AGN unified scheme and evolution: a *Suzaku* view

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ABSTRACT

We present broad band *Suzaku* observations of a small sample of hard X–ray selected (> 10 keV), nearby Seyfert 2 galaxies and discuss the results in the context of AGN unified model. We also review the issues related to the space density of heavily obscured, Compton Thick AGN in the local Universe and the perspectives for the search of these objects at high redshifts.

KEY WORDS: X-rays: active galaxies — X-rays: spectroscopy

1. Introduction

Since the discovery of polarized broad emission lines in the archetypal Seyfert 2 galaxy NGC 1068 (Antonucci & Miller 1985), the AGN Unified Model (UM) was tested over the entire electromagnetic spectrum. While it has been realized that its original formulation was too simple to explain the large body of observational data, it still provides a useful framework for AGN studies.

Hard X–ray observations of Seyfert galaxies have shown that absorption by circumnuclear gas and dust, presumably with a toroidal geometry, is almost ubiquitous among optically classified Type 2 objects. Deep and wide X–ray surveys, combined with pointed observations of nearby bright AGN, allowed to probe a large interval of luminosities, redshifts and column densities and thus to test the AGN UM in the X–ray band.

A wide range of absorbing column densities is observed among Seyfert 2 and is required to fit the X–ray background (XRB) spectrum (Gilli et al 2007; Treister et al. 2009). Absorption is much less common at high X–ray luminosities with a trend similar to that observed at optical and infrared wavelengths (Simpson 2005, Maiolino et al. 2007). There are also hints of an increasing fraction of obscured AGN towards high redshifts (La Franca et al. 2005; Treister et al. 2006). Besides providing additional tests to the UM, the above trends are most likely closely related to the growth and evolution of Supermassive Black Holes (SMBHs). According to current models (e.g. Hopkins et al. 2008) all the galaxies undergo a phase of heavy, possibly Compton Thick ($N_H > 10^{24}$ cm^{-2}) obscuration, strong accretion and star formation. The census of obscured AGN may thus provide useful insights on our understanding of a key phase of SMBH and galaxy co-evolution. Due to the lack of sensitive X–ray observations above 10 keV, Compton Thick AGN can be efficiently detected and recognized as such only in the local Universe.

In the following we present *Suzaku* observations of a small sample of hard X–ray selected Seyfert 2. The goal is to characterize the physics and geometry of the obscuring gas and, a first step, to investigate their local space density. We also briefly discuss the search for the most obscured sources in various X–ray surveys and the implications for the study of their properties at high redshifts.

2. Suzaku observations of nearby Seyfert 2 galaxies

We have conceived a program with *Suzaku* (Mitsuda et al. 2007) to observe five nearby, relatively X–ray bright ($> 10^{-11}$ erg cm^{-2} s^{-1}) AGN. The sources were selected from the INTEGRAL/IBIS (Beckmann et al. 2006) and SWIFT/BAT (Markwardt et al. 2005) catalogues. The column densities, as inferred from archival *Chandra* and XMM–*Newton* observations, are of the order of 10^{23-24} cm^{-2}, though affected by large errors. For all the sources in the sample, a significant detection is achieved with the hard X–ray detector up to 40–50 keV along with a good quality X–ray spectrum with the XIS CCD below 10 keV (Fig. 1 and Comastri et al. 2009). The high energy (> 2-3 keV) spectra are fitted with an absorbed power law plus a reflection component and an iron line.

