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Obscured Active Galactic Nuclei and Obscured Accretion

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Abstract

Most of the local active galactic nucleus (AGN) population is obscured and much of the X-ray background originates in obscured AGNs. The contribution of obscured accretion to the growth of massive black holes is discussed here. The recent identification of significant samples of the X-ray sources that dominate the X-ray background intensity has shown a redshift peak at 0.7–0.8, rather than the redshift of 2 found for bright optical quasars. Obscured accretion has a faster evolution than unobscured accretion. The lower redshift and luminosity of most obscured AGNs mean that although they dominate the absorption-corrected intensity of the X-ray background by a factor of about 3 over unobscured objects, they make only an equal contribution to the local mass density in black holes. Obscured and unobscured AGNs together contribute about $4 \times 10^5\,M_\odot\,\mathrm{Mpc}^{-3}$. Type 2 quasars and Compton-thick objects may give another $10^5\,M_\odot\,\mathrm{Mpc}^{-3}$, but no more unless direct determinations from the $M_\bullet - \sigma$ relation seriously underestimate the local black hole mass density, or unless most massive black holes are rapidly spinning (so having a higher radiative efficiency than the 10% assumed above). Obscured accretion probably dominates the growth of black holes with masses below a few times $10^8\,M_\odot$, whereas optically bright quasars dominate at higher masses. The luminosity absorbed by the dusty gas in obscured AGNs is reradiated in the mid-infrared and far-infrared bands. The contribution of AGNs drops from about 20% of the mid-infrared background to just a few percent of the far-infrared background.

1.1 Introduction

The X-ray background (XRB) is dominated by the emission from active galactic nuclei (AGNs). This enables a census to be made of the radiative growth of massive black holes. The infrared and sub-mm backgrounds (hereafter IRB) are dominated by emission from star formation. Together the backgrounds provide measures of the evolution of black holes and galaxies.

The situation is complicated, however, by the fact that the bulk of the XRB is due to highly obscured AGNs. This was first predicted by Setti & Woltjer (1989), elaborated on by Madau, Ghisellini, & Fabian (1994), Comastri et al. (1995), Gilli, Risaliti, & Salvati (1999), and others, and demonstrated by direct resolving of the XRB with *Chandra* by Mushotzky et al. (2000), Brandt et al. (2001), Giacconi et al. (2001), and Rosati et al. (2002), and with *XMM-Newton* by Hasinger et al. (2001). Simple pre-*Chandra*/*XMM-Newton* estimates (Fabian & Iwasawa 1999), based on a comparison of the intensity of the 2–10 keV XRB, which is dominated by obscured AGNs with that of the soft XRB below 1 keV, which is dominated by unobscured quasars, indicated that most accretion may be obscured (i.e., occurring behind a line-of-sight column density exceeding $N_{\rm H} = 10^{22}\,{\rm cm}^{-2}$). This assumed that the redshift evolution of obscured and unobscured objects is the same. Recent *Chandra* and *XMM-Newton* data, however, show that this is not the case.

That obscured AGNs are common and need to be included in estimates of accretion power is obvious from the fact that the three nearest AGNs with intrinsic X-ray luminosities above $10^{40}\,{\rm erg\,s^{-1}}$ (NGC 4945, the Circinus galaxy, and Centaurus A) are all highly obscured with $N_{\rm H} > 10^{23}\,{\rm cm}^{-2}$ (Matt et al. 2000). Two (NGC 4945 and Circinus) are even Compton-thick with $N_{\rm H} > 1.5 \times 10^{24}\,{\rm cm}^{-2}$. This situation has only been slowly appreciated, perhaps due to NGC 4945 appearing as a starburst galaxy at all non-X-ray wavelengths and to the Circinus galaxy lying close to the Galactic plane.

Nevertheless, it has long been known that the number density of Seyfert 2 galaxies, where the active nucleus is obscured, exceeds that of Seyfert 1 galaxies, although selection effects complicate making a comparison at a fixed bolometric AGN luminosity. Geometrical unification has often been assumed, with Seyfert 2s being Seyfert 1s viewed through a surrounding torus for which the opening angle is about 60°. More recent X-ray studies, particularly with *BeppoSAX*, have been showing that this picture probably applies to only a subset of AGNs.

Here, the evidence for distant obscured AGNs is reviewed and their contribution to the XRB examined. The total energy density due to accretion is then deduced from the spectrum of the XRB, and via Sołtan's (1982) method converted into a local black hole mass density due to radiative growth. Comparison with the locally determined black hole mass density from quiescent galaxies shows that there could be a problem in terms of excessive growth, unless (1) the radiative efficiency of most accretion is higher than that for a standard accretion disk around a Schwarzschild (non-spinning) black hole (e.g., Elvis, Risaliti, & Zamorani 2002), (2) the bolometric correction is lower, or (3) the redshift distribution peaks at $z < 2$.

The problem is illustrated well by the recent estimate for the growth of bright optical quasars by Yu & Tremaine (2002), which allows for little obscured accretion, particularly in massive objects. It is shown here that if their estimate for the local black hole mass density from direct measurements of nearby quiescent galaxies can be revised upward by a factor of 1.5–2, to be in agreement with that of Ferrarese (2002), and factors due to (2) and (3) above are also revised in accord with recent XRB studies, then agreement can be found for a radiative efficiency of 0.1. About equal amounts of the local black hole mass density are then due to obscured and to unobscured accretion.

The X-ray and UV energy absorbed in the obscuring gas is reradiated in the far-infrared and sub-mm bands. A few percent of the energy density in these backgrounds is due to accretion, but most is due to star formation.

1.2 Obscured AGNs

Most Seyfert 2 galaxies contain obscured AGNs, with 2–10 keV X-ray luminosities typically up to about $10^{44}\,{\rm erg\,s^{-1}}$. In studies of local, optically selected Seyfert 2s with *BeppoSAX*, Maiolino et al. (1998) have shown that about one-half are Compton thick. In general this half are the classical, optical Seyfert 2 galaxies and the other, Compton-thin, half corresponds to the optical intermediate classes of Seyfert 1.8 and 1.9 (Risaliti, Maiolino, & Salvati 1999).

