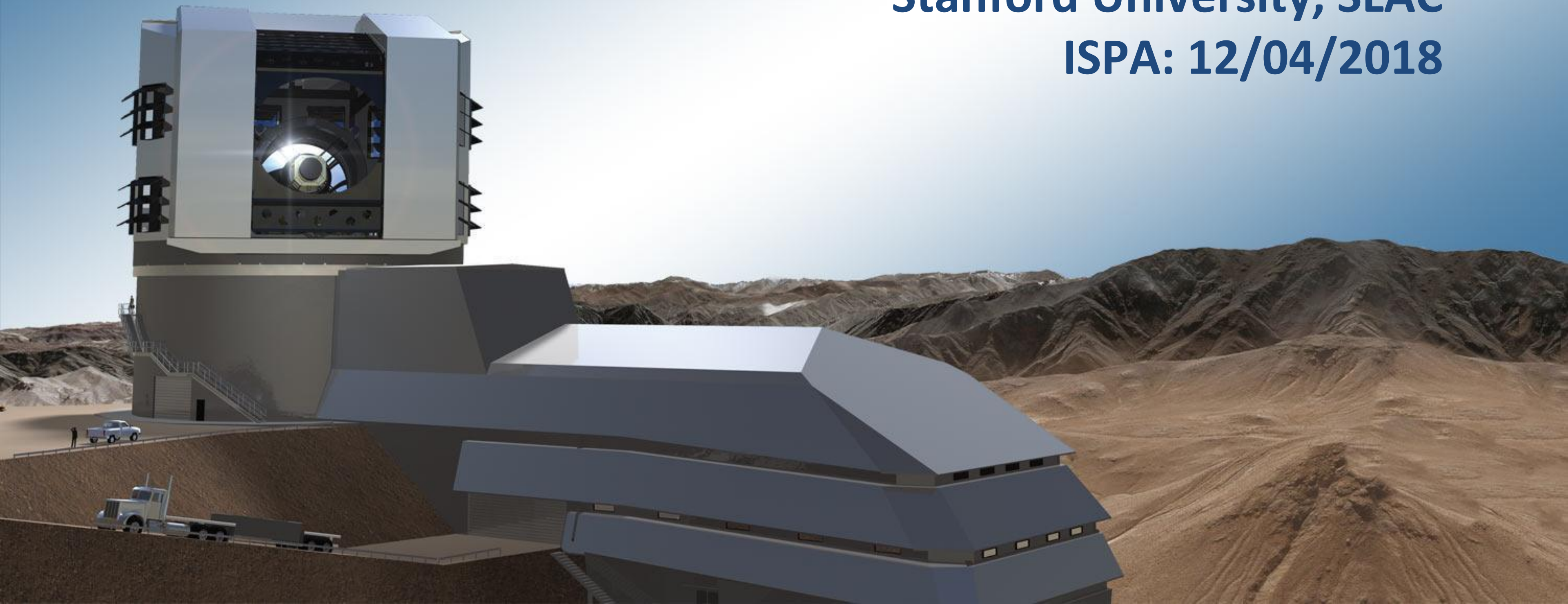
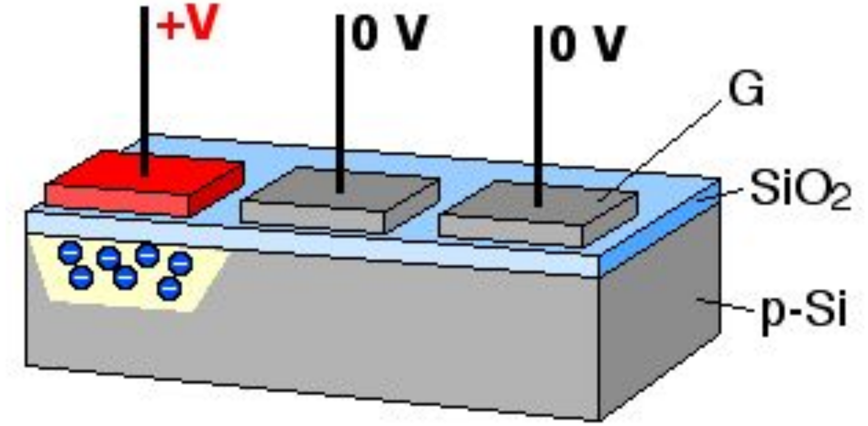


CCD Charge Transfer



Credit: Michael Schmind

Each pixel-to-pixel transfer of charge is driven by:

- Self-induced drift/electrostatic repulsion at high signal
- Fringing fields at low signal
- Thermal diffusion in intermediate cases

Dependent on CCD temperature, clock timing and clock voltages.

Sources of Deferred Charge

Effects dependent on number of transfers:

- Transfer due to self-induced drift, fringing fields, and diffusion
- Uniformly distributed single electron traps
  - Bulk traps
  - Radiation-induced traps

Effects independent on number of transfers:

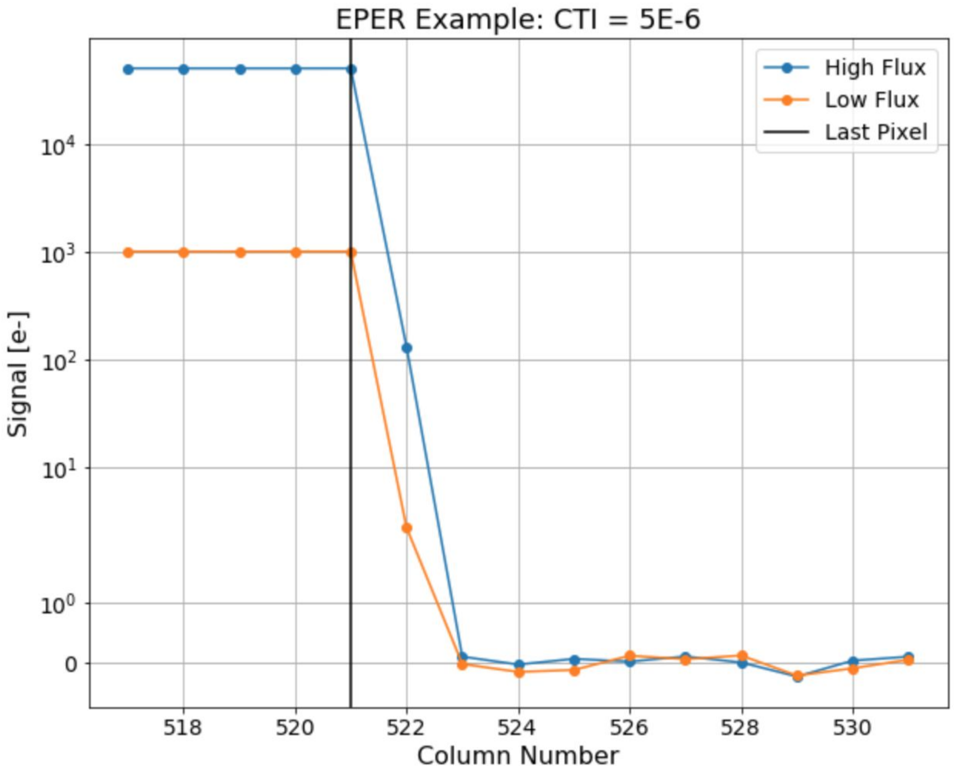
- Design traps - fixed charge loss of up to O(100) e-
- Process traps - fixed charge loss of O(10) e-
- Electronic effects
  - Drifting bias offset
  - Incomplete reset of the sense node

Deferred Charge Measurement

Large Synoptic Survey Telescope

Charge Transfer Inefficiency (CTI) - ratio of electrons not transferred between two pixels, to the total electrons before the transfer.

Extended Pixel Edge Response (EPER) - measurement of deferred charge in the overscan pixel region, after a flat field image.



$$\mathrm{CTI} = \frac{S_{\mathrm{overscan}}}{N_T S_{\mathrm{lastpixel}}}$$

ITL Serial Deferred Charge

LSST Sensor Testing

LSST Serial CTI Specification: < 5E-6

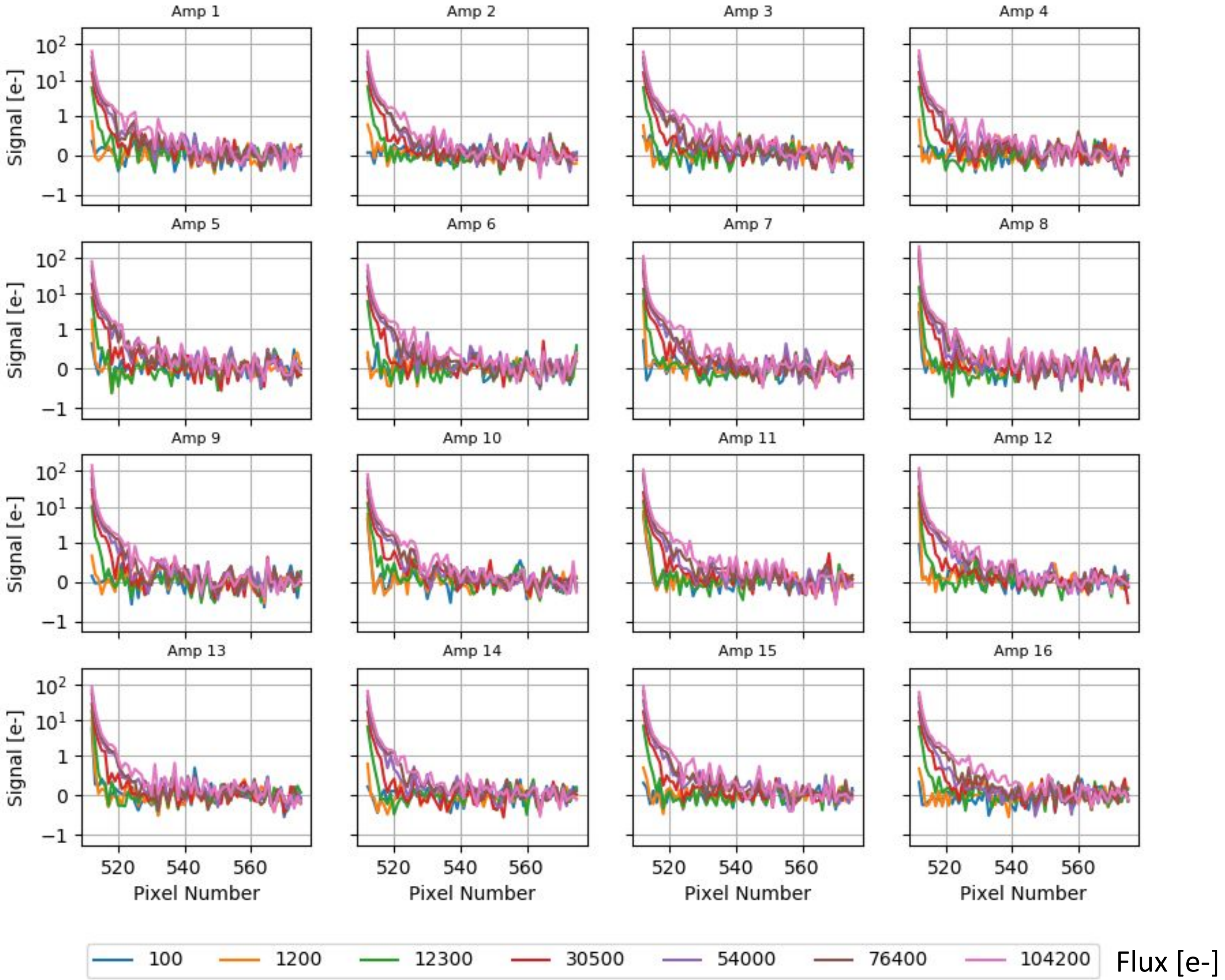
- Measured with EPER at 50,000 e- and 1,000 e-
- Additional analysis using Fe55 X-ray events
- Data from testing of assembled rafts

