Spectroscopic identification of ten faint hard X-ray sources discovered by Chandra *

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Abstract

We report optical spectroscopic identifications of 10 hard (2–10 keV) X-ray selected sources discovered by Chandra. The X-ray flux of the sources ranges between \(1.5 \times 10^{-14}\) erg cm\(^{-2}\) s\(^{-1}\), the lower value being 3 times fainter than in previous BeppoSAX and ASCA surveys. Their R band magnitudes are in the range 12.8–22. Six of the Chandra sources are broad line quasars with redshifts between 0.42 and 1.19, while the optical identification of the remaining four is quite varied: two are X-ray obscured, emission line AGN at \(z=0.272\) and \(z=0.683\), one is a starburst galaxy at \(z=0.016\) and one, most unusually, is an apparently normal galaxy at \(z=0.158\). These findings confirm and extend down to fainter X–ray fluxes the BeppoSAX results, in providing samples with a wide range of X-ray and optical properties.

The ratio between the soft X-ray and the optical luminosity of the \(z=0.158\) galaxy is a factor at least 30 higher than that of normal galaxies, and similar to those of AGN. The high X–ray luminosity and the lack of optical emission lines suggest an AGN in which either continuum beaming dominates, or emission lines are obscured or not efficiently produced.

Key words: X-rays: galaxies, cosmology: diffuse radiation, galaxies: quasars, galaxies: starburst
1 Introduction

The Chandra X-ray Observatory was launched on July 23 1999, carrying on board a revolutionary high resolution mirror assembly, with a Point Spread Function of 0.5 arcsec (half power radius) over the broad 0.1 to 10 keV band (Van Speybroeck, et al. 1997). This, together with the aspect camera which at the moment provides attitude solutions with errors of the order of 1-2 arcsec, allows the study of spatial extent of X-ray sources on similar scales, i.e. smaller or similar to the size of a L* galaxy at any redshift; and gives X-ray source positions at least as good as 2–3 arcsec, immediately allowing the unambiguous identification of the optical counterparts of faint X-ray sources. Consequently, the determination of the source redshifts via optical spectroscopy becomes highly efficient.

The improvement provided by Chandra is especially significant in the hard (2–10 keV) X-ray band. Surveys of the hard X-ray sky have been performed in the past by ASCA and BeppoSAX (Ueda et al. 1998, Della Ceca et al. 1999, Fiore et al. 2000a, Giommi et al. 2000, Comastri et al. 2000). However, the large error boxes (1-2 arcmin) limited the optical identification process to classes of objects with low surface density, at a given optical magnitude limit. As a result, most of the identified sources are emission line AGN (Fiore et al. 1999, Akiyama et al. 2000, and La Franca et al. in preparation). About 30 % of the BeppoSAX HELLAS survey sources studied spectroscopically down to R=20.5 have escaped a secure identification (Fiore et al. 2000b, La Franca et al. in preparation), although many normal galaxies and stars have been observed in these error-boxes.

Chandra’s unprecedented capabilities make identifications unambiguous, and open up the possibility of searching for and studying classes of sources not previously recognized as strong hard X-ray emitters, and of assessing their contribution to the hard X-ray cosmic background (XRB; e.g. Griffiths & Padovani 1990). In particular, it will be possible for the first time to begin studying normal galaxies at z > 0.1, as well as possible “minority” hard X-ray source populations (Kim & Elvis 1999).

We have started a pilot project of spectroscopic identification of Chandra sources in two medium–deep fields that were visible from La Silla in Jan-

* Based on observations carried out at the ESO–La Silla Telescopes

1 When the data are definitively reprocessed, the aspect for image reconstruction should be ~ 0.5 arcsec and the source positions should be better than 1 arcsec
uary 2000, with the aim of verifying the feasibility of such studies with 4m class telescopes. The results on 10 X-ray sources are very encouraging and are described in the following.

