The X-ray spectra of Compton-thick Seyfert 2 galaxies as seen by BeppoSAX

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ABSTRACT
Results from BeppoSAX observations of Compton–thick Seyfert 2 galaxies are summarized and reviewed, and their general properties derived and discussed. In five out of the seven observed sources, the nucleus is directly visible at high X-ray energies, where the photons penetrate absorbers with column densities in the range \(1.1 - 4.3 \times 10^{24} \text{ cm}^{-2}\). In the other two sources, NGC 1068 and NGC 7674, the nucleus is instead totally obscured at all energies, implying even larger column densities. In most sources there is unambiguous evidence of a reflection component from optically thick, cold matter, while in two (or maybe four) cases there is also evidence of reflection from ionized matter. For the sources with a measured X-ray luminosity, a comparison with the infrared luminosity is made; while in two cases (the Circinus galaxy and NGC 4945) the IR emission appears to be dominated by starburst activity, in the other three sources (NGC 6240, Mrk 3 and TOL 0109-383) it is likely to be dominated by reprocessing of the UV and X-ray photons emitted by an AGN.

Key words: galaxies: active – galaxies: Seyfert – X-rays: galaxies

1 INTRODUCTION
Compton–thick Seyfert 2 galaxies are by definition those AGN in which the X-ray obscuring matter has a column density equal to or larger than the inverse Thomson cross section, i.e. \(N_H \geq \sigma_T^{-1} = 1.5 \times 10^{24} \text{ cm}^{-2}\). The Thomson cross section is equal to the photoelectric cross section at around 10 keV (assuming cosmic abundances), and this energy may be assumed as the boundary between photoelectric- and Compton-dominated regimes. By chance, this is also the upper energy of the working band of many past X-ray satellites, which therefore could observe Compton–thick sources only in the photoelectric regime, where the X-ray emission is dominated by scattered components. BeppoSAX (Boella et al. 1997), thanks to the unprecedented sensitivity of its high energy collimated detector, the PDS (Frontera et al. 1997), has now extended the sensitive observing range well into the Compton–dominated regime.

There are several reasons why Compton–thick sources deserve to be studied. Firstly, most AGN, in the local universe at least, are obscured by Compton–thick matter (Maiolino et al. 1998). Therefore, they are an important ingredient not only of the Cosmic X-ray Background, but also of the IR background, where most of the absorbed radiation is re-emitted (Fabian & Iwasawa 1999). Secondly, the heavy absorption means that spectral components, which would otherwise have been completely dominated by the nuclear emission, can be observed. In particular, in the \(\sim 1 - 10 \text{ keV}\) band the emission is dominated by reflection from both cold and ionized matter of the nuclear radiation, and the geometrical and physical properties of the circumnuclear matter can then be studied (e.g. Matt, Brandt & Fabian 1996).

In this paper we summarize and discuss the results from the BeppoSAX Core Program on bright Compton–thick Seyfert 2 galaxies, as well as sources observed in other programs which were found to be Compton–thick, and explore the consequences.

\[H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}\] is adopted throughout the paper.

2 BEPPOSAX OBSERVATIONS AND RESULTS ON SINGLE SOURCES
In this section we recall the main BeppoSAX results on NGC 1068 (Matt et al. 1997, Guainazzi et al. 1999), the Circinus Galaxy (Matt et al. 1999, Guainazzi et al. 1999), NGC 6240 (Vignati et al. 1999), Mrk 3 (Cappi et al. 1999),
Table 1. Exposure times and count rates for the BeppoSAX observations of Compton–thick sources.