Serial Deferred Charge Results:

- Majority of channels meet LSST specifications, but…
    - Deferred charge seen in overscans at high flux
    - Deferred charge seen in Fe55 hits at low flux

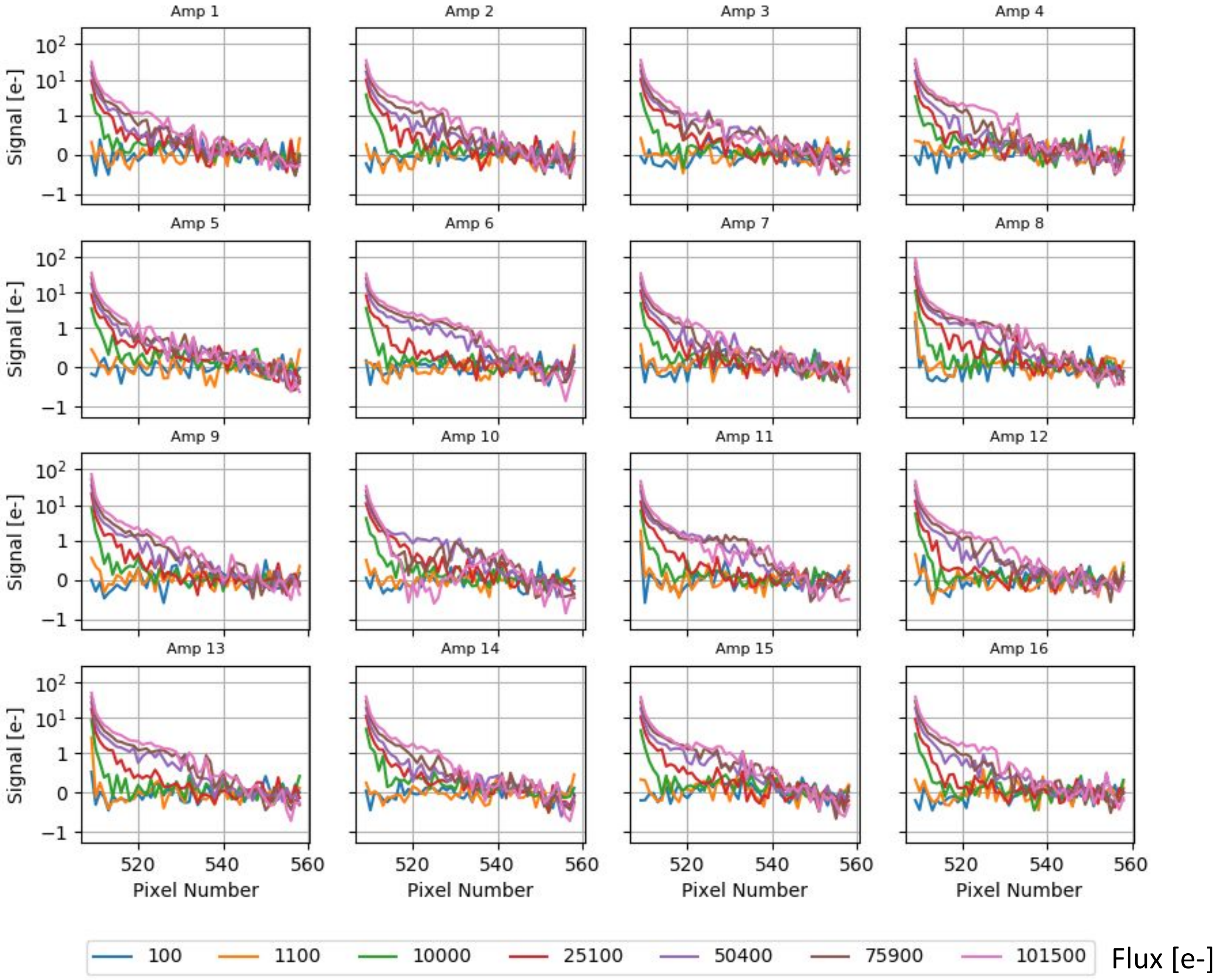
The following results are from one typical ITL production sensor.

High Flux Deferred Charge



Overscan traces at different fluxes show deferred charge signal at high flux.

High Flux Deferred Charge



Similar effect seen more strongly in vendor data.

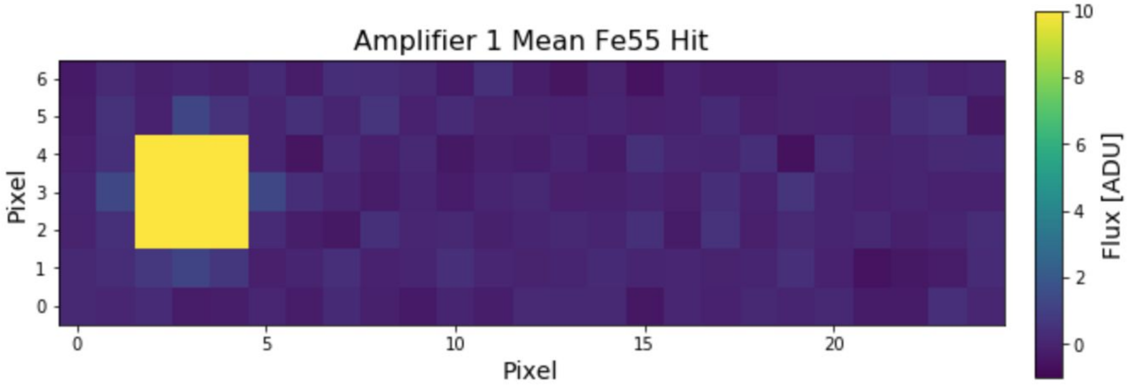
Low Flux Deferred Charge

Analysis of Fe55 hits:

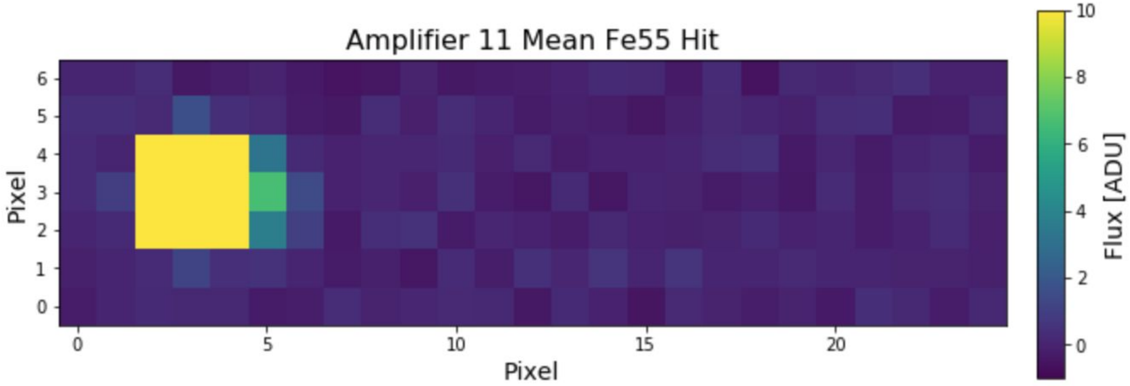
- Take many Fe55 acquisitions (w/ or w/out “sky” background)
- Aggregate identified Fe55 hits using a median stack

No sky background:

Nominal:



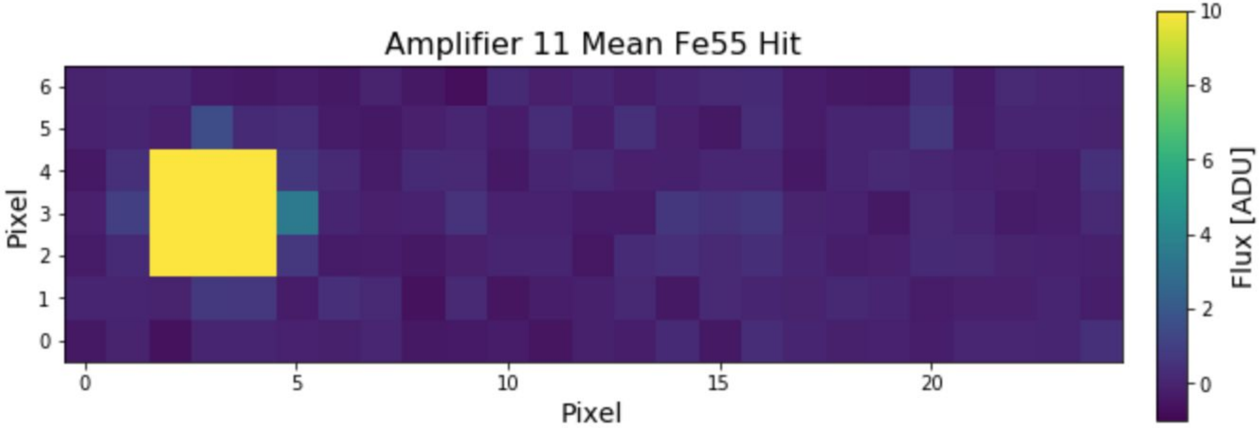
Affected:



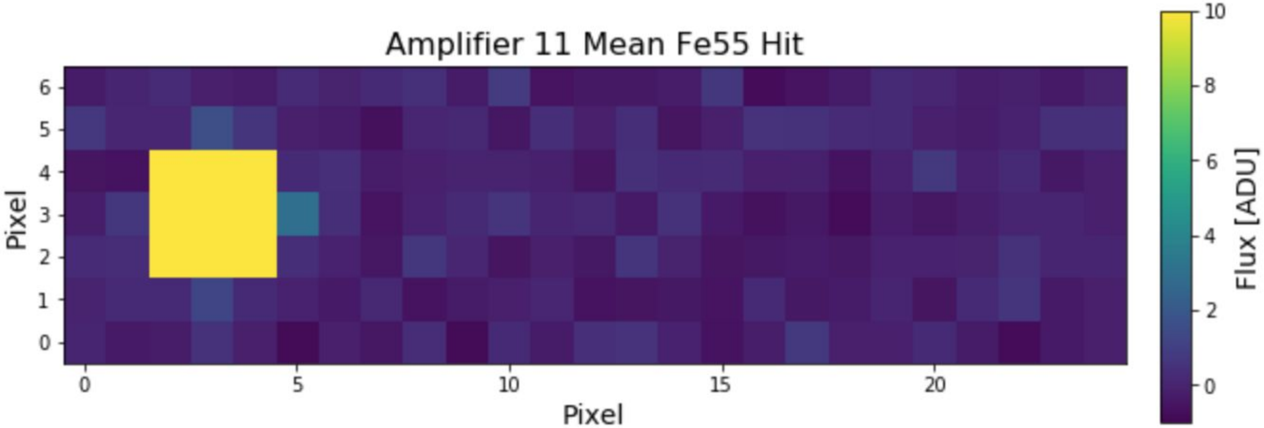
Low Flux Deferred Charge

Effect is lessened with increasing “sky” background, but still present.

