

MAS-CCD: spurious charge findings

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Discussion



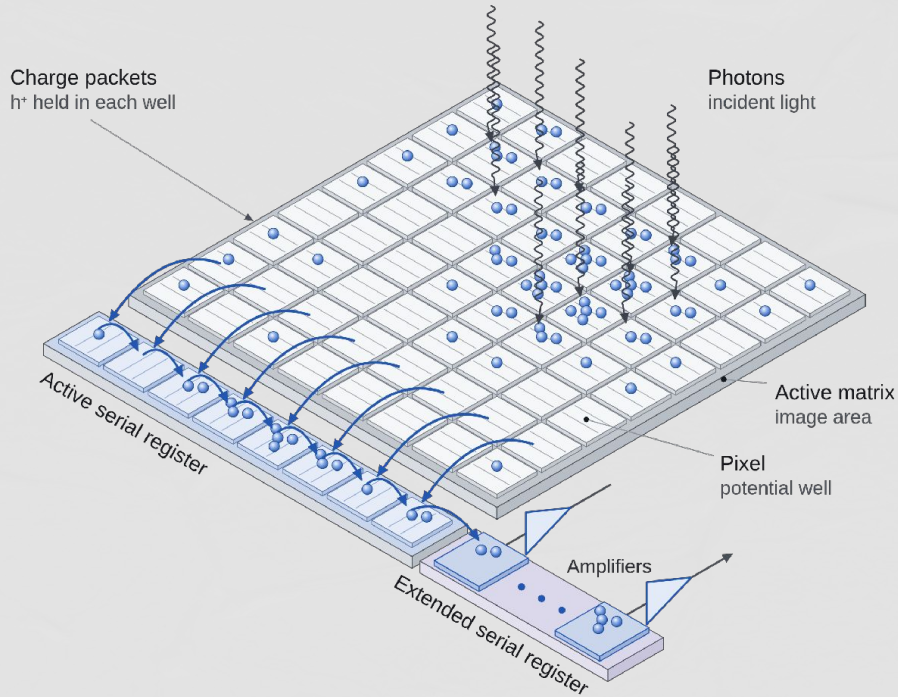
01

SC Fundamentals & Measurement Techniques





About MAS architecture

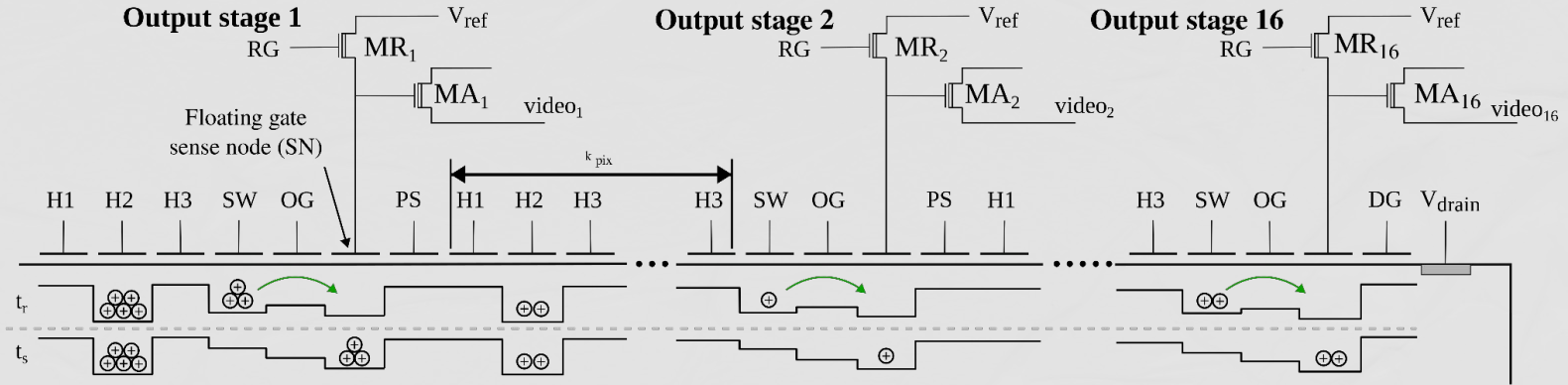


- **Active matrix:** collects the charge
- **Active serial register:** moves pixels toward the amplifiers
- **Extended serial register:** hosts the readout amplifier chain



