Obscured AGN: the hidden side of the X–ray Universe

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Most Active Galactic Nuclei (AGN) are ‘obscured’, i.e. the nucleus is hiding behind a screen of absorbing material. The advantage of having the nucleus obscured is to make easier the observations of those emission components which originate in circumnuclear matter outside the absorbing regions, because in this case they are not outshined by the nuclear emission. This is particularly important in X–rays, where spatial resolution is (with the notable exception of Chandra) poorer than in the optical, and the study of circumnuclear regions is often based on spectral analysis only.

The properties of circumnuclear matter, in the light of recent high spectral and/or angular resolution Chandra and XMM–Newton observations, will be reviewed in Sec. 2. In Sec. 3 we will discuss obscured AGN in the framework of the Unification Model. Recent discoveries of X–ray obscured Seyfert 1, and of X–ray loud but optically normal galaxies, are calling for a revision of the Unification Model.

Obscured AGN have also a cosmological relevance. Not only are they a fundamental ingredient of synthesis models of the Cosmic X–ray Background (XRB), but provide a link between the XRB and the Cosmic Infrared Background, as briefly discussed in Sec. 4.

Keywords: X-ray Astronomy; Active Galactic Nuclei

1. Introduction

Both direct (surveys) and indirect (synthesis models of the Cosmic X–ray Background, CXRB) methods clearly indicate that most AGN are ‘obscured’ in X–rays, i.e. that their nucleus is hidden behind an absorbing material, which prevents the nuclear emission from being directly observed up to the energy (if any, see below) at which the material becomes transparent (this energy depending of course on the column density of the absorber, see Fig. 1). Indeed, the three closest AGN (Circinus Galaxy, NCG 4945 and Centaurus A) are all heavily obscured. The absorbing matter is often very thick, its column density exceeding the value, $\sigma_T^{-1} = 1.5 \times 10^{-24}$ cm$^{-2}$, for which the Compton scattering optical depth equals unity (in these cases, the sources are called ‘Compton–thick’. If the column density is smaller than $\sigma_T^{-1}$ but still in excess of the Galactic one, the source is called ‘Compton–thin’). Compton–thick sources provide the most favourable case for studying the circumnuclear matter, because the emission from this matter (arising from reflection and reprocessing of the nuclear radiation) is not significantly diluted by the primary emission not only in soft X–rays but up to 10 keV at least.
Those familiar with the Unification Model for Seyfert Galaxies (Antonucci 1993) have probably noted that I have used the term 'obscured' instead of the most common term 'type 2'. The reason is that there is increasing evidence that optical classifications (from which the terms type 1 and 2 derives) and X–ray classifications sometimes disagree with what expected from the Unification Model; in fact a number of sources clearly obscured in X–rays are either of type 1, on one extreme, or dull, on the other extreme, when observed in the optical. I will discuss

The Unification Model for Seyfert galaxies assumes that Seyfert 1s (in which both Broad and Narrow lines are visible in the optical spectrum) and Seyfert 2s (where only Narrow lines are observed) are intrinsically the same. The nucleus (i.e. the Black Hole with the accretion disc and the Broad Line regions) is surrounded by optically and geometrically thick matter, probably axisymmetric (usually called the ‘torus’). If the line–of–sight does not intercept the torus, the nucleus is visible and the source is classified as type 1. Otherwise, only the Narrow Line regions are visible and the source is classified as type 2. In this scenario, a one–to–one relation between optical type 1 and X–ray unobscured sources, and between type 2 and X–ray obscured sources, is expected.
this point in greater detail in Sec.3. To avoid confusion, I will confine here the terms type 1 and type 2 to their original meaning (based on the presence or not of broad permitted lines in the optical spectrum). In any case, I will give for granted, in agreement with the Unification Model, that the basic X-ray properties of unobscured and obscured AGN are the same, the latter being simply seen through a screen of cold matter.

