

The bolometric luminosity of type 2 AGN from extinction-corrected [OIII]: no evidence for Eddington-limited sources.

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ABSTRACT

Context. There have been recent claims that a significant fraction of type 2 AGN accrete close or even above the Eddington limit. In type 2 AGN the bolometric luminosity (L_b) is generally inferred from the [OIII] emission line luminosity (L_{OIII}). The key issue, in order to estimate the bolometric luminosity in these AGN, is therefore to know the bolometric correction to be applied to L_{OIII} . A complication arises from the fact that the observed L_{OIII} is affected by extinction, likely due to dust within the narrow line region. The extinction-corrected [OIII] luminosity (L_{OIII}^c) is a better estimator of the nuclear luminosity than L_{OIII} . However, so far only the bolometric correction to be applied to the uncorrected L_{OIII} has been evaluated.

Aims. This paper is devoted to estimate the bolometric correction $C_{OIII}=L_b/L_{OIII}^c$ in order to derive the Eddington ratios for the type 2 AGN in a sample of SDSS objects.

Methods. We have collected from the literature 61 sources with reliable estimate of both L_{OIII}^c and X-ray luminosities (L_X). To estimate C_{OIII} , we combined the observed correlation between L_{OIII}^c and L_X with the X-ray bolometric correction.

Results. We found, contrary to previous studies, a linear correlation between L_{OIII}^c and L_X . We estimated C_{OIII} using the luminosity-dependent X-ray bolometric correction of Marconi et al. (2004), and we found a mean value of C_{OIII} in the luminosity ranges $\log L_{OIII}=38-40$, $40-42$, and $42-44$ of 87, 142 and 454 respectively. We used it to calculate the Eddington ratio distribution of type 2 SDSS AGN at $0.3 < z < 0.4$ and we found that these sources are not accreting near their Eddington limit, contrary to previous claims.

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

1. Introduction

Active galactic nuclei (AGN) are believed to be powered by accretion of gas onto the black hole located at the centre of galaxies. The AGN bolometric luminosity (L_b) depends on the mass accretion rate and on the efficiency for the conversion of gravitational energy into radiation. In this scenario, the luminosity produced by a black hole has a physical limit, the Eddington limit ($L_{Edd} \approx 1.3 \times 10^{38} (M_{BH}/M_\odot) \text{ erg/s}$), at which the radiation pressure due to the accretion of the infalling matter balances the gravitational force of the black hole. The ratio between the bolometric and Eddington luminosity, $\lambda = L_b/L_{Edd}$, is referred to as the Eddington ratio.

The knowledge of the Eddington ratio distribution and its evolution is very important to constrain the predictions of theoretical models which link the evolution of the galaxies in the hierarchical clustering scenario with the quasar evolution (e.g. Menci et al. 2003, 2004). In fact, all predictions regarding AGN, such as the luminosity function or the black hole mass function of AGN relics, depends on the assumptions about this quantity. The estimate of the Eddington ratio requires measurements of the black hole mass, M_{BH} , and of the bolometric luminosity, L_b .

According to the unification model (Antonucci 1993), in the AGN classified as type 1 the optical/UV continuum source and the surrounding broad emission line region (BLR) are viewed without any substantial obscuration, while in type 2 AGN these

regions suffer obscuration along the observer’s line of sight by intervening dusty material, most of which is likely associated with a circumnuclear structure often referred to as the torus. Even if some exceptions have been found (e.g. Bianchi et al. 2008), the unification model can be safely assumed to provide a useful reference frame for the vast majority of sources.

Progress in reverberation mapping of type 1 AGN (Peterson et al. 2004, 2005) provided rather good evidence that the BLR size depends on the optical continuum luminosity (Kaspi et al. 2000, 2005; Bentz et al. 2006). This size-luminosity relation, combined with the gas velocity derived from the width of the emission lines, under the assumption that the BLR clouds are in Keplerian motion around the black hole, has been widely used to estimate the black hole masses, in large samples of type 1 AGN up to $z \approx 4$ (e.g. Woo & Urry 2002; McLure & Dunlop 2004; Warner et al. 2004; Kollmeier et al. 2006; Vestergaard 2002, 2004; Netzer & Trakhtenbrot 2007). The Eddington ratio is then obtained by applying a bolometric correction to the optical luminosity. These authors seemed to agree on a practically constant value of λ ($\lambda \approx 0.25$ Kollmeier et al. 2006) at all z , irrespective of luminosity and black hole mass, after selection effects had been properly taken into account (but see Netzer & Trakhtenbrot 2007 for a recent result indicating a dependence of λ on both M_{BH} and z up to $z \approx 0.75$).

In type 2 AGN the BLR is not visible and the M_{BH} estimate is usually obtained through the empirical relationships between the black hole mass and the properties of the spheroidal compo-

nent of the host galaxy (e.g. Magorrian et al. 1998; Gebhardt et al. 2000a; Ferrarese & Merritt 2000; Tremaine et al. 2002). This method has been applied to a very large sample of type 2 AGN in the local Universe (Kauffmann et al. 2003; Heckman et al. 2004 here-in-after H04; Kauffmann & Heckman 2008). At higher z , however this method becomes more difficult to apply, especially in spiral galaxies where it is necessary to disentangle the contribution of the bulge from that of the disk. A step forward in this direction has been recently made by Bian et al. (2006, here-in-after B06), which were able to estimate the black hole masses for a subsample of SDSS type 2 AGN at $0.3 < z < 0.83$ from the Zakamska et al. (2003) sample. The black hole mass estimate was obtained from the stellar velocity dispersion measurements (σ_*) and the $M_{BH}-\sigma_*$ relation of Tremaine et al. (2002).

