



# CTI implementation in the Gaia simulator

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## ABSTRACT

Charge Transfer Inefficiency (CTI) due to radiation damage in Gaia CCDs will affect all the data produced by Gaia. The CTI causes **charge loss and a distortion of the effective PSF/LSF** that must be taken into account in the data reduction process. Therefore, the inclusion of a model of this effect in the Gaia simulator is a crucial point to be sure that the calibration algorithms can recover the unaffected image and the required accuracy can be achieved.

Both GIBIS and GASS simulators include CTI models, more accurate in the case in GIBIS and with some approximations in the case of GASS. In this work we explain both implementations and compare the results for some particular cases.

## THE CTI PROBLEM

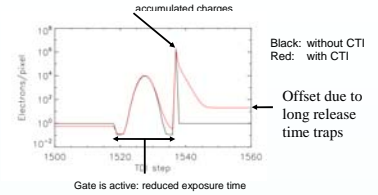
Point defects in the CCD semiconductor lattice due to particle irradiation can "capture" electrons inside the CCD and release them at a later time. This process introduces a loss of photo electrons from a light source and distorts its PSF/LSF. The actual effects depend on various different aspects:

### Technical issues:

- Gate activity ---- **adaption of exp. time to the star brightness**
- Charge injections ---- **artificially introduced charges for CTI reduction**
- AC movement of objects ---- **caused by the scanning law**

### Astrophysical issues:

- Cosmic rays ---- **inject charges in the CCD**
- Sky background ---- **acts as a diffuse optical background**
- Star density ---- **keeps traps filled and depends on the transit history**
- Spatial energy distribution ---- **not detected extended objects (e.g. galaxies)**
- Spectral energy distributions ---- **shape of spectra & spectra lines**



Example of the read-out for a source with gate activity. The source moves from right to left (i.e. smaller TDI steps are read out first)

## GIBIS MODEL

**GIBIS** (Gaia Instrument and Basic Image Simulator) is a pixel level simulator. It combines detailed models of the instrumental response and astronomical objects to produce highly realistic simulations.

### GIBIS requirements for a CTI Implementation

- treat CTI effects as realistic as possible.
- simulate some seconds of observing time within reasonable computation time: the output of Gaia is 1966 x 1017.5 pixels/second/CCD for 102 CCDs!

Model has to be fast and thus simplified...

- do not deal with effects on sub-pixel level.
- use simplified electron density distributions (not time-dependent on sub TDI period level).
- do not deal with positions of traps within the pixel.

### THE CTI MODEL (A. Short)

- Density-based: computes capture probability of an electron from a homogenous electron density.

- Not computing with discrete traps/electrons at certain locations but with *averages*.

#### Within one CCD pixel:

- Assume  $N_e$  "free" electrons within a confinement volume  $V$  uniformly distributed.

- get the finite charge capture time from density:

$$n_e = N_e/V; \tau_c = 1/(\sigma v_{th} n_e)$$

- Charge release according to an exponential from each trap species with time scale  $\tau_r$ .

- Initial value problem:

$$\begin{array}{l} \text{Initial value} \\ \text{problem:} \end{array} \quad \begin{array}{l} \frac{dN_e}{dt} = \frac{N_e}{\tau_c} - \frac{N_e}{\tau_r} \\ N_e(t_0) = N_{e,0} \end{array} \quad \begin{array}{l} N_e(t_0) = N_{e,0} \\ N_e(t_0) = N_{e,0} \end{array} \quad \begin{array}{l} N_e + N_t = \text{const.} \\ N_e + N_t = \text{const.} \end{array}$$

#### Parameters of the model:

- $n$  trap species, for each species:
- number of traps per pixel
- electron capture cross section
- release time constant

General form of the solution of the IVP:

$$N_e(t) = A - \frac{B}{1 + C \tanh(Dt)}$$

Computational "bottle neck": computing the *tanh* for each TDI step  $\sim 2.1$  ms/pixel for a full CTI simulation.

CTI for a RVS spectrum (10 x 1260 pixels) can be simulated in 26.5.