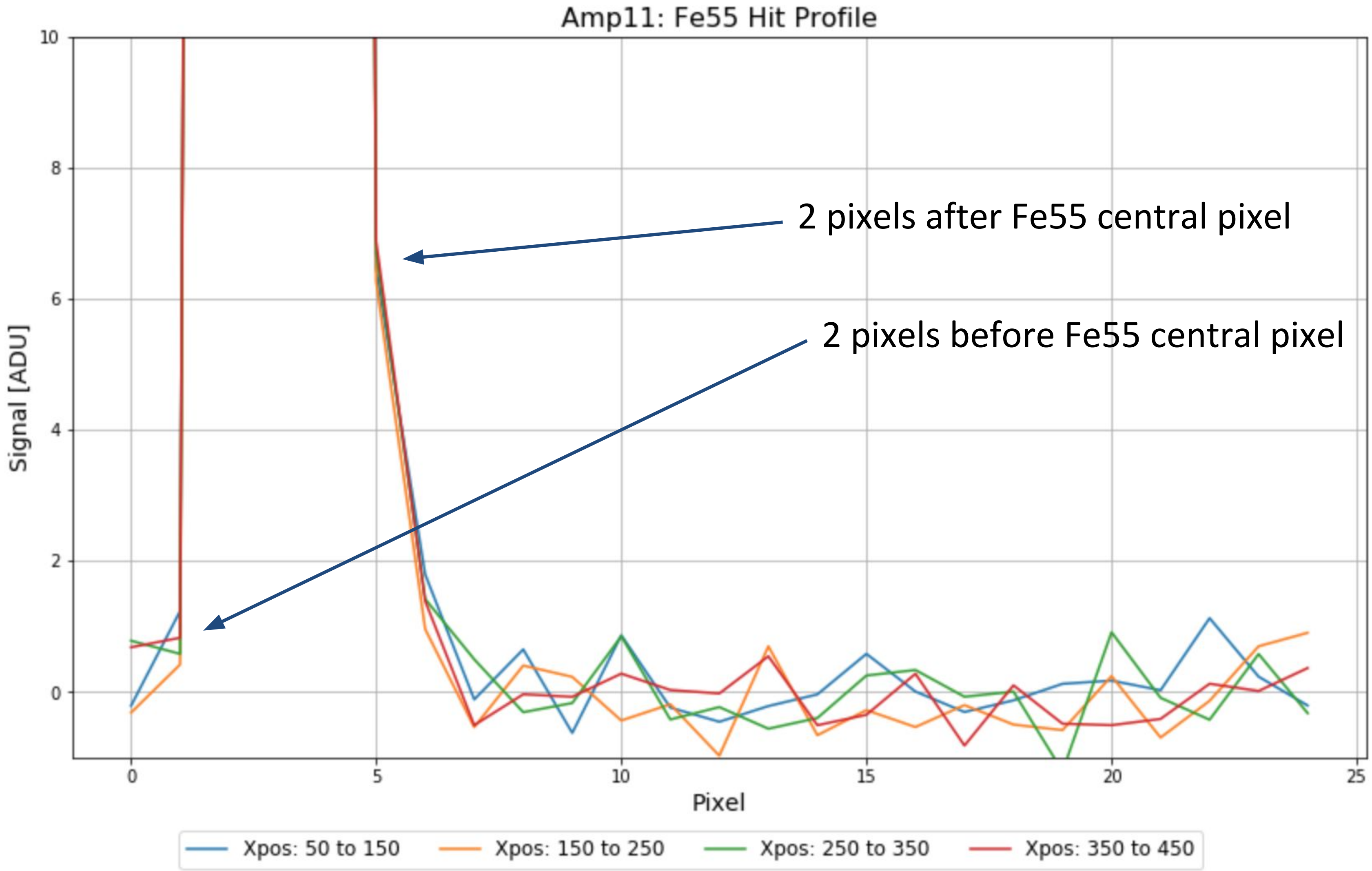
50 ADU :



100 ADU:



Low Flux Deferred Charge

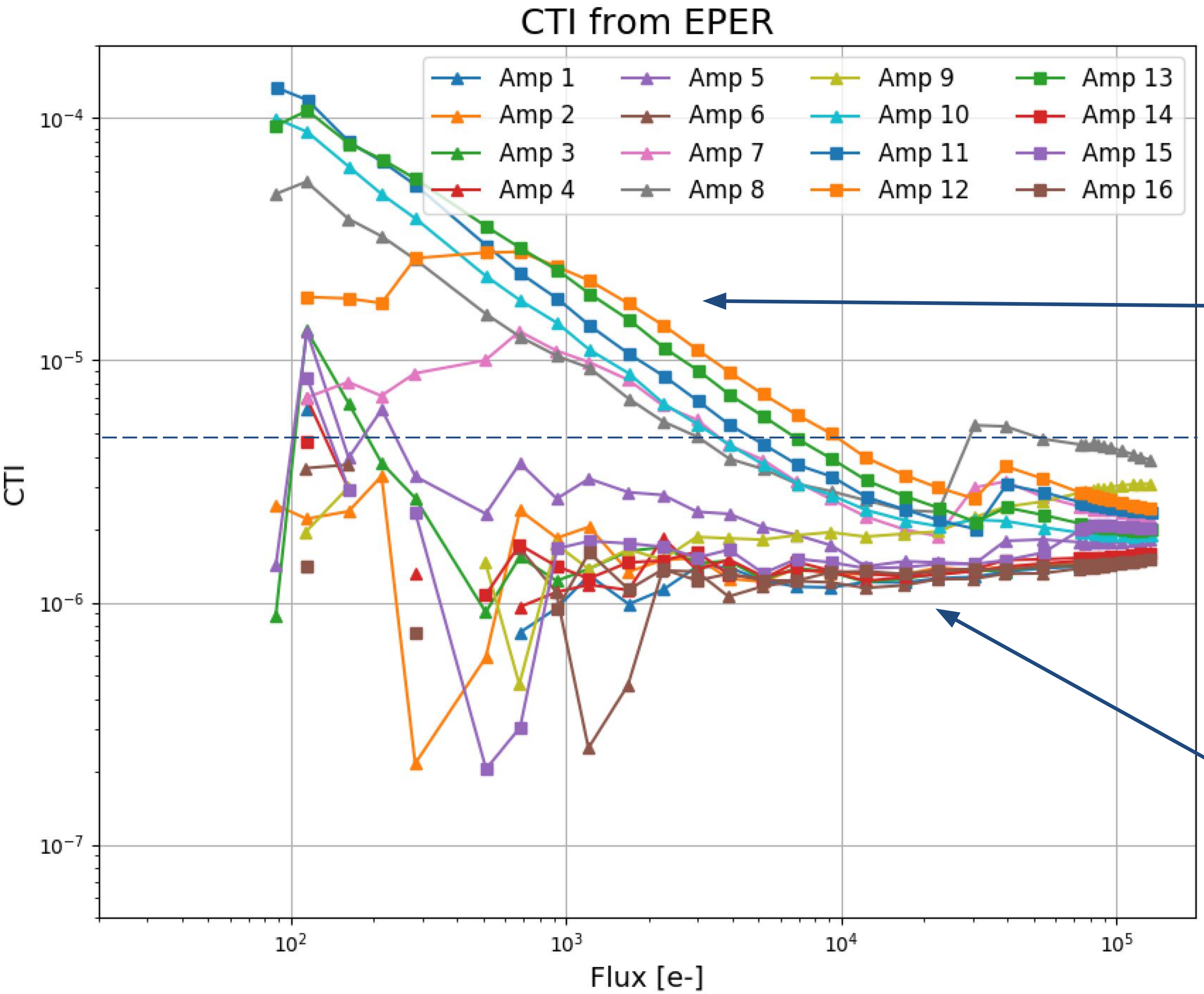


2 pixels after Fe55 central pixel

2 pixels before Fe55 central pixel

Coarse binning in the serial direction shows no dependence on number of transfers.

