OTELO Survey: X–ray emitters in the Groth Field II. Properties of the AGN population

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Abstract We present the results from the analysis of the optical broadband and X-ray properties of a large sample of active galactic nuclei (AGN) in the Groth-Westphal Strip (GWS) field. The description of the observational material and data processing is described in a separate paper (Pović et al., 2008a, in these proceedings). Here the main findings are presented.

1 Observational Material

The observation material comprises, on the one hand, a catalogue of 639 X–ray sources (Sánchez-Portal et al., 2007; Pović et al., 2008a,b) (70% detected with a significance $\geq 3\sigma$ level) within an area of some 0.24 square degrees and a limiting flux of 4.8×10^{-16} erg cm^{-2} s^{-1} above 3σ level, and on the other, a large catalogue of $\sim$44000 objects detected in optical *BVRI* broad bands covering a similar area. 340 optical counterparts of the X–ray sources have been found within the common area. The optical structural parameters of these counterparts have been computed and a morphological classification has been derived (Pović et al., 2008a,b, see Fig. 1). The main parameters considered are the Abraham asymmetry (A) and concentration (C) indexes. A thorough description of the observational data, catalogues, detection procedures, cross-matching and morphological analysis can be found in Pović et al. (2008a) in these proceedings (hereafter Paper I) and Pović et al. (2008b).

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2 Nuclear Classification

We have devised a criterion for performing a coarse nuclear type classification of our sample objects, based on simple diagnostic diagrams relating X–ray-to-optical flux ratios (X/O) to the X–ray colours or hardness ratios (HR; see Paper I for a definition). The typical value of X/O flux ratios for X–ray selected AGN (both type 1 or BLAGN and type 2 or NLAGN) is in the range between 0.1 and 10 (Fiore et al., 2003). For optically selected type 1 AGNs the typical value is X/O $\simeq 1$ (Alexander et al., 2001; Fiore et al., 2003). At high X/O flux ratios (well above 10) we can find BLAGN and NLAGN as well as high-z high-luminosity obscured AGN (type 2 QSOs), high-z clusters of galaxies and extreme BL Lac objects. Finally, the X/O < 0.1 region is typically populated by coronal emitting stars, normal galaxies (both early type and star-forming) and nearby heavily absorbed (Compton-thick) AGN.

The criterion applied to classify our sample is based on the results of Della Ceca et al. (2004, hereafter DC04) on the *XMM–Newton* Bright Serendipitous Survey; they found that, when plotting the HR$(2-4.5keV/0.5-2keV)$ against X/O, computed as the ratio of the observed X–ray flux in the 0.5–4.5 keV energy range to the optical R-band flux, most (85%) of the BLAGN identified by means of optical spectroscopy were tightly packed in a small rectangular region of the diagram, while NLAGN (type 2) tended to populate a wide area of the diagram (towards harder values of the hardness ratio). We applied the same approach to our sample, combining the HR$(2-4.5keV/0.5-2keV)$ hardness ratio (that is quite sensitive to absorption) with the the X/O ratio computed as $F_{0.5-4.5\mathrm{keV}}/F_R$, where the optical flux F_R has been derived from the Petrosian magnitudes in the R band. The resulting diagram, that also includes host morphology information, is shown in Fig. 2. We set the right edge of this box, HR$(2-4.5keV/0.5-2keV) \approx -0.35$ as a coarse boundary separating 'unobscured' AGN (BLAGN) and 'obscured' AGN (NLAGN) (DC04). We

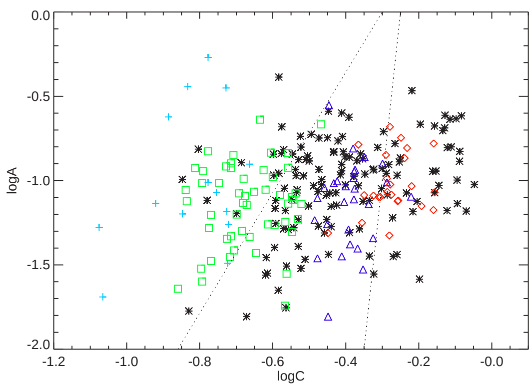

Fig. 1 Morphological classification of the optical counterparts based on the A and C indexes. Symbols are as follows: ◇: E/S0; △: S0/S0a-Sa; □: young spirals (Sab-Sbcd); +: late type (Sdm-Irr) and $*$: compact objects. Dotted lines separate the locii of elliptical, spiral and peculiar galaxies (from right to left) derived from HST imaging by Abraham et al. (1996). There is a small shift of our concentration and asymmetry indexes towards smaller values due to the influence of the seeing conditions.

find that a large fraction of our objects, 63% [1], fall inside the region of BLAGNs, while 51% of the sample is placed within the small BLAGN box defined by DC04. Regarding morphology, we do not find a clear evidence of relationship between nuclear and morphological types. Nevertheless, we can see that the majority of objects identified as compact (65%) are placed in the BLAGN region. It is also interesting to highlight the relationship between the X/O ratio and the host galaxy morphology, with early-type galaxies having generally lower values for X/O ratio and an opposite behaviour of late-type objects. Finally, we find that only about 7% of our sample objects are placed in the lower region of the diagram (i.e. that typical of stars/normal galaxies/Compton-thick AGN).

