The BeppoSAX High Energy Large Area Survey (HELLAS)

F. Fiore[1,2,3], P. Giommi[1], F. La Franca[4], G. Matt[4], G.C. Perola[4], A. Comastri[5], S. Molendi[6], M. Elvis[3], I Gioia[7,8] F. Tamburelli[1], D. Ricci[1], F. Pompilio[4]

[1] BeppoSAX Science Data Center, via Corcolle 19, I-00131 Roma, Italy

[2] Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio, Italy

[3] Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138

[4] Universita' Roma Tre, Via della Vasca Navale 84, I-00146 Roma, Italy

[5] Osservatorio Astronomico di Bologna, via Ranzani 1, I-40127 Bologna, Italy

[6] IFCTR/CNR, via Bassini 15, I-20133 Milano Italy

[7] Institute for Astronomy, Hawaii, 96822 USA [8] IRA/CNR, Bologna, Italy

ABSTRACT

We have surveyed ~ 50 deg^2 of sky in the largely unexplored 5-10 keV band using the BeppoSAX MECS instrument, finding 180 sources. After correction for the non uniform sky coverage we find about 18 sources deg^{-2} with $F_{5-10keV} \gtrsim 5 \times 10^{-14}$ erg cm^{-2} s^{-1} , and resolve 30-40 % of the hard 5-10 keV Cosmic X-ray Background (XRB). Optical identification of a first small sample of sources show that most (11 out of 14) are AGN. Six of these show evidence of absorption/extinction in X-ray/optical, thus providing support to the scenario in which the hard XRB is largely made by obscured AGN (Setti & Woltjer 1989, Comastri et al. 1995).

1. Introduction

Hard X-ray selection is an efficient way to separate sources accretion-powered, such as Active Galactic Nuclei (AGN), from sources dominated by starlight emission, which heavily populate optical and IR surveys. Hard X-rays are also less affected by selection biases than other bands. For example, optical and UV color selection is often biased against objects with even modest extinction, or with an intrinsically 'red' emission spectrum. Soft X-ray selection is biased against highly obscured objects, a column density of a few times 10^{22} cm^{-2} is sufficient to reduce by ~ 100 times nuclear emission below 2 keV. The same column has negligible effect in the 5-10 keV band. This band is now accessible to surveys, thanks to the imaging instruments on board the ASCA and BeppoSAX satellites.

Hard X-ray selection permits us to: a) directly resolve the sources making most of the hard XRB (the energy density of the XRB at 5-10 keV is 2-3 times higher than at 1 keV, where previous X-ray surveys have provided most information). b) Measure the fraction of obscured to unobscured objects or, more generally, the distribution of absorbing columns of AGN. c) Search for previously 'rare' AGN, like 'red' quasars or other minority AGN populations (Kim & Elvis 1998) and quantify their fractional contribution to the AGN family. This allows us to start tackling the following open questions: (1) Is the hard XRB mostly made by AGN, like the soft XRB? (2) Is the XRB characteristic shape due to a large population of absorbed AGN? (3) Can we distinguish between different scenarios? AGN synthesis models for the XRB based on unification schemes (Antonucci 1993) assume the same evolution for type 1 and type 2 objects and predict a sizeble population of 'quasar 2' (with $L_X > 10^{44}$ erg s^{-1} and logN_H >23). Alternatively, the bulk of the hard XRB could be made by a large population of lower luminosity Seyfert 1.8-2 like galaxies, as in scenarios where the absorption takes place in a starburst region surrounding the nucleus (Fabian et al. 1998). In this case the amount of the absorbing gas may depend on the nuclear mass and consequently also on its luminosity. The evolution of the type 2 AGN luminosity function would then be strongly affected by the nuclear environment and may imply a link between AGN evolution and the history of star-formation (Madau et al. 1996).

