Effects of CTI on Roman CGI under Photon-counting Frame Rates -- Report

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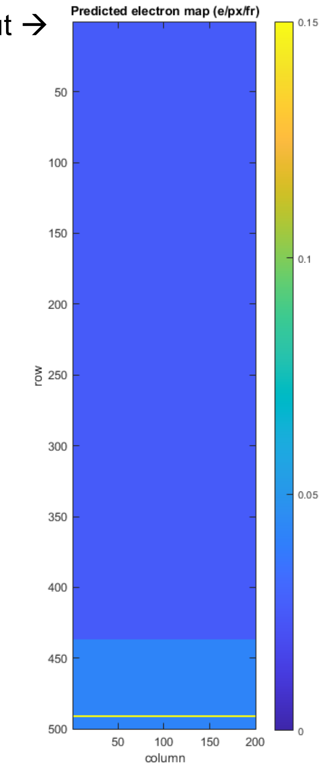
CTI simulation parameters

- Want to answer question:
  - What effect does CTI have on Roman CGI EXCAM observations of 100 ppb exoplanet flux after 18 months in space at photon-counted frame rates? Charge traps simulated using **ArCTIc** software (v 7.0.4)* using well-fill exponent = 0.58.
- Simulation software setup:
  - Simulation parameters:
    - Short exposures (2s) – photon counting frame rate,
    - EM_gain = 1.0,
    - 1.0, 1.5, 3.0, 5.0 yrs orbit time exposures.
  - Scene generator makes a simple exoplanet fluxmap (line of charge):
    - 500 rows,
    - 0.06 ph/s/px line charge at row 490,
    - 0.009 ph/s/px background (bottom 65 rows).
  - Simple detector model:
    - QE = 0.9; dark current (0.0028 e/s/px); CIC (0.02 e/s/px),
    - Poisson noise, ← **ArCTIc** call here
    - EM gain stage noise,
    - Bias offset (10,000 e),
    - e/DN = 1/20; no clipping to set bit dynamic range; read noise = 0.
  - Five species of traps followed in parallel readout, with densities increasing over time from expected radiation damage accumulation to EXCAM (see next slide).
  - Comparison frames generated by bypassing **ArCTIc**.
  - Thresholding not applied. That makes these simulations effectively analog.

*https://github.com/jkeger/arctic

Readout →



Trap Species Parameters

- Parameters based on trap pumping of several CCD201 EMCCDs exposed to various p fluences as reported in Bush *et al.* (2021, *JATIS* 7(1), 016003).
- CBE 10 MeV p fluence for Roman 5.25 yr lifetime is 1e9 p/cm^2.
- Release times calculated from values in Table 10 using Shockley-Read-Hall theory.
- Assumed 13μm^3/pix charge packet volume (upper limit, N. Bush, priv. comm.).

Species	Energy level	Em. cross section
	(eV)	(cm^2)
VV^{--}	0.235 ± 0.005	$(2.6 \pm 0.5) \times 10^{-15}$
Si-E	0.475 ± 0.015	$(3.7 \pm 0.8) \times 10^{-14}$
Si-U	0.37 ± 0.01	$(8.7 \pm 0.7) \times 10^{-15}$
VV^{-}	0.42 ± 0.01	$(2.0 \pm 1.0) \times 10^{-15}$
Si-A	0.165	6.1×10^{-15}

Table 10: Charge trap properties that are independent of radiation exposure.

Trap species	Trap density growth rate	Initial density	Density @ 21 months
	(traps/μm^3/yr)	(traps/μm^3)	(traps/μm^3)
VV^{--}	1.6×10^{-4}	5.1×10^{-4}	7.9×10^{-4}
Si-E	8.9×10^{-4}	1.4×10^{-3}	2.9×10^{-3}
Si-U	3.9×10^{-5}	8.7×10^{-5}	1.6×10^{-4}
VV^{-}	1.3×10^{-4}	4.2×10^{-4}	6.5×10^{-4}
Si-A	1.7×10^{-3}	2.6×10^{-3}	5.5×10^{-3}

Table 11: Charge trap density growth rates for each trap species.