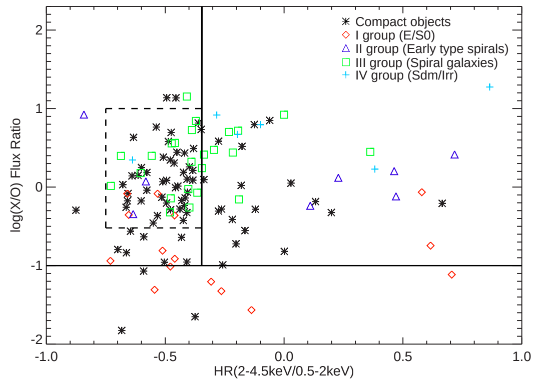

Fig. 2 Relationship between X/O ratio and the hardness ratio, in the range (2-4.5keV/0.5-2keV), for the different morphological types. Solid lines separate BLAGN and NLAGN regions and the area with $X/O < 1$, where stars, normal galaxies and Compton-thick AGNs can be found. Dashed line box presents the 'BLAGN' region from DC04

3 X–ray and Optical Properties

We have studied the relation between broad-band X–ray properties, namely hardness ratios, the X/O ratio or the derived nuclear classification and those derived from the optical data, mainly colours, morphological parameters (C and A) and the morphological group. When combining the X/O ratio with optical colours (B–R and B–I) for the different morphological groups and nuclear types, We observe that compact and late-type objects tend to show bluer colours, while early-type galaxies tend to present redder colours, as expected. On the other hand, there is a mild tendency for BLAGN to show bluer colours than those found in NLAGN.

When representing the X/O ratio vs. the Abraham concentration index C we find a strong anticorrelation between these two parameters (Fig. 3). This result is consistent with that found in Section 2 above, that is the tendency of early-type galaxies to have lower than average X/O values and the opposite behaviour in late-type ones.

[1] All fractions given here are relative to the total number of X–ray objects having optical counterpart and $\mathrm{HR}(2-4.5keV/0.5-2keV) \neq 0$.

As seen in Fig. 3, all morphological groups tend to follow the same relation. This is also observed for the two nuclear type groups (BLAGN and NLAGN). On the other hand, we did not find any clear correlation between HR$(2-4.5keV/0.5-2keV)$ and the concentration index, suggesting that the observed anticorrelation is not related to obscuration.

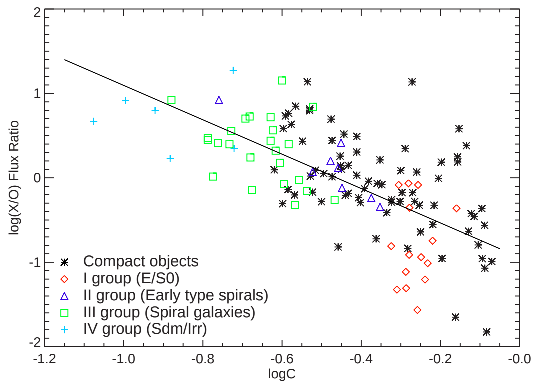

Fig. 3 Relationship between Log(X/O) and the Abraham concentration index (C); a clear anticorrelation is observed. The different morphological types are represented with symbols as in Fig. 1.

The physical origin of the observed anticorrelation is not well established. First of all, it is not easy to disentangle possible bias effects that superimposed to variable seeing conditions. It has been pointed out the existence of redshift-dependent biases in both A and C, due to the reduction of apparent size and surface brightness with respect to the sky background with increasing z, along with poorer sampling and lower S/N (Brinchmann et al., 1998; Conselice et al., 2003); on the other hand, there is a "bandpass shift" with respect to the rest wavelength (Bershady et al., 2000). Even if these effects combine to produce some uncertainty in the morphological classification of galaxies, generally in the sense of shifting objects to apparently later Hubble types (i.e. with lower C values), A and C relation seems to be reproducible out to z = 3, within a reasonable scatter (Conselice et al., 2003). Moreover, there can be a truly evolutionary effect in the AGN host galaxies, indicating that galaxies at higher redshift are intrinsically less concentrated (Grogin et al., 2005).

At this stage we cannot apply any correction which depends on the redshift, although this is one of the objectives of our future work. However, a preliminary evaluation of the dependency of the concentration index C with redshift z, carried out with a subsample of 84 objects with spectroscopic redshifts form the DEEP2 catalogue, shows a much weaker dependency of C on z. On the other hand, C and z seem to be uncorrelated for compact objects.

So, although the biases described above might contribute partially to it, the observed anticorrelation seems to be also a result of a true physical effect. In order to attempt to explain it, we need first to understand the physical connections of the two observables C and X/O. The concentration index (C) is tightly linearly correlated to the central velocity dispersion (Graham et al., 2001a,b), which is in turn related to the nuclear black hole (BH) mass (e.g. Magorrian et al., 1998). Therefore, the concentration and the nuclear BH mass (M_{BH}) are (monotonically) associated. The physical connections of the X–ray-to-optical flux ratio are not so evident. The X/O ratio measures the X–ray flux (in the 0.5–4.5 keV band), normalised with the R-band optical flux of the whole galaxy (nucleus, bulge and disc). It should be noted that no bandpass, or K-correction is performed; therefore if the sample spans a large redshift range the interpretation of the quantity becomes more problematic. If the nuclear luminosity is large compared with that of the host galaxy, the X/O ratio can be thought as a measure of the X–ray to optical spectral index, α_{OX}[2]. This parameter has been found to be strongly anticorrelated with the UV luminosity $L_{2500\mathring{A}}$, without a significant correlation with redshift (Steffen et al., 2006). On the other hand Bian (2005) found a strong correlation between the hard/soft X–ray spectral index, α_X and the Eddington ratio in a sample of 41 BLAGN and narrow-line Seyfert 1 (NLS1) galaxies observed with ASCA. Other works have confirmed this correlation (Grupe, 2004; Shemmer et al., 2006). The relationship between α_X and α_{OX} has not been thoroughly studied in large samples of AGN, but a linear correlation has been found between both spectral indexes in a sample comprising 22 out of 23 quasars in the complete the Palomar-Green X–ray sample with $z < 0.4$ and $M_B <$ -23 (Shang et al., 2007). If this last correlation holds for our sample, X/O could be tracing the Eddington ratio in the large nuclear luminosity limit. In addition, if the host galaxy luminosity is large when compared with the nuclear luminosity ($L_{bulge+disc} \gg L_{nucleus}$), the X/O ratio can be thought as a lower bound of the X–ray-to-bulge luminosity ratio, that is in turn a (weak) measure of the AGN Eddington ratio $L/L_{Edd} \propto L/M_{BH}$, assuming that the X–ray luminosity represents the nuclear luminosity and the bulge luminosity is proportional to the bulge mass (and therefore to M_{BH}).

Hence, we can guess a loose correlation between X/O and the energy production efficiency of the AGN. Under these assumptions, the C vs. X/O relation traces the correlation between the Eddington ratio and the nuclear BH mass. The obtained result could therefore suggest that early-type galaxies, having poor matter supply to feed the activity, have lower Eddington rates than those of late-type, with larger reserves of the gas for AGN feeding.

This suggested approach is consistent with the results obtained by Ballo et al. (2006, 2007) in a sample of X–ray selected AGNs at $z \leq 1$. They obtained that AGNs with large SMBH ($M_{BH} > 3 \times 10^6$ M$\odot$), have low X–ray luminosity and Eddington rate $\ll 1$, and conversely, that smaller SMBH have higher luminosity in X–rays and Eddington rate ≈ 1, which corresponds to a more efficient accretion rate.

Our approach is also consistent with the results of Wu & Liu (2004), which studied the black hole masses and Eddington rates of a sample of 135 double–peaked broad line AGNs, observed in two surveys: SDSS and a survey of BLAGN radio emitters. They obtained that if the separation between the line peaks decrease (this separation is directly related with the FWHM of the line and, at the same time, correlated with the black hole mass), the Eddington rate increases.

[2] This relation is usually defined as $\alpha_{OX} = 0.3838 \log(f_{2keV}/f_{2500\mathring{A}})$

Kawakatu et al. (2007) found an anticorrelation between the mass of a SMBH and the infrared-to-Eddington luminosity ratio, L_{IR}/L_{Edd}, for a sample of ultraluminous infrared galaxies with type 1 Seyfert nuclei (type 1 ULIRGs) and nearby QSOs, which also could be consistent with our approach. The anticorrelation is interpreted as a link between the mass of a SMBH and the rate of mass accretion onto a SMBH, normalized by the AGN Eddington rate, which indicates that the growth of the black hole is determinated by the external mass supply process, and not the AGN Eddington-limited mechanism, changing its mass accretion rate from super-Eddington to sub-Eddington.

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