About MAS architecture

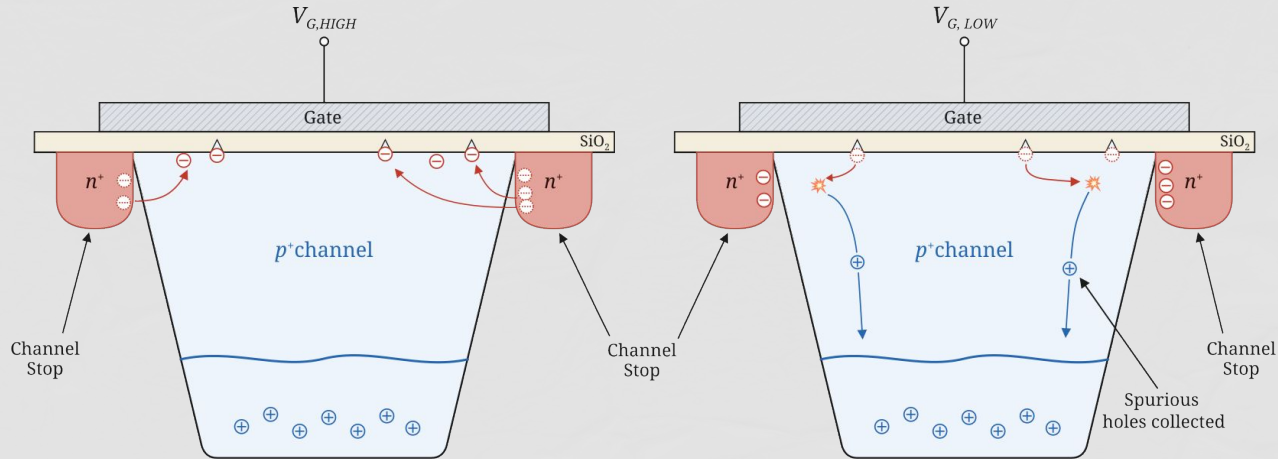
- The MAS-CCD places a **chain of in-line floating-gate amplifiers** along the serial register.
- Averaging the N_{amp} amplifiers lowers readout noise as $1/\sqrt{N_{\text{amp}}}$ at **same speed** compared with previous generation Skipper-CCD.
- This work measures the **SC added by transfers** and **where in the chain it originates**.



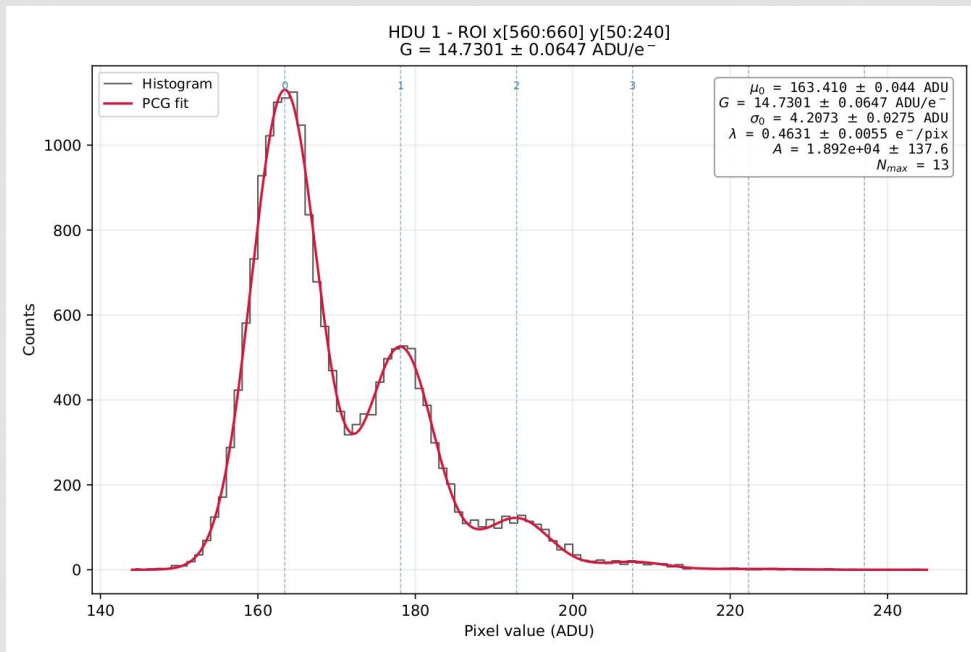


About SC generation

- The literature attributes the SC process to clocking of the gate phases.
- When V_G is driven to its HIGH state, electrons migrate from the channel stops toward the Si-SiO₂ interface, where some become trapped in interface defects.
- Trapped electrons that are later released under the V_G LOW state are subject to a high electric field that promotes impact ionization. The resulting holes are collected in the potential well.