Not surprisingly, heavy absorption with column densities in excess of 10^{23} cm^{-2} is measured in all the sources. Three of them are Compton Thick ($N_H > 10^{24}$ cm^{-2}) and among those, two are best fitted by a reflection dominated spectrum. A summary of the spectral fit parameters, relevant for the present discussion, is reported in Table 1. Soft X–ray emission, in excess of that expected
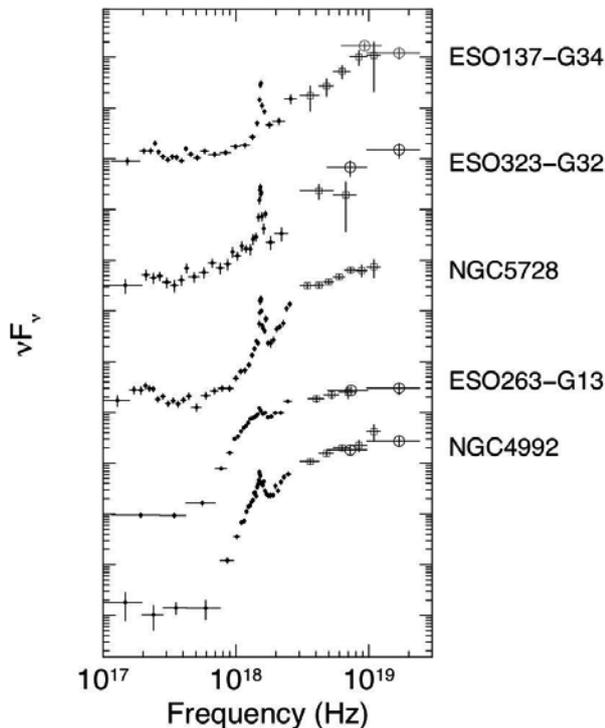
Fig. 1. The Suzaku spectra of the Seyfert 2 galaxy sample. The open circles at high energies are from Integral.
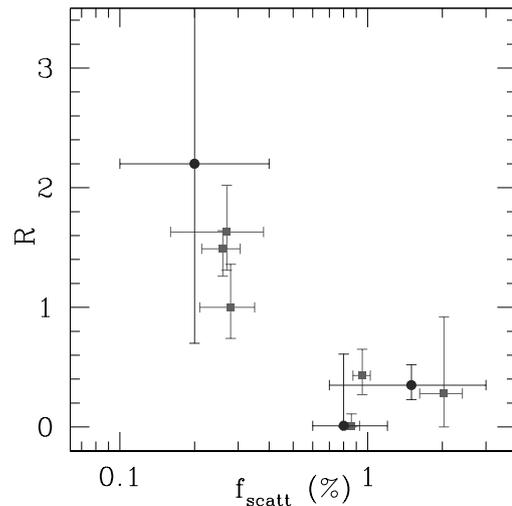

Fig. 2. Scattering fraction vs reflection component intensity. Red points are from Eguchi et al. (2009), blue points refer to the 3 objects in the present sample for which the scattering fraction could be estimated.

by an extrapolation to lower energy of the absorbed spectrum, is clearly observed in all objects with only one exception. The low energy spectrum is fitted with two different models: (i) a partial covering (leaky absorber) model and (ii) a power law plus narrow Gaussian lines to approximate the emission of circumnuclear gas photoionized by the central nucleus.

2.1. Partial covering model

The fits with a partial covering model, which provides a good description of the broad band spectra, allow us to compute the fraction (f) of primary X–ray emission scattered into the line of sight and related to the covering fraction of the absorbing matter (e.g. the postulated torus in AGN UM). Interesting enough, the measured values of f and the intensity of the reflection component (R) follow the correlation suggested by Eguchi et al. (2009) based on the analysis of a small sample of 6 Seyfert 2 galaxies detected by SWIFT/BAT and selected in a very similar way (Fig. 2). Following Eguchi et al (2009), sources with a low scattering fraction, dubbed "New Type" AGN, are associated to a geometrically and optically thick configuration of the obscuring gas seen rather face on. On the basis of a solid angle argument, they predict a large population of heavily Compton Thick AGN ($N_H > 10^{25}$ cm^{-2}) with extremely low scattering fraction which would remain largely unde-

tected even in hard X–ray observations. While it may be premature to invoke the presence of a new population on the basis of the present data, the existence of fully covered, heavily obscured AGN would have important consequences for the census of SMBHs.

Table 1. Suzaku sample

Source Name	N_H (cm^{-2})	$f(\%)$	R	Kα EW (eV)
ESO137-G34	10^{25}	...	...	1350
ESO323-G32	10^{25}	...	...	2200
NGC 5728	$1.5\ 10^{24}$	1.5	0.35	1040
ESO263-G13	$2.6\ 10^{23}$	0.8	<0.6	80
NGC 4992	$5.5\ 10^{23}$	0.2	2.2	450

2.2. Soft X–ray emission lines

An equally good description in terms of spectral fits quality is obtained assuming that the soft X–ray emission is due to a blend of emission lines which are tipically resolved in good signal to noise XMM–Newton reflection grating spectra (Guainazzi & Bianchi 2007). While photoionization codes (e.g. XSTAR) are usually adopted to model high resolution soft X–ray spectra, the statistical quality of the available CCD data is such that a simple parameterization, in terms of a power law plus narrow Gaussian lines, is well suited for the present purposes. The power law slope is free to vary and is independent from that of the obscured high energy continuum to possibly account for "residual" emission from thermal gas.
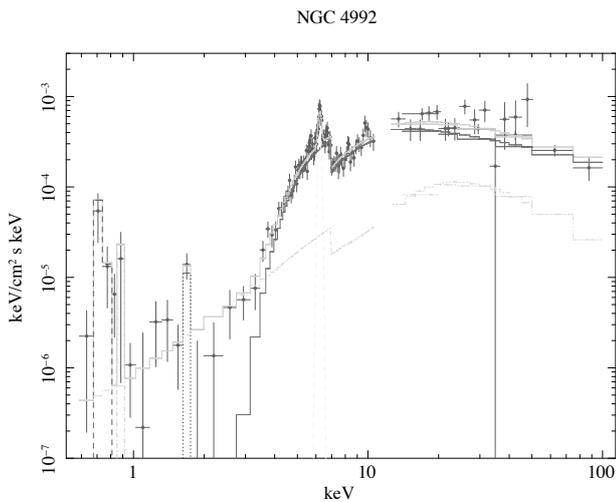
NGC 4992

