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

M. Weiler
C. Babusiaux

Observatoire de Paris – Meudon, GEPI

Introduction

Protons are evil:

- Proton irradiation causes defects in the CCD semiconductor lattice
- These defects act as traps for electrons transfered 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

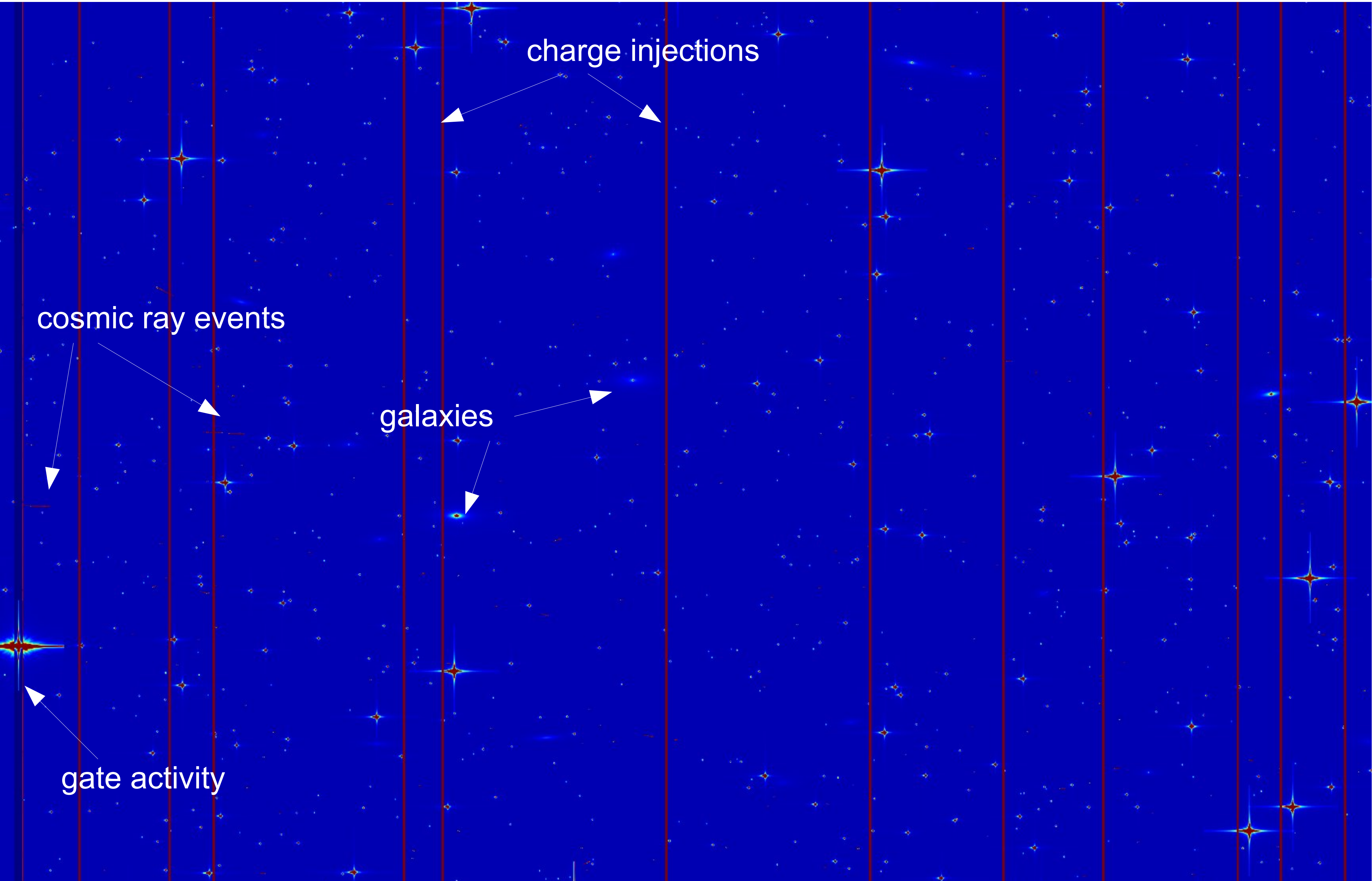
- As realistic as possible

