XMM-Newton observations of Seyfert galaxies from the Palomar spectroscopic survey: the X-ray absorption distribution

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ABSTRACT

We present *XMM-Newton* spectral analysis of all 38 Seyfert galaxies from the Palomar spectroscopic sample of galaxies. These are found at distances of up to 67 Mpc and cover the absorbed 2–10 keV luminosity range $\sim 10^{38}$ – 10^{43} erg s $^{-1}$. Our aim is to determine the distribution of the X-ray absorption in the local Universe. Three of these are Compton-thick with column densities just above 10^{24} cm $^{-2}$ and high equivalent width FeK $_{\alpha}$ lines (>700 eV). Five more sources have low values of the X-ray to [OIII] flux ratio suggesting that they could be associated with obscured nuclei. Their individual spectra show neither high absorbing columns nor flat spectral indices. However, their stacked spectrum reveals an absorbing column density of $N_{\text{H}} \sim 10^{23}$ cm $^{-2}$. Therefore the fraction of absorbed sources ($>10^{22}$ cm $^{-2}$) could be as high as $55 \pm 12\%$. A number of Seyfert-2 appear to host unabsorbed nuclei. These are associated with low-luminosity sources $L_{\text{X}} < 3 \times 10^{41}$ erg s $^{-1}$. Their stacked spectrum again shows no absorption while inspection of the *Chandra* images, where available, shows that contamination from nearby sources does not affect the *XMM-Newton* spectra in most cases. Nevertheless, such low luminosity sources are not contributing significantly to the X-ray background flux. When we consider only the brighter, $>10^{41}$ erg s $^{-1}$, 21 sources, we find that the fraction of absorbed nuclei rises to $75 \pm 19\%$ while that of Compton-thick sources to 15–20%. The fraction of Compton-thick AGN is lower than that predicted by the X-ray background synthesis model in the same luminosity and redshift range.

Key words. surveys – X-rays: galaxies – X-rays: general

1. Introduction

The moderate to high redshift Universe has been probed at unparalleled depth with the most sensitive observations performed at X-ray wavelengths in the *Chandra* Deep fields. The *Chandra* 2Ms observations (Alexander et al. 2003; Luo et al. 2008) resolved about 80 per cent of the extragalactic X-ray light in the hard 2–10 keV band (see Brandt & Hasinger 2005, for a review). These deep surveys find a sky density of 5000 sources per square degree, the vast majority of which are found to be AGN through optical spectroscopy (e.g. Barger et al. 2003). In contrast, the optical surveys for QSOs (e.g. the COMBO-17 survey) reach only a surface density about an order of magnitude lower (e.g. Wolf et al. 2003). This clearly demonstrates the power of X-ray surveys for detecting AGN. This is because hard X-rays can penetrate large amounts of gas without suffering from significant absorption. Indeed detailed spectral analysis on X-ray selected AGN reveals large amount of obscuration (e.g. Akylas et al. 2006; Tozzi et al. 2006; Georgantopoulos et al. 2007). In particular, about two thirds of the X-ray sources, over all luminosities, present column densities higher than 10^{22} cm $^{-2}$. These high absorbing columns are believed to originate in a molecular torus surrounding the nucleus.

However, even the efficient 2–10 keV X-ray surveys may be missing a fraction of highly obscured sources. This is because at very high obscuring column densities ($>10^{24}$ cm $^{-2}$, corresponding to an optical reddening of $A_{\text{V}} > 100$), the X-ray photons with energies between 2 and 10 keV are absorbed. These are the

Compton-thick AGN (see Comastri 2004, for a review) where the Compton scattering on the bound electrons becomes significant. Despite the fact that Compton-thick AGN are abundant in our vicinity (e.g. NGC 1068, Circinus), only a few tens of Compton-thick sources have been identified from X-ray data (Comastri 2004). Although the population of Compton-thick sources remains elusive there is concrete evidence for its presence. The X-ray background synthesis models can explain the peak of the X-ray background at 30–40 keV, where most of its energy density lies, (Frontera et al. 2007; Churazov et al. 2007) only by invoking a large number of Compton-thick AGN (Gilli et al. 2007). Additional evidence for the presence of a Compton-thick population comes from the directly measured space density of black holes in the local Universe. It is found that this space density is a factor of two higher than that predicted from the X-ray luminosity function (Marconi et al. 2004). This immediately suggests that the X-ray luminosity function is missing an appreciable number of obscured AGN.

In recent years there have been many efforts to uncover heavily obscured and in particular Compton-thick AGN in the local Universe by examining IR or optically selected, [OIII], AGN samples. This is because both the IR and the narrow-line region originate beyond the obscuring region and thus represent an isotropic property of the AGN. Risaliti et al. (1999) examine the X-ray properties of a large sample of [OIII] selected Seyfert-2 galaxies whose X-ray spectra were available in the literature. They find a large fraction of Compton-thick sources (over half of their sample). Their estimates are complemented by

more recent *XMM-Newton* observations of local AGN samples (Capri et al. 2006; Panessa et al. 2006; Guainazzi et al. 2005). All these authors also claim a large Compton-thick AGN fraction exceeding 30 per cent of the Seyfert-2 population. The advent of the *SWIFT* and *INTEGRAL* missions which carry X-ray detectors with imaging capabilities (e.g. Barthelmy et al. 2005; Ubertini et al. 2003) in ultra-hard X-rays (15–200 keV) try to shed new light on the absorption properties of AGN in the local Universe. In principle, at these ultra-hard X-rays obscuration should play a negligible role, at least up to column densities as high as 10^{25} cm^{-2} . However, because of the limited effective area the above surveys can provide X-ray samples, down to very bright fluxes $10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$, with limited quality spectra. Again *XMM-Newton* observations are often required to determine the column density in each source. Interestingly, these surveys find only a limited number of Compton-thick sources (Markwardt et al. 2005; Bassani et al. 2006; Malizia et al. 2007; Ajello 2008; Winter et al. 2008; Tueller et al. 2008; Sazonov et al. 2008).

Here, we present *XMM-Newton* observations of all 38 Seyfert galaxies in the Palomar spectroscopic sample of nearby galaxies (Ho et al. 1997). This is the largest complete optically selected AGN sample in the local Universe analyzed so far. 23 of the Seyfert galaxies presented here have already been discussed in previous works (e.g. Capri et al. 2006). For 5 of them newer *XMM-Newton* observations are available and are presented here. The current work should provide the most unbiased census of the AGN column density distribution at low redshifts and luminosities.

2. The sample

The Seyfert sample used in this study is derived from the Palomar optical spectroscopic survey of nearby galaxies (Ho et al. 1995). This survey has taken high quality spectra of 486 bright ($B_T < 12.5$ mag), northern ($\delta > 0^\circ$) galaxies selected from the Revised Shapley-Ames Catalogue of Bright Galaxies (RSAC, Sandage & Tammann 1979) and produced a comprehensive and homogeneous catalogue of nearby Seyfert galaxies. The catalogue is 100% complete to $B_T < 12.0$ mag and 80% complete to $B_T < 12.5$ mag (Sandage et al. 1981).