Low Flux Deferred Charge

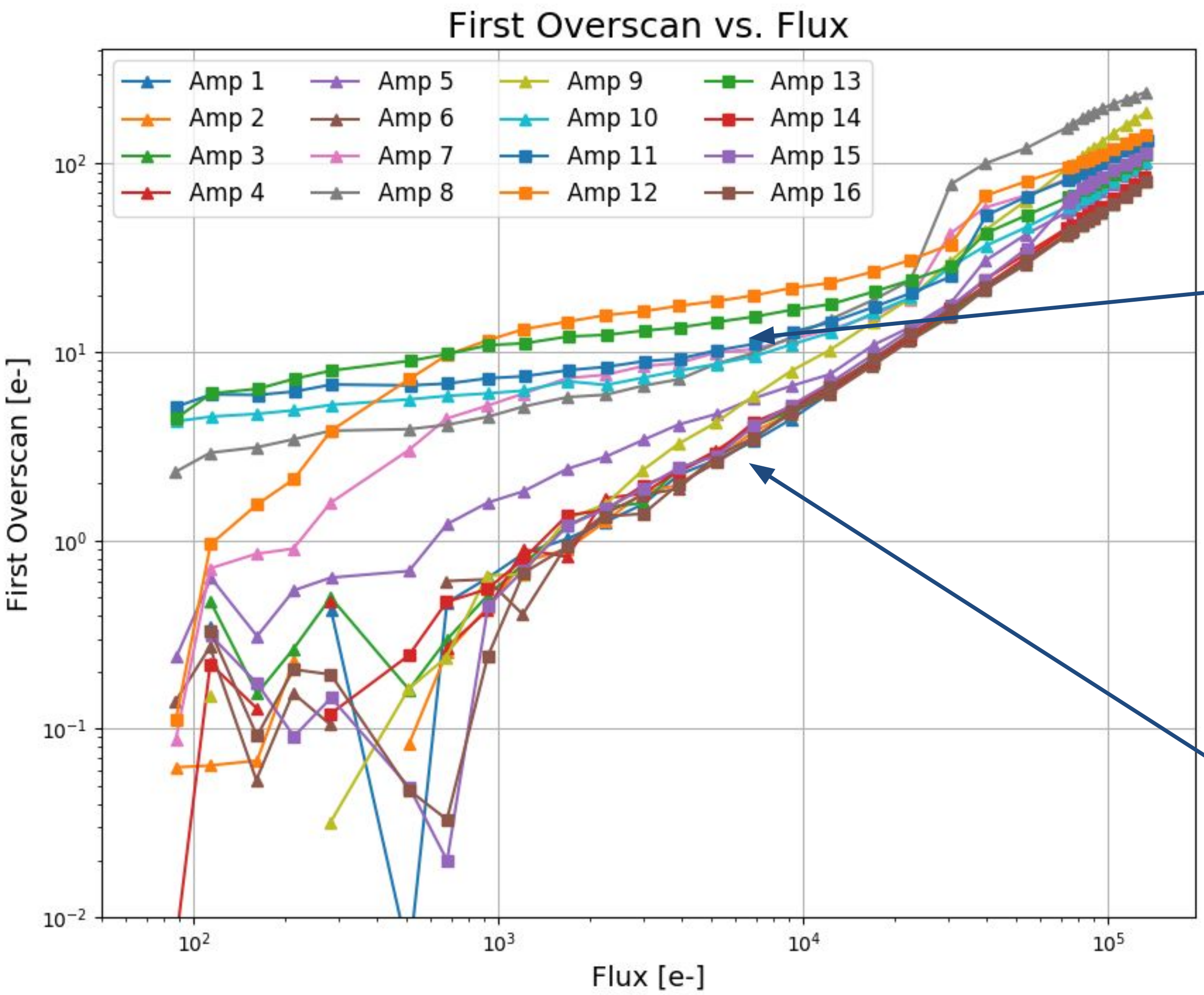


Affected channels
(CTI + low flux effect)

Nominal channels
(CTI only)

This effect is reflected in EPER measurements as high CTI at low flux but is NOT necessarily dependent on # of transfers.

Low Flux Deferred Charge



Affected channels

Nominal channels

Signal in the first overscan provides evidence of a trap (<10 e-).

Deferred Charge Summary

Two effects at work:

- All channels show deferred charge effects at high flux.
    - Flux dependent, exponential decay in overscans.
    - Present in both vendor (Archon controller) and raft data (REB controller).
- Some channels show deferred charge effects at low flux.
    - Non-proportional, very high CTI from EPER measurements.
    - Asymmetry in aggregated Fe55 profiles.
    - No dependence on number of transfers.
    - Evidence for a constant number of trapped electrons.

Phenomenological Modeling

Modeling Assumptions

Model the following deferred charge effects in separate regimes:

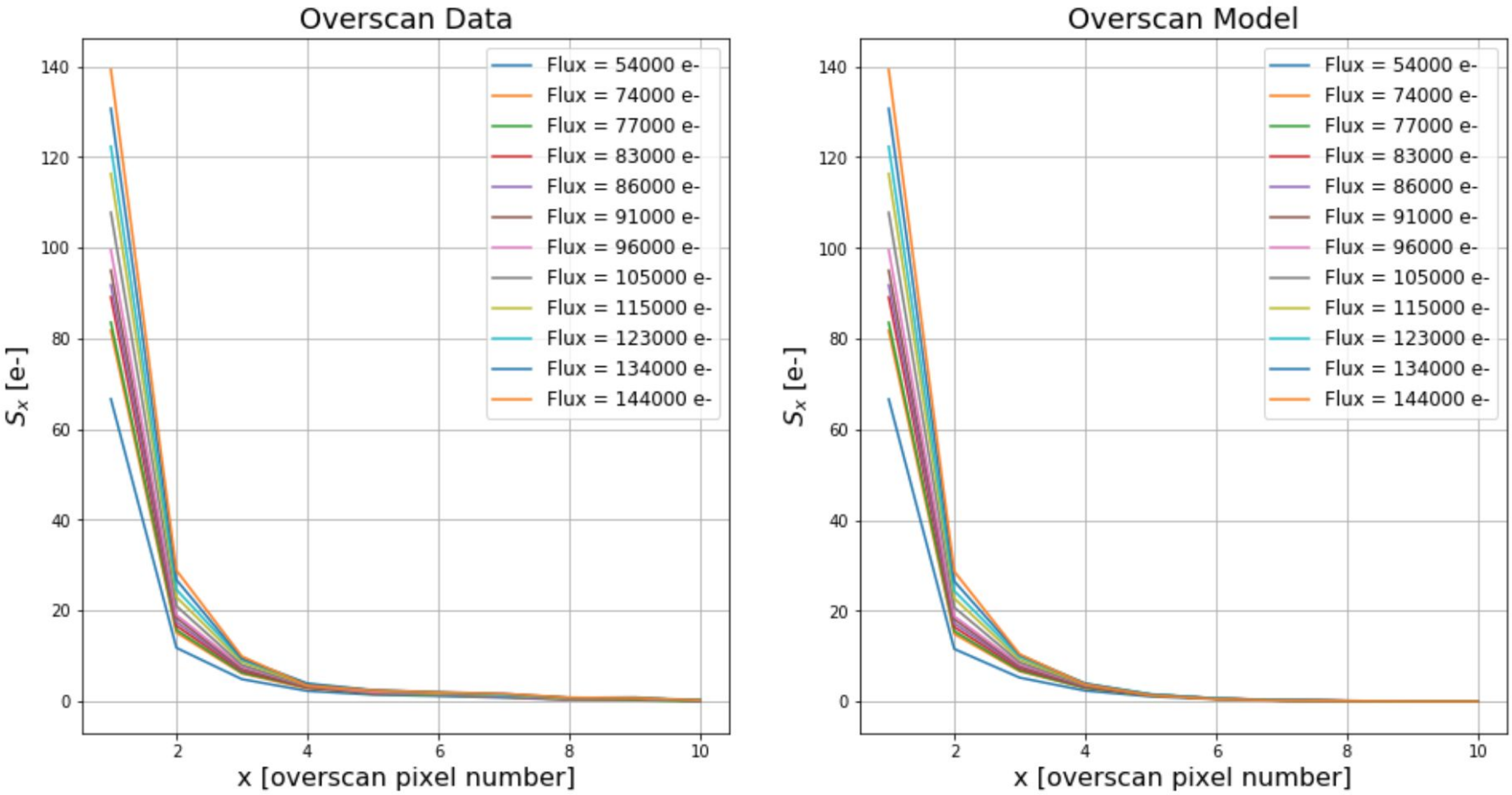
High Flux (>50,000 e-):

- Proportional CTI component
  - Assume constant or small linear dependence.
- Video channel electronic effect
  - Assume flux-dependent exponential decay.
  - Assume no dependence on number of transfers.
- Negligible contribution from low-flux component.

$$S(x,F) = A(F)e^{-x/\tau_{\mathrm{high}}} + \mathrm{CTI}^{x} N_T F$$

x = overscan pixel number
N_T = number of transfers
F = Flux in last pixel

High Flux Exponential Model



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High Flux Exponential Model

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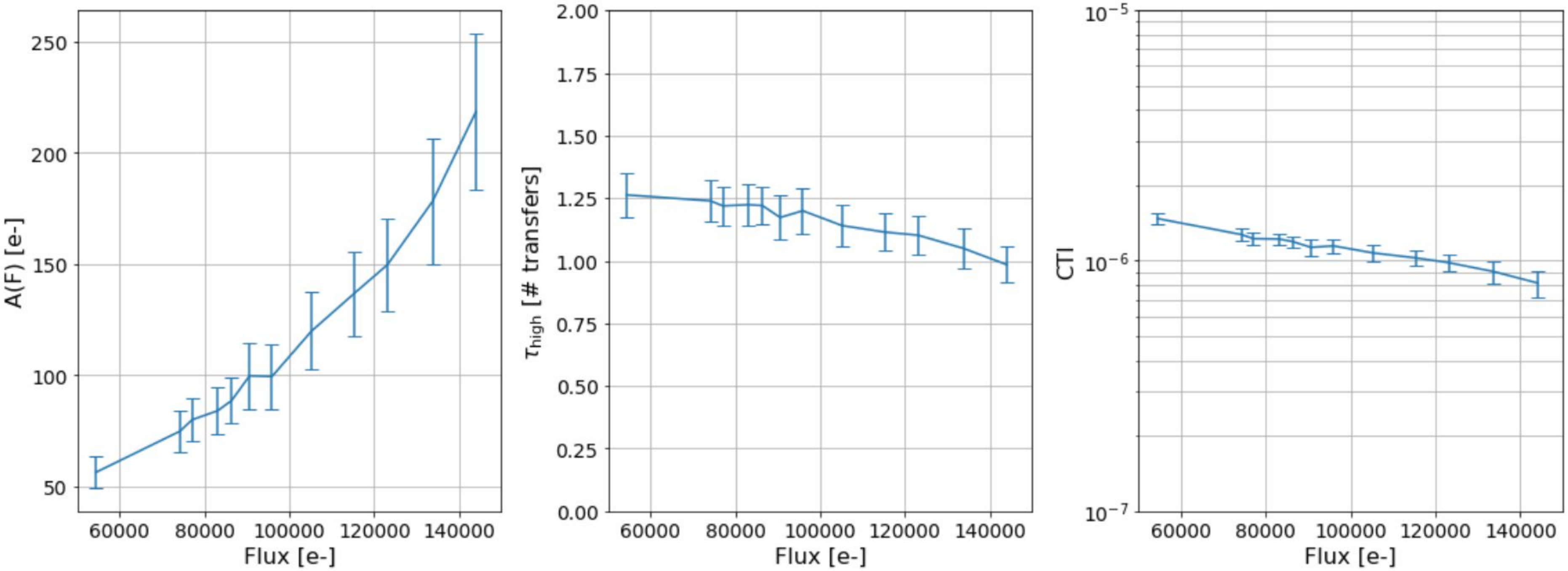


High Flux Results:

- A(F) increases with flux, though not a “simple” linear relation.
- Tau and CTI relatively stable over 60,000 e- to 140,000 e- range.

