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The Simbol-X view of the unresolved X–ray background

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Abstract. We will briefly discuss the importance of sensitive X–ray observations above 10 keV for a better understanding of the physical mechanisms associated to the Supermassive Black Hole primary emission and to the cosmological evolution of the most obscured Active Galactic Nuclei.

Key words. Galaxies: active – X-rays – Cosmology: observations

1. Introduction

The fraction of the hard X-ray background (XRB) resolved into discrete sources by deep *Chandra* and XMM-*Newton* observations smoothly decreases from practically 100% below 2–3 keV to about 50% in the 6–10 keV energy range (Worsley et al. 2005), becoming negligible at energies above 10 keV, where the bulk of the energy density is produced.

The shape and intensity of the unresolved XRB calculated by Worsley et al. (2005) is well described by a "peaky" spectrum which is similar to that computed by folding the average spectrum of heavily obscured ($N_H > 10^{23}$ cm^{-2}) and Compton Thick ($N_H > 10^{24}$ cm^{-2}; hereinafter CT) AGN over the redshift range $z \sim 0.5$–1.5 (e.g., Comastri 2004a).

The search for and the characterization of this population has become increasingly important in the last years and represents the last obstacle towards a complete census of accreting Supermassive Black Holes (SMBHs). According to the most recent version of XRB synthesis models (Gilli et al. 2007), heavily obscured and CT AGN are thought to be numerically as relevant as less obscured Compton Thin AGN. As a consequence, their impact on the astrophysics and evolution of AGN population as a whole cannot be neglected.

It is convenient to consider absorption in the CT regime in two classes: mildly and heavily CT (see Comastri 2004b). The column density of the absorbing gas of the former class is just above the unity optical depth for Compton scattering, while it is much larger than unity for the latter. The primary radiation in mildly

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CT AGN is able to penetrate the obscuring gas and is visible above $\sim$ 10 keV, while Compton down-scattering mimics absorption over the entire energy range for heavily CT AGN. As far as the XRB is concerned, the most relevant contribution is expected to come from mildly CT AGN which are expected to be as bright as unobscured AGN above 10–15 keV. Though the flux of the primary emission is strongly depressed, also heavily CT AGN may provide some contribution to the XRB which depend on their scattering/reflection efficiency, most likely correlated with the geometry of the obscuring gas.

At present, the best estimates of the basic properties of mildly CT AGN rely on the observations obtained with the `PDS` instrument onboard *BeppoSAX* (Risaliti et al. 1999; Guainazzi et al. 2005). CT absorption, at least among nearby AGN, appears to be rather common. The relative fraction depends on the adopted selection criterium and can be as high as 50–60% for optically selected Seyfert 2 galaxies. More recently, `BAT`/*Swift* (Ajello et al. 2007) and `IBIS`/*INTEGRAL* (i.e., Bird et al. 2007) have surveyed the hard X–ray sky. Although these surveys have provided relatively large numbers of hard X–ray sources (e.g., Krivonos et al. 2007), they are limited to bright fluxes ($S_{10-100keV} > 10^{-11}$ erg cm^{-2} s^{-1}), thus sampling only the very local Universe. As a consequence, the resolved fraction of the hard (> 10 keV) XRB is of the order of a few percent (Sazonov et al. 2007).

Assuming the absorption distribution determined in the local Universe and folding it with cosmological evolution in AGN synthesis models, it is possible to predict the relative number of CT AGN in a purely hard X–ray selected sample. Though the error bars suffer from small number statistics, there is a fairly good agreement with the model predictions (Figure 1), implying that CT absorption should be common also at high redshift and luminosities. However, only a few CT AGN are known beyond the local Universe (e.g. Comastri 2004b; Della Ceca et al. 2007). Even the deepest X–ray surveys in the 2–10 keV band (e.g., Tozzi et al. 2006; Georgantopoulos et al. 2007) uncovered only a dozen of candidate heavily obscured CT AGN and await for better spectroscopic X–ray data for a confirmation.

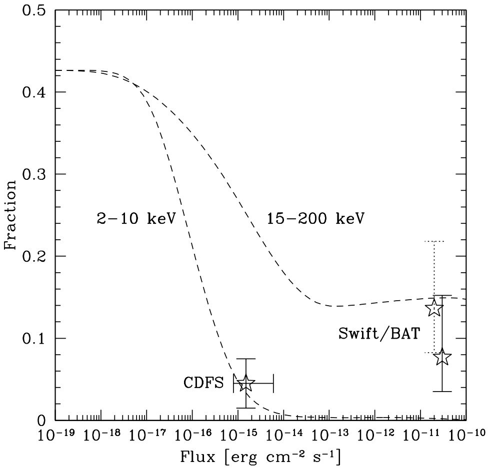

Fig. 1. The predicted fraction of CT AGN (adapted from Gilli et al. 2007) as a function of X-ray flux in two different energy ranges, as labeled. The points with error bars correspond to the estimates in the *Chandra* Deep Field South (CDFS; Tozzi et al. 2006) at faint fluxes, and from Swift/BAT survey (Markwardt et al. 2005). The upper point is computed assuming that the unidentified sources are all CT AGN.