Species	Release time constant	Release time constant
	(s)	(pixels)
VV^{--}	5.90×10^{-5}	5.69×10^{-1}
Si-E	$5.39 \times 10^{+1}$	$5.20 \times 10^{+5}$
Si-U	1.76×10^{-1}	$1.70 \times 10^{+3}$
VV^{-}	$2.38 \times 10^{+1}$	$2.30 \times 10^{+5}$
Si-A	2.07×10^{-7}	2.00×10^{-3}

Table 12: Charge trap release time constants for each species.

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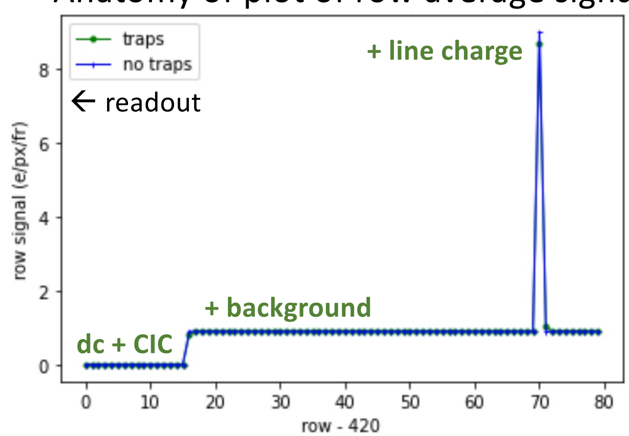
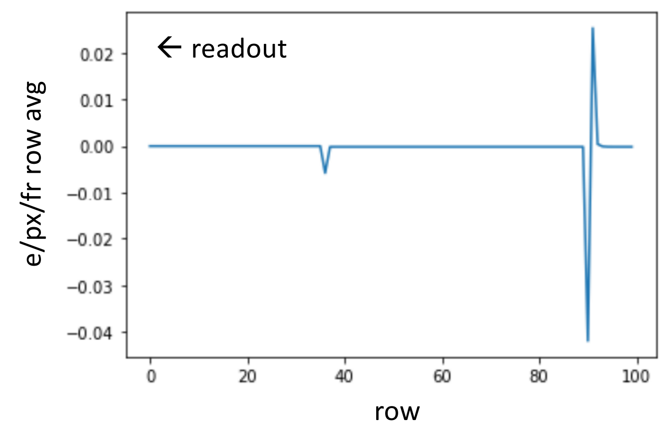
CTI simulation checks

- Tests (all passed):
  - Linearity of CTI with number of rows (noiseless),
  - Linearity of CTI with orbit time (noiseless),
  - Shape of difference between CTI before and after (noiseless),
  - Saving FITS versus CSV files,
  - CPU parallel versus serial computation,
  - Adequate e/DN to sample low signal values.