Two methods to measure SC



Pixel-value histogram with Poisson + Gaussian fit

1. Poisson fitting (conventional)

Pixel-value histograms follow a **Poisson + Gaussian** distribution. SC is the λ of the fitted Poisson.

2. Covariance method (this work)

Estimates SC **directly**, without a histogram fit, by using the **multiple amplifiers** of the MAS architecture.



02

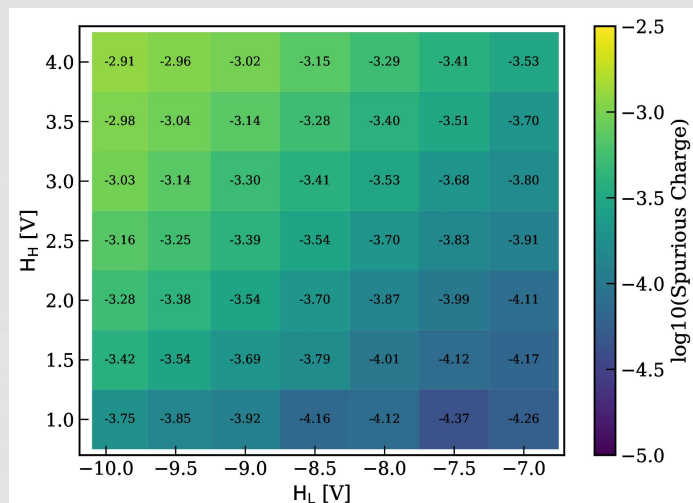
Voltage Dependence Study



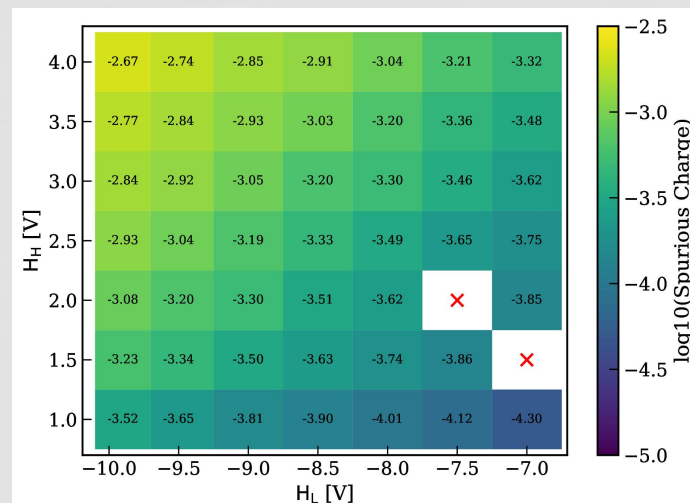
Voltage scan

Previous studies have demonstrated the dependence of **SC** on the voltage swing of the **H1**, **H2**, and **H3** clocks in the horizontal register.

We scanned the H-clock voltage space (**H_H**, **H_L**) under different conditions.