2. The HELLAS survey

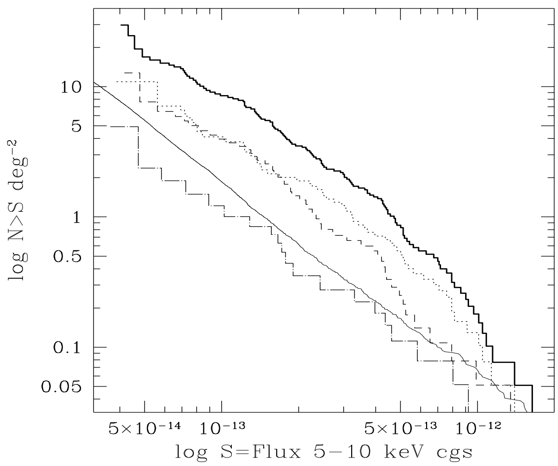
We decided to perform a high energy survey using the BeppoSAX (Boella et al. 1997a) MECS X-ray imaging instrument (Boella et al. 1997b). Details can be found in Fiore et al. (1998a,1999). The HELLAS survey has been performed in the hard 5-10 keV band for the following reasons. 1) This band is the closest to the peak of the XRB energy density that is reachable with the current imaging X-ray telescopes. 2) The BeppoSAX MECS PSF greatly improves with energy: in the 5-10 keV band it is a factor of ~ 2 sharper than in the softer 1-5 keV band (providing a 95 % error radius of 1 arcmin), which allows easier optical identification of the sources. 3) Including the softer 1-5 MECS range only increases the background for heavily cut-off sources with few photons below 5 keV, thus reducing the chances of detecting faint hard sources. About 180 sources have been detected at a confidence level $\gtrsim 3.5\sigma$. The count rates were converted to fluxes using the HR=4.5-10 keV/1.3-4.5 keV hardness ratio to estimate the spectral shape. A logN-logS function has been computed excluding from the sample the sources detected at offaxis angles > 22 arcmin or near the strongback support of the MECS beryllium window, to minimize possible systematic errors due uncertainties in the MECS calibration in these regions. Figure 1 shows the cumulative 5-10 keV logN-logS after correction for the energy dependent sky coverage. We find about 18 sources deg^{-2} at our flux limit of $F_{5-10\ keV} = 5 \times 10^{-14}$ erg cm^{-2} s^{-1} (also see Giommi et al 1998). This logN-logS corresponds to a resolved fraction of the 5-10 XRB equal to 30–40 %, depending on the XRB normalization (see Comastri 1998). 18 sources deg^{-2} is similar to the space density of optically selected quasars at B=20-21 (Zitelli et al 1992). AXAF and XMM will reach fluxes 500–100 times fainter, respectively, than BeppoSAX and ASCA, and so will find a density of sources higher or comparable to that of AGN surveys performed in any other band, even if the X-ray logN-logS flattens below 5×10^{-14} to a slope between 0.5 and 1 (as suggested by fluctuation analysis of ROSAT HRI deep fields, Hasinger et al. 1998).

We have divided the HELLAS sample into three groups of sources, depending on their spectral hardness. The three resulting logN-logS are shown in Figure 1, along with the prediction for the 5-10 keV band obtained by extrapolating the ROSAT 0.5-2 keV logN-logS assuming an unabsorbed power law spectrum of $\alpha = 1$. This extrapolation falls short of the total observed logN-logS by a factor of ~ 5 but is close to the logN-logS of the softer HELLAS sources, in agreement with the suggestion that the hard X-ray source population is dominated by obscured sources.