#### Procedure for one pixel and one TDI step:

- Integration from  $t = 0$  to  $t = \tau_{TDI}$ .
- Electrons from previous pixel shifted in regarded pixel.
- Photoelectrons are produced in the pixel *instantaneously*. Getting  $N_{e,0}$  and  $n_{e,c}$ .
- They interact with the traps for one TDI period ( $\sim 1$  ms): trapping and release.

Loop over all TDI periods for one CCD:

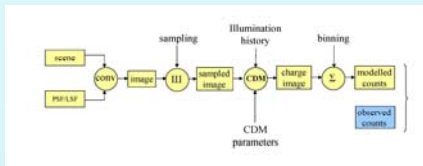
- The "free" charges  $N_e$  after 1 TDI period are "shifted" in next pixel.
- The value for captured electrons  $N_c$  is initial value for next TDI step.

## GASS MODEL

**GASS** (GAia System Simulator) is a telemetry simulator. Its main target is to simulate a big amount of data as it will be send by the satellite. Some simplifications in the instrumental response and astronomical objects are needed in order to reduce the computation time.

### CTI Implementation: CDM-01 model (L. Lindegren)

- Simple analytical model
- Phenomenological, macroscopic description



#### Charge release model:

$$\begin{array}{l} r(s_i, f_i) = (1 - e^{-\lambda t}) R f_i = \eta R f_i \\ c(s_i, f_i) = q(s_i) c_A(s_i, f_i) + (1 - q(s_i)) c_B(s_i, f_i) \end{array}$$

$$\text{Propagation: } f_{i+1} = (1 - \eta) f_i + c_i / R$$

#### Simplifications (no illumination history taken into account):

- The model is initialized every charge injection (CI).
- $f_i$  (and then  $c_i$  and  $r_i$ ) are not computed outside the window.
- At the first TDI of the window  $f_i$  is computed according to  $f_i = f_i(t_{ci}); t_{ci}$ : time since last CI.
- The model is applied inside the window.
- The charge of the window is not stored for the computation of the next window.

$$d_i = s_i - c_i + r_i$$

$d_i$ : distorted counts (charge image)

$s_i$ : sampled images

$c_i$ : captured electrons

$r_i$ : released electrons

$c_i$  and  $r_i$  depends on current and previous pixel values

$R$ : scaling parameter for the total number of traps

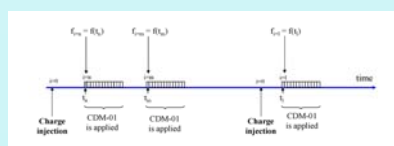
$s_i$ : input value

$\Delta t$ : TDI period

$c_A$  and  $c_B$ : depends on  $R, K, F$  (parameters) and  $f_i$

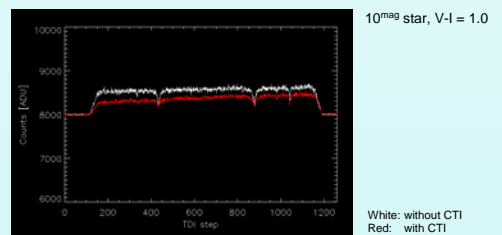
$q(s_i)$ : transit function between  $C_A$  and  $C_B$ . Depends on  $S$  (signal size for small to large signal transition) and  $s_i$

$f_i$ : equivalent fill level. Minimum level of  $s_i$  required for part of the charged to be captured

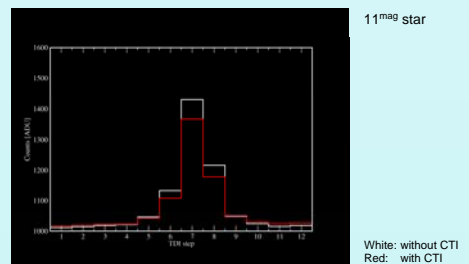


## EXAMPLES

### RVS spectra (GIBIS simulation):



### AF2 (GASS simulation):



## REFERENCES

- L. Lindegren, 2008, "Modelling radiation damage effects for Gaia: A first-order Charge Distorsion Model (CDM-01), GAIA-C3-TN-LU-LL-075-01
- A. Short, 2008, "A simple analytical model of electron trapping in CCDs", GAIA-CH-TN-ESA-AS-014-1