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Obscured AGN in Multiwavelength Surveys

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Abstract. Using a simple unification model for AGN, with a fixed ratio of obscured to unobscured AGN of 3:1, we explain the X-ray, optical and infrared properties of the X-ray sources in the GOODS fields. That is, the GOODS data are consistent with the existence of a large population of obscured AGN out to high redshifts. About half of these are so obscured that they are missed even by hard X-ray observations, and are detected only in deep infrared observations. The previously reported decreasing trend of obscured to total AGN ratio with increasing X-ray luminosity can be explained entirely as a selection effect.

Key words. galaxies: active, quasars: general, X-rays: galaxies,diffuse background

1. Introduction

The long-standing problem of explaining the nature of the extragalactic X-ray background (XRB) is finally being solved. Recently, the deepest Chandra and XMM observations have resolved $\sim 70 - 90\%$ of the XRB into point sources, the vast majority of them identified as active galactic nuclei (AGN). However, some problems remain. The hard spectrum of the XRB, much harder than that of the typical unobscured AGN (Mushotzky, Cowie, Barger, & Arnaud 2000), means that most of the emission comes from *obscured* AGN (Setti & Woltjer 1989), yet the observed ratio of obscured to unobscured AGN in the XMM/Chandra deep fields is only $\sim 2:1$, much lower than the 4:1 ratio inferred from population synthesis models (Gilli et al. 2001). Also, such models predict a redshift distribution that peaks at $z \sim 1.4$, while the deep field AGN distributions peak at a much lower redshift, $z \sim 0.7$ (Hasinger 2002).

To find the large numbers of obscured AGN predicted by XRB models has proved to be a very hard task. Wide-area optical surveys like the Sloan Digital Sky Survey, which discovered a large number of unobscured AGN, are not very efficient for detecting obscured AGN given their low optical fluxes and lack of broad emission lines. Therefore, multiwavelength surveys — in particular at hard X-rays and infrared wavelengths, where most of the obscured AGN emission is found — are required to obtain a more complete census of the AGN population.

This was one of the main motivations for the Great Observatories Origin Deep Survey (GOODS), which consists of deep imaging in the far infrared with the Spitzer Space Telescope (Dickinson & Giavalisco 2002) and

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in the optical with the Hubble Space Telescope (Giavalisco et al. 2004) on the footprints of the two deepest Chandra fields (Giacconi et al. 2001; Brandt et al. 2001). The total area is roughly 60 times larger than the original Hubble Deep Field and reaches nearly the same optical flux limit. With extensive coverage over five decades in energy from 24 μm to 8 keV, the GOODS survey is well suited to find a high-redshift population of obscured AGN if they exist. A complementary approach, given the relatively low surface density of AGN (compared to normal galaxies), is to target higher luminosity AGN over a wider area of the sky, an approach followed by the CYDER (Castander et al. 2003) survey, for example. Here we describe the multiwavelength properties of AGN detected in X-rays in the GOODS North and South fields, which represent an order of magnitude more objects than in most previous works.

2. The Model

Much work on black hole demographics begins with the AGN found in a given survey, correcting where possible for selection biases to infer the underlying population. If selection effects are strong, however, one ends up making large extrapolations using little information. We therefore took a different approach: we asked, if there is a substantial population of obscured AGN, what would be seen in a deep multiwavelength survey like GOODS? Our work is presented by Treister et al. (2004a); here we briefly describe our assumptions and results.

To derive the number counts at any wavelength we start with a hard X-ray luminosity function, an assumed cosmic evolution, and a library of spectral energy distributions. We use the hard X-rays as a starting point because observations from 2-10 keV in the rest frame are less affected by obscuration and therefore provide a less biased view of the AGN population. In this work, we use the luminosity function and evolution of Ueda et al. (2003, hereafter U03). We construct SEDs as a function of only two parameters, the intrinsic hard X-ray luminosity and the neutral hydrogen column density (N_H) along the line of sight. For the X-ray spectrum, a simple power law with slope $\Gamma = 1.9$ plus photoelectric absorption with solar abundances was assumed. In the optical, we use the SDSS composite quasar SED (Vanden Berk et al. 2001), absorbed using Milky-Way type extinction plus an L_* elliptical host galaxy. In the infrared region, the dusty torus emission models of Nenkova et al. (2002) were used.

The dependence of the luminosity function on the column density is calculated separately using an "N_H function" presented in Equation 6 of U03, which is based on the relative number of sources at each N_H observed in their sample. The N_H distribution was calculated based on the unified paradigm, in which the torus has a fixed geometry and dust distribution. Our model comprises this N_H function, combined with U03 luminosity function and evolution and the previously described library of AGN SEDs.

3. Results

Using the model described in the past section, we computed the expected hard X-ray flux and optical magnitude distribution for the X-ray sources in the GOODS fields. Compared to the observed distribution, the agreement is remarkable, showing that this model is able to account for the observed AGN population in these deep Chandra fields, as shown in Fig. 1. Also, the predicted and observed redshift distributions are consistent once that selection effects in the observed sample are accounted for. The need for optical spectroscopy generates the largest selection effect in this sample, since most obscured AGN are faint in the optical, meaning it is much harder to obtain spectroscopic redshifts for them.