In type 2 AGN, since the primary optical/UV radiation is much affected by dust extinction, the bolometric luminosity is generally inferred from the [OIII] emission line luminosity (L_{OIII}). The [OIII] emission line arises in the much larger narrow line region (NLR), where the gas is photoionized by the continuum radiation escaping within the opening angle of the torus. The observed flux is therefore weakly affected by the viewing angle relative to the torus and its luminosity provides an indication of the nuclear luminosity. The key issue, in order to estimate λ in these AGN, is therefore to have a bolometric correction factor in hand to be applied to L_{OIII} .

H04 computed a mean bolometric correction factor to the observed [OIII] luminosity, and used it to estimate the Eddington ratio distribution of local ($z \approx 0.1$) type 2 AGN. This bolometric correction factor was also used by B06 to estimate the λ -distribution of their sample. B06 found a mean value of this distribution $\langle \lambda \rangle \approx 1$, which would reveal a population of high Eddington ratio sources which differs from that observed in the local Universe and in type 1 AGN. If confirmed, this result would have enormous impact on the way that massive black holes grow along cosmic time, as most of this growth as expected to occur at significant redshift and in obscured objects.

However, L_{OIII} is only an indirect estimator of the nuclear luminosity, which depends on the geometry of the system, on the amount of gas, and on any possible shielding effect which may affect the ionizing radiation seen by the NLR. This implies an intrinsic scatter in the $L_{OIII}-L_b$ relation and therefore an uncertainty in the λ estimate. A further complication arises from the fact that the [OIII] emission line is affected by extinction, likely due to dust within the NLR. In some cases the reddening due to the NLR can be evaluated, and the extinction-corrected [OIII] luminosity (L_{OIII}^c) is a more direct estimator of the nuclear luminosity than L_{OIII} . We estimated the [OIII] bolometric correction following a similar method adopted by H04, but we used the extinction-corrected [OIII] luminosity instead of the observed one.

Then we used this bolometric correction to calculate the Eddington ratio of the sources from the B06 sample for which the extinction-corrections are available. Moreover, we have observed with XMM-Newton 8 sources of the B06 sample, in order to have an independent estimate of the bolometric luminosity through X-ray luminosity.

The paper is organised as follows. In Sect. 2 the bolometric correction estimate is described. Sect. 3 is devoted to the estimate of the Eddington ratio distribution. Discussion and conclusions follow in Sect. 4.

2. The $L_X-L_{OIII}^c$ luminosity relation

H04 estimated the bolometric correction (BC) to the observed [OIII] luminosity, L_{OIII} , in a two-step process. First they estimated the mean ratio between the monochromatic continuum luminosity at 5000 Å and the [OIII] luminosity, L_{5000}/L_{OIII} , in a sample of type 1 AGN. Then they calculated the mean ratio between the bolometric luminosity and L_{5000} using the average type 1 AGN intrinsic spectral energy distribution (SED) of Marconi et al. (2004).

They found $L_b/L_{OIII} \approx 3500$. As discussed in H04, they did not correct L_{OIII} for dust extinction in the NLR, because the extinction correction is usually made by measuring the observed Balmer decrement ($H\alpha/H\beta$), and in type 1 AGN this procedure requires deblending the narrow components from the broad ones.

In Seyfert galaxies optically classified as type 1.5, 1.8, 1.9 and 2, in which the narrow components of the $H\alpha$ and $H\beta$ lines dominate the line profiles (Osterbrock & Ferland 2006), the estimate of the Balmer decrement can instead be considered reliable. So we used these Seyfert types to estimate the BC to convert the extinction-corrected [OIII] luminosity, L_{OIII}^c , to the bolometric luminosity.

In these Seyfert types the bolometric luminosity cannot be easily determined because the primary optical/UV radiation is highly obscured. In X-rays, however, the nuclear emission could be directly estimated, provided that the absorbing matter is Compton-thin (i.e. $N_H < \sigma_T^{-1} = 1.5 \times 10^{24} \text{ cm}^{-2}$; if the matter is Compton-thick, no nuclear radiation is visible below 10 keV, with the Compton reflection component usually dominating the spectrum).

Assuming that the X-ray bolometric correction is the same in type 1 and in type 2 AGN, we used the relation between L_{OIII}^c and the absorption corrected X-ray luminosity and the X-ray bolometric correction of type 1 and Compton-thin type 2 AGN to estimate the [OIII] bolometric correction (C_{OIII}).

We have collected a sample from the literature for which reliable estimates of the Balmer decrement, L_{OIII} and L_X were available. We have discarded Seyfert galaxies with optical classification ≤ 1.2 and X-ray Compton-thick sources. The final sample consists of 61 sources: 5 from Mulchaey et al. (1994)¹, 12 from Panessa et al. (2006, P06 hereafter), and 44 from Bassani et al. (1999, B99 hereafter, 8 of these 44 sources are also included in the P06 sample). We used the B99 relation to derive L_{OIII}^c from the Balmer decrement:

$$L_{OIII}^c = L_{OIII} \left(\frac{(H\alpha/H\beta)_{obs}}{3.0} \right)^{2.94}. \quad (1)$$

which assumes an intrinsic Balmer decrement equal to 3.0 as expected in the NLR (see Osterbrock & Ferland 2006).

In Fig. 1 (top panel) the distribution of the ratio between the (2-10) keV luminosity and the extinction-corrected [OIII] luminosity for our sample is shown. The mean of this distribution is

$$\left\langle \log \left(\frac{L_X}{L_{OIII}^c} \right) \right\rangle = 1.09 \quad (2)$$

and the dispersion is 0.63 dex.