2 X-ray data

The Chandra X-ray Observatory consists of four pairs of concentric Wolter I mirrors reflecting 0.1-10 keV X-rays into one of the four focal plane detectors: ACIS-I, ACIS-S, HRC-I or HRC-S (Weisskopf, O’Dell & VanSpeybroeck 1996). All the results presented in the following were obtained with the $16'\times16'$ ACIS-I CCD instrument. Table 1 gives the log of the Chandra observations. One field is centered on the $z=0.6$ quasar PKS0312−77, the other is located 180° away from the radiant point of the Leonid meteor shower. Level 2 processed data (Fabbiano et al. in preparation) were obtained from the Chandra public archive. Data were cleaned and analyzed using the CIAO Software (release V1.1, Elvis et al. in preparation). Time intervals with large background rate were removed, as well as hot pixels and bad columns. Only the standard event grades (0, 2, 3, 4 and 6) were used.

Sources were detected in images accumulated in the 2–10 keV band (channels 136-680). Robust sliding-cell algorithms were used to locate the sources. We used both the celldetect program available in the CXC data analysis package CIAO (Dobrzycki et al. 1999) and a variation of the DETECT routine included in the XIMAGE package (Giommi et al. 1991). The method consists in first convolving the X-ray image with a wavelet function, in order to smooth the image and increase contrast, and then running a standard sliding cell detection method on the smoothed image. The quality of each detection was checked interactively.

Final net counts are estimated from the original (un–smoothed) image, to preserve Poisson statistics. A binning factor of 2 (i.e. pixels of $\sim 1$ arcsec) and source box sizes of 6 arcsec (offaxis angle $< 5'$), 10 arcsec ($5' <$ offaxis angle $< 10'$) and 30 arcsec (offaxis angle $> 10'$) maximize the signal to noise ratio, given the local background, PSF and source intensity. The background is calculated using source-free boxes near the sources. This is usually very low in the 2–10 keV band, i.e. 0.15–0.3 counts per 6 arcsec detection box side, per 10 ks.

For this study only sources with more than 10, 15 and 40 counts in the 6 arcsec, 10 arcsec and 30 arcsec detection cells respectively, are considered. Given a conservative background of 0.6, 1.5 and 15 counts in the detection cells this corresponds to a Poisson probability for a background fluctuation of $10^{-9}$ in all cases. The total number of detection cells can be estimated in
Table 1
Chandra observations

| Field               | $N_H$(Gal) | Date       | ACIS            | Exposure |
|---------------------|------------|------------|-----------------|----------|
| PKS0312-770         | 8.0        | 1999 Sept. 8 | ACIS-I, 4 chips | 14789    |
| LEONID ANTI-RAD     | 2.5        | 1999 Nov. 17 | ACIS-I, 4 chips | 20630    |

about 7800 6" cells plus 5000 10" cells plus a few tens of 30" cells in each observation (4 ACIS-I chips). Therefore, the total number of spurious sources in the two fields (0.14 deg²) at the chosen detection thresholds is absolutely negligible ($10^{-5}$). Thirteen sources detected in the 2–10 keV images passed these thresholds. All but one are also detected in the softer 0.5–2 keV band (the non–detected source has about 6 counts in the soft band).

Count rates were corrected for the PSF and the telescope vignetting calculated at 4.5 keV (2–10 keV band) and 1.5 keV (0.5–2 keV band) using Figures 3.8 and 3.10 of the AXAF Observatory Guide (1997). The correction is about 25 % at an off-axis angle of 12 arcmin and 10 % at 6 arcmin. Fluxes in the 2–10 keV band were computed assuming a count rate to flux conversion factor of $2.5 \times 10^{-11}$ erg cm⁻² s⁻¹ per count s⁻¹. Fluxes in the 0.5–2 keV were computed assuming factors of $5.2 \times 10^{-12}$ and $4.6 \times 10^{-12}$ erg cm⁻² s⁻¹ per count s⁻¹ for Leonid Anti-Rad and the PKS0312–770 fields respectively. These conversion factors are appropriate for power law models with $\alpha_E = 0.7$ (2–10 keV) and $\alpha_E = 1.0$ (0.5–2 keV) respectively, assuming the Galactic absorbing column densities quoted in Table 1. Table 2 gives for the thirteen detected sources the X-ray position and off-axis angle, the 2–10 keV and 0.5–2 keV counts (corrected for the PSF and the vignetting) and the corresponding fluxes.