2. The properties of circumnuclear matter

(a) Physical properties of reflecting matter

The advent of high spectral and spatial resolution X-ray instruments on board Chandra and XMM-Newton is now allowing the study of the circumnuclear matter in obscured sources in much greater detail than before (and it is now becoming feasible to study this matter also in unobscured sources, despite the heavy dilution by the nuclear radiation). The results obtained by these instruments are improving and refining, but not revolutionizing, the previous scenario (for the relief and pleasure of those people who in the past struggled to find a coherent picture out of much poorer data). In Fig. 2 the differences in the line spectrum when observed with a CCD and with a grating instrument are shown in the case of the Circinus Galaxy.

The spectrum of the reflected component depends on the ionization state of the matter. If the matter is highly ionized, Compton scattering is the most important process and the spectrum (at least up to a few tens of keV, where Compton recoil becomes important) is very similar to the primary one. If instead the matter is neutral (and optically thick), the resulting spectrum is the so-called ‘Compton reflection’ with a broad bump between 10 and 100 keV (e.g. George & Fabian 1991; Matt et al. 1991). In both cases strong emission lines are also expected: iron lines from He– and H–like ions may be present in the former case; a EW~1–2 keV 6.4
keV iron line is present in the latter case (e.g. Matt et al. 1996b). More complex continuum and line spectra are expected for mildly ionized material.

The study of the circumnuclear matter is easier in Compton–thick sources, just because the nucleus is completely obscured up to at least 10 keV, i.e. in the band where imaging and high resolution spectroscopic instruments work. Emission from off–nuclear regions is the only visible in these sources, and may be studied in great detail. The number and complexity of these regions are much different from source to source. In the Circinus Galaxy, the results obtained by Bianchi et al. (2001) from ASCA and BeppoSAX data have been basically confirmed by Chandra (Sambruna et al. 2001a,b; see also Fig 3): the spectrum down to about 2 keV is dominated by one, optically thick and with low ionization reflecting region (unresolved even with Chandra), most likely the inner surface of the \( N_H \sim 4 \times 10^{24} \text{ cm}^{-2} \) absorbing matter (Matt et al. 1999b) assuming, as customary, that the latter is (in the first approximation at least) axysimmetric. A second, ionized component extended over about 50 pc becomes important below 2 keV, where it provides about half of the flux (Sambruna et al. 2001a,b).

The continuum and line spectra are instead much more complex in NGC 1068. Even if significant extended emission has been observed by Chandra, most of the emission is unresolved (Young et at. 2001). ASCA and BeppoSAX data already indicated the presence of more than one reflecting regions. Bianchi et al. (2001; see also references therein) have indeed shown that at least three different regions are needed to explain the line spectrum: the first is optically thin and moderately ionized, and it is responsible for the K\( \alpha \) lines of elements like Mg, Si and S; the second one is optically thin but highly ionized, and responsible for the He– and H–like Fe K\( \alpha \) lines; the third one is optically thick and of low ionization, and it is responsible for the 6.4 keV Fe and the O\( \text{vii} \) K\( \alpha \) lines. The last region is again likely to be the inner surface of the absorber, which in this source has a column density \( \geq 10^{25} \text{ cm}^{-2} \) (Matt et al. 1997). XMM–Newton grating spectra (e.g. Behar et al. 2002; Kinkhabwala et al. 2002) have definitely proved that the emitting gas responsible for the line spectrum is in photoionization equilibrium, the emission lines being due to both recombination and resonant scattering (as predicted by e.g. Band et al. 1990; Krolik & Kriss 1995; Matt et al. 1996b), and are suggesting that the scenario is even more complex than deduced by low resolution spectra. Photoionization equilibrium seems also able to explain the Chandra–HETG line spectrum of Mrk 3 (Sako et al. 2000). In the latter source the softest part (i.e. below about 3 keV) of the spectrum is spatially extended along the [O III] ionization cone, while the high–energy spectrum is unresolved and consistent with reflection by cold and optically thick material, once more to be associated with the \( N_H \sim 10^{24} \text{ cm}^{-2} \) absorber (Cappi et al. 1999).

Combining these results with those discussed by Matt et al. (2000), who studied a sample of bright Compton–thick sources observed by BeppoSAX, it is possible to conclude that reprocessing from optically thick, almost neutral matter is quite common. As said above, it seems natural to identify this matter with the inner surface of the absorber, as all these sources are Compton–thick. (We will see later that this matter is likely to be present also in most unobscured sources, according to the Unification Model, but even in Compton–thin obscured sources, which is less obvious). In order not to exceed the dynamical mass, at least in Circinus and NGC 1068 the matter must be fairly close to the black hole, within a few tens of

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(b) Compton-thin or compton-thick?