<table>
<thead>
<tr>
<th>Source</th>
<th>Date of obs</th>
<th>Exp. time (MECS) (ks)</th>
<th>LECS CR (s⁻¹)</th>
<th>MECS CR (s⁻¹)</th>
<th>PDS CR (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 1068</td>
<td>1996-Dec/1998-Jan-11</td>
<td>101.6/37.3</td>
<td>0.110</td>
<td>0.096ᵃ/0.073ᵇ</td>
<td>0.21</td>
</tr>
<tr>
<td>Circinus Galaxy</td>
<td>1998-Mar-13</td>
<td>137.7</td>
<td>0.065</td>
<td>0.132ᵇ</td>
<td>2.01</td>
</tr>
<tr>
<td>NGC 6240</td>
<td>1998-Aug-14</td>
<td>119.4</td>
<td>0.012</td>
<td>0.024ᵇ</td>
<td>0.38</td>
</tr>
<tr>
<td>Mrk 3³</td>
<td>1997-Apr-16</td>
<td>112.8</td>
<td>0.021</td>
<td>0.060ᵃ</td>
<td>1.16</td>
</tr>
<tr>
<td>NGC 7674</td>
<td>1996-Nov-25</td>
<td>116.0</td>
<td>0.003</td>
<td>0.005ᵃ</td>
<td>0.13</td>
</tr>
<tr>
<td>NGC 4945</td>
<td>1999-Jul-01</td>
<td>93.8</td>
<td>0.031</td>
<td>0.057ᵇ</td>
<td>2.77</td>
</tr>
<tr>
<td>TOL 0109-383</td>
<td>1999-Jul-26</td>
<td>64.3</td>
<td>0.005</td>
<td>0.010ᵇ</td>
<td>0.16</td>
</tr>
</tbody>
</table>


NGC 7674 (Malaguti et al. 1998), NGC 4945 (Guainazzi et al. 2000a), and Tololo 0109-383 (Iwasawa et al. 2000). In the following we will make use of results from three BeppoSAX instruments: the LECS, MECS and PDS, working in the 0.1-10, 2-10 and 15-200 energy ranges, respectively. Details on the data reduction and analysis can be found in the above papers.

A summary of the observations is given in Table 1, and the main results of the spectral fittings in Table 2. On 1997 May 6 one of the 3 MECS units failed, and therefore observations after that date have been performed with 2 MECS units only.

2.1 NGC 1068

The archetypal Seyfert 2 and Compton–thick source NGC 1068 has been observed by BeppoSAX twice, one year apart. The nucleus is completely obscured at all energies (Matt et al. 1997), and therefore the column density of the absorbing matter should exceed \(\sim 10^{25}\) cm\(^{-2}\). The soft X-ray band is dominated by thermal-like emission, probably related to the starburst region. In the 2–10 keV band, the emission is a mixture of cold and ionized reflection (see also Iwasawa, Fabian & Matt 1997), the latter being complex as implied by the line spectrum (Netzer & Turner 1997; Guainazzi et al. 1999). At higher energies, is the cold reflection component which dominates.

There is also evidence for energy-dependent flux variability (Guainazzi et al. 2000b), best explained by a variation of the spectral shape of the ionized reflector component, obviously echoing a variation in the primary, nuclear continuum. This would limit the dimension of the reflecting region to less than 1 pc.

2.2 The Circinus Galaxy

At variance with NGC 1068, is the Circinus Galaxy the nucleus of which can be directly seen in the PDS band, piercing through a 4.3\(\times 10^{24}\) cm\(^{-2}\) absorber. Here and after the transmission components have been modeled including Compton scattering from a spherical distribution of matter (an assumption which will be justified in Sec. 3.1) as described in Matt et al. (1999) and Matt, Pompilio & La Franca (1999). Cold reflection is evident, as both Kα and Kβ iron fluorescent lines have been clearly detected. On the contrary, no clear evidence of ionized reflection is present, the Mg, Si and S lines (Matt et al. 1996; Guainazzi et al. 1999) possibly arising from the same medium producing the above iron lines (Bianchi et al. 2000). The intrinsic 2–10 keV luminosity deduced from the best fit is \(\sim 10^{42}\) erg s\(^{-1}\).