¹ We have used L_{OIII} and Balmer decrement from Mulchaey et al. (1994) and the X-ray luminosities from Bianchi et al. 2009a.

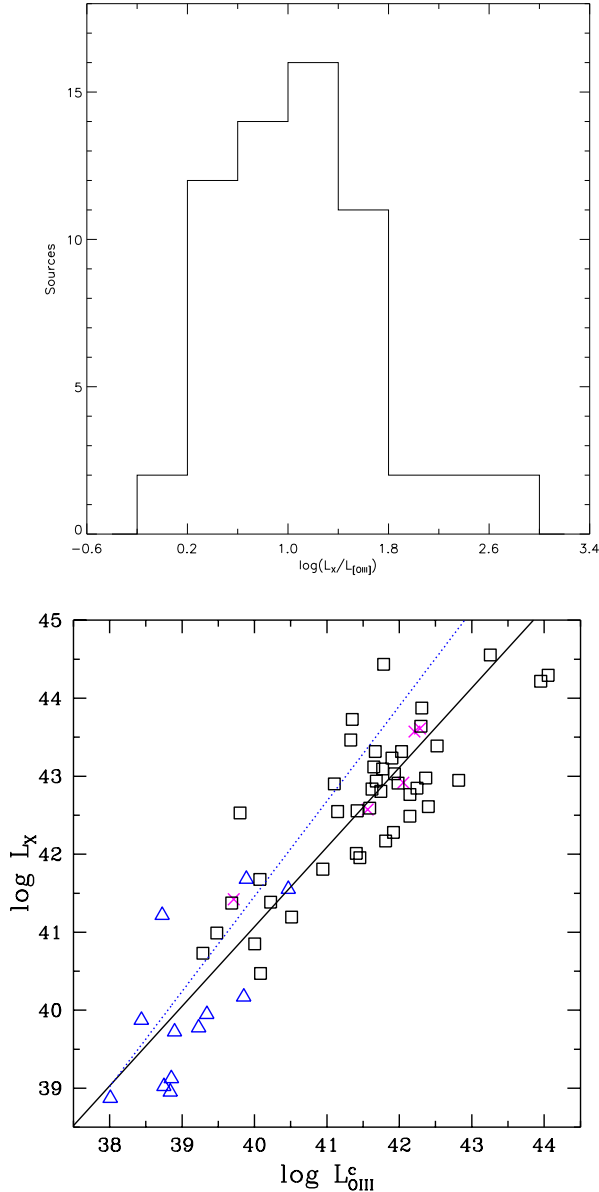


Fig. 1. Distribution of $\log(L_X/L_{[OIII]}^c)$ (top) and $\log L_X - \log L_{[OIII]}^c$ relation (bottom). The solid line is the best fit relation Eq. (3) for the 61 sources from Mulchaey et al. (1994) (crosses), B99 (squares) and P06 (triangles), while the dotted line is the best fit relation obtained by P06.

The bottom panel of Fig. 1 shows L_X versus $L_{[OIII]}^c$. The correlation is highly significant² (Spearman rank correlation coefficient $\rho=0.86$, $P=1.6 \times 10^{-18}$). In order to quantify any distance-driven effects which may be present in a luminosity-luminosity correlation, we also performed a “scrambling test” (see e.g. Bregman 2005; Merloni et al. 2006; Bianchi et al. 2009b). The correlation appears not to be affected by distance effects: not even a data-set out of the 100000 simulated ones has a correlation coefficient as large as the one measured in the real data-set.

² We consider statistically significant the correlations whose null hypothesis probability, P , is lower than 1×10^{-3} , which correspond to a confidence level of 99.9%.

An ordinary least-square bisector procedure gives the following best fit:

$$\log\left(\frac{L_X}{10^{42} \text{ erg/s}}\right) = (1.11 \pm 0.10) + (1.02 \pm 0.06) \log\left(\frac{L_{[OIII]}^c}{10^{42} \text{ erg/s}}\right) \quad (3)$$

i.e. we found a linear correlation between L_X and $L_{[OIII]}^c$. P06 investigated the same correlation finding that $L_X \propto L_{[OIII]}^c$ (1.22±0.06). They included in their analysis type 1 AGN, type 2 AGN and Compton-thick sources (in the latter case they assumed that the intrinsic X-ray luminosity is 60 times larger than the observed one) and covered about five orders of magnitude in both [OIII] luminosity and X-ray luminosity. It should be recalled that the P06 sample is optically selected while our sample, mainly based on the B99 catalogue, includes both optically selected and X-ray selected AGN. As discussed in several papers, most recently in Heckman et al. 2005 and Netzer et al. (2006, N06 hereafter), X-ray selected samples are likely to be biased towards X-ray bright sources and hence produce a larger X/[OIII] ratio compared to optically selected ones. The 44 sources which we have selected from the B99 catalogue have all $\log L_{[OIII]}^c > 39.3$. The presence of X-ray selected objects among these sources should therefore tend to make the $L_X - L_{[OIII]}^c$ relationship steeper than found by P06, which, as it can also be seen in Fig. 1, is exactly the opposite of what we found. On the other hand, the high luminosity ranges in P06 are populated nearly completely by type 1 AGN, for which we consider unreliable the estimate of $L_{[OIII]}^c$. The steeper slope of the $L_X - L_{[OIII]}^c$ relation found by P06 could indeed be due to an underestimate of the reddening in these AGN types.