It has been recently suggested that selection via mid–IR and optical colors is promising to pick up high-z heavily obscured AGN (Fiore et al. 2007a; Daddi et al. 2007). Stacking the *Chandra* counts of sources selected on the basis of mid infrared (24μm) excess emission wrt the near–infrared optical flux, a strong signal is revealed in the hard band (up to 4–6 keV), which implies, at the average source redshift (z~2), $N_H \sim 10^{24}$ cm^{-2}. Despite the similarities in the source selection and stacking techniques, the estimated space density of the candidate high-z CT AGN differs by up a factor 3–5. The difference can be ascribed at least in part to the slightly different luminosity ranges sampled. According to Fiore et al. (2007a) the "missing" population of luminous ($L_X > 10^{44}$ erg s^{-1}) candidate CT AGN at $z \sim 2$ would have the right size to explain the *unresolved* XRB, while following Daddi et al. (2007) it may be

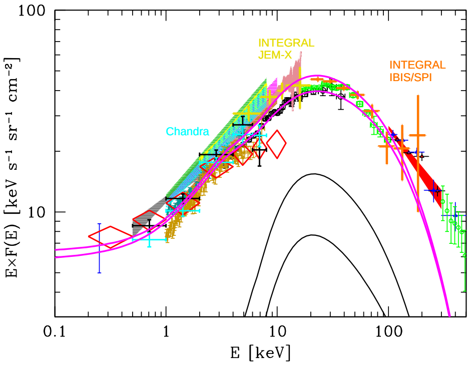

Fig. 2. The contribution of reflection dominated AGN in the Gilli et al. (2007) model (lower black line) can be increased up to a factor 4 (upper black line) and still be consistent with present uncertainties on the XRB level.

significantly more numerous than predicted by synthesis models especially at low ($L_X < 10^{43}$ erg s^{-1}) luminosities. The above estimates are affected by large uncertainties, however they strongly point towards the existence of a sizable population of accreting heavily obscured SMBHs at high redshift. The direct detection of the CT AGN population over the redshift range most densely populated by less obscured sources contributing to the XRB ($z \sim 0.7$–1) bears important implications for our understanding of SMBH evolution. Moreover, a reliable determination of their luminosity function is a key parameter to reconcile the relic SMBH mass function with the local one estimated through the local $M_{BH} - \sigma / M_{BH} - M_{bulge}$ relationships and galaxies luminosity function (Marconi et al. 2004; Merloni et al. 2004).

2. Current hard X–ray observations

The expected fraction of CT AGN in the 15–200 keV band as a function of flux is reported in Figure 1. The advantage of the hard X–ray selection wrt the 2–10 keV band is evident. The `INTEGRAL` and `Swift` all sky hard X–ray surveys have provided the first flux limited samples which can be compared with model predictions. There is a fairly good agreement, but the statistics is still dominated by fluctuations associated to small numbers. Moreover, the CT nature of `Swift` and `INTEGRAL` sources is estimated combining low signal to noise ratio hard X–ray (> 10 keV) spectra with observations at lower energies, mainly with *Chandra* and XMM–*Newton*. Follow–up observations of candidate CT AGN from the surveys described above were performed with *Suzaku*. The hard X–ray detector and the XIS CCD camera onboard the Japanese satellite are sensitive over a broad energy range (∼ 0.5–60 keV) and return good quality spectra for relatively bright hard X–ray sources. Interestingly enough, *Suzaku* follow–up observations of hard X–ray selected `INTEGRAL` and `Swift` sources (Ueda et al. 2007; Comastri et al. 2007), only barely detected below 10 keV, suggest that a population of extremely hard sources, appearing only above 5–6 keV, may have escaped detection by surveys at lower energies. Their high energy spectrum (> 5–10 keV) is dominated by a strong reflection component from optically thick material, while there is no evidence for the presence of a soft X–ray component, presumably due to scattering of the nuclear radiation, and common among Seyfert 2 galaxies. A possible explanation is that the geometrical distribution of the obscuring/reflecting gas is different from known Type 2 AGN.

By requiring that their integrated emissivity does not exceed the XRB level and associated uncertainties at 30 keV (e.g. Churazov et al. 2007; Frontera et al. 2007), and assuming the same evolution of X–ray selected AGN (e.g. Hasinger et al. 2005; La Franca et al. 2005) it is, in principle, possible to constrain their number density. The hypothetic population of reflection dominated AGN could be up to a factor 4 more numerous than CT AGN (Figure 2). Such an estimate is highly uncertain and strongly depends upon the assumption of a reflection dominated spectrum. The bottom line of such an exercise is that there might be room for a previously unknown population of obscured AGN emerging only above 5–10 keV.

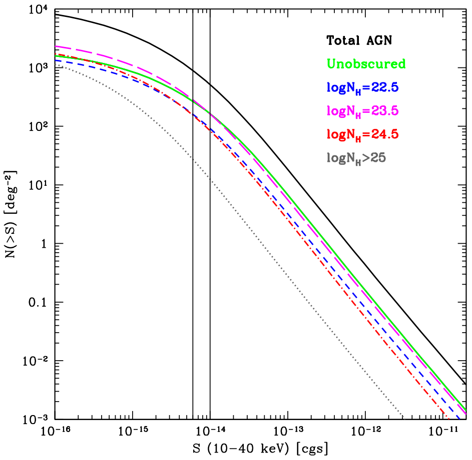

Fig. 3. The model predicted logN–logS in the 10–40 keV band. The number counts for different absorption column densities are reported with the labeled colour code. The two vertical lines correspond to the expected limiting fluxes for the present SimbolX configuration: $\sim 6 \times 10^{-15}$ cgs on-axis and $\sim 10^{-14}$ cgs for an off-axis angle of 5 arcmin.

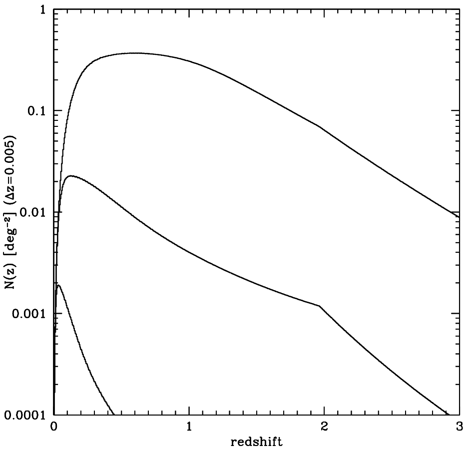

Fig. 4. The redshift distribution of CT AGN for three different limiting fluxes (10^{-12} – 10^{-13} – 10^{-14} erg cm^{-2} s^{-1}) from bottom to top.

3. Future imaging X–ray surveys

Imaging observations above 10 keV will offer a unique opportunity to address at least some of the issues mentioned above. The expected *SimbolX* capabilities are such to make possible the detection of a statistically significant sample of heavily obscured and CT AGN up to $z \sim 1$. The expected quality of the spectral data over the range of fluxes accessible to *SimbolX* is extensively discussed in a companion paper (Della Ceca et al. 2007).

The expected number counts in the 10–40 keV band (Figure 3) are obtained extrapolating the spectral energy and absorption distributions of the Gilli et al (2007) synthesis model. The hard X–ray source surface density keeps a steep (close to Euclidean) slope down to the expected sensitivity limits of *SimbolX* observations ($\sim$ 10^{-14} erg cm^{-2} s^{-1}) in the 10–40 keV band. More specifically, a few hundreds CT AGN per square degree are predicted at the limits of a deep survey. By scaling the estimated space densities for the *SimbolX* field of view, our estimates translate in a few up to about ten CT AGN in a deep (1 Msec) pointing. Taking into account the off-axis sensitivity and the fact that the faintest sources will be detected with a number of counts insufficient for X–ray spectral analysis, the search for the most obscured AGN cannot be pursued only with deep pointings. A comprehensive understanding of the physics and evolution of distant and obscured AGN, as well as of different classes of cosmic sources, requires a close synergy between deep and wide area surveys. Indeed, the evolution of X–ray selected AGN was determined by a large number of surveys which have extensively sampled the solid angle vs. depth discovery space (see Fig. 1 of Brandt & Hasinger 2005). A possible strategy is discussed in the Fiore et al (2007b) companion paper.

The predicted redshift distribution of CT AGN at three different limiting fluxes is reported in Figure 4. Not surprisingly, the peak moves to higher redshifts as the sensitivity increases. A pronounced high redshift ($z \sim 0.5$–2) tail starts to develop at fluxes around 10^{-13} erg cm^{-2} s^{-1} and lower. As far as the search for obscured accretion at high redshift is concerned, the best trade–off would be to maximize the area covered close these fluxes.

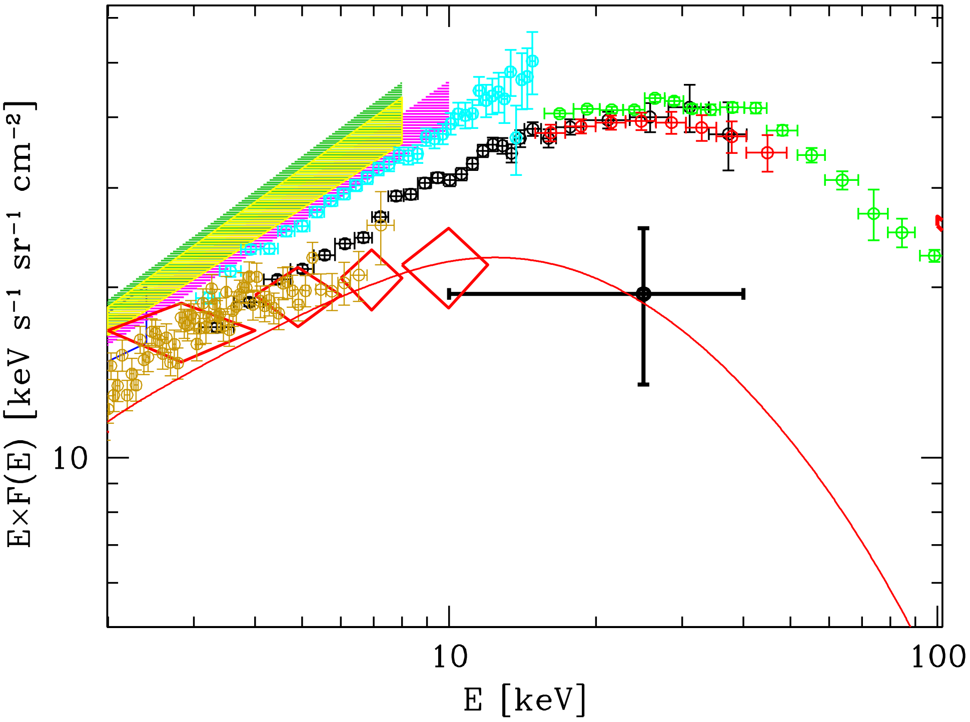

Fig. 5. The fraction of the 10–40 keV XRB which will be resolved by a deep 1 Ms *SimbolX* pointing (point with error bars). The XRB measurements below 10 keV are from *Chandra* and XMM–*Newton* as well as the resolved fraction in deep fields (gold points and red squares). while the points extending up to ~ 15 keV are from RXTE (Revnivtsev et al. 2003). At high energy, the HEAO1–A4 spectrum (Gruber et al. 1999; green points) is reported along with the recent *BeppoSAX* PDS observations (Frontera et al. 2007; red points). The red solid line represents an AGN synthesis model (see Comastri 2004a) which reproduces the observed level of the resolved XRB below 10 keV.

4. Conclusions

Deep *SimbolX* surveys will be able to resolve about half of the XRB in the 10–40 keV energy range (Figure 5). This achievement will represents a major step forward. In fact, at present, less than a few percent of the XRB in that band is resolved. A comparison with an extrapolation of an AGN synthesis model (Comastri 2004a) tuned to reproduce the resolved background below 10 keV is reported in Fig 5. Although the level of the XRB predicted to be resolved by `SimboX` is close to the model extrapolation, it will be possible, with the present configuration, to probe the entire range of absorption of the XRB sources. Several “new”

CT AGN (see Fiore et al. 2007b), which are undetected even in the deepest XMM–*Newton* and *Chandra* surveys (Fig. 1), will be revealed. Moreover, given that the fraction of CT AGN is expected to steeply increase just below $\sim 10^{-14}$ erg cm^{-2} s^{-1}, it would be highly rewarding to push the limiting flux to somewhat lower fluxes. It is worth remarking that the resolution of a significant fraction of the XRB has always brought significant advances in our understanding of AGN evolution. *ROSAT* deep surveys showed that luminous unobscured quasars at high redshift ($z \sim 1.5$–2) were responsible for most of the soft (around 1 keV) XRB (Lehmann et al. 2001). Later on, thanks to *Chandra* and XMM–*Newton* deep surveys, it was demonstrated that the bulk of the XRB at least up to 5–6 keV is originating in relatively low luminosity sources, most of them obscured, at $z \sim 1$ (Brandt & Hasinger 2005). While we expect to uncover the so far elusive population of CT AGN up to relatively high redshift, it may well be possible that the content of the X–ray sky above ~ 10 keV is different from what predicted. We look forward to new unexpected findings which could be obtained by pushing imaging observations in the so far unexplored hard X–ray band.

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