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DOCUMENT

CHEOPS CTI: a rough estimate of induced noise

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1 REFERENCE DOCUMENTS

[RD1] "Tests on the proton-irradiated CCD47-20 13351-06-20", Peter Verhoeve, ESA-SRE-FV-CHP-TR-0004, Issue 1.0, 13/10/2015

2 INTRODUCTION

Charge Transfer Inefficiency (CTI) will introduce noise in the CHEOPS observations. Currently CTI effects are not included in the noise budget. It is the aim of this short note to provide a first (rough) estimate of the magnitude of the effect, based on measurements by Peter Verhoeve ([RD1]), a simple model, and coupled to the spacecraft jitter. Depending on the outcome of this quick and simple analysis, the priority of further studying CTI-effects (e.g. in CHEOPSim) can be assessed.

3 ANALYSIS

Input parameters are mainly based on Peter Verhoeve's measurements for a CCD exposed to an equivalent 10 MeV dose of 10^{10} p/cm^2 (about two to three times the CHEOPS predicted EOL dose). The relevant parameters are: a pixel with 8000 electrons loses 7% of its electrons in a roughly exponential tail. For simplicity I assume a tail length (1/e) of 100 pixels. This long tail originates from the fast transfer into the storage area and ignores the shorter tail resulting from the slower read-out of the storage area (which is position dependent). The PSF used is 'PSF_HotMap1_worst/Field1/PSF_Field1_Smaller_W_330_1100nm_Dwave5nm', while the spacecraft movement is taken from 'Case2_4RW_notBlinded_1Hz.txt' (ignoring the first three minutes, where the offset pointing is large).

The method involves projecting the PSF on the CCD taking into account spacecraft jitter, smearing the PSF with the simple, phenomenological model described below, integrating over a fixed aperture with radius 35 pixels, obtaining flux series and estimating the noise by rebinning to the appropriate time scale. No other effects are taken into account. Since the CTI effect is stronger for low level signals, and the noise budget is tightest for this star, a magnitude 9 star (7.38 10^6 electrons in 10s integration time) was used. The case of the magnitude 12 star was not considered, since more margin in the noise budget is present.

3.1 The CTI toy model

The model used is a very simple model, and describes by no means the complexity of real CTI effects. For example, each pixel is smeared completely independently from neighbouring pixel, while in reality there is a strong interaction due to trap filling of preceding pixels. Also no background is considered here (which fills the traps partly and should have a beneficial effect). For each pixel a percentage of the flux is taken and distributed in the following pixels (up to the edge of the 200x200 window; another approximation). The trails are added to the original image (taking into account the loss in each pixel). From the lab experiments a value of 7% loss for 8000 electrons was derived, which scales with the intensity, I, as $I^{-0.65}$ (this value is derived from PLATO CCDs, see RD1). At the lowest pixels values the loss percentage was limited to 100%. A higher loss percentage than 100% is clearly unphysical, but this is caused by the fact that the CTI scales with $I^{-0.65}$, while here the loss is scaled with intensity. However, a test run with a proper scaling of CTI, instead of loss, with intensity, shows identical results. An example of the obtained images (without and with aperture) is displayed in Figure 1.