N06 studied the relation between $L_{[OIII]}$ and L_X in samples of type 1 and type 2 AGN. They found that the ratio between $L_{[OIII]}$ and L_X decreases with L_X , and for type 2 AGN the same result was obtained also using the extinction-corrected [OIII] luminosity. In the latter case, they used the B99 catalogue excluding sources with optical classification ≤ 1.5 and Compton-thick sources. They found $\log(L_{[OIII]}^c/L_X) = (15.0 \pm 4.0) - (0.38 \pm 0.09) \log L_X$, which implies $L_X \propto L_{[OIII]}^c$ 1.61, i.e. a correlation with an even steeper slope than that obtained by P06. Our analysis differs from that of N06 only for the inclusion of the AGN optically classified as type 1.5. Excluding these sources from our sample, we found for the remaining 52 sources: $\log(L_X/10^{42} \text{ erg/s}) = (1.08 \pm 0.11) + (1.04 \pm 0.06) \log(L_{[OIII]}^c/10^{42} \text{ erg/s})$ ($\rho=0.85$, $p=2.0 \times 10^{-15}$), i.e. a significant linear correlation also in this case. The discrepancy between the results may be due to the smaller range of luminosities covered by N06, which do not include sources with $L_X \leq 10^{40} \text{ erg/s}$. Unfortunately we cannot make a clear comparison with N06 because they did not perform a simple $L_X - L_{[OIII]}^c$ fit and an extrapolation of the resulting slope from their fit may be misleading. Moreover N06 did not explicitly report the method they used to compute the linear regression and the significance of the correlation they found.

The relation between L_X and $L_{[OIII]}^c$ can be combined with the X-ray bolometric correction (XBC) to obtain the [OIII] bolometric correction factor, $C_{[OIII]}$. Adopting the luminosity-dependent XBC of Marconi et al. (2004), we found a mean value of $C_{[OIII]}$ in the luminosity ranges $\log L_{[OIII]} = 38-40$, $40-42$, and $42-44$ of 87, 142 and 454 respectively.

As a cautionary remark, it must be noted that the XBC may suffer from large uncertainties.

Marconi et al. (2004) and Hopkins et al. (2007) accounted for variations of AGN SEDs with luminosity using the anti-

correlation between the optical-to-X-ray spectral index (α_{OX}) and the luminosity at 2500 Å (L_{2500}) (e.g. Vignali et al. 2003a), but Hopkins et al. (2007) found that intrinsic spread in AGN SEDs could give rise to variation of a factor of ~ 2 in the XBC, even when luminosity dependence is taken into account.

Moreover, the very dependence on luminosity of the X-ray bolometric correction has been questioned by Vasudevan & Fabian (2007), who estimate it from the observed SEDs of 54 AGNs. They found evidence of a large scatter in the XBC, with no simple dependence on luminosity, and suggested instead the Eddington ratio as the physical quantity the bolometric correction depends on.

Very recently, Kauffmann & Heckman (2008) anticipated an estimate of C_{OIII} .

They found C_{OIII} in the range ~ 500 to 800. Because the details of their analysis have not been published yet, for the time being we are not able to discuss the origin of this discrepancy.

3. The Eddington ratio distribution of type 2 SDSS AGN at $0.3 < z < 0.4$

B06 measured the stellar velocity dispersion, σ_* , for 30 sources of the $0.3 < z < 0.8$ SDSS type 2 AGN sample of Zakamska et al. (2003). The stellar velocity dispersion was obtained by fitting the profile of heavy element absorption lines which are mainly associated with the old stellar population in the bulge. Then, they estimated the black hole masses from σ_* , adopting the Tremaine et al. (2002) relation.

The B06 subsample is representative of the total sample of Zakamska et al. (2003) with respect to L_{OIII} . Indeed, the observation of significant stellar absorption features, which is the key point to accurately measure σ_* , does not appear to depend on the nuclear luminosity of the sources, as confirmed by a t-test (see B06).

For 15 sources B06 calculated the [OIII] line luminosity corrected for extinction using the observed Balmer decrement and Eq. (1). Therefore all these sources have $z \leq 0.4$, because of the limited wavelength coverage of the SDSS spectroscopy (≈ 3800 - 9200 Å). The ratio between L_{OIII}^c and L_{OIII} , is between 0.6 and 17.8. In three objects the observed Balmer decrement is lower than the theoretical value, most likely due to an imperfect subtraction of the starlight. We assigned zero extinction to these objects.

Figure 4 in B06 shows the distribution of the Eddington ratios of the 15 sources where we have a reliable estimate of L_{OIII}^c . This distribution is surprising for its mean value, $\langle \lambda \rangle \approx 1$, because it would reveal a population of high Eddington ratio sources which is not observed in the local Universe, such Eddington ratios are neither observed in type 1 AGN at higher redshift.

However, it is important to note that B06 obtained this distribution estimating the bolometric luminosity from L_{OIII}^c and the BC given by H04. This bolometric correction applies to L_{OIII} and not to L_{OIII}^c , therefore B06 overestimated in a systematic manner L_b and hence λ .

In this section we used C_{OIII} , as computed in Sect. 2, to calculate the Eddington ratio distribution of the type 2 SDSS AGN of the B06 sample.

First of all we have tested the reliability of deriving λ from the [OIII] line luminosity in an optically selected sample, adopting the C_{OIII} we derived in a collection of X-ray selected and optically selected sources. To this aim we used the P06 subsample used in Sect. 2. In the top panel of Fig. 2 the Eddington ratio estimates obtained from L_{OIII}^c and C_{OIII} (λ_{OIII}) are compared with those obtained from L_X and the XBC of Marconi et al. 2004 (λ_X) (the black hole masses are taken from Table 2 of P06). We found a good agreement between the X-ray and the [OIII] estimates. For the 8 SDSS AGN of the B06 sample for which we have XMM-Newton observations we can repeat the above check. The bottom panel of Fig. 2 shows λ_X versus λ_{OIII} obtained from L_{OIII}^c and C_{OIII} (crosses) and versus λ_{OIII} obtained by B06 (squares). As expected, the λ_{OIII} obtained by B06 are systematically larger than those derived from the X-ray luminosity, while this effect disappears when the proper bolometric correction is used.