2.3 NGC 6240

The direct nuclear emission of NGC 6240 is revealed by the PDS (Vignati et al. 1999; see also Netzer, Turner & George 1998 for ASCA results). The column density is \(2\times 10^{24}\) cm\(^{-2}\). An ionized reflector is also clearly present: a power law continuum is required by the data, and there is clear evidence for ionized iron lines (see also Iwasawa & Comastri 1998). Evidence for cold reflection is instead ambiguous. The intrinsic 2–10 keV luminosity deduced from the best fit is \(\sim 1.2\times 10^{44}\) erg s\(^{-1}\).

2.4 Mrk 3

The BeppoSAX data on this source have been discussed in detail by Cappi et al. (1999). For an easier comparison with the other sources in this sample, we re-analyzed the high energy part of the spectrum adopting the transmission model of Matt, Pompilio & La Franca (1999). The direct nuclear radiation is seen through an absorber of \(1.1\times 10^{24}\) cm\(^{-2}\) (and therefore, strictly speaking, the source is not Compton–thick according to the above definition). The intrinsic 2–10 keV luminosity is \(\sim 0.9\times 10^{44}\) erg s\(^{-1}\).

A cold reflection component is clearly required by the data (Cappi et al. 1999). There is evidence for an unabsorbed power law component too, suggesting the presence of an ionized reflector. Moreover, the iron line is broad, which would suggest a blend of cold and ionized lines. However, ASCA did not find evidence for a substantial broadening of the line, even if a weak additional line at \(\sim 6.8\) keV is possibly present (Iwasawa 1996). The existence of an ionized reflector must therefore still be considered an open issue.
2.5 NGC 7674

This source has been analysed and discussed by Malaguti et al. (1998). As for NGC 1068, the nucleus is completely hidden at all energies, which implies a column density \( \gtrsim 10^{25} \) cm\(^{-2}\). The emission above a few keV is dominated by a cold reflection component, and the evidence for ionized reflection is scanty. The apparently broad iron line can actually be fitted by a blend of K\(\alpha\) and K\(\beta\) fluorescent lines.

2.6 NGC 4945

This is the archetypal “moderately thick” source, where the nucleus becomes visible above about 10 keV (Iwasawa et al. 1993; Done, Smith & Madejski 1996). Modeling the BeppoSAX data (Guainazzi et al. 2000a) with the transmission model mentioned before, a column density for the absorber of \(2.2(+0.3,-0.4) \times 10^{24} \) cm\(^{-2}\), and a power law photon index of 1.4\(\pm\)0.3 are obtained. The intrinsic 2–10 keV luminosity is \(3 \times 10^{42} \) erg s\(^{-1}\). This value differs significantly from that quoted in Iwasawa et al. (1993) because they did not include Compton scattering in the fitting model.

Contrary to the other sources, no clear evidence is found for either the cold or the ionized reflector, the spectrum below 8 keV being dominated by extended, rather than nuclear, emission.

2.7 TOLOLO 0109-383

Tololo 0109-383 (NGC 424) has been observed by BeppoSAX on 1999 July 26–28 for a net exposure time of 64 ks in the MECS and PDS, and 24.6 ks in the LECS. The fit with the usual model gives a column density of about \(2 \times 10^{24} \) cm\(^{-2}\) (with the power law index fixed to 2: the quality of the data is not good enough to allow for a simultaneous estimate of both the column density and the power law index). The resulting intrinsic 2–10 keV luminosity is \(2 \times 10^{43} \) erg s\(^{-1}\). Evidence for both a cold and ionized reflection components are present.

A complete analysis of the BeppoSAX data, along with those from a previous ASCA observation, will be presented in Iwasawa et al. (2000).

3 GENERAL COMMENTS ON HIGHLY OBSCURED SOURCES

3.1 The covering factor

The first question to address is the spatial distribution of the X–ray absorbing matter, and in particular its covering factor. Even if formally the transmitted spectrum depends on the covering factor, as it changes the importance of Compton scattering into our line of sight of photons initially emitted in other directions (Matt, Pompilio & LaFranca 1999), the quality of the data is not good enough to reach any conclusion from spectral fitting. We have therefore to resort to indirect arguments. The first one comes from the common presence of reflection from cold matter, signaled by the 6.4 keV fluorescent iron line and the Compton reflection component, the latter often dominating the spectrum at energies where the nuclear emission is completely blocked. When the

### Table 2. Summary of the main properties of the sources in the sample. CR and WR stand for Cold reflection and Warm reflection.

