Obscured accreting black holes at high redshift

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Abstract. A significant fraction of the accreting black holes powering high redshift AGN are obscured by large columns of dust and gas. For this reason, luminous type 2 quasars can be efficiently discovered combining hard X–ray and near–infrared observations. We will briefly discuss the most recent results.

1 Introduction

The space density of luminous quasars in the distant Universe represents a key observational ingredient to understand the formation and evolution of supermassive black holes (SMBHs). The hard X–ray energy range (above 2 keV) is well suited for this purpose as it provides an unbiased view of the obscured accretion power which is responsible for the majority of the SMBH energy output recorded in the X–ray background (XRB) spectrum.

The capabilities of both Chandra and XMM–Newton in performing sensitive X–ray surveys have been continuously exploited in the last four years. As a result, large samples of X–ray sources spanning a wide range of fluxes (from a few $10^{-13}$ down to about $10^{-16}$ erg cm$^{-2}$ s$^{-1}$) are available for reliable statistical studies on the extragalactic X–ray source population. Despite extensive campaigns of spectroscopic follow–up observations with the largest, ground–based telescopes, the X–ray source classification remains challenging. The most important reason is that the optical counterparts of many X–ray sources are too faint even for 8–10 m class telescopes (Fig. 1). The spectroscopic completeness of the deepest Chandra surveys (CDFS and CDFN) is of the order of 50–70 %. Deep multiband photometry is usually employed to estimate redshifts and, over restricted portions of the sky, a much higher completeness level could be achieved.

A detailed discussion on the optical identification breakdown is beyond the purposes of this paper and can be found elsewhere ([2], [18], [9]). The general picture emerging from the spectroscopic observations can be summarized as follow:

• Unobscured broad–line AGN are found up to redshift 5 and constitute the dominant population at relatively bright X–ray fluxes ($> 10^{-14}$ erg cm$^{-2}$ s$^{-1}$) [3]
The 2–10 keV flux vs. the R–band magnitude for X–ray selected sources in the Chandra (blue small squares) and HELAS2XMM (red large open circles).

- The space density of obscured AGN increases towards fainter fluxes. Clear signatures of X–ray and/or optical obscuration are typically detected (though some mismatch between optical and X–ray absorbing properties is present). The luminosity and redshift distribution of obscured sources is skewed toward lower values and most of them are classified as Seyfert galaxies ($L_X < 10^{44}$ erg s$^{-1}$ and $z < 1–1.5$) rather than quasars.

- The discovery of relatively high X–ray luminosity AGN hosted in the nuclei of optically normal galaxies. Whether they are heavily absorbed Seyfert galaxies, low–luminosity AGN whose emission is diluted by the host galaxy starlight or something more exotic is still subject of debate [5].

The most important findings emerging from the identification process concern the redshift and absorption distribution of X–ray selected sources. The former is peaked at lower redshifts ($z \approx 1$) than expected on the basis of population synthesis models for the XRB [11]. The latter seems to indicate a lack of obscured, luminous sources with respect to model predictions.

On the one hand, the results described above favour a late formation of the XRB (i.e. [17]) and call for a major revision of the AGN synthesis models which are based on the unified scheme. On the other hand, it has been suggested [19] that selection effects against the identification of obscured AGN combined with the small solid angle covered by deep surveys prevent from a reliable comparison with model predictions.
2 Large Area Surveys

A sizable number of hard X-ray surveys have been performed with both XMM-Newton and Chandra over large area (of the order of a few square degrees). The ultimate goal of these efforts is to provide a statistically robust estimate of the luminosity function and cosmological evolution of obscured accreting black holes hopefully free from the selection effects described above. Though differing in several details, the observing strategy of the various large-area surveys is designed to maximize the trade off between area and depth and thus X-ray satellite observing time (for an updated list of recent X-ray surveys see [4]). Wide-area surveys efficiently target objects in the range of fluxes around the knee of the source counts ($\log F_X = -14 \pm 1$ erg cm$^{-2}$ s$^{-1}$) and thus properly sample the sources which contribute mostly to the XRB. An important benefit is that the average magnitude of the optical counterparts is relatively bright and the follow-up spectroscopic identification is within the capabilities of available telescopes. On the other hand, the large number of X-ray sources discovered in many different non-contiguous pointings makes the follow-up identification extremely time consuming.

Targets with peculiar and/or extreme properties are therefore the subject of detailed follow-up multiwavelength observations. The results of a vigorous program of spectroscopic observations with FORS@VLT [9], deep near-infrared photometry with ISAAC@VLT [14], and X-ray spectroscopy [16], strongly indicate that sources with high X-ray to optical flux ratio (high $X/O$) in the HEllas2Xmm survey [1] are obscured AGN at moderate to high redshifts. The derived X-ray luminosities and the narrow optical lines of the brightest targets allow us to classify them as type 2 quasars at $z=0.7-2$. A similar range of redshifts is implied using the R–K colour of the host galaxies of fainter X-ray sources [14].

Thanks to the identification of about 50% of the high $X/O$ sources in the HEllas2Xmm survey, it has been possible to discover a linear correlation between the $X/O$ ratio and 2–10 keV luminosity [9], namely: $\log L_{2-10} = \log f_X/f_{\text{opt}} + 43.05$. The correlation holds for optically obscured sources and has been tested and calibrated combining the optical and X-ray data of the HEllas2Xmm survey with well defined subsamples of identified sources in the deep Chandra fields at fluxes larger than $3\times10^{-15}$ erg cm$^{-2}$ s$^{-1}$.