The black hole mass, the [OIII] line luminosity, the extinction-corrected [OIII] line luminosity, the (2-10) keV observed flux (F_X^{obs}) and the intrinsic (i.e. de-absorbed) (2-10) keV luminosity (L_X^{int}) of the X-ray observed sources are listed in Table 1. The X-ray data reduction and the estimate of L_X^{int} either from X-ray spectral fitting or extrapolated from the observed X-ray count rates (or upper limits) are reported in the Appendix.

Figure 3 shows the λ -distribution of the B06 sample obtained using L_{OIII}^c and C_{OIII} to estimate the bolometric luminosity. This distribution is obviously shifted to lower λ values with respect to that obtained by B06: the mean of this distribution is $\langle \lambda \rangle \approx 0.1$, a value which is similar to that estimated in other AGN samples.

We have checked whether the width of the observed λ -distribution indicates a physical spread in the Eddington ratios or it can be due to the dispersion in the L_{OIII}^c - L_b relation. In practice, we checked if the observed distribution is consistent with a log-normal distribution centered at $\log \lambda = -1$ and with width equal to the dispersion in the L_X - L_{OIII}^c relation (0.63 dex). A Kolmogorov-Smirnov test gives $D=0.27$, which corresponds to a probability of 0.18 for the null hypothesis that the two distributions are drawn from the same parent population.

4. Conclusions

In this paper we estimate the bolometric correction factor, C_{OIII} , needed to convert the extinction-corrected [OIII] line luminosity to bolometric luminosity.

We determined C_{OIII} in a two-step process. First we studied the L_X - L_{OIII}^c relation in a sample of 61 Seyfert galaxies with reliable measurement of both L_{OIII}^c and L_X , i.e. we selected galaxies with reliable measurement of the Balmer decrement (Seyfert galaxies with optical classification ≥ 1.5) and X-ray Compton-thin sources. The bolometric correction C_{OIII} was then obtained by combining the mean ratio between L_X and L_{OIII}^c with the luminosity-dependent X-ray bolometric correction of Marconi et al. (2004). We found a mean value of C_{OIII} in the luminosity ranges $\log L_{OIII} = 38$ - 40 , 40 - 42 , and 42 - 44 of 87, 142 and 454 respectively.

Similarly, H04 estimated the [OIII] bolometric correction combining the mean ratio between L_{5000} and L_{OIII} in a sample of type 1 AGN with the 5000 Angstrom continuum to L_{bol} correction from Marconi et al. (2004). H04 did not correct L_{OIII} for the extinction in the NLR, therefore their bolometric correction applies to the ‘‘observed’’ [OIII] luminosities. Compared to H04

Source (1)	M_{BH} (2)	L_{OIII} (3)	L_{OIII}^c (4)	F_X^{obs} (5)	L_X^{int} (6)
SDSSJ075920.21+351903.4	8.36	7.59	8.84	1.3×10^{-14}	43.92*
SDSSJ083945.98+384319.0	8.16	8.60†	9.71†	2.3×10^{-13}	44.26
SDSSJ084041.05+383819.9	7.71	8.62	9.48	$<4.4 \times 10^{-14}$	<44.07
SDSSJ092318.04+010144.7	8.53	8.94	9.31	$<4.0 \times 10^{-14}$	<44.24
SDSSJ094820.38+582526.4	7.01	7.89	9.08	$<4.2 \times 10^{-14}$	<44.17
SDSSJ133735.01-012815.6	8.75	8.72	9.56	$<6.0 \times 10^{-14}$	<44.25
SDSSJ143027.66-005614.8	7.61	8.36	9.23	$<8.6 \times 10^{-14}$	<44.38
SDSSJ143928.23+001538.0	8.01	8.08	9.22	6.6×10^{-14}	43.88

Table 1. (1) SDSS name. (2) log of the black hole mass in units of M_\odot from B06. (3) log of the [OIII] line luminosity in units of L_\odot from Zakamska et al (2003). (4) log of the extinction-corrected [OIII] line luminosity in units of L_\odot from B06. (5) Observed X-ray flux in units of $\text{erg s}^{-1} \text{cm}^{-2}$ (see the Appendix). (6) log of the de-absorbed X-ray luminosity in units of erg s^{-1} (see the Appendix). (*) Compton-thick source: L_X^{int} is obtained assuming that the ratio between the reflected and the primary component is 0.05. (†) this source has $z=0.424$ so the SDSS spectrum does not cover the spectral range necessary to measure the $H\alpha$ line. The [OIII] line luminosity and the Balmer decrement measurements are obtained from observation collected with the 2.2 m telescope at the Centro Astronómico Hispano Alemán (CAHA) at Calar Alto.