Anatomy of plot of row average signal

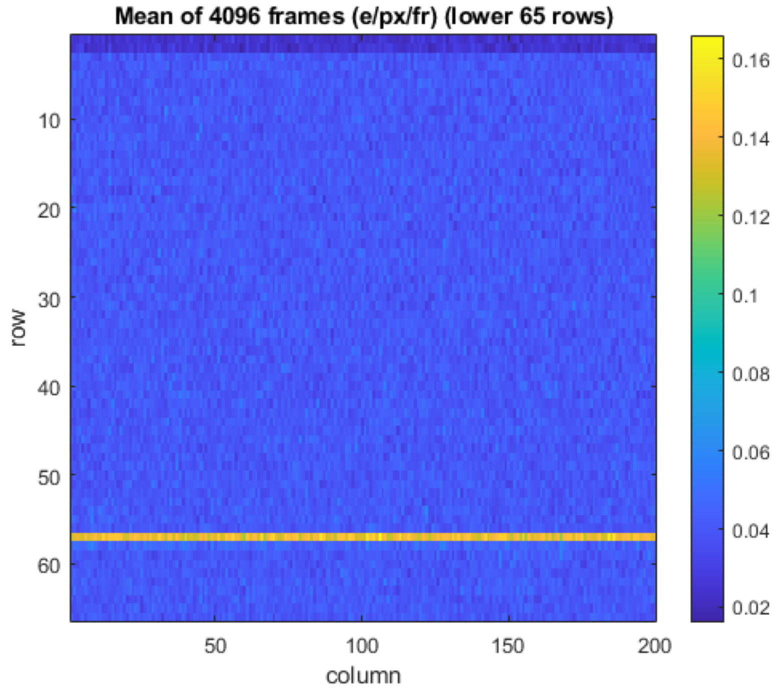


Arcticpy (output – input), noiseless



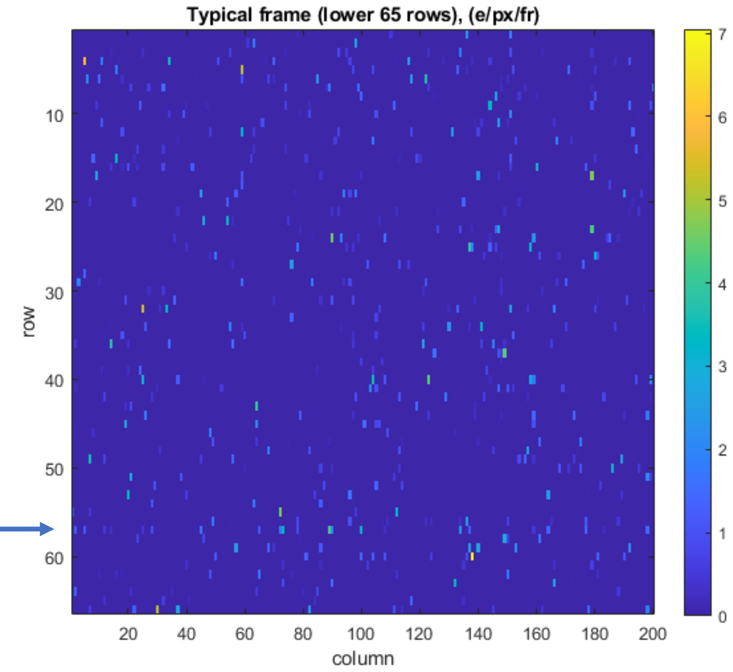
Simulated frames examples

- Average of "traps" frames (1.5 yrs):



- Typical frame:

"line charge"



Signal Loss – Nominal TTR5 Epoch: 1.5 yrs in orbit

- Signal is in one row, and traps smear it in the upstream direction.
- We estimate signal recovery effect (e.g. by fitting to smeared shape) simply by binning, since most of the loss is to the next row (ROE specific).

24,576 frames @ 200 cols/frame = 4.9e6 columns

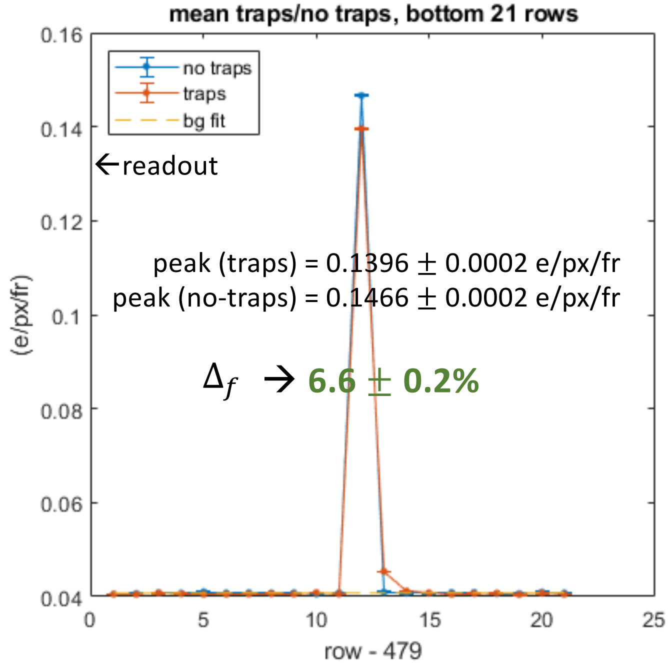
$$\Delta_f = \frac{p_0 - p_t}{S_0} = \frac{\delta p}{S_0}$$