<table>
<thead>
<tr>
<th>Source</th>
<th>(N_\beta)</th>
<th>CR</th>
<th>WR</th>
<th>(L_\beta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 1068(^{1,2})</td>
<td>(\gtrsim 10)</td>
<td>Y</td>
<td>Y</td>
<td>? (&gt; 1)</td>
</tr>
<tr>
<td>Circinus Galaxy(^{2,3})</td>
<td>4.3</td>
<td>Y</td>
<td>N (?)</td>
<td>~0.01</td>
</tr>
<tr>
<td>NGC 6240(^4)</td>
<td>2.2</td>
<td>Y (?)</td>
<td>Y</td>
<td>~1.2</td>
</tr>
<tr>
<td>Mrk 3(^5,9)</td>
<td>1.1</td>
<td>Y</td>
<td>Y?</td>
<td>0.9</td>
</tr>
<tr>
<td>NGC 7674(^6)</td>
<td>(\gtrsim 10)</td>
<td>Y</td>
<td>N (?)</td>
<td>?</td>
</tr>
<tr>
<td>NGC 4945(^7)</td>
<td>2.2</td>
<td>N</td>
<td>N</td>
<td>~0.03</td>
</tr>
<tr>
<td>TOL 0109-383(^8)</td>
<td>2.0</td>
<td>Y</td>
<td>Y?</td>
<td>~0.2</td>
</tr>
</tbody>
</table>

\(^{1}\) in units of \(10^{24} \) cm\(^{-2}\); \(^{2}\) 2–10 keV luminosity in units of \(10^{44} \) erg s\(^{-1}\).


intensities of these features are compared with the direct continuum, a rather large covering factor is deduced (see next section).

Further, and even stronger, evidence in favour of a large covering factor comes from a statistical argument. As shown by Maiolino et al. (1998) and Risaliti, Maiolino & Salvati (1999), the fraction of Compton–thick sources is fairly high, being possibly as large as one half of all Seyfert 2 galaxies. (Because the Risaliti, Maiolino & Salvati 1999 sample is based on [OIII] fluxes, this fraction may even be underestimated, as e.g. NGC 6240 and NGC 4945 would have been missed, see below). The covering factor of the Compton–thick matter must, therefore, be large.

3.2 How common are they?

As mentioned above, the fraction of Compton–thick sources among optically-selected Seyfert 2 galaxies is large, 50 per cent at least. As Seyfert 2 galaxies outnumber Seyfert 1 galaxies by a large factor, this means that most AGN are heavily obscured. Moreover, this fraction may be even larger among IR–selected sources. A simple argument may be used for a crude estimate of the fraction of highly obscured AGN.

The three nearest AGN, the Circinus Galaxy, NGC 4945 and Centaurus A are all heavily obscured (Centaurus A has a column density of \(~10^{23}\) cm\(^{-2}\) and an intrinsic 2–10 keV luminosity of \(~6 \times 10^{41} \) erg s\(^{-1}\), e.g. Turner et al. 1997; Grandi et al. 1999). Let us make a simple calculation to estimate the probability to find three AGN within about 4 Mpc. Let us first assume that the density in the nearby Universe is representative of that of the Universe as a whole (the local density within a sphere of radius corresponding to 500 km s\(^{-1}\) is 1.25 times the mean density of the Universe, according to Schlegel et al. 1994). Integrating the Miyaji et al. (1998) local 0.5–2 keV X–ray Luminosity Function (XLF) down to \(~5 \times 10^{41} \) erg s\(^{-1}\) gives a density of \(2 \times 10^{-4} \) Mpc\(^{-3}\). This XLF is dominated by relatively unobscured AGN, with column densities of less than \(10^{22}\) cm\(^{-2}\) or so. The number of AGN
expected from the soft XLF within 4 Mpc is then 0.05, i.e. 60 times less than observed. The probability of observing 3 or more unrelated AGN within that volume is then about $2 \times 10^{-5}$. It is clear that the obscured ($>10^{23} \text{ cm}^{-2}$) sources must outnumber the unobscured ones by a large factor, by about an order of magnitude if the above probability is to rise to one per cent.