For the purpose of this work we consider all the Seyfert galaxies from the Palomar survey. Sources lying in-between the Seyfert-Liner or the Seyfert-Transient boundary have been excluded. Furthermore seven Seyfert galaxies (i.e. NGC 1068, NGC 1358, NGC 1667, NGC 2639, NGC 3185, NGC 4235, NGC 5548), which have been included in the Palomar survey for various reasons (see Ho et al. 1995), even though they did not satisfy the survey selection criteria, are also excluded.

There are 40 Seyfert galaxies comprising the optical sample. 9 sources are classified as type-1 (contains types 1, 1.2, 1.5) and 31 as type-2 (contains types 1.8, 1.9, 2) Seyfert galaxies. However NGC 4051, NGC 4395 and NGC 4639 which have been initially classified as Seyfert 1.2, 1.8 and 1 by Ho et al. (1997) has been re-classified as type-1.5, 1 and 1.5 respectively (see Capri et al. 2006; Panessa et al. 2006; Baskin & Laor 2008). Moreover NGC 185 which is classified as a Seyfert-2 may not contain an active nucleus since it presents line intensity ratios possibly produced by stellar processes (Ho & Ulvestad 2001).

The main characteristics of these sources, taken from Ho et al. (1997), are listed in Table 1. Some galaxies listed here present B_T fainter than the formal limit of the Palomar survey. According to Ho et al. (1995) this discrepancy can be attributed to errors in the apparent magnitudes given in the RSAC.

3. X-ray observations

The X-ray data have been obtained with the EPIC (European Photon Imaging Cameras, Strüder et al. 2001; Turner et al. 2001) on board *XMM-Newton*. Thirty sources have been recovered from the *XMM-Newton* archive while the remaining ten objects (marked with a “★” in Table 2) have been observed by us during the Guest Observer program.

The log of all the *XMM-Newton* observations is shown in Table 2. The data have been analysed using the Scientific Analysis Software (SAS v.7.1). We produce event files for both the PN and the MOS observations using the *EPCHAIN* and *EMCHAIN* tasks of SAS respectively. The event files are screened for high particle background periods. In our analysis we deal only with events corresponding to patterns 0–4 for the PN and 0–12 for the MOS instruments.

The source spectra are extracted from circular regions with radius of 20 arcsec. This area encircles at least the 70 per cent of the all the X-ray photons at off-axis angles less than 10 arcmin. A ten times larger source-free area is used for the background estimation. The response and ancillary files are also produced using SAS tasks *RMFGEN* and *ARFGEN* respectively.

We note that 18 of the *XMM-Newton* observations presented here, coincide with these presented in Capri et al. (2006). However we choose to re-analyze these common data-sets in order to present a uniform treatment of the sample.

4. X-ray spectral analysis

We investigate the X-ray properties of the sources in our sample by performing spectral fittings with *XSPEC* v.12.4 software package. 2 sources are excluded from the X-ray spectral analysis: the Seyfert-2 galaxy NGC185 for being undetected in the X-rays (see also Sect. 2), and the Seyfert-1.5 galaxy NGC 1275 which belongs to the Perseus cluster and whose X-ray image shows that its flux is heavily contaminated by diffuse emission.

The X-ray spectra are binned to give a minimum of 15 counts so Gaussian statistics can be applied. We fit the PN and the MOS data simultaneously in the 0.3–10 keV range. However in some cases where a very complex behaviour is present we perform the spectral fits only in the 2–10 keV band. These latter cases are denoted with an asterisk (★) in Table 3.

The normalization parameters for each instrument are left free to vary within 5 per cent in respect to each other to account for the remaining calibration uncertainties.

We assume a standard power-law model with two absorption components ($wa*wa*po$ in *XSPEC* notation) to account for the source continuum emission. The first absorption column models the Galactic absorption. Its fixed values are obtained from Dickey & Lockman (1990) and are listed in Table 3. The second absorption component represents the AGN intrinsic absorption and is left as a free parameter during the model fitting procedure. A Gaussian component has also been included to describe the FeK_α emission line.

When the fitting procedure gives a rejection probability less than 90 per cent we accept the above “standard model”. However when this simple parametrization is not sufficient to model the whole spectrum additional components are included. For example soft-excess emission and reflection are common features in the X-ray spectra of Seyfert galaxies and can be modeled using additional *XSPEC* models.

In particular we fit a second power-law model, with Γ fixed to the direct component value, to account for the scattered X-ray radiation and/or a *Raymond-Smith* to model the contribution from

Table 1. The sample.

Name	α (J2000)	δ (J2000)	B_T (mag)	D (Mpc)	Class
(1)	(2)	(3)	(4)	(5)	(6)
NGC 0185	00 38 57.40	+48 20 14.4	10.10	0.7	S2
NGC 0676	01 48 57.38	+05 54 25.70	10.50	19.5	S2:
NGC 1058	02 43 30.24	+37 20 27.20	11.83	9.1	S2
NGC 1167	03 01 42.40	+35 12 21.00	13.38	65.3	S2
NGC 1275	03 19 48.16	+41 30 42.38	12.64	70.1	S1.5
NGC 2273	06 50 08.71	+60 50 45.01	12.55	28.4	S2
NGC 2655	08 55 38.84	+78 13 25.20	10.96	24.4	S2
NGC 3031	09 55 33.17	+69 03 55.06	7.89	1.4	S1.5
NGC 3079	10 01 58.53	+55 40 50.10	11.54	20.4	S2
NGC 3147	10 16 53.27	+73 24 02.40	11.43	40.9	S2
NGC 3227	10 23 30.58	+19 51 53.99	11.10	20.6	S1.5
NGC 3254	10 29 19.96	+29 29 29.60	12.41	23.6	S2
NGC 3486	11 00 24.10	+28 58 31.60	11.05	7.4	S2
NGC 3516	11 06 47.49	+72 34 06.80	12.50	38.9	S1.2
NGC 3735	11 35 57.49	+70 32 07.70	12.50	41.0	S2:
NGC 3941	11 52 55.42	+36 59 10.50	11.25	18.9	S2:
NGC 3976	11 55 57.35	+06 44 57.00	12.30	37.7	S2:
NGC 3982	11 56 28.10	+55 07 30.50	11.78	17.0	S1.9
NGC 4051	12 03 09.61	+44 31 52.80	11.88	17.0	S1.2
NGC 4138	12 09 29.87	+43 41 06.00	12.16	17.0	S1.9
NGC 4151	12 10 32.57	+39 24 20.63	11.50	20.3	S1.5
NGC 4168	12 12 17.30	+13 12 17.9	12.11	16.8	S1.9:
NGC 4169	12 12 18.93	+29 10 44.00	13.15	50.4	S2
NGC 4258	12 18 57.54	+47 18 14.30	9.10	6.8	S1.9
NGC 4378	12 25 18.14	+04 55 31.60	12.63	35.1	S2
NGC 4388	12 25 46.70	+12 39 40.92	11.76	16.8	S1.9
NGC 4395	12 25 48.93	+33 32 47.80	10.64	3.6	S1.8
NGC 4472	12 29 46.76	+07 59 59.90	9.37	16.8	S2::
NGC 4477	12 30 02.22	+13 38 11.30	11.38	16.8	S2
NGC 4501	12 31 59.34	+14 25 13.40	10.36	16.8	S2
NGC 4565	12 36 21.07	+25 59 13.50	10.42	9.7	S1.9
NGC 4639	12 42 52.51	+13 15 24.10	12.24	16.8	S1
NGC 4698	12 48 22.98	+08 29 14.80	11.46	16.8	S2
NGC 4725	12 50 26.69	+25 30 02.30	10.11	12.4	S2:
NGC 5033	13 13 27.52	+36 35 37.78	10.75	18.7	S1.5
NGC 5194	13 29 52.37	+47 11 40.80	8.96	7.7	S2
NGC 5273	13 42 08.33	+35 39 15.17	12.44	21.3	S1.5
NGC 6951	20 37 14.41	+66 06 19.70	11.64	24.1	S2
NGC 7479	23 04 56.69	+12 19 23.20	11.60	32.4	S1.9
NGC 7743	23 44 21.44	+09 56 03.60	12.38	24.4	S2