Unless the nucleus is directly observed above $\sim 10$ keV (a task possible in recent years with BeppoSAX and RXTE, and only for column densities not exceeding $\sim 10^{25}$ cm$^{-2}$, see Matt et al. 2000), the signature of Compton–thick absorption is a reflection dominated X–ray spectrum. Sometimes, however, a pure reflection spectrum may lead to a wrong classification. The classical case is NGC 4051, which was observed by BeppoSAX in a low flux state, in which the nucleus was switched off and only the reflection component was visible (Guainazzi et al. 1998). The source
was a well known Seyfert 1, otherwise it would have been classified as a Compton–thick absorbed AGN. A similar, even if somewhat less dramatic, change occurred in the Compton–thin \((N_H \sim 10^{22} \text{ cm}^{-2})\) source NGC 2992 (Gilli et al. 2000) which, during a BeppoSAX observation, was almost switched off, with the reflection component thus becoming very prominent. Subsequent BeppoSAX observations of NGC 4051 and NGC 2992 found that both sources had recovered their normal, bright state. In both cases it seems pretty obvious that what changed was the nuclear flux, rather than the properties of the absorption. It is also clear that the reflecting matter must be located at large distances from the black hole to echo the already switched–off primary emission; in fact, reflection from the accretion disc would disappear almost immediately. It is worth noting that, in the case of NGC 2992, the absorbing matter (which is Compton–thin) must be different from the reflecting matter (which is Compton–thick). Because the galaxy is edge–on, and given the rather small column density, it is possible that the thin absorber is the disc of the host galaxy.

Recently, two more sources underwent a similar transition. NGC 6300 and UGC 4203 were both Compton–thick when observed by RXTE (Leighly et al. 1999) and ASCA (Awaki et al. 2000), respectively, but become Compton–thin when observed later on by BeppoSAX (Guainazzi 2002) and XMM–Newton (Guainazzi et al. 2002). The ASCA and XMM–Newton spectra of UGC 4203 are presented in Fig. 2. While a change in the properties of the absorber cannot be completely ruled out, the explanation in terms of a ‘switching–off’ of the sources during their first observation seems the most natural. The ‘thin’ absorbers in these two sources have column densities of a few \(\times 10^{23} \text{ cm}^{-2}\), and the host galaxies are seen at low inclination angles (UGC 4203 is basically face–on), so the galactic disc cannot be the cause for the Compton–thin absorption. This therefore strongly suggests that in these two sources both Compton–thin (the absorber) and Compton–thick (the reflecting) cold, circumnuclear regions are present.

(c) Two different regions?

Because X–ray absorption is very common in AGN, the covering factor of the absorbing matter must be large. Heavy absorption is also very common: about half of the optically selected Seyfert 2s in the local Universe are Compton–thick (e.g. Maiolino et al. 1998). Indeed, the very first object observed by XMM–Newton in the framework of a program devoted to study the absorption properties of optically selected Seyfert 2s, NGC 4968, is clearly a Compton–thick source (Guainazzi et al., in preparation). Even allowing for a number of misclassifications due to the switching–off of the nucleus rather than a true Compton–thick absorption, as discussed in the previous paragraph, it is clear that optically thick circumnuclear matter is common.

Risaliti et al. (1999) have shown that there is a relation between optical classification and column density, at least for optically selected AGN: Intermediate (1.8–1.9) Seyferts are usually Compton–thin, while classical Seyfert 2s are Compton–thick. From the results discussed in the previous paragraph, it seems that the two components may be present in the same source (another case of Compton–thin absorber with Compton–thick reflection is NGC 5506, Matt et al. 2001).

