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C. Charbonnel, F. Combes and R. Samadi (eds)

SIMULATING CHARGE TRANSFER INEFFICIENCY EFFECTS ON FUTURE GAIA DATA

Weiler, M.[1] and Babusiaux, C.[1]

Abstract. Gaia is an ESA cornerstone mission to perform high-accuracy astrometry as well as photometry of about 10^9 objects in the sky down to 20^{mag}. For the brightest objects also spectrocopic observations will be obtained. To reach the accuracy aimed for, the data calibration has to correct for Charge Transfer Inefficiency effects in the CCDs, resulting from particle irradiation in space. This work presents first attempts to simulate the influence of such effects upon the expected data Gaia will provide - an essential step towards the development of calibration procedures.

1 Introduction

The Gaia spacecraft will scan the whole sky continuously during five years. All non-extended astronomical sources brighter than 20^{mag} will be automatically detected and the CCD data within a window allocated to the source will be sent to ground. The CCDs will be operated in Time Delay and Integration mode (TDI), shifting the electrical charges produced by the light of the source with the same velocity towards the read-out register as with which the source moves over the focal plane due to the scanning. From the windows allocated to a source on different CCDs, the position of the center of the Point-Spread-Function (PSF), the brightness of the source, and, using the spectroscopic instrument, the position of spectral lines will be determined (Lindegren et al. 2008).

2 What is Charge Transfer Inefficiency?

In the space environment, the CCDs will be subject to particle irradiation, mainly by protons of solar origin. The particles can cause displacements of atoms from their regular position within the CCD semiconductor lattice. Such vacancy defects result in localized electronic energy levels between the valence band and the conduction band. Electrons from the conduction band can enter these energy levels and getting thus excluded from the charge transfer until a re-emission to the conduction band. The defects are therefore called ”traps”, while the full effect is called Charge Transfer Inefficiency (CTI). It leads to a ”smearing” of the PSF, complicating the data analysis.
Since electron release time scales can reach up to hundreds of seconds, sources that have passed over the CCD before a particular other source can influence the CTI effects. Traps may still be filled by electrons from the preceding source, or electrons captured from the source before are released into the PSF of the following source.

3 How are Charge Transfer Inefficiency Effects Modeled?

The current modeling approach, a certain number of electrons inside a CCD pixel access a certain number of traps and fill these traps completely, while the remaining number of traps inside the pixel remains empty. It is assumed that the electrons are captured instantaneously by the traps (i.e. the capture time constant is much smaller than the residence time inside one pixel), and that the electrons are re-emitted according to a sum of five exponentials. Each exponential represents a particular type of trap, characterized by its release time constant. Such different types of traps could be realized by complexes of two or more vacancy defects in the lattice, or by

[1] Observatoire de Paris-Meudon, GEPI, 92195 Meudon, France

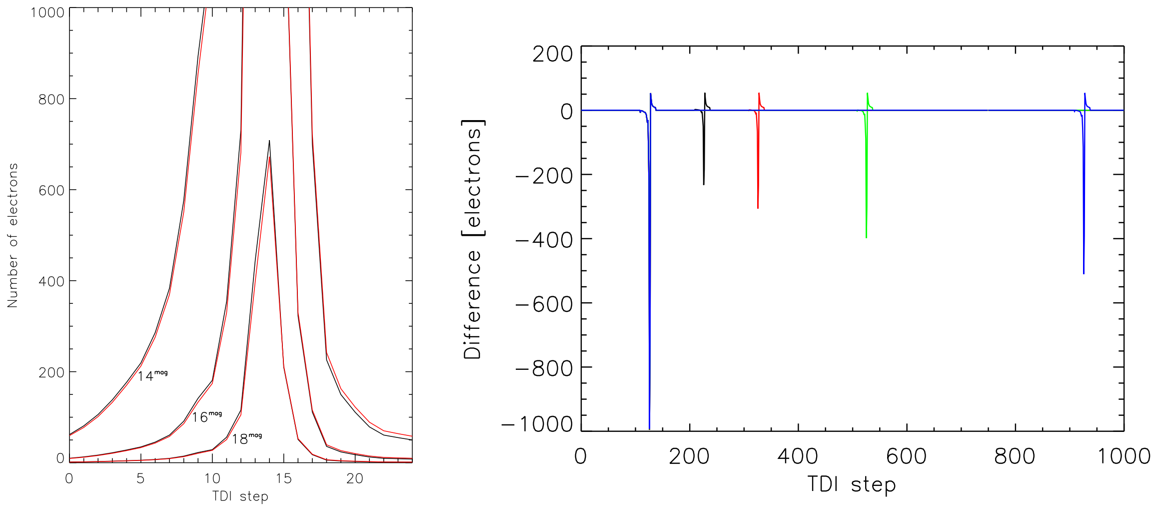

Fig. 1. Left: Cut through the central part of the PSF of stars with three different magnitudes. Black lines: without CTI effects, red lines: with CTI effects. **Right:** Difference in electrons between simulations with and without CTI effects for two consecutive stars. The different colours represent the results for different separations of the stars. In both images pixels were read out in the order of increasing numbers of TDI steps.

complexes of vacancy defects and dopants. The model keeps track of the amounts of electrons that have passed through a CCD pixel before, and thus allows to compute the fraction of empty traps and the release probability of electrons from filled traps at any TDI step. The model is included in the Gaia Instrument and Basic Image Simulator, GIBIS, that allows to simulate Gaia data, taking the physical properties of the sources as well as the optical, electronic, and mechanical properties of the Gaia spacecraft and instruments into account (Babusiaux 2005).

4 Simulation Results

First results of the modeling of CTI effects for simple source configurations are presented in Fig. 1. The left shows the central row of the PSF of stars of three different magnitudes with and without CTI effects. One can see a loss of electrons on the leading edge of the PSF and the center due to electron capture, and an excess of electrons on the trailing edge due to re-emission. The right shows the difference in electrons between a simulation without and with CTI effects for two consecutive stars of the same brightness (14^{mag}). In all cases one sees again the typical loss of electrons on the leading edge of the PSF and an excess of electrons on the trailing edge. For the trailing star, the charge loss is reduced compared to the leading star since traps are filled by electrons captured from the leading star. The larger the distance between the leading and the trailing star is, the less effective is the reduction of CTI effects for the trailing star.

5 Outlook

For more effective simulations of CTI effects, more realistic models are currently developed. These models will release strong assumptions such as the instantaneous capture of electrons. Furthermore, new models aim for faster computations in order to simulate the CCD read-out over longer times. For a more accurate modeling of the CTI effects, better constrained trap parameters (number, release time constants) are required.

References

Babusiaux, C. 2005, ESASP 576, 417

Lindegren, L., et al. 2008, IAU Symposium, Vol. 248, 217-223