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

G. Gonzalez, D. Nemati, B. Nemati

July 5, 2022
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,
  - 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
### 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/cm².
- Release times calculated from values in Table 10 using Shockley-Read-Hall theory.
- Assumed 13μm³/pix charge packet volume (upper limit, N. Bush, priv. comm.).

<table>
<thead>
<tr>
<th>Species</th>
<th>Energy level</th>
<th>Em. cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>VV⁻⁻</td>
<td>0.235 ± 0.005</td>
<td>(2.6 ± 0.5) × 10⁻¹⁵</td>
</tr>
<tr>
<td>Si-E</td>
<td>0.475 ± 0.015</td>
<td>(3.7 ± 0.8) × 10⁻¹⁴</td>
</tr>
<tr>
<td>Si-U</td>
<td>0.37 ± 0.01</td>
<td>(8.7 ± 0.7) × 10⁻¹⁵</td>
</tr>
<tr>
<td>VV⁻</td>
<td>0.42 ± 0.01</td>
<td>(2.0 ± 1.0) × 10⁻¹⁵</td>
</tr>
<tr>
<td>Si-A</td>
<td>0.165</td>
<td>6.1 × 10⁻¹⁵</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Trap species</th>
<th>Trap density growth rate (traps/μm³/yr)</th>
<th>Initial density (traps/μm³)</th>
<th>Density @ 21 months (traps/μm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VV⁻⁻</td>
<td>1.6 × 10⁻⁴</td>
<td>5.1 × 10⁻⁴</td>
<td>7.9 × 10⁻⁴</td>
</tr>
<tr>
<td>Si-E</td>
<td>8.9 × 10⁻⁴</td>
<td>1.4 × 10⁻³</td>
<td>2.9 × 10⁻³</td>
</tr>
<tr>
<td>Si-U</td>
<td>3.9 × 10⁻⁵</td>
<td>8.7 × 10⁻⁵</td>
<td>1.6 × 10⁻⁴</td>
</tr>
<tr>
<td>VV⁻</td>
<td>1.3 × 10⁻⁴</td>
<td>4.2 × 10⁻⁴</td>
<td>6.5 × 10⁻⁴</td>
</tr>
<tr>
<td>Si-A</td>
<td>1.7 × 10⁻³</td>
<td>2.6 × 10⁻³</td>
<td>5.5 × 10⁻³</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Species</th>
<th>Release time constant (s)</th>
<th>Release time constant (pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VV⁻⁻</td>
<td>5.90 × 10⁻⁵</td>
<td>5.69 × 10⁻¹</td>
</tr>
<tr>
<td>Si-E</td>
<td>5.39 × 10⁺¹</td>
<td>5.20 × 10⁺⁵</td>
</tr>
<tr>
<td>Si-U</td>
<td>1.76 × 10⁻¹</td>
<td>1.70 × 10⁺³</td>
</tr>
<tr>
<td>VV⁻</td>
<td>2.38 × 10⁺¹</td>
<td>2.30 × 10⁺⁵</td>
</tr>
<tr>
<td>Si-A</td>
<td>2.07 × 10⁻⁷</td>
<td>2.00 × 10⁻³</td>
</tr>
</tbody>
</table>

**Table 12:** Charge trap release time constants for each species.
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.
Simulated frames examples

- Average of “traps” frames (1.5 yrs):

- Typical frame:
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).

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

\[ \frac{\sigma_{\Delta f}}{\Delta_f} = \frac{\sigma_{\delta p}}{\delta p} \bigoplus \frac{\sigma_{S_0}}{S_0} \]

and \( S_0 = p_0 - bg_{fit} \)

\( \sigma \)'s calculated from Poisson stats.

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

\[ \Delta_f \rightarrow 6.6 \pm 0.2\% \]

\[ \Delta_f \rightarrow 2.5 \pm 0.2\% \]
Signal Loss – 1.0 yr in orbit

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

\[ \Delta_f \rightarrow 5.2 \pm 0.2\% \]

\[ \Delta_f \rightarrow 1.4 \pm 0.2\% \]
Signal Loss – 3.0 yrs in orbit

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

\[ \Delta_f \rightarrow 8.7 \pm 0.2\% \]

\[ \Delta_f \rightarrow 2.5 \pm 0.2\% \]
Signal Loss – 5.0 yrs in orbit

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

\[ \text{peak (traps)} = 0.1828 \pm 0.0001 \text{ e/px/fr} \]
\[ \text{peak (no-traps)} = 0.1874 \pm 0.0001 \text{ e/px/fr} \]
\[ \Delta_f \rightarrow 4.3 \pm 0.2\% \]
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.