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The XMM-Newton medium-energy X-ray 'all-sky' survey

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Abstract. The great collecting area of the mirrors coupled with the high quantum efficiency of the EPIC detectors have made XMM-*Newton* the most sensitive X-ray observatory flown to date. We use data taken with the EPIC-pn camera during slewing manoeuvres to perform an X-ray survey of the sky. Slews have been subdivided into small images and source searched in three distinct energy bands; a soft (0.2-2 keV) band, a medium-energy (2-12 keV) band and a total XMM-*Newton* band (0.2-12 keV). A 'clean' catalogue containing 4300 sources has been produced, from 10,000 degrees^2. In the medium-energy X-ray band 450 sources have been detected down to a flux limit of 4×10^{-12} ergs s^{-1} cm^{-2}. The first full sky images have been produced from all of the available data (30% of the sky) and although sparse, begin to reveal large-scale structures. The slew survey dataset will eventually cover some 60% of the sky and will leave a useful legacy for long-tem variability studies with new generation satellites such as Simbol-X.

Key words. X-rays: general – surveys

1. Introduction

It was long recognised that XMM-Newton (Jansen et al. 2001) with its great collecting area, efficient CCDs, wide energy band and tight point-spread function (PSF) has the potential to make an important contribution to our knowledge of the local universe from its slew data (Lumb 1998; Jones & Lumb 1998). An initial assessment of the actual slew data, taken in-orbit, showed that the sensitivity is good and the quality of the data high (Freyberg et al. 2005).

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During slews, all the three imaging EPIC cameras take data in the observing mode set in the previous pointed observation and with the Medium filter in place. The slew speed of 90 degrees per hour combined with the slow (2.6s) readout time of the MOS detectors (Turner et al. 2001) means that sources appear as long streaks in the MOS cameras but are well formed in the fast observing modes of the pn camera (Strüder et al. 2001). For this reason, only the EPIC-pn data have been analysed.

In the 2–12 keV energy band, which is termed the *hard* band within the XMM-*Newton* slew project but which we will call the *medium* band here, the flux limit for the EPIC-pn detector is $F_{2-12} = 4 \times 10^{-12}$ erg cm^{-2}s^{-1}, a factor of 5–10 deeper than previous all-sky surveys. The astrometric accuracy is 8 arcseconds (1 sigma) allowing easy identification of a counterpart for the majority of sources.

The slew data has been carefully reduced, to avoid detector artifacts (Saxton et al. 2005), processed into images and source searched using the detection chain within the XMM-*Newton* Science Analysis Software (SAS). The resulting sources have been catalogued and a summary of the scientific highlights , including the mapping of the VELA SNR, the detection of a large number of clusters of galaxies, very bright and highly variable sources has been presented in Read et al. (2006).

2. Catalogues

In May 2006 the first catalogue of XMM-*Newton* slew sources (XMMSL1) was issued via the XMM Science Archive (XSA). It contained 5180 detections with a detection likelihood (Cruddace, Hasinger, & Schmitt 1988) $DET\_ML > 8$ from which a CLEAN catalogue, with 2692 higher significance sources was extracted. An update to this (XMMSL1D1) was issued in August 2007 increasing the numbers to 4300 clean sources, 450 of which are in the medium energy (2–12 keV) band. Further increments will be issued periodically as XMM-*Newton* continues to survey the sky.

The slew paths for the released catalogue are shown in Fig. 1, where a significant overlap can be seen at the ecliptic poles. The total area covered by the released catalogues is 10,000 deg^2 corresponding to 20% of the sky after correcting for overlaps. Around 60% of the sky should be covered by the date of the Simbol-X launch.

A full-sky slew image from all of the available data is shown in Fig. 2. While still very sparse, large features, such as the Vela SNR and the Cygnus loop, stand out clearly while point sources are hardly apparent at this scale. A zoom into the Galactic centre (Fig. 3) picks out the bright Galactic binaries and transients, many of which have been detected at hard energies by Integral and will be important targets for Simbol-X. In Fig. 4 (upper) we plot the sources colour-coded by hardness ratio and source strength. The bright, harder sources can be seen clustered around the Galactic plane. We find ~ 0.04 medium band sources per square degree and their positions and strengths are plotted in the lower panel of Fig. 4.

Fig. 1. The paths of the slews used in the construction of XMMSL1D1 in equatorial coordinates (RA,DEC).

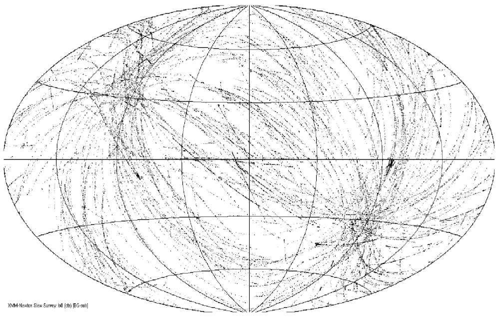

Fig. 2. An image of the sky in the full (0.2–12 keV) energy band from all of the slews taken to date (Galactic coordinates). Data taken at times of high background have been removed.

