THE XMM-NEWTON EPIC PN CAMERA: SPATIAL DISTRIBUTION OF THE INTERNAL BACKGROUND FLUORESCENCE LINES

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Abstract

The “background” observed with the EPIC pn instrument aboard XMM-Newton is comprised of several cosmic background and non-cosmic “foreground” components.

Studies of the cosmic X-ray background require detailed knowledge about the spatial, spectral, and temporal behaviour of the various constituents. The intrinsic instrument background shows several X-ray fluorescence lines, most prominent at 1.5, 7.5, 8.0, 8.6, and 17.4 keV due to Kα line emission of Al, Ni, Cu, Zn, and Mo, respectively. Additionally, a few more weaker lines can be seen.

The lines of nickel, copper, and molybdenum show strong spatial inhomogeneities correlated with structures of the electronics board mounted below the sensitive CCD area. There are no important astrophysical lines for $z = 0$ in the corresponding energy range. The other relatively strong line, Al-Kα at 1.5 keV, is spatially homogeneous and caused by aluminum that is more distant in the camera itself. The internal background rate is approximately $0.1\,\mathrm{cts\,s^{-1}\,keV^{-1}}$ in the $2-7$ keV band for the whole field-of-view. The internal background is not vignetted and should be subtracted before any vignetting correction is applied to the data.

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

1. Introduction

The ESA cornerstone observatory XMM-Newton (Jansen et al. 2001) with its large collecting area telescopes is not only used to observe bright point-like sources but also low-surface-brightness objects. Analysis of extended X-ray emission (like supernova remnants, clusters of galaxies, or the interstellar medium itself) that fill significant portions of the field-of-view requires a detailed knowledge of non-cosmic contributions to the detected events as the “background” may not be obtainable from the same exposure.

The EPIC pn-CCD camera (Pfeffermann et al. 1999, Strüder et al. 2001) is located behind one of the three X-ray telescopes. Detected events originate from photons (but occasionally also from soft protons) that have passed through the highly-nested mirror module and thus suffer from vignetting. Additionally there is a contribution by high energetic particles as well as by events created in the camera itself and by noise in the CCDs. As these X-rays (or any parental particles) have not passed through the X-ray telescopes they do not appear to be vignetted. Before

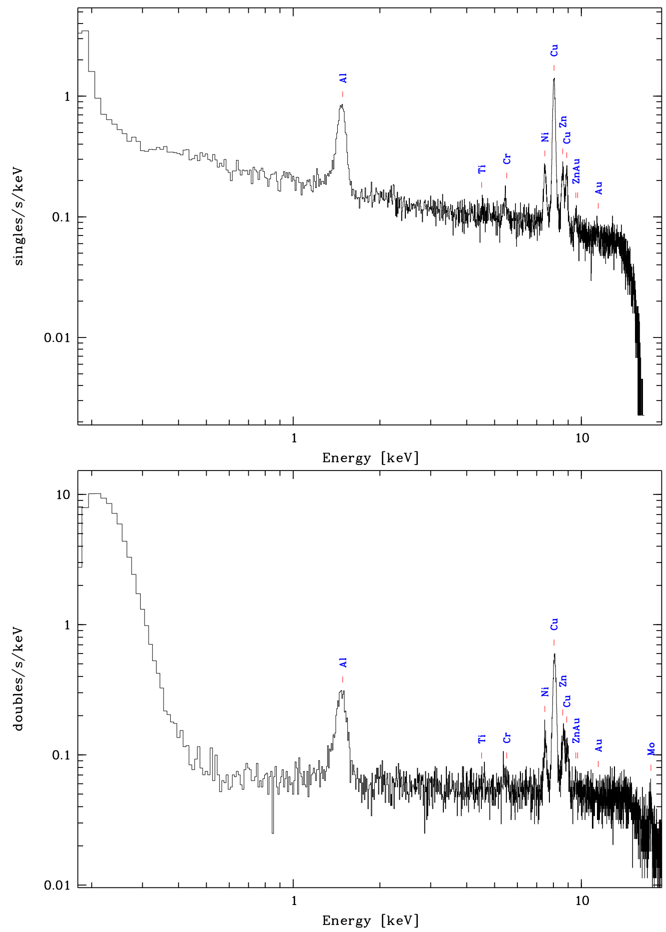

Figure 1. EPIC pn spectra ($0.2-18$ keV) *of the full detector area using the observation 0059_0122320701_PNS003 (see Tab. 1) in single-pixel events (top) and double-pixel events (bottom), filter wheel in closed position. The most prominent features are the Al-Kα, Ni-Kα, and Cu-Kα lines which will be discussed later in the paper. Note also the Mo-Kα line at* 17.4 keV *which is only visible in the doubles due to the onboard MIP rejection threshold which suppresses individual events above* 15 keV*. The different spectral slope is due to the energy dependence of the single/double ratio.*

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Table 1. EPIC pn "Closed" filter observations used in this analysis: Full Frame (FF) & Extended Full Frame (eFF) modes

Rev	ObsId	ExpId	Mode	Time	Date
0046	0120900201	PNU019	FF	9.4 ks	09-03-2000
0059	0122320701	PNS003	FF	49.5 ks	05-04-2000
0266	0136750301	PNU002	FF	28.0 ks	22-05-2001
0355	0106660401	PNS003	eFF	30.0 ks	16-11-2001

any corrections for vignetting is applied to the data these non-vignetted contributions should be subtracted in order not to artificially increase their intensities at larger off-axis angles. High-accuracy spatial studies should carefully take into account inhomogeneities in the intrinsic background. This is obvious for extended sources but also important for selecting background regions for point-source analysis (for applications see Freyberg & Breitschwerdt (2002)).

Here we present an analysis of "Closed" and "CalClosed" filter position data taken with the EPIC pn camera in orbit.

2. Data reduction

The "Closed" filter position (see Appendix A) has been used only a few times – except for several very short exposures – to determine the intrinsic background of the camera. These four data sets are summarized in Tab. 1. The internal calibration source emits strong lines (Al-Kα, Mn-Kα, and Mn-Kβ) at 1.5, 5.9, and 6.5 keV, respectively, accompanied by quite strong continuum background and minor contributions of other elements. These spectral features are not representative for the intrinsic background. Therefore data containing the internal calibration source (filter position "CalClosed") can be only used above $\sim$ 7.0 keV for studies of the internal background. As is demonstrated by Freyberg et al. (2002) the "Closed" and the "CalClosed" spectra agree very well in this high energy band.

All data were processed using the latest available SAS version and calibration files. The event files were screened for bad pixels and columns. Spectra were accumulated using separately single-pixel and double-pixel events only. For image creation `PATTERN=0` was used except in the case of molybdenum ($1 \leq$ `PATTERN` ≤ 4).

The EPIC pn internal background shows besides continuum emission several characteristic fluorescence lines mainly excited by high-energy particles. Figure 1 shows the spectra of the observation 0059_0122320701_PNS003 (see Tab. 1) for singles events (upper panel) and double events (lower panel). The increase at lower energies in the spectrum for doubles originates in the higher noise close to the read-out node (CAMEX). The Mo-Kα line above 17 keV is only visible in the double spectrum (lower panel) because the onboard MIP rejection suppresses individual events with energies above 15 keV (compare upper panel).

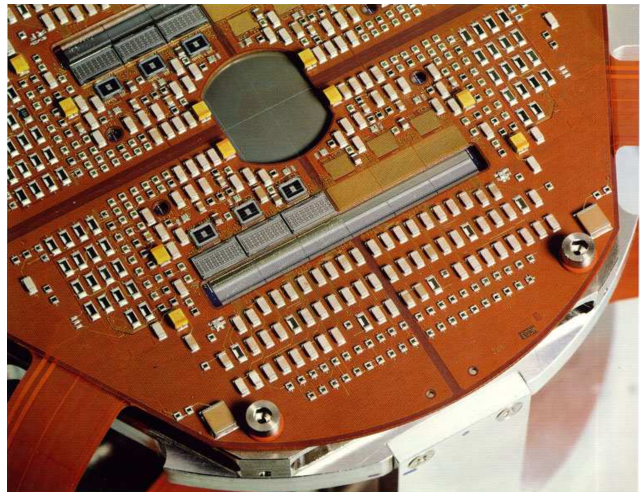

Figure 2. Image of the EPIC pn electronics board mounted below the CCD wafer, taken from the XMM-Newton EPIC pn gallery at the Max-Planck-Institut für extraterrestrische Physik (http://wave.xray.mpe.mpg.de/xmm/epic/gallery)

3. Spatial distribution

Figure 2 gives an overview of the electronics board mounted below the EPIC pn CCDs. The board is made up of four parts (one for each quadrant, in two symmetry flavours, in the image the board is not fully equipped) consisting of two layers of copper with a layer of molybdenum in between, with a venting hole in the center of the field-of-view. The nickel is contained in thin layers below the electronic components. Using narrow-band images (adjusted to the FWHM, cf. Fig. 1 in Haberl et al. 2002) one can investigate the spatial distribution of the fluorescence lines excited by high-energetic particles.

Figure 3 summarizes the spatial distribution of the strongest X-ray fluorescence lines seen in Fig. 1 together with the layout of the board (upper left) scaled to the size of the X-ray images. All "CalClosed" and "Closed" data in FF and eFF modes (Tab. 1) between revolutions 46 and 355 have been incorporated for the images in Fig. 3 (without several engineering observations in non-nominal setup) while only "Closed" data were usable for Fig. 4.

In the light of the Cu-Kα line (sampled in 7.8 – 8.2 keV) the venting hole in the middle and four holes at the right and left are visible which correspond to holes in the board. Between the quadrants a slightly larger gap is seen. At the top and bottom one can recognize locally a small decrease in intensity which fits nicely the enhancements in Ni-Kα (lower left, integrated over 7.3 – 7.6 keV). This can be interpreted as absorption of the copper line by nickel which shines brighter at the position of the CAMEX (larger features) and TIMEX chips (smaller features) – they are easily found in the layout at the top and bottom. The central Ni hole is larger than for Cu due to absence of electronic components there. Comparison of the layout

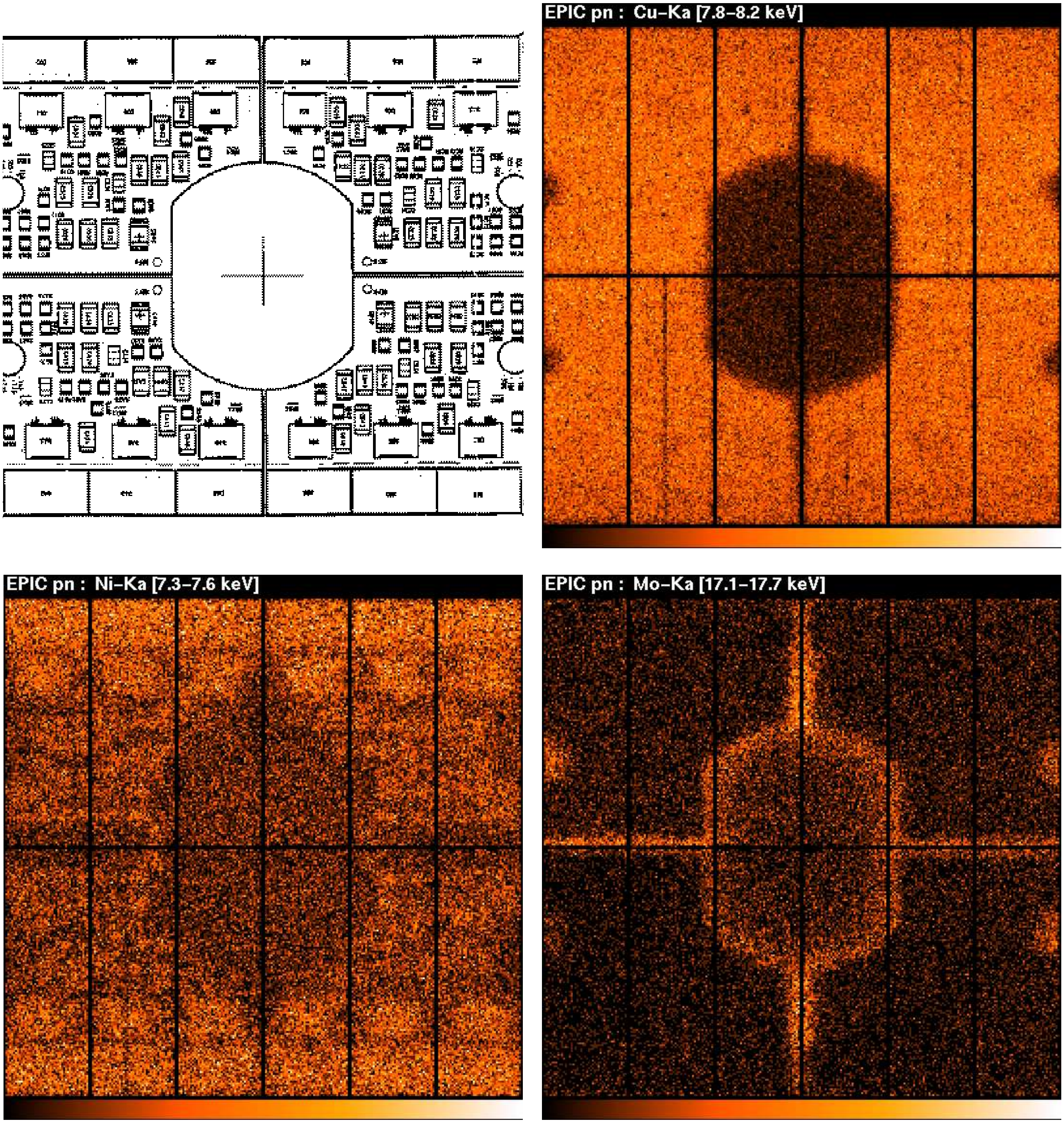

Figure 3. Upper left: layout of the electronics board (see Fig. 2). Lower left: Nickel (7.3 − 7.6 keV)*. Upper right: Copper* (7.8 − 8.2 keV)*. Lower right: Molybdenum* (17.1 − 17.7 keV)*. The absolute normalization of the images can be inferred from the spectra (singles, doubles) in Fig. 1). For details see text.*

components shows the significance of the fine structure in the Ni distribution. Finally, the image in the Mo-Kα line (17.1 − 17.7 keV) shows general enhancements where the molybdenum core is not obscured by the board itself but its emission can leave at the edges of the quadrants, the venting hole, and the feed-through holes at the sides. Due to variations in the inclination angle of the emission the central region is generally brighter than the other parts.

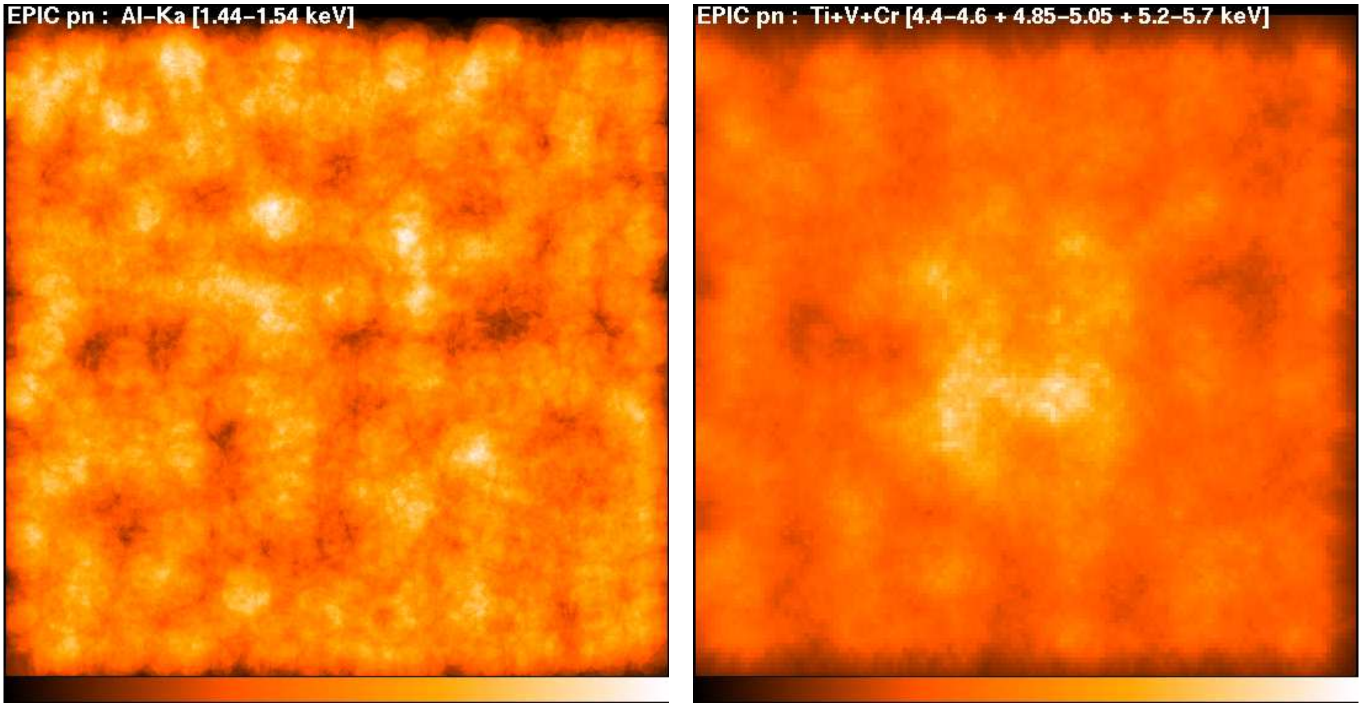

Figure 4. Left: smoothed image in the Al Kα line $(1.44-1.54\,\mathrm{keV})$*, the fluctuations are due to low statistics and are insignificant. Right: smoothed image in the Ti+V+Cr Kα lines. For details see text.*

In Fig. 4 the Al-Kα line image does not show significant spatial variations, the energy range $4.4-5.7\,\mathrm{keV}$ exhibits an increase in the center of the field-of-view, probably due to a supporting screw to damp vibrations – however at a *very low* level (compare Fig. 1). There is no significant fluorescence at Cu-L (0.93 keV) and Mo-L (2.3 keV) where the latter energy is close to the Au-M edge and thus of principal interest for mirror and effective area calibrations.

Finally – somewhat amusingly: the images (e.g. Fig. 3) illustrate the ability of the EPIC pn camera to look not only into the deep sky but also at itself.

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References

Briel U.G., Dennerl K., Freyberg M.J. et al. 2002, these proceedings

Dennerl K., Briel U.G., Freyberg M.J., Haberl F., Meidinger N., Zavlin V.E. 2002, these proceedings

Freyberg M.J., Breitschwerdt D. 2002, these proceedings

Freyberg M.J., Briel U.G., Dennerl K., Haberl F., Hartner G., Kendziorra E., Kirsch M. 2002, these proceedings

Haberl F., Briel U.G., Dennerl K., Zavlin V.E. 2002, these proceedings

Jansen F.J., Lumb D., Altieri B. et al. 2001, A&A 365, L1

Pfeffermann E., Bräuninger H., Bihler E. et al. 1999, SPIE 3765, 184

Strüder L., Briel U., Dennerl K. et al. 2001, A&A 365, L18

Appendix A: EPIC pn filter wheel positions

The filter wheel in front of the EPIC pn detector (and similar the MOS detectors) houses six different filters at "stop positions" separated by an angle of $\sim 60°$: Open, Closed, Thin1, Thin2, Medium, Thick. These fixed positions are reached by command `FWGOTO_n` with $n = 0..5$, respectively (see EPCS FM User Manual EPIC-MPE-HB-ED/028). Values of the filter wheel position sensor potentiometer (FWSPOT, housekeeping parameter F1122) for these positions are of the order of $n \times 60° - 5\overset{\circ}{.}5$ (e.g. Thin1 $\sim 114\overset{\circ}{.}5$). The FWSPOT digitization step size is $\sim 0\overset{\circ}{.}838$. The corresponding calibration ("no-stop") positions (CalOpen, CalClosed, CalThin1, CalThin2, CalMedium, CalThick) are obtained by turning the filter wheel back by $\sim 4°$ (via command `FWCAL`, e.g. CalThin1 $\sim 110\overset{\circ}{.}5$); the radioactive ^{55}Fe internal calibration source with an aluminum target then illuminates the sensitive CCD area through a hole. The resulting Al-Kα and Mn-Kα lines are used for in-orbit spectral calibration; for details see Briel et al. (2002), Dennerl et al. (2002), and Freyberg et al. (2002).