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

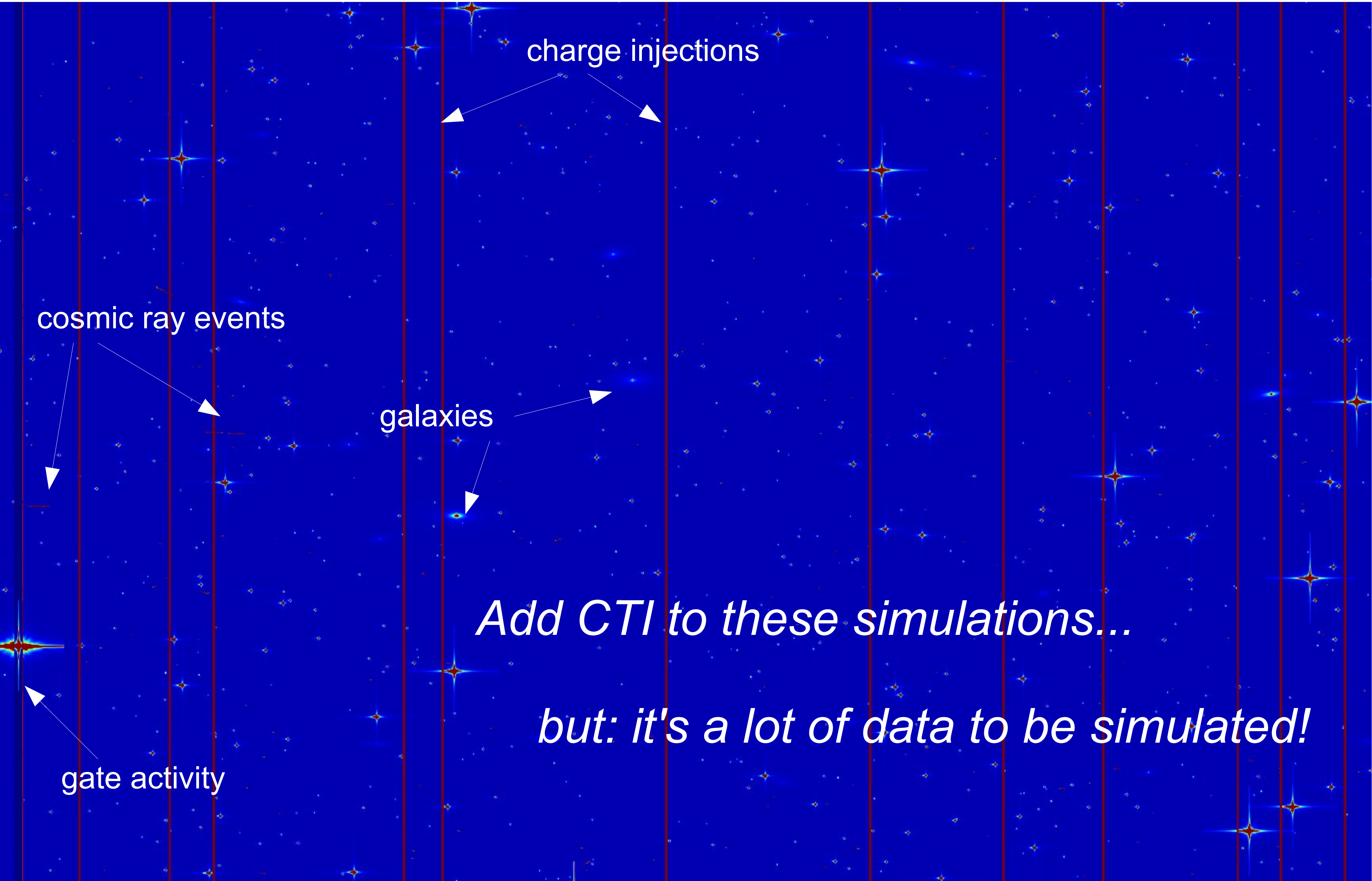
- Includes an
  universe model: *stars, galaxies, asteroids,...*
  instrument model: *gates, on-board detection,scanning law...*

GIBIS is potentially a useful tool for CTI simulations

GIBIS example: *AF2 simulation*



GIBIS example: *AF2 simulation*



CTI models in GIBIS:

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

<u>Characteristics:</u>

- 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

<u>Performance:</u>

- 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

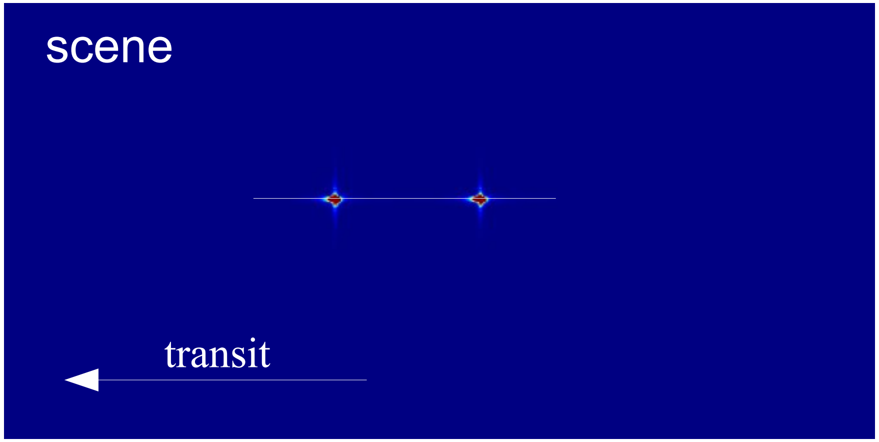
minimum value:	0.9 e^- / pixel / transit
median value:	1.7 e^- / pixel / transit
maximum value:	6.2 e^- / pixel / transit

(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?

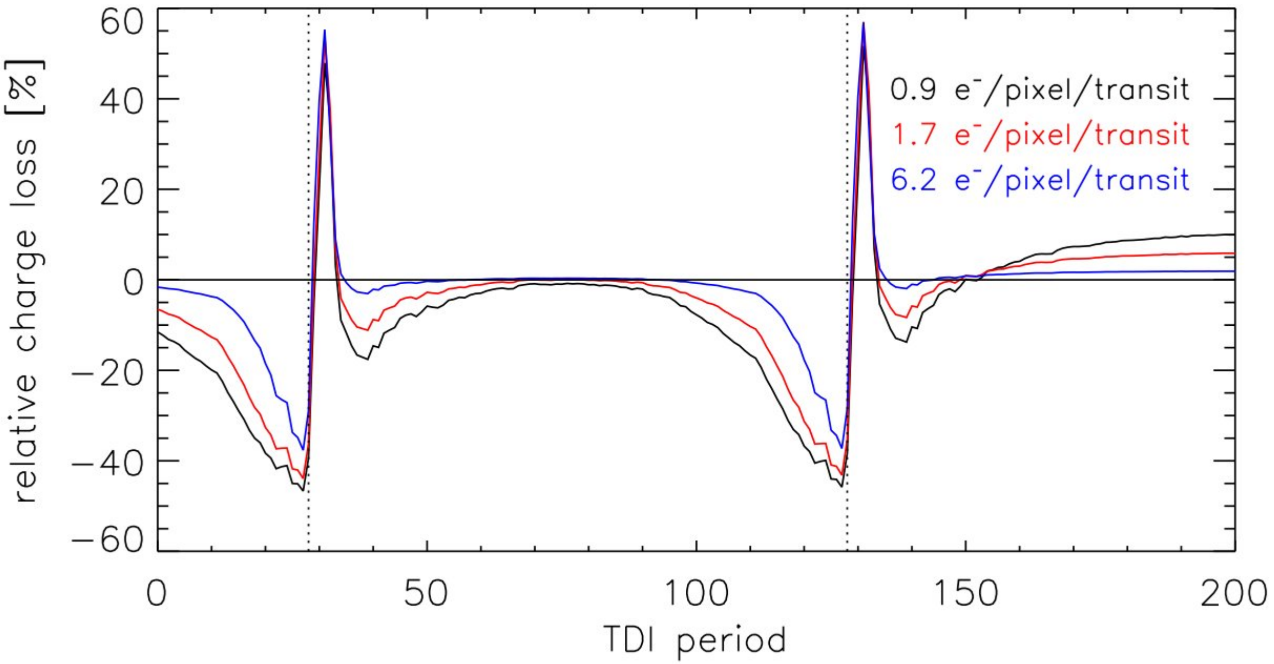
Sky Background Brightness



Example case:

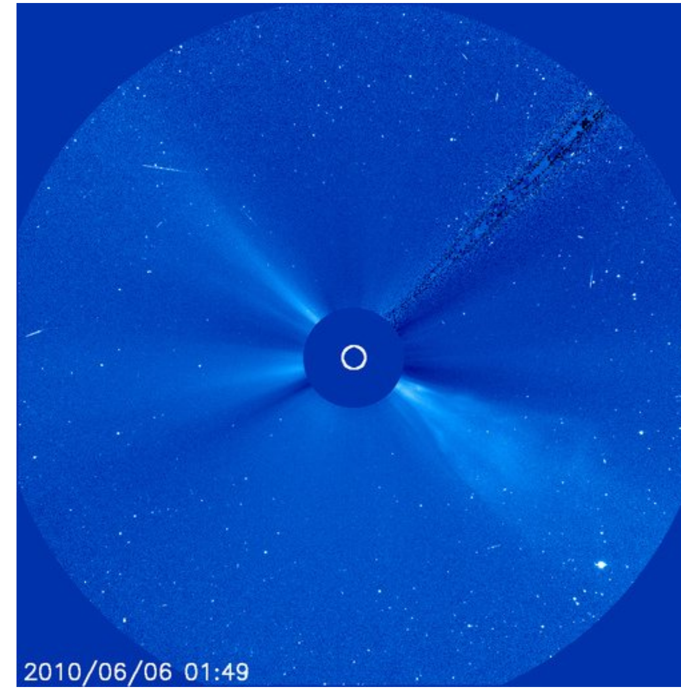
two stars of 18mag after each other

comparing charge loss per pixel with different sky backgrounds



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

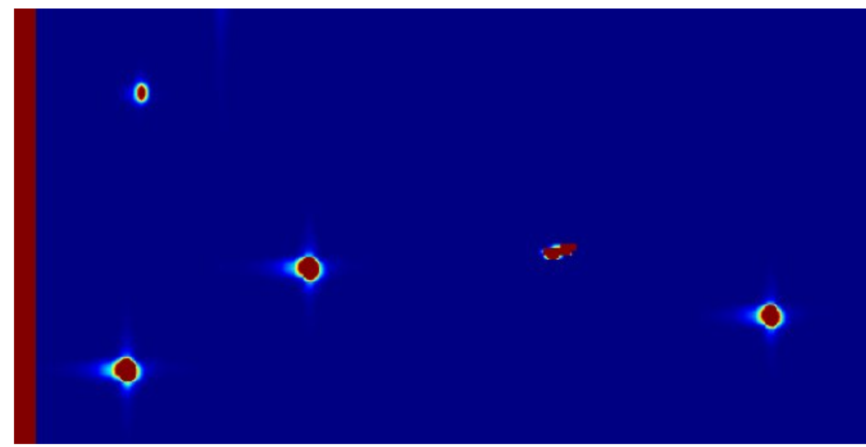
Cosmic Ray Events



- 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 transfered together with the photo-generated charges

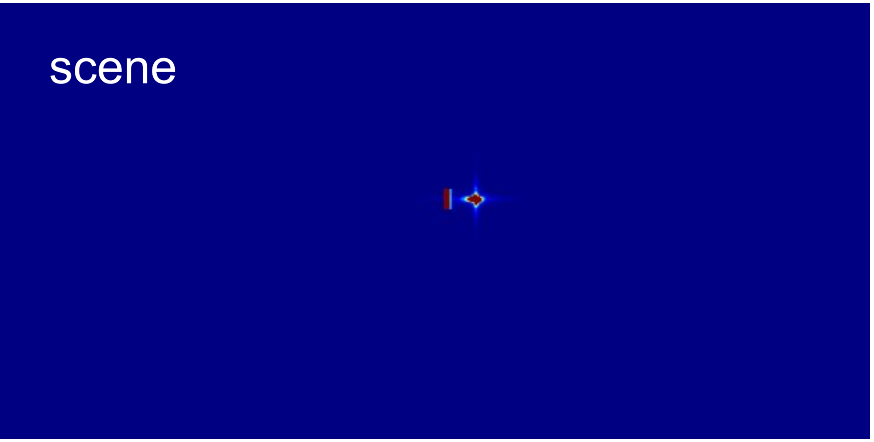


- These charges (=*"cosmics"*) represent random charge injections in different positions within the CCD

- There will be no knowledge on *cosmics* during data analysis

What is their effect on CTI effects?

