1 Introduction

Over the past few years, extensive studies have been carried out to determine the complete census of the active galactic nuclei (AGN) population, in particular the bright, obscured objects (optically type 2 QSOs), invoked by the synthesis models of the X-ray background (XRB, Setti & Woltjer 1989; Comastri et al. 1995; Comastri 2001; Gilli et al. 2001, 2007). The deepest surveys carried out to date by Chandra and XMM-Newton have resolved >90% (Mushotzky et al. 2000; Hastinger et al. 2001; Alexander et al. 2003) of the XRB spectrum at energies below 5 keV, however a large number of the obscured AGN are still missing. For these reasons, many studies have been addressed to reveal this elusive class of objects, primarily focused on the X-ray band, but also involving multi-wavelength studies (Zakamska et al. 2003, 2004; Martínez-Sansigre et al. 2006).

In previous studies, the X-ray-to-optical flux ratio ($f_X/f_{\text{opt}}$), defined here as the ratio between the X-ray flux (usually in the 2–10 keV energy band) and R-band flux, has been commonly used to provide a first classification of the X-ray population (Maccacaro et al. 1988): normal galaxies have typically $f_X/f_{\text{opt}} \leq 0.1$ (e.g. Giacconi et al. 2001; Lehmann et al. 2001) while the dominant X-ray selected AGN population has $0.1 < f_X/f_{\text{opt}} < 10$ (e.g. Akiyama et al. 2000; Alexander et al. 2001; Fiore et al. 2003); obscured AGN typically have $f_X/f_{\text{opt}} \sim 10$ or above (e.g. Mignoli et al. 2004).

Recently, a new interesting class of objects with extreme values of the X-ray-to-optical flux ratio ($f_X/f_{\text{opt}} > 10$) has been found from deep X-ray surveys; these objects, called Extreme X-ray-to-Optical ratio sources (EXOs, Koekemoer et al. 2004), are usually detected in X-rays and in near-IR, but completely undetected in the optical bands. Although a few turn out to be BL Lac objects, high-redshift clusters of galaxies or rare Galactic objects (e.g. X-ray binaries, cataclysmic variables, isolated neutron stars or ultraluminous X-ray sources), the majority are almost certainly type 2 AGN (Fiore et al. 2003), where the nucleus is heavily obscured by dust in the UV/optical/IR whilst the X-ray flux, although strongly absorbed at low energies (below ~2 keV), is much less affected by absorption above ~2 keV.

As expected in this scenario, a significant fraction of the EXO population shows the extremely red colours of EROs (extremely red objects, typical $R - K \geq 5$, Elston et al. 1988; see Fiore et al. 2003; Mignoli et al. 2004). EXOs with optical-NIR colours of EROs are thus amongst the best candidates to be highly absorbed, highly obscured AGN, i.e. type 2 AGN.

However, almost by definition, sources with such extreme $f_X/f_{\text{opt}}$ have faint optical magnitudes and this is even more true for the faint X-ray sources found in the deep, pencil-beam surveys (Koekemoer et al. 2004; Civano et al. 2005). At such faint
X-ray fluxes ($f_X = 10^{-15} - 10^{-16}$ erg cm$^{-2}$ s$^{-1}$), sources with $f_X/f_{\text{opt}} > 10$ have R magnitudes ~25.5–28, so the optical follow-up observations are very difficult or impossible. Studies performed at higher X-ray fluxes ($f_X = 10^{-14} - 10^{-15}$ erg cm$^{-2}$ s$^{-1}$, e.g. Fiore et al. 2003; Miglioli et al. 2004; Severgnini et al. 2006), for which optical data are available, have classified more than a half of their EXO sources as type 2 QSOs.

In this paper, we report the results obtained from the multi-wavelength analysis of 2XMM J123204+215255, the most extreme source amongst a sample of 130 bright ($f_X \geq 10^{-11}$ erg cm$^{-2}$ s$^{-1}$) X-ray selected EXOs (Del Moro et al., in prep.) from the 2XMMp catalogue (the pre-release of the Second XMM-Newton Serendipitous Source Catalogue, Watson et al. 2008). The whole sample is described in Sect. 2.1. The X-ray and optical/NIR properties of 2XMM J123204+215255 are discussed in Sects. 2.2 and 2.3, respectively; a detailed description of the NIR spectrum is presented in Sect. 2.4. An SED model analysis and results are discussed in Sect. 3, followed by the conclusions (Sect. 4). Throughout the paper we assume a cosmological model with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.27$ and $\Omega_\Lambda = 0.73$ (Spergel et al. 2003).