$N_{\text{samp}} = 10$



$N_{\text{samp}} = 40$

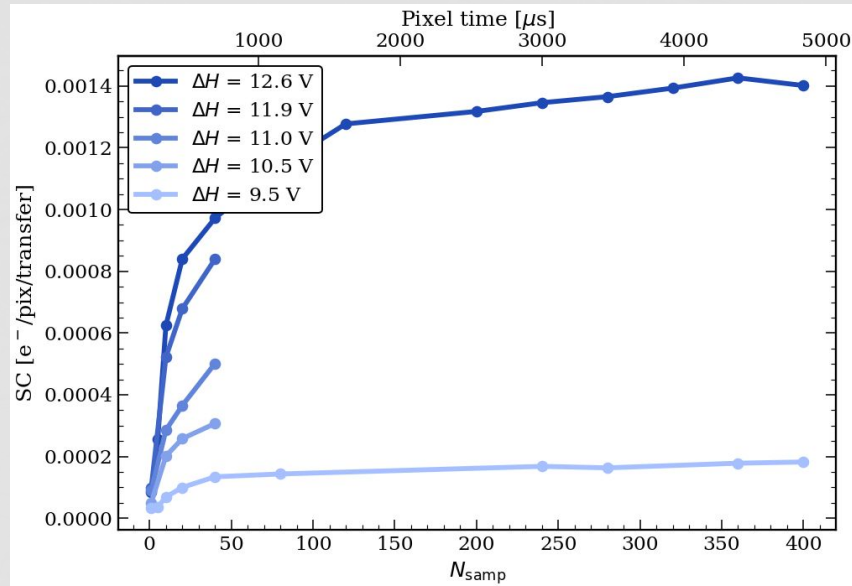
03

Time & Sampling Dependence Study



Time & sampling

- The increase in **SC** levels across matrices at increasing sampling motivated this study.
- A scan in pixel time was conducted by varying the samples per pixel, N_{samp} .
- Samples per pixel were translated into pixel readout time to reveal the time dependence.



04

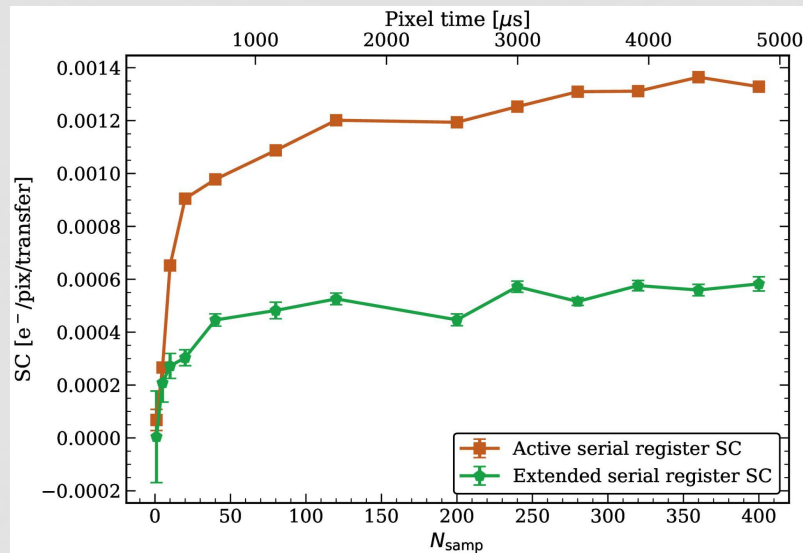
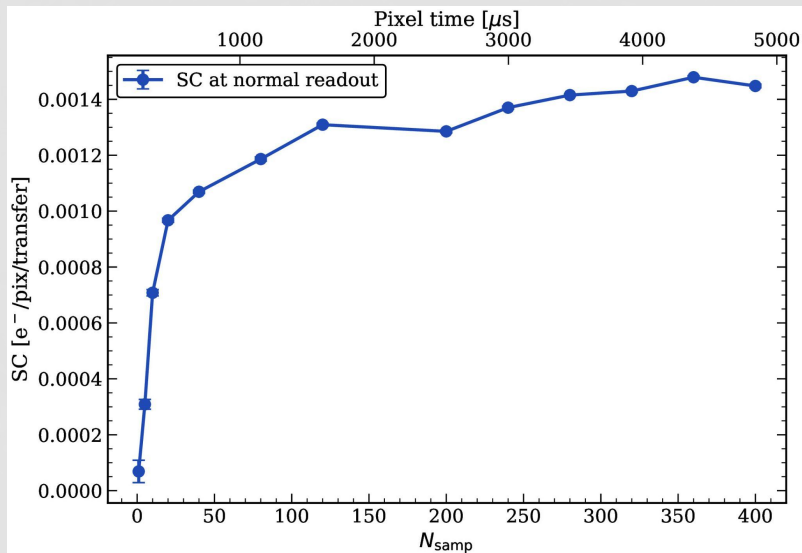
Geometry Dependence Study