$$\frac{\sigma_{\Delta_f}}{\Delta_f} = \frac{\sigma_{\delta p}}{\delta p} \oplus \frac{\sigma_{S_0}}{S_0}$$

and $S_0 = p_0 - bg_{fit}$

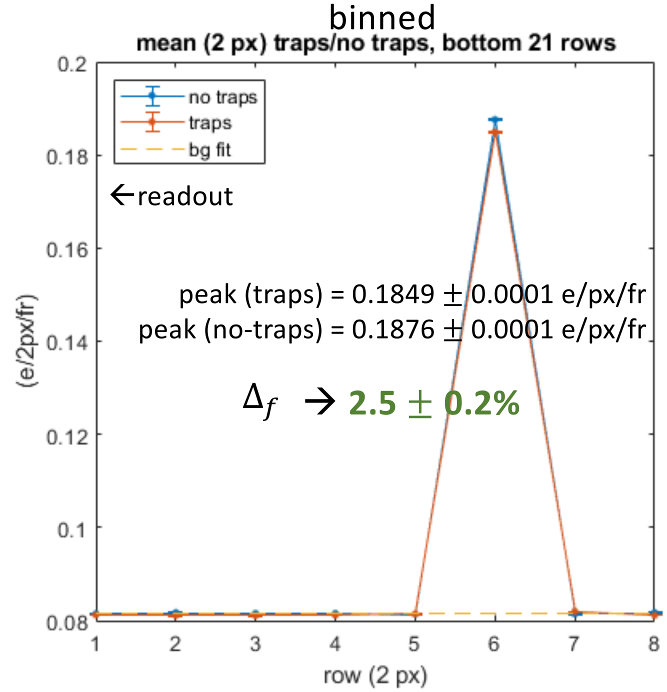
σ's calculated from Poisson stats.