2. Observations and results

2.1. The EXO sample

The object we present in this paper is part of a sample selected from a cross-correlation between the 2XMMp$^2$ and the Sloan Digital Sky Survey, Data Release 5 (SDSS-DR5, Adelman-McCarthy et al. 2007) catalogues, which yields about 20,000 secure matches. SDSS optical counterparts have been detected on the basis of positional matching, using an adaptation of the likelihood ratio method (e.g. Sutherland & Saunders 1992) to optimise the choice of correct counterpart and minimise the contamination by chance matches. Full details of our approach will appear in Del Moro et al., in preparation.

Our sample consists of relatively bright X-ray sources with $f_X \geq 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ (0.2–12 keV energy band) and extreme X-ray-to-optical flux ratio ($f_X/f_{\text{opt}} > 10$, in the 2–10 keV band). Each XMM and SDSS image of the sample objects has been carefully checked by eye in order to reject all the problematic cases: spurious X-ray detections, sources close to the edge of the XMM-Newton field of view, extended X-ray sources$^3$, optical counterparts in big nearby galaxies (HII region emissions). Because we are selecting extreme X-ray-to-optical flux ratio objects, the counterparts of our sources are typically faint in the optical, at our sensitivity limits, making it difficult in some cases to differentiate between the possibility that the true match is fainter than the SDSS limit or that the correct counterpart is a faint object with low likelihood ratio (and hence with a higher probability to be a chance match). The effects of this ambiguity are that the $f_X/f_{\text{opt}}$ values, in these cases, will be underestimated (i.e. if the counterpart is fainter than the SDSS limit). In this sense our sample is robust.

The sample resulting from these selection processes consists of 130 sources for which ~30% (including 2XMM J123204+215255) have no optical counterpart in the SDSS imaging data within 7″ from the X-ray position (see Sect. 2.2), down to a magnitude limit of $r' = 22.5$.

2.2. X-ray properties of 2XMM J123204+215255

The source 2XMM J123204+215255 is the most extreme X-ray-to-optical flux ratio object amongst our EXO sample. It is a bright X-ray source with $f_X = 8.8^{+0.7}_{-0.6} \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ (in the 2–10 keV energy band). On the basis of the lack of an SDSS counterpart it has $f_X/f_{\text{opt}} > 278$, already one of the highest ratios recorded, whilst as we show below, new data demonstrate the ratio to be $f_X/f_{\text{opt}} > 3300$, making it the highest known X-ray-to-optical flux ratio source outside the Galaxy. The source has been detected in an XMM-Newton observation with target “NGP Rift 3” which was made in July 2001 with an exposure time of ~15 ks with pn and ~20 ks with MOS1 and MOS2.

The statistical position error for 2XMM J123204+215255 is 0.3″. Taking into account the expected systematic error component for the 2XMMp catalogue of 0.35″, determined from a comparison of catalogue positions with the SDSS-DR5 Quasar Catalog (see Watson et al. 2008), we expect the counterpart to lie within ~1.4″ (99% confidence). The comparison with the SDSS Quasar Catalog shows that there are a very small number of outliers at large separations in excess of what is expected statistically (presumably indicating a larger systematic error component in these rare cases), but in no case the separation is >7 arcsec. We adopt this value as the most conservative upper limit on the possible separation of the true counterpart.

To study the X-ray spectrum of 2XMM J123204+215255, the data have been processed using the standard SAS v.7.1.0 tasks (XMM-Newton Science Analysis System, Gabriel et al. 2004). We extracted the spectrum of the source using an elliptical region to reproduce the shape of the Point Spread Function (PSF) of the XMM Telescopes at the source position. The corresponding background spectrum has been extracted using an annular region with radii 30″ and 90″, centred on the source position, removing any other detected nearby sources. The data have been then filtered for high background intervals. The total EPIC number of counts in the 0.2–12 keV energy band after the filtering is 2234. The spectral analysis has been performed with XSPEC v.11.3.2 (Arnaud 1996), grouping the number of counts to a minimum of 10 counts per bin, in order to use the $\chi^2$ statistic. We find an acceptable fit to a simple model composed of a power-law plus Galactic and intrinsic absorptions; fixing $N_{\text{H}}^\text{gal} = 2 \times 10^{20}$ cm$^{-2}$, the best fit parameters are photon index $\Gamma = 1.7 \pm 0.2$ and hydrogen column density $N_H = (1.2 \pm 0.2) \times 10^{22}$ cm$^{-2}$ (assuming $z = 0$), with $\chi^2$/d.o.f. = 118.0/106.