Decoupling the SC process

- Initially, we assumed the same rate of SC in the active (SC_{act}) and extended (SC_{ext}).
- That was not true:

$$\alpha = \frac{mN_{act}}{\lambda_1 N_p} = SC_{ext}/SC_{act}$$



05

Transfer Dependence & Generation Sites

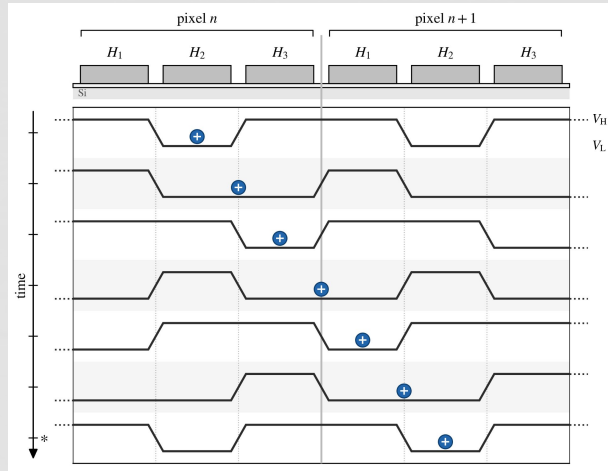




About the clocking sequences

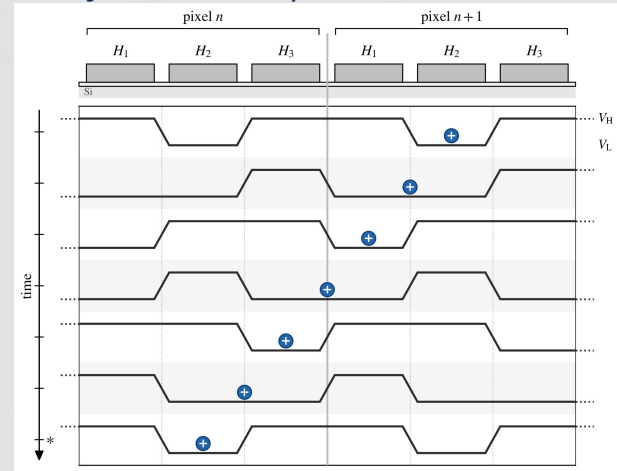
Forward shift (H)

Shifts the charge one pixel **toward** the output amplifiers: the standard readout direction.



Reverse shift (RH)

Same states in reverse order: shifts the charge one pixel **away from** the amplifiers.



The last state of a shift can be stretched to a chosen pixel time. **H_n** and **RH_n** denote a shift stretched to the pixel time of a readout at $N_{\text{samp}} = n$.



About the acquisitions

Reference (■)

$$RH_1 + H_{40}$$

Fast reverse shifts, then a normal readout at $N_{\text{samp}} = 40$.



We expect an increasing gradient towards the last pixel of the active region.

Slow-reverse (■)

$$RH_{40} + H_{40}$$

Reverse shifts stretched to the pixel time of $N_{\text{samp}} = 40$, then the same readout.



If RH_{40} adds the same SC level as H_{40} , we expect twice as much SC towards the last pixel of the active region.

Pumping (■)

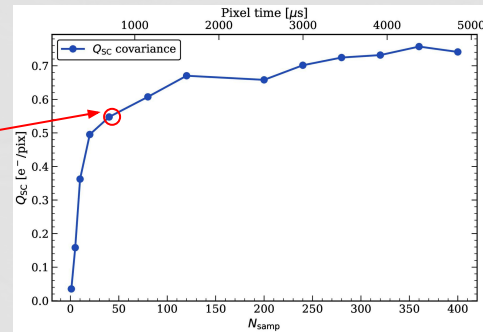
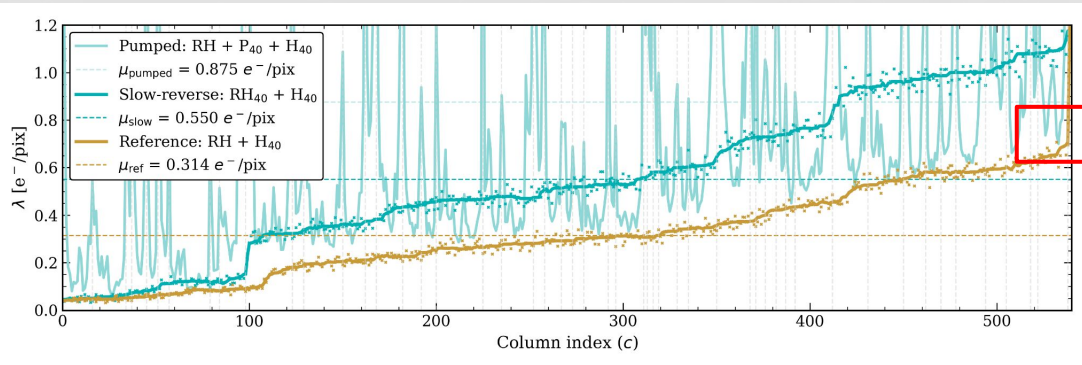
$$RH_1 + P_{40} + H_{40}$$

Fast reverse shifts, then pump cycles on each pixel, then the same readout. A pump cycle is $P_n = RH_n + H_n$.



