The evolution of AGN in the Hard X-rays from HELLAS

F. La Franca¹, F. Fiore², C. Vignali³, A. Comastri⁴, F. Pompilio⁵, plus HELLAS consortium
¹) Dipartimento di Fisica, Università Roma Tre, Via della Vasca Navale 84, I-00146 Roma, Italy
²) Osservatorio Astronomico di Roma, Via Frascati 33, I-00044 Monteporzio Catone, Italy
³) Dipartimento di Astronomia, Via Ranzani 1, I-40127 Bologna, Italy
⁴) Osservatorio Astronomico di Bologna, Via Ranzani 1, I-40127 Bologna, Italy
⁵) SISSA, Via Beirut 4, I-34014 Trieste, Italy

Abstract. We present optical spectroscopic identification of sources identified in the BeppoSAX MECS fields of the High Energy LLarge Area Survey (HELLAS). In total 62 sources from a sample of 115 brighter than \( F_{5–10\text{keV}} > 5 \times 10^{-14} \text{cgs} \) have been identified. We find a density of 13-21 sources/deg² at \( F_{5–10\text{keV}} > 5 \times 10^{-14} \text{cgs} \), which contribute to 20–30% of the hard X-ray background. Evidences are found for type 1 AGN being more absorbed with increasing redshift or luminosity. The low redshift (\( z < 0.2 \)) ratio of type 2 to type 1 AGN is 3 ± 1.5, in agreement with the unified models for AGN. The luminosity function of type 1 AGN in the 2-10 keV band is preliminary fitted by a two-power law function evolving according to a pure luminosity evolution model: \( L \propto (1 + z)^2.2 \).

1. Introduction

Hard X-ray observations are the most efficient way of tracing emission due to accretion mechanisms, such in Active Galactic Nuclei (AGN), and sensitive hard X-ray surveys are powerful tools to select large samples of AGN less biased against absorption and extinction. In this framework we decided to take advantage of the large field of view and good sensitivity of the BeppoSAX MECS instrument (Boella et al. 1997a,b) to survey tens to hundreds of square degrees at fluxes \( \gtrsim 5 – 10 \times 10^{-14} \text{erg cm}^{-2}\text{s}^{-1} \) (Fiore et al. 2000a), and using higher sensitivity XMM-Newton and Chandra observations to extend the survey down to \( \sim 10^{-14} \text{erg cm}^{-2}\text{s}^{-1} \) on several deg². The results from the optical identification of a sample of faint Chandra sources discovered over the first 0.14 deg² have been published by Fiore et al. (2000b). This approach is complementary to deep pencil beam surveys (\( \sim 0.1 \text{deg}² \)), see e.g. Mushotzky et al. 2000, Hornschemeier et al. 2000), as we cover a different portion of the redshift–luminosity plane. Our purpose is to study cosmic source populations at fluxes where the X-ray flux is high enough to provide X-ray spectral information in higher sensitivity follow-up observations. This would allow the determination of the distribution
of absorbing columns in the sources making the hard XRB, providing strong constraints on AGN synthesis models for the XRB (e.g. Comastri et al. 1995).

2. The HELLAS survey

The High Energy Large Area Survey (HELLAS, Fiore et al. 1999, 2000a, 2000c) has been carried out in the 4.5-10 keV band because: a) this is the band closest to the maximum of the XRB energy density which is reachable with the current imaging X-ray telescopes, and b) the BeppoSAX MECS Point Spread Function (PSF) greatly improves with energy, providing a 95% error radius of 1′ in the hard band (Fiore et al. 2000a), thus allowing optical identification of the X-ray sources.

About 80 deg$^2$ of sky have been surveyed so far using 142 BeppoSAX MECS fields at $|b| > 18$ deg. 147 sources have been found with $F(5-10 keV) > 5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$. We find a density of 13-21 sources per square degree at $F_{5-10 keV} > 5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, which contribute to 20 – 30 % of the hard XRB in this energy range.

For the spectroscopical identifications we concentrated in a reduced subsample of 110 MECS fields having $-60^\circ < \delta < +79^\circ$, and excluding the regions with $5^h < \alpha < 6.5^h$ and $16.9^h < \alpha < 20^h$. In this subsample the sky coverage is $\sim 55$ deg$^2$ at $5 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, and 0.5 deg$^2$ at $5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$. We found in total 115 such sources with $F(5-10 keV) > 5 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$.
3. Optical identifications

Correlations of the HELLAS spectroscopic subsample of 115 sources with catalogs of cosmic sources provide 26 coincidences (7 radio-loud AGN, 13 radio-quiet AGN, 6 clusters of galaxies). Optical spectroscopic follow-ups have been performed on 49 of the 89 remaining HELLAS error-boxes, providing 36 new identifications (Fiore et al. 1999, La Franca et al. 2000 in preparation). We limited the optical identification process to objects with surface density < 40 deg$^{-2}$ to keep the number of spurious identifications in the whole sample < 3$^{-4}$. As a consequence, we chose a limit of R= 20.5 for Broad line AGN; R= 19 for Narrow line AGN (Sy1.8-2); and R= 17.5 for Emission line galaxies (LINERS and Starbursts). According to these limits we found 13 “empty” fields in total. The summary of the spectroscopic identifications is shown in Table 1.

| Type                  | Total | New from catalogs | from catalogs |
|-----------------------|-------|-------------------|---------------|
| HELLAS                | 62    | 36                | 26            |
| Type 1 AGN            | 36    | 21                | 15            |
| Type 1.8-2 AGN        | 12    | 11                | 1             |
| Emission line galaxies| 5     | 4                 | 1             |
| BL-Lacs               | 2     | 0                 | 2             |
| Radio galaxies        | 1     | 0                 | 1             |
| Clusters of galaxies  | 6     | 0                 | 6             |

The correlation with existing catalogues did identify only 2 type 2 AGN and emission line galaxies. This is explained as there are no existing large catalogues of such objects. Consequently a bias is introduced in the observed fractions of the populations of the identified sources against type 2 AGN and narrow emission line galaxies. However the flux distribution of the sample of the 26 sources identified through cross-correlations with catalogues is similar (according to the KS tests) to that of the total sample of 115 sources, and to the sample of 36 sources identified at the telescopes. In this case we can correct for the introduced biases. Applying these corrections we derive a value of 52% for the true fraction of type 1 AGN in the total sample, and 29% for narrow emission line galaxies and type 2 AGN. The remaining 19% are either AGN with optical magnitudes fainter than our spectroscopic limits or clusters of galaxies, BL-Lac etc. etc.

These numbers do not correctly address the question on the estimate of the ratio of type 1 and 2 AGN. Our sample is also biased against high redshift type 2 AGN which are indeed fainter than our spectroscopic optical limit of $R=19$ for Narrow line AGN (Sy1.8-2), and $R= 17.5$ for emission line galaxies. For this reason all the spectroscopic identified type 2 AGN have $z < 0.4$. A first preliminary estimate can be drawn by taking into account only the AGN having $z < 0.2$. In this case we estimate that the ratio of the number of type 2 AGN and emission line galaxies to the number of type 1 AGN is $3\pm 1.5$, in agreement
Figure 2. The softness ratio \((S-H)/(S+H)\) versus the redshift for the identified sources. open circles = broad line, 'blue' continuum quasars and Sy1; stars= broad line 'red' continuum quasars; filled circles= type 1.8-1.9-2.0 AGN; filled squares= starburst galaxies and LINERS; open triangles= radio-loud AGN; open squares= clusters of galaxies. Dotted lines show the expected softness ratio for a power law model with \(\alpha_E=0.4\) (lower line) and \(\alpha_E = 0.8\) (upper line). Dashed lines show the expectations of absorbed power law models (with \(\alpha_E = 0.8\) and \(\log N_{H} = 22.7, 23.0, 22.7\), from bottom to top) with the absorber at the source redshift.

with the unified models for AGN. More accurate analysis via model predictions from the evolution of type 1 and 2 AGN are underway.

In Figure 2 we plot the softness ratio \((S-H)/(S+H)\) as a function of the redshift for the 53 identified sources detected far from the beryllium strong-back supporting the MECS window. Note that the softness ratios of constant column density models strongly increases with the redshift. Most of the narrow line AGN have \((S-H)/(S+H)\) inconsistent with that expected from a power law model with \(\alpha_E = 0.4\). Absorbing columns, of the order of \(10^{22.5-23.5}\) cm\(^{-2}\), are most likely implied. Note also that some of the broad line AGN have \((S-H)/(S+H)\) inconsistent with that expected for a \(\alpha_E = 0.8\) power law, in particular at high redshift. The \((S-H)/(S+H)\) of the 24 broad line AGN is marginally anti-correlated with \(z\) (Spearman rank correlation coefficient of -0.364, corresponding to a probability of 92%). The number of sources is not large enough to reach a definite conclusion. Similar results have been recently found in ASCA samples by Akiyama et al. (2000) and Della Ceca et al. (2000). XMM-Newton and Chandra follow-up observations may easily confirm or disregard a significant absorbing column in these high \(z\) broad line quasars.
4. The evolution of AGN

We combined our sample of hard X-ray selected AGN with other samples of AGN identified by Grossan (1992), Boyle et al. (1998), and Akiyama et al. (2000). A total of 151 type 1 AGN have been used in the redshift range $0 < z < 3$. Values of $H_0 = 50$ Km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$, $\Lambda = 0$ have been used. The 2-10 keV luminosities have been computed using the k-correction derived from the model of the spectrum of type 1 AGN as in Pompilio, La Franca and Matt (2000). The coverage of the $L-z$ plane by the whole sample of type 1 AGN is shown in Figure 3a.