Modeling Assumptions

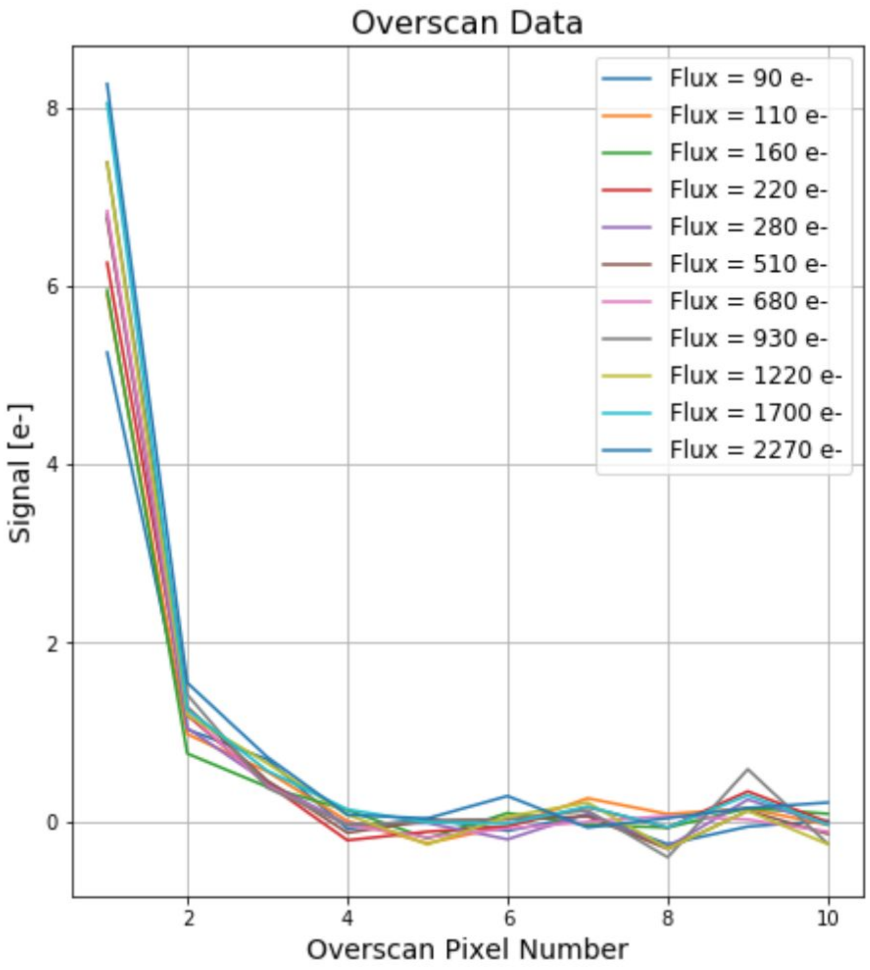
Low Flux (<3000 e-):

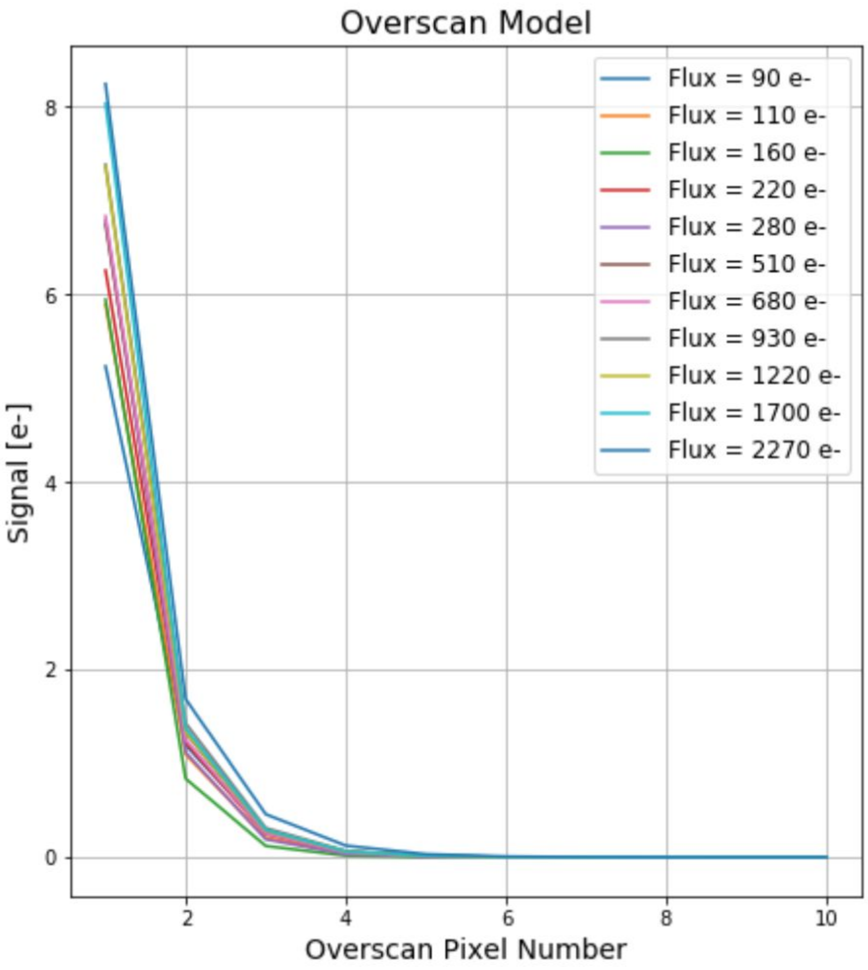
- Proportional CTI component
    - Contributes only to first overscan.
    - Calculated by extrapolating from high flux CTI results.
- Trap of O(10) e- at the start of the serial register.
    - Assume trapped charge is constant with flux in this regime.
    - Assume exponential release of trapped charge.
    - Assume no dependence on number of transfers.
- Negligible contribution from high-flux component.

$$S(x, F) = C_{\text{trap}} e^{-x/\tau_{\text{low}}} + \text{CTI}^{x} N_T F$$

x = overscan pixel number
N_T = number of transfers
F = Flux in last pixel

Low Flux Exponential Model





$$S(x, F) = C_{\mathrm{trap}} e^{-x/\tau_{\mathrm{low}}} + \mathrm{CTI}^{x} N_T F$$

Low Flux Exponential Model

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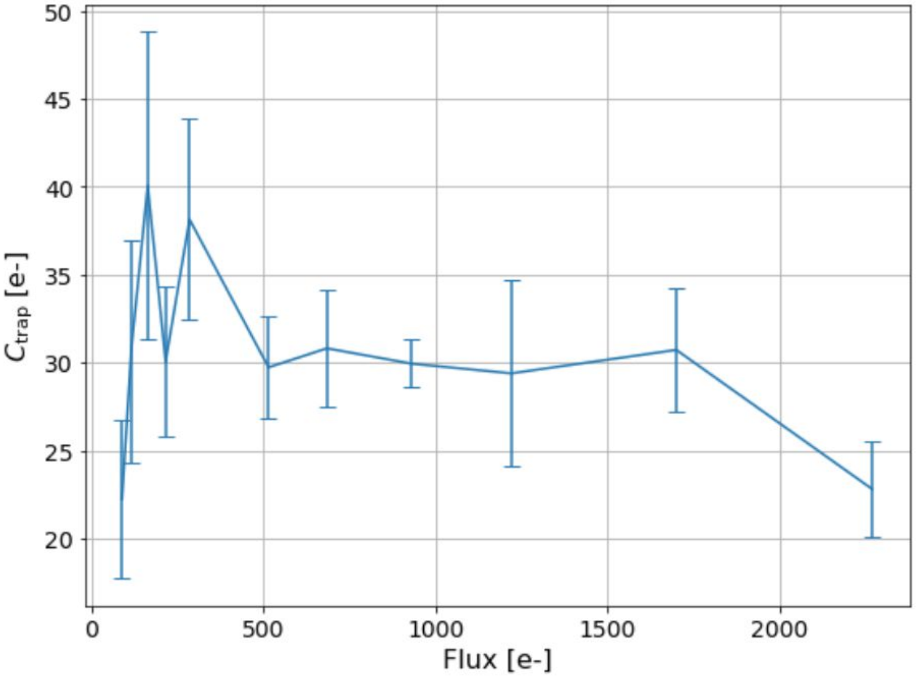
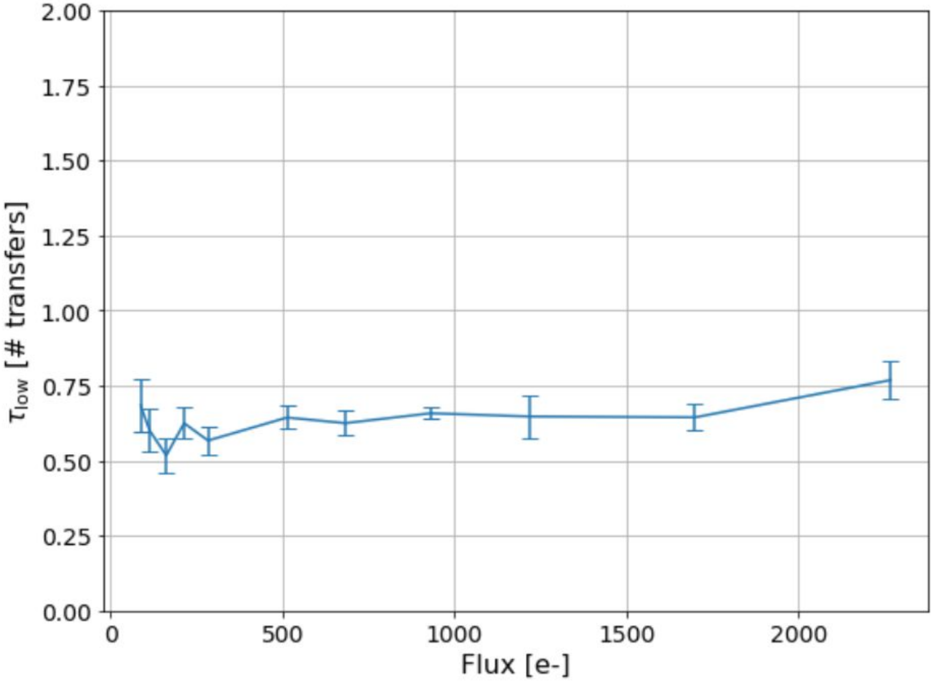




Low Flux Results:

- Fit results provide evidence for fast release trap.
    - Constant regime trapped charge between 100 e- and 1700 e-.
    - Fluxes not low enough to fully probe proportional trapped charge regime.

