Implementation of models for Charge Transfer Inefficiency (CTI) in the Gaia pixel-level data simulator

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Protons are evil:

- Proton irradiation causes defects in the CCD semiconductor lattice
- These defects act as traps for electrons transferred in the CCD: charges are taken away and released at a later time
- The observed LSFs of all objects are deformed, the centroid is shifted and the signal with the transmitted window is reduced

The actual “damage” due to these effects depend on various aspects:

- The history of charges in the particular CCD
- CCD operations: Gate activity, Charge injections
- Physical effects: sky background brightness, cosmic ray events
Simulations with GIBIS

Simulations on such a level of detail is provided by the *Gaia Instrument and Basic Image Simulator*, GIBIS

- Provides pixel-level simulations of the full CCDs of all Gaia instruments: *SM, AF, BP, RP, RVS*

- As realistic as possible

- Short periods of time *(seconds, minutes...)*

- Includes an
  - universe model: *stars, galaxies, asteroids,...*
  - instrument model: *gates, on-board detection, scanning law,...*

GIBIS is potentially a useful tool for CTI simulations
GIBIS example:  

AF2 simulation

charge injections

cosmic ray events

galaxies

gate activity
GIBIS example: AF2 simulation

Add CTI to these simulations...

but: it's a lot of data to be simulated!
CTI models in GIBIS:

1) Model by Safa & Marchais  (GAIA-ASF-TCN-PLM-00071)

Characteristics:

- Line-by-line approach: AC-velocity of Zero is assumed

- Volume-based: number of traps seen by a charge package scale with its size

- Simulations on TDI-period level

- Scans through the past of each pixel: computational effort increased dramatically with the length of the signal to be simulated

Performance:

- Only AF

- Only up to three stars

- Gate activity included

no future
CTI models in GIBIS:
2) Analytical model by A. Short (GAIA-CH-TN-ESA-AS-014-1)

Characteristics:
- Line-by-line approach
- Density based: homogeneous electron density within a given pixel volume
- Simulation on TDI-period level without scanning through the history

Performance:
- Simulations for all instruments possible, but slow
- Gate activity included
- Can simulate cosmics

Flexible model, but too slow for “mass application”
CTI models in GIBIS:

3) CDM02  

(GAIA-CH-TN-ESA-AS-015-1)

Characteristics:

- Line-by-line approach

- scaling between density-based and volume-based possible: homogeneous electron density within a volume that scales with number of charges in a pixel

- TDI-line level: not every TDI-step is simulated

- For TDI mode and Imaging mode available: can be used for CTI in the CCD imaging section and for CTI in the read-out register

Performance:

- Simulations for all instruments are possible, incl. read-out register

- very fast

- no gate activity, no cosmics

   good for “mass applications”, but not too detailed
GIBIS + CTI: examples

Example computations with the Analytical Model
currently only this model allows for simulations of cosmics

1) Sky background brightness

2) Cosmics (not a standard GIBIS feature)

Warning:
- Model parameters (number of traps per pixel, charge release time constants, ...) are only preliminary by now
- Validation still ongoing
Sky Background Brightness

- Background brightness is caused by zodiacal light and unresolved stars
- It thus varies over the sky with a 6h-period

  minimum value: 0.9 e⁻/pixel/transit
  median value: 1.7 e⁻/pixel/transit
  maximum value: 6.2 e⁻/pixel/transit

  (Jos de Bruijne, GAIA-CA-TN-ESA-JDB-031-1)

- Sky background acts like a diffuse optical background and keeps a (small) fraction of traps permanently filled

  How does this affect the CTI in different parts of the sky?
Sky Background Brightness

Example case:

two stars of 18mag after each other

comparing charge loss per pixel with different sky backgrounds

Up to 20% difference in charge loss for different sky backgrounds
Cosmic Ray Events

- Only a minority of irradiating particles interact significantly with nuclei in the semiconductor

- Most particles loose energy due to interactions with electrons in the CCD

- They thus produce free charges that are transferred together with the photo-generated charges

- These charges (="cosmics") represent random charge injections in different positions within the CCD

- There will be no knowledge on cosmics during data analysis

What is their effect on CTI effects?
Cosmic Ray Events

Example:

cosmic in front of a $18^{\text{mag}}$ and $14^{\text{mag}}$ star
3000 e$^-$/pixel in the cosmic
produced in TDI period 100, 2000, or 4000
Cosmic Ray Events

Comparison between CTI with and without cosmic:

![Graph showing relative difference in charge loss with TDI steps 100, 2000, and 4000. The graph indicates a several percent difference in charge loss.]

→ several percent difference in charge loss
Tools for CTI simulations are available in GIBIS:
- for all instruments
- for imaging section and read-out register

CTI simulations can be selected by the GIBIS user
- see GIBIS simulation method page

Complex situations can be simulated:
- e.g. sky background, *cosmics*, gate activity,...

A systematic study of different aspects is still lacking
- but will be done as the model parameters are better constrained