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 $A_V > 100$), 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. NGC1068, 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, Comastri & Hasinger 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 (Cappi et al. 2006, Panessa et al. 2006, Guainazzi et al. 2005). All these authors also claim a large Compton-thick 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 $10^{-11}$ erg cm$^{-2}$ 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. Cappi 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, Filippenko, & Sargent 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, Tenmann & Yahil 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. NGC1068, NGC1358, NGC1667, NGC2639, NGC3185, NGC4235, NGC5548), 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 NGC4051, NGC4395 and NGC4639 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 Cappi et al. 2006, Panessa et al. 2006, Baskin & Laor 2008). Moreover NGC185 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 "$\ast$" 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 Cappi et al. (2006). However we choose to re-analyze these common
Table 1. The sample

| Name   | α(J2000) | δ(J2000) | $B_T$ (mag) | D(Mpc) | Class |
|--------|----------|----------|-------------|--------|-------|
| 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 | +37 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 26.00 | 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 3944 | 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 & 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.

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 section 2), and the Seyfert-1.5 galaxy NGC1275 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
Table 2. Log of the XMM-Newton observations

| Name       | Obs. Date   | Obs. ID       | PN Exposure | Filter |
|------------|-------------|---------------|-------------|--------|
|            |             |               | MOS1 | MOS2 | MOS1 | MOS2 |
| NGC 185    | 2001-01-09  | 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  | 0101400301    | 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   | 2001-11-09  | 0107460701    | 11313 | 13483 | 13598 | Thin | Thin | Thin |
| NGC 4051   | 2002-11-22  | 0157560101    | 10197 | 6369  | 6385  | Medium | Thin | Thin |
| NGC 4138   | 2001-11-26  | 0112551201    | 9999  | 14365 | 14365 | Medium | Thin | Thin |
| NGC 4151   | 2003-05-26  | 0435020601    | 18454 | 18602 | 18607 | Medium | Medium | Medium |
| NGC 4168   | 2001-12-04  | 0112550501    | 18498 | 12695 | 12701 | Thin | Thin | Thin |
| NGC 4258   | 2006-11-17  | 0400560301    | 11068 | 12695 | 12701 | Thin | Thin | Thin |
| 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  | 0142890101    | 10596 | 10942 | 10940 | Medium | Medium | Medium |
| NGC 4472   | 2001-01-01  | 0200130101    | 89503 | 94179 | 94185 | Thin | Thin | Thin |
| NGC 4477   | 2002-06-08  | 0125521001    | 9500  | 13501 | 13527 | Thin | Thin | Thin |
| NGC 4501   | 2002-06-08  | 0112550801    | 2885  | 13387 | 13385 | Medium | Thin | Thin |
| NGC 4565   | 2001-07-01  | 0112550301    | 10010 | 14261 | 14263 | Thin | Medium | Thin |
| NGC 4639   | 2001-12-16  | 0112550101    | 10000 | 14365 | 14265 | Medium | Thin | Thin |
| NGC 4698   | 2001-12-17  | 0112551101    | 11755 | 16112 | 16112 | Thin | Thin | Thin |
| NGC 4725   | 2002-06-14  | 0112550401    | 13369 | 17244 | 17244 | Thin | Thin | Thin |
| NGC 5033   | 2002-12-18  | 0094360501    | 9999  | 11616 | 11666 | Thin | Medium | Medium |
| NGC 5194   | 2003-01-15  | 0303420101    | 19047 | 49944 | 49351 | Thin | Thin | Thin |
| NGC 5273   | 2002-06-14  | 0112551701    | 10392 | 16065 | 16094 | Thin | Thin | Thin |
| NGC 6951*  | 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, 4 & 5: Net exposure time for the EPIC instruments
Columns 6, 7 & 8: Applied filter
* Denotes sources observed during our Guest Observer program.

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 (\(w_{\text{a}}^*w_{\text{a}}^*p_{\text{o}}\) 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\(\alpha\) 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 $\Gamma$ fixed to the direct component value, to account for the scattered X-ray radiation and/or a Raymond-Smith to model the contribution from 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. NGC1358, NGC3079, NGC3735). 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 NGC3486, NGC3079, NGC4051 and NGC4388 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 NGC1058 and NGC4725 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 of absorption ($< 10^{21} \text{cm}^{-2}$) while the 3 Seyfert-1.5 sources (NGC3227, NGC3516, and NGC4151) present a considerable amount of $N_H (> 10^{22} \text{cm}^{-2})$. Our sample contains 30 Seyfert-2 galaxies. The column densities in this population vary from the Galactic to the Compton-thick limit ($N_H > 10^{24} \text{cm}^{-2}$). However, the apparent number of significantly obscured sources is rather small. Only 12 out of 30 type-2 sources present absorption greater than $10^{22} \text{cm}^{-2}$.