If P_{40} adds all the SC generated in a normal $N_{\text{samp}} = 40$ readout, we expect to match that SC level by isolating it.

SC curves along the active serial



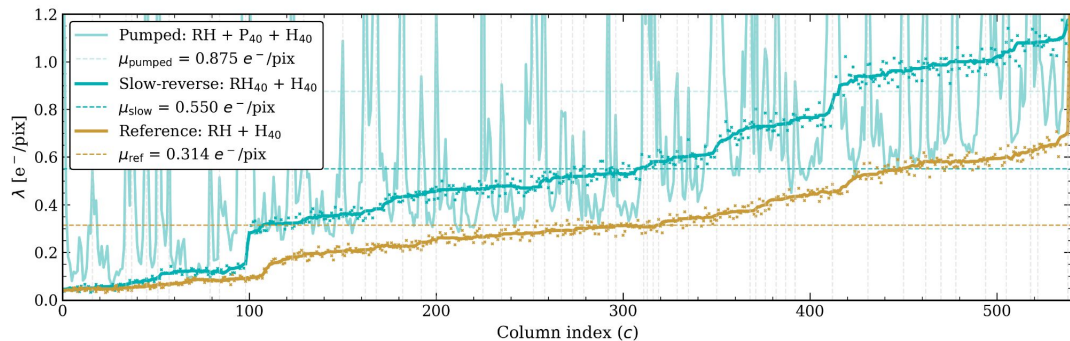
Common offset = 0.03 e⁻/pix, subtracted from both acquisitions.

Reference: $\mu_{\text{ref}} = 0.314$ e⁻/pix $\rightarrow \mu_{\text{ref,corr}} = 0.284$ e⁻/pix

Slow-reverse: $\mu_{\text{slow}} = 0.55$ e⁻/pix $\rightarrow \mu_{\text{slow,corr}} = 0.52$ e⁻/pix

The SC at the end of the active register (red box) matches the time scan at the same pixel time (red circle).

SC curves along the active serial

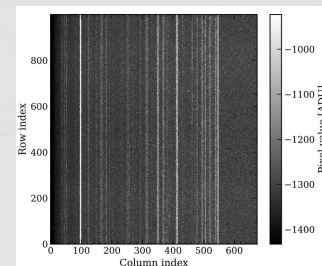
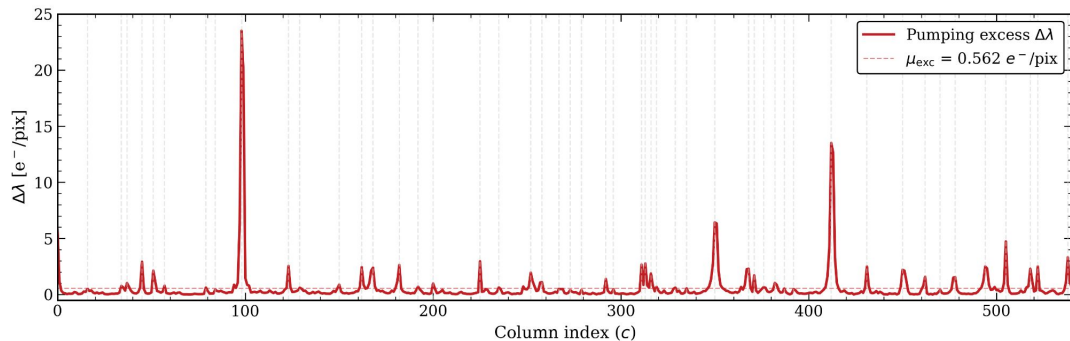


The red curve is the difference between the **Pumping** and **Reference** acquisitions:

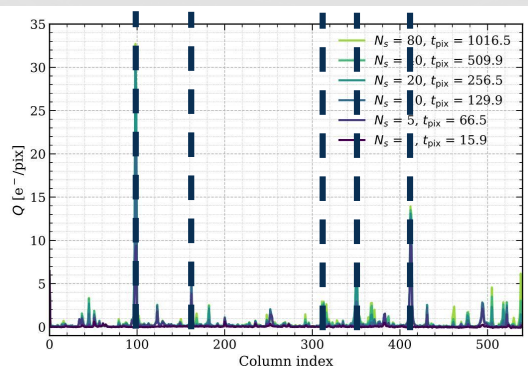
$$\Delta\lambda(c) = \lambda_{\text{pumped}}(c) - \lambda_{\text{ref}}(c)$$

Its mean is the **SC** generated by the pumping alone.

Next question: are these peaks *generation sites*?



Generation sites



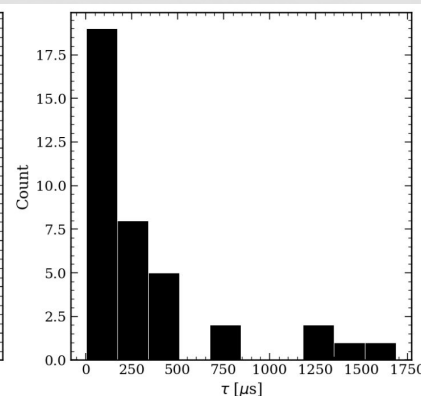
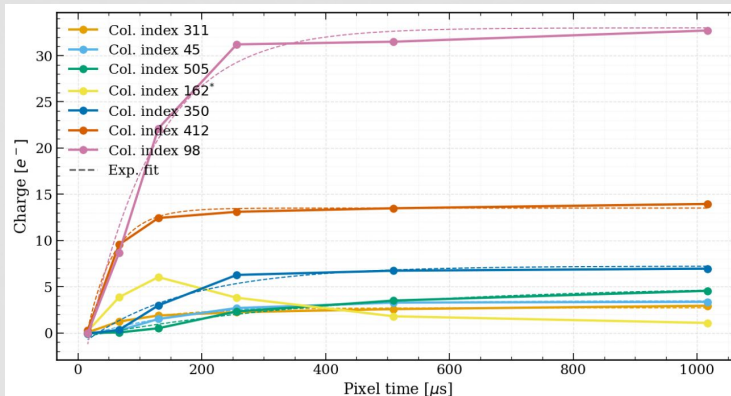
Testing the generation sites hypothesis.

We ran the same **RH₁ + P_n + H₄₀** sequence for *different equivalent samples per pixel*.

Decomposed the most prominent peaks by their temporal dependence.

Fitted:

$$Q_{sc}(t) = A \cdot (1 - \exp(-t / \tau))$$



06

Discussion





What we found (and how to move forward)

Extended serial register

The contribution of the extended serial register to total **SC** is small.

Moving forward: this allows extending the number of in-line amplifiers without degrading performance.

Low SC levels

Measured SC @ NSAMP 1 (MAS-CCD, larger swing):

$$5 \times 10^{-5} \pm 1.1 \times 10^{-5} \text{ e}^-/\text{pix}/\text{transfer}$$

Measured SC @ NSAMP 40 (Skipper-CCD, lower swing):

$$2.6 \times 10^{-9} \pm 6.67 \times 10^{-10} \text{ e}^-/\text{pix}/\text{transfer}$$

Moving forward: confirm low level of SC at fast-readout speed need dedicated larger study.

Dependence on pixel time

Although voltage swing and transfer dependence also have an impact, pixel time matters most.

Moving forward: this encourages faster readout scheme, which minimize SC impact on performance.

Generation sites

Generation sites could explain the SC generation across the serial register.

Moving forward: sites must be studied further and included in upcoming irradiation studies.

Thanks!

Do you have any questions?