Distant obscured AGNs (redshift $z > 0.3$) are now being found in large numbers by X-ray observations with *Chandra* and *XMM-Newton* (Mushotzky et al. 2000; Alexander et al. 2001; Barger et al. 2001; Brandt et al. 2001; Crawford et al. 2001; Giacconi et al. 2001; Hasinger et al. 2001; Rosati et al. 2002). Most of the serendipitous sources found in an X-ray image above 1 keV made with these telescopes are obscured. Source variability in many cases makes an AGN identification unambiguous. The determination of column densities requires that the source is identified and its redshift known. Where significant samples are available (e.g., Alexander et al. 2001; Barger et al. 2002; Mainieri et al. 2002), more than two-thirds are Compton thin with $10^{21} < N_{\rm H} < 10^{23}\,{\rm cm^{-2}}$; most of the remainder are unobscured. The absorption-corrected, 2–10 keV luminosity of the obscured objects is typically in the range of $10^{42} - 10^{44}\,{\rm erg\,s^{-1}}$. Only a handful of obscured AGNs have yet been found with 2–10 keV luminosities exceeding the level of $\sim 3 \times 10^{44}\,{\rm erg\,s^{-1}}$, corresponding to a quasar [Crawford et al. 2002; Norman et al. 2002; Stern et al. 2002; Wilman et al. 2003; Mainieri et al. 2002; the last authors define a quasar as $L(0.5-10\,{\rm keV}) > 10^{44}\,{\rm erg\,s^{-1}}$].

Note that there is not complete agreement between optical and X-ray classification of some of the Compton-thin AGNs. Some show X-ray absorption but little optical extinction (Maiolino et al. 2001), and vice versa, and some X-ray obscured objects show no detectable narrow-line region at optical or infrared wavelengths (e.g., Comastri et al. 2002; Gandhi, Crawford, & Fabian 2002). When there is a large covering fraction of the nucleus by dusty gas, there need be little or no optical/UV narrow-line region. The terms Type 2 and Type 1 when applied to X-ray sources are commonly referring to whether there is absorption or not, irrespective of the optical spectrum.

Another class of obscured AGNs are the powerful radio galaxies. These have large column densities (probably in a torus perpendicular to the radio axis) of $\sim 10^{23}\,{\rm cm^{-2}}$ or more (e.g., Cygnus A, Ueno et al 1994; 3C 294 at $z = 1.786$, Fabian et al. 2003; B2 0902 at $z = 3.2$, Fabian, Crawford, & Iwasawa 2002; see Fig. 1.1). These are sufficiently rare that their contribution to the XRB intensity is negligible.

Source counts from deep X-ray surveys show that most of the XRB is now resolved (Fig. 1.2), with a major uncertainty being the actual intensity of the XRB measured by wide-beam instruments. The counts flatten below a flux of about $10^{-14}\,{\rm erg\,cm^{-2}\,s^{-1}}$ in the 2–10 keV band, above which more than 60% of the XRB intensity originates. At much lower fluxes more and more starburst galaxies are detected (Alexander et al. 2002a; Hornschemeier et al. 2002). They make a negligible contribution to the total XRB intensity (Brandt et al. 2002).

1.3 X-ray Constraints on the Radiative Growth of Massive Black Holes

The basic method for deducing the local density in black holes due to growth by accretion that emitted measurable radiation is that originally due to Sołtan (1982). From

$$E = \eta M c^2,$$

where η is the efficiency with which mass is turned into radiation ($\eta = 0.06$ for a standard thin disk around a non-spinning black hole; a typical assumed value for an accreting black hole is 0.1), we find

