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Multi-wavelength surveys of obscured AGN

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Abstract. Several key goals require measuring the number of all AGN in the Universe, and the evolution of the ratio of obscured to unobscured AGN with redshift. Hard X-rays can penetrate most obscuring dust columns to reveal the AGN that remains hidden in all other wavelengths, thus, combined with other wavelengths can provide us with accurate demographics of AGN. I will present and discuss some of the results coming from recent multi-wavelength surveys, placing particular focus on the systematic study of obscured AGN.

Key words. Galaxy: Active Galactic Nuclei – Galaxy: Obscured AGN - Galaxy: AGN Unification – Galaxy: X-Ray Background

1. Introduction

Active Galactic Nuclei (AGN) are signposts for galaxy formation. It is thus very important to understand their nature and evolution vs. cosmic time, and the black hole - galaxy connection. Furthermore, AGN are of cosmological significance because they may play an important role in the re-ionization of the Universe and they probably comprise most of the X-ray background radiation (Mushotzky et al. (2000); Alexander et al. (2001, 2003); Hasinger (2002); Rosati et al. (2002)).

Obscured AGN most likely dominate the population of SMBH (Gilli et al. (2001)), however, very few obscured AGN are known beyond z~0.3 (Hasinger (2001); Stern et al. (2002); Norman et al. (2002); Dawson et al. (2003)) and it remains unclear whether this is due to an intrinsic rarity or is the result of biased surveys. Standard UV excess/color selection techniques or broad emission line survey methods usually miss the highly obscured AGN, being biased towards the highly luminous AGN at high z and the numerous weaker AGN observed in the local Universe. The obscured AGN can only be detected in the hard X-rays (>2 keV), which can penetrate most obscuring dust columns to reveal the AGN , and in the mid and far-IR wavelengths, where the majority of their bolometric luminosity is observed. Many deep multi-wavelength surveys, such as GOODS (Giavalisco et al. (2004)), are motivated by the possible discovery of a previously unknown high-z population of obscured AGN. A complementary approach, given the relatively low surface density of AGN (compared to normal galaxies), is to target high-luminosity AGN over a wider area of the sky. Examples of such surveys are CHAMP (Green et al. (2004)), CYDER (Castander et al. (2003)), SEXSI (Harrison et al. (2003)), HELLAS2XMM (Baldi et al. (2002)).

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2. Biases

However, X-ray surveys are not devoid of biases. Indeed, we find that the observed redshift distribution of X-ray sources is peaked at lower redshift (z~0.7) and the ratio of obscured to unobscured AGN is substantially lower (2-2.5) than the values required by X-ray background models (respectively, z$\sim$1.4 and ratios of 4:1 locally to 10:1 at z=1.3). The most obvious explanation is that X-ray flux-limited samples suffer incompleteness at high column densities, estimated to be (for the GOODS fields) 75% for $N_H = 10^{23}\mathrm{cm}^{-2}$ and 30% for $N_H = 10^{24}\mathrm{cm}^{-2}$ Treister et al. (2004). Furthermore, as Treister et al. (2004) showed, deriving a hard X-ray luminosity function (LF) or redshift distribution, imposes an effective optical cut at R<24 mag, since optical spectroscopy is required to obtain accurate redshifts. Thus, published redshift distributions can be missing optically-faint sources, which could be either low-luminosity unobscured AGN or obscured AGN, and this spectroscopic incompleteness is expected to increase with redshift.

3. X-Ray-to-Optical Fluxes

The X-ray-to-optical flux ratio is known to be strongly indicative of high obscuration in high luminosity AGN, probably representing the high-redshift obscured AGN population (Alexander et al. (2001); Koekemoer et al. (2002); Fiore et al. (2003); Mignoli et al. (2004); Gandhi et al. (2004)). Fiore et al. (2003) found that 20% of hard X-ray selected sources have f_X/f_{opt} $\sim$10 times higher than that of optically selected AGN. Among the sources with the highest ratio, the 2/3 are absorbed QSO the rest being type 1 QSO. Interestingly, Perola et al. (2004) found that about 10% of the sources with $\log N_H$ >22 are optically classified as unabsorbed (type 1) AGN, and they all have $\log L_{2-10keV}$ >44. There are two possible explanations for this: either the dust-to-gas ratio is substantially different than the assumed Galactic value, or the X-ray absorbing gas and the gas and dust obscuring the broad line region (BLR) are geometrically separated. One could add a third factor, the variability in the X-ray absorbing column or/and in the optical emission.