unbinned



bottom 21 rows

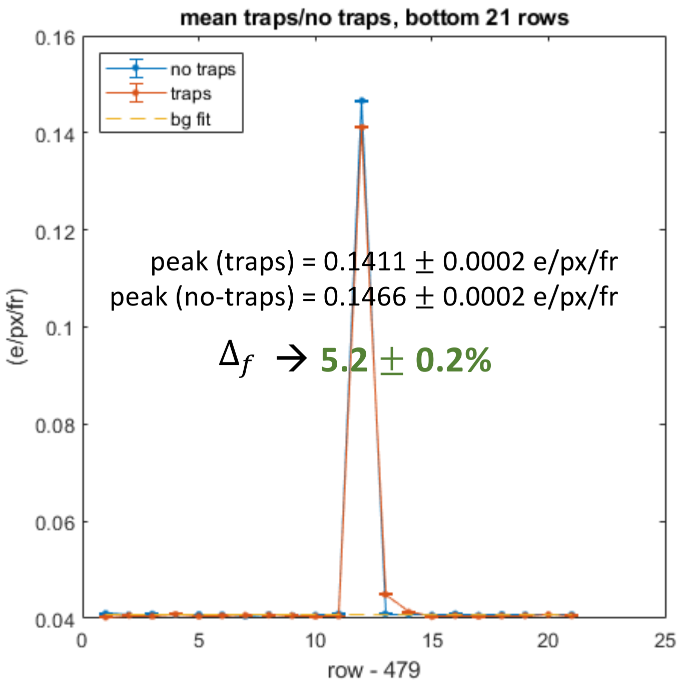
binned



Signal Loss – 1.0 yr in orbit

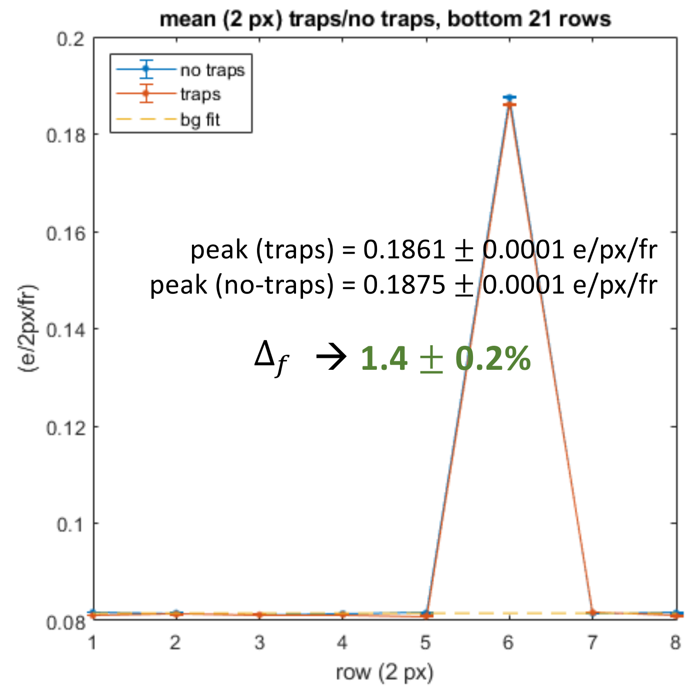
- 24,576 frames @ 200 cols/fr = 4.9e6 columns

unbinned



bottom 21 rows

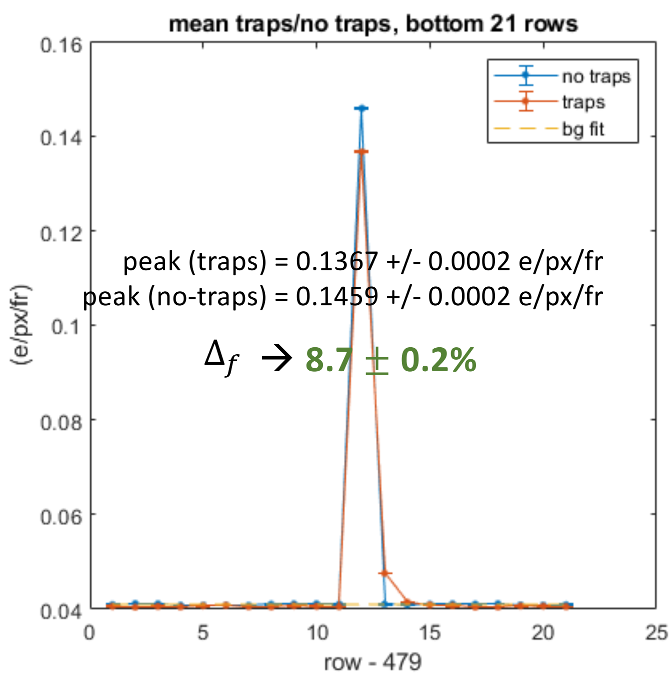
binned



Signal Loss – 3.0 yrs in orbit

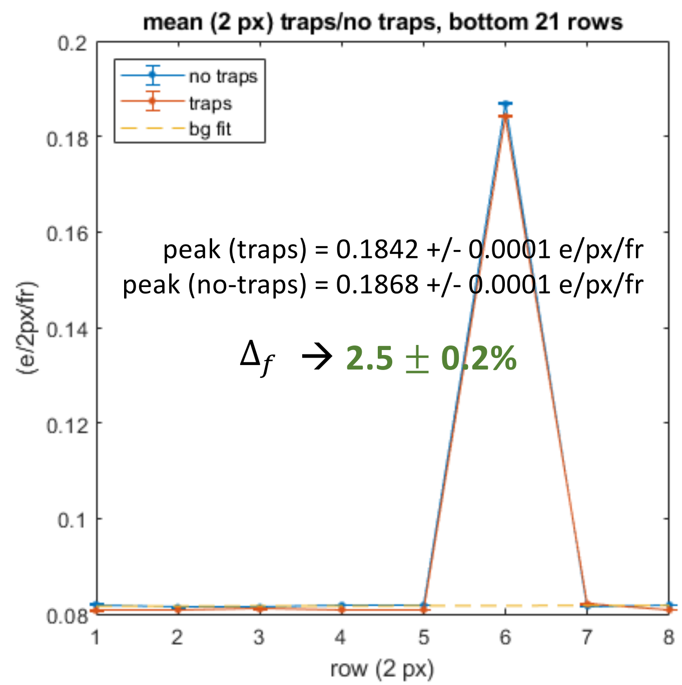
- 24,576 frames @ 200 cols/fr = 4.9e6 columns