Cosmic Ray Events

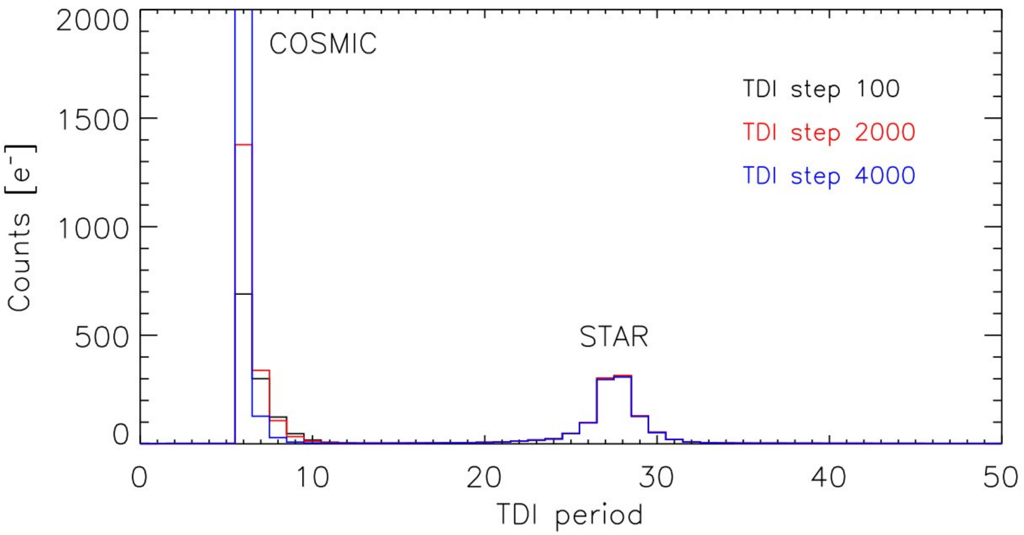


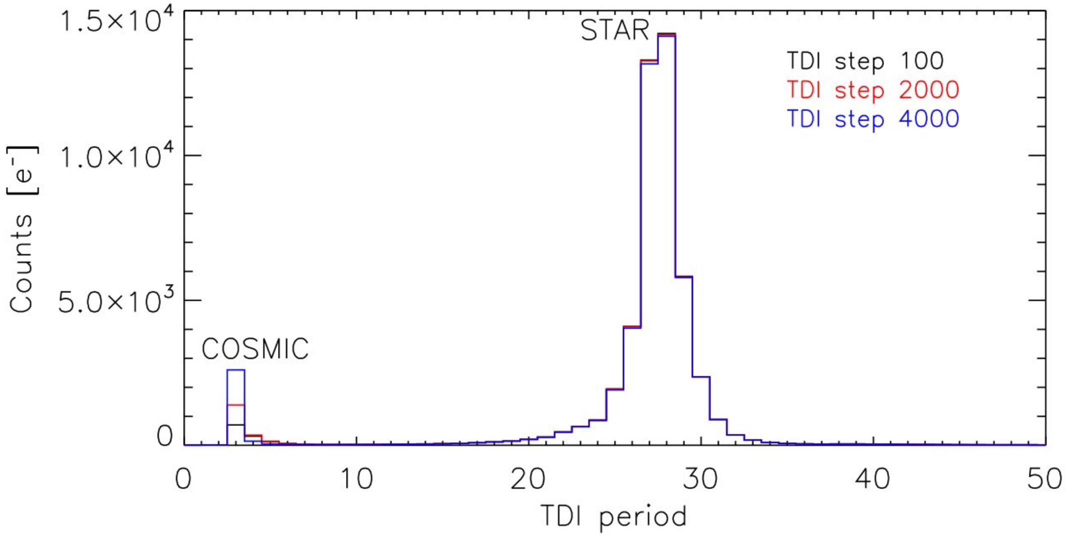
Example:

cosmic in front of a 18^{mag} and 14^{mag} star

3000 e^{-}/pixel in the *cosmic*

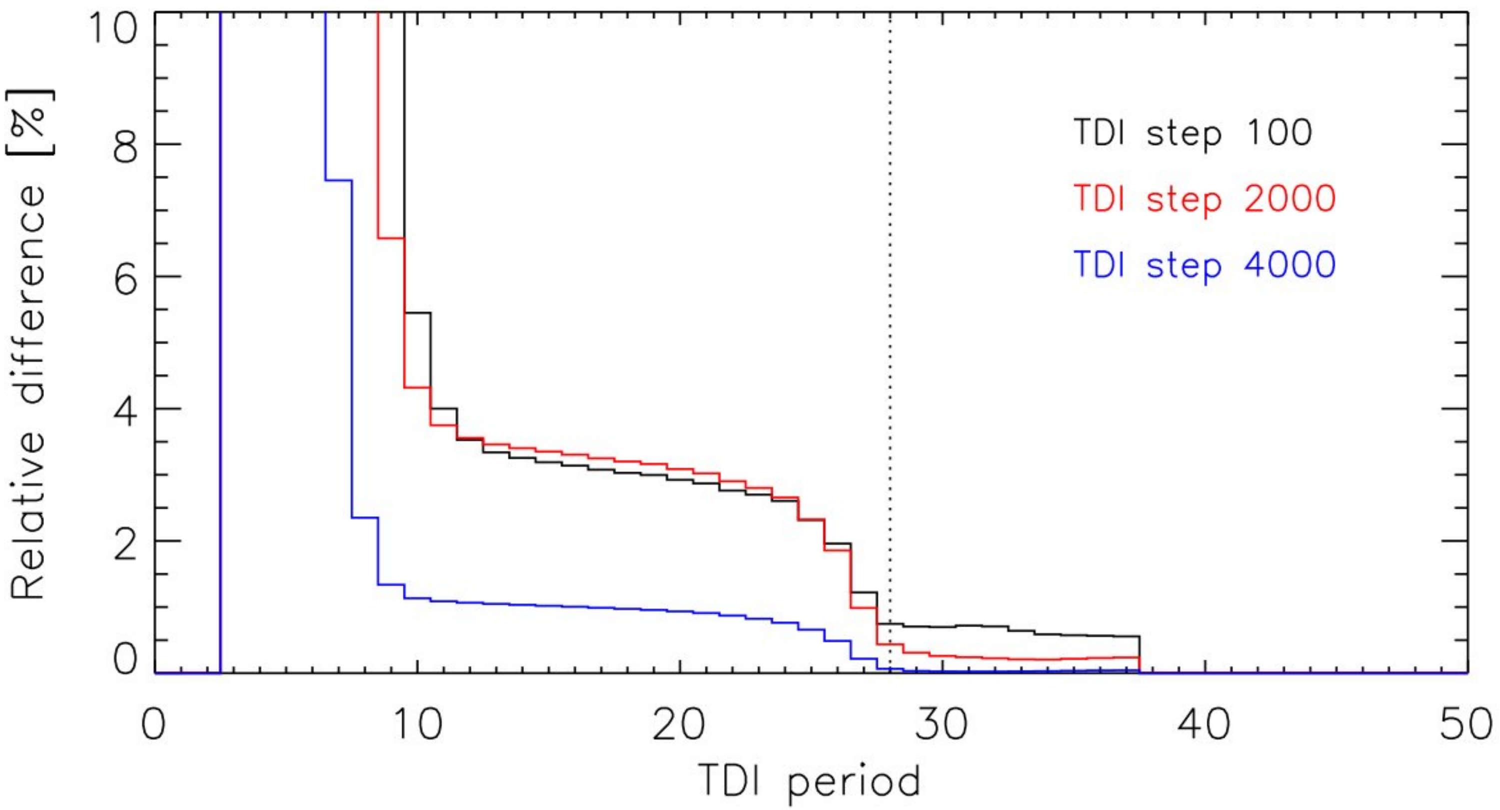
produced in TDI period 100, 2000, or 4000





Cosmic Ray Events

Comparison between CTI with and without *cosmic*:



➡ **several percent difference in charge loss**

Summary

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