Column 1: Galaxy name. Columns 2 and 3: optical coordinates. Column 4: Total apparent B magnitude taken from Ho et al. (1997). Column 5: source distance in Mpc from Ho et al. (1997). Column 6: optical classification from Ho et al. (1997). Quality ratings, are given by “:” and “::” for uncertain and highly uncertain classification.

diffuse emission in the host galaxy. A flattening of the spectrum is usually indicative of reflected radiation from the backside of the torus. The reflected radiation is modelled using the *PEXRAV* model (Magdziarz & Zdziarski 1995). In order to accept the new component we apply the F-test criterion. If the addition of the new component significantly improves the fit at the 90 per cent confidence level, then it is accepted. Other characteristics such as ionized features could also be considered however once a reasonable fit is obtained (i.e. with rejection probability less than 90 per cent) we do not include additional components.

The best fit parameters for all the sources are reported in Table 3. The errors quoted correspond to the 90 per cent confidence level for one interesting parameter. We note here that some of the sources listed show a rather steep photon index. In many cases this happens because of the fixed value of the continuum power-law photon index to the photon index of the soft component (e.g. NGC 1358, NGC 3079, NGC 3735). When these parameters are untied the continuum power-law photon index becomes harder.

18 of the X-ray observations presented here have already been shown in Cappi et al. (2006). In most of these the results are in agreement. However some deviations also appear and are discussed below. In the cases of NGC 3486, NGC 3079, NGC 4051 and NGC 4388 the comparison is not straightforward since we use of a different spectral fitting model. When the same model is applied as a test, there is no significant difference in the results. In the cases of NGC 1058 and NGC 4725 our results show a steeper power-law photon index than that presented in Cappi et al. (2006). However we point out that the results are consistent within the 90 per cent confidence level.

The *XMM-Newton* X-ray spectra of our sources are presented in Fig. 6. For each object the upper panel shows the X-ray spectrum along with the model presented in Table 3 while the lower panel shows the residuals.

5. X-ray absorption

The spectral fitting results are presented in Table 3. There are 8 type-1 Seyferts in our sample. Five of them show small amounts

Table 2. Log of the *XMM-Newton* observations.

Name	Obs. Date	Obs. ID	Exposure			Filter	MOS1	MOS2
			PN	MOS1	MOS2			
NGC 185	2004-01-09	0204790301	–	11393	11334	closed	Medium	Medium
NGC 676	2002-07-14	0112551501	17754	21127	21127	Thick	Thin	Thin
NGC 1058	2002-02-01	0112550201	12902	17019	17019	Medium	Thin	Thin
NGC 1167*	2005-08-04	0301650101	9937	11448	11448	Thin	Thin	Thin
NGC 1275	2006-01-29	0305780101	119697	124801	124832	Medium	Medium	Medium
NGC 2273	2003-09-05	0140951001	11076	12709	12714	Medium	Medium	Medium
NGC 2655*	2005-09-04	0301650301	9850	11564	11570	Thin	Thin	Thin
NGC 3031	2001-04-22	0111800101	129550	82790	83150	Medium	Medium	Medium
NGC 3079	2001-04-13	0110930201	20023	24661	24663	Thin	Medium	Medium
NGC 3147	2006-10-06	0405020601	14963	16923	16912	Thin	Thin	Thin
NGC 3227	2000-11-28	0101040301	34734	37198	37201	Medium	Medium	Medium
NGC 3254*	2005-10-31	0301650401	9869	11489	11481	Thin	Thin	Thin
NGC 3486	2001-05-09	0112550101	9057	6398	6385	Medium	Thin	Thin
NGC 3516	2001-11-09	0107460701	12829	12901	12900	Thin	Thin	Thin
NGC 3735*	2005-09-27	0301650501	9312	16466	16471	Thin	Thin	Thin
NGC 3941	2001-05-09	0112551401	9389	14635	14331	Medium	Thin	Thin
NGC 3976*	2006-06-16	0301651801	11313	13483	13598	Thin	Thin	Thin
NGC 3982	2004-06-15	0204651201	10197	11674	11679	Thin	Thin	Thin
NGC 4051	2002-11-22	0157560101	49808	51510	51520	Medium	Medium	Medium
NGC 4138	2001-11-26	0112551201	9999	14365	14365	Medium	Thin	Thin
NGC 4151	2003-05-26	0143500201	18454	18602	18607	Medium	Medium	Medium
NGC 4168	2001-12-04	0112550501	18498	22864	22849	Medium	Thin	Thin
NGC 4169*	2006-06-20	0301651701	11068	12695	12701	Thin	Thin	Thin
NGC 4258	2006-11-17	0400560301	62607	64179	64184	Medium	Medium	Medium
NGC 4378*	2006-01-08	0301650801	10963	12602	12604	Thin	Thin	Thin
NGC 4388	2002-12-12	0110930701	8292	11666	11666	Thin	Medium	Medium
NGC 4395	2003-11-30	0142830101	10596	10942	10940	Medium	Medium	Medium
NGC 4472	2004-01-01	0200130101	89503	94179	94185	Thin	Thin	Thin
NGC 4477	2002-06-08	0112552101	9500	13501	13527	Medium	Thin	Thin
NGC 4501	2002-06-08	0112550801	2885	13387	13385	Medium	Thin	Thin
NGC 4565	2001-07-01	0112550301	10010	14261	14263	Medium	Thin	Thin
NGC 4639	2001-12-16	0112551001	10000	14365	14265	Medium	Thin	Thin
NGC 4698	2001-12-17	0112551101	11755	16112	16112	Medium	Thin	Thin
NGC 4725	2002-06-14	0112550401	13369	17244	17244	Medium	Thin	Thin
NGC 5033	2002-12-18	0094360501	9999	11616	11614	Medium	Medium	Medium
NGC 5194	2003-01-15	0303420101	19047	49944	49351	Thin	Thin	Thin
NGC 5273	2002-06-14	0112551701	10392	16065	16094	Medium	Thin	Thin
NGC 6951*	2005-06-05	0301651401	7951	9664	9669	Thin	Thin	Thin
NGC 7479*	2005-06-05	0301651201	12315	15740	15750	Thin	Thin	Thin
NGC 7743*	2005-06-15	0301651001	11847	13283	13348	Thin	Thin	Thin