3 Optical spectroscopy

Optical counterparts were found in the USNO catalogue down to $R \sim 20$ in ten cases, in the DSS2 E(R) images in two cases (LAR1 and LAR3), and on EFOSC2 R band image in the last case (P4). Optical counterparts were found for 11 sources with a typical displacement of $\lesssim 2$ arcsec. In one case (LAR4) the displacement is of 4". We consider the identification secure because a) LAR4 is observed by ACIS at an offaxis angle of 12 arcmin, where the PSF is highly asymmetric and broader than 10 arcsec, making the X-ray position more uncertain, and b) the optical source is a bright, broad line quasar, the surface density of which is so low that the probability to find one by chance at 4" from an X-ray source is negligible. In fact, the probability of finding any
Table 2
Chandra hard X-ray selected sources

| ID | CXOUJ        | RA   | Dec   | offaxis | Counts | Counts | Flux   | Flux   | R   | z   | $L_{2-10keV}^e$ | $M_V$ | class |
|----|--------------|------|-------|---------|--------|--------|--------|--------|-----|----|----------------|-------|--------|
|    |              | J2000| J2000 | arcmin  | 2-10keV| 0.5-2keV| 2-10keV| 0.5-2keV|     |    |                |       |        |
|    |              |      |       |         | 10^{-14} | cgs   | 10^{-14} | cgs   | mag |     |             | erg s^{-1} |        |
| PKS0312-770 field |
| P1 | 031015.9-765131 | 03 10 15.9 | -76 51 31.7 | 5.7 | 142 | 564 | 24.0 | 17.5 | 19.2 | 1.187 | 45.57 | -26.1 | AGN |
| P2 | 031209.2-765213 | 03 12 09.2 | -76 52 13.1 | 1.3 | 33.0 | 110 | 5.6 | 3.5 | 18.7 | 0.890 | 44.60 | -25.6 | AGN |
| P3 | 031238.9-765134 | 03 12 38.9 | -76 51 34.1 | 2.6 | 13.4 | 18.6 | 2.3 | 0.58 | 19.3 | 0.158 | 42.45 | -20.5 | gal. |
| P4 | 031253.8-765415 | 03 12 53.8 | -76 54 15.0 | 4.1 | 33.7 | 76.0 | 5.7 | 2.4 | 22.1 | 0.683 | 44.31 | -21.4 | AGN |
| P5 | 031312.1-765431 | 03 13 12.1 | -76 54 31.5 | 5.2 | 44.4 | 198 | 7.7 | 6.2 | 20.0 | 1.124 | 45.00 | -25.1 | AGN |
| P6 | 031314.5-765557 | 03 13 14.5 | -76 55 57.1 | 6.1 | 63.3 | 198 | 10.7 | 6.2 | 19.2 | 0.420 | 44.08 | -23.0 | AGN |
| LEONIDS ANTI-RAD field |
| LAR1 | 221249.1-221132 | 22 12 49.1 | -22 11 32.8 | 5.7 | 21.2 | 72.0 | 2.6 | 1.8 | 20.0 |       |       |       |    |
| LAR2 | 221254.6-220801 | 22 12 54.6 | -22 08 01.0 | 4.8 | 13.0 | 11.3 | 1.6 | 0.29 | 17.9 |       |       |       |    |
| LAR3 | 221255.8-221004 | 22 12 55.8 | -22 10 04.4 | 4.0 | 13.0 | 70.1 | 1.6 | 1.8 | 19.4 |       |       |       |    |
| LAR4 | 221257.4-222134 | 22 12 57.4 | -22 21 34.7 | 12.0 | 47.3 | 189 | 5.8 | 4.8 | 17.3 | 1.167 | 44.93 | -27.9 | AGN |
| LAR5 | 221313.0-220425 | 22 13 13.0 | -22 04 25.4 | 6.0 | 39.2 | 107 | 4.8 | 2.7 | 12.8 | 0.016 | 40.73 | -21.8 | starb. |
| LAR6 | 221318.4-221020 | 22 13 18.4 | -22 10 20.6 | 1.4 | 29.0 | 6.2 | 3.6 | 0.16 | 18.1 | 0.272 | 43.17 | -23.0 | AGN |
| LAR7 | 221323.2-220724 | 22 13 23.2 | -22 07 24.3 | 3.9 | 45.1 | 241 | 5.5 | 6.1 | 19.5 | 0.725 | 44.36 | -24.2 | AGN |