All these pieces of evidence suggests that the Compton–thin and Compton–thick
Figure 4. The softness ratio (S-H)/(S+H) as a function of redshift for the identified BeppoSAX HELLAS sources. S and H are the counts in the 1.3–4.5 and 4.5–10 keV bands, respectively. Note that there are a number of absorbed type 1 AGN. From Comastri et al. (2001).

materials have different origins and locations, as originally proposed by Maiolino & Rieke (1995). Matt (2000) has suggested that the Compton–thin matter should be associated with the dust lanes at distances of hundred of parsecs which Malkan et al. (1998) found to be common in Seyfert galaxies, while the Compton–thick matter should be much closer to the nucleus, and associated with the ‘torus’ envisaged in the Unification Model (Antonucci 1993). A similar scenario has been proposed by Weaver (2002), who identifies the Compton–thin absorbers with starburst region clouds. In any case it is clear that the Unification Model should be somewhat revised to accommodate this further component. Other problems with the Unification Model have emerged from recent X–ray surveys and will be discussed in the next section.

3. Obscured AGN and the Unification Model

A first (actually not very serious) problem for the Unification Model has been already mentioned: the co–existence of two kinds of cold, circumnuclear matter, which
suggests that the torus (i.e. the Compton–thick matter) is not the only possible absorbing/reflecting region. The inclusion of dust lanes and/or starburst regions to the basic ingredients should be all what is needed to explain the observations.

There are, however, more serious problems. First of all, type 1 sources may be obscured in X–rays. Maiolino et al. (2001a) found a number of broad lines QSOs with significant X–ray absorption. Several sources in e.g. the BeppoSAX HELLAS (Fiore et al. 2001), the ASCA HSS (Della Ceca et al. 2001) and the XMM–Newton HELLAS2XMM (Fiore et al. 2002) surveys appear to be absorbed in X–rays, but optically identified with type 1 AGN (see Fig. [4]). Recently, it has been shown (e.g. Gallagher et al. 2002; Mathur et al. 2001) that the X–ray weakness of BAL QSOs discovered by ROSAT is due to excess absorption (but it is still not clear whether the X–ray absorption is associated with the UV one, and therefore significantly ionized). For these absorbed blue QSOs, and in general for all the AGN for which optical extinction is lower than expected from X–ray absorption (there are several cases among Seyfert 2s), a possible explanation is that the dust/gas ratio of the absorber is much lower than in the Galactic interstellar medium, probably due to dust sublimation. Another possibility is that the optical and X–ray absorbers cover different regions: the very nucleus for the X–ray absorber, a larger region for the optical one. Recently, Maiolino et al. (2001b) suggested an explanation in terms of different dust grain size with respect to the ISM. Whatever the solution, it is clear that optical and X–ray observations may sometimes lead to different classifications.

There are also X–ray loud sources (and sometimes, but not always, with hard spectra, thus suggesting obscuration) that do not appear as AGN in the optical (or even do not have an optical counterpart, implying a very large X–to–optical ratio). Such a population is starting to emerge at fluxes of about $10^{-14}$ erg cm$^{-2}$ s$^{-1}$ (e.g. Mushotzky et al. 2000; Fiore et al. 2001; Barger et al. 2001; Alexander et al. 2001), now easily probed by Chandra and XMM–Newton. The nature of these X–ray Bright, Optically Normal Galaxies (XBONG, as they were christened by Comastri et al. 2002a, where a detailed discussion of the properties of 10 bona fide sources of this class can be found) is still matter of debate. A large fraction of these sources have X–ray luminosities exceeding $10^{42}$ erg s$^{-1}$, well in the AGN regime. My personal feeling is that most, if not all, of them will turn out to be obscured AGN, in which the obscuration is such to prevent even the formation (or the visibility) of the Narrow lines. Compton–thick obscuration may explain the not particularly hard spectrum of some of them, if reflection from ionized matter is not negligible with respect to reflection from cold matter (with an appropriate choice of the bands, even the archetypal Compton–thick source, NGC 1068, would appear as a very soft source indeed!) It is worth recalling that cases of obscured AGN whose optical spectrum, even if not really ‘normal’, is nevertheless different from that of an AGN are already known: NGC 6240 and NGC 4945 are the best examples, see Matt (2002) and references therein.