Column 1: name of the Galaxy. Column 2: start observation date (UTC). Column 3: observation identifier. Columns 3–5: net exposure time for the EPIC instruments. Columns 6–8: applied filter. * Denotes sources observed during our Guest Observer program.

of absorption ($<10^{21} \text{ cm}^{-2}$) while the 3 Seyfert-1.5 sources (NGC 3227, NGC 3516, and NGC 4151) present a considerable amount of $N_{\text{H}}(>10^{22} \text{ cm}^{-2})$. Our sample contains 30 Seyfert-2 galaxies. The column densities in this population vary from the Galactic to the Compton-thick limit ($N_{\text{H}} > 10^{24} \text{ cm}^{-2}$). However, the apparent number of significantly obscured sources is rather small. Only 12 out of 30 type-2 sources present absorption greater than 10^{22} cm^{-2} .

5.1. Compton-thick sources

The fraction of Compton-thick sources is more difficult to estimate. This is because the *XMM-Newton* effective area sharply decreases at energies higher than 6 keV. Given the limited *XMM-Newton* bandpass, which extends up to about 10 keV, we are not able to measure the absorption turnover for highly absorbed sources. A column density of $\sim 10^{24} \text{ cm}^{-2}$ suppresses 90% of the flux in the 2–10 keV band. Therefore, we can obtain a direct measurement of the obscuration only up to column

densities reaching at most a few times 10^{24} cm^{-2} . In the case of Compton-thick AGN the X-ray spectrum is dominated by scattered components from cold or warm material as well as an FeK_{α} with high equivalent width (Matt et al. 2000). Then to unveil the presence of a Compton-thick nucleus we apply the following diagnostics.

- Flat X-ray spectrum ($\Gamma < 1$). This implies the presence of a strong reflection component, which intrinsically flattens the X-ray spectrum at higher energies (e.g. Matt et al. 2000).
- High Equivalent Width of the FeK_{α} line ($\sim 1 \text{ keV}$). This characteristic is consistent with a Compton-thick nucleus since then the line is measured against a much depressed continuum (Leahy & Creighton 1993) or a pure reflected component.
- Low X-ray to optical flux ratio. Bassani et al. (1999) have showed that the 2–10 KeV to the [OIII] $\lambda 5007$ flux ratio is very effective in the identification of Compton-thick sources. This is because the [OIII] $\lambda 5007$ (hereafter [OIII]) flux which

Table 3. Spectral fits.

Name (1)	$N_{\text{H,GAL}}$ (2)	N_{H} (3)	Γ_{cont} (4)	kT (5)	EW_{FeK} (6)	F_{X} (7)	L_{X} (8)	f_{scat} (9)	f_{refl} (10)	χ^2_{ν} (11)
NGC 676	4.7	<0.13	$2.10^{+0.50}_{-0.27}$	—	—	1.12	0.05	—	—	22.5/17
NGC 1058	5.4	<0.53	$3.40^{+2.65}_{-1.69}$	—	—	0.24	0.02	—	—	31.1/34
NGC 1167	9.8	$0.32^{+0.08}_{-0.41}$	$2.10^{+0.50}_{-0.27}$	$0.33^{+0.08}_{-0.04}$	—	0.9	0.4	—	—	22.52/17
NGC 2273	6.4	$104.70^{+15.90}_{-7.36}$	$1.84^{+0.12}_{-0.05}$	$0.77^{+0.08}_{-0.13}$	1500^{+303}_{-240}	89.4	8.5	0.01	1.35	125.1/114
NGC 2655	2.2	$42.69^{+5.68}_{-5.30}$	$2.61^{+0.30}_{-0.26}$	$0.73^{+0.30}_{-0.26}$	110.4	0.01	7.8	—	—	240.1/194
NGC 3031*	5.6	$0.05^{+0.02}_{-0.01}$	$1.91^{+0.02}_{-0.08}$	$1.10^{+0.02}_{-0.02}$	53^{+11}_{-14}	1164.7	0.3	—	—	1439.9/1350
NGC 3079	0.9	$201^{+28.5}_{-89.8}$	$2.56^{+0.22}_{-0.23}$	$0.84^{+0.02}_{-0.03}$	700^{+200}_{-210}	38.4	1.8	0.01	0.14	301.9/245
NGC 3147	2.9	$0.07^{+0.01}_{-0.01}$	$1.56^{+0.04}_{-0.03}$	—	144^{+101}_{-55}	155.8	31.1	—	—	562.1/585
NGC 3227	2.0	$6.42^{+0.15}_{-0.17}$	$1.44^{+0.04}_{-0.04}$	—	152^{+22}_{-41}	866.3	43.9	0.06	10.12	2089.4/2082
NGC 3254	1.8	<0.12	1.9 (fixed)	—	—	0.7	0.05	—	—	4.23/5
NGC 3486	1.7	$8.42^{+28.9}_{-4.17}$	1.9 (fixed)	$0.37^{+0.06}_{-0.05}$	—	8.5	0.06	—	—	30.29/44
NGC 3516*	3.5	$1.04^{+0.32}_{-0.49}$	$1.58^{+0.02}_{-0.04}$	—	180^{+13}_{-16}	1460.3	264.1	—	—	2483.9/2056
NGC 3735	1.3	$15.23^{+55.43}_{-10.17}$	$2.85^{+0.67}_{-0.49}$	—	—	17.21	3.4	0.11	—	139.7/131
NGC 3941	1.9	<0.09	$2.02^{+0.35}_{-0.24}$	—	—	4.19	0.2	—	—	87.97/84
NGC 3976	1.1	$0.12^{+0.07}_{-0.06}$	$2.01^{+0.04}_{-0.03}$	—	—	7.3	1.2	—	—	109.42/109
NGC3982	1.0	$43.23^{+28.11}_{-16.96}$	$2.53^{+0.44}_{-0.42}$	$0.28^{+0.04}_{-0.04}$	802^{+678}_{-420}	16.60	0.6	0.025	—	109.42/109
NGC 4051*	1.2	$0.53^{+0.21}_{-0.35}$	$2.08^{+0.11}_{-0.18}$	—	155^{+14}_{-18}	650.32	22.4	—	9.7	2315.34/2225
NGC 4138	1.3	$8.85^{+0.41}_{-0.44}$	$1.63^{+0.05}_{-0.05}$	—	80^{+41}_{-34}	554.3	19.1	0.009	—	473.04/449
NGC 4151*	2.3	$5.14^{+0.13}_{-0.14}$	$1.55^{+0.03}_{-0.03}$	—	69^{+11}_{-10}	21000.5	1034.4	—	2.54	109.42/109
NGC 4168	2.4	<0.06	$2.02^{+0.14}_{-0.12}$	—	—	0.6	0.2	—	—	72.2/73
NGC 4169	1.7	$13.47^{+6.07}_{-3.31}$	$2.01^{+0.79}_{-0.44}$	—	—	23.5	6.9	0.017	—	22.87/30
NGC4258*	1.6	$6.8^{+0.35}_{-0.28}$	$1.62^{+0.07}_{-0.05}$	—	41^{+17}_{-19}	380.9	2.1	—	—	1227.17/1258
NGC4378	1.7	$0.18^{+0.06}_{-0.06}$	$1.55^{+0.19}_{-0.15}$	—	—	14.7	2.1	—	—	31.84/38
NGC4388	2.6	$32.14^{+1.19}_{-1.05}$	$1.86^{+0.09}_{-0.08}$	—	173^{+15}_{-32}	2007.3	70.8	0.006	—	1050.7/923
NGC 4395*	1.9	$1.02^{+0.11}_{-0.10}$	$1.18^{+0.03}_{-0.02}$	—	80^{+16}_{-9}	590.5	1.2	—	—	2298.85/2008
NGC 4472*	1.5	<0.82	$1.65^{+0.26}_{-0.14}$	$0.87^{+0.15}_{-0.11}$	—	21.5	0.7	—	—	283.25/292
NGC 4477	2.4	<0.02	$2.12^{+0.25}_{-0.17}$	$0.41^{+0.04}_{-0.16}$	—	3.7	0.1	—	—	62.9/58
NGC 4501	2.6	<0.06	$1.95^{+0.19}_{-0.18}$	$0.66^{+0.01}_{-0.01}$	—	0.6	0.2	—	—	40.31/32
NGC 4565	1.2	$0.16^{+0.03}_{-0.03}$	$1.87^{+0.14}_{-0.09}$	—	—	20.7	0.2	—	—	102.5/88
NGC 4639	2.2	<0.04	$1.79^{+0.06}_{-0.05}$	—	—	48.2	1.6	—	—	268.42/250
NGC 4698	1.8	<0.07	$1.73^{+0.22}_{-0.27}$	—	—	4.8	0.1	—	—	33.82/33
NGC 4725	0.8	<0.03	$2.68^{+0.27}_{-0.23}$	$0.23^{+0.03}_{-0.03}$	—	2.3	0.04	—	—	64.4/71
NGC5033	1.1	<0.04	$1.72^{+0.02}_{-0.02}$	—	286^{+81}_{-71}	—	440.6	18.3	—	999.1/974
NGC 5194*	1.8	< 0.65	$1.16^{+0.14}_{-0.23}$	—	1730^{+422}_{-275}	25.5	0.2	—	—	89.33/91
NGC 5273*	0.9	$0.72^{+0.07}_{-0.09}$	$1.44^{+0.07}_{-0.09}$	—	191^{+52}_{-72}	706.7	38.2	—	—	612.24/635
NGC 6951	12.4	$0.40^{+0.31}_{-0.15}$	$2.59^{+0.53}_{-0.30}$	$0.67^{+0.16}_{-0.18}$	—	4.8	0.3	—	—	32.33/55
NGC 7479	5.3	$40.2^{+11.44}_{-8.75}$	$2.56^{+0.15}_{-0.16}$	$0.27^{+0.07}_{-0.07}$	480^{+210}_{-390}	22.5	2.8	0.004	—	137.3/133
NGC 7743	4.8	$0.3^{+0.18}_{-0.14}$	$3.63^{+1.14}_{-1.03}$	$0.23^{+0.06}_{-0.06}$	—	1.0	0.07	—	—	16.7/18