$$\varepsilon_{\rm rad}(1+z) = \eta \rho_\bullet c^2.$$

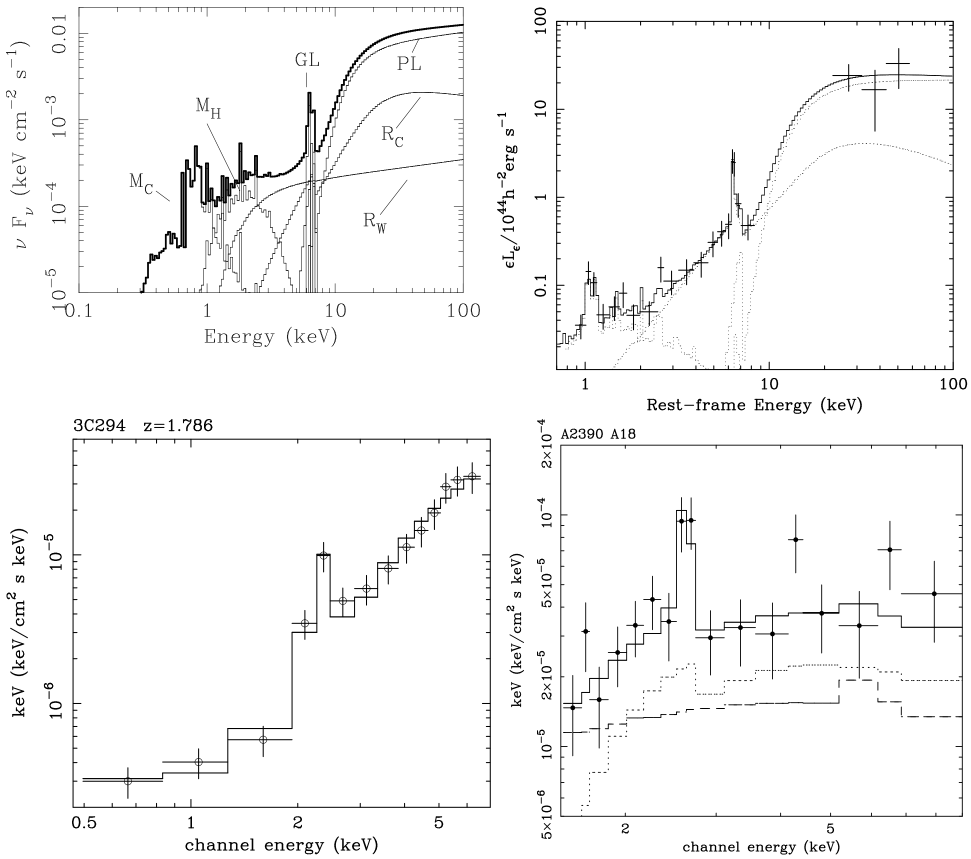

Fig. 1.1. Examples of the νF_ν X-ray spectra of obscured AGNs. *Top left:* Model spectrum that fits the *BeppoSAX* data on NGC 6240 (Vignati et al. 1999). The heavily absorbed power law (PL) and Gaussian line (GL) emission of iron are shown, with hot and cold reflection and emission components. *Top right:* IRAS 09104+4109 has a 2–10 keV luminosity of $\sim 10^{46}$ erg s^{-1} behind a column density of 3×10^{24} cm^{-2} (Franceschini et al. 2000; Iwasawa, Fabian, & Ettori 2001). *Lower left:* is 3C 294, a powerful radio galaxy at $z = 1.786$ with an X-ray luminosity of $\sim 10^{45}$ erg s^{-1} and a column density of 8×10^{23} cm^{-2}. *Lower right:* is an *XMM-Newton* spectrum (Gandhi 2002) of serendipitous source A18 at $z = 1.467$ in the field of the rich galaxy cluster A2390 that has a 2–10 keV luminosity of $\sim 10^{45}$ erg s^{-1} and $N_{\rm H} \approx 2 \times 10^{23}$ cm^{-2}. The level of contaminating cluster emission to the spectrum is indicated by the dashed line.

$\varepsilon_{\rm rad}$ is the observed energy density in that radiation now, $\rho_\bullet$ is the mean mass density added to the black holes, and z is the mean redshift of the population. Note that the result is independent of the assumed cosmology and requires only that the redshift distribution of the sources be known.

$\varepsilon_{\rm rad}$ is determined from either the images and spectra of the sources themselves or from the background radiation they produce (Fig. 1.3). A bolometric correction κ from the observed band to the total luminosity is required. $\rho_\bullet$ is either determined from the above equation, giving $\rho_\bullet^{\rm AGN}$, or is measured from local galaxies $\rho_\bullet^{\rm direct}$ using the black hole mass to galaxy

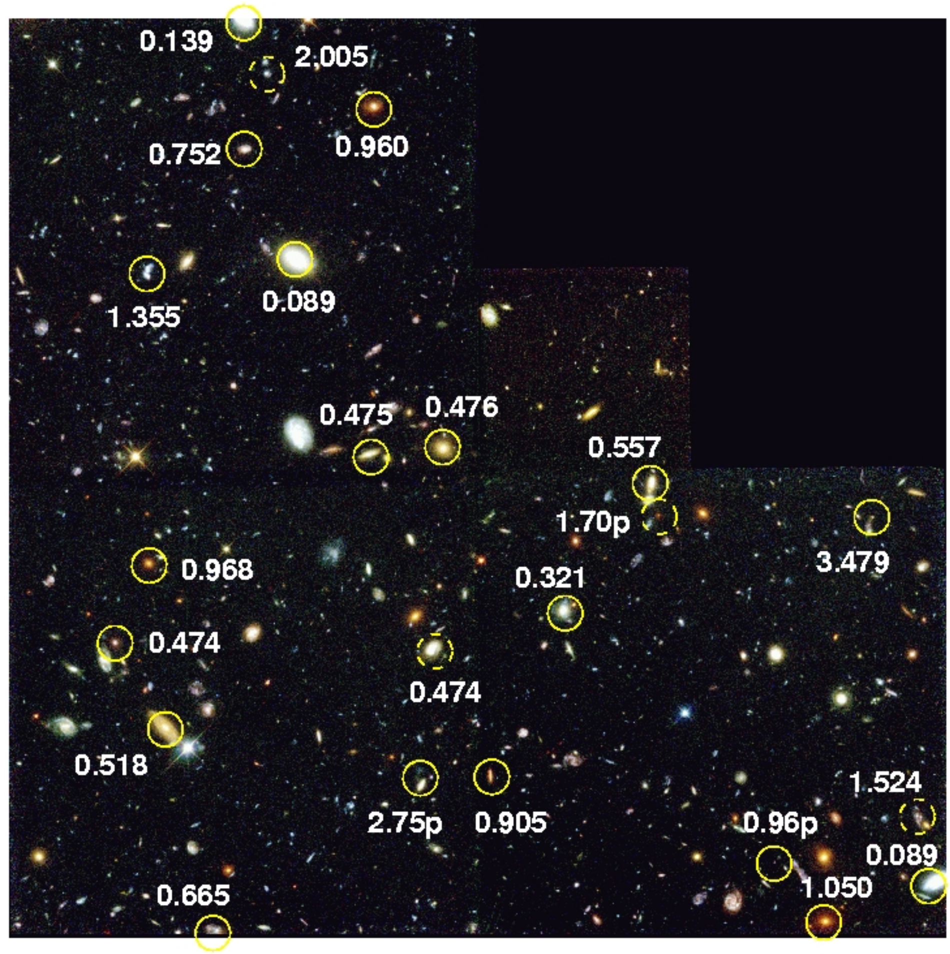

Fig. 1.2. *Chandra* sources from a 2 Ms exposure of the HDF-N superposed on a *Hubble Space Telescope* optical image (kindly provided by W. N. Brandt; see, e.g., Brandt et al. 2002). Source redshifts are indicated ("p" means photometric).

bulge velocity dispersion ($M_\bullet - \sigma$) relation (from Ferrarese & Merritt 2000 or Gebhardt et al. 2000), the less well-known velocity dispersion function for galaxies or a proxy for it, and the Hubble constant (in order to determine volumes). The variables are η, z, H_0, and κ.

Various attempts have recently been made to compare the values of $\rho_\bullet^{\rm AGN}$ and $\rho_\bullet^{\rm direct}$. In units of $10^5\,M_\odot$ Mpc^{-3} for $\rho_\bullet$, and adopting $H_0 = 75\,{\rm km\,s^{-1}}$ Mpc^{-1},, Ferrarese (2002) obtained $\rho_\bullet^{\rm direct} = 4-5$, whereas Yu & Tremaine (2002) find $\rho_\bullet^{\rm direct} = 3 \pm 0.5$. Using bright optical quasars only and $\eta = 0.1$, Yu & Tremaine (2002) obtain $\rho_\bullet^{\rm AGN} = 2.2$. They consider that