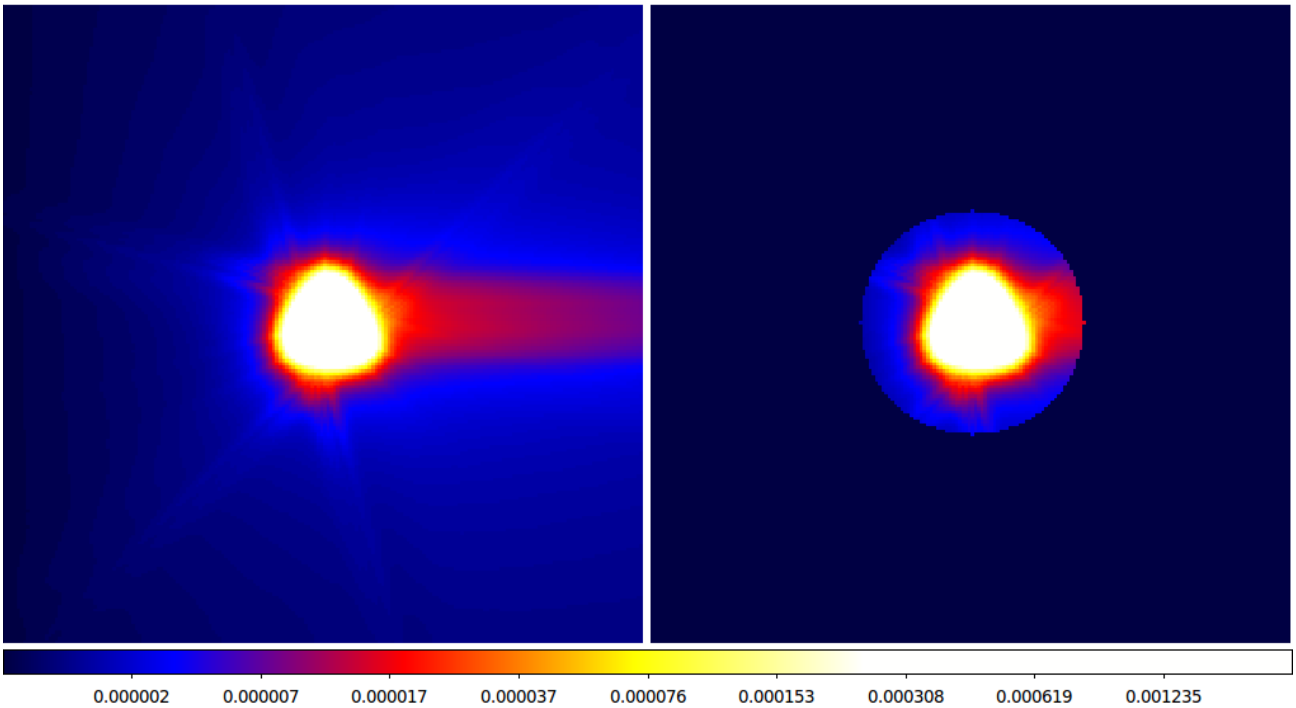

Figure 1 - The PSF as smeared through the simple and phenomenological CTI model. Scale is logarithmic and optimized to show the tails. On the right only data within the aperture is displayed. Note that the orientation of image is such that the parallel trail is in the horizontal direction.

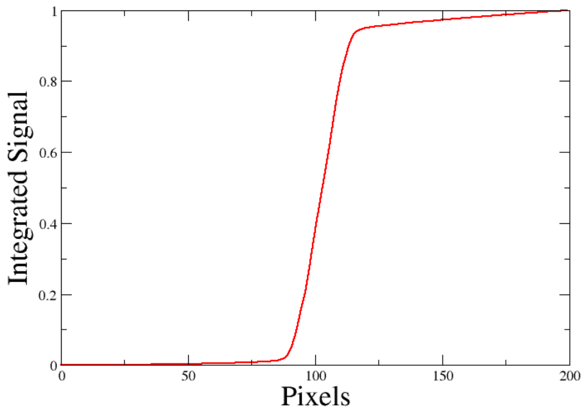

Figure 2 - Integrated signal along the parallel direction, showing the trail and the extent of the PSF.

4 RESULTS

Three cases were studied: the nominal case as described below, a case where the exponential length of the trails was lowered to 50 pixels (equivalent to a two times slower read-out of the storage area), and a case where the AOCS excursions were scaled by a factor of three, in order to provide excursions which are closer to the requirements.
In Table 1 the noise values are reported for the three cases. The three cases are also displayed in Figure 3.

Case	Noise (ppm)
Nominal	~10
Trail length 50 pixels	~13
Jitter scaled by factor 3	~33

Table 1- Obtained noise value at 6 hours resulting from inclusion of a simple CTI model for three cases.