Column 1: Galaxy name. Column 2: galactic column density in units of 10^{20} cm^{-2} . Column 3: observed column density in units of 10^{22} cm^{-2} . Column 4: power-law photon index of the continuum emission. Column 5: temperature of the Raymond-Smith model. Column 6: equivalent width of the FeK_{α} emission. Column 7: observed 2–10 keV flux in units of $10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2}$. Column 8: observed 2–10 keV luminosity in units of $10^{40} \text{ erg s}^{-1}$. Column 9: ratio of the normalizations of the scattered to the continuum emission. Column 10: ratio of the normalizations of the reflected to the continuum emission. Column 11: reduced χ^2 . * Indicates source with very complex spectra for which only a rough parametrization in the 2–10 keV band is presented here.

comes from large (usually kpc) scales, remains unabsorbed while the X-ray flux is diminished because of absorption.

These criteria however should be considered with caution. For example high Equivalent Width (EW) lines may also appear in the case of anisotropic distribution of the scattering medium (Ghisellini et al. 1991), or in the case where there is a time

lag between the reprocessed and the direct component (e.g. NGC 2992, Weaver et al. 1996). Also there have been reports of Compton-thick sources where the value of FeK_{α} line EW is well below 1 keV (e.g. Awaki et al. 2000, for Mkn1210).

In Fig. 1 we plot the column density obtained from the spectral fittings as a function of the X-ray to optical flux ratio,

Fig. 1. Distribution of the N_{H} values as a function of the $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ ratio. Filled boxes and circles denote Seyfert-1 and Seyfert-2 galaxies respectively. The triangles show Seyfert-2 galaxies with large $EW(>700 \text{ eV})$. The solid lines represent the mean N_{H} vs. $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ relation followed by the Seyfert-1 in our sample together with the $\pm 3\sigma$ dispersion (see text).

$F_{2-10 \text{ keV}}/F_{\text{[OIII]}}$. The [OIII] fluxes are corrected for the optical reddening using the formula described in Basanni et al. (1999): $F_{\text{[OIII]COR}} = F_{\text{[OIII]OBS}}[(H_{\alpha}/H_{\beta})/(H_{\alpha}/H_{\beta})_0]^{2.94}$, where the intrinsic Balmer decrement $(H_{\alpha}/H_{\beta})_0$ equals 3.

The solid lines in Fig. 1 show the expected correlation between these quantities, assuming a photon index of 1.8 and 1% reflected radiation (see also Maiolino et al. 1998; Cappi et al. 2006). The starting point in the x-axis for the middle solid line is determined by averaging the $F_{2-10\text{ keV}}/F_{[\text{OIII}]}$ values of the Seyfert-1 population only, while the lines at right and left show the 3σ dispersion. The sources occupying the low ($F_{2-10\text{ keV}}/F_{[\text{OIII}]}$, N_{H}) region in this plot could be possibly highly obscured or Compton-thick AGN.