* $H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0$; $^{b}$ near R=10 star; $^{c}$ galaxy, centroid at 6 arcsec from the X-ray centroid; $^{d}$ APMBGC 601-093+120.
R≤22 galaxy in a 4″ radius error-box by chance is <0.04, while the same probability for an AGN is at least ten times smaller. Therefore the number of AGN misidentifications in our sample is <0.05. The number of expected galaxy misidentifications at R≤20 is <0.2, while that of R≤22 is <0.5. In one case (LAR2) no optical counterpart brighter than R ~ 20 is present in the X-ray error box. However a R=18 galaxy, with an optical extension of about 3 arcsec, is present at 6 arcsec from the X-ray position. Therefore the galaxy outskirts touch the X-ray errorbox. We conservatively consider this identification uncertain.

We obtained long slit spectra of ten counterparts[^2] using EFOSC2 at the ESO 3.6m telescope on January 3-6 2000. Spectra were obtained using grism N.6 in the 3800-8100 Å range and a slit 2 arcsec wide, corresponding to a resolution of 26 Å.

The complete set of flux-calibrated spectra is shown in Figure 1. R magnitude, redshift, optical and X-ray luminosity, and a classification of the optical spectrum are given in Table 2. Classification of narrow line objects is done using standard line ratio diagnostics (e.g. Osterbrook 1981, Tresse et al. 1996), in particular the [OIII]λ5007/Hβ, [SII]λ6725/Hα and [OIII]λ5007/[OII]λ3727 line ratios.

We find six broad line quasars at redshift between 0.42 and 1.19 and 2–10 keV X-ray luminosities in the range 10^{44} – 4 × 10^{45} erg s^{-1}. The four remaining source identifications are as follows:

LAR5 is identified with a bright z=0.016 starburst galaxy with an X-ray luminosity of ~ 6 × 10^{40} erg s^{-1}, similar to that of other starburst galaxies of similar optical luminosity (Ptak et al. 1999).

In LAR6, although [OIII] and Hβ are detected, the spectrum is rather noisy and it is not clear if Hβ has broad wings. Optical classification is therefore uncertain. The 2–10 keV luminosity of ~ 2×10^{43} erg s^{-1} and the X-ray softness ratio (see below) suggest that LAR6 is an obscured AGN.

P3 is identified with a normal galaxy without strong emission lines (only a weak [OII] line with an equivalent width of 5 ± 1 Å is apparent in the spectrum). The X-ray and optical luminosities are L_{2–10keV} ~ 3 × 10^{42} erg s^{-1} and M_V = −20.5. The galaxy continuum is very red, suggesting an early type galaxy. The Calcium break is 0.44±0.11, consistent with little or no dilution from non–stellar light. A faint Hδ is detected in absorption (equivalent width of −3.8 ± 2.3 Å).

