The BeppoSAX view of the hard X–ray background

A. Comastri\(^1\), F. Fiore\(^2,3,4\), P. Giommi\(^3\), F. La Franca\(^5\), M. Elvis\(^4\), G. Matt\(^5\), S. Molendi\(^6\), G.C. Perola\(^5\)

\(^1\)Osservatorio Astronomico di Bologna, via Ranzani 1, I–40127 Bologna, Italy
comastri@astbo3.bo.astro.it
\(^2\)Osservatorio Astronomico di Roma, via Frascati 33, I–00044, Monteporzio Catone, Italy
fiore@quasar.mporzio.astro.it
\(^3\)SAX Science Data Center c/o Nuova Telespazio, via Corolle 19, I–00131, Roma, Italy
giommi@napa.sdc.asi.it
\(^4\)Harvard Smithsonian Center for Astrophysics, 60 Garden street, MA–02138, Cambridge, USA
elvis@head-cfa.harvard.edu
\(^5\)Dipartimento di Fisica Università “Roma Tre”, via della Vasca Navale 84, I–00146, Roma, Italy
matt@haendel.fis.uniroma3.it, lafranca@amaldi.fis.uniroma3.it, perola@amaldi.fis.uniroma3.it
\(^6\)Istituto di Fisica Cosmica e Tecnologie Relative - CNR, via Bassini 15, I–20133, Milano, Italy
silvano@ifctr.mi.cnr.it

ABSTRACT

First results on a medium–deep X–ray survey in the “new” 5–10 keV band carried out with the MECS detectors onboard BeppoSAX are presented. The High Energy Large Area Survey (HELLAS) is aimed to directly explore a band where the energy density of the X–ray background is more than twice than that in the soft (0.5–2.0 keV) band. The optical identification follow-up of the first ten HELLAS hard X–ray sources indicate that Active Galactic Nuclei are the dominant population at 5–10 keV fluxes of the order of $10^{-13}$ erg cm$^{-2}$ s$^{-1}$. We discuss the implications of these findings for the AGN synthesis models for the XRB.

1 INTRODUCTION

The recent X–ray surveys at both soft (0.5–2.0 keV) and hard (2–10 keV) energies have provided a major improvements in our knowledge of the nature of faint X–ray sources and on the origin of the X–ray Background (XRB). Deep X–ray observations in the Lockman hole carried out with the ROSAT PSPC and HRI detectors have resolved into discrete sources about 70–80% of the 0.5–2 keV XRB (Hasinger et al. 1998). Optical identifications of a complete sample of 50 ROSAT sources at the 0.5–2.0 keV flux limit of $\sim 5.5 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ reveal that a large fraction ($\sim 85\%$) of them are AGNs (Schmidt et al. 1998). At higher energies (above 2 keV) the lack of imaging capabilities has been a major problem for several years. For this reason only a few hundreds of bright ($S_{2–10\text{keV}} > 3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$) sources discovered by HEAO1 (Piccinotti et al. 1982; Wood et al. 1984) were known before the launch of ASCA. The first ASCA surveys (Georgantopoulos et al. 1997; Cagnoni, Della Ceca, Maccacaro 1998; Ueda et al. 1998) provided a dramatic improvement (about a factor 300) in terms of limiting flux. As a result a significant fraction ($\sim 30\%$) of the 2–10 keV XRB is already resolved into discrete sources at a limiting flux of $\sim 10^{-13}$ erg cm$^{-2}$ s$^{-1}$. Programs to optically identify these sources have already started (Boyle et al. 1998) suggesting that also at higher energies AGN constitute the dominant population and
adding further evidence on the fact that the bulk of the XRB is made by the integrated emission of Active Galactic Nuclei.

Detailed modelling of the XRB spectral intensities in terms of the integrated contribution of AGNs has been hampered by the fact that the 2–10 keV AGN spectra are much steeper than the XRB spectrum (the “spectral paradox”). It has been proposed (Setti & Wolter 1989) that this problem can be solved assuming an important contribution from sources with spectral shapes flattened by absorption. Based on this proposal the 3–100 keV XRB spectral intensity (Fig. 1) and source counts in different energy bands (Fig. 2) can be reproduced by the combined emission of Seyfert galaxies and quasars (type 1) and obscured (type 2) AGNs with a range of column densities and luminosities (Matt & Fabian 1994; Madau et al. 1994; Comastri et al. 1995).