In two cases (NGC 2273, NGC 3079) we can immediately tell the presence of a Compton-thick nucleus through the presence of an absorption turnover in the spectral fittings. Both sources present high values of the FeK_α line EW (>700 eV). One more source (NGC 5194), despite the fact that it presents the highest value of FeK_α (~ 1700 eV), shows no absorption at all. However, the very flat X-ray spectrum and the very low $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ value further suggest that this is a highly obscured or a Compton-thick source. According to the $N_{\text{H}}-F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ relation a minimum value for the N_{H} is $4 \times 10^{23} \text{ cm}^{-2}$ (see Fig. 1).

There are also 5 Seyfert-2 galaxies (NGC 676, NGC 1167, NGC 3254, NGC 6951 and NGC 7743) occupying the low $F_{2-10 \text{ keV}}/F_{\text{[OIII]}}$ regime. We do not consider NGC 4169 because of the large error in the estimation of the [OIII] flux (see Ho et al. 1997). These, according to the expected $N_{\text{H}}-F_{2-10 \text{ keV}}/F_{\text{[OIII]}}$ relation, should present high values of N_{H} . According to Fig. 1, the minimum N_{H} value is $\sim 2 \times 10^{23} \text{ cm}^{-2}$ for NGC 676, $\sim 6 \times 10^{23} \text{ cm}^{-2}$ for NGC 6951 and $\sim 10^{24} \text{ cm}^{-2}$ for NGC 1167 and NGC 7743. However, the X-ray spectral fittings show low absorption ($< 10^{22} \text{ cm}^{-2}$) while in addition there is no indication for a flat photon index or strong FeK $_{\alpha}$ line. This may be due to the limited photon statistics in the hard ($> 2 \text{ keV}$) band, which

Fig. 2. Stacked X-ray spectrum of the Seyfert-2 Galaxies NGC 0676, NGC 1167, NGC 3254, NGC 6951 and NGC 7743. The best fit model and residuals are also shown.

Fig. 3. The estimated N_{H} distribution of the Seyfert galaxies in our sample (solid line). The vertical arrows in the last N_{H} bin ($\text{Log}(N_{\text{H}}) > 24 \text{ cm}^{-2}$) show the upper and the lower limits for the number of the Compton-thick sources in our sample.

does not allow us to examine in detail the spectral characteristics. Note however, that in the spectrum of at least two sources (NGC 1167 and NGC 7743) there is some indication for a flattening at hard energies which could suggest a heavily buried or reflected component. We investigate further this issue by deriving the mean, stacked X-ray spectrum. We use the *MATHPHA* tasks of *FTOOLS* to derive the weighted stacked X-ray spectrum of the five EPIC-PN observations. The corresponding ancillary files are also produced using *ADDRMF* and *ADDARF* tasks of *FTOOLS*. We perform no correction for the rest-frame energy because the differences in the redshifts are negligible. An absorbed power-law model plus a Gaussian line and a soft excess component (Raymond-Smith model) reproduce well the mean spectrum (Table 4). In Fig. 2 we present the data along with the best-fit. The average spectrum shows significant absorption consistent with the measured value of the FeK_α line EW.

Our results above can be summarised as follows. The number of absorbed nuclei ($N_{\text{H}} > 10^{22} \text{ cm}^{-2}$) are 21 out of 38 or $55 \pm 12\%$. The number of Compton-thick sources is three i.e. $8 \pm 5\%$ although, if we adopt the extreme case where all the low $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ host Compton-thick nuclei this number would rise to 8 or $21 \pm 7\%$. Our estimates on the amount of N_{H} in the local universe are illustrated in Fig. 3. The solid line describes

Table 4. The stacked X-ray spectrum of the 5 Seyfert-2 galaxies with low $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$.

N_{H} (cm^{-2})	Γ	kT (keV)	EW_{FeK} (eV)	χ^2_{ν}
$10.30^{+2.01}_{-1.91}$	$1.71^{+0.08}_{-0.17}$	$0.73^{+0.13}_{-0.12}$	255^{+243}_{-146}	72.41/91

Fig. 4. The derived N_{H} distribution of the Seyfert galaxies in the bright (solid line) and the faint (dashed line) sub-samples. The vertical arrows in the Compton-thick regime ($\text{Log}(N_{\text{H}}) > 24 \text{ cm}^{-2}$) define the upper and lower limit for the number of the Compton-thick sources in our sample.

the N_{H} distribution. The vertical arrows in the highest N_{H} bin show the upper and lower limits for the number of Compton-thick sources.

5.2. The absorption in the bright sub-sample

Our findings should play an important role to the XRB synthesis models (Comastri et al. 1995; Gilli et al. 2007). Gilli et al. (2007) assume in their models a lower luminosity of $10^{41} \text{ erg s}^{-1}$. However, the intrinsic 2–10 keV luminosity of our sources starts from as low as a few times $10^{38} \text{ erg s}^{-1}$ which is about 3 orders of magnitude lower. Therefore it is useful to present our results separately for the fainter ($L_{2-10 \text{ keV}} < 10^{41} \text{ erg s}^{-1}$) and the brighter ($L_{2-10 \text{ keV}} > 10^{41} \text{ erg s}^{-1}$) sub-sample containing 21 and 17 sources respectively (see Fig. 4). The intrinsic L_{X} values are determined using the best fitting results. For the three Compton-thick sources the intrinsic L_{X} has been estimated assuming that 1% of the intrinsic luminosity is actually observed below 10 keV due to scattering and or reflection (e.g. Comastri 2004). In the bright sample the fraction of the highly absorbed sources is $\sim 75\%$ and the Compton-thick sources most probably account for 15–20% of the total population. This fraction can reach a maximum of 29 % in the unlikely case where all the low $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ sources host a Compton-thick nucleus.

5.3. Unabsorbed Seyfert-2 galaxies

The X-ray spectral analysis reveals several Seyfert-2 galaxies with very little or no X-ray absorption. As we have already discussed some of these, i.e. the five with low X-ray to [OIII] flux ratio are most probably associated with a highly obscured or even a Compton-thick nucleus. In Fig. 1 there are 12 additional Seyfert-2 galaxies (NGC 1058, NGC 3147, NGCC 3941, NGC 3976, NGC 4168, NGC 4378, NGC 4472, NGC 4477, NGC 4501, NGC 4565, NGC 4698 and NGC 4725) with N_{H} less than 10^{22} cm^{-2} but an average $F_{2-10 \text{ keV}}/F_{[\text{OIII}]}$ value. This behaviour is not unknown (e.g. Pappa et al. 2001;

Glozzi et al. 2007). In particular NGC 3147 is a well established example, through simultaneous optical and X-ray observations, of a spectroscopically classified Seyfert-2 galaxy with very little or no absorption (Bianchi et al. 2008). NGC 4698 and NGC 4565 have also been discussed to be good candidates, (see Georgantopoulos & Zezas 2003; Panessa & Bassani 2002).