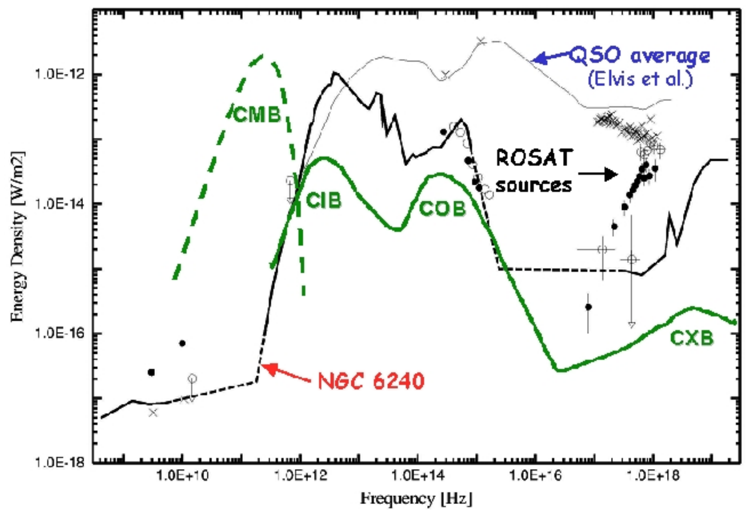

Fig. 1.3. Overview of the intensity of the background radiations (CIB=IRB, COB, and CXB=XRB) together with schematic spectral energy distributions of a nearby obscured AGN, NGC 6240, and of the average unobscured quasar. (Kindly provided by G. Hasinger; see Hasinger 2003.)

this agrees well enough with their value of $\rho_\bullet^{\rm direct}$ that there is no room for significant growth by obscured accretion. In other words, they find that the mean density in local black holes can be wholly due to radiatively efficient accretion in an optically bright (and unobscured) quasar phase.

The result of Yu & Tremaine (2002) contrasts with that obtained from the XRB by Fabian & Iwasawa (1999). In order to use the XRB some correction has to be made for absorption. This was accomplished by noting that the mean spectra of unobscured quasars is a power law with an energy index of unity in the 1–20 keV band. Therefore the minimum correction is that required to push the XRB spectrum, which is a power law of index 0.4 in the 2–10 keV band, up to an index of one, matching at the EI_E peak in the XRB (Fig. 1.4). This process emphasizes the importance of obscured accretion since the unobscured objects dominate below 1 keV, which is a level 4 times below that of the resultant absorption-corrected minimum spectrum. In the absorption-corrected sense there is 3 times more energy density in the obscured objects than in the unobscured ones. This could imply that obscured accretion dominates the growth of massive black holes, contrary to the conclusion of Yu & Tremaine (2002).

The value for $\rho_\bullet^{\rm AGN}$ obtained in this way from the XRB is 6–9 (Fabian & Iwasawa 1999)

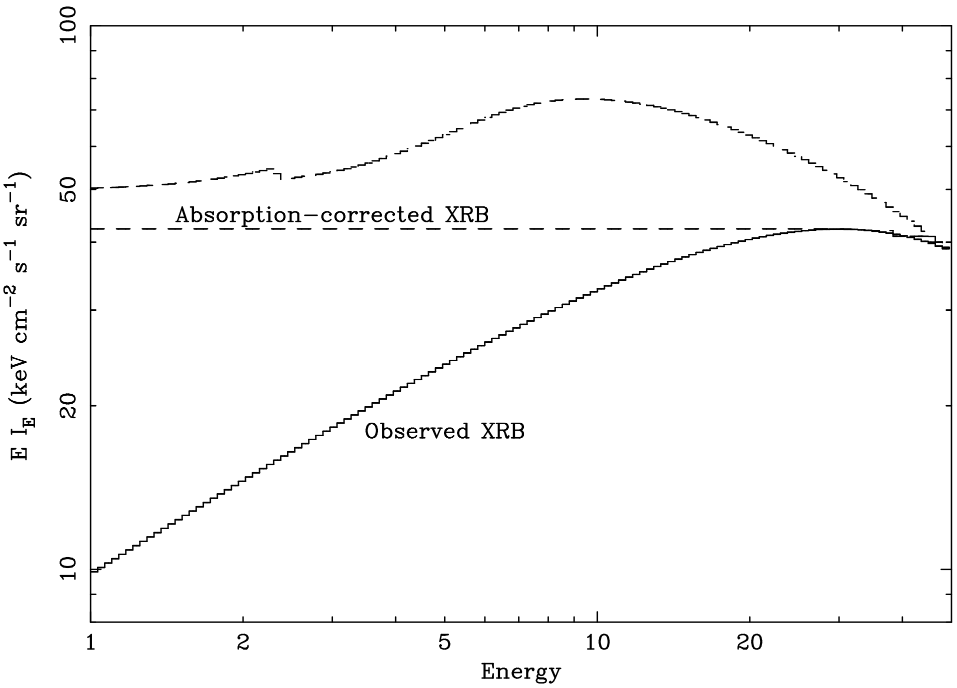

Fig. 1.4. Observed EI_E spectrum of the XRB. The spectrum of a typical unobscured AGN is a horizontal line (energy index of unity). The minimum correction to the XRB is the horizontal line (dashed) that matches the XRB spectral peak. Disk reflection (indicated by top line) could increase this estimate. (Adapted from Fabian & Iwasawa 1999.)

and 7.5–16.8 (Elvis et al. 2002). The bolometric correction was that relevant for quasars (from the work of Elvis et al. 1994), $\kappa_X = 30-50$, $\eta = 0.1$, and $z = 2$.

The XRB value for $\rho_\bullet^{\rm AGN}$ was below the value of $\rho_\bullet^{\rm direct}$ in 1999, when the local quiescent black holes masses (Magorrian et al. 1998) were about 3–5 times higher than are found now. If current values of $\rho_\bullet^{\rm direct} = 3-5$ are used then it might seem that there is a problem. Elvis et al. (2002) have argued that it implies $\eta > 0.15$ and therefore that all massive black holes are spinning rapidly. This could cause some problems with merger-based galaxy and black hole growth schemes (Hughes & Blandford 2003).

High radiative efficiency also means that the mass-doubling time (assuming that the sources are Eddington limited) exceeds 60 Myr, which could cause problems in growing massive objects from much smaller seed black holes. Perhaps, however, the plunge region within the innermost stable orbit is being tapped by the action of magnetic fields in the disk, thus yielding a higher efficiency without spin (Gammie 1999; Krolik 1999; Agol & Krolik 2000). Another possibility is that many black holes are ejected in mergers, although the required large fraction seems doubtful.