Though characterized by a not-negligible dispersion (about 0.4 dex), this relation can be used to compute X-ray luminosities and then redshifts from the observed $X/O$ ratio. The accuracy in the redshift estimate (“X-photo–z” [10]) is fairly good $\sigma(\Delta z/(1+z)) \approx 0.2$.

3 The high-redshift Universe

The space density of high luminosity ($L_X > 10^{44}$ erg s$^{-1}$) obscured ($N_H > 10^{22}$) type 2 quasars among optically faint Chandra deep fields sources has been estimated by Padovani et al. (2004) [15] using the “X-photo–z” technique. In
order to select absorbed sources, a simple criterion based on the Hardness Ratio [HR = (H–S)/(H+S) > –0.2, where H and S is the number of counts in the 2–8 keV and 0.5–2 keV bands, respectively] is adopted. About half (31/68) of the Chandra sources with an hard X–ray spectrum are candidate type 2 quasars. Their number counts, computed assuming the X/O vs $L_{2-10\text{keV}}$ relation, are reported in Figure 2 along with the results obtained from the HELAS2XMM survey [16].

The observed surface densities are compared with the number counts of luminous ($L_X > 10^{44} \text{erg s}^{-1}$) obscured ($N_H > 10^{22} \text{cm}^{-2}$) AGN predicted by XRB synthesis models [8]. The evolution of the X–ray luminosity function is parameterized by a pure luminosity law [$L(z) \propto L(z = 0) \times (1 + z)^{2.6}$] up to $z = 1.5$ and constant up to a maximum redshift $z_{\text{max}}$.

Model predictions are shown in Figure 2 for three different values of the maximum redshift over which the integration of the XLF is performed. At their face value the results indicate that in order to reproduce the number counts of type 2 quasars as predicted by [15], a maximum redshift as high as $z_{\text{max}} \simeq 7$ is required.

The existence of a population of very high–redshift obscured quasars hiding among the optically faint counterparts of X–ray sources has been put forward by [12]. Seven Chandra sources with robust detections in the X–ray band (25–90 counts) are not detected in deep multiband HST ACS observations. Their extreme values of the X/O ratio (EXO’s) and in particular the lack of detection

**Fig. 2.** The number counts of luminous [$L_X > 10^{44} \text{erg s}^{-1}$] obscured ($N_H > 10^{22} \text{cm}^{-2}$) quasars as estimated by Perola et al. (2004, open square), and Padovani et al. (2004, filled squares). Continuous lines represent the expected number counts from the XRB synthesis models as described in the text.
Fig. 3. The X/O ratio as a function of 2–10 keV absorption–corrected luminosity for a sample of hard X–ray selected Chandra sources (CDFN = squares; CDFS = triangles; spectro–z = filled symbols; photo–z = open symbols; star = redshift obtained from the iron line). Left panel: optically “bright” objects $R < 25$, Right panel: optically faint objects $R > 25$

in the $z_{850}$ ACS band are consistent with a redshift above 6–7 such that their Lyα emission is redshifted out of the ACS bands. However making use of recent Spitzer observations in the IRAC filters (3.6–8.4 µm) and deep K′ data, it has been suggested [13] that their multiband photometric data are well fitted by early–type templates at redshifts 2–5, and in only one case a redshift as high as 6 is supported by SED fitting.

Given that only one spectroscopically confirmed quasar at $z > 5$ has been so far discovered in the Chandra deep fields [2], the possibility that even a few very high–z, presumably obscured, quasars could be hiding among high X/O and EXO’s would have important consequences for the AGN evolution. However, before claiming that such a population has been indeed revealed, additional and more robust observational evidences should be provided.

The identification of type 2 quasars using the “X–photo–z” technique is based on the assumption that the $X/O$ vs. $L_{2–10keV}$ correlation can be extrapolated beyond the magnitudes over which it has been calibrated ($R < 24–25$). In order to address this point, we [7] have collected redshift measurements (mainly photo–z) for all the sources in the Chandra deep fields with $X/O > 10$. The results are reported in Figure 3 where the sample is divided according to the optical magnitude. While relatively bright $R < 25$ sources lie, though with a substantial scatter, on the relation, optically faint objects appear to have lower luminosities than expected. Similar conclusions are reached by [3] (see their Figure 6). On the other hand, it is also important to note that at faint optical magnitudes the probability to find by chance a galaxy in the X–ray error box increases dramatically (i.e. up to about 0.25–0.30 for $R=26$ and an error circle radius of
2 arcsec, without considering source clustering). Furthermore, photo–z estimates often involve the determination of source’s magnitudes in images of very different quality (e.g. space versus ground based telescopes) and, as a consequence, are affected by systematic errors.

Even if the X/O ratio appears to be an efficient selection method to search for high–z, obscured type 2 quasars [6], a reliable estimate of their number and luminosity densities must await for medium–deep, large–area hard X–ray surveys allowing to sample, with an adequate statistic, the brightest sources. For a given X/O their optical counterparts are, on average, brighter and thus within the spectroscopic capabilities of present telescopes. For extremely optically faint sources deep near–infrared photometry coupled with Spitzer observations would allow us to overcome the problem of chance coincidences. Significant progress are foreseen once the rich multiwavelength database of the ongoing COSMOS (2 square degrees) and ELAIS–S1 (0.5 square degrees) surveys will be exploited.

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