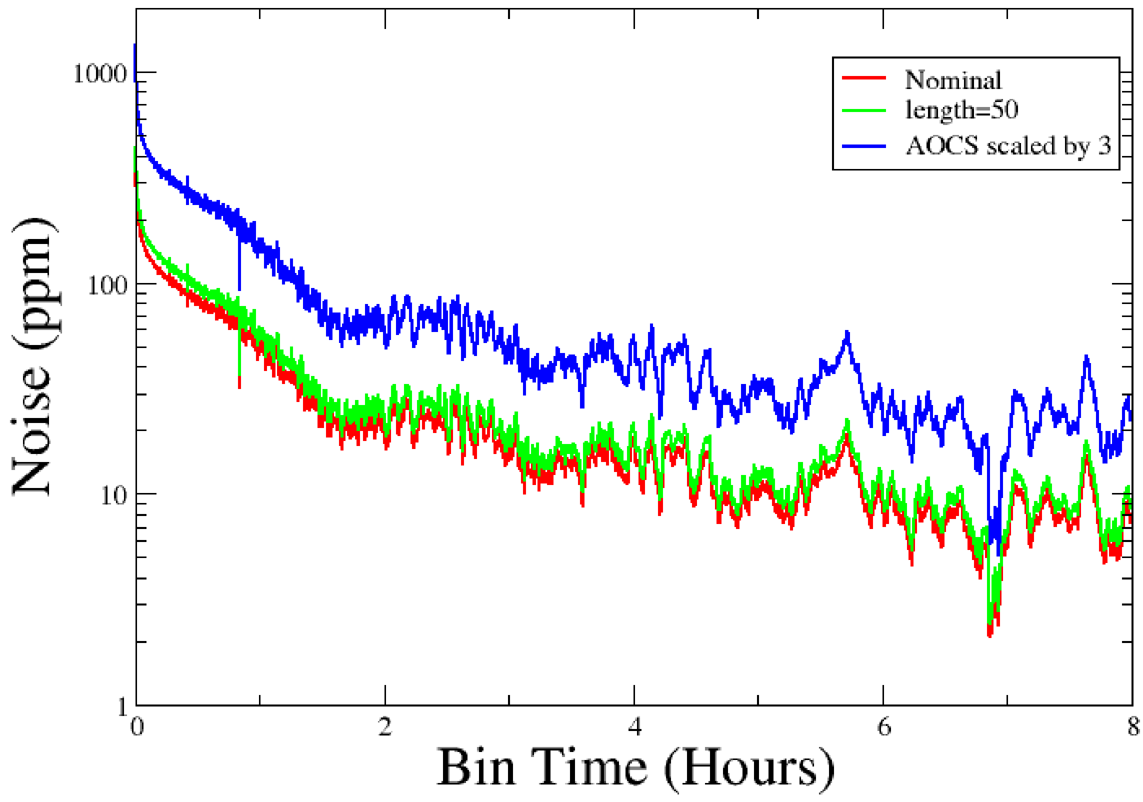

Figure 3- Noise as a function of time for the three cases.

Note that the noise values reported above do not include the results of (additional) flux losses outside the aperture. About 4% of the flux is lost outside the aperture due to the CTI effect. This would correspond to an increase in the photon shot noise of about 2%, which is probably negligible.

5 CONCLUSION

Using a very simple CTI model some initial estimates for the noise due to CTI effects were obtained. Depending on some assumptions the estimated effect for a proton dose of 1^{10} p/cm^2 (10 MeV equivalent) ranges from 10 to 33 ppm. Since this is significantly more than the CHEOPS EOL dose, these numbers can be scaled down to about 3-5 to 12-16 ppm, depending on the exact value of the EOL dose which is currently being discussed. This is a relatively small effect for the nominal AOCS performance, but has been obtained with a simple model and ignoring the contribution from the trails of (rotating) background stars. For AOCS excursions closer to the requirement the noise contribution is a very significant contribution. It is therefore concluded that a more precise modelling is required to have more confidence on the magnitude of the CTI effect. Especially emphasis should be placed on the effect of the trails of background stars rotating in and out of the aperture. This could be an important effect, depending on the brightnesses and spatial distribution of the background stars. The simplest way to do this would be inclusion of a simple CTI smearing model into CHEOPSim.