A consistency check on this result can be done by comparing the local Infrared Luminosity Function (ILF; Sanders & Mirabel 1996) with the Piccinotti Luminosity Function (XLF; Piccinotti et al. 1982). Heavily obscured AGN are only a minority in the Piccinotti sample, but they should be common in the Infrared one. Therefore, the ratio between the counts in the two bands should give the maximum ratio between obscured and unobscured AGNs. The two LFs have a similar shape. Applying bolometric corrections ($L_{\text{bol}} \sim 10 \times L_{2-10\text{keV}}$ for low luminosity AGNs), it is found that the ILF is about 20 times the XLF. (As ULIRGs have very strong evolution, Kim & Sanders 1998, this number is probably even larger at higher redshift.) Therefore, the number density of heavily obscured AGN may be as much as 20 times that of the unobscured ones, in the local Universe, and even more in the past.

The estimated ratio between obscured and unobscured sources is larger than usually assumed, but it must be remembered that there is increasing evidence that many heavily obscured AGN are simply missed in optical and infrared surveys due to the faintness or even lack of a (visible) Narrow Line Region (NLR: one of the three sources just discussed, NGC 4945, is an example). This point is briefly discussed in the next paragraph.

### 3.3 Optical appearance

Two sources in our sample, NGC 4945 and NGC 6240, are classified, based on optical emission lines ratios, as LINERs rather than Seyfert 2 galaxies (e.g., Veilleux & Osterbrock 1987; Baldwin, Phillips and Terlevich 1981). For these sources, the NLR is either heavily obscured or absent altogether. This suggests that the optical classification may be misleading, not surprisingly as it is based on properties, like the Narrow Line Regions, which after all are secondary and by no means necessary to define an AGN. (It may be worth noting that a similar warning has been given also by Ivison et al. 2000, based on SCUBA sub-mm observations). The fact that heavily obscured sources may lack a visible NLR has several possible consequences. First, estimates of the fraction of Compton–thick sources, being based on [OIII] selected samples (Malolino et al. 1998) may be biased in favour of less obscured sources (or sources with a smaller covering factor). Second, this may (at least partly) explain the difficulties in finding type 2 QSO, when searched for in the optical. NGC 6240 is the classical example, its luminosity being well into the quasar regime. X-ray surveys are certainly the best way of searching for highly obscured, high luminosity sources.

### 4 THE IRON ABUNDANCE

At 10 keV or more, where the photoelectric cut–off occurs for Compton–thick sources, the main absorption opacity is provided by iron, and the detailed spectrum should be dependent on the iron abundance. In the fits described in the previous section, the iron abundance is assumed to be the cosmic one (Anders & Grevesse 1983). However, the metallicity in the environment of an AGN may well be different than in interstellar matter, and there are models of chemical evolution in galaxies which predict a significant metallicity enhancement (Hamann & Ferland 1993; Matteucci & Padovani 1993). From a comparison between the iron line EW and the Compton reflection continuum in a sample of Seyfert 1 galaxies observed by BeppoSAX, an iron abundance close to the cosmic value (say, within a factor of 2 or so) is found (Matt 2000). However, an estimate with an independent method is certainly useful. We therefore explored the possibility to have a significant iron overabundance in the two brightest moderately thick sources, the Circinus Galaxy and NGC 4945.

