THE GALACTIC PLANE OBSERVED BY XMM-NEWTON

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Abstract

In AO-1 we proposed an ambitious long-term survey of selected regions of our Galaxy (the XGPS survey) using the EPIC CCD cameras on XMM-Newton. The first phase of this programme, which aims to survey a strip of the Galactic plane in the Scutum region, is currently underway. Here we report on the preliminary results from the first 15 survey pointings. We show that the XGPS survey strategy of fairly shallow (5–10 ks) exposures but wide-angle coverage is well tuned to the goal of providing a large catalogue of predominantly Galactic sources at relatively faint X-ray fluxes in the hard 2–6 keV band.

Key words: XMM-Newton: Galactic Plane: Serendipitous Surveys

1. Introduction

With XMM-Newton we are able, for the first time, to produce high sensitivity, coherent surveys of selected regions of our Galaxy. The preliminary goal of the XMM-Newton Galactic Plane Survey (hereafter the XGPS survey) is to map a 5° strip of the Galactic Plane near Galactic longitude 22°. In addition to five XMM GT fields, a total of 40 short observations amounting to 200 ks exposure time were awarded for this purpose in AO-1. Here we report on the preliminary results from this programme relating to nature of the Galactic X-ray source population and the origin of the bright X-ray emission which forms the so-called Galactic X-ray Ridge.

2. The XGPS Source Catalogue

The primary purpose of the XGPS survey is to study the X-ray source population of the Galaxy at faint fluxes. To date 15 pointings are available from the XGPS survey, for which we have carried out source detection in three energy bands - soft (0.4–2 keV), hard (2–6 keV) and combined (0.4–6 keV). In total 223 discrete sources have been detected at a significance level greater than 5σ in either the EPIC-pn and/or EPIC-MOS cameras. A subset of these sources can be seen in Fig. 1 which shows a mosaic of the hard-band images from the MOS 1/2 cameras. Only one of these sources has a counterpart in the extensive, but low spatial resolution, survey of the Galactic Plane carried out by ASCA (Sugizaki et al. 2001). The brightest source (by approximately an order of magnitude), which is clearly visible on the eastern side of the mosaiced region, does not appear in the ASCA catalogue and is therefore a transient.

2.1. The Transient Source

The bulk of the discrete X-ray sources detected in the XGPS survey are comprised of only a few tens of counts. However, in one of the survey fields (XGPS_009), there is a source, at RA 18h 28m 34.0s, DEC -10° 36' 59" (J2000), which contains several thousand counts. The X-ray spectrum of this object is shown in Fig. 2. Fitting an absorbed thermal bremsstrahlung model yields a temperature of \( \sim 5\) keV and an absorption column of \( \sim 6 \times 10^{22}\) cm\(^{-2}\). This column density is consistent with either an extragalactic or a distant Galactic origin. In the latter case (assuming a distance of \( \sim 15\) kpc) the observed flux is equivalent to an X-ray luminosity of \( \sim 10^{35}\) erg s\(^{-1}\), suggesting the possibility that this is a Be-star X-ray binary observed in a transient outburst state.

Figure 2. The X-ray spectrum of the transient source in the XGPS_009 field.
2.2. Detection of SNR G20.0-0.2

One important objective of the XGPS survey is to search for X-ray faint supernova remnants (SNR) with a view to placing improved constraints on the Galactic supernova rate and SNR evolution timescales. In this context we have detected an extended hard X-ray source coincident with the known SNR G20.0-0.2. This remnant, although well documented through radio observations (Becker & Helfand 1985), has not previously been observed in X-rays. Fig. 3 shows a smoothed image from one of the XGPS fields (Ridge3), based on the summation of the pn and MOS 1/2 datasets. The supernova remnant is clearly visible at the bottom of the image; its X-ray flux is $\sim 3.5 \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ (2–6 keV).

The spectrum of the SNR may be found by using the whole of the Ridge3 field (with sources removed) as a background template. Fig. 4 shows the resulting background subtracted X-ray spectrum. We have fitted a simple absorbed power-law model to these data; the derived parameter values are photon index $\Gamma = 2.1 \pm 0.7$ and absorption column density $N_{\text{H}} = 4.4 \pm 1.8 \times 10^{22}$ cm$^{-2}$.

The fact that G20.0-0.2 has not been seen in X-rays before is not surprising given its relatively low X-ray surface brightness, even though it appears to have a centre-filled X-ray morphology. Table 1 compares the inferred radio and X-ray luminosities of G20.0-0.2 with those of the two Crab-like SNRs, 3C58 and G21.5-0.9, and the Crab itself. Although the radio luminosity of G20.0-0.2 is on a par with 3C58 and G21.5-0.9, its X-ray luminosity is the lowest of the four SNR by a factor of $\sim 2$ and is almost 4 orders of magnitude lower than that of the Crab nebula.

3. The Log N - Log S Function

We have used the X-ray source catalogue derived from the XGPS fields to construct a log N - log S curve for the low Galactic latitude sky. The normalisation and slope of this relation can, in principle, provide important information on the spatial distribution and luminosity function of the various Galactic source populations, albeit bound-up with line-of-sight absorption effects. Fig. 5 shows the log N - log S distribution, after correcting for sky coverage effects, for XMM-Newton sources detected in the hard (2–6 keV)
Figure 4. The MOS spectrum of SNR G20.0-0.2.