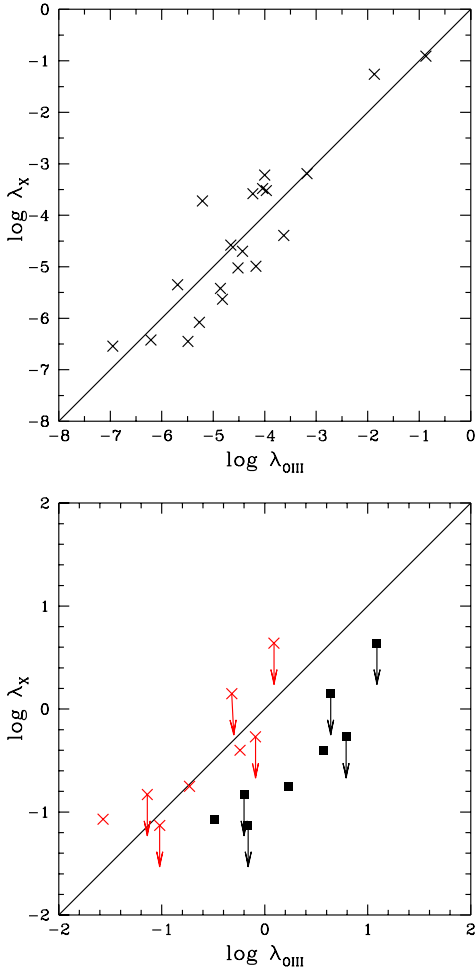


Fig. 2. Top: λ_X vs. λ_{OIII} for the sources in the P06 subsample. Bottom: λ_X vs. λ_{OIII} obtained by B06 (squares) and from L_{OIII}^c and C_{OIII} (crosses), for the B06 sources with the XMM-Newton observations.

our estimate of the [OIII] bolometric correction is not subject to the scatter due to the extinction in the NLR, which we estimated to be about 0.6 dex from our sample.

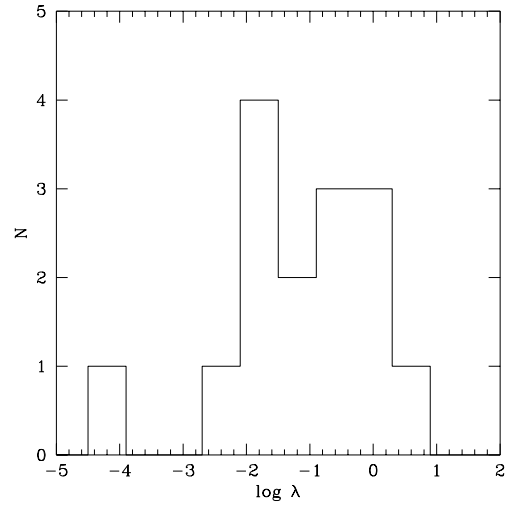


Fig. 3. Eddington ratio distribution of the B06 sample which is obtained estimating λ from L_{OIII}^c and C_{OIII} .

The [OIII] line luminosity is an indirect estimator of the nuclear luminosity, depending on the geometry of the system, and on any possible shielding effect which may affect the ionizing radiation seen by the NLR. The amount of gas which is exposed to the ionizing radiation depends on the torus opening angle. Bianchi et al. (2007, and references therein) confirmed the Iwasawa-Taniguchi (IT) effect, i.e. the anti-correlation between the iron line equivalent width and the X-ray luminosity. The simplest explanation for the IT effect is in terms of a decrease of the torus covering factor (and hence an increase of its opening angle) with luminosity, which may also explain the observed decrease with luminosity of the ratio between mid-IR and bolometric luminosities (Maiolino et al. 2007; Treister et al. 2008). If this explanation is correct, we would expect a less than linear relation between L_X and L_{OIII}^c , differently from what we found (the situation is even worse with the more than linear relations found by P06 and N06). This problem will be addressed in a forthcoming paper.

We used C_{OIII} to estimate the Eddington ratio distribution of type 2 SDSS AGN at $0.3 < z < 0.4$ from the B06 sample. B06 found that the mean of this distribution is $\langle \lambda \rangle \simeq 1$, thus reveal-

ing a population of high Eddington ratio sources which is absent in the local Universe and in type 1 AGN at higher redshift (e.g. Woo & Urry 2002; McLure & Dunlop 2004; Warner et al. 2004; Kollmeier et al. 2006; Vestergaard 2002, 2004; Netzer & Trakhtenbrot 2007). However, we have demonstrated, with the help of the X-ray luminosities, that B06 have overestimated in a systematic manner the bolometric luminosities and hence the Eddington ratios, which we found to be $\langle \lambda \rangle \approx 0.1$, similar to what found in other AGN samples.

