THE XMM-NEWTON EPIC PN CAMERA: SPECTRAL AND TEMPORAL PROPERTIES OF THE INTERNAL BACKGROUND

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Abstract

We present a summary of spectral and temporal properties of the internal background in the EPIC pn camera aboard XMM-Newton using the filter wheel “Closed” and “CalClosed” positions. This is also compared with science observations (thin filter).

Key words: Missions: XMM-Newton – EPIC pn – filter wheel – calibration – X-ray fluorescence – background

1. Introduction

The performance of the EPIC pn camera (Pfeffermann et al. 1999, Strüder et al. 2001) aboard XMM-Newton is verified in orbit by observations of dedicated astrophysical objects (e.g. Haberl et al. 2002) as well as by exposures using the filter wheel in “Closed” and “CalClosed” positions (see Freyberg et al. 2002 and references therein). *Closed* data are used to analyse the internal background over the whole available energy range without “disturbance” by cosmic X-rays or energetic particles passing through the telescope. Above the highest energy of the internal calibration source emission in the *CalClosed* data (i.e. the Mn-Kβ line at $\sim$ 6.4 keV) the events can also be used to investigate spatial, spectral, and temporal properties of the detector. This filter position is also used when no scientific observations can be performed due to high radiation. The spatial properties of the internal background have been described by Freyberg et al. (2002), here we concentrate on spectral and temporal features.

2. Global spectra

Figure 1 shows a spectrum of all available “CalClosed” data in nominal setup in FullFrame (FF) and Extended-FullFrame (eFF) modes, with a total integration time of 1258 ks. The upper panel contains the spectrum of single-pixel events while in the bottom panel only double-pixel events are used. Due to the high statistics also weak lines are clearly visible like Au-Lβ (11.4 keV) or the Mo-Kα and Mo-Kβ lines at 17.4 and 19.6 keV (bottom), respectively. Especially the only very small deviation of the high-energy lines (< 0.3%) from the nominal positions demonstrates the accuracy of the energy corrections even beyond the X-ray telescope energy band. Similarly in Fig. 2 spectra of merged “Closed” data are shown for singles (top) and doubles (bottom), with an integration time of 105 ks.

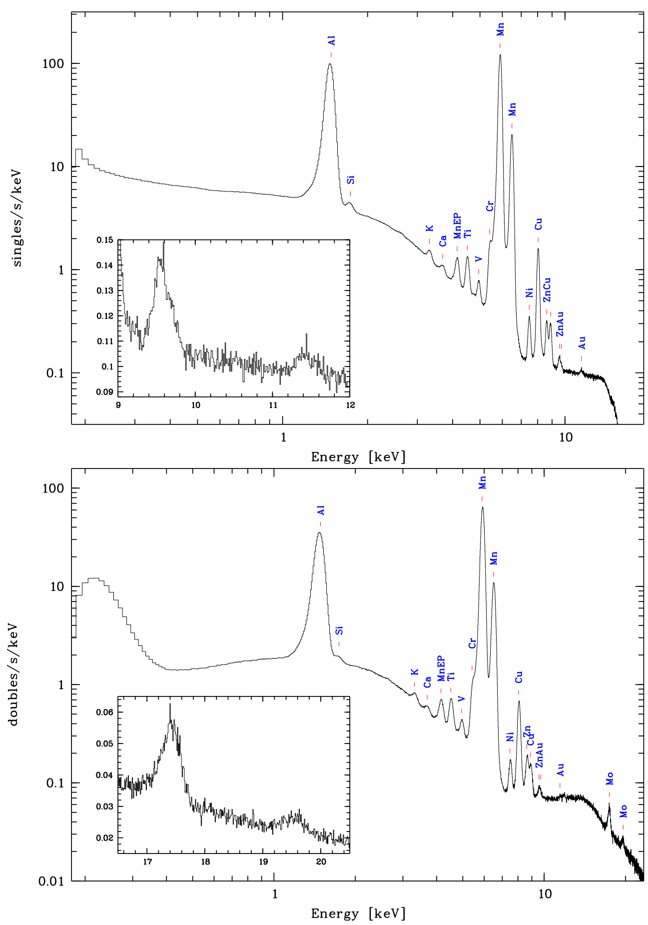

Figure 1. EPIC pn spectra of 1258 ks merged “CalClosed” data (internal calibration source) with single-pixel events (top) and double-pixel events (bottom), 10 eV *bins. Characteristic line energies are marked. The singles spectrum cuts off at* $\sim$ 15 keV *due to the onboard MIP rejection (see Appendix) and higher energies are only obtained with doubles. For details see text.*

3. Selected spectra

Figure 3 compares the single (upper panel) and double (lower panel) spectra of a long “CalClosed” measurement

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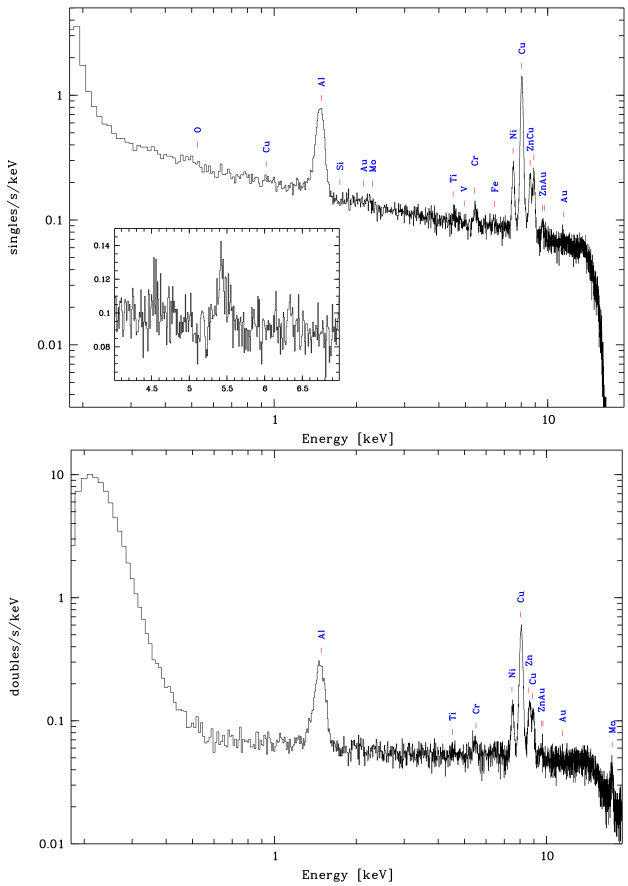

Figure 2. EPIC pn spectra of 105 ks merged "Closed" data (internal background), similar to Fig. 1: singles (top), doubles (bottom), with several line positions for illustration purposes. Both panels have the same relative ordinate dynamic range.

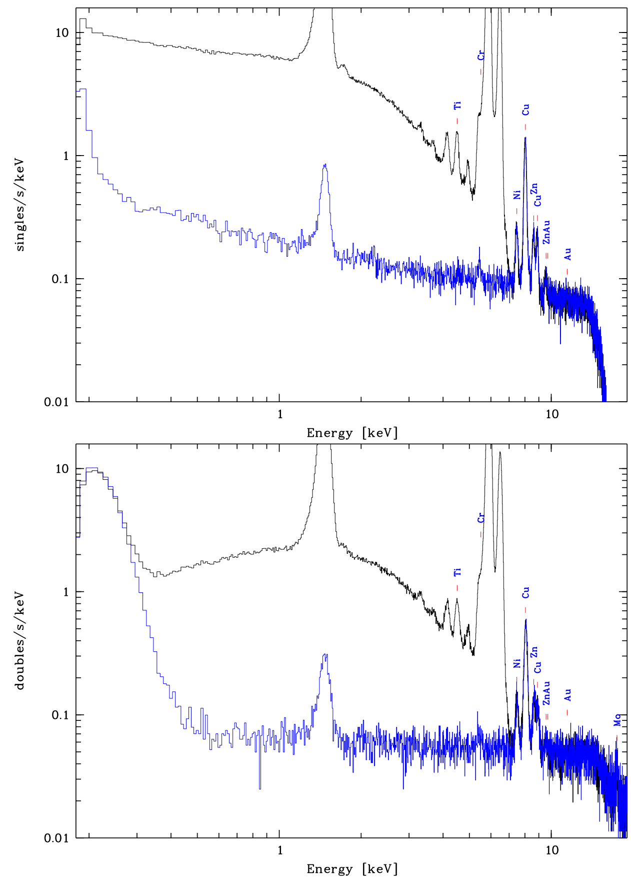

Figure 3. Spectral comparison of "CalClosed" data with "Closed" data (0080_0124700101_PNS003, black; 0059_0122320701_PNS003, blue, respectively). singles (top), doubles (bottom); for details see text.

Table 1. EPIC pn data sets mentioned explicitly in the text

Identifier	Mode–Filter	t [ks]	Date
0059_0122320701_PNS003	FF–Closed	49.5	05-04-2000
0080_0124700101_PNS003	FF–CalClosed	69.0	17-05-2000
0089_0125960201_PNS003	FF–Thin1	14.0	04-06-2000
0242_0109890301_PNS005	FF–CalClosed	76.4	04-04-2001
0321_0112480201_PNS001	eFF–Thin1	13.3	09-09-2001
0355_0106660401_PNS003	eFF–Closed	30.0	16-11-2001

(0080_0124700101_PNS003, black) with a "Closed" exposure (0059_0122320701_PNS003, blue) done with similar conditions (see Tab. 1). Above ~ 7 keV the spectra agree remarkably well which shows that the high-energy internal background can not only be inferred from "Closed" but also from "CalClosed" data. This is exploited in the narrow-band fluorescent images by Freyberg et al. (2002). The different spectral slope for single (`PATTERN=0`) and double ($1 \leq$ `PATTERN` ≤ 4) event spectra (e.g. Fig. 2) for exposure 0059_0122320701_PNS003 is illustrated in Fig. 4. The pattern distributions (top) and fractions (bottom) are plotted for singles, doubles, triples, and quadruples (the maximum event size that can be due to a single photon) along with the model fractions for singles and doubles caused by sky X-rays, using the SAS task `epatplot`. There is a small but significant overabundance of singles for the internal background which may be due to "backside" (actually front-side) illumination of the wafer by radiation from the electronics board. The shadowing observation 0321_0112480201_PNS001 (eFF, Ophiuchus Cloud, see Freyberg & Breitschwerdt 2002) is compared with the internal background exposure 0355_0106660401_PNS003 (eFF), the corresponding single spectra are shown in Fig. 5 in black (Thin1 = 160 nm polyimide + 40 nm Al) and blue (Closed = 1 mm Al), respectively.

4. Temporal effects

Figure 6 shows the long-term decay (see Tab. 1) of the internal calibration source along with the effect of increased continuum by very high background radiation. Fig. 7 summarizes the relations of the $10-12$ keV count rates versus time and versus "Discarded Line Counter" (`NDISCLIN`, see Appendix). From Rev. 200 on a slight increase is seen

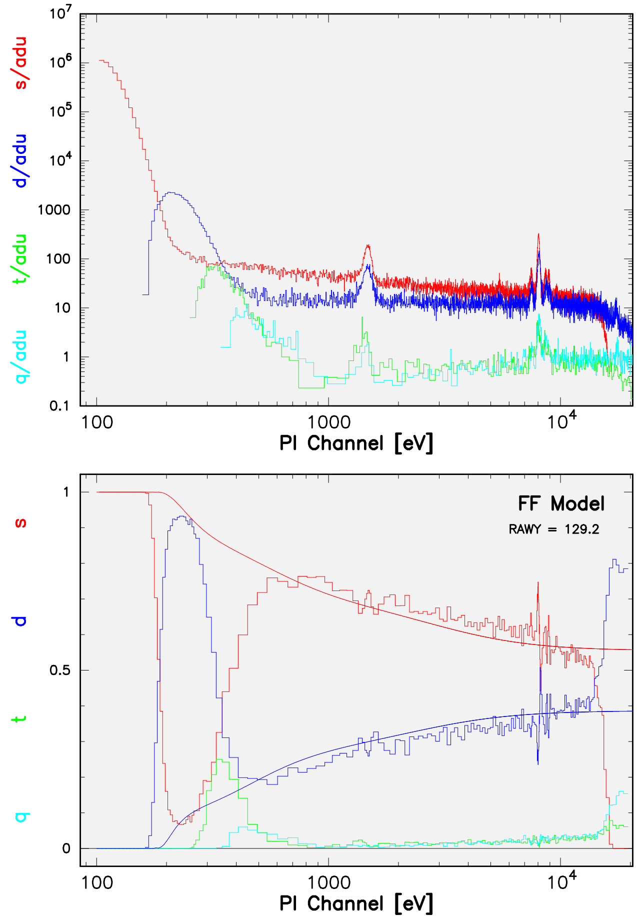

Figure 4. Event pattern distributions and fractions for 0059_0122320701_PNS003 ("Closed"), for details see text.

(top) while the lower NDISCLIN values (blue) are due to setup changes in Rev. 223 (MIPSEL $= 2 \rightarrow 1$). The lack of a clear correlation is supported by Fig. 8 where the total number of events per 20 readout cycles (NEPDH) is plotted sequentially (top panel) and several soft-proton flares can be seen. The bottom panel portrays the relation of the slightly smoothed number of events (NEPDH_SM) with the number of rejected columns (NDISCLIN_SM): there seems to be one almost unrelated component (almost constant NDISCLIN with varying NEPDH) and another strong correlated component which could explain the difficulty to identify a simple single-component relation between high-energy count rate and MIP rate.

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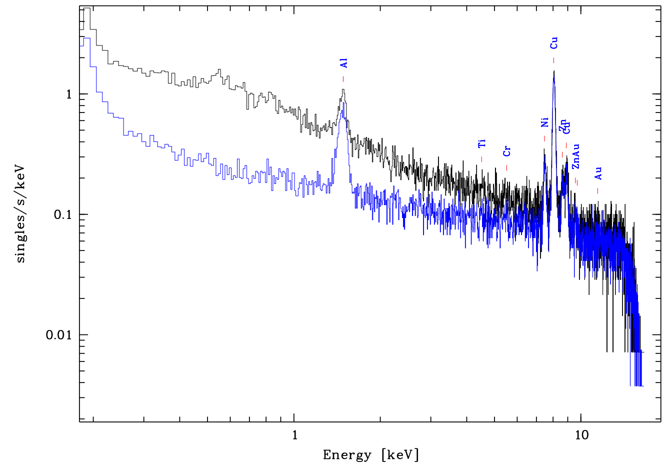

Figure 5. Spectral comparison of ExtendedFullFrame mode data with filter Thin1 (0321_0112480201_PNS001, black) and Closed (0355_0106660401_PNS003, blue), singles.

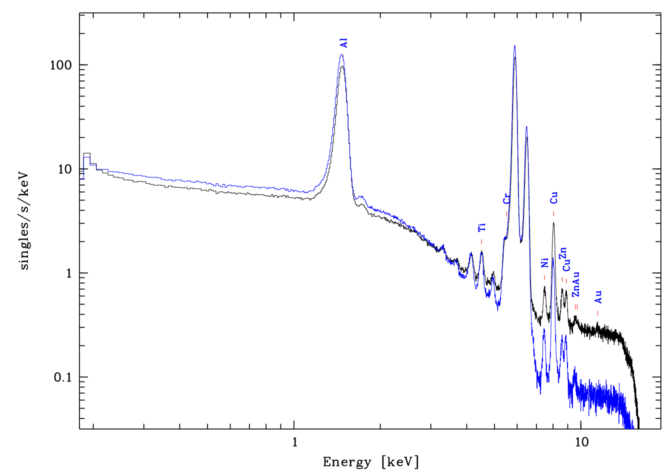

Figure 6. Comparison of low-background "CalClosed" (0080_0124700101_PNS003, blue) with high-background "CalClosed" (0242_0109890301_PNS005, black), singles only, time lag ~ 0.88 a (Tab. 1). The weakening in the Al and Mn lines and in the low-energy continuum is due to the decay of the ^{55}Fe source ($T_{1/2} \sim 2.7$a), the increase mostly visible above ~ 7 keV is caused by excessively high particle radiation.

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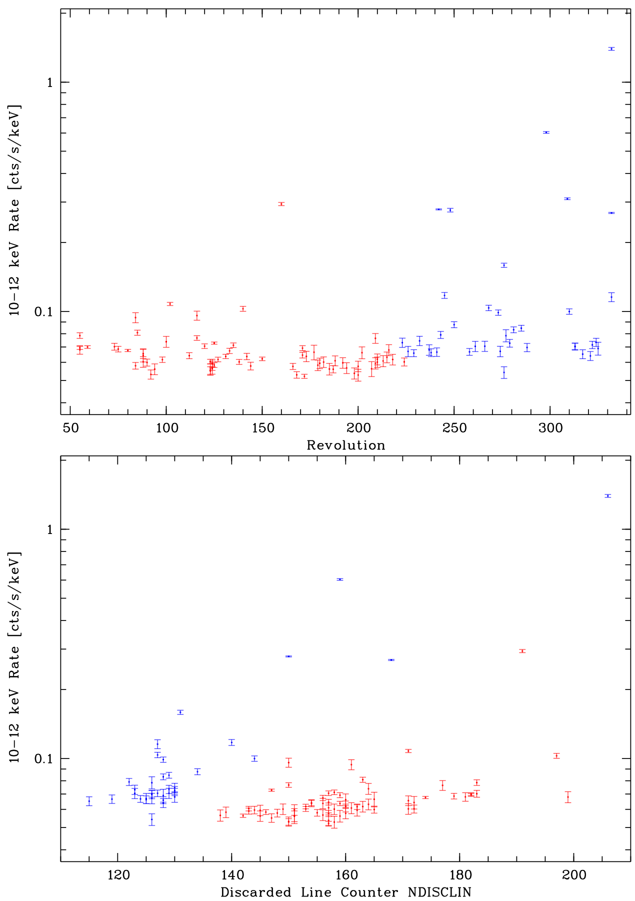

Figure 7. Lightcurve of the $10-12\,\mathrm{keV}$ *rates in "CalClosed" FF mode data, singles (top), the same intensities plotted versus the corresponding average "Discarded Line Counter" (bottom, without Revs. 248 and 309). For details see text and Appendix.*

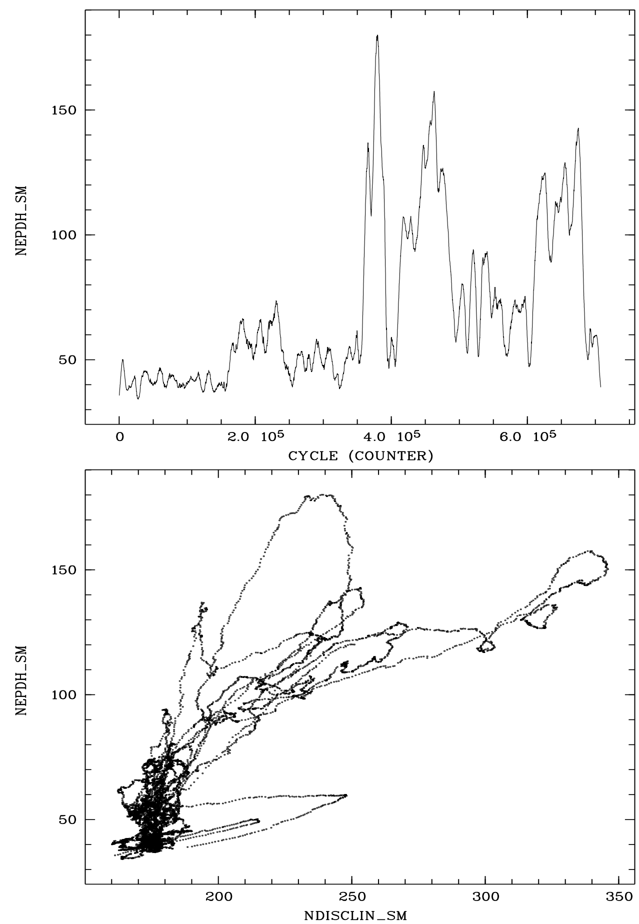

Figure 8. Exposure 0089_0125960201_PNS003 (see Tab. 1): light curve (top) and relation of count rate with MIP rate (bottom), each point samples $1.5\,\mathrm{s}$*. For details see text.*

Appendix A: EPIC pn MIP rejection

To reduce the background and telemetry rate the on-board software of the EPIC pn camera is able to reject minimum ionizing particles (MIPs) by selecting on event amplitudes for the FullFrame (FF), ExtendedFullFrame (eFF), and LargeWindow (LW) modes. For the faster readout modes – SmallWindow (SW), FastTiming (TI), and FastBurst (BU) – the processor is too slow to finish with the rejection analysis of a frame before the data of the next frame arrive in the event analyzer (EPEA). The algorithm makes use of several programmable parameters stored in the auxiliary housekeeping file (`PAH`), where values for quadrants 0, 1, 2, and 3 occupy the column name range `F15xx`, `F16xx`, `F17xx`, and `F18xx`, respectively. For brevity we give in the following only the numbers for quadrant 1 (together with the current value – the figures were changed during the mission). The MIP rejection scheme (`SENDMODE`, `F1635`) can be switched-off (value: `NO MIP CORR.`), done row-wise (`MIP CORREC.1`) or done column-wise (`MIP CORREC.2`, default). At the read-out events have an amplitude offset of `CMCORR` [adu] (`F1625` = 512). If the amplitude which is read-out for a pixel exceeds a threshold of `MIP` [adu] (`F1626` = 3512) then this event is rejected, also all events in this column, and also all events in the next `MIPSEL` (`F1636` = 1) columns to the left and to the right in this readout frame. If the number of pixels above this threshold exceeds `MAXMIP` (`F1627` = 63) then all events of this frame are rejected. The number of rejected columns during `MAXFRC` (`F1638` = 20) analysed frames for a specific quadrant is written as "Discarded Line Counter" `NDISCLIN` to the `PNAUX2` extension of the auxiliary file (`AUX`), i.e. about every $1.5\,\mathrm{s}$ for the normal FF mode. There is no time-resolved spatial information about the distribution of rejected columns, only the total number of rejections of a column during an exposure is available in the discarded line files (`DLI`). If the on-board MIP rejection is switched off or if there are still MIPs found in the data due to incomplete rejection by e.g. too high event rates then the SAS software (task `epframes`) applies the algorithm described above to the data and screens the MIPs on-ground. For a pre-launch description see Kendziorra et al. (1999).