[^2]: the three objects not observed in the Leonid anti-rad field have optical magnitudes and X-ray fluxes similar to those of the ten observed objects. The four sources observed in this field were selected by chance.
The spectrum of P4 is rather noisy because the source lies only 9 arcsec from a 10 mag star, which strongly enhances the background. We identify P4 with an AGN at z=0.683 thanks to a rather strong [OII] and weaker [NeIII] and MgII emission lines. The MgII to [OII] intensity ratio of $\sim 0.9$ is much smaller than in broad line quasars and similar to those of type 2 AGN (Woltjer 1990). The 2–10 keV luminosity of $\sim 2 \times 10^{44}$ erg s$^{-1}$ and the X-ray softness ratio (see below) suggest that P4 is a moderately obscured quasar.

We have searched the NVSS, IRAS faint source catalog, clusters of galaxies
(ACO, Abell, Corwin & Orowin 1989), normal galaxies, stars and AGN catalogs, finding only one coincidence: LAR5 is identified with an APM galaxy.

4 X-ray and optical properties

4.1 X-ray versus optical imaging

The high spatial resolution of the Chandra telescope allows for the first time a comparison of X-ray and optical images at similar, arcsec, resolution.

We have studied the spatial extent of the X-ray sources by comparing their count profiles with the Chandra PSF, taking into account its dependence on the off-axis angle (as calibrated on the ground). The spatial extent is smaller than a few arcsec in all cases and therefore consistent with their being point sources. Conversely, at least three of the optical counterparts are extended galaxies (“gal.” in Table 2).

Figures 2a,b show the X-ray (2–10 keV) contours overlaid on the optical R band images of the \( z=0.158 \) galaxy (P3) and the \( z=0.016 \) starburst galaxy (LAR5) obtained with EFOSC2.

Galaxy P3 is bulge dominated, the size of the bulge being 2–3 arcsec. Also galaxy LAR5 has a bright bulge, of similar size. These sizes are similar to or smaller than the Chandra PSF at the off-axis angle where the sources were detected in ACIS-I (2.6 arcmin and 6 arcmin respectively). Both galaxies are extended (up to 10–20 arcsec). If the X-ray emission were connected to the outer parts of the galaxy, it would have been resolved by Chandra. Both X-ray sources are centered on the galaxy nuclei. The X-ray source in LAR5 appears slightly elongated in a direction perpendicular to the galaxy major axis, as seen in several nearby starburst galaxies (e.g. Fabbiano et al. 1992, Dahlem et al. 1998). However, this elongation may also be due to the degradation of the Chandra PSF at the offaxis-angle of this source (6 arcmin).

4.2 X-ray to optical flux ratio

Figure 3 shows the X-ray to optical flux ratios of the thirteen Chandra sources as a function of the 2–10 keV flux, and compares them with those of local AGN and of the AGN found in the BeppoSAX HELLAS survey. This Figure shows that the X-ray to optical ratio of most Chandra sources is similar to that of local and HELLAS AGN. Their optical magnitude is bright enough to allow redshift determination with 4m or 8m class telescopes.
Fig. 2. *Chandra* ACIS-I (contours) and R band images (grayscale) of CXOUJ031238.9–7651, P3 (a), and CXOUJ221313.0–220425, LAR5 (b). The second source was observed by ACIS-I at an off-axis angle of 6 arcmin leading to contours slightly elongated in the East-West direction.

At fainter fluxes Figure 3 shows the sources recently optically identified by Mushotzky et al. (2000). R band fluxes have been computed assuming R-I=0.3. The flux ratio of about 60% of the Mushotzky et al. *Chandra* sources is within the range of values covered by brighter AGN (i.e. log($f_X/f_R$) from -2 to 1). The remaining 40% show an X-ray to optical ratio higher than that of the brighter *Chandra* sources presented here and of the local AGN (see Figure 3). As discussed by Mushotzky et al. (2000) the nature of these optically faint sources is mysterious. Many of them have optical magnitude fainter than R~24 which make difficult to obtain a precise redshift through optical spectroscopy.

The $z=0.158$ normal galaxy has an X-ray to optical ratio of 0.36, much higher than the typical value of nearby normal galaxies (see section 5.2).

4.3 *X-ray spectral properties*

For most of the *Chandra* sources the total number of detected counts is <100, preventing the use of proper spectral fitting procedures to study their spectrum. The broad band X-ray spectral properties can only be investigated using count ratios. If the spectrum is parameterized as an absorbed power law and the redshift of the source absorber is known, the column density can be evaluated. Following Fiore et al. (1998), we assume here that the X-ray absorber redshift coincides with the optical redshift. Figure 4 shows the softness ratio
\[ \frac{S-H}{S+H} \] (S=0.5–2 keV band, H=2–10 keV band) of the ten spectroscopically identified Chandra sources as a function of the redshift. Errors include counting statistics only. Dashed lines show the expectation of power law models with \( \alpha_E = 0.8 \) absorbed by varying column densities in the source frame. Two of the Chandra sources (P3 and LAR6) have a softness ratio inconsistent with that expected by an intrinsically unobscured power law at better than the 90% confidence level. In particular, LAR6 is likely to be obscured by a column of \( 5 - 10 \times 10^{22} \) cm\(^{-2}\).

It is worth noting that the column densities implied by Figure 4 are probably lower limits to the columns toward the nuclear hard X-ray source, because highly obscured AGN usually have strong soft components (e.g. Schachter et al. 1998, Maiolino et al. 1998, Della Ceca et al. 1999, Fiore et al. 2000a,b). To quantify this possible underestimate we simulated ACIS-I observations of three highly obscured type 2 AGN (NGC1068, \( N_H > 10^{25} \) cm\(^{-2}\); the Circinus Galaxy \( N_H = 4.3 \times 10^{24} \) cm\(^{-2}\); and NGC6240, \( N_H = 2.2 \times 10^{24} \) cm\(^{-2}\)), based on ASCA and BeppoSAX results (Matt et al. 1997, 1999, Iwasawa & Comastri 1998, Vignati et al. 1999). The \( \frac{S-H}{S+H} \) observed by ACIS-I would have been 0.88, –0.08 and 0.57 respectively. The results are strongly dependent from the sources spectral shape and redshift. At \( z=1 \) the simulated hardness ratios are 0.53, –0.30 and –0.05 respectively.

We also note that relatively low values of \( \frac{S-H}{S+H} \) can be produced by intrinsically flat and unobscured power laws (for example the P3 hardness ratio of 0.16 would correspond to \( \alpha_E = 0.2 \)). Efficient X-ray follow-up of relatively bright X–ray sources with XMM will provide a relatively accurate measure of the intrinsic spectrum through proper spectral fitting allowing to remove the ambiguity between an intrinsically flat spectrum and a spectrum flattened by absorption.

5 Discussion

5.1 Faint X-ray sources and the XRB

One of the main goals of hard X-ray surveys is to investigate the origin of the hard X-ray cosmic background. The most popular model explains the XRB in terms of a mixture of obscured and unobscured AGN (Setti & Woltjer 1989) following a strong cosmological evolution.

The relatively small number of sources in the present survey (only thirteen), implies a \( \sim 30\% \) statistical error on their number density. This limits the
Fig. 3. X-ray to optical ratio versus the 2–10 keV flux. Diagonal lines identify loci of constant apparent R magnitude. Chandra new identifications: big symbols; HEL-LAS AGN: small symbols; local AGN (X-ray and optically selected): dotted small symbols. Different symbols mark identified sources: open circles = broad line quasars and Sy1; open triangles = type 1.8-1.9-2.0 AGN; filled squares = starburst galaxies and LINERS; filled circles = normal galaxies. Skeletal triangles identify Chandra sources from this paper without redshifts and optical classification. Crosses refer to Chandra sources identified by Mushotzky et al. (2000). Circled Crosses = quasars; squared crosses = sources with a redshift but unpublished optical classification.

Fig. 4. The softness ratio \((S-H)/(S+H)\) as a function of redshift for the identified sources. Symbols as in Figure 3. Dotted lines show the expected softness ratio for a power law model with \(\alpha_E = 0.8\). Dashed lines show the expectation of absorbed power law models (with \(\alpha_E = 0.8\) and \(\log N_H = 23, 22.7, 22.3, 22, 21.7\) and 21, from bottom to top) with the absorber at the source redshift.