4. Differential Luminosity Evolution

Hard X-ray LF have revealed that BL AGN dominate the number densities at the higher X-ray luminosities, while non-BL AGN dominate at the lower X-ray luminosities (Steffen et al. (2003)). Ueda et al. (2003) confirmed the luminosity dependence of the fraction of absorbed sources (decreasing with luminosity), while its z dependence seems to not be significant. Fiore et al. (2003) found that the low X-ray luminosity sources increase in number backward in time at a much slower rate than the high X-ray luminosity sources. The former reach a maximum at z$\sim$1 and then level off at z>2, similar to the evolution of actively star forming galaxies. The latter show strong evolution up to z=2-3, following the evolution of spheroids.

This differential evolution between obscured and unobscured AGN indicates that, either the simple orientation unification model for AGN needs to be modified to include an X-ray dependent covering factor (e.g. the opening angle of the dust torus is larger in luminous AGN), or that the BL and non-BL AGN are intrinsically different. Perola et al. (2004) suggested that modifying the shape and evolution of the LF and the N_H distribution as a function of luminosity simultaneously, could help improve the models so that they reproduce the data. Ueda et al. (2003) showed that the cosmological evolution of the hard X-ray LF could be best described by a luminosity-dependent density evolution model, where the cutoff redshift increases with luminosity. This would imply that the luminous AGN (quasars) are formed in earlier epochs than the less luminous AGN (which is consistent with the claims of Cowie et al. (2003) and Hasinger (2003)).

5. Optical Spectral Types and Host Galaxies

Barger et al. (2005) argued that, since the optical spectra of X-ray sources suffer varying degrees of AGN mixing with the host galaxy spectrum (this further depending on redshift), instead of using the conventional AGN classification scheme, they have devised four optical spectral classes for X-ray selected sources. They showed that one can separate BL AGN from non-BL AGN on the basis of X-ray colours/spectra, but for the narrow-line (NL) AGN there is no clear dependence of the absorbing column density on the optical spectral type or optical line widths. They do find a luminosity dependence in optical spectral type, both in the sense of BL AGN dominating at large $L_X > 10^{44}$ ergs s^{-1} noted earlier, as well as, between optically normal galaxies and AGN (the cross-over point lying at $L_X < 10^{43}$ ergs s^{-1} at z=0.25 and at $L_X < 10^{44}$ ergs s^{-1} near z=1). Their suggestion is pure luminosity evolution in both the LF and the spectral type mix, indicating, as before, a luminosity dependent unified model.

The rapid drop in the luminosities of BH (both BL and NL AGN) with decreasing redshift between z=1 and z=0, indicates a drop in the overall energy density production by the AGN. The authors put forward two possible explanations: mass starvation (declining accretion rate of all super-massive black holes (SMBH), regardless of mass), or AGN downsizing (the more massive black holes are being preferentially starved, while the less massive continue to accrete). They prefer the latter, since the most X-ray luminous AGN lie in the most optically luminous host galaxies, and the latter seems to have completely disappeared at low redshifts.

Furthermore, Barger et al. (2005) discuss the fact that the accretion history of SMBH may be strongly linked to the star formation history in their host galaxies. The density evolution of luminous AGN resembles the formation history of early type galaxies (Franceschini et al. (1999)), in accordance with the Magorrian relation (Magorrian et al. (1998)) found in the local Universe. This put together with recent findings that the star formation of early type galaxies peaks earlier (z~3) than that of late type galaxies (z~1.5). (Balland et al. (2003)), suggest that luminous AGN lived preferentially in galaxies with large spheroid components and their SMBH grew in parallel with strong starbursts at earlier epochs (possibly as a result of mergers), followed by a rapid decrease of their activities after z<2. Late-type galaxies, on the other hand, made starbursts later or/and slower and are hosting less luminous AGN whose activity continued until recently (z=1). Furthermore, since there seems to be a difference in the peak star formation (earlier) and AGN (later) activity for both early and late type galaxies, as indicated by the above peak redshifts, this would imply that the AGN activity in a galaxy occurs in a later phase than a major starburst (Ueda et al. (2003)).

6. Conclusions

It is clear that only $\sim 1/2 - 1/4$ of the SMBH mass density was fabricated in BL AGN, this leaving plenty of room for obscured accretion. All the new evidence outlined above, despite the problems and new issues that it raised, has helped enormously to improve our understanding of the elusive population of obscured AGN in the Universe, constraining the formation history of both the luminous unobscured quasars and the less luminous obscured AGN, which are the main contributors of the X-ray background.

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