1.4 The Redshift Distribution of Obscured Sources

The above discussion using the XRB assumed that the evolution of the obscured AGNs is the same as that of unobscured quasars, which peaks at $z \approx 2$. Recent results from source identifications (Alexander et al. 2001; Barger et al. 2002; Mainieri et al. 2002; Rosati et al. 2002; Hasinger 2003) have, however, shown that the obscured objects peak at a lower redshift of about $z \approx 0.7$. The identification of a complete sample has not yet been carried out, but, as noted by the above authors, the results from partial samples already show that there are many more sources found below redshift 1 than would be expected from any model based on quasar evolution. This is a very important result.

The immediate effect on the problem in the last section is the drop in z and also of κ. Most, but not all, of the X-ray sources now have absorption-corrected, 2–10 keV luminosities below $10^{44}\,\mathrm{erg\,s^{-1}}$ and are strictly not quasars. Although this luminosity distinction is somewhat arbitrary, the key point is that Seyferts have a 2–10 keV bolometric correction factor κ of 10–20, rather than 30–50 typical of quasars.

It is difficult to determine κ for Seyfert galaxies since the dominant thermal disk emission lies in the rest-frame EUV. Moreover, the low redshift of most of the well-studied ones means that the disk emission, unlike that in quasars, is not shifted into easily observable bands. I have used results from *ASTRO-1, EUVE*, and *FUSE* and find that $\kappa = 12 - 18$, using data on Mrk 335 (Zheng et al. 1995), NGC 3783, (Krolik & Kriss 2001) and NGC 5548 (Magdziarz et al. 1998).

Together, the joint effects of the lower redshift peak and lower bolometric correction reduce the value of $\rho_\bullet^{\mathrm{AGN}}$ for obscured sources by a factor of up to 3. The net result is that optically bright (unobscured) Type 1 quasars give $\rho_\bullet^{\mathrm{AGN}} \approx 2$, and obscured, Type 2 AGNs now give a similar value, totaling about 4, again in units of $10^5\,M_\odot\,\mathrm{Mpc^{-3}}$. This then agrees well with the values from local studies of $\rho_\bullet^{\mathrm{direct}}$.

[Note that the change in κ with luminosity means that a lower limit for the intrinsic 2–10 keV luminosity of quasars is difficult to determine at the present time. The origin of the optical definition is somewhat arbitrary. The properties of objects appear to change around $L(2-10\,\mathrm{keV}) = 3 \times 10^{44}\,\mathrm{erg\,s^{-1}}$, which is the limit used here.]

1.4.1 Some Implications for Obscured Sources

The discovery that obscured AGNs follow a much steeper evolution than optically bright quasars means that they are a different population. The lack of any unobscured counterpart implies that the obscuration covers a large part of the sky as seen by the source itself. There can be no simple torus or geometrical unification picture for these objects. The large covering fraction of absorbing material may explain why there is little in the way of an optical/UV narrow-line region seen for some of the identified X-ray sources (particularly if the absorbing gas is dusty; see, e.g., Gandhi et al. 2002).

Interestingly, there is another population of objects that does evolve in a similar way to the obscured X-ray population, namely dust-enshrouded starburst galaxies. Chary & Elbaz (2001) show that distant luminous and ultraluminous infrared galaxies seen with *ISO* evolve very rapidly to $z \approx 0.8$. There is some overlap between *ISO* and *Chandra/XMM-Newton* X-ray sources in deep images (Wilman, Fabian, & Gandhi 2000; Alexander et al. 2002a; Fadda et al. 2002), and it is plausible that a subset ($\sim 20\%$) of the dusty starburst galaxies are X-ray detectable Type 2 AGNs. The inner parts of the starburst itself may, through winds and supernovae, be responsible for inflating the absorbing gas so that it has a large covering fraction as seen from the center (Fabian et al. 1998; Wada & Norman 2002).

It is not yet clear from identification work quite what fraction of the X-ray sources dominating the XRB are dusty starbursts. Very (and extremely) red objects are reasonably common counterparts of the *Chandra* serendipitous X-ray sources (Alexander et al. 2002b); yet, they are a heterogeneous class (e.g., Smail et al. 2002) that includes both dusty starbursts and old early-type galaxies.

A further point is that Seyfert galaxies typically operate at about 10% of the Eddington limit. If the XRB objects are similar, then from the inferred luminosities, the black hole masses are in the range of $10^6 - 3 \times 10^8 \, M_\odot$, below that generally implied for quasars ($\sim 10^8$ to $> 10^9 \, M_\odot$). Thus, unobscured accretion seen in optically bright quasars may make most of the black holes above $3 \times 10^8 \, M_\odot$ and obscured accretion those at lower masses.

What we do not know is whether quasars passed though an obscured phase early on (see, e.g., Fabian 1999), perhaps when their masses were $10^8 \, M_\odot$ or less. As discussed earlier, there are some Type 2 quasars being found in deep X-ray surveys, but not in large numbers. Also there is little evidence yet for a population of distant Compton-thick objects ($N_{\rm H} > 1.5 \times 10^{24} \, {\rm cm}^{-2}$). Of course, these are likely to be difficult to identify spectroscopically. Wilman (2002) has provided arguments against any significant Compton-thick population. There may still be a Compton-thick population to fill in the νI_ν peak in the XRB, but it could well be at *low* redshift ($z < 0.5$). It requires a instruments like the *Swift* BAT and EXIST to uncover this population in detail.

Unless the estimates for $\rho_\bullet^{\rm direct}$ are revised upward in the future, there is little room for $\rho_\bullet^{\rm AGN}$ in terms of Type 2 quasars or Compton-thick objects, with a limit being $\lesssim 1 \times 10^5 \, M_\odot \, {\rm Mpc}^{-3}$.

1.5 Models for the Evolution of the XRB

The newly discovered redshift distribution (Fig. 1.5) for the obscured AGNs has prompted some new synthesis models for the XRB in which the obscured objects have a steeper evolution than the unobscured ones (Franceschini, Braito, & Fadda 2002; Gandhi & Fabian 2003).