The most extensively studied among XBONG is probably ‘P3’, one of the sources in the sample of Fiore et al. (2000). This object was observed in radio (ATCA), near–IR (ISAAC/VLT), optical (ESO 3.6m) and X–rays (both Chandra and XMM–Newton), and discussed in Comastri et al. (2002b). The X–ray luminosity (a few times $10^{42}$ erg s$^{-1}$ if the source is Compton–thin; $\lesssim 10^{44}$ erg s$^{-1}$ if Compton–thick) and hard X–ray spectrum clearly indicate the presence of an AGN for which, however, there are no signatures at longer wavelengths. The analysis of the SED
makes the ADAF solution rather unlikely. An heavy obscured AGN appears to be
the most likely explanation, even if a rather extreme BL Lac cannot be ruled out.

Of course, what just said does not mean that there are no relations whatsoever
between optical and X-ray appearances. More often than not, the optical (X-ray)
appearance is just what one would predict from the Unification Model after ob-
serving the X-ray (optical) emission. Moreover, we are not aware of any certainly
unobscured AGN which are not type 1, and of any type 2 which are not obscured
(even if Pappa et al. 2001 presented a couple of possible cases). So, at present the
‘strict’ (in the sense of no unambiguous exceptions found yet) relations between
optical and X-ray classifications may be reduced to:

\[
\text{type 1} \leftarrow \text{unobscured} \quad \text{type 2} \rightarrow \text{obsured}
\]

It is worth noting that support for one of the predictions of the Unification
Model, i.e. that Seyfert 1 galaxies have the ‘torus’ (and therefore would become
Seyfert 2 if observed at different angles) is coming from recent Chandra and XMM–
Newton observations, which are indicating that the presence of narrow iron Kα
lines (therefore produced in distant matter; iron lines from the accretion disc being
expected to be broad due to kinematic and relativistic effects, see Fabian, this
volume) are rather common (e.g.: Yaqoob et al. 2002, Weaver 2002 and references
therein for Chandra results; Matt et al. 2001, Pounds & Reeves 2002 and references
therein for XMM–Newton results).

4. Obscured AGN and the X-ray and IR Cosmic
Backgrounds

Obscured AGN are a basic ingredient in synthesis models for the CXRB (e.g. Setti
& Woltjer 1989; Comastri et al. 1995). The mixture of unobscured and obscured
(with a spread of column densities) AGN is able to reproduce well the spectral
shape of the CXRB, so solving the long standing problem known as the 'spectral
paradox'. A large fraction of the CXRB below 10 keV has been now resolved in
discrete sources, many of them optically identified as AGN (and part of them, as
said above, assumed to be AGN due to their X-ray luminosity). Some problems are
still to be solved (see talks by Hasinger and Brandt in this volume) but, after 40
years from its discovery, the main issue, i.e. what class of sources make the CXRB
(or at least most of it), can be now considered settled (and this despite that the
bulk of the CXRB, which peaks around 30 keV, is still far to be resolved for lack
of sensitive imaging instruments in that band).

Cosmic backgrounds have been recently measured also in other bands, notably
the sub-mm and IR. When looking at the Spectral Energy Distribution of the
extragalactic Backgrounds, the CXRB may appear almost negligible if compared
with the cosmic IR background (CIRB). However, the luminosity we observe in the
CXRB is only a fraction, probably of the order of 10-20%, of the energy actually
emitted, the remaining flux having been absorbed by the circumnuclear matter,
and re-emitted at longer wavelengths, mostly in the mid-IR. Fabian & Iwasawa
(1999) estimated that a by no means negligible fraction (several tens per cent)
of the CIRB is actually due to X-ray photons absorbed and reprocessed from the

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obscuring medium (see also Risaliti et al. 2002). Indeed, by cross–correlating IR and X–ray deep observations Fadda et al. (2002) found an AGN contribution of around 15% of the CIRB at 15µ. From optical spectroscopic identifications of ISO/ELAIS sources, Matute et al. (2002) estimate a contribution at 15µ of 10-15%. These two estimates are both likely to be lower limits, as in the former case some Compton–thick sources may have been missed, and in the latter case AGN which are bright in IR but do not show AGN–like optical lines, like NGC 6240 and NGC 4945 (Matt 2002) may have not been recognized as AGN.

Whatever the real number is, it is clear that accretion and star formation are processes of comparable importance in the history of the Universe.

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