It is possible that some of our new unabsorbed candidates are contaminated by nearby luminous X-ray sources that we are unable to resolve owing to the X-ray telescope’s angular resolution. An inspection of the available *Chandra* images which have a superior resolution (0.5 arcsec FWHM) could be very helpful towards this direction. All but three sources (NGC 3941, NGC 3976 and NGC 4378) present archival *Chandra* data. Although a detailed analysis of the properties of the unabsorbed Seyfert-2 galaxies is the scope of a forthcoming paper, we briefly report on whether there is any evidence for contamination. NGC 1058 and NGC 4168 are significantly contaminated from nearby luminous X-ray sources (see also Foschini et al. 2002; Cappi et al. 2006) while NGC 4472 suffers from very strong diffuse emission. Finally, inspection of *XMM-Newton* images show that NGC 3941 and NGC 4501 are contaminated (less than 30% of the counts) by nearby sources (see also Foschini et al. 2002; Cappi et al. 2006).

We further try to examine the X-ray properties of unobserved Seyfert-2 galaxies by deriving their stacked spectrum. We use *MATHPHA* task of *FTOOLS* software to create the weighted mean X-ray spectrum of the EPIC-PN observations. Weighted mean ancillary files are produced using the *ADDRMF* and *ADDARF* tasks of *FTOOLS*. NGC 3147, NGC 4565 and NGC 4698 are not considered in the mean spectrum since there is already evidence that they do not present any absorption. We also exclude the five contaminated sources leaving the cases of NGC 3976, NGC 4725, NGC 4378 and NGC 4477 to be considered.

We try to detect any spectral feature, such as the FeK_{α} line, that could give away the presence of a hidden nucleus in this population as marginally suggested in some cases (e.g. Brightman & Nandra 2008). We fit the average spectrum with an absorbed power-law model plus a Raymond-Smith model. The spectral fitting results are listed in table 5. There is no significant evidence for the presence of an FeK_{α} emission line. Nevertheless, if we choose to include a Gaussian component, the upper limit of the EW is $\sim 600 \text{ eV}$ at the 90 per cent confidence level. In Fig. 6 we present the mean spectrum along with the best fit model and the residuals. Assuming that all these sources are truly unabsorbed Seyfert-2 galaxies then their total fraction accounts for ~ 20 per cent of the total population.

It has been proposed that the unabsorbed Seyfert-2 galaxies are “naked” nuclei i.e. they lack a Broad-Line-Region, BLR, (see Ho 2008, for a review). Various theoretical models could explain this behaviour. Nicastro (2000) presented a model which relates the width of the Broad Emission Lines of AGN to the Keplerian velocity of an accretion disk at a critical distance from the central black hole. Under this scheme the Broad Line Region is linked to the accretion rate of the AGN i.e. below a minimum accretion rate the BLR cannot form. Recently Elitzur & Shlosman (2006) presented an alternative model which depicts the torus as

Table 5. The stacked X-ray spectrum of the unabsorbed Seyfert-2 galaxies.

N_{H} (cm^{-2})	Γ	kT (keV)	EW_{FeK} (eV)	χ^2_{ν}
<0.1	$2.02^{+0.18}_{-0.15}$	$0.37^{+0.07}_{-0.08}$	<600	118.6/125

Table 6. Accretion rates and luminosities for the unabsorbed Seyfert-2 galaxies.

Name	$\text{Log}(M_{\text{BH}}/M_{\odot})$	$\text{Log}(L_{\text{BOL}})$	$L_{\text{BOL}}/L_{\text{EDD}} \times 10^{-4}$
NGC 1058	4.9	39.8	5.5
NGC 3147	8.8	43.0	1.1
NGC 4168	7.9	41.3	0.15
NGC 4378	7.9	41.8	0.50
NGC 4472	8.8	41.4	0.026
NGC 4477	7.9	40.5	0.025
NGC 4501	7.9	41.3	0.17
NGC 4725	7.5	40.1	0.027
NGC 4565	7.7	40.8	0.084
NGC 4698	7.8	40.5	0.030

Column 1: name. Column 2: black hole mass in units of Solar Masses. Column 3: bolometric luminosity in units of erg s^{-1} . Column 4: accretion rate $L_{\text{BOL}}/L_{\text{EDD}}$. **Fig. 6.** Stacked X-ray spectrum of the unabsorbed Seyfert-2 Galaxies. The best fit model and the residuals are also shown.

the inner region of clumpy wind outflowing from the accretion disc. According to this model the torus and the BLR disappear when the bolometric luminosity decreases below $\sim 10^{42} \text{ erg s}^{-1}$ because the accretion onto the central black hole can no longer sustain the required cloud outflow rate.

In Table 6 we try to compare our results with the above model predictions. In Col. 1 we give an estimate for the mass of the central Black Hole, taken from Panessa et al. (2006) and McElroy (1995). The mass estimation is inferred from the mass-velocity dispersion correlation. In the case of NGC 3976 there is no information available in the literature. In Col. 2 we calculate the bolometric luminosities using the corrections determined by Elvis et al. (1994) i.e., $L_{\text{BOL}} = 35 \times L_{2-10 \text{ keV}} \text{ erg s}^{-1}$. In Col. 3 we give the accretion rate estimator given by $L_{\text{BOL}}/L_{\text{EDD}} \approx 1.3 \times 10^{38} M/M_{\odot}$. The Eddington Luminosity (L_{EDD}) is given by $L_{\text{EDD}} = 4\pi G M m_p c / \sigma_T$ where M is the black hole mass, m_p is the proton mass, σ_T is the Thomson scattering cross section.

All the sources present very low accretion rates, well below the threshold of $1-4 \times 10^{-3}$ proposed by Nicastro (2000) and Nicastro et al. (2003). Furthermore all these sources (but NGC 3147) present very low bolometric luminosities also below

the critical value of $10^{42} \text{ erg s}^{-1}$ predicted by Elitzur & Shlosman (2006). This supports the idea that the key parameter is not the orientation but an intrinsic parameter (low accretion rate or luminosity), which prevents the formation of the BLR.

6. Discussion

6.1. Comparison with other optically selected samples

In this work we present *XMM-Newton* observations of all the Seyfert galaxies from the Palomar survey (Ho et al. 1995). We find that ~ 50 per cent of the Seyfert population is absorbed by $N_{\text{H}} > 10^{22} \text{ cm}^{-2}$. In this sample we have identified 3 Compton-thick sources which translates to a fraction of ~ 8 per cent. Five more sources possibly host a highly absorbed or a Compton thick nucleus. In the very extreme, and rather unlikely case were all these candidates are true Compton-thick sources their fraction reaches 20 per cent of the total population.

Cappi et al. (2006) and Pannessa et al. (2006), also using data from the Palomar survey, provide estimates for the fraction of obscured AGN in the local universe. These authors find that about 50% of their sources are obscured ($>10^{22} \text{ cm}^{-2}$). Their estimates on the fraction of Compton thick sources suggest an absolute minimum of 20 per cent of the total population. This result comes in contradiction with our findings. However their sample includes 2 objects not fulfilling the Palomar Survey selection criteria (see also Sect. 2). These are the 2 Compton-thick AGN NGC 1068 and NGC 3185. When we exclude these an agreement is found.

