

The XMM-Newton Slew Survey

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1. Introduction

The current (April 2005) XMM archive contains ~ 374 slew exposures which give a uniform coverage over $\sim 10,000$ square degrees ($\sim 25\%$ of the sky). The exposures use the EPIC medium filters, with the observing mode set to that of the previous observation. Average slew length is $\sim 70^\circ$, and the slew speed is about 90° per hour, i.e. the on-source time is ≈ 14 s (uncorrected for vignetting).

While potentially of great interest, the shallow nature of the observations, the potential contamination by optical stars and the contribution made by previous all-sky surveys, in particular that of ROSAT (Voges et al. 1999), made it unclear whether the XMM slew datasets would provide significant new scientific results. Here we describe the results of pilot studies, the current status of the XMM-Newton Slew Survey and the results that have arisen.

2. Preliminary Pilot Studies

In obtaining calibrated event files from the EPIC slew datasets, a small SAS OAL change was necessary. Furthermore, the normal tangential projection used in the SAS is not valid over a whole slew, and consequently the slews needed to be subdivided into 1 degree^2 images to maintain astrometry. Whereas sources detected in the MOS cameras are extended into an unusable, long $4'$

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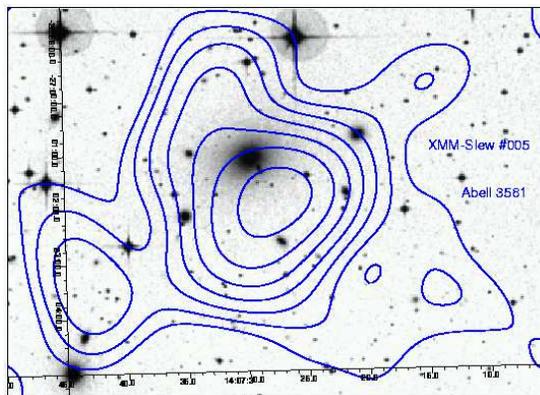


Fig. 1. Contours of X-ray emission from a single slew across the galaxy cluster Abell 3581, superimposed on a DSS image. There is only ≈ 10 s of on-source exposure here.

streak, due to the 2.6 s frame time, the short frame time of the pn camera gives rise to extents (essentially the slew PSF) that are not noticeable ($6''$ for pn FF mode, $18''$ for pn eFF mode). For this reason plus the additional MOS background, it was concluded that just the pn slew data would be analysed.

A first study of 9 slew datasets yielded ≈ 0.5 sources per sq. degree to a detection likelihood threshold of 10. Of these, 10% appeared associated with bright stars, 45% had ROSAT All-Sky Survey (RASS) counterparts, and $\approx 35\%$ were unidentified. We also found that we are sensitive to source extension in the brighter sources (e.g. see Fig.1).

A new operations strategy was put into place after this study: MOS slews are to be used only

for (closed) calibration; All pn slews larger than 900 s are to be down-linked and processed; For FF, eFF and LW modes, medium filter shall be used (otherwise, closed filter).

A second pilot study investigated the optimum processing and source-search strategies. Via SAS and other changes, we were able to create and use correct exposure maps – these produced no unusual effects, though uneven (and heightened) slew exposure is observed at the start/end of slews (the ‘closed-loop’). The optimum source-searching strategy was found to be usage of a semi-standard ‘eboxdetect (local) + espinemap + eboxdetect (map) + emldetect’ method, tuned to \sim zero background, and performed on a single image containing 0.2–0.5 keV singles (pattern 0) plus 0.5–12.0 keV pattern 0–4 events. This resulted in the largest numbers of detected sources, whilst minimising the numbers of spurious sources due to detector anomalies. Again, the source density was found to be ≈ 0.5 sources per sq. degree.