The GOODS fields will be observed by Spitzer in the four IRAC bands (3.6, 4.5, 5.8 and 8 microns) and in the MIPS 24 microns band. Currently, we have obtained data in the North and South fields in the IRAC bands and only in the North field with MIPS. Preliminary results show that both the overall shape and normalization of the predicted and observed distributions agree very well once that the predicted infrared fluxes are reduced by a constant

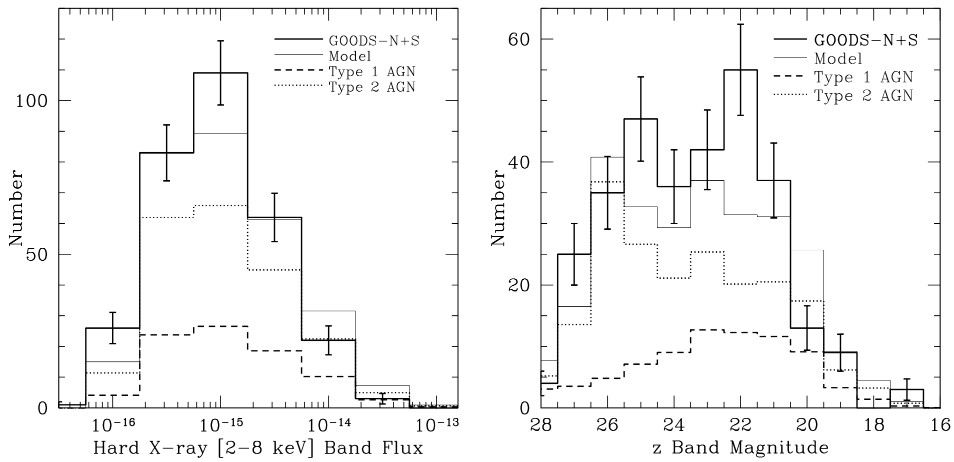

Fig. 1. X-ray fluxes and z-band magnitudes of GOODS AGN. *(Left)* Hard X-ray flux (2-8.0 keV) distribution for X-ray sources in the combined GOODS fields (*heavy solid line*, compared to number counts calculated from a simple unification model (*light solid line*). Individual contributions from unobscured (*dashed line*) and obscured (*dotted line*) AGN are shown separately. *(Right)* Distribution of observed *z*-band magnitudes for GOODS X-ray sources (*heavy solid line*), compared to model distribution (*light solid line*).

factor of ∼ 2. This may indicate that the overall torus emission was overestimated, suggesting a smaller mass for the average AGN dust torus. Also, this model suggests that only half the AGN in the GOODS fields are detected in the deep Chandra X-ray observations, with the remaining half being very obscured, moderate luminosity AGN. All these missed AGN will be luminous enough to be easily detected in the GOODS Spitzer observations.

Previous work (Hasinger 2004;U03) found an apparent decrease of the ratio of obscured to total AGN with increasing X-ray luminosity. Again, this can be explained as a selection effect against the determination of spectroscopic redshifts for obscured AGN at higher luminosities, in particular at higher redshifts were most of them are found (Fig. 2; Treister et al. 2004b).

4. Conclusions

We compared the multiwavelength properties of the hard X-ray sources detected in the GOODS fields with a simple AGN unification model and showed that the data are consistent with a large number of obscured AGN at high redshifts. Optical spectroscopy is very hard for such AGN, even with modern 8-m class telescopes, and thus they are normally excluded from AGN surveys that rely on optical spectroscopy to determine redshifts (and thus luminosities). Once this selection effect is considered, the predicted and observed optical and hard X-ray flux distributions and redshift distributions are in agreement.

According to our predictions and early observations all the AGN detected in X-rays will be bright in the infrared bands and will be detected in the deep Spitzer observations of the GOODS fields. However, ∼ 50% of the AGN in the field were not detected in these deep X-ray observations, all them being obscured AGN at high redshifts; these will be detected only in infrared observations, where most of the absorbed energy is re-emited.

We also found that the previously reported decrease in the obscured to total AGN ratio with increasing X-ray luminosity can be explained as a selection effect against the detection of obscured AGN at high redshift, where most of the high luminosity AGN can be found.

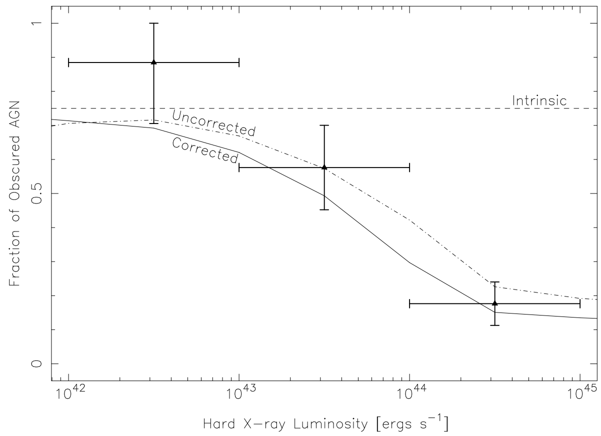

Fig. 2. The fraction of obscured AGN versus X-ray luminosity, shown here for X-ray sources in the combined CYDER and GOODS surveys, appears to decrease with X-ray luminosity, as has been seen in previous work (Hasinger 2004;U03). (*Dot-dashed line:*) Predicted trend for a unified model with a constant intrinsic ratio of obscured to total AGN of 3:4 (*dashed line*), considering only objects with optical magnitude $R < 24$ mag (i.e., the optical cut for spectroscopy) and ignoring the (observationally unknown) effects of obscuration and K correction in calculating the X-ray luminosity. *Solid line:* Predicted trend after correcting the intrinsic hard X-ray luminosity for obscuration and redshift effects.

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