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References

- Antonucci, R. R. J., 1993, *ARA&A*, 31, 473
 Bassani, L., Dadina, M., Maiolino, R., et al., 1999, *ApJS*, 121, 473 (B99)
 Bentz, M. C., Peterson, B. M., Pogge, R. W., Vestergaard, M., & Onken, C. A., 2006, *ApJ*, 644, 133
 Bian, W., Gu, Q., Zhao, Y., Chao, L., & Cui, Q., 2006 *MNRAS* 372, 876 (B06)
 Bianchi, S., Guainazzi, M., Matt, G., & Fonseca Bonilla, N., 2007, *A&A*, 467, L19
 Bianchi, S., Corral, A., Panessa, et al., 2008, *MNRAS*, 385, 195
 Bianchi, S., Guainazzi, M., Matt, G., Fonseca Bonilla, N., & Ponti, G., 2009a, *A&A*, 495, 421
 Bianchi, S., Fonseca Bonilla, N., Guainazzi, M., Matt, G., & Ponti, G., 2009b, *A&A*, arXiv0905.0267
 Bregman, J. N., 2005 arXiv0511368
 Ferrarese L., & Merritt, D., 2000, *ApJ*, 539, L9
 Gebhardt, K., Kormendy, J., Ho, L. C., et al., 2000a, *ApJ*, 539, L13
 Heckman, T., Kauffmann, G., Brinchmann, J., et al., 2004, *ApJ*, 613, 109 (H04)
 Heckman, T. M., Ptak, A., Hornschemeier, A., & Kauffmann, G., 2005, *ApJ*, 634, 161
 Hopkins, P. F., Richards, G. T., & Hernquist, L., 2007, *ApJ*, 654, 731
 Kaspi, S., Maoz, D., Netzer, H., et al., 2005, *ApJ*, 629, 61
 Kaspi, S., Smith, P. S., Netzer, H., et al., 2000, *ApJ*, 533, 631
 Kauffmann, G., Heckman, T.M., Tremonti, C., et al., 2003b, *MNRAS*, 346, 1055
 Kauffmann, G., & Heckman, T.M., 2008 arXiv0812.1224
 Kollmeier, J. A., Onken, C. A., Kochanek, C. S., et al., 2005 *ApJ*, 648, 128
 Magorrian, J., Tremaine, S., Richstone, et al., 1998, *AJ*, 115 2285
 Maiolino, R., Shemmer, O., Imanishi, M., et al., 2007, *A&A*, 468, 979.
 Marconi, A., Risaliti, G., Gilli, R., et al., 2004, *MNRAS*, 351, 169
 Matt, G., Guainazzi, M., Maiolino, R., et al., 1999, *A&A* 341, L39
 McLure, R. J., & Dunlop, J. S., 2004, *MNRAS*, 352, 1390
 Menci, N., Cavaliere, A., Fontana, A., et al., 2003, *ApJ*, 587, L63
 Menci, N., Fiore, F., Perola, G. C., & Cavaliere, A., 2004, *ApJ*, 606, 58
 Merloni, A., Körding, E., Heinz, S., et al., 2006, *NewA*, 11..567
 Mulchaey, J. S., Koratkar, A., Ward, M. J., et al., 1994, *ApJ*, 436, 586
 Netzer, H., Mainieri, V., Rosati, P., & Trakhtenbrot, 2006, *A&A*, 453, 525 (N06)
 Netzer, H., & Trakhtenbrot, B., 2007, *ApJ*, 654, 754
 Osterbrock, D. E., & Ferland, G. J., 2006 Book Review: *ASTROPHYSICS OF GASEOUS NEBULAE AND ACTIVE GALACTIC NUCLEI (2ND EDITION)* / University Science Books
 Panessa, F., Bassani, L., Cappi, M., et al., 2006, *A&A* 455, 173 (P06)
 Peterson, B. M., Ferrarese, L., Gilbert, K. M., et al., 2004, *ApJ*, 613, 682
 Peterson, B. M., Bentz, M. C., Desroches, L. B., et al., 2005, *ApJ*, 632, 799
 Treister E., Krolik J.H., & Dullemond C., 2008, *ApJ*, 679, 140
 Tremaine, S., Gebhardt, K., Bender, R., et al., 2002, *ApJ*, 574, 740
 Vasudevan, R. V., & Fabian, A., 2007 *MNRAS*, 381, 1235
 Vestergaard, M., 2002, *ApJ*, 571, 733
 Vestergaard, M., 2004, *ApJ*, 601, 676
 Vignali, C., Brandt, W. N., & Schneider, D. P., 2003, *AJ*, 125, 433
 Warner, C., Hamann, F., & Dietrich, M., 2004, *ApJ*, 608, 136
 Woo, J., & Urry, C. M., 2002, *ApJ*, 579, 530
 Zakamska, N. L., Strauss, M. A., Krolik, J. H., et al., 2003, *AJ*, 126, 2125

Appendix A: The X-ray data

Of the 8 sources presented in this paper, 7 were observed as a part of our *XMM-Newton* proposal ID 050206 and ID 055120, and one was observed serendipitously.

The data have been processed using the *XMM-Newton* Science Analysis Software (SAS) v.8.0. The raw event files (the Observation Data Files, ODF), have been linearized with the *XMM-SAS* pipeline EPPROC for the PN camera, and we generated calibration files using the *XMM-SAS* pipeline CIFBUILD. Event files were cleaned from bad pixel (hot pixels and events out of the field of view) and we have selected events spread at most in two contiguous pixels (pattern=0-4). We removed periods of high background levels by analysing the light curves of the count rate at energies higher than 10 keV. Response functions (the ancillary response file and the redistribution matrix file) for spectral fitting were generated using the SAS tasks RMFGEN and ARFGEN. We have extracted the PN counts in a circular region, with radius of 15", centered at the source position, and the background counts in the source-free regions close to the target.

The SDSS name, redshift, exposure times (filtered for good time intervals), X-ray PN count rates (or 5σ upper limits) in the rest frame energy ranges (0.5-2) keV and (2-10) keV are listed in Table A.1.

Of the 8 sources, two are detected (i.e. the Poisson probability of a spurious background excess is less than 2.7×10^{-3}) in the (0.5-10) keV band, two in the soft band (0.5-2 keV) only and one in the hard band (2-10 keV) only.

Sufficient counts for a spectral fitting in the 2-10 keV band were collected only from three sources: SDSSJ075920.21+351903.4 SDSSJ143928.23+001538.0 and SDSSJ083945.98+384319.0.

Spectral analysis was carried out with XSPEC v.12.4.0 using data accumulated in energy bins with 5 counts each and the C-statistic (Cash 1979). The spectral fits are shown in Fig. A.1.

The X-ray spectra in the (0.5-10) keV band are fitted with an absorbed power-law continuum plus a Compton-reflection component and a soft-excess component, modelled with a power-law with photon index equal to the one of the primary continuum. The parameters of the fits along with the observed (2-10) keV flux, and the de-absorbed (2-10) keV luminosity are shown in Table A.2. In SDSSJ075920.21+351903.4 an iron line with equivalent width of about 2.6 keV is also detected, revealing that this source is Compton-thick. In Compton-thick sources the primary X-ray emission is totally suppressed below 10 keV, the hard X-ray emission is accounted for by reflection of the primary nuclear emission off the inner walls of optically thick circumnuclear matter.