Fig. 3. The unfolded spectrum of NGC 4992, fitted with an absorbed power law plus a Iron line at high (> 3–4 keV) energies. The weak soft X–ray spectrum can be fitted with a power law and a sum of Gaussian lines.
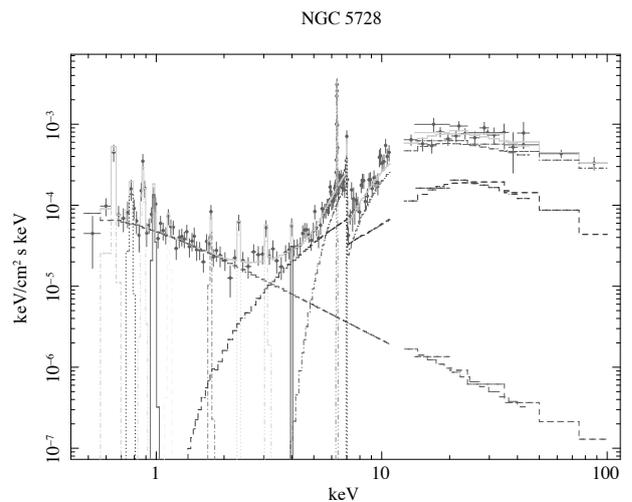
NGC 5728

Fig. 4. The unfolded spectrum of NGC 5728, fitted with the same model adopted for NGC 4992. The nuclear source is obscured by Compton Thick gas and strong Kα and Kβ iron lines are detected

Individual, narrow Gaussian lines are then added at the best fit energy of the most common transitions observed in other Seyfert galaxies. The line energy and intensity are free parameters of the fit. The number of lines considered for each source depends from the actual counting statistics. The ionized Oxygen OVIII line at 0.65 keV and NEIX at 0.92 keV are present in all the objects. A large fraction of the soft X–ray flux in NGC 4992, the source with the lowest scattering fraction in our sample (Fig. 3), can be accounted for in terms of line emission. The richest line spectrum is that of NGC 5728 where nine indipendent lines (from Oxygen to Calcium) can be fitted (Fig. 4).

The best fit parameters of the hard X–ray continuum are fully consistent with those obtained with a partial covering fit.

Both models provide a good description of the observed spectra and it is not possible, with the available counting statistics, to choose a "best fit" model. The explanation of the soft X–ray excess as a blend of unresolved (at the CCD resolution) lines from a photoionized plasma is consistent with previous X–ray observations of nearby, obscured AGN (Guainazzi & Bianchi 2007).

3.   The space density of obscured AGN

Hard X–ray selection is, in principle, almost unbiased against heavy obscuration and thus considered to be well suited to estimate the intrinsic absorption distribution of AGN and, in particular, the relative fraction of Compton Thick AGN in the local Universe. The large majority of INTEGRAL/IBIS and SWIFT/BAT flux limited samples of bright AGN were observed by XMM and *Chandra* and were the subject of follow–up dedicated programs with

Suzaku. Surprisingly, only the already known Compton Thick AGN were recovered by the above mentioned hard X–ray surveys and no examples of newly discovered Compton Thick sources are reported in the literature. As a consequence, the relative fraction of Compton Thick AGN falls short by a factor of about 2 than that predicted by the Gilli et al. (2007) XRB synthesis model at the INTEGRAL and SWIFT limiting fluxes. A relatively low contribution of CT AGN is predicted by the XRB synthesis model of Treister et al. (2009). By fixing the low redshift CT AGN fraction to that observed by hard X–ray surveys, they conclude that the total contribution of Compton Thick obscured accretion to the XRB is of the order of 10%, to be compared with about 25% of Gilli et al. (2007).