3. Optical spectroscopic identifications

Ten percent of the HELLAS sources have been identified with previously know AGN (13), clusters of galaxies (3), stars (1) and Cataclismic Variables (1). The 13 AGN were discovered in radio, soft X-ray, and optical surveys, and therefore this sample is biased against highly absorbed sources. To remedy this bias we have started a program to spectroscopically identify the rest of the HELLAS sample. Between 1 and 7 optical candidates were identified on APM scans of the E (R) POSS plates down to R$\sim$ 20m, within a conservative error-box of $60''$ radius around each X-ray source. *Unlike previous identification campaigns of ASCA sources, which take advantage of correlations with ROSAT source catalogs or Radio catalogs, our strategy was to obtain spectra of all candidates down to the chosen R=20 magnitude limit. To avoid any possible selection bias we do not require the HELLAS sources to be detected also at other (softer) energies.* We carried out spectroscopic identification of optical candidates for the HELLAS sources using the RC spectrograph (RCSP) at the Kitt Peak 4m telescope for 9 sources, the FAST spectrograph at the Whipple 60" telescope for 1 source, the Hawaii 88" for 2 sources and EFOSC2 at the ESO 3.6m for 2 sources (Fiore et al. 1998b).

The observations of the fourteen error-boxes led to 13 new identifications (Fiore et al. 1998b). Five AGN are normal broad line "blue" quasars (0.2 <z< 1.3). Two AGN are broad line 'red' quasars ($\alpha \sim -3$, B-R=2.9 and 2.6, 0.2 <z< 0.4). Four objects at 0.04 <z< 0.34 have an [OIII]/H_β flux ratio of about 10, typical of Seyfert 2 galaxies, but show broad ($\sim$ 4000 km s^{-1}) H_α or H_β wings. We identified these objects as intermediate type 1.8-1.9 AGN. Two narrow emission line galaxies (0.08 <z< 0.18) have diagnostic line ratios indicating lower excitation than in Seyfert 1.8-2 galaxies but higher than in HII galaxies. We classify them as LINERS. One of the fourteen HELLAS sources observed still remain unidentified. Figure 2 shows the spectra of a 'red' quasar and of a type 1.9 AGN. These first identifications confirm that most of the HELLAS sources are indeed AGN. The source breakdown is however rather peculiar. In addition to five normal broad line quasars, typically found in optical and soft X-ray surveys, we found six "intermediate" AGN and two LINERS. These objects are "intermediate" both for their optical spectra which places them between type 1 and type 2 AGN and because of their X-ray absorption, which is typically logN_H=22.5-23 (estimated from hardness ratios). 'Red' quasars have been selected in the past in the radio band (Smith & Spinrad 1998, Webster et al. 1995) or in soft X-rays (provided that the absorbing column is not too thick, $A_V \lesssim 2$, logN_H < 21.7, Kim & Elvis 1998). Their number density relative to normal "blue" quasars is thought to be no more than a few percent.



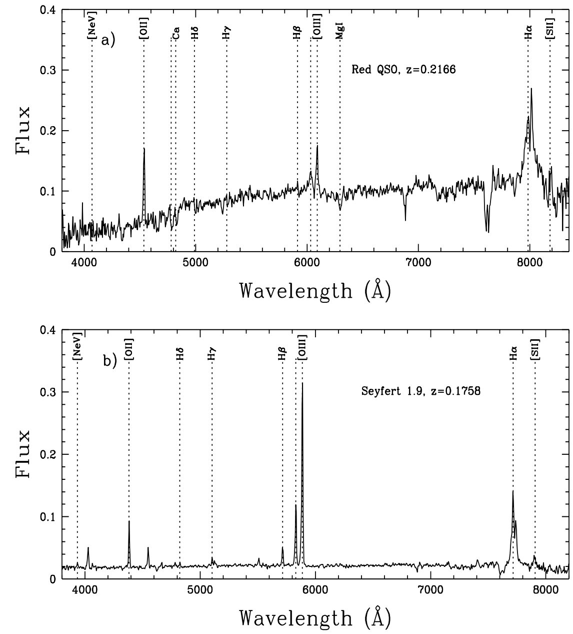


Fig. 1.— **Figure 1**: HELLAS 5-10 keV total logN-logS (thick line). The dotted, dashed and dot dashed lines shows the logN-logS of the hard (HR< -0.27, roughly corresponding to a column of logN_H >23 for a power law spectrum of $\alpha_E = 0.8$ and z=0), intermediate (-0.27<HR<0.27), and soft (HR> 0.27, logN_H <22) HELLAS sources. The solid thin line shows the prediction from the ROSAT 0.5-2 keV logN-logS, assuming an unabsorbed power law spectrum with $\alpha_E = 1$. **Figure 2**: The spectra of the type 1.9 AGN 1SAXJ1218.9+2958 and of the red quasar 1SAXJ1353.9+1820