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 $10^{24} \text{cm}^{-2}$. 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$_\alpha$ 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$_\alpha$ line ($\sim 1 \text{keV}$). This characteristic is consistent with a Compton-thick nucleus since 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 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. NGC2992, Weaver et al. 1996). Also there have been reports of Compton-thick sources where the value of FeK$_\alpha$ 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, $F_{2-10 \text{keV}}/F_{\text{[OIII]}}$. The [OIII] fluxes are corrected for the optical reddening using the formula described in Basanni et al. (1999): $F_{\text{[OIII]}}/F_{\text{[OIII]cor}} = (H_\alpha/H_\beta)/(H_\alpha/H_\beta)_{\alpha}^{-2.94}$, where the intrinsic Balmer decrement $(H_\alpha/H_\beta)_{\alpha}$ 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 $F_{2-10 \text{ keV}} / F_{[OIII]}$ values of the Seyfert-1 population only, while the lines at right and left show the 3σ dispersion. The sources occupying the low ($F_{2-10 \text{ keV}} / F_{[OIII]}$, $N_H$) region in this plot could be possibly highly obscured or Compton-thick AGN.

In two cases (NGC2273, NGC3079) we can immediately tell the presence of a Compton-thick nucleus through the presence of an absorption turnover in the

diagram.
spectral fittings. Both sources present high values of the FeK$_\alpha$ line EW ($> 700$ eV). One more source (NGC5194), despite the fact that it presents the highest value of FeK$_\alpha$ ($\sim 1700$ eV), shows no absorption at all. However, the very flat X-ray spectrum and the very low $F_{2-10 keV}/F_{[OIII]}$ value further suggest that this is a highly obscured or a Compton-thick source. According to the $N_H$-$F_{2-10 keV}/F_{[OIII]}$ relation a minimum value for the $N_H$ is $4 \times 10^{22}$ cm$^{-2}$ (see Fig. 1).

There are also 5 Seyfert-2 galaxies (NGC676, NGC1167, NGC3254, NGC6951 and NGC7743) occupying the low $F_{2-10 keV}/F_{[OIII]}$ regime. We do not consider NGC4169 because of the large error in the estimation of the [OIII] flux (see Ho et al. 1997). These, according to the expected $N_H$-$F_{2-10 keV}/F_{[OIII]}$ relation, should present high values of $N_H$. According to Fig. 1 the minimum $N_H$ value is $\sim 2 \times 10^{23}$ cm$^{-2}$ for NGC676, $\sim 6 \times 10^{23}$ cm$^{-2}$ for NGC6951 and $\sim 10^{24}$ cm$^{-2}$ for NGC1167 and NGC7743. However, the X-ray spectral fittings show low absorption ($< 10^{22}$ 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 ($> 2$ keV) band, which does not allow us to examine in detail the spectral characteristics. Note however, that in the spectrum of at least two sources (NGC1167 and NGC7743) 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 1). 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$_\alpha$ line EW.

Our results above can be summarised as follows. The number of absorbed nuclei ($N_H > 10^{22}$ cm$^{-2}$) are 21 out of 38 or 55 ± 12%. The number of Compton-thick sources is three i.e. 8 ± 5% although, if we adopt the extreme case where all the low $F_{2-10 keV}/F_{[OIII]}$ host Compton-thick nuclei this number would rise to 8 or 21 ± 7 %. Our estimates on the amount of $N_H$ in the local universe are illustrated in Fig. 2. The solid line describes 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 $10^{41}$ ergs s$^{-1}$. However, the intrinsic 2-10 keV luminosity of our sources starts from as low as a few times $10^{38}$ ergs s$^{-1}$ which is about 3 orders of magnitude lower. Therefore it is useful to present our results separately for the fainter ($L_{2-10 keV} < 10^{41}$ ergs s$^{-1}$) and the brighter ($L_{2-10 keV} > 10^{41}$ ergs s$^{-1}$) sub-sample containing 21 and 17 sources respectively (see Fig. 3). The intrinsic $L_X$ values are determined using the best fitting results. For the three Compton-thick sources the intrinsic $L_X$ has been

![Fig. 1. Distribution of the $N_H$ values as a function of the $F_{2-10 keV}/F_{[OIII]}$ ratio. Filled boxes and circles denote Seyfert-1 and Seyfert-2 galaxies respectively. The triangles show Seyfert-2 galaxies with large EW(>700 eV). The solid lines represent the mean $N_H$ vs. $F_{2-10 keV}/F_{[OIII]}$ relation followed by the Seyfert-1 in our sample together with the ±3σ dispersion (see text).](image1)