The sample of Grossan (1992) consists of 84 type 1 AGN and 12 type 2 AGN, predominantly at low redshift ($z < 0.3$). The sample covers an area of 26919 deg$^2$ down to a flux limit of $1.8 \times 10^{-11}$ cgs. The sample of Boyle et al. (1998) consists of 12 AGN1 and 6 AGN2. The sample of Akiyama et al. (2000) consists of 25 AGN1, 5 AGN2, 2 clusters, 1 star and 1 unidentified source.

We carried out a maximum likelihood analysis to derive best-fit parameters which described the 2-10 keV luminosity function and its cosmological evolution. Following Boyle et al. (1988) and Ceballos and Barcons (1996), we chose a two-power-law representation for the QSO LF:

$$\Phi(L_X) = K_1 L_X^{-\gamma_1} : \quad L_X < L_X^*(z = 0)$$

$$\Phi(L_X) = K_2 L_X^{-\gamma_2} : \quad L_X > L_X^*(z = 0).$$

Where $K_1 \equiv K_2 (L_X^*/10^{44}\text{erg s}^{-1})^{(\gamma_1-\gamma_2)}$. A standard power-law luminosity evolution model was used to parameterize the cosmological evolution of this luminosity function: $L_X^*(z) = L_X^*(0)(1 + z)^k$. 

Figure 3. a) The luminosity/redshift plane of the sample of type 1 AGN used in the computation of the luminosity function. b) The luminosity function of type 1 AGN as fitted by a pure luminosity evolution model at redshifts 0.1, 0.6, and 2.0. The densities have been corrected for evolution within the redshift bins.
A preliminary estimate of the fitted luminosity function is shown in Figure 3b. The corresponding fitted values are $\gamma_1 = 1.8$, $\gamma_2 = 3.1$, $k = 2.2$, $logL_X^* (z = 0) = 44.1$ erg s$^{-1}$, $K_2 = 8.8 \times 10^{-7}$ Mpc$^{-3}$/(10$^{44}$ erg s$^{-1}$). No redshift cut-off in the luminosity evolution has been applied. This result is in good agreement with the previous estimate from Boyle et al. (1998) on a smaller sample of 95 type 1 AGN (see Figure 3b). The evolved luminosity function shows a density excess of low luminosity high redshift objects. A more detailed study of the luminosity function which will take into account a possible redshift cut-off and density evolution is underway.

Acknowledgments. We thank the BeppoSAX SDC, SOC and OCC teams for the successful operation of the satellite and preliminary data reduction and screening. This research has been partly supported by ASI ARS/99/75 contract and MURST Cofin-98-02-32 contract.

References

Akiyama, M., Ohta, K., Tamura, N., et. al., 2000, ApJ, 532, 700
Boella, G., Butler, R.C., Perola, G.C., et al., 1997a, A&AS, 122, 299
Boella, G., Chiappetti, L., Conti, G., et al., 1997b, A&AS, 122, 327
Boyle, B.J., Georgantopoulos, I., Blair, A.J., Stewart G.C., Griffiths, R.E., 
Shanks, T., Gunn, K.F., Almaini. O., 1998, MNRAS, 296, 1
Ceballos, M.T., Barcons, X., 1996, MNRAS, 282, 493
Comastri, A., Setti, G., Zamorani, G. & Hasinger, G. 1995, A&A, 296, 1
Della Ceca, R., Braito, V., Cagnoni, I., Maccacaro, T., 2000, Proceedings 
of the Fourth Italian Conference on AGN, MemSAIt in press, [astro-
ph/0007433]
Fiore, F., La Franca, F., Giommi, P., et al., 1999, MNRAS, 306, L55
Fiore, F., Giommi, P., Vignali, C., et al., 2000a, MNRAS, submitted
Fiore, F., La Franca, F., Vignali, C., Comastri, A., Matt, G., Perola G.C., 
Cappi, M., Elvis M., Nicastro, F., 2000b, New Astronomy, 5, 143
Fiore, F., et al., 2000c, Proceedings of ”X-Ray Astronomy’99”, Bologna (Italy), [astro-ph/0007118]
Grossan, B.A., 1992, PhD thesis, MIT
Hornschemeier, A.E., Brandt, W.N., Garmire, G.P., et al., 2000, ApJ, 541, 49
Mushotzky, R.F., Cowie, L.L., Barger, A.J., Arnaud, K.A., 2000, Nature, 404, 459
Pompilio, F., La Franca, F., Matt, G., 2000, A&A, 353, 440