Risaliti et al. (1999) study the X-ray absorption in a sample of 45 Seyfert-2 galaxies finding that a considerable fraction of these are associated with Compton-thick nuclei. A direct comparison with our results is not straightforward since these authors exclude all the sources with $F_{[\text{OIII}]}$ $> 4 \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$. However we think that only a luminosity cutoff could reveal column density distribution of the population that contributes to the XRB (see Sect. 5.2).

6.2. X-ray background synthesis models

The XRB synthesis models can provide tight constraints on the number density of Compton-thick sources. These models attempt to fit the spectrum of the X-ray background roughly in

Fig. 6. The *XMM-Newton* X-ray spectra for all the sources in our sample. *The upper panel* shows the X-ray spectrum and the best fit model listed in Table 3 and the lower panel the residuals.

the 1–100 keV range. It is well established that a large number of Compton-thick sources is needed (Gilli et al. 2007; but see Treister et al. 2009) to reproduce the hump of the X-ray background spectrum at 30–40 keV where most of its energy density

lies (Churazov et al. 2007; Frontera et al. 2007). Here, we compare the fraction of the Compton-thick sources predicted by the model of Gilli et al. (2007) with our results. We use the publicly

Fig. 6. continued.

available POMPA software¹. This predicts the number counts at a given redshift, flux and luminosity range using the best-fit

results for the fraction of obscured, Compton-thick sources, of the X-ray background synthesis model of Gilli et al. (2007).

¹ www.bo.astro.it/~gilli/counts.html

Fig. 6. continued.

We restrict the comparison to low redshifts $z < 0.017$ and X-ray luminosities in the bin $10^{41} < L_{2-10 \text{ keV}} < 10^{44}$. As our

sample is not flux limited in the X-rays, we have to choose a flux limit deep enough to ensure that all sources in this luminosity

Fig. 6. continued.

and redshift bin are detected. A flux limit of $10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$ satisfies this constraint. The X-ray background synthesis models predict a fraction of Compton-thick sources of about 40%

which is higher compared with our results $15 \pm 8\%$. Only if all the low $F_X/F_{\text{[OIII]}}$ Seyfert-2 galaxies are associated with a

Fig. 6. continued.

Compton-thick nuclei the discrepancy would become less pronounced.

Optically selected samples can still miss a fraction of Compton-thick AGN. For example, NGC 6240 is classified as a LINER in the optical while *BeppoSAX* observations show the presence of a Compton-thick nucleus (Vignati et al. 1999). Moreover *SUZAKU* observations (Ueda et al. 2007; Comastri et al. 2007) have demonstrated that a small fraction of AGN may have a 4π coverage, instead of the usually assumed toroidal structure. These sources will not exhibit the usual high excitation narrow emission lines and therefore will not be classified as AGN on the basis of their optical spectrum.

Recent results based on *INTEGRAL* and *SWIFT* observations reveal a small fraction of Compton-thick sources (e.g. Treister et al. 2009; Sazonov et al. 2008; Sazonov et al. 2007; Ajello et al. 2008). In particular at the flux limit of $\sim 10^{-11}$ erg cm $^{-2}$ s $^{-1}$ in the

17–60 keV energy band, *INTEGRAL* observations find 10–15% Compton-thick sources. The *SWIFT*/BAT hard X-ray survey failed to identify any Compton-thick AGN. This non detection discards the hypothesis that their fraction accounts for the 20 per cent of the total AGN at $>2\sigma$ confidence level. It is true however that some heavily obscured Compton-thick sources with $N_H \sim 10^{25-26}$ cm $^{-2}$ would be missed even by these ultra hard X-ray surveys.

6.3. Less absorption at very low luminosities

In the low-luminosity sub-sample (intrinsic L_{2-10} keV $< 10^{41}$ erg s $^{-1}$) the fraction of obscured sources diminishes to 30%. This result comes in apparent contradiction with recent findings suggesting an increasing fraction of obscuration with decreasing luminosity (e.g. Akylas et al. 2006; La Franca et al. 2005).

This behaviour may reflect a physical dependence of the column density with intrinsic luminosity as suggested by Elitzur & Shlosman (2006). These authors present a model where the torus and the BLR disappear when the bolometric luminosity decreases below $\sim 10^{42} \text{ erg s}^{-1}$ because the accretion onto the central black hole can no longer sustain the required cloud outflow rate. It is interesting to note that the corresponding luminosity in the 2–10 keV band is about several $\times 10^{40} \text{ erg s}^{-1}$, assuming the Spectral Energy Distribution of Elvis et al. (1994). Interestingly, almost all of our Seyfert-2 sources with no absorption present luminosities below this limit (with the exception of NGC 3147). We note however, there are sources (NGC 3486, NGC 3982) with low luminosity, which present column densities around 10^{22} – 10^{23} cm^{-2} . Alternatively, it is possible that at least in a few cases, the large XMM-Newton Point Spread Function results in contamination by nearby sources. Thus the nuclear X-ray emission could be out-shined giving the impression that there is no obscuration (e.g. Brightman & Nandra 2008). However, both the inspection of the *Chandra* images as well as the stacked spectrum of the unabsorbed sources do not favour such a scenario.

7. Conclusions

XMM-Newton observations are available for all 38 Seyfert galaxies from the Palomar spectroscopic sample of galaxies of Ho et al. (1995, 1997). Our goal is to determine the distribution of the X-ray absorption in the local Universe through X-ray spectroscopy. Our sample consists of 30 Seyfert-2 and 8 Seyfert-1 galaxies. The results can be summarised as follows:

- We find a high fraction of obscured sources ($>10^{22} \text{ cm}^{-2}$) of about 50%.
- A number of sources present low $F_X/F_{\text{[OIII]}}$ ratio. Their individual spectra show no evidence of high absorbing column densities. However, their stacked spectrum shows significant amount of absorption ($\sim 3 \times 10^{23} \text{ cm}^{-2}$).
- Considering only the bright sub-sample ($L_{2-10 \text{ keV}} > 10^{41} \text{ erg s}^{-1}$), i.e. only these sources which contribute a significant amount to the X-ray background flux, we find that 75% of our sources are obscured.
- In the bright sub-sample there are at least 3 Compton-thick AGN translating to a fraction of 15% which is lower than the predictions of the X-ray background synthesis models at this luminosity and redshift range. Only if we consider, the rather unlikely scenario, where all Seyfert-2 galaxies with a low $F_X/F_{\text{[OIII]}}$ ratio are associated with Compton-thick sources we would alleviate this discrepancy.
- We find a large number of unobscured Seyfert-2 galaxies. All these have low luminosities $L_{2-10 \text{ keV}} < 3 \times 10^{41} \text{ erg s}^{-1}$. Inspection of the *Chandra* images, where available, demonstrates that in most cases these are not contaminated by nearby sources. Furthermore, their stacked spectrum reveals no absorption. It is most likely that these are genuinely unobscured sources in accordance with the predictions of the models of Elitzur & Shlosman (2006).

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