The luminosity reported in Table A.2 is obtained assuming that the ratio between the reflected and the primary component is 0.05, similar to what observed in the Circinus galaxy, one of the best studied Compton-thick sources (Matt et al. 1999).

The upper limits in the X-ray luminosity, listed in Table 1, for the other sources are extrapolated from the observed count rates (column (5) of Table A.1) assuming a typical spectrum of

Source (1)	z (2)	Exp. (3)	Count rate (0.5-2) keV (4)	Count rate (2-10) keV (5)
SDSSJ075920.21+351903.4	0.328	19.16	<1.7	0.9 ^{+0.4} _{-0.3}
SDSSJ083945.98+384319.0	0.424	16.00	1.1 ^{+0.3} _{-0.3}	6.7 ^{+0.7} _{-0.7}
SDSSJ084041.05+383819.9	0.313	16.00	<2.3	<2.0
SDSSJ092318.04+010144.7	0.386	23.36	1.2 ^{+0.4} _{-0.3}	<1.8
SDSSJ094820.38+582526.4	0.353	31.38	1.6 ^{+0.3} _{-0.3}	<1.9
SDSSJ133735.01-012815.6	0.329	6.11	<4.2	<2.7
SDSSJ143027.66-005614.8	0.318	7.49	<4.0	<3.9
SDSSJ143928.23+001538.0	0.339	19.32	1.2 ^{+0.4} _{-0.3}	3.3 ^{+0.5} _{-0.4}

Table A.1. (1) SDSS name. (2) Redshift. (3) Exposure time filtered for good time intervals in units of Ks. (4) Observed count rates in rest-frame (0.5-2) keV band in units of 10^{-3} counts s^{-1} . (5) Observed count rates in rest-frame (2-10) keV band in units of 10^{-3} counts s^{-1}

Source (1)	Γ (2)	N_H (3)	F_{2-10}^{obs} (4)	$\log L_X^{int}$ (5)
SDSSJ075920.21+351903.4	1.9 (fixed)	–	1.3×10^{-14}	43.92*
SDSSJ083945.98+384319.0	1.9 (fixed)	$3.28^{+0.95}_{-0.78} \times 10^{22}$	2.3×10^{-13}	44.26
SDSSJ143928.23+001538.0	1.9 (fixed)	$27.1^{+15}_{-10.2} \times 10^{22}$	6.6×10^{-14}	43.88

Table A.2. (1) SDSS name. (2) Power-law photon index. (3) Hydrogen column density (4) observed flux in the (2-10) keV band in units of $\text{erg s}^{-1} \text{cm}^{-2}$. (5) \log of the absorption-corrected luminosity in the (2-10) keV band in units of erg s^{-1} . (*) L_X^{int} is obtained assuming that the ratio between the reflected and the primary component is 0.05

Compton-thick sources. The spectrum is assumed to be a power-law with photon index $\Gamma=1.9$ absorbed by column density of $N_H=1.5 \times 10^{24}$, plus a pure Compton reflection component with an iron line (at 6.4 keV and with equivalent width $EW=1$ keV with respect of the pexrav component). The ratio between the reflected and the primary component is assumed to be 0.05. We have chosen this spectrum because we wanted to study the extreme case of obscuration which implies the higher intrinsic X-ray luminosities and therefore the higher bolometric luminosities.

We have used this method to estimate L_X^{int} also in the sources detected only in the soft band, because from the comparison between the observed X-ray luminosity and that predicted from L_{OIII}^c and Eq. (2) we argued that they are heavily absorbed sources. Therefore the soft X-ray emission is not the primary soft X-ray emissions but a soft excess component.

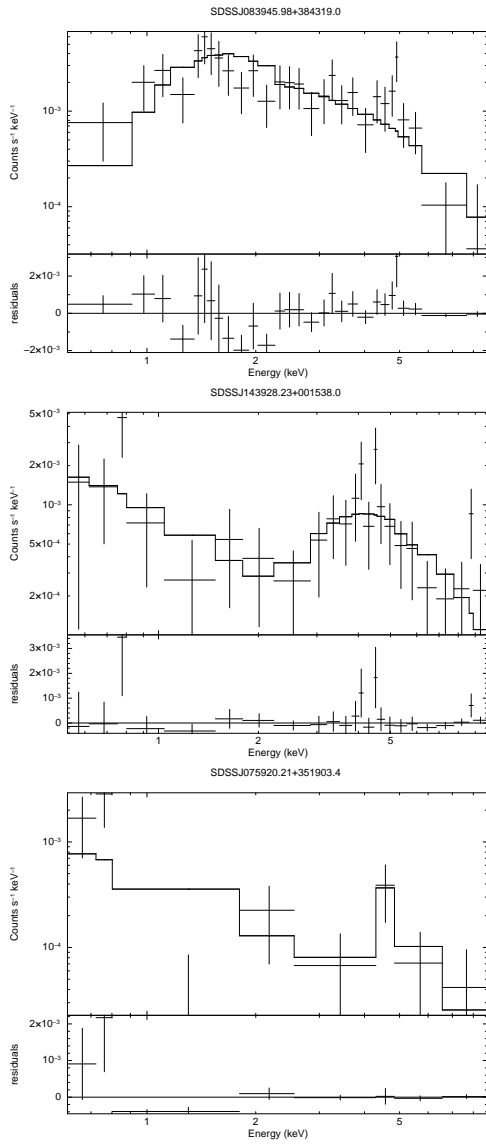


Fig. A.1. XMM-Newton spectra of SDSSJ083945.98+384319.0, SDSSJ143928.23+001538.0 and SDSSJ075920.21+351903.4 from top to bottom.