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EPIC MOS long-term stability and radiation damage effects

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Abstract. The effect of the radiation environment on the EPIC MOS detectors is analysed. An empirical model of the Charge Transfer Inefficiency (CTI) degradation since launch has been developed and coded into the SAS. It allows an appropriate correction to limit the degradation of the energy resolution. The beneficial effect of the MOS CCDs cooling to mitigate the radiation damages is also shown.

1. Introduction

The two EPIC MOS cameras comprise 14 CCD detectors. Their long-term stability is monitored routinely at the *XMM-Newton* SOC. The exposures with the internal calibration sources, acquired at regular intervals are used to monitor i) the level of activity of bad pixels, ii) the electronic background level (offset) and iii) the CTI and its effect on the energy resolution and scale.

2. Bad pixels

MOS hot pixels are defined as having a recurrence frequency above 1%. They develop during the mission as a consequence of radiation damage, mostly after the most powerful Coronal Mass Ejections (CMEs). They have to be masked out in successive on-board bad pixel tables, and flagged accordingly in the CCFs (Current Calibration Files) as small dead areas. Their number was drastically reduced to a few per CCD after the cooling of the detectors in Nov. 2002 (rev. 533). The large fraction of the few remaining hot pixels are defects from two micrometeoroid impacts: on MOS2 during the perigee of revolutions 107/108 (July 2000) and for MOS1 in revolution 325 (Sept. 2001).

3. Background

The electronic offset level of the MOSs is measured for each calibration source exposure by using the E4 energy of the events (sum of energy of pixels below the threshold in a 5x5 corona). The small down wards trend observed for some CCDs was corrected by decreasing the level of their fixed-offset used for all exposures by 1 ADU.

4. Charge Transfer Inefficiency

The evolution of the MOS parallel CTI is shown in Fig. 1 for MOS2. The jumps or

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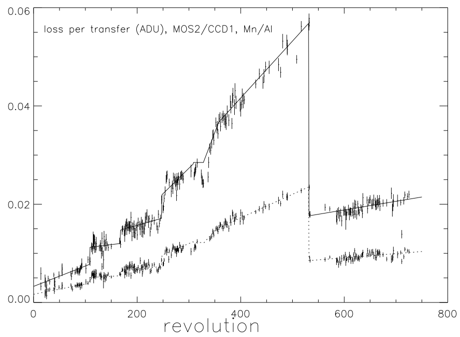

Fig. 1. Evolution of the CTI for the MOS2 central CCD, expressed as ADU signal losses per transfer, at the two energies of the calibration source, AlK_α (1487 eV) and MnK_α (5896 eV)

step increases are caused by the strongest solar CMEs (e.g. the 2000 Bastille Day solar flare around rev 110) or a series of CMEs (e.g. around revs 350). With time the degradation rate increased as if the detectors suffered a gradual "softening" to radiation. The beneficial effect of the CCD cooling from -100 to -120^oC in revolution 533 can be appreciated, reducing the CTI by a factor 3 for most CCDs and limiting the degradation rate to acceptable levels (d(CTI)/dt ~ 2.10^{-6} /year at 6 keV).

The serial CTI is mostly constant since launch, as the CCD frame store and serial register are not affected by solar proton irradiation and more shielded against high-energy radiation.

The time and energy dependence of the CTI, with the poor leverage of only two energies from the calibration source lines, has been modeled as:

$$CTIY(E,t) = (A + Bt)E^\alpha$$

where: CTIY is the ADU loss per transfer, E the raw PHA (in ADUs), t the time and A,B & α ($\alpha \sim$ 0.45-0.65) constants per CCD per time intervals (8 so far in the mission). Hence the MOS CTI scales roughly with $E^{-0.5}$ and improves toward higher energies. At revolution 700 the CTI was $\sim 1.2{\cdot}10^{-5}$ (at 6 keV).

The algorithm has been implemented in the SAS and the CTI parameters stored in the CTI CCFs. This CTI model is overlayed on the measurements in Fig. 1 Combined with an appropriate gain calibration, also time dependent to remove residuals, this yields an energy scale accuracy of better than 5 eV (as of SAS 6.0) on the whole MOS energy range, and allows the energy resolution to stabilize after the CCD cooling (FWHM = 77 eV at 1.5k eV and 140 eV at 6 keV).

The pn back-illuminated CCDs, which are much less sensitive to soft-proton radiation than the MOSs, due to the depth of the burried channels, are degrading at a similar rate when the pixel size is taken into consideration. This fact shows that a relative low dose of soft-protons is reaching the CCDs, and hence that the operational procedures to protect the CCDs against radiation are pertinent. The total soft-proton accumulated by the MOS CCDs in three years of operations is estimated at $\sim 10^6$ cm^{-2} by using the counts of the pn discarded lines above the MIPS quiescent level.

5. Conclusions

The MOS radiation damage has been mitigated with the cooling of the CCDs, limiting the CTI degradation rate and leaving good prospects for the long-term stability. The CTI has been modeled successfully with an empirical model in the SAS.

References

Abbey A.F. et al., "Cooling out the radiation damage on the EPIC MOS CCDs", Nucl. Inst. and Meth. in Phy. Res., 2003