A difficulty in making such models is the lack of any X-ray luminosity functions for Type 2 AGNs. Gandhi & Fabian (2003) used the $15 \, \mu m$ *ISO/IRAS* infrared luminosity function of Xu et al. (1998). Spectral energy distributions suggest that $L(2-10 \, {\rm keV}) \approx L(15 \, \mu m)$, and using that we normalize to the local 2–10 keV X-ray luminosity function of Piccinotti et al. (1982). A power-law distribution in column density is assumed. A reasonable fit to the spectrum of the XRB is obtained if the emissivity due to Type 2 AGNs evolves as $(1+z)^4$ out to $z = 0.7$ and then remains flat to higher redshifts (at least to $z = 1.5$). $\rho_\bullet^{\rm AGN}$ from this model is in accord with the values in § 1.4. The model can also reproduce well the X-ray source counts, provided that some density evolution is included.

Gandhi & Fabian (2003) tested whether the iron emission line produced by fluorescence in the absorption process is detectable in the spectrum (Matt & Fabian 1994) and found that it should give a small peak in the XRB spectrum over the 3–4 keV band. Interestingly, there is a bump in the *ASCA* spectrum of the XRB at that point (Gendreau 1996), although it is not statistically significant. *XMM-Newton* should do better and could thereby confirm, in an integral manner, the redshift distribution of the component sources of the XRB.

1.6 Some Comments on Fueling and Obscuration

Rapid fueling of a black hole requires a plentiful gas supply, which, if distributed, is likely to coincide with a starburst. Star formation can churn the gas up through winds and supernovae and make the covering fraction of cold absorbing gas large (Fabian et al. 1998;

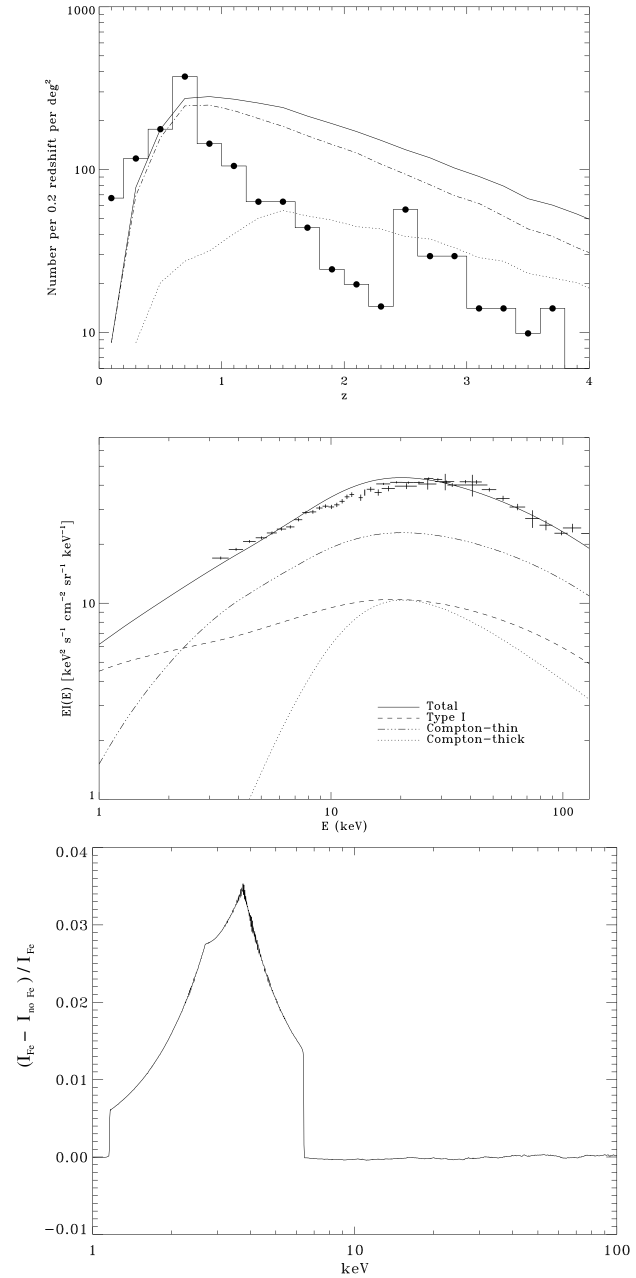

Fig. 1.5. *Top:* The observed serendipitous X-ray source distribution with redshift (Hasinger 2003), with the predictions from the model of Gandhi & Fabian (2003). Type 1 and 2 sources are the dotted and dashed lines, respectively. Source identifications are not complete, so more sources may fill in above $z = 1$. The numbers found below $z = 1$ already far exceed the predictions of the model by Gilli, Salvati, & Hasinger (2001). *Middle:* Matching the model to the XRB spectrum. It is not clear that a significant Compton-thick population is required. *Bottom:* The spectral residuals expected due to the presence of iron fluorescence emission in the sources.

Wada & Norman 2002). The coincidence between the *ISO* dusty starburst population and the obscured Type 2 AGNs should not then be too surprising. What has yet to be explained is why there is such a dramatic and rapid decrease in this activity since a redshift of 0.7 [proportional to $(1+z)^4$], over the last 5 Gyr.

The question is then raised of why quasars are unobscured. It could be the high luminosity that drives away all nearby gas. Perhaps, as indicated above, the optically bright quasars are of higher mass (above $10^8\,M_\odot$) than the typical Type 2 AGNs, or they are closer to the Eddington limit. Powerful radio galaxies, which have very luminous and presumably massive nuclei do, however, provide counter examples; although the radio outbursts may all be young ($< 10^7$ yr) and due to even higher mass black holes, they could be well sub-Eddington. A significant population of Type 2 quasars may yet emerge from the complete identification of large, deep X-ray samples.

The Eddington limit for a central black hole will always be significantly less than the Eddington limit for the galaxy bulge. That assumes, however, only radiation pressure through electron scattering. A nuclear wind or radiation pressure acting on dusty cold gas (which has a much larger absorption cross section than electron scattering) can make the relevant limiting luminosity for the galaxy bulge more than the Eddington limit for the nucleus itself (Fabian 1999; Fabian, Wilman, & Crawford 2002). Consequently an obscured nucleus can increase in luminosity and then blow away the obscuring gas and its own fuel supply (see also Silk & Rees 1998). This can help relate the final black hole mass to the mass and potential well of its host bulge. The tight $M_\bullet-\sigma$ relation found locally (Ferrarese & Merritt 2000; Gebhardt et al. 2000) does, however, suggest that a single mechanism is acting throughout the entire mass range.