Table 1. A comparison of the X-ray and radio luminosities of 4 SNRs. Here the X-ray band is defined as 0.1–4 keV and radio band as 10^7–10^11 Hz.

| SNR    | L_x  | L_R  | Log(L_x/L_R) |
|--------|------|------|--------------|
| 3C58   | 8.7 × 10^{33} | 2.0 × 10^{34} | -0.4         |
| G21.5-0.9 | 1.7 × 10^{35} | 1.8 × 10^{33} | 1.0          |
| Crab   | 3.7 × 10^{37} | 1.8 × 10^{35} | 2.3          |
| G20.0-0.2 | 4.6 × 10^{33} | 1.8 × 10^{34} | -0.6         |

One crucial step in the follow-up of any X-ray survey is the optical identification of the X-ray counterparts of the discrete sources detected in the survey. For one field in the XGPS survey, namely relatively short (5–10 ks) observations but fairly wide-angle coverage is rather well tuned to studying Galactic X-ray source populations at faint fluxes.

A crucial step in the follow-up of any X-ray survey is the identification of the optical counterparts of the discrete sources detected in the survey. For one field in the XGPS region (the so-called Ridge 3 field), a preliminary investigation of the optical counterparts has been conducted through the auspices of the AXIS project (Barcons et al. 2002). Based on sources derived from an earlier source detection analysis, Motch et al. (2002) found that out of 21 X-ray sources in the Ridge3 field, 11 can be identified as stellar coronae from the optical spectrum of a counterpart within the 90% error circle. With our current source detection procedure in the three energy bands (as detailed above) we now find 29 source in the Ridge 3 field at the 5σ confidence level (encompassing all but one of the original list of 21 sources).

We have investigated the correlation between the hardness of the X-ray source and the brightness of the potential optical counterpart. There is a clear trend for the softer X-ray sources to have counterparts with significantly brighter R-magnitudes than those for harder sources. Although the chance of coincidental optical correlations is not too high even at R≈20, if we place a limit at R≈17, then this leaves 11 X-ray sources with potential (bright) counterparts. Of these, 8 have relatively soft X-ray spectra, consistent with the findings of Motch et al. (2002) that these are probably stellar coronal sources. Excluding a few identified dMe stars, the bulk of the remaining ~ 60% of the sample, including almost all the spectrally hard sources, are candidate X-ray binaries and CVs, based on the source count analysis. However, one of the sources is particularly interesting because it is very soft and yet has no visible optical counterpart to R≈21. This is a candidate for an isolated neutron star, although further analysis is needed to confirm this.

5. Spectrum of the Diffuse Background

The spectrum of the unresolved Galactic Ridge X-ray emission (GRXE) was extracted from the EPIC MOS observations by masking out the known sources and summing the remaining data from all the observations. The contribution of the hard particle component of the EPIC background was estimated using the edge regions of the MOS CCDs not illuminated by the sky (i.e., the regions of the detector which fall outside of the telescope field of view).

Figure 3 shows the resulting background-subtracted spectrum. A segment of the spectrum just below 2 keV is omitted due to the presence of strong instrumental Al and Si fluorescent lines, which are not uniformly distributed across the CCDs and hence are difficult to remove fully in the background subtraction process. We have fit this spectrum with a multi-temperature thermal (MEKAL) model (to account for emission from hot Galactic plasma) and an absorbed power-law continuum (representative of the extragalactic Cosmic X-ray Background). Best-fit temperatures of ~ 0.1, ~ 0.6 and ~ 7 keV were derived. Several emission lines visible in the softer part of the spectrum testify to the presence of the lower temperature components, whereas the iron Kα emission line detected at 6.7 keV will

band. For comparison equivalent results are also shown for sources detected by ASCA (Sugizaki et al. 2001) and in recent deep Chandra (Ebisawa et al. 2001) observations. As can be seen in the figure, the flux range probed by the XGPS survey is intermediate between that achieved in the ASCA and Chandra programmes. The slope of the log N - log S curve, over the full flux range sampled by the three missions is, as expected, flatter than that measured for the extragalactic sky. Some comparisons with simple source distribution and luminosity models are also shown (Fig. 3). Preliminary analysis suggests that the Galactic population dominates these low latitude counts down to a flux of 5 × 10^{-14} erg s cm^{-2} (2–6 keV) below which the extragalactic contamination grows rapidly. Confirmation of this may be found in the hardness ratio distribution of the sources, which shows a wide spread of values, consistent with the view that a highly absorbed extragalactic population emerges only at the lower end of flux range sampled in the XGPS survey.

This analysis demonstrates that the strategy of the XGPS survey, namely relatively short (5–10 ks) observations but fairly wide-angle coverage is rather well tuned to studying Galactic X-ray source populations at faint fluxes.
be associated with the higher temperature plasma. The measured surface brightness in the 2–10 keV band of the unresolved background was $\sim 10^{-10}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$. For comparison the integrated signal in the source population resolved by XMM-Newton is $\sim 1.2 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$ deg$^{-2}$ for sources with fluxes between $3 \times 10^{-14} - 10^{-12}$ erg s$^{-1}$ cm$^{-2}$ (2–10 keV).

6. Conclusions

The XGPS survey has so far yielded over 200 point source detections from 15 XMM-Newton observations. A realistic target for the full AO1 programme is therefore an X-ray source catalogue with between 500 and 1000 entries. This will provide a valuable resource for studying the Galactic X-ray source population at faint fluxes (i.e., down to $F_X \sim 3 \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$). The full XGPS survey will also allow a detailed analysis of the spectrum and distribution of the diffuse cosmic X-ray background on the Galactic plane. For example, the detection of spatial variations in the background intensity on scales of about a degree would provide insight into origin and confinement mechanisms of the high temperature plasma which gives rise to the Galactic X-ray Ridge emission.

Figure 5. The hard (2–6 keV) band log $N$ - log $S$ plot based on XMM-Newton, Chandra and ASCA observations. The curves show the predicted source counts for various Galactic source populations.

Figure 6. The spectrum of the diffuse cosmic background in the Galactic Plane. This is the unresolved component of the Galactic X-ray Ridge.

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