In contrast we found a fraction of about 20 %. Hard X-rays selection appears to be an efficient way of discovering 'red' quasars over a broad range of column densities. A comparison with ROSAT and ASCA is telling: the fraction of AGN showing evidence of obscuration of the nucleus in either optical or X-rays (6 out of 11 high excitation AGN) is $0.55^{+0.11}_{-0.14}$ (Gehrels 1986, 67 % confidence intervals). Including the two LINERS brings this fraction to $0.62^{+0.10}_{-0.11}$. The fraction of intermediate AGN + narrow line galaxies in the ROSAT 0.5-2 keV survey of the Lockman hole (Schmidt et al. 1998) is 0.26±0.09 (10 out of 39 objects). The same fraction in the ASCA-ROSAT combined surveys of Boyle et al. (1998) and Akiyama et al. (1998) is 0.33±0.08 (20 out of 61 objetcs). The HELLAS fraction including (excluding) LINERS is different from the ROSAT and ASCA-ROSAT fractions at the 99 % and 95 % (92 % and 80 %) confidence level respectively. These differences are probably due the fact that ROSAT and ASCA-ROSAT surveys, using soft X-ray data, are biased against faint highly obscured objects.

4. Conclusions

Hard X-ray surveys are the most efficient and unbiased way to search for any form of accretion process in the Universe. The advent of imaging instrument sensitive above 2 keV opens up new frontiers in the study of the X-ray sky, in that they allow us to go "deeper" (i.e. to find sources $\sim 100 - 1000$ fainter than in the HEAO-1, EXOSAT and *Ginga* surveys) and explore nearly untouched "planes" in discovery space (e.g. absorption in sources at z$>$ 0.1, extreme spectral shapes). We have started a program to identify a few hundred hard (5-10 keV) X-ray selected sources. Preliminary results based on a small sample of sources show that most (11 out of 14) are AGN, half of which showing evidence of absorption at the level predicted by AGN synthesis models of the XRB (Comastri et al. 1995). The first identifications are also providing surprises. In addition to normal broad line blue quasars we are finding a few LINERS, 'red' quasars, and several "intermediate", relatively low luminosity ($L_X = 10^{43}$ erg s^{-1}, M$_B$=-20) AGN. This rich diversity contrasts with the uniformity of spectra found in optical/UV and soft X-ray surveys, and suggest that the AGN selection criteria inherited from these works have restricted our view of the true range of AGN spectra (Elvis 1992). The AGN phenomenon, e.g. accretion, is likely to manifest itself in a wider and more complex way than we used to know.

We did not find any luminous, narrow line and highly absorbed quasar (the so called 'quasar 2'). This is not surprising, since their number, as predicted by the Comastri et al. (1995) XRB model at our flux limit, is 0.4 deg^{-2}, i.e only 5 among the 180 HELLAS sources. However, other recent studies (Boyle et al. 1998, Akiyama et al., these proceedings) also failed to find objects of this kind. Although the statistics are not yet good enough to reach strong conclusions, these results do suggest that the bulk of the hard XRB could be made by a large population of lower luminosity Seyfert 1.8-2 like galaxies and moderately absorbed 'red' quasars, i.e. 'minority' objects in optical and soft X-ray surveys. In this regard, it is worth remarking that a sizeble population of low luminosity AGN (M$_B$ in the range –17; –20) may exist at very faint optical fluxes (V=26-27) in the Hubble Deep Field North (Jarvis &MacAlpine 1998). This conclusion will be soon tested by the deep and high spatial resolution surveys that will be performed by AXAF and XMM in the next 1–2 years. Deep observations of the Hubble Deep Fields with these observatories should be able to find the X-ray emission from these putative Active Nuclei.

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