#### 4.1 The Circinus Galaxy

For the sake of simplicity, we adopted the fitting model in which the spectrum is simply attenuated by absorption and scattering (WABS in XSPEC), corresponding to the physical situation of a small cloud along the line of sight. We substituted the model WABS to WABS, as the former allows for variable element abundances. We first fixed the iron abundance to 5 times the cosmic value, finding an acceptable fit ($\chi^2=122, 119$ d.o.f), but worse than the fit with the iron abundance fixed to the cosmic value, which gives $\chi^2=112/119$ d.o.f.

We then permitted the iron abundance to vary. The fit does not significantly improve, and the best fit value for the iron abundance is, in units of the cosmic value, equal to $1.5\pm0.5$ (90 per cent confidence level). Therefore, we conclude that the iron abundance is consistent with the cosmic value, and constrained to be no more than a factor of 2 larger.

#### 4.2 NGC 4945

The fit with the iron abundance assumed to be 5 times the cosmic value is significantly worse ($\chi^2=94/27$ d.o.f against $\chi^2=35/28$ d.o.f), and completely unacceptable. Leaving the iron abundance free to vary, the improvement in the quality of the fit is marginal, and a best fit value of $1.7^{+0.2}_{-0.2}$ is found. As in Circinus Galaxy, also in NGC 4945 the iron abundance is constrained to be no more than 2 times the cosmic value.

### 5 THE COLD REFLECTOR

The cold reflector is clearly detected in all sources but NGC 6240, where its presence is ambiguous, and NGC 4945, for which only an upper limit can be obtained. The fact that this component is so common is not surprising, as in Compton–thick Seyfert 2 galaxies there is, by definition, optically thick circumnuclear material, and unless the covering factor is small (but see previous section) or the geometry particularly unfavourable, reflection from this material should be observed.

The geometry of the absorber is highly uncertain, but
let us assume the geometry envisaged by Ghisellini, Haardt & Matt (1994), i.e. a torus with a half-opening angle of 30°.

From the ratio between the reflected and direct luminosities it is possible to estimate the inclination angle of the torus, which for Circinus, NGC 6240 (from the best fit value; in this source the Compton reflection component is not strongly required by the data), Mrk 3 and Tololo 0109-383 yields a value smaller than 45°. The only exception among moderately thick sources is NGC 4945, for which the upper limit to the reflection component translates to a lower limit of about 50° to the inclination angle. For NGC 1068 and NGC 7674 this calculation is not possible, because we do not have a measurement of the direct continuum. However, from water maser (Greenhill et al. 1997) and X-ray (Matt et al. 1997) measurements there are reasons to believe that NGC 1068 is observed almost edge-on. The relation between inclination angle and column density is plotted in Fig. 1. Even if the uncertainties on the inclination angles are fairly large, and the estimate admittedly model-dependent, there may be a correlation between the two quantities (dominated, it must be said, by NGC 1068), which is naturally explained if there is a density profile in the torus, matter being more dense in the equatorial plane.

Finally, it is worth noting that the small inclination angles deduced for the moderately thick sources is derived from the rather large ratio between reflected and direct intensities. If the covering factor of the cold matter were much smaller than in our assumed geometry, it would be very difficult to account for the observed values of this ratio. This is a further argument in favour of a large covering factor of the cold circumnuclear matter.

### 6 WHERE DOES THE FLUORESCENT IRON LINE ORIGINATE?

As discussed above, in most sources there is clear evidence for Compton reflection from neutral (or low ionization) matter. It is natural to attribute the fluorescent 6.4 keV iron line to the same matter (e.g. Matt, Brandt & Fabian 1997). However, at least part of the line may arise from transmission rather than reflection, if the column density is not too large. Of course, it is quite possible that the absorbing and reflecting matter are just one and the same medium. In this case, the distinction is between line photons emitted from the inner and directly visible surface of the matter, and those escaping from the outer boundary to reach the observer. If this is the case, the relative importance of reflected and transmitted line photons depends on the geometry of the system (the reflected photons increasing with the fraction of illuminated matter observable to us) and the covering factor of the matter.