All these models rely on AGN unified schemes, which require, in their strictest version (Antonucci 1993), a type 1 nucleus in all AGN, surrounded by a geometrically thick torus, blocking the line of sight to the nucleus (continuum and broad lines) in type 2 objects. The same X–ray luminosity function and cosmic evolution usually parameterized as pure luminosity evolution, is then assumed for both type 1 and type 2 AGN, which imply the existence of a population of highly absorbed high luminosity quasars (type 2 QSOs). Even if the discovery of a few type 2 QSO candidates has been reported (e.g. Otha et al. 1996) this population has proved to be elusive and no compelling evidence for any type 2 QSO exists (Halpern et al. 1998). Alternatively, the bulk of the hard XRB could be made by a larger population of lower luminosity Seyfert 2 like galaxies, possibly subject to a different cosmological evolution, as predicted in scenarios where the absorption takes place in a starburst region surrounding the nucleus (Fabian et al. 1998). Is is interesting to note that a new estimate of the evolution of the soft X–ray luminosity function from ROSAT data (Miyaji, Hasinger, Schmidt 1999a) indicates a more complex behaviour which is best parameterized with luminosity dependent density evolution. Based on these new results Miyaji, Hasinger, Schmidt (1999b) have worked out an AGN synthesis model which is able to reproduce the observational constraints.

Given that the contribution of absorbed sources (irrespective of their nature and cosmological evolution properties) increases with energy (Fig. 1), a crucial test for the XRB models and in particular on the spectral and evolutive properties of obscured AGNs would require the comparison of their predictions with the results of optical identifications of complete samples of X–ray sources possibly selected in the hard X–ray band.

2 THE HELLAS SURVEY

BeppoSAX (Boella et al. 1997a) provides a good opportunity to investigate the hard X-ray sky, thanks to an improved sensitivity of the MECS instrument (Boella et al. 1997b above 5 keV (5–10 keV flux limit of ~ 0.002 mCrab in 100 ks, to be compared with the 0.5–1 mCrab flux limit of the HEAO1-A2 and Ginga surveys), and improved point spread function (error circles of 1 arcmin, 95% confidence radius) which allows optical counterparts to X-ray sources to be identified. The BeppoSAX High Energy LLarge Area Survey (HELLAS, Fiore et al. 1999, in preparation) has cataloged some 170 sources in several MECS observations with exposure times between 10 and 300 ks in the 5–10 keV band. Moreover about 500 sources in the 1.5–10 keV band at the flux limit of $5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ have been detected in the same fields. The HELLAS sources surface density is of the order of 20 sources per square degree at the limiting flux of $5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ (Giommi et al. 1998), implying that between 30 and 40 % of the XRB (depending on its normalization) is already resolved in sources.

In order to investigate the nature of the HELLAS sources we have begun a program to identify their optical counterparts. In particular we want to address the following points:
Figure 1: The AGN synthesis model (solid line) fit to the XRB spectrum. The black points in the 3–300 keV band are from HEAO1, while the grey points and bow-tie regions in the 1–7 keV band are from ASCA. The dotted line represents the contribution from unabsorbed objects. The dash–dotted lines represent the contribution of obscured AGNs and are labeled by the logarithm of the column density (see Comastri 1999 for details). The vertical thick lines mark the 5–10 keV band of the HELLAS survey. In this band the energy density of the XRB is about twice that in the soft band. The increased contribution of absorbed objects is also evident.

Figure 2: The AGN synthesis models predicted counts in the 0.5–2.0 keV (left panel) and 2–10 keV (right panel) energy ranges compared with observational data. The meaning of the various curves is the same as in figure 1, the dashed upper curve represents the summed contribution of AGNs and clusters of galaxies. Data points in the 0.5–2.0 keV band are from Hasinger et al. 1998; in the 2–10 keV band, from bright to faint fluxes, are from Piccinotti et al. 1982; Cagnoni et al. 1998; Giommi et al. 1998; Ogasaka et al. 1998. The bow-tie region is from a fluctuation analysis of ASCA data by Gendreau, Barcons & Fabian 1998.
• If they are obscured AGNs of the XRB synthesis models which is the range of absorbing column densities and X-ray luminosities?

• What is the space density and cosmological evolution of obscured type 2 AGNs? Is it different from type 1?

• Are the absorbed sources optically classified as type 2 objects? Is there any relation between X-ray absorption and optical reddening?

3 THE OPTICAL IDENTIFICATION

Optical spectroscopy in the 3450–8000 Å range with a resolution of ~ 7 Å of a subsample of 10 HELLAS sources has been carried out on March 1998 from the Kitt Peak Observatory 4 meter telescope. The sources, selected only on the basis of visibility reasons, should be representative of the whole HELLAS sample. Indeed they span a relatively wide range in X-ray fluxes (~ 7 × 10^{-14} – 10^{-12} erg cm^{-2} s^{-1} in the 5–10 keV energy range) and X-ray hardness ratios. In order to avoid further possible selection biases all the optical counterparts, at the magnitude limit of R=20, within each HELLAS error box (of about 1 arcmin radius) have been observed. The most likely counterpart of the X-ray source has been identified among objects with large hard X-ray to optical flux ratio like AGN Galactic binaries, clusters of galaxies, bright galaxies or stars. A detailed discussion of the optical and X-ray properties of this subsample can be found in Fiore et al. (1999), while the complete set of optical spectra and finding charts will be presented in La Franca et al. (1999 in preparation).

Here we briefly summarize the first results of the identification process. In eight cases out of ten only one plausible candidate has been found: three broad line quasars in the redshift range 0.8–1.28 with a blue continuum spectrum; two broad emission line quasars with a very red optical continuum (0.2 < z < 0.35); 3 narrow emission line galaxies identified with type 1.8–2.0 Seyferts on the basis of diagnostic lines diagrams (z < 0.4). In one error box two optical counterparts may contribute to the hard X-ray flux. The diagnostic line ratios suggest lower excitation than Seyfert galaxies and thus we classify them as LINERS. Finally in one case we were not able to find a plausible identification.

The probability of finding by chance these sources taking into account the mean surface density of AGNs and LINERS at the limiting magnitude R=20 in our error boxes is very low (< 0.2 %). The optical identification follow–up provides thus strong evidence that AGNs are the dominant source population in the 5–10 keV band at fluxes of the order of ~ 10^{-13} erg cm^{-2} s^{-1}.

4 DISCUSSION

The X-ray number counts of the HELLAS sources (Giommi et al. 1999 in preparation; Fiore et al. 1999 in preparation) are compared with the predictions of the AGN synthesis model of Comastri et al. (1995) in the 5–10 keV band. The BeppoSAX error bars (Fig. 3) have been computed assuming a range of spectral indices for the count rate to flux conversion and the uncertainties in the MECS off–axis sensitivity. There is a relatively good agreement between data and model predictions at the faint flux limit of HELLAS (~ 5 ×10^{-14} erg cm^{-2} s^{-1}). The discrepancy at brighter fluxes may be due to the contribution of other sources (i.e. stars and galaxies) not included in the model and/or to small residual calibration problems. A more detailed discussion of the BeppoSAX source counts and associated calibration uncertainties in the 5–10 keV band will be presented elsewhere (Giommi et al. 1999; Fiore et al. 1999).

Even if the sample is small we have tried to compare the X-ray and optical properties of the identified sources. An estimate of the absorbing column density has been made using the observed hardness ratios.
Figure 3: The AGN synthesis model prediction (solid line) are compared with the HELLAS log N – log S error bars and at bright fluxes with the HEAO1–A2 AGN counts (Piccinotti et al. 1982) converted to the 5–10 keV band assuming a power law spectrum with energy index $\alpha = 0.8$. The dotted line represents the contribution from unabsorbed and relatively unobscured objects ($\log N_H < 23$). The dot–dashed line represents the contribution of obscured AGNs ($\log N_H > 23$). The upper dashed line is a preliminary estimate of the summed contribution of AGNs and clusters of galaxies and measured redshifts assuming an average power law spectrum ($F_\nu \propto \nu^{-\alpha}$) with energy index $\alpha = 0.8$. We have found evidence for absorption in five sources with estimated column densities in the range $\log N_H \sim 22.5–23.2$. Moreover 4 of the absorbed sources show evidence of extinction also in the optical spectrum (the 3 Seyfert 1.8-2.0 galaxies and 1 red quasar). The fraction of obscured AGNs seems to be higher than in previous ROSAT and ROSAT/ASCA surveys (Schmidt et al. 1998; Akiyama et al. 1998) supporting the AGN synthesis models for the hard XRB. In particular the expected number of heavily obscured sources ($\log N_H > 23$) according to the Comastri et al. (1995) model is of the order of 30% at the HELLAS flux limit (dashed line in figure 3) in agreement with the present findings. Clearly a much improved source statistic and further optical identifications are needed to confirm these results.

A major improvement in our understanding of the origin of the hard X–ray background and on the AGN content of X-ray surveys must await the identification of a few hundred hard X–ray selected sources. The complete identification of the entire HELLAS sample, which is actually in progress, will allow us to measure the relative fraction of type 2 and type 1 hard X–ray selected AGNs and to study for the first time the X–ray luminosity function and evolution of obscured AGNs.

This would constitute a crucial piece of information for the modelling of the XRB. Indeed a significant intrinsic dispersion in the X–ray spectral slopes distribution (as in the case of a significant number of absorbed sources with flat spectra) can affect the space density and evolution of the entire population if not properly taken into account. In particular as shown by Francis (1993) and Page et al. (1996) such a dispersion in the X–ray spectra introduces spurious density and/or luminosity evolution and, as a consequence, an incorrect estimate of the AGN contribution to the XRB.
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