3. Current Status and Results

Initial processing and event file creation has been performed for all available 374 slews (including 206 FF, 61 eFF, 30 LW). For 54 of these slews (31 FF, 19 eFF, 4 LW), images and exposure maps have been created and source-searched. This has been done in 3 separate bands: full band (0.2–0.5 keV [pattern=0] + 0.5–12.0 keV [pattern=0–4]), soft band (0.2–0.5 keV [pattern=0] + 0.5–2.0 keV [pattern=0–4]), and hard band (2.0–12.0 keV [pattern=0–4]). 780 sources have been detected in the total band, 645 in the soft band, and 96 in the hard band. Furthermore, at the faint end, 68 sources are detected only in the soft band, and 20 sources are detected only in the hard band. The total of 868 sources in 1800 sq. degrees is again ≈ 0.5 sources per sq. degree.

Many different processing problems currently affect several of the slews. Though concentrating on slews which process cleanly, we are finding solutions to individual problems as we progress. Some slews contain sections with high exposure, related to the closed-loop slew phase, and these sub-images are currently excluded. Also high-background (flaring) slews ($\sim 25\%$) are excluded at present, though we can probably recover a lot of this data by GTI subsetting. At present, we are source-searching 219 slews and expect to find ~ 3600 sources.

A great variety of sources have already been detected, including stars, galaxies, both

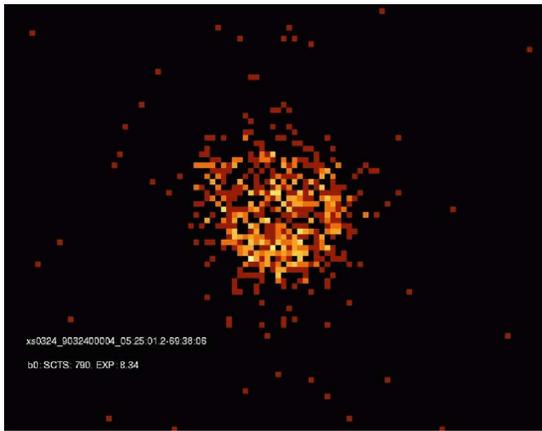


Fig. 2. XMM slew X-ray emission from N132D.

interacting and normal, AGN, clusters, and SNR (e.g. N132D – see Fig. 2), plus other unusual sources, that we know, as yet, nothing about, and extremely bright sources, with (at present) up to 350 ct s^{-1} . A large variation in source hardness is also seen. Furthermore, several sources are detected in more than one slew, yielding variability information. One source, so far detected in three separate slews, appears to have varied in flux by a factor of ~ 2 .

Again, $\sim 10\%$ of sources appear associated with bright stars. This does not appear to be due to optical loading however, as no correlation is observed between source counts and optical magnitude for the bright stars so far detected as slew sources. This is consistent with predictions that 5 counts are expected above 200 eV only for stars brighter than $V = 3.75$ – hence, the vast majority of the stellar slew sources appear to be genuine X-ray sources.

Correlations of the obtained sky positions both with 2MASS and with RASS indicate that the pointing accuracy of the slew is very good – $\sim 6''$, but that there is an additional second type of positional error. This is an attitude-related error of $0\text{--}60''$ (mean $30''$), but only in the slew direction, and this results in a thin, slew-oriented ‘error ellipse’ around each source. We believe we may be able to remove the second slew-attitude error by re-processing the attitude data. The $\sim 6''$ error will remain of course, but this is easily small enough to allow good optical follow-up.

Approximately 60% of the non-extended slew sources have RASS counterparts. Fig. 3 shows the RASS count rate versus the XMM Slew count rate for the current matches. The scatter in count rate ratio may be due to several factors, including genuine source variabil-