1.7 Contributions to the Far-infrared and Sub-mm Backgrounds

The X-ray and UV luminosity absorbed in dusty Type 2 AGNs is re-emitted in the far-infrared. Much work remains to be done, but it is plausibly reradiated at about $100\,\mu m$ in the rest frame. From an *ISO* study Fadda et al. (2002; see also Alexander et al. 2002a) find that AGNs contribute about 17% of the infrared background at $15\,\mu m$. In a νF_ν sense this contribution will rise by about a factor of 2 out to a few $100\,\mu m$ (see, e.g., Crawford et al. 2002), whereas the IRB rises by about a factor of 10, such that the total contribution of AGNs to the whole IRB will be 3%–4%.

The AGN fractional contribution to the IRB is highest at the shorter wavelengths and drops at the longer wavelengths. Only if there is some as yet unidentified population of Compton-thick objects can this fraction be much larger and important at long wavelengths, in the sub-mm. The margin for such a population, given the agreement between the predicted and observed local black hole densities, is small. The *Chandra* medium-deep detection rate for serendipitous SCUBA sources is low (Bautz et al. 2000; Fabian et al. 2000; Hornschemeier et al. 2000; Barger et al. 2001; Almaini et al. 2003). In the 2 Ms CDF-N, Alexander et al (2003) detect 7 out of 10 bright SCUBA sources and classify 5 as AGNs. They find luminosities that are Seyfert-like and conclude that the sub-mm emission is dominated by starbursts.

Fabian & Iwasawa (1999) determined the IRB contribution to be 2 nW m^{-2} sr^{-1}, while Elvis et al. (2002) found 3.6–8 nW m^{-2} sr^{-1}; these values are to be compared with a total integrated intensity of 40 nW m^{-2} sr^{-1} for the IRB. Revising the bolometric correction factor

κ down to 15 then makes these predictions range between $\sim 1-3$ nW m^{-2} sr^{-1}. In other words, AGNs, principally obscured ones, contribute a few percent to the IRB.

Our understanding of the source composition of the IRB will receive an enormous boost from the imminent launch and operation of *SIRTF*.

1.8 Summary

The XRB and X-ray source populations show that there is much obscured accretion in the Universe. This creates a black hole growth crisis if the Yu & Tremaine (2002) analysis stands, unless AGNs are all particularly radiatively efficient ($\eta > 0.15$), perhaps with rapidly spinning black holes (Elvis et al. 2002). However, if the mean local density of black holes is between 4 and $5 \times 10^5 M_\odot$ Mpc^{-3}, as deduced by Ferrarese (2002), then there is consistency for $\eta \approx 0.1$ between the density predicted for both obscured and unobscured AGNs using the XRB. They contribute roughly equal amounts to the local mass density of black holes, with obscured accretion contributing most for black holes with masses below about $3 \times 10^8 M_\odot$ and unobscured quasars contributing most above that value.

The overall picture is that the most massive black holes (above the break in the present mass function at about $3 \times 10^8 M_\odot$) are built earlier (by $z \approx 1.5$) than the lower mass ones below the break (which are built by $z \approx 0.7$). This means that the lower mass ones take about twice as long to assemble. As the Universe ages, the black holes that remain active are becoming increasingly obscured.

The fraction of the mass density from obscured accretion is lower than estimated earlier because the sources evolve differently to quasars, peaking at $z = 0.7$ rather than 2. Also their luminosities are in the range of Seyferts which locally have a lower bolometric correction. This makes the contribution of obscured accretion to the mass density in black holes at about 50%. Uncertainties due to the level of spin and efficiency for both obscured and unobscured AGNs remain, and to the exact evolution of complete samples of the X-ray sources. Also there could be populations of Type 2 quasars and distant Compton-thick sources yet to be discovered. Such populations can only make a significant contribution if either optically bright quasars are found to be rapidly spinning or the local mass density in black holes has been seriously underestimated.

The covering fraction of the obscured Type 2 AGNs which dominate the XRB must be very high, or the unobscured fraction would already have been noticed. The obscuring material probably forms part of a compact, inner dusty starburst in the host galaxy. The absorbed luminosity is reradiated in the mid-infrared to far-infrared bands and contributes a few per cent of the IRB.

Complete Type 2 AGNs samples at all redshifts are urgently needed. Obscured accretion, which is best studied at X-ray wavelengths, must be studied in order for the growth and evolution of massive black holes to be understood.

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References

Agol, E., & Krolik, J. H. 2000, ApJ, 528, 161
Alexander, D. M., et al. 2003, AJ, 125, 383

Alexander, D. M., Aussel, H., Bauer, F. E., Brandt, W. N., Hornschemeier, A. E., Vignali, C., Garmire, G. P., & Schneider, D. P. 2002a, ApJ, 568, L85
Alexander, D. M., Brandt, W. N., Hornschemeier, A. E., Garmire, G. P., Schneider, D. P., & Bauer, F. E. 2001, AJ, 122, 2156
Alexander, D. M., Vignali, C., Bauer, F. E., Brandt, W. N., Hornschemeier, A. E., Garmire, G. P., & Schneider, D. P. 2002b, AJ, 123, 1149
Almaini, O., et al. 2003, MNRAS, 338, 303
Barger, A. J., Cowie, L. L., Brandt, W. N., Capak, P., Garmire, G. P., Hornschemeier, A. E., Steffen, A. T., & Wehner, E. H. 2002, AJ, 124, 1838
Barger, A. J., Cowie, L. L., Mushotzky, R. F., & Richards, E. A. 2001, AJ, 121, 662
Bautz, M. W., Malm, M. R., Baganoff, F. K., Ricker, G. R., Canizares, C. R., Brandt, W. N., Hornschemeier, A. E., & Garmire, G. P. 2000, ApJ, 543, L119
Brandt, W. N., et al. 2001, AJ, 122, 1
Brandt, W. N., Alexander, D. M., Bauer, F. E., & Hornschemeier, A. E. 2002, Phil. Trans. Roy. Soc., 360, 2057
Chary, R., & Elbaz, D. 2001, ApJ, 556, 562
Comastri, A., et al. 2002, ApJ, 571, 771
Comastri, A., Setti, G., Zamorani, G., & Hasinger, G. 1995, A&A, 296, 1
Crawford, C. S., Fabian, A. C., Gandhi, P., Wilman, R. J., & Johnstone, R. M. 2001, MNRAS, 324, 427
Crawford, C. S., Gandhi, P., Fabian, A. C., Wilman, R. J., Johnstone, R. M., Barger, A. J., & Cowie, L. L. 2002, MNRAS, 333, 809
Elvis, M., et al. 1994, ApJS, 95, 1
Elvis, M., Risaliti, G., & Zamorani, G. 2002, ApJ, 565, L75
Fabian, A. C. 1999, MNRAS, 308, L39
Fabian, A. C., et al. 2000, MNRAS, 315, L8
Fabian, A. C., Barcons, X., Almaini, O., & Iwasawa, K. 1998, MNRAS, 297, L11
Fabian, A. C., Crawford, C. S., & Iwasawa, K. 2002, MNRAS, 331, L57
Fabian, A. C., & Iwasawa, K. 1999, MNRAS, 303, L34
Fabian, A. C., Sanders, J. S., Crawford, C. C., & Ettori, S. 2003, MNRAS, 341, 729
Fabian, A. C., Wilman, R. J., & Crawford, C. S. 2002, MNRAS, 324, 427
Fadda, D., Flores, H., Hasinger, G., Franceschini, A., Altieri, B., Cesarsky, C., Elbaz, D., & Ferrando, P. 2002, A&A, 383, 838
Ferrarese, L. 2002, in Current High-Energy Emission around Black Holes, ed. C.-H. Lee & H.-Y. Chang (Singapore: World Scientific), 3
Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9
Franceschini, A., Bassani, L., Cappi, L., Granato, G. L., Malaguti, G., Palazzi, E., & Persic, M. 2000, A&A, 353, 910
Franceschini, A., Braito, V., & Fadda, D. 2002, MNRAS, 335, L51
Gammie, C. F. 1999, ApJ, 522, L57
Gandhi, P. 2002, Ph.D. Thesis, Cambridge University
Gandhi, P., Crawford, C. S., & Fabian, A. C. 2002, MNRAS, 337, 781
Gandhi, P., & Fabian, A. C. 2003, MNRAS, 339, 1095
Gebhardt, K., et al. 2000, ApJ, 539, L13
Gendreau, K. 1995, Ph.D. Thesis, Massachusetts Institute of Technology
Giacconi, R., et al. 2001, ApJ, 551, 624
Gilli, R., Risaliti, G., & Salvati, M. 1999, A&A, 347, 424
Gilli, R., Salvati, M., & Hasinger, G. 2001, A&A, 366, 407
Hasinger, G. 2003, in New Visions of the X-ray Universe in the XMM-Newton and Chandra Era, ed. F. Jansen (Nordwijk: ESA), ESA SP-488 (astro-ph/0202430)
Hasinger, G., et al. 2001, A&A, 365, L45
Hornschemeier, A. E., et al. 2000, ApJ, 541, 49
Hornschemeier, A. E., et al. 2001, ApJ, 554, 742
Hornschemeier, A. E., Brandt, W. N., Alexander, D. M., Bauer, F. E., Garmire, G. P., Schneider, D. P., Bautz, M. W., & Chartas, G. 2002, ApJ, 568, 62
Hughes, S. A., & Blandford, R. D. 2003, ApJ, 585, L101
Iwasawa, K., Fabian, A. C., & Ettori, S. 2001, MNRAS, 321, L15
Krolik, J. H. 1999, ApJ, 515, L73
Krolik, J. H., & Kriss, G. A. 2001, ApJ, 561, 684

Madau, P., Ghisellini, G., & Fabian, A. C. 1994, MNRAS, 270, L17
Magdziarz, P., Blaes, O. M., Zdziarski, A. A., Johnson, W. N., & Smith, D. A. 1998, MNRAS, 301, 179
Magorrian, J., et al. 1998, AJ, 115, 2285
Mainieri, V., Bergeron, J., Hasinger, G., Lehmann, I., Rosati, P., Schmidt, M., Szokoly, G., & Della Ceca, R. 2002, A&A, 393, 425
Maiolino, R., Marconi, A., Salvati, M., Risaliti, G., Severgnini, P., La Franca, F., & Vanzi, L. 2001, A&A, 365, 37
Maiolino, R., Salvati, M., Bassani, L., Dadina, M., Della Ceca, R., Matt, G., Risaliti, G., & Zamorani, G. 1998, A&A, 338, 781
Matt, G., & Fabian, A. C. 1994, MNRAS, 267, 187
Matt, G., Fabian, A. C., Guainazzi, M., Iwasawa, K., Bassani, L., & Malaguti, G. 2000, MNRAS, 318, 173
Merritt, D., & Ferrarese, L. 2001, MNRAS, 320, L30
Mushotzky, R. F., Cowie, L. L., Barger, A. J., & Arnaud, K. A. 2000, Nature, 404, 459
Norman, C., et al. 2002, ApJ, 571, 218
Piccinotti, G., Mushotzky, R. F., Boldt, E. A., Holt, S. S., Marshall, F. E., Serlemitsos, P. J., & Shafer, R. A. 1982, ApJ, 253, 485
Risaliti, G., Maiolino, R., & Salvati, M. 1999, ApJ, 522, 157
Rosati, P., et al. 2002, ApJ, 566, 667
Setti, G., & Woltjer, L. 1989, A&A, 224, L21
Silk, J., & Rees, M. J 1998, A&A, 331, L1
Smail, I., Owen, F. N., Morrison, G., Keel, W. C., Ivison, R. J., & Ledlow, M. J. 2002, ApJ, 581, 844
Sołtan, A. 1982, MNRAS, 200, 115
Stern, D., et al. 2002, ApJ, 568, 71
Ueno, S., Koyama, K., Nishida, M., Yamauchi, S., & Ward, M. J. 1994, ApJ, 431, L1
Vignati, P., et al. 1999, A&A, 349, L57
Wada, K., & Norman, C. A. 2002, ApJ, 566, L21
Wilman, R. J. 2002, preprint
Wilman, R. J., Fabian, A. C., Crawford, C. S., & Cutri, R. M. 2003, MNRAS, 338, L19
Wilman, R. J., Fabian, A. C., & Gandhi, P. 2000, MNRAS, 318, L11
Xu, C., et al. 1998, ApJ, 508, 576
Yu, Q., & Tremaine, S. 2002, MNRAS, 335, 965
Zheng, W., et al. 1995, ApJ, 444, 632