Repeating the X-ray spectral analysis for $z = 1.87$, anticipating the result presented below (Sect. 2.4), we obtained a best fit to the data with a photon index $\Gamma = 1.5 \pm 0.1$ and a column density $N_H = (1.8 \pm 0.3) \times 10^{23}$ cm$^{-2}$ (Fig. 1). We note the presence of marginally significant structure in the spectrum residuals at energy ~1.5–3 keV which might be related to red-shifted line or edge features. The reality of these features clearly require confirmation at higher signal-to-noise.

2.3. Optical/IR properties

As noted above (Sect. 2.1), there is no counterpart for 2XMM J123204+215255 in SDSS DR5 within 7″ (Sect. 2.2) from the X-ray position in any of the SDSS bands ($u'$, $g'$, $r'$, $\text{i}'$, $\text{z}'$.

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$^2$ Although this object was originally selected from the 2XMMp, we adopt the nomenclature and catalogue parameters from the 2XMM catalogue throughout as 2XMM effectively supersedes 2XMMp.

$^3$ As we are looking for AGN, we want to select only X-ray point-like sources in our sample, so extended sources are considered as “problematic cases” amongst our selection criteria.
2.4. IR spectrum

2XMM J123204+215255 was observed in the H + K bands with the Multi-Object Infrared Camera and Spectrograph (MOIRCS, Ichikawa et al. 2006) at the Subaru Telescope in March 2007. The observation was performed in long-slit spectroscopy mode using the HK500 grism and 0.8″ slit width, under a seeing of 0.6″. The spectrum covers a wavelength range of 13 000–23 000 Å with a spectral resolution of ≈40 Å (~5 pix) FWHM estimated from the width of OH airglow lines.

We took 6 target frames with 7 min exposure each, thus the total on-source integration time was 42 min. The telescope was dithered after every single exposure and the target was observed at different positions along one of the 1.5″ slit (1′′ from the slit centre). After sky subtraction, carried out by subtracting adjacent object frames from each other, flat-fielding was performed using dome-flat frames. These sky-subtracted and flat-fielded frames were then shifted, mirrored and combined to determine the average intensity value at each pixel with a 3σ clipping algorithm. Atmospheric absorption correction and flux calibration have been performed using the spectrum of a bright star (HD 119496, spectral type of A2V). The standard star spectrum was taken at the end of the night at a similar airmass to the target and with the same instrumental setup.

The observed spectrum (Fig. 3) reveals a red continuum emission, which is well represented by $f_i \propto \lambda$. Using this form and extrapolating it out to the wavelengths longer than 23 000 Å, the K-band magnitude of this source is estimated to be 19.7 ± 0.1 mag in the AB system without any corrections (the emission line is at the edge of the K-band and its effect on this estimate can be ignored). This is consistent with the UKIRT-WFCAM photometry (K = 19.9 ± 0.05, see Sect. 2.3 and Table 1) within the uncertainties. An estimated ~10% of the total flux from the object falls outside the slit width in the 0.6″ seeing conditions of the observation. As the slit losses are uncertain and the magnitude estimates from the spectroscopy are consistent with the UKIRT imaging, we therefore do not apply any slit-loss corrections to the emission line fluxes estimated below, but note that they have ~10−20% systematic uncertainty.

As shown in Fig. 3, a single broad emission line (FWHM = 5280 ± 331 km s$^{-1}$) is clearly visible on the red continuum in the observed spectrum at 18837 ± 7 Å (line centroid). The line flux is $f = (5 \pm 0.2) \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$ (uncorrected for absorption; Table 2). The emission line centre and line width have been estimated by fitting a Gaussian to the spectrum in the vicinity of the line after the continuum was subtracted, whilst the line flux was estimated by directly integrating the continuum-subtracted line profile. The derived Equivalent Width (EW) is $EW = 2500 \pm 140 \, \text{Å}$. All the uncertainties are estimated from the 1σ errors in the Gaussian fitting process.

Although there are no other significant emission or absorption lines visible in the spectrum, the most likely interpretation is that the line detected is Hα. We also considered other possible interpretations for this line:

1) if it were one of the Paschen series the implied redshift would be $z < 1$ which seems unlikely as the host galaxy is not detected in the optical (and would thus be a very low luminosity object) and the detected line flux would be much higher than expected;

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UKIRT-WFCAM J-band image shows a single broad emission line (FWHM) showing a single broad emission line (FWHM) demonstrating a single broad emission line (FWHM) and the expected Hα line is just at the wavelength range where the spectrum is sensitive to this feature. The dashed vertical lines indicate the central wavelengths of Hα and the IR counterpart detected in the UKIRT-WFCAM J and K bands. The K-band image shows an apparently stellar counterpart (K = 19.9, AB). The circles have a radius of 7′′ and are centred on the X-ray position.