The main problem when comparing model predictions and observations is that the flux limit of count rate limited surveys depends on the actual intrinsic spectrum of the sources (Zamorani et al. 1988). Harder sources would generally produce less counts (because of the decrease of the effective area toward the higher energies), and therefore they would pass a detection threshold only if their flux is higher than that of softer sources with similar count rate. In order to quantify this effect we have folded a heavily absorbed \(10^{23} \text{ cm}^{-2}\) power law spectrum \((\alpha_E = 0.8)\) with the Chandra sensitivity, and computed the flux limit corresponding to the count rate threshold. This turns out to be a factor 5–6 higher than that of an unabsorbed power law. Taking into account the column density distribution predicted by the Comastri et al. (1995) synthesis model and the Chandra sensitivity, the predicted fraction of obscured (\(\log N_H > 22\))
sources is 20–30 %. The softness ratio results (Figure 4) suggest that at least 3 out of 10 optically identified sources may be absorbed by column densities equal or higher than $10^{22}$ cm$^{-2}$. Furthermore, one of the three unidentified objects has a hard spectrum, as can be judged from the hard to soft X-ray flux ratio of Table 2. We therefore conclude that the present observations are consistent with the predictions of AGN synthesis models for the XRB.

5.2 P3: an X-ray loud normal galaxy?

A surprising result from our pilot study is the detection of a luminous X-ray source in an otherwise normal galaxy (P3). The X-ray luminosities of $L_{2-10\text{keV}} \sim 3 \times 10^{42}$ erg s$^{-1}$, $L_{0.5-2\text{keV}} \sim 0.8 \times 10^{42}$ erg s$^{-1}$ are about a factor 30 higher than those expected on the basis of the optical luminosity ($L_B = 10^{10} L_\odot$) for both spiral (Fabbiano et al. 1992) and Elliptical/S0 (Eskridge, Fabbiano & Kim 1995; Pellegrini 1999) galaxies.

A few optically “dull” galaxies with strong X-ray emission have been reported in the past (e.g. 3C264 and NGC4156, Elvis et al. 1981; J2310–437, Tananbaum et al. 1997; Griffiths et al. 1996) and more recently in a deep Chandra observation (Mushotzky et al. 2000). Hard power law tails have been also discovered in a few nearby elliptical galaxies (Allen, Di Matteo & Fabian 2000). The presence of relatively strong X-ray emission in objects with no evidence of activity in the optical spectrum is still not well understood.

One possibility would be a large contribution from a beamed non-thermal component in the X-ray band (Elvis et al. 1981, Tananbaum et al. 1997, Worrall et al. 1999) as for BL Lacertae objects. If P3 hosts a BL Lac then the non-thermal featureless optical continuum would reduce the height of the Calcium break from a typical value of 0.5 found in elliptical and S0 galaxies to < 0.25 (Stocke et al. 1991). This threshold has been raised to about 0.4 by Marcha and Browne (1995) to take into account the spread of galaxy luminosity and sizes. The P3 Calcium break of 0.44±0.11 does not allow to rule out the presence of a BL Lacertae object, even if it would be a rather extreme member of its class. If this is the case, the radio flux predicted from the observed X-ray flux would be in the 0.1–30 mJy range (Padovani & Giommi 1996). The PMN (Griffith et al. 1991) limit of about 50 mJy is not useful to settle this issue.

An obscured AGN could also provide a viable explanation. Indeed the P3 hardness ratio implies a substantial column for a typical AGN X-ray continuum. The optical emission lines could also be completely hidden except for a weak [OII] emission feature. It is worth remarking that examples of X-ray obscured AGN with neither BLR nor NLR already exist (e.g. NGC4945, Marconi et al. 2000; NGC6240, Vignati et al. 1999 and references therein), even if in these
cases emission lines related to starburst emission are present.

