TITLE
ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR**
EDITORS

AXIS (An XMM-Newton International Survey): a progress report

Xavier Barcons & Francisco J. Carrera, on behalf of the AXIS consortium and the XMM-Newton Survey Science Centre

Instituto de Física de Cantabria (Consejo Superior de Investigaciones Científicas-Universidad de Cantabria), 39005 Santander, Spain

Abstract. AXIS is a follow-up programme aiming at the identification of serendipitous X-ray sources identified by XMM-Newton, as part of the XMM-Newton Survey Science Centre activities. AXIS has so far provided optical/IR imaging for ~ 70 XMM-Newton target fields and spectroscopic identifications for > 125 X-ray sources. Here we report on some highlights of the survey, especially on the medium sensitivity high-galactic latitude survey and on the Galactic Plane survey.

1. Introduction

The unique combination of large field of view and effective area of the EPIC cameras on board XMM-Newton (Jansen et al 2001) provides a serendipitous sky survey in X-rays that is expected to grow at a rate of 30-150 sources per pointing. The follow-up and identification of these sources is one of the main tasks of the XMM-Newton Survey Science Centre (SSC, Watson et al 2001). The way this extensive task is being approached by the SSC, mostly in terms of ground-based imaging and spectroscopy, is described here.

AXIS (An XMM-Newton International Survey) is an on-going observational follow-up programme, part of the SSC activities, which has been awarded (under the International Time Programme scheme) over 80 observing nights in the Observatorio del Roque de los Muchachos (Canary Islands, Spain) for the period April 2000 to April 2002. Here we report on the main achievements of this programme, especially the high-galactic latitude medium sensitivity survey and the Galactic Plane Survey.

2. The XMM-Newton Survey Science Centre follow-up and identification programme

As the number of new X-ray sources in the XMM-Newton serendipitous sky survey is expected to grow at a rate of $\sim 50,000$ per year (i.e., comparable to the pre-XMM-Newton census of X-ray sources), any identification programme has to rely on some sort of statistical identification scheme. The way this has been conceived is in terms of conducting an extensive optical and infrared imaging programme, which will provide multi-colour photometry in the optical and the near infrared to be used in conjunction with the X-ray information (fluxes, hardness ratios) in order to provide some sort of probabilistic identification for the X-ray sources. This approach was first suggested in the Einstein Medium Sensitivity Survey (Stocke et al 1991) and it represents an optical/IR/X-ray generalisation of the photometric redshift techniques.

Indeed to train this scheme, we need a large number of proper spectroscopic identifications for various unbiased source samples. At high galactic latitudes ($\mid b \mid > 20°$) the aim is to construct 3 large samples (with up to 1000 sources each) with 0.5-4.5 keV limiting fluxes at $10^{-13}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (bright), $10^{-14}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (medium) and $10^{-15}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (faint). The energy band has been chosen in terms of the XMM-Newton EPIC efficiency being virtually flat, and therefore the spectral dependence of countrate to flux conversion being very weak. Experience has demonstrated that, although nominally this is not a much harder band than the *Einstein* or *Rosat* bands, the high efficiency at the hard end of this band reached by EPIC does enable the inclusion of very hard sources. In the Galactic Plane survey, the aim is to identify sources with flux $> 7 \times 10^{-15}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ (total band 0.2–10 keV), spanning different galactic environments and latitudes.

3. The current status of AXIS

AXIS has used so far about 1/3 of its observing time. There is a bias favouring imaging time during this first period with respect to the overall allocation of the observations, so the final achievements of the project cannot be simply scaled up from the present numbers.

We use the WFC for optical imaging (a 4-CCD 4kx2k camera covering virtually all the EPIC field of view in a single shot) and CIRSI (which needs 4 adjacent pointings to cover the EPIC field fo view), both on the 2.5m INT telescope. The aim is to cover the following bands: u, g', r', i', Z (similar to Sloan filters) and H (CIRSI does not offer K-band imaging). For the Galactic Plane fields we also aim at providing Hα imaging in order to single out active objects. As of March 2001 a total of 71 XMM-Newton fields have been imaged in at least one of these filters (this includes a PATT imaging programme lead by M.G. Watson), with the following breakdown: u(20), g'(53), r'(58), i'(52), Z(48), Hα (14) and H(4). All imaging goes fainter than $\mathrm{i}' = 22$ (in most cases well beyond $i' = 23$) which is the optical spectroscopy limit for AXIS.

Details on how X-ray source lists are produced and registered to an astrometric reference frame and how candidate counterparts are found in the optical images (primarily i') can be found elsewhere (Barcons et al 2001). It is worth emphasizing that in the high galactic latitude medium sensitivity sample, where we reach a flux limit of $2 \times 10^{-14}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$, counterparts are found for more than 90% of the X-ray sources and that in 3/4 of them the counterpart is unique. The situation changes somewhat at very low galactic latitude where confusion is important and colour selection needs often to be used to priorize candidate couterparts.

Table 1 shows the breakdown of identified X-ray sources as of March 2001. These have been obtained via optical spectroscopy of the candidate counterparts shown in the optical images. These identifications have been drawn from 10 high-galactic latitude fields and 2 low galactic plane fields (one at $b = -1°$ and another one at $b = +16°$). Although these identifications are not complete in any sense, they show that Broad-line AGN are to be the dominant source population outside the galactic plane at medium flux levels and that stars with active coronae are to be the dominant contributors in the galactic plane (especially at very low galactic latitude).

Table 1. Serendipitous X-ray sources identified in the AXIS programme

Source type	$\mid b \mid > 20°$	$\mid b \mid < 20°$	Total
Broad-line AGN	55	5	60
Active coronae	10	14	24
Other stars	10	11	21
Narrow-line em gals	9	2	11
Other galaxies	11	-	11
Accreting binaries	-	1	1
Total	95	33	128

4. Highlights from the high-galactic latitude medium sample

A small sample at high galactic latitude and with flux limit of 2×10^{-14} erg cm^{-2} s^{-1} has been completed. This consists of 2 XMM-Newton fields, covering ~ 0.3deg^2 in total where 43 X-ray sources (targets excluded) down to the above flux limit have been found. Full details of this can be found in Barcons et al (2001).

Out of the 43 X-ray sources, 41 show candidate counterparts in the optical images. Optical spectroscopy has enabled us to positively identify 33 of these and a further 2 have *probable* (very likely) identifications (totalling 82% of the sample). The breakdown is as follows: 25 Broad-line AGN, 5 Narrow-line emission galaxies (all of them luminous enough to host an AGN), 3 Galaxies and 2 active coronal stars.

There are several highlights to emphasize from this sample, including

- The surface density of AGN (including Broad-line and Narrow-line AGN) reaches $\sim 100\,\mathrm{deg}^{-2}$.
- The redshift distribution, peaking at $z \sim 1-2$ is fairly consistent with that expected from simple synthesis models for the XRB (Comastri et al 1995). Further, if we assign Broad-Line AGN to unabsorbed AGN, the synthesis models predict $\sim 60\%$ of these objects at our flux level and we find about $61-75\%$ (depending on the nature of the unidentified sources).
- Among the sample of BLAGN we find 2 ($z = 1.82$, $z = 1.91$) Broad-Absorption-Line (BAL) AGN. These objects have been practically inexistent in previous X-ray selected samples. The exceptions have been 1 BAL AGN in the Einstein Medium Sensitivity Survey ($z = 2.027$, Stocke et al 1991) and more recently the ELAIS/BeppoSAX survey ($z = 2.2$ Alexander et al 2001), the *Chandra* deep survey ($z = 2.75$, Giacconi et al 2001) and the survey of *Rosat* hard X-ray sources ($z = 2.21$, Page et al 2001). In the present sample BAL QSOs constitute 6-8% of the population of BLAGN,

similar to optical surveys. The unique sensitivity of XMM-Newton at hard photon energies (even at 4.5 keV) might be the reason why X-rays can be seen through the ejected material in BAL QSOs.

5. Highlights from the Galactic Plane Survey

As expected most of the sources found in the Galactic Plane survey are stars with active coronae. The one difference to emphasize with respect to previous studies (e.g. with *Rosat*) is that due to the enhanced sensitivity of XMM-Newton the optical emission lines are in some cases very weak.

Another interesting finding of the Galactic Plane survey has been the Be accreting binary SS397 in the field of the supernova remnant G21.5-09. The optical counterpart of this source exhibits a highly reddened ($A_V = 5.5$) Be spectrum whose X-ray to bolometric luminosity ratio calls for a binary accreting system framework. The rather low X-ray luminosity ($\sim 10^{32}\,\mathrm{erg\,s^{-1}}$) is consistent with both a neutron star and a white dwarf companion.

6. Outlook

The sensitivity of XMM-Newton at high photon energies is opening new views of the X-ray Universe. Systematic identifications of serendipitous X-ray sources reveal the presence of sources that were practically absent in previous X-ray surveys (e.g., BAL QSOs or active coronae with weak lines). By the end of the AXIS project we expect to have identified several hundreds of sources both in the bright and medium sensitivity samples at high galactic latitudes as well as several hundred sources in the galactic plane. Then we will have the tool to characterize in detail the major source populations as well as to detect minority populations.

Acknowledgments. We are grateful to the AXIS team for their contribution (information under `http://www.ifca.unican.es/~ xray/AXIS`). Partial financial support for this work was provided by the spanish Ministry of Science and Technology under project AYA2000-1690.

References

Alexander D.M. et al, 2001, ApJ, in the press

Barcons X. et al, 2001, in preparation

Comastri A., Setti G., Zamorani G., Hasinger G., 1995, A&A, 296, 1

Giacconi, R. et al, 2001, ApJ, 551, 624

Jansen F. et al, 2001, A&A, 365, L1

Page M.J., Mittaz J.P.D., Carrera F.J., 2001, MNRAS, in the press (astro-ph/0103055)

Stocke J.T. et al, 1991, ApJS, 76, 813

Watson M.G. et al, 2001, A&A, 365, L51