Summary

Encouraging results for 3-component model for overscan results:

$$S(x,F) = A(F)e^{-x/\tau_{\mathrm{high}}} + C_{\mathrm{trap}}e^{-x/\tau_{\mathrm{low}}} + \mathrm{CTI}^x N_T F$$

Next steps:

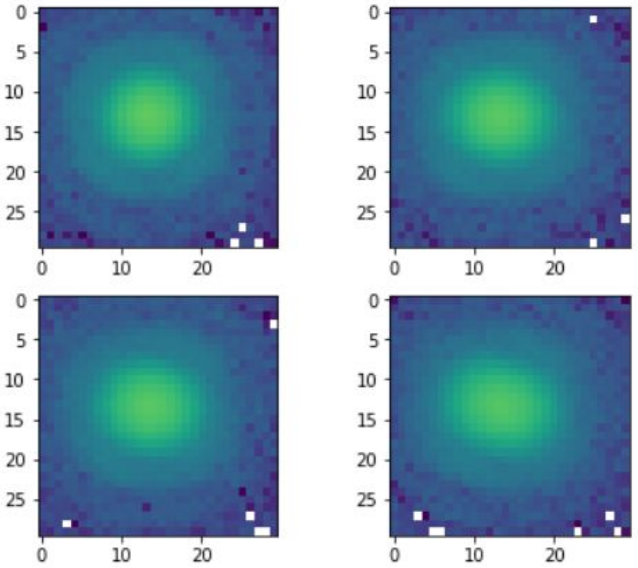
- Generalize for multiple amplifiers
- Joint fitting of all data to the model

What about realistic sources?

- Use model to simulate deferred charge effects on realistic sources and Fe55 X-rays events.
- Analyze images of realistic sources and compare with predictions from model.

Backup Slides

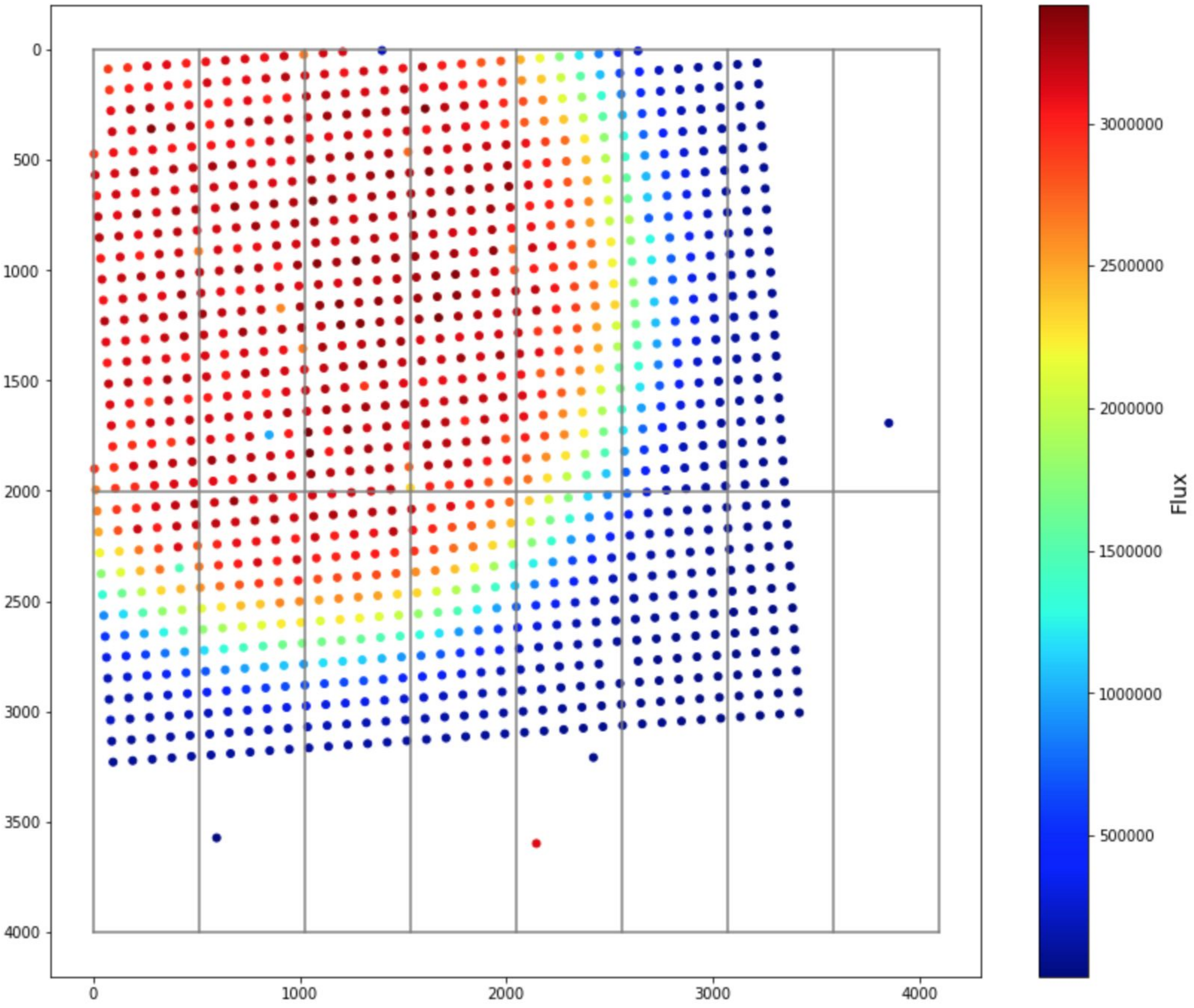
Deferred Charge for Realistic Sources



Measuring deferred charge in realistic sources:

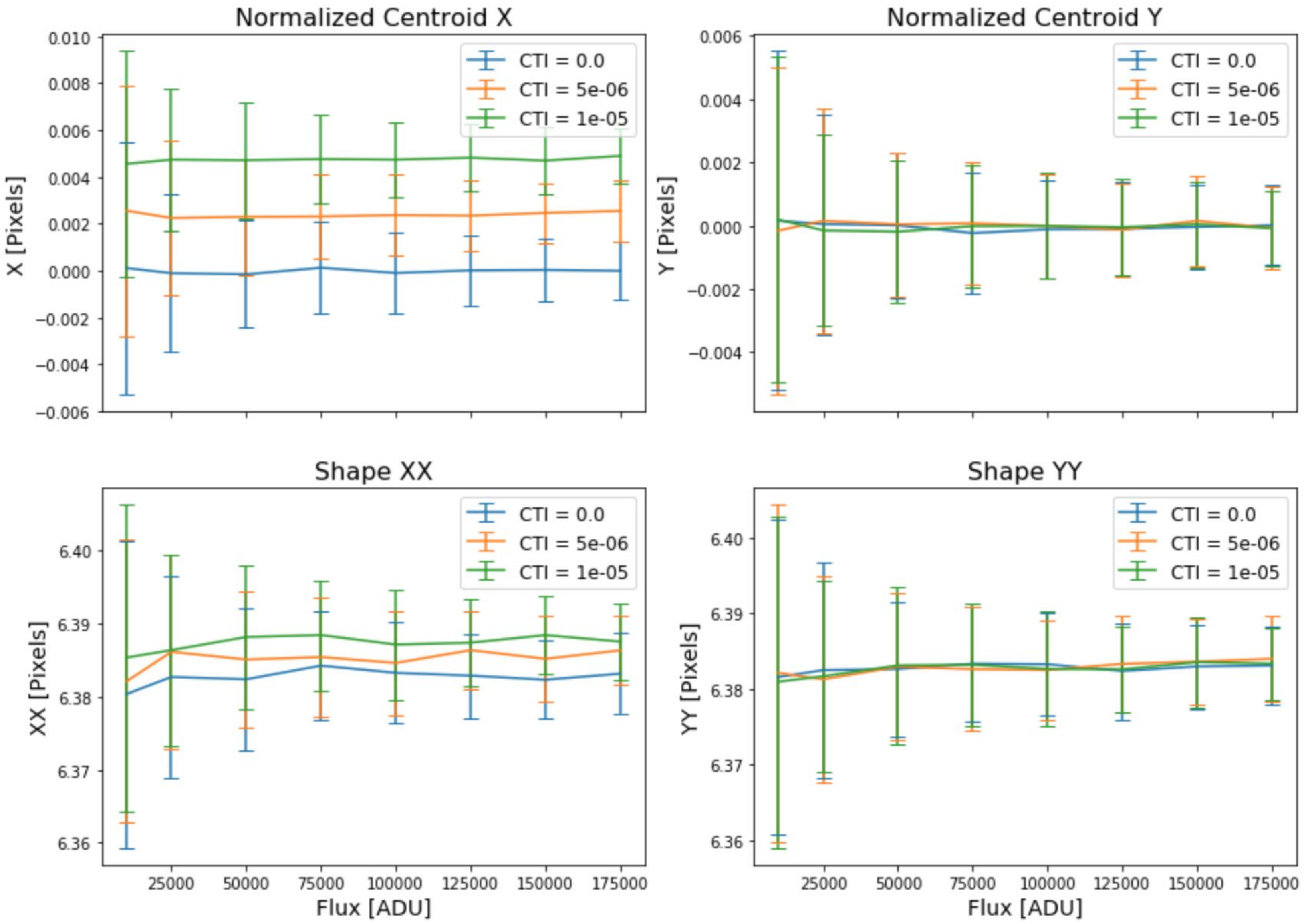
1. Project grid of “spots” onto the CCD.
2. Use HSM for source moment calculations.
3. Study deferred charge effects as function of:
    a. Position
    b. Flux
    c. “Sky” background