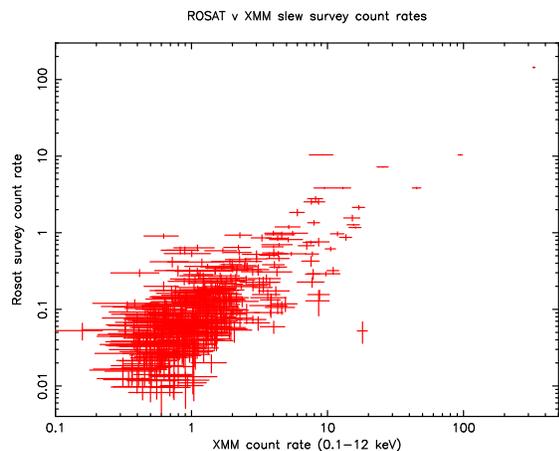


Fig. 3. RASS (0.1–2.4 keV) count rate versus XMM Slew (0.2–2.0 keV) (pn) count rate for 407 matches.

ity. It is seen that the harder slew sources are generally not observed in the RASS – the slew sources with RASS counterparts are on average spectrally softer, whereas the slew sources without RASS counterparts are on average spectrally harder.

The soft and hard band XMM-Slew survey flux limits, $6.2 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$ (soft band) and $4.0 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ (hard band), are shown, together with other ‘all-sky’ flux limits in Fig. 4. The soft band limit is similar to the RASS limit, and the hard band limit is very much deeper than any other all-sky survey.

Initial processing of the slew data is now finished. The creation of images and exposure maps, and the source-searching of these is ongoing, as is the creation of the catalogues, the creation of DSS images, the checking for and flagging of spurious sources and bright stars, the calculating of hardness ratios and the cross-correlating with RASS and other catalogues. It is envisaged that a final catalogue will be created and ingested into the XMM-Newton XSA (at ESAC) by the end of 2005. We are also hoping to begin investigating extended sources and searching co-added slews in the near future.

4. Concluding Remarks

The XMM archive currently contains slew exposures which give a uniform coverage of $\sim 10,000$ square degrees. Analysis of a subset of these data has revealed that thousands of entirely new

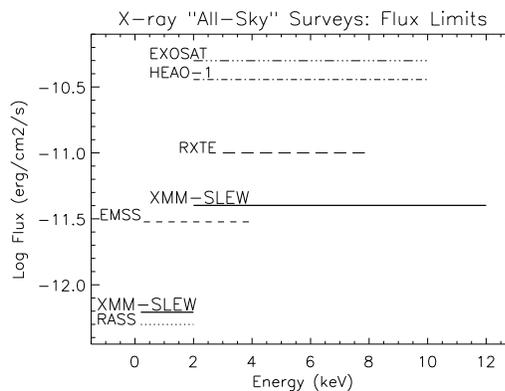


Fig. 4. X-ray ‘all-sky’ flux limits: Logarithm of the limiting flux and the relevant X-ray band. RASS: $5.0 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$, EMSS: $3.0 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ (but only 2% of the sky), HEAO-1: $3.6 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, Exosat: $5.0 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, RXTE: $1.0 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$ (but with only 1° positional accuracy).

sources and perhaps new classes of sources will be discovered.

All available slew datasets have undergone initial processing. These data cover $\sim 25\%$ of the sky, and at the current rate, XMM-Newton should have completed an all-sky slew survey by 2012. To date, 54 slews (covering $\approx 4.5\%$ of the sky) have been source-searched using the optimum strategies. We are detecting ~ 0.5 sources per sq. degree (to a detection likelihood of $[\approx 3.9\sigma]$).

The current slew survey soft band (0.2–2.0 keV) detection limit is close (to within $\sim 20\%$) of the ROSAT All-Sky Survey (RASS) limit. The hard band (2.0–12.0 keV) detection limit is the deepest ever, going more than 10 times deeper than Exosat and HEAO-1, and over 2.5 times deeper than RXTE (which only has 1° positional accuracy anyway).

The XMM slew positional accuracy appears very good ($\approx 6''$), but there exists an additional 1-D attitude error (of $30''$ mean), along the slew direction. This error may be removable via re-analysis of the existing attitude data. We further aim to recover science from slews affected by times of high background. We are currently on schedule to have a final catalogue by the end of 2005.

References

Voges, W., et al., 1999, A&A 349, 389