To evaluate the relative importance of transmission for the fluorescent iron line, we have calculated, by means of Monte Carlo simulations, the line equivalent width (with respect to the continuum impinging on the inner surface of the absorbing matter) as a function of the column density of the matter, assumed to be spherically distributed. The expected values, as well as the observed ones for the sources for which the column density can be measured, are shown in Fig. 2. The error bars have been calculated considering only the statistical error on the line flux. The error on the continuum is systematic rather than statistic, being largely due to the uncertainty on the modeling of the absorber. For Circinus the calculated value falls dramatically short of the observed one, implying that the dominant line component is the reflected one (see also Matt et al. 1999). The same is probably true for Tololo 0109-383, but here the error bars, especially on the column density, are too large to permit a definite conclusion. On the contrary, for NGC 4945 and Mrk 3 the transmitted component may entirely account for the observed iron line (for Mrk 3, a slight iron underabundance would be even required). While the spectral fitting of NGC 4945 does not actually require a Compton reflection component, for Mrk 3 it appears to be an important ingredient; the only solution to this apparent paradox is that the covering factor of the matter is significantly smaller than 1. For NGC 6240, a reflection component seems also required, but unfortunately the spectral fitting is rather ambiguous in this respect.

### 7 THE IONIZED REFLECTOR(S)

In the X-ray spectrum of some of the sources discussed here there is also evidence for a significant contribution from warm (i.e. mildly ionized) and/or hot (i.e. highly ionized) reflectors. They are best studied by looking at line emission, and therefore BeppoSAX is not the ideal satellite in this respect, even if the broad band has improved our knowledge of the ionized reflector(s) in NGC 1068 (Guainazzi et al. 1999) by better constraining its shape and luminosity, as well as by detecting the O vii emission line. There is no doubt, however, that substantial progress will be achieved by high resolution instruments like gratings and calorimeters.
An intriguing result is the possible detection of energy dependent flux variability in NGC 1068 on the time scale of about a year, best explained in terms of a spectral variation of the ionized reflector component (Guainazzi et al. 2000b). This, if true, implies that the size of the ionized reflector should be of the order of a parsec at most. A more detailed discussion on the implications of this finding can be found in the above paper.

8 COMPARISON WITH THE INFRARED: AGN VS. STARBURST

For the 5 objects in our sample for which we have a measurement of the intrinsic X-ray flux, we can compare it to the IR flux. For the latter, we used the IRAS colours as reported in the NASA/IPAC Extragalactic Database (NED: http://nedwww.ipac.caltech.edu/) apart from Circinus, for which the fluxes were calculated on the basis of ISO results (Moorwood et al. 1996; R. Maiolino and A. Marconi, private communication). In Fig. 3 we show the 2-10 keV emission (corrected for absorption) vs. the IR flux, the latter defined as:

\[ F_{IR} = S_{12} \nu_{12} + S_{25} \nu_{25} + S_{60} \nu_{60} + S_{100} \nu_{100} \]  

(1)

In Fig. 4 we report the IR/X-ray ratio versus an IR colour, defined as \((S_{60} \nu_{60} + S_{100} \nu_{100})/(S_{12} \nu_{12} + S_{25} \nu_{25})\). The ratio is dramatically different from source to source, ranging from 7 for Mrk 3 to 187 for NGC 4945. As can be seen from Fig. 4, this ratio is higher for the sources with the cooler IR colour. A cool colour may indicate either an important contribution from a starburst component or strong absorption at shorter wavelengths. The fact that the IR/X-ray ratio is larger for the cooler sources favours the former hypothesis.

A related question is what is the main source of emitted power, i.e. accretion vs. starlight. For Mrk 3 and Tololo 0109-383, both IR colours and IR/X-rays flux ratio indicate unambiguously that the AGN dominates over starburst. The situation is more complex for the other three sources, which have cooler IR colours suggestive of a strong starburst contribution. As discussed by Vignati et al. (1999), for NGC 6240 the bolometric AGN luminosity derived assuming the Quasar SED of Elvis et al. (1994), i.e. \(L_{bol} \sim 30L_{2-10\text{keV}}\), is of the same order of the IR luminosity. Therefore, a large fraction of the IR flux should arise from the reprocessing of the nuclear UV and X-ray photons, even if a significant
contribution from starburst it is also possible, especially at the longer wavelengths.