Deferred Charge for Realistic Sources



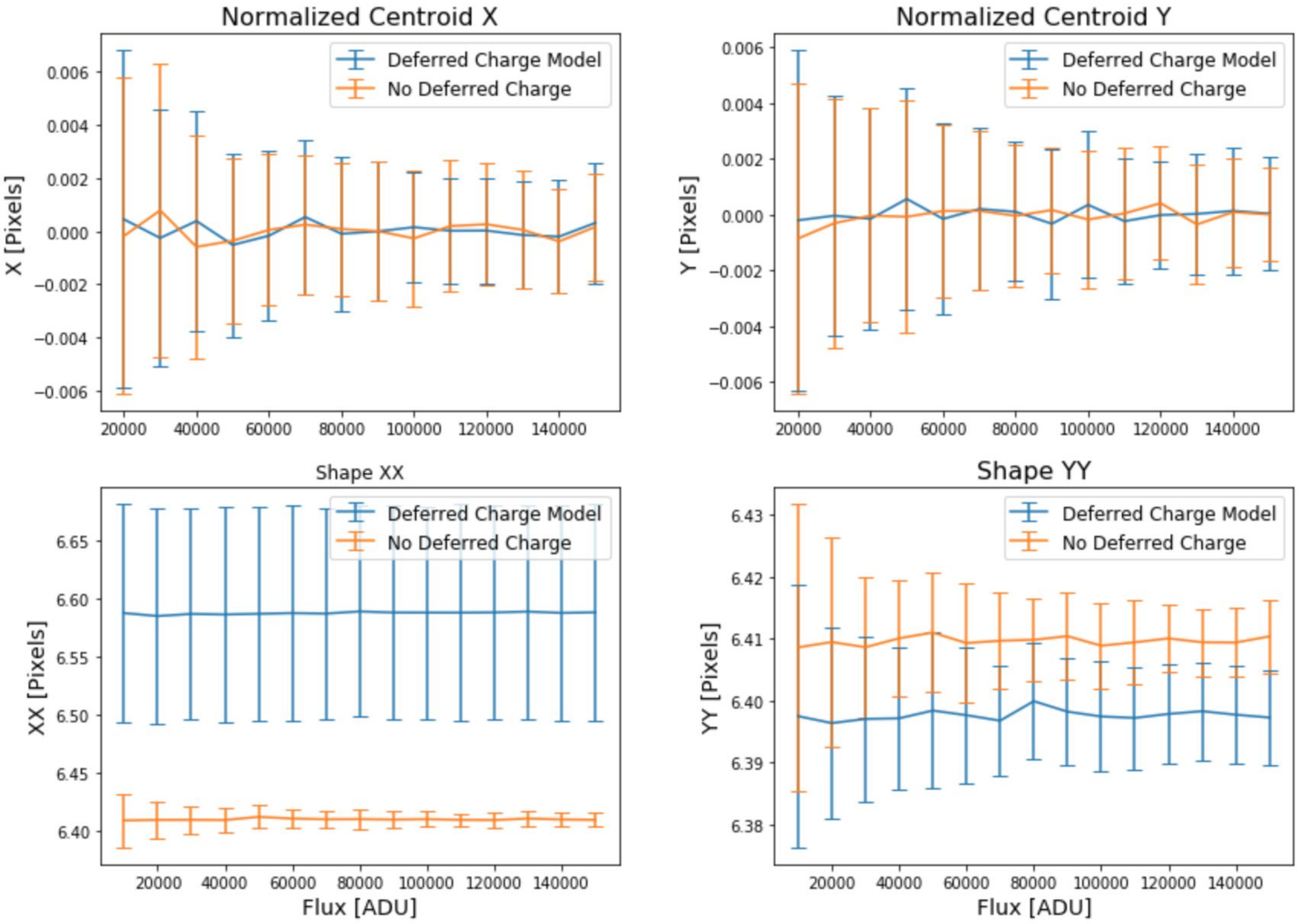
Real projected sources on LSST CCD.

Deferred Charge for Realistic Sources



Simulated sources with only proportional CTI (500 transfers)

Deferred Charge for Realistic Sources


Normalized Centroid X

Normalized Centroid Y

Shape XX

Shape YY

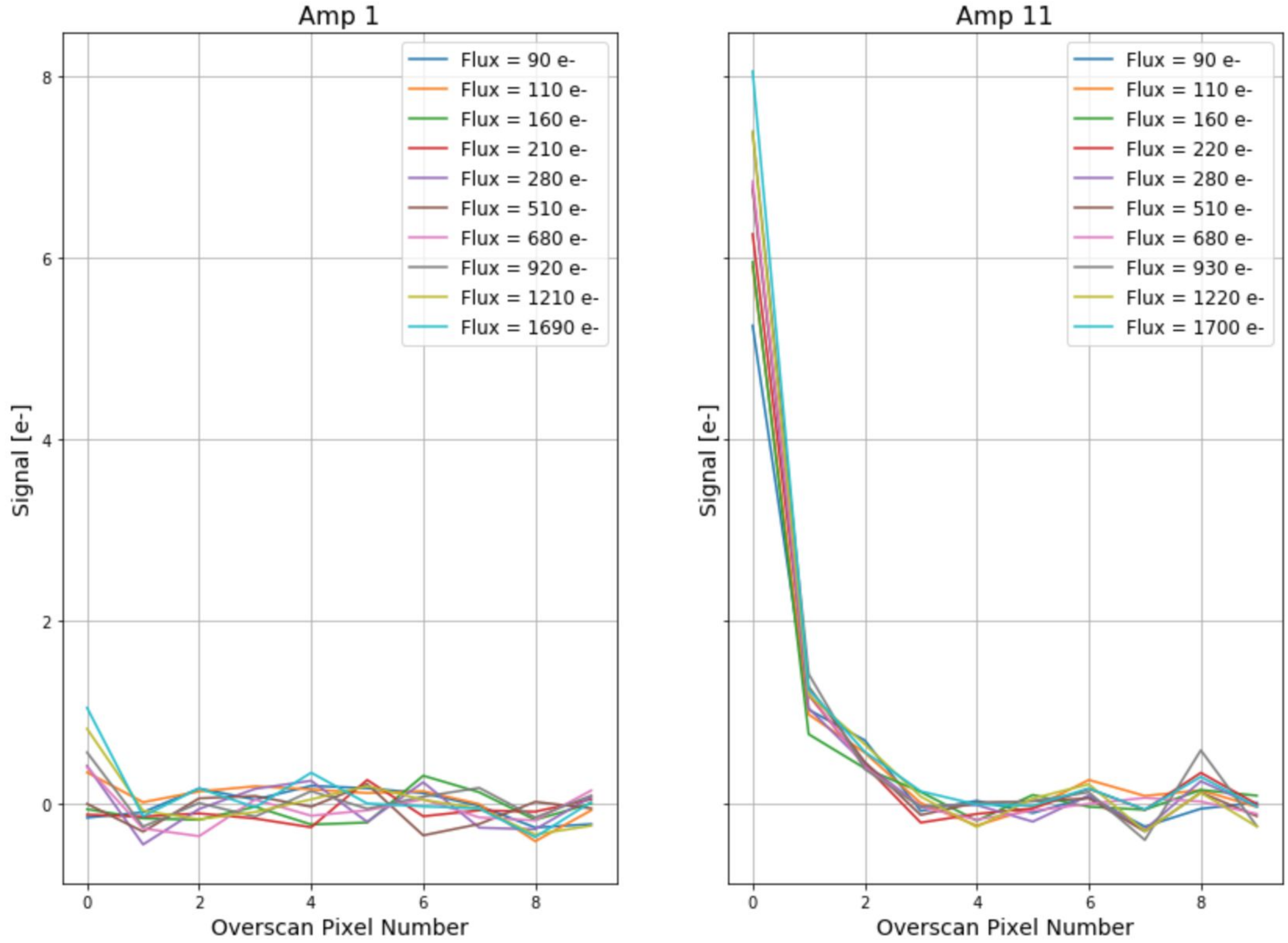
Simulated sources with high flux deferred charge model.

Summary

Current Work:

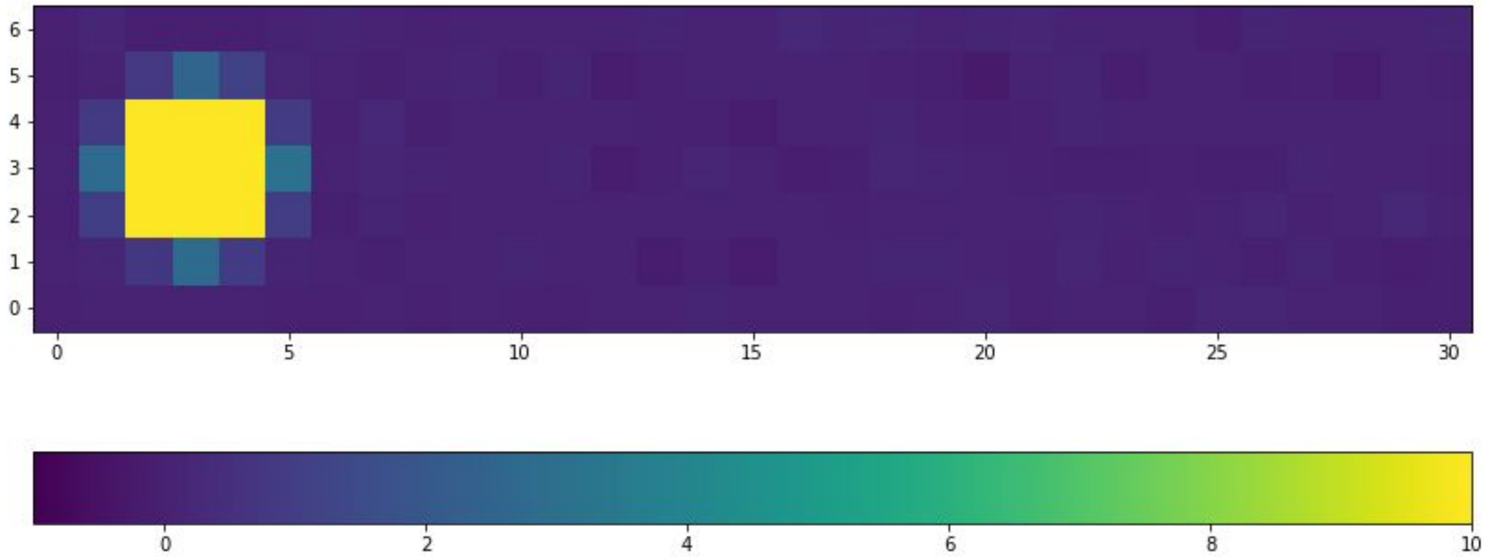
- “Spot” projector has been built and tested at SLAC.
- Source moment measurements dominated by vibrations in the test set-up.
    - Characterizing effects of vibrations on moment results.
    - Minimization of vibrations by modifying the test set-up.

Low Flux EPER



Comparison of two amplifiers, showing large CTI discrepancies at low flux.