Table 1. Multi-wavelength properties of 2XMM J123204+215255.

| IAU Name         | RA Dec [h:m:s][d:m:s] | EPIC cts | f2–10 keV [10^{-13} erg cm^{-2} s^{-1}] | L2–10 keV [10^{46} erg s^{-1}] | fα/fopt | rbd | ic | jbd | Kd |
|------------------|-----------------------|----------|--------------------------------------|---------------------------------|---------|-----|----|-----|-----|
| 2XMM J123204+215255 | 12:32:04.91+21:52:55.4 | 2234     | 8.8^{+0.7}_{-2.6}                   | 1.6                             | >278 (>3300) | >22.5 | >25.2 | >22.2 | 19.9 |

* Total pn+MOS1+MOS2 counts. * SDSS (AB). * NOT (AB). * UKIRT-WFCAM (AB). * Expected value derived from i-band limit, see text.

For a redshift z = 1.87, the intrinsic X-ray luminosity for the source is L_X = 1.6 × 10^{40} erg s^{-1} (2–10 keV rest-frame) and the X-ray spectrum has a large column density (N_H ≈ 2 × 10^{23} cm^{-2}; Sect. 2.2). The X-ray properties of 2XMM J123204+215255 are thus those of a very luminous, heavily absorbed AGN, with spectral parameters typical for a type 2 QSO.

In contrast the IR spectrum shows a broad Hα emission line and the IR counterpart detected in the K-band has a probable stellar morphology, characteristics of a type 1 object. To further complicate the story the predicted emission line fluxes are much higher than those observed (see Table 2).

Using the correlation between hard X-ray luminosities and Hα and [OIII] luminosities from Panessa et al. (2006):

\[ \log L_X = (1.06 \pm 0.04) \log L_{\text{H\alpha}} - (1.14 \pm 1.78) \]

\[ \log L_X = (1.22 \pm 0.06) \log L_{[\text{OIII}]} - (7.34 \pm 2.53) \]
the predicted flux for Hα is \( f_{\text{H}\alpha} \approx 1.7 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \), which is about 30 times higher than the detected line flux (uncorrected for absorption) and the predicted fluxes for [OIII] and Hβ are \( f_{\text{[OIII]}} \approx 2.9 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1} \) and \( f_{\text{H}\beta} \approx 4.8 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1} \) (assuming the standard Hα/Hβ ratio, e.g. Ward et al. 1988), whereas these lines are not detected at all.

In order to see whether it was possible to reconcile the X-ray, optical and near IR characteristics of this object, we carried out simple modelling of the IR spectral continuum using a composite Spectral Energy Distribution (SED) with two components: one corresponding to the host galaxy and one to a typical QSO (Fig. 4). As QSOs are typically found to be hosted by massive elliptical galaxies (McLeod & Rieke 1995; Arnett et al. 1998; Dunlop et al. 2003), we adopted a 5 Gyr early-type galaxy template, generated with the GRASIL code (Silva et al. 1998). To reproduce the QSO we adopted a composite spectrum of a type 1 QSO with the highest IR/optical ratio (from Polletta et al. 2007). In the model the QSO SED component has intrinsic absorption, i.e. nuclear extinction, parameterised by a rest-frame equivalent \( A_V \) and represented by the Small Magellanic Cloud (SMC) extinction curve from Pei (1992), whilst both the QSO and galaxy SEDs have fixed Galactic absorption (\( N_{\text{H}10} = 2 \times 10^{22} \text{ cm}^{-2} \)), using the Milky Way extinction curve (Pei 1992). The other free parameter in the model is the Galaxy Fraction (\( g \)), which we define as the ratio between the host galaxy and the intrinsic QSO fluxes in the rest-frame wavelength range \( \lambda_1 = 4160 \text{ Å} < \lambda < \lambda_2 = 4210 \text{ Å} \), chosen because it avoids most of the galaxy absorption lines and the quasar emission lines (Vanden Berk et al. 2006), i.e.:

\[
g = \frac{\int_{\lambda_1}^{\lambda_2} f_{\text{gal}} \text{ d} \lambda}{\int_{\lambda_1}^{\lambda_2} f_{\text{QSO}} \text{ d} \lambda}.
\]

We used this SED model to fit the IR continuum (Fig. 3) in the wavelength range 14500–23000 Å. As we aimed to reproduce only the spectral continuum, we excluded the emission line from the fitting; we excluded also the wavelengths below 14500 Å because of the lower S/N in this part of the spectrum and to avoid the wavelengths of the expected [OIII] and the Hβ emission lines. After binning the spectrum, we computed \( \chi^2 \) values for a grid of possible nuclear extinction and Galaxy Fraction (\( g \)) parameters and we determined confidence intervals for the two free parameters using the usual \( \chi^2 \) prescription (Fig. 5). Our modelling provides strong constraints on the rest-frame equivalent \( A_V \approx 3.2–5.0 \) (90% confidence), while the galaxy contribution is not strongly constrained. The best-fit of the near IR spectrum and the residuals of the fitting are shown in Fig. 4. We can also use the model fit results to constrain the expected \( r' \), \( i' \) and \( J\)-band magnitudes. Our best-fit model predicts \( r' \approx 27.7, i' \approx 26.3 \) and \( J \approx 22.6 \), values consistent with the upper limits discussed in Sect. 2.3. We note that the general properties of 2XMM J123204+215255 are rather similar to the object presented by Severgnini et al. (2006), although our source has higher extinction and has not yet been detected in the optical band. Our constraints on the host galaxy mass are comparable to, or somewhat lower than, that inferred by Severgnini et al. (2006) for their object.

Our modelling cannot of course be considered as definitive, as it is limited by the restricted wavelength coverage of our data, by the fact that we cannot be sure of the intrinsic SEDs for the galaxy and AGN components and by the assumption that just two components will adequately represent the data. We can however examine how our results depends on the choice of the SED components in the spectral range we are investigating, by using different QSO templates (from Polletta et al. 2007) in the fitting process. For this range of templates we find variations of \( \leq 10\% \) in the derived rest-frame equivalent \( A_V \). As in all the models we tested the contribution of the galaxy appears to be only few percent of the total emission there is clearly little sensitivity to the precise shape of the galaxy SED adopted.

Table 2. Observed and predicted line fluxes of 2XMM J123204+215255.

| Line | Observed flux$^a$ [erg cm$^{-2}$ s$^{-1}$] | Predicted flux$^b$ [erg cm$^{-2}$ s$^{-1}$] | Corrected flux [erg cm$^{-2}$ s$^{-1}$] | $A_V^f$ [mag] |
|------|---------------------------------|------------------|------------------|-----------|
| Hα   | \((5 \pm 0.2) \times 10^{-16}\)  | \(1.7 \times 10^{-14}\) | \(4.6 \times 10^{-15}\) | 2.4       |
| Hβ   | \(<1 \times 10^{-16}\)           | \(<1 \times 10^{-16}\) | \(<1 \times 10^{-16}\) | 5.3       |
| [OIII]| \(<3 \times 10^{-17}\)           | \(<3 \times 10^{-17}\) | \(<3 \times 10^{-17}\) | 5.3       |

$^a$ Uncorrected for extinction, measured from the IR spectrum.

$^b$ From the correlations of Panessa et al. (2006).

$^c$ Extinction estimated from the model.

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**Fig. 4.** Best-fit model of the NIR spectrum (magenta points); green circles: photometric measurements and upperlimits of the $r'$, $i'$, $J$ and $K$-band magnitudes; red line: galaxy SED; blue line: absorbed QSO SED; grey dash-dotted line: unabsorbed QSO SED; black line: resulting SED (QSO + host galaxy). In the lower panel the residuals of the fitting are shown.

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With the model parameters obtained from our analysis, the extinction for the QSO component in the $J$-band (close to Hβ and [OIII]) corresponds to \( A_J = 5.3 \) mag and \( A_K = 2.4 \) mag in the $K$-band, in the vicinity of the redshifted Hα line. Correcting the observed Hα flux for this extinction (\( A_H \)) gives a value \( f_{\text{H}\alpha} \approx 4.6 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1} \), which is lower than the flux expected from the \( L_X - L_{\text{H}\alpha} \) correlation of Panessa et al. (2006) (see Table 2), but well within the scatter of the correlation. The much higher extinction (\( A_J \approx 5.3 \)) at the Hβ line is fully consistent with its non-detection.
The lack of detection of the [OIII] line is not explained in the model, as this line is expected to originate in the Narrow-Line Region (NLR) which should not be affected by the large extinction of the nuclear region. However, the weakness or disappearance of the [OIII] emission line has already been reported for high-luminosity AGN (see Yuan & Wills 2003; Netzer et al. 2004; Sulentic et al. 2004). A possible explanation may be related to the fact that the simple scaling law: \( R_{\text{NLR}} \propto L_{\text{ion}}^{1/2} \) (where \( R_{\text{NLR}} \) is the radius of the Narrow Line Region and \( L_{\text{ion}} \) is the ionising source luminosity, Netzer et al. 2004), which may explain the correlation between the X-ray and the [OIII] luminosities at lower values, must break down when the NLR radius becomes comparable with the size of the galaxy.

Another possible explanation may be the presence of obscuring dust outside the torus, at larger distances from the nucleus. This dust could reside in the NLR (Polletta et al. 2008) or in the host galaxy (Rigby et al. 2006; Martínez-Sansigre et al. 2006; Brand et al. 2007) and could thus absorb the emission coming from the Narrow Line Region. This interpretation is equally consistent with the observed red continuum and the extinction of the broad lines whilst also providing an explanation for the absence of any narrow lines in the IR spectrum. However, as it is not possible to constrain the location of the obscuring dust with the present data, neither interpretation can be rejected.

Finally we note that the values obtained for the optical extinction from our modelling are significantly lower than naively expected from the measured X-ray column density. This can most easily be parameterised by a dust-to-gas ratio which is about 20–25 times lower than the standard Galactic value (\( A_V = N_{\text{H}}/(1.8 \times 10^{21}) \), e.g. Predehl & Schmitt 1995). Such low ratios have been reported in several previous studies of AGN (Maccacaro et al. 1982; Maiolino et al. 2001b; Akiyama et al. 2002; Willott et al. 2004). In this comparison, as is the case in the other papers cited, we are assuming the simplest possible geometry where the dust and gas are co-spatial and lie in a uniform foreground screen\(^4\). One possible explanation for the high ratio is a different dust grain size distribution dominated by large grains, whose formation is naturally expected in the high density environments, like those characterising the circum-nuclear region of AGNs. This dust grain distribution makes the extinction curve flatter than the Galactic one and yields a higher \( N_{\text{H}}/A_V \) ratio (Maiolino et al. 2001a; Maiolino 2002). This would not be a valid explanation if the absorption is on kpc-scales as discussed above.

4 This assumption may lead to an underestimation of the effective extinction of the source (e.g. MacKenty et al. 2000). More realistic dust and gas distributions can of course lead to different conclusions about high extinction ratios.
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References

Adelman-McCarthy, J. K., Agüeros, M. A., Allam, S. S., et al. 2007, ApJS, 172, 634

Akiyama, M., Ohta, K., Yamada, T., et al. 2000, ApJ, 532, 700

Akiyama, M., Ueda, Y., & Ohta, K. 2002, ApJ, 567, 451

Alexander, D. M., Brandt, W. N., Hornschemeier, A. E., et al. 2001, AJ, 122, 2156

Alexander, D. M., Bauer, F. E., Brandt, W. N., et al. 2003, AJ, 126, 539

Aretxaga, I., Terlevich, R. J., & Boyle, B. J. 1998, MNRAS, 296, 643

Arnaud, K. A. 1996, in Astronomical Data Analysis Software and Systems V, ed. G. H. Jacoby & J. Barnes, ASP Conf. Ser., 101, 17

Brand, K., Dey, A., Desai, V., et al. 2007, ApJ, 663, 204

Civano, F., Comastri, A., & Brusa, M. 2005, MNRAS, 358, 693

Comastri, A. 2001, X-ray Astronomy: Stellar Endpoints, AGN, and the Diffuse X-ray Background, AIP Conf. Proc., 599, 73

Comastri, A., Setti, G., Zamorani, G., & Hasinger, G. 1995, A&A, 296, 1

Dunlop, J. S., McLure, R. J., Kukula, M. J., et al. 2003, MNRAS, 340, 1095

Elston, R., Rieke, G. H., & Rieke, M. J. 1988, ApJ, 331, L77

Fiore, F., Brusa, M., Cocchia, F., et al. 2003, A&A, 409, 79

Gabriel, C., Denby, M., Fyfe, D. J., et al. 2004, in Astronomical Data Analysis Software and Systems (ADASS) XIII, ed. F. Ochsenbein, M. G. Allen, & D. Egret, ASP Conf. Ser., