Stability of the EPIC-pn camera

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1 Change Log

V3.0 - Updated for data from 2020, 2021 and 2022
V2.0 - Updated for data from 2018 and 2019 - 2019-03-06
V1.0 - Original - 2017-11-21

2 Introduction

The flux measured by the EPIC detectors is derived from the number of counts recorded which depends on calibration quantities such as the quantum efficiency of the detector. Ideally this should be constant across the mission and if found to vary, time-dependent calibration should be added into the analysis system to ensure that the extracted flux does not vary with time. Currently the analysis system uses a single quantum efficiency from launch to the current date for the EPIC-pn camera.

Naze, Oskinova & Gosset (2013) reported on an analysis of the star Zeta Puppis, which they found to vary on medium (1 - several days) and long (months to years) timescales in the EPIC and RGS cameras. On the long-term they analysed EPIC observations from revolutions 636 (2003-05-30) to 1983 (2010-10-07) measuring a linear decay in flux in the 0.3-4 keV band and independently in energy bands of 0.3-0.6, 0.6-1.2 and 1.2-4.0 keV for all the EPIC and RGS cameras. The authors suggested that this trend may be due to a reduction in the sensitivity of all of the cameras rather than an intrinsic behaviour of Zeta Puppis.

In this technical note we analyse the behaviour of the EPIC-pn camera only. Naze, Oskinova & Gosset inferred a possible decay in sensitivity of the EPIC-pn camera from observations made with the *Thick* filter, and taken predominantly in the small window mode, of 6% in the 0.3-0.6, 0.6-1.2 keV and 0.3-4 keV bands, 4% over 0.9-2 keV and 2% in the 1.2-4 keV band between 2003 and 2010.

To investigate the stability of the detector we have looked at the LMC supernova remnant

(SNR), N132D (SNR J052501-693842), which is believed to emit constant X-ray flux. This object is a calibration source and has been observed frequently between 2000 and 2022 with a number of observing modes and filters. To avoid problems with pile-up we have restricted our analysis to observations taken in *small window* observing mode, most of which have used the *thin1* filter (Table 1).

In the next section we report on an analysis of these observations.

3 Analysis

We will investigate the stability of the detector over two energy bands; a soft band of energy 0.3-2.5 keV and a medium band with energies 2.0-6.0 keV. The SNR is contained in the EPIC-pn camera within a circle of radius 85 arcseconds (1700 detector pixels; see Fig.1), which fits comfortably into the small window provided that the source is well-centred[1]. The total count rate in this region is ~ 64 and ~ 1.1 c/s in the soft and medium bands respectively, with the background typically contributing $\sim 0.1\%$ of the total in the soft and 1-2% in the medium band. The source plus background and background-only spectra are shown in Fig.2 for observation 0414180901, where the background has been taken from a small region in the corner of the small window and scaled to the size of the source region (a factor 16 larger). We see that spectra from the source and background regions have a similar count rate above ~ 10 keV suggesting that in this energy range the data is background dominated. For lower energies, the background region will be contaminated by the source flux and because it is impossible to find a truly source-free region within the small window we need to use a more complicated background estimation technique

We attempt to find the typical spectrum of the background by analysing a source-free region from a full-frame observation made with the *medium* filter (obsid=0085150301; date=2001-10-21) and another with the *thin1* filter (obsid=0790381501; date=2017-02-15). Background flares were removed in the same way as shown below for the analysis of the SNR. The number of counts found in this region in each energy range (Table 2) can then be used to calculate the ratio of background counts in the 10-12 keV range to that of the 0.3-2.5 and 2-6 keV ranges. We will use the count rate measured from the source in the 10-12 keV band, scaled by these ratios, to estimate the background in the bands of interest in each observation.

The count rate of N132D was extracted from the source region in each energy band by the following procedure

- Create a set of GTIs where the 10-12 keV count rate over the whole small window is < 0.4 c/s.

```
tabgtigen table=rates_10_12.ds gtiset=EPICgti.fits expression=RATE<=0.4
```

[1]Some observations made in 2002 placed the SNR towards the edge of the small window and can not be used in this analysis.

- Create an image of the field of view, for each band, using a selection expression of the form:

```
#XMMEA_EP && PATTERN<=4 && gti(EPICgti.fits) && (PI in [300:2500])
```

- Find the centre coordinates of the remanant (Xcen, Ycen) by eye from the low-energy band image and then find the count rate in each image using:

```
eregionanalyse imageset=image_2000_6000.ds
                    srcexp='(X,Y) in circle(Xcen,Ycen,1700)' backval=0.0
```

- Find the background in this observation for each band by scaling the count rate in the 10-12 keV image by the factors in Tab. 2.
- Subtract the scaled background from the count rates for each band.

The background-subtracted count rates for each epoch are given in table 1 and plotted for the two bands in Fig. 3. One-sigma statistical errors are given.

4 Results

From Fig 3. and Table 1 we see that the 0.3-2.5 keV flux in the *thin1* filter is constant to better than 0.5% between 2003-12-24 and 2022-02-23 and to 0.1% between 2004-12-21 and 2022-02-23. The medium-energy, 2-6 keV, band flux is generally constant to $\sim 1\%$ between 2003-12-24 and 2022-02-23 except for excursions of +3% in 2015 and -3% in 2021.

A measurement in 2001-10-20 taken with the *medium* filter is lower than the mean soft band count rate by 2.5% which might be expected from the reduced low-energy throughput of this filter relative to the *thin1* filter. In an attempt to estimate the effect on the count rate of the change of filter from *thin1* to *medium* we have roughly fit the spectrum of N132D with a model of tbabs*tbabs*(mekal1 + mekal2) with absorption in our galaxy of 6×10^{19} cm^{-2}, instrinsic absorption in the LMC of 1.85×10^{21} cm^{-2} and mekal models of temperature 0.245 and 0.995 keV. Using this model and the *fakeit* command in *XSPEC* we find that the count rate in the *medium* filter will be 2.9% and 1.6% less than that registered by the *thin* filter for the soft and medium energy bands respectively. Applying these model-dependent factors to the 2001-10-20 observation increases the count rate for this point to 64.10 and 1.156 c/s for the two bands.

Excluding the *medium* filter point then we find that the 0.3-2.5 keV response of the EPIC-pn detector has not varied by more than 0.5% between 2003-12-24 and 2022-02-23. If we include the observation of 2001-10-20 and make a correction for the properties of the filters then we find that the count rates registered by the detector for N132D vary by no more than 0.5% between 2001-10-20 and 2022-02-23.

The medium-energy, 2-6 keV, band flux has been constant to 1% for most measurements taken between 2003-12-24 and 2022-02-23, consistent with the typical statistical errors

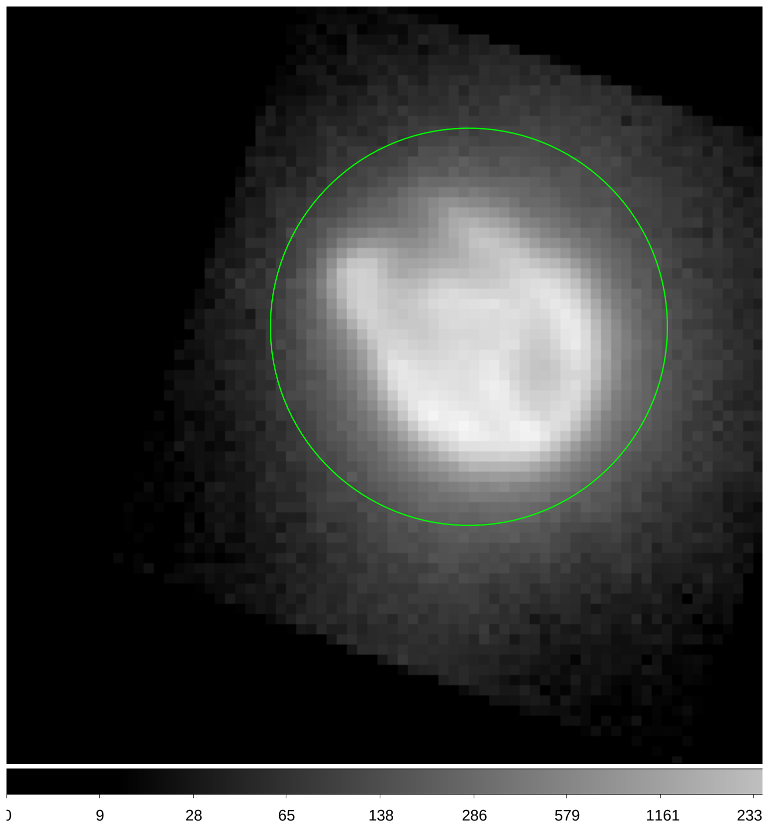

Figure 1: N132D in the EPIC-pn camera, small window. The remnant is enclosed within an 85 arcsecond raduis circle.

of 0.7%. An increase of flux of 3% and a decrease of 3% were seen in 2015 and 2021 respectively. The origin of this variation is unknown.

5 Vignetting

In the analysis, no correction has been made for vignetting as the variation in placing within the small window has been slight. To check this assumption we have looked at the calibrated vignetting throughput, at the centre of the source region of the 12 observations. The remnant is centred at off-axis angles ranging from 68.4 to 75.0 arcseconds, which corresponds to a vignetting correction at 2 keV of 0.9825 to 0.9795. This should introduce a count rate difference of 0.3% at 600 eV (where the spectrum peaks), 0.3% at 2 keV and 0.2% at 6 keV over the course of the observations. The variations in the well-constrained

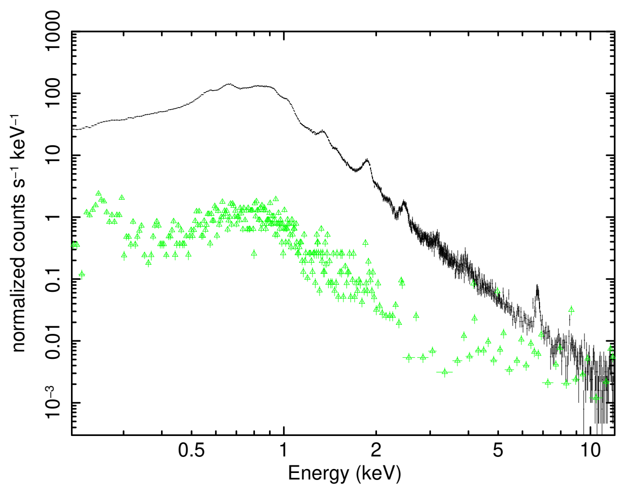

Figure 2: Spectra from the source region of N132D (black) and a background region at the edge of the small window (green) from observation 0414180901 after removing background flares. The background counts have been scaled by a factor 16 to account for the different region sizes. At energies from 10-12 keV the source and background regions show roughly equal counts showing that this part of the spectrum is dominated by the background rather than by emission from the SNR.

Table 1: **Observations of N132D used in the stability analysis**

OBSID	Start Date	exposure (s)	Filter	Rate[a] 0.3-2.5 keV	2-6 keV	10-12 keV
0129340901	2001-10-20	24604	Medium	62.29 ± 0.06	1.138 ± 0.008	0.0031
0129341401	2003-12-24	28728	Thin	64.11 ± 0.06	1.141 ± 0.008	0.0026
0129341701	2004-12-21	24919	Thin	63.75 ± 0.06	1.140 ± 0.008	0.0030
0129342001	2006-02-07	30476	Thin	63.83 ± 0.06	1.126 ± 0.007	0.0066
0414180101	2007-02-05	35411	Thin	63.83 ± 0.05	1.135 ± 0.007	0.0051
0414180201	2008-02-06	29431	Thin	63.89 ± 0.06	1.139 ± 0.008	0.0056
0414180401	2009-02-12	28911	Thin	63.62 ± 0.06	1.134 ± 0.008	0.0183
0414180501	2010-02-08	33819	Thin	63.78 ± 0.05	1.121 ± 0.007	0.0056
0414180601	2014-02-05	61100	Thin	63.80 ± 0.04	1.159 ± 0.006	0.0106
0414180701	2015-02-12	45000	Thin	63.82 ± 0.05	1.180 ± 0.006	0.0104
0414180801	2016-02-15	57800	Thin	63.90 ± 0.05	1.155 ± 0.006	0.0062
0414180901	2017-02-17	44999	Thin	63.84 ± 0.05	1.139 ± 0.007	0.0043
0811012401	2018-02-23	33701	Thin	63.69 ± 0.05	1.136 ± 0.007	0.0028
0811012501	2019-02-27	51118	Thin	63.74 ± 0.05	1.144 ± 0.005	0.0027
0853782401	2019-12-11	24500	Thin	63.97 ± 0.05	1.157 ± 0.007	0.0037
0811012601	2020-02-23	46632	Thin	63.78 ± 0.05	1.113 ± 0.006	0.0038
0811012701	2021-02-22	42101	Thin	63.74 ± 0.04	1.103 ± 0.006	0.0068
0811012801	2022-02-23	39826	Thin	63.66 ± 0.04	1.126 ± 0.005	0.0029

[a] Background-subtracted count rate from a circle of radius 85 arcsecs about N132D in the soft and medium energy bands and the total 10-12 keV count rate from the same region (c/s). The 10-12 keV count rate is scaled by factors in table 2 and used as the background for the soft and medium bands.

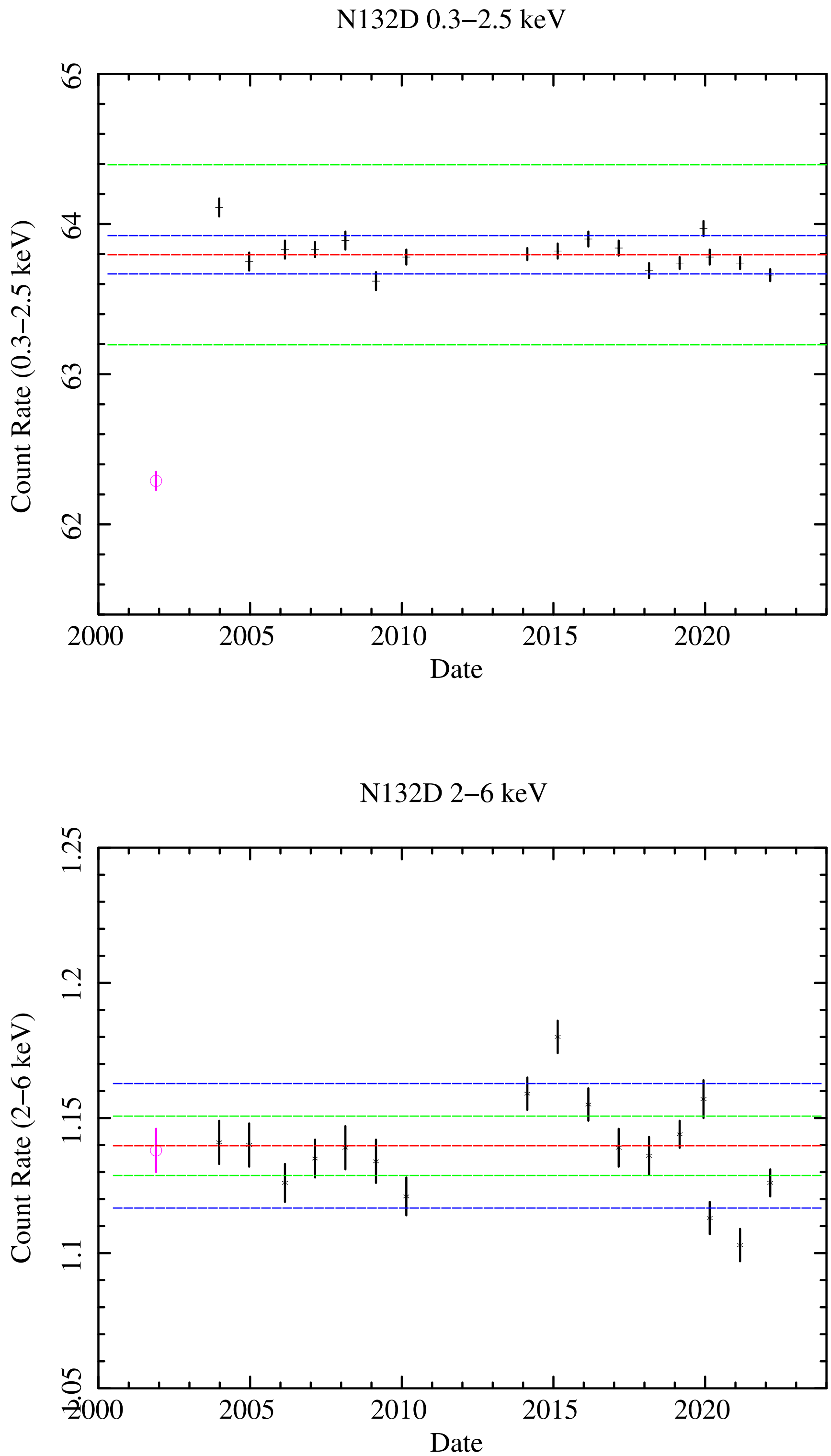

Figure 3: Upper: 0.3-2.5 keV background-subtracted count rate from a circle of radius 85 arcseconds centred on N132D. The dashed red line gives the mean value of 63.8 c/s while the blue and green dashed lines give a variation of 0.2% and 1% about this mean respectively. All observations were made with the *thin1* filter except that of 2001-10-20 which was made with the *medium* filter and is shown in magenta. Lower: 2-6 keV background-subtracted count rate from N132D. The mean rate of 1.4 c/s is shown as a dashed red line while the 1% and 2% variations about the mean are shown as green and blue dashed lines respectively.

Table 2: **Background counts**

Energy band (keV)	counts[a]	ratio[b]
Thin filter		
10.0-12.0	984	1.0
0.3-2.5	11283	11.47
2.0-6.0	3712	3.77
Medium filter		
10.0-12.0	318	1.0
0.3-2.5	3184	10.01
2.0-6.0	1161	3.65

[a] The counts found in each energy band for a source-free region of an observation made with the *Thin* and *Medium* filters after flare removal.
[b] Scale factor of the count rate in each band wrt the count rate between 10 and 12 keV. This is the factor adopted to convert the 10-12 keV count rates into background count rates in each observation.

soft X-ray light curve tend to be smaller than this (Fig. 3).

As a more precise check we integrate the vignetting over the spatial distribution of the SNR for observation 012941701 (2004-12-12; 74 arcsecs off-axis) at 600 eV and compare with that of observation 0414180601 (2014-05-02; 68.4 arcsecs off-axis) and find a ratio of 0.29% in vignetting and hence effective area. The difference in measured background-subtracted count rate between these observations is just 0.08%. This suggests either that the vignetting is a little flatter around the optical axis than the current calibration model suggests or that other factors are fortuitously working in the opposite direction to flatten the light curve at the 0.2% level.

In any case we see that vignetting effects do not influence the conclusion that the response of the EPIC-pn camera is stable over the course of the mission.

6 Conclusions

Observations of the SNR N132D have shown that the response of the EPIC-pn detector has been stable over the course of the mission in the 0.3-2.5 keV energy band to within 0.5%. In the medium energy, 2-6 keV, band the detector has registered variations in the SNR count rate of up to 3.5% about the mean between 2001-10-20 and 2022-02-23. These variations have no apparent long-term trend. Otherwise, the medium energy band has returned a constant flux to within $\sim 1\%$ over the course of the mission.

These results imply that the EPIC-pn detector is stable at low and medium energies (0.3-6 keV) and has not suffered a measurable degradation in its response to date. This in turn implies that the reduction of flux seen in Zeta Puppis by Naze, Oskinova & Gosset between 2003 and 2010 was caused by non-instrumental effects.

References

Naze, Y., Oskinova, L. M. & Gosset, E. 2013, ApJ, 763, 143.