Simulated Fe55 Results



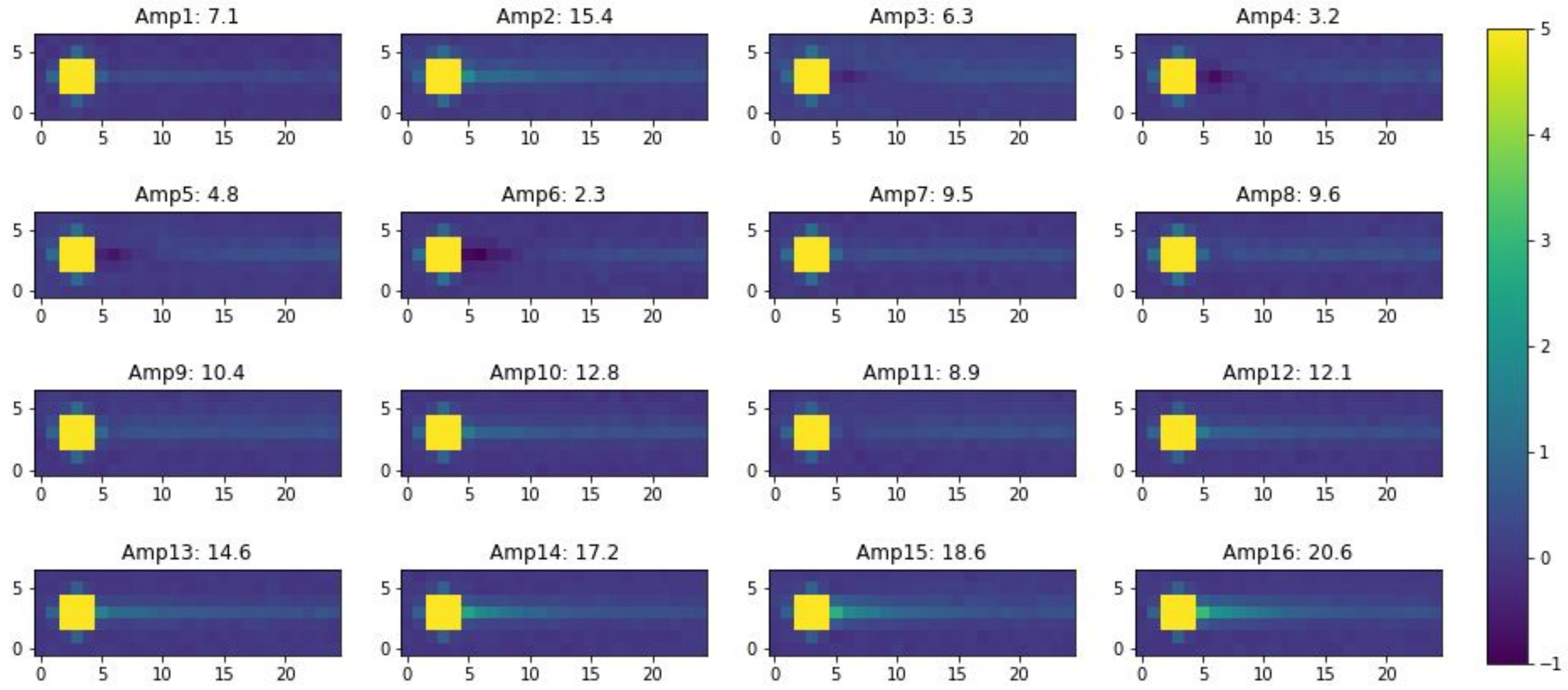
High Flux Effects Only:

- Fit parameters extrapolated to low flux.
- Randomly simulated Fe55 hits across an amplifier.
- Applied deferred charge model (CTI+Exponential Decay).

Unable to recover Fe55 asymmetry and non-proportional CTI.

E2V Serial Deferred Charge

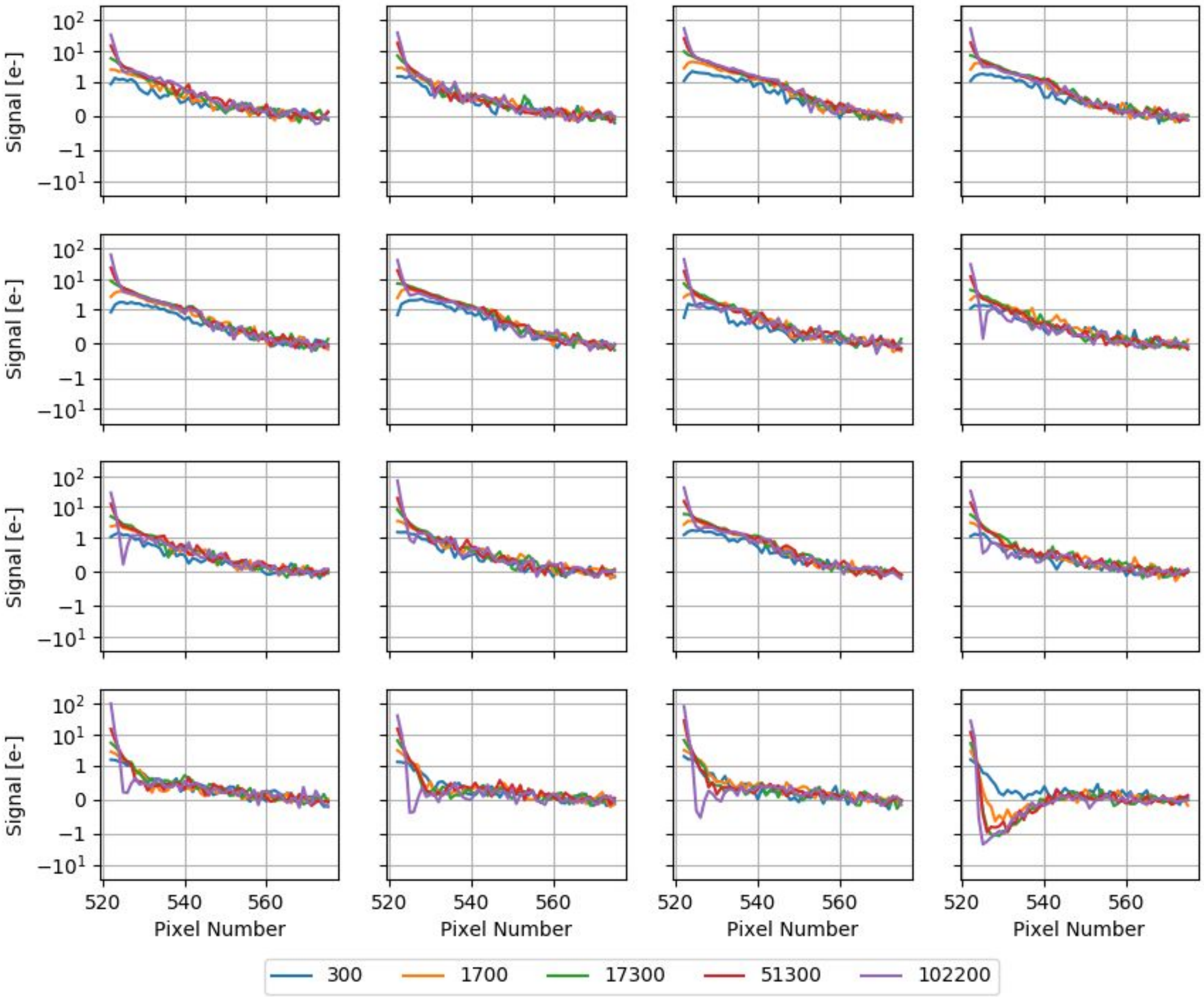
Fe55 Results



Fe55 analysis:

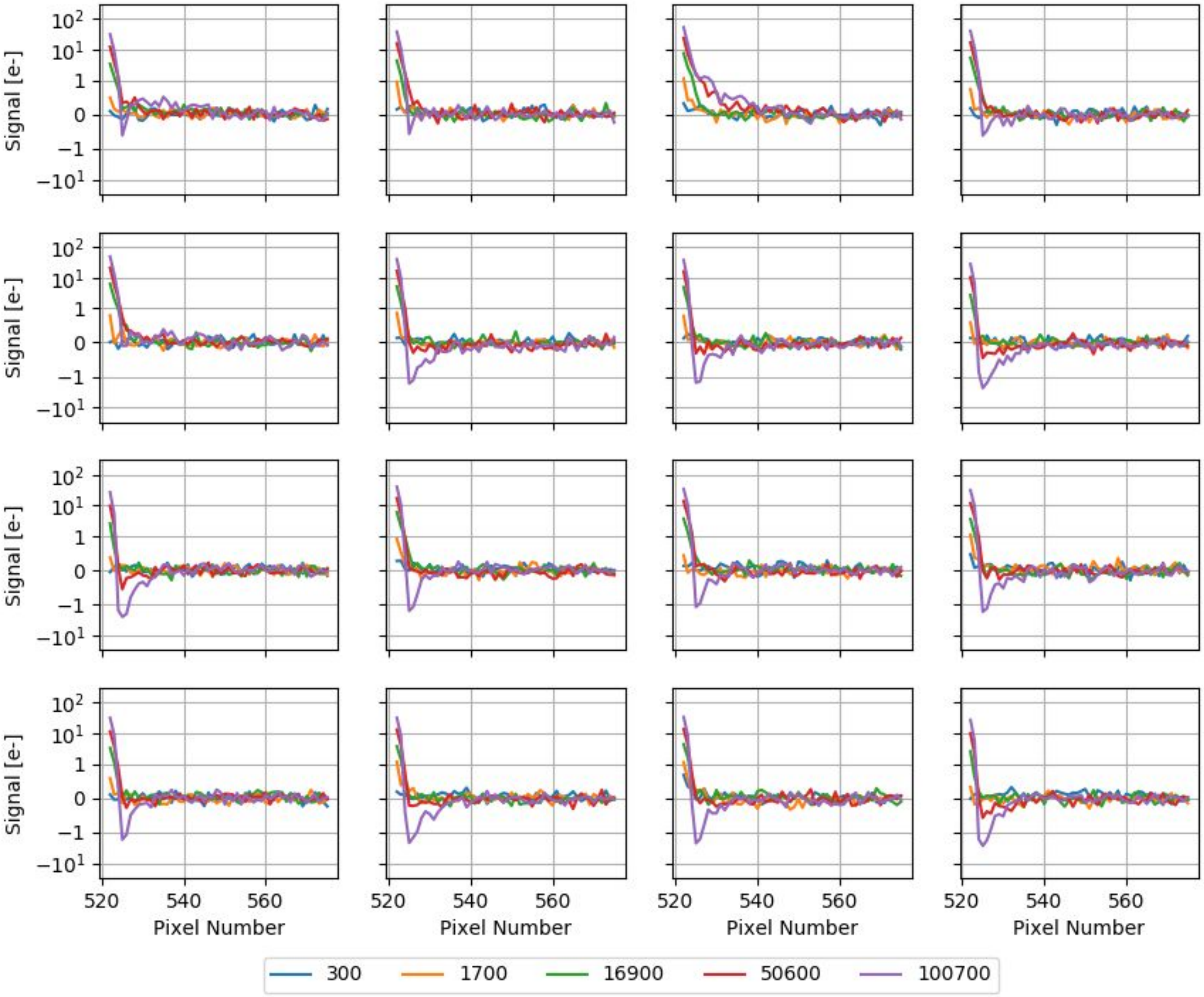
- No position dependence.
- Large affect even at low fluxes.

Overscan Traces



Trailing charge (no flux dependence) seen in E2V sensors at BNL.

Overscan Traces (New Operating Conditions)



Effect disappears with increasing reset gate voltage swing.