Finally the presence of a low–radiative–efficiency accretion flow (ADAF) might also be tenable. The putative central black hole mass estimated from the observed B luminosity of the galaxy’s bulge following the Magorrian et al. (1998) relation is about $4 \times 10^8 \, M_\odot$ (this is actually an upper limit, as we have assumed for the bulge luminosity of the entire galaxy, see Fig. 2a). If the X–ray emission comes from the nucleus, and it is a sizeable fraction of the bolometric luminosity, its Eddington ratio is of the order of $10^{-4}$, consistent with the ADAF regime (Narayan et al. 1998). An estimate of the 8.4 GHz flux has been obtained assuming the ADAF spectral models calculated by Di Matteo et al. (2000) as well as the X–ray to radio flux ratios of a few ADAF candidates observed at the VLA (Di Matteo et al. 1999) rescaled to the P3 X–ray flux. In both cases the maximum expected radio emission is of the order of a few mJy and thus well below the present limit. The ADAF contribution to the optical–UV light strongly depends on the adopted model (see figure 2 in Di Matteo et al. 2000). The P3 hardness ratio is consistent with a very flat power law ($\alpha \sim 0.2 \pm 0.3$), and a wind model is therefore to be preferred. If this is the case, the ADAF flux in the optical–UV would be much fainter (at least two order of magnitude) than that of the host galaxy, again consistent with the present findings.

6 Conclusions

We have carried out a pilot program to study the faint hard X-ray source population using the revolutionary capabilities of the Chandra satellite. We identified ten 2–10 keV selected sources from two 4-chip, medium deep Chandra fields covering about 0.14 deg$^2$ of sky at fluxes in the range $1.5 - 25 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, a factor of 3 fainter than previous ASCA and BeppoSAX surveys. Recently, Mushotzky et al. (2000) reported detection of faint X-ray sources from a single 1-chip field (0.0175 deg$^2$) at fluxes $0.3 - 3 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$. Our results fill the gap between the shallow BeppoSAX and ASCA surveys and the deep Chandra field.

Almost all sources have an optical counterpart within 2 arcsec. Optical spectra allow us to measure their redshifts, and assess their optical classification. We find six broad line quasars, two emission line AGN (LAR6 and P4), one starburst galaxy (LAR5), and one apparently normal galaxy at $z=0.158$ (P3). LAR6 and P4 are likely to be obscured in X-ray by a column densities of $\approx 10^{23}$ cm$^{-2}$ and $\approx 10^{22}$ cm$^{-2}$ respectively. The X-ray source in the $z=0.158$ normal galaxy P3 may be covered by a column density of about $10^{22}$ cm$^{-2}$ too.
The spatial extension of all X-ray sources is smaller than a few arcsec in all cases, and it is roughly consistent with the Chandra PSF. The X-ray sources associated with the \( z=0.016 \) starburst galaxy LAR5 and the \( z=0.158 \) normal galaxy P3 appear coincident with the galaxy nuclei.

The X-ray to optical luminosity ratio of P3 is higher by a factor of at least 30 than those of normal galaxies, while it is similar to those of AGN. The high X-ray luminosity and the lack of optical emission lines suggest an AGN in which either continuum beaming is important or emission lines are absorbed or not efficiently produced. In any case, objects like P3 would be missed or ignored in optical surveys or in X-ray surveys with large error boxes. It is only thanks to the new revolutionary capabilities of Chandra that this kind of sources can be detected and identified.

Based on the ASCA and BeppoSAX surveys at fluxes \( > 5 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \) and on our first Chandra identifications, which push the flux limit down to \( \sim 2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \), the hard X-ray sky appears populated by a large fraction of broad line AGN (about 50%), by a mixture of intermediate AGN (type 1.8-2.0 and composite starburst/AGN) and, most intriguingly, also by X-ray luminous apparently normal galaxies. These populations span ranges of X-ray and optical properties wider than previously thought.

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