![Fig. 2. Stacked X-ray spectrum of the Seyfert-2 Galaxies NGC0676, NGC1167, NGC3254, NGC6951 and NGC7743. The best fit model and residuals are also shown.](image2)
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$^{-2}$) | $\Gamma$ | $kT$ (keV) | EW$_{\text{FeK}}$ (eV) | $\chi^2$ |
|------------------|---------|-----------|-----------------|--------|
| 1.80$^{+0.04}_{-0.01}$ | 1.71$^{+0.06}_{-0.17}$ | 0.73$^{+0.15}_{-0.12}$ | 255$^{+255}_{-130}$ | 72.41/91 |

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 (NGC1058, NGC3147, NGC3941, NGC3976, NGC4168, NGC4378, NGC4472, NGC4477, NGC4501, NGC4565, NGC4698 and NGC4725) 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, Gliozzi, Sambruna & Foschini 2007). In particular NGC3147 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). NGC4698 and NGC4565 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 (NGC3941, NGC3976 and NGC4378) 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. NGC1058 and NGC4168 are significantly contaminated from nearby luminous X-ray sources (see also Foschini et al. 2002, Cappi et al 2006) while NGC4472 suffers from very strong diffuse emission. Finally, inspection of XMM-Newton images show that NGC3941 and NGC4501 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 unobscured 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. NGC3147, NGC4565 and NGC4698 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 NGC3976, NGC4725, NGC4378 and NGC4477 to be considered.

We try to detect any spectral feature, such as the FeK$_\alpha$ 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 spec-
The mass estimation is the mass of the central Black Hole, taken from Panessa et al. (2006) and McElroy (1995). The mass estimation 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, $\sigma_T$ 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 NGC3147) present very low bolometric luminosities also below the critical value of $10^{42}$ 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 $\sim$50 per cent of the Seyfert population is absorbed by $N_H > 10^{22}$ cm$^{-2}$. In this sample we have identified 3 Compton-thick sources which translates to a fraction of $\sim$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 Pannesa 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 ($> 10^{22}$ 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 Section 2). These are the 2 Compton-thick AGN NGC1068 and NGC3185. 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 $F_{\text{bol}} > 4 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$. However we think that only a luminosity cutoff could reveal column density distribution of the population that contributes to the XRB (see Section 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 the 1-100 keV range. It is well established that a large number of Compton-thick sources is needed (Gilli et al. 2007) 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 available POMPA software[^1]. 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). Here, we compare the fraction of the Compton-thick nuclei the discrepancy would become less pronounced.

Optically selected samples can still miss a fraction of Compton-thick AGN. For example, NGC6240 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 and 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.

[^1]: www.bo.astro.it/~gilli/counts.html

Recent results based on INTEGRAL and SWIFT observations reveal a small fraction of Compton-thick sources (e.g. 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 > 2σ 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 \( L_{2-10} < 10^{41} \) 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 \( \sim 10^{42} \) 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 \( \times 10^{40} \) 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.

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

| \( N_H \) (cm\(^{-2}\)) | \( \Gamma \) | \( kT \) (keV) | \( EW_{F\alpha K} \) (eV) | \( \chi^2 \) |
|-------------------------|---------|------------|----------------|------|
| < 0.1                  | 2.02\(^{+0.08}_{-0.15}\) | 0.37\(^{+0.06}_{-0.09}\) | < 600 | 118.6/125 |

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

| Name     | \( \log(M_{BH}/M_\odot) \) | \( \log(L_{BOL}) \) | \( L_{BOL}/L_{EDD} \times 10^{-4} \) |
|----------|-------------------|-----------------|-----------------------------|
| 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 ergs s\(^{-1}\)
Column 4: Accretion rate \( L_{BOL}/L_{EDD} \)

[^1]: www.bo.astro.it/~gilli/counts.html
(with the exception of NGC3147). We note however, there are sources (NGC3486, NGC3982) 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 ($>10^{22}$ cm$^{-2}$) of about 50%.
- A number of sources present low $F_{\text{X}}/F_{\text{OIII}}$ ratio. Their individual spectra show no evidence of high absorbing column densities. However, their stacked spectrum shows significant amount of absorption ($\sim 3 \times 10^{23}$ cm$^{-2}$)
- Considering only the bright sub-sample ($L_{2-10} \text{ keV} > 10^{41}$ 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 $F_{\text{X}}/F_{\text{OIII}}$ 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 $L_{2-10} \text{ keV} < 3 \times 10^{41}$ 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 & Sloshman (2006).

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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.
NGC1068

Normalized counts s⁻¹ keV⁻¹ vs Energy (keV) for NGC1068.

The plot shows the normalized counts per second per kiloelectronvolt versus energy in keV. The residuals are also depicted, possibly indicating the difference between the observed data and a model fit. The energy range is from 5 keV to higher energies, and the counts range from normalized values of 0.1 to 10⁻³.
NGC3185

Energy (keV)

normalized counts s^{-1} keV^{-1}

residuals