3. Variability

In the soft X-ray band the Rosat All-Sky Survey (RASS; Voges et al. (1999)) provides an excellent resource for searching for source variability. A very small number of sources (11), have been found to exhibit giant flux changes of a factor greater than 20 in ex-

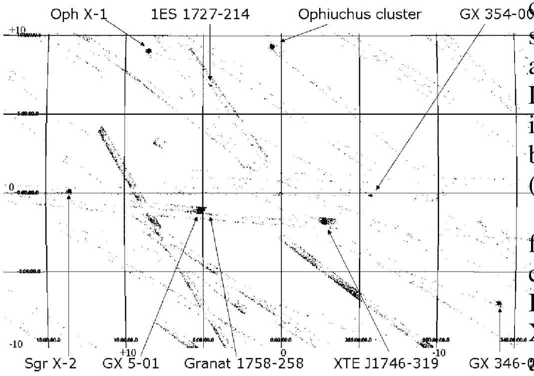

Fig. 3. An exposure corrected medium-energy band (2-12 keV) image of the galactic centre region.

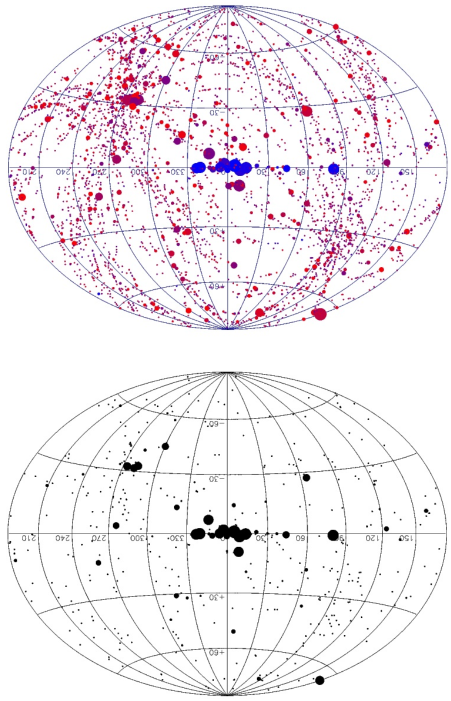

Fig. 4. An AITOFF projection in Galactic coordinates of sources from the XMMSL1D1 slew survey, where the circle size scales logarithmically with the count rate. Top panel: the total band sources; the hardness ratio is colour-coded such that light red is soft and blue is hard. Bottom panel: the medium band sources.

cess of the RASS upper limits. The Galactic sources are a flare star, two eclipsing binaries, a Dwarf Nova and a probable new Nova in the LMC. Six Galaxies have shown high variability, four of which are AGN and two which have been classified as tidal disruption candidates (Esquej et al. 2007).

A sensitive comparison of medium band flux variability is only currently possible by comparing sources observed in different slews. In the slews 9068800003 and 9068900004 the X-ray transient XTE_J1746-319 was seen with a 2–12 keV flux of 2×10^{-9} ergs s^{-1} cm^{-2} . Three years later in a test for a new XMM-*Newton* observing mode the source was not visible (upper limit $F_{2-12} < 1 \times 10^{-12}$ ergs s^{-1} cm^{-2}), implying a variability of greater than a factor 2000.

Future X-ray missions will be able to use the XMM-*Newton* slew survey to detect transient sources and long-term variability in the medium-energy band.

Variability studies need tools to calculate upper limits from current and legacy missions. For this purpose, a multi-mission upper-limit server is being developed at the XMM SOC.

4. Identifications

All sources (from XMMSL1D1) have been cross-correlated with Simbad, Ned, X-ray catalogues, the Abell and Zwicky cluster catalogues and the Integral bright source catalogue. Some 80% of the soft band and 65% of the medium band sources have a plausible counterpart. Of the identified medium-band sources we find that 50% are extragalactic (mainly broad-line Seyfert galaxies), 30% are galactic and the remainder are unclassified. A program of follow-up optical observations has been initiated to try and categorize the unidentified medium band sources.

5. Summary

The XMM-*Newton* slew survey, with an expected sky coverage of 60% by the end of the mission, a positional accuracy of 8" and a limiting 2–12 keV flux of 4×10^{-12} ergs s^{-1} cm^{-2}, will provide an important resource for future medium-energy X-ray variability studies. This will help Simbol-X, eRosita and MAXI to be powerful probes of long-term variability.

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