For Circinus and NGC 4945 the situation is different. For low-luminosity AGNs like these two Seyferts (which are the sources with the lowest intrinsic L_X in our sample by far), the bolometric correction should be lower (about 10 instead of 30), and it is possible that the IR flux is actually dominated by starburst emission (it is worth noting that the required starburst luminosity for Circinus and NGC 4945 is much lower than that would be required to account for the IR luminosity of NGC 6240)

9 ARE THERE TYPE 2 QSO?

Finally, a few general considerations on the vexed question of the existence of type 2 quasars may be appropriate here. At least two sources in our sample have a 2–10 keV luminosity of order of 10^{44} erg s^{-1}, and therefore, using the SED of Elvis et al. (1994), a bolometric luminosity equal or exceeding 10^{45} erg s^{-1}, well within the Quasar regime (there are also other examples, as listed by Vignati et al. 1999). But even more important is to remark that the QSO 2 debate is largely based on a misunderstanding, as the case of NGC 6240 makes clear. If one assumes the classical optical-spectroscopic classification, NGC 6240 is certainly not a type 2 QSO, since it lacks the emission line spectrum typical of the Narrow Line Region. However, it must not be forgotten that the original classification, even if it has been very useful in the past, is based on AGN properties that are secondary and not needed to define an AGN in the modern sense. In X-ray terminology, a type 2 AGN is simply a source in which the X-ray emitting region (i.e. the black hole and its immediate surroundings) is obscured, no matter if the BLR and NLR are visible or not. Since X-ray emission is a fundamental property of an AGN, a classification based on X-ray properties is clearly to be preferred, being much less ambiguous. Moreover, and contrary to the infrared band, in X-rays accretion is certainly much more important than emission associated with stellar processes. The issue of the fraction and luminosity dependence of “type 2” (or, better, obscured) AGN will therefore be addressed (and hopefully settled) by X-ray surveys like those that will be performed by Chandra and XMM.

10 CONCLUSIONS

Compton–thick Seyfert 2 galaxies are very likely the most common subclass of AGN in the local Universe (Maiolino et al. 1998), and possibly also at high redshifts (Fabian 1999). The hard X-ray band is certainly the best with which to study these sources, because part of the nuclear radiation can penetrate the obscuring matter, if the column density does not exceed a few times 10^{22} cm^{-2}. This is the reason why BeppoSAX has permitted a great advance in this limited but important field. Unfortunately, even this instrument does not allow the exploration of hard X-rays beyond the local Universe, and the cosmological evolution of the column density and covering factor of the absorber, which are important in order to understand the growth of the black holes and its relation with the star formation rate (e.g. Fabian 1999), is still unknown. Moreover, only a small fraction of the extragalactic sky has been covered so far at these energies with sufficient sensitivity, which implies that many sources like NGC 4945 and Circinus are still awaiting discovery. To make significant progresses in this field, a large improvement in sensitivity (like that will be provided by Constellation–X^4), and large area, deep surveys (like that provided by Swift\textsuperscript{\dag} and, even better, that proposed with the EXIST\textsuperscript{\dag\dag} project) are needed.

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REFERENCES

Elvis M., et al., 1994, APJS 95, 1

\textsuperscript{*} http://constellation.gsfc.nasa.gov/
\textsuperscript{\dag} http://swift.gsfc.nasa.gov/
\textsuperscript{\dag\dag} http://hea-www.harvard.edu/EXIST/EXIST.html
G. Matt, et al.

Matt G., Pompiilio F., La Franca F., 1999, New As., 4, 191
Sanders D.B., Mirabel I.F., 1996, ARAA, 34, 749