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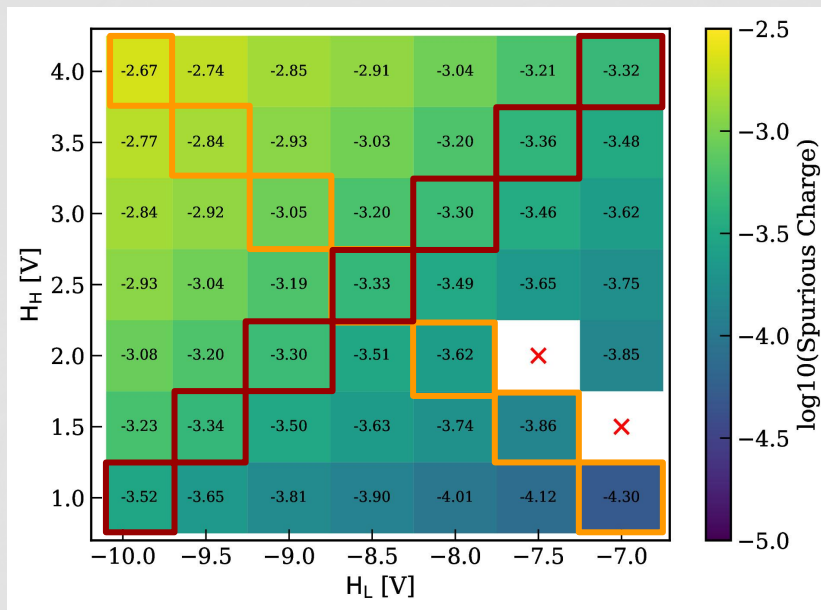
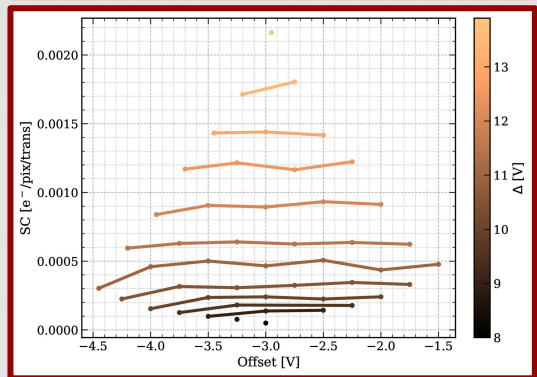
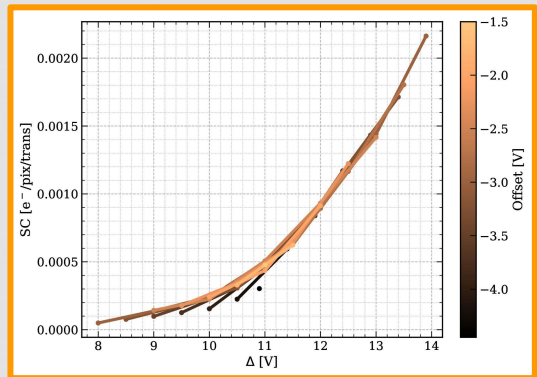
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Voltage scan

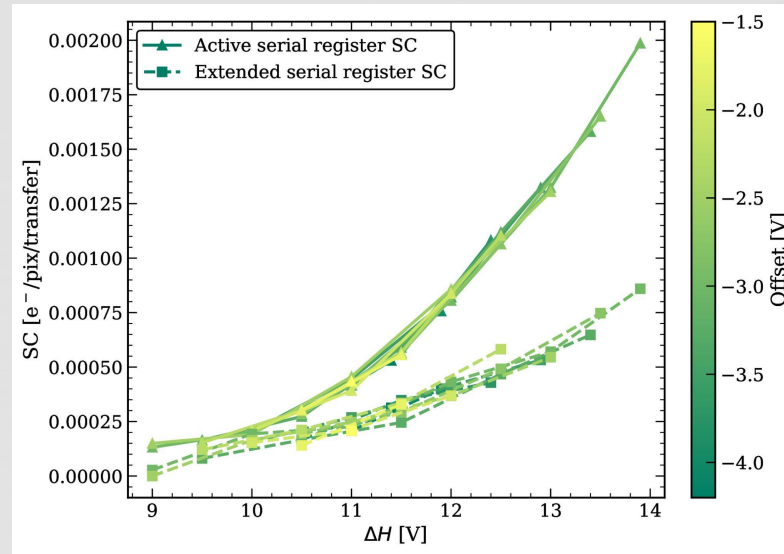


$N_{\text{samp}} = 40$



Decoupling the SC process

The swing and offset dependence of the **SC matrix** (slide 24) also decouples into two processes:



Voltage swing



Time & sampling

- At a fixed N_{samp} value, a modified sequence holds the charge below the H_2 gate.
- Time spent in last state corresponds to larger N_{samp} values.