It is important to stress that the observed fraction in the local Universe is estimated using a relatively low number of sources and indeed the associated errors are large. Nevertheless, it seems that present observations are favouring a relatively low space density of heavily obscured sources. It is possible to reduce the discrepancy between the the original Gilli et al. (2007) model predictions and the observations assuming a lower ratio (0.3 instead of 1) between obscured and unobscured, luminous ($L_X > 10^{44}$ erg s^{-1}) AGN (upper envelope of the shaded region in figure 5). A better agreement (lower envelope of the shaded region in figure 5) is obtained assuming a slightly different N_H distribution. More specifically, the space density of transmission dominated Compton thick AGN, detectable by surveys above 10 keV, is reduced and, at the same time, that of Compton thin and reflection dominated sources is increased in such a way to keep approximately constant the total number of obscured AGN in the model and to fit the XRB spectrum.
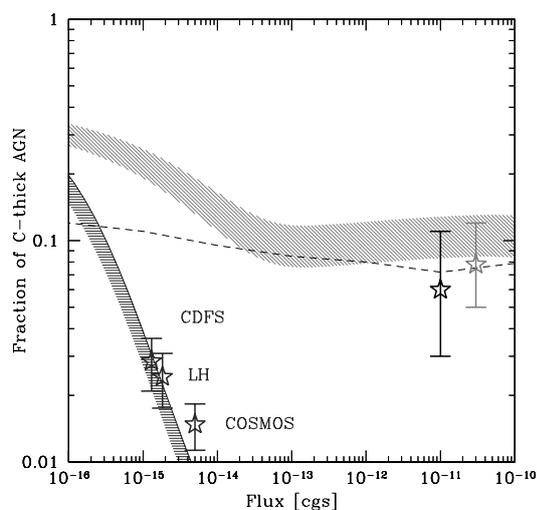
Fig. 5. The fraction of Compton thick AGN as a function of the X–ray flux. The dashed line and the yellow shaded region correspond to the predictions of Treister et al. (2009) and Gilli et al. (2007) respectively for the 20–40 keV band, while the points with error bars are the observational estimates from BAT and IBIS. The blue shaded region and the points at low X–ray fluxes correspond to the Gilli et al predictions in the 2–10 keV band and the "observed" fraction in various surveys as labeled, respectively.

Fig. 6. The XMM-Newton spectrum of a candidate Compton Thick AGN in the CDFS (for a total exposure time of $\sim$ 1.5 Ms).

The discrepancy between the two models is now negligible at bright X–ray fluxes, while it remains significant at lower fluxes and higher redshifts.

Deep *Chandra* surveys have unveiled several examples of heavily obscured candidate Compton Thick AGN (Tozzi et al. 2006; Georgantopoulos et al. 2009). At the face value the observed fraction is consistent with the Gilli et al. (2007) predictions in the 2–10 keV band, though the statistical fluctuations, due to the low number of objects and systematics errors associated to the column density determination, may well be larger than those plotted in figure 5.

A significant improvement in the study of Compton thick AGN at $z \sim 1$, and possibly beyond is expected by the ongoing ultra–deep (2.5 Msec) XMM–*Newton* survey in the CDFS. Thanks to the large throughput of XMM it will be possible to obtain good quality X–ray spectra for a sizable number of sources. The *pn* spectrum of a candidate CT AGN at $z = 1.53$ in the Tozzi et al. (2006) sample, obtained with about half of the total final exposure, is reported in figure 6. A strong (EW of about 1 keV) Kα line is detected on top of a very hard continuum and is interpreted as the signature of Compton Thick obscuration.

Indirect searches for Compton Thick AGN at $z \simeq 2$, using a mid–IR optical color selection (Daddi et al. 2007; Fiore et al. 2008; 2009), seem to suggest that heavily obscured accretion at high redshift may be common, in line with the 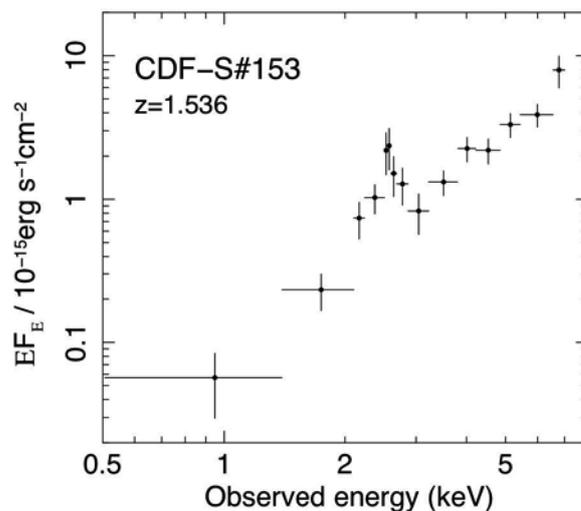theoretical expectations. However the possible contamination from starbust galaxies is a serious issue and the determination of the space density of Compton thick AGN at high–z is still affected by large uncertainities. Forthcoming HERSCHEL observations will allow to disentangle starburst from nuclear emission, extending previous studies with SPITZER to higher redshifts.

The direct detection of high redshift, heavily obscured Compton Thick AGN and the statistical study of their properties (luminosity function and evolution) cannot be achieved without imaging observations in the hard X–rays. In this respect, a major step forward is expected by future planned missions such as ASTRO-H and NUSTAR.

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