unbinned



bottom 21 rows

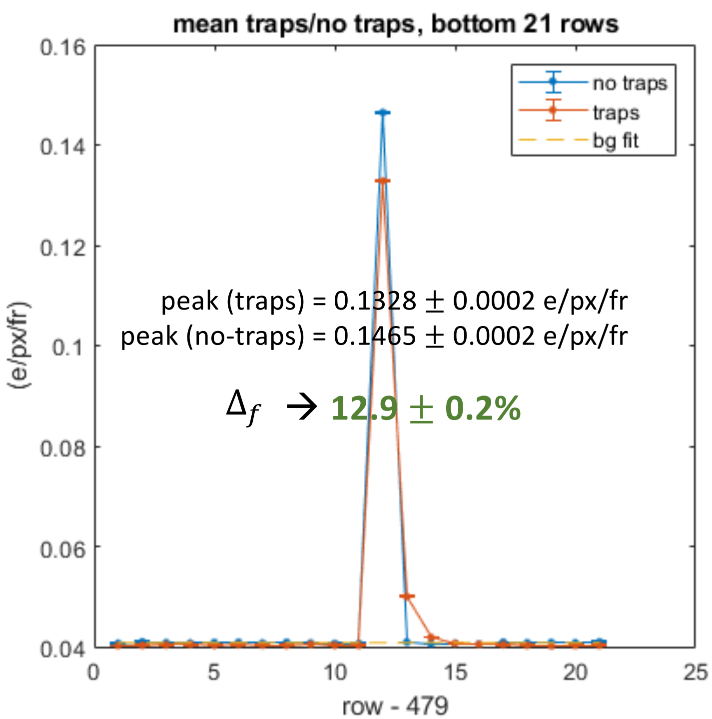
binned



Signal Loss – 5.0 yrs in orbit

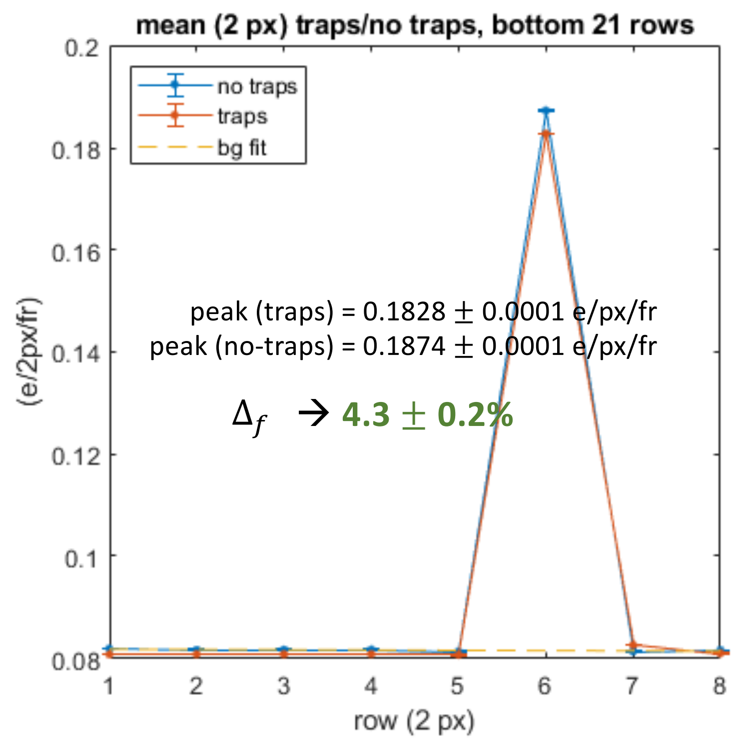
- 24,576 frames @ 200 cols/fr = 4.9e6 columns

unbinned



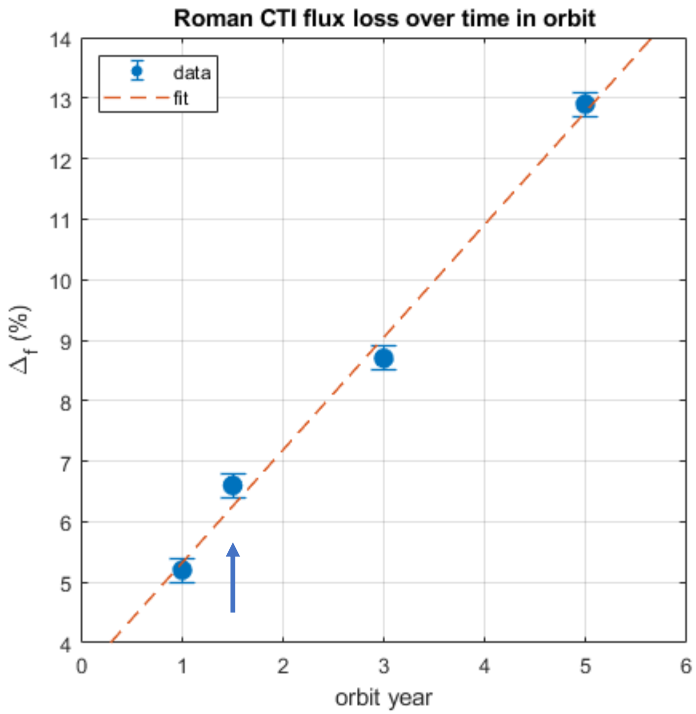
bottom 21 rows

binned

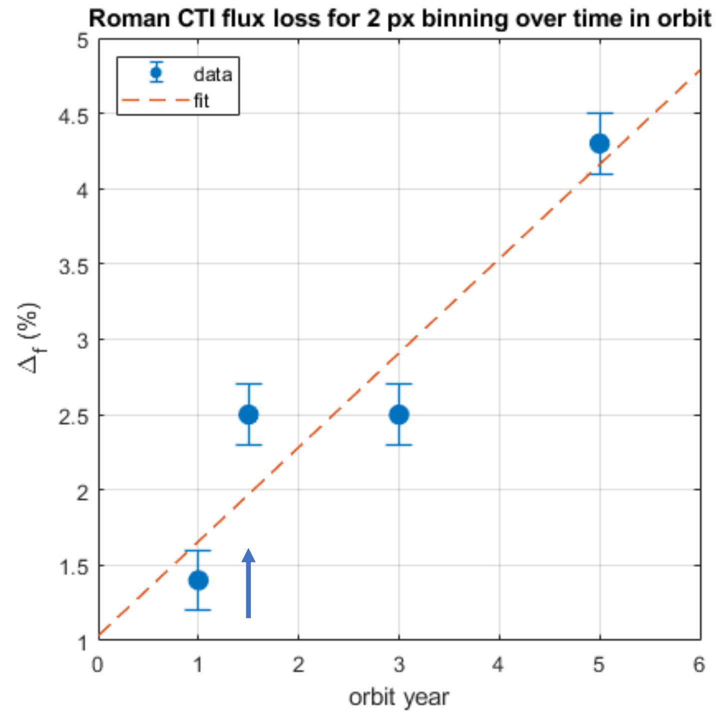


CTI effect on flux loss with orbit time

- Flux loss summary plots:



6.3% flux loss from fit at 1.5 yrs



2.0% flux loss from fit at 1.5 yrs

Summary

- CTI:
  - Results in Roman CGI exoplanet flux loss of 6.3% at 1.5 yrs in orbit.
  - effect on binned (2 px) data is 2.0% flux loss at 1.5 yrs in orbit.
    - Binning captures the smeared signal that is potentially recoverable.
- Conclusions and recommendations:
  - Making no correction leads to a signal loss that exceeds the allocation (2.7%).
  - But, fitting to the expected shape which includes the smeared signal, recovers most of the loss, bringing the CTI effect (2.0%) to within allocation at 1.5 yrs.

Changes from last year

- Why did results change from last year?
  - Increased sample size of simulations to improve statistics,
  - Used newer ArCTIc software (as opposed to ArCTIcpy), which includes at least one error correction by Richard Massey's team,
  - Included CIC this time,
  - Did not apply thresholding this time; it introduces a systematic error with high EM gain values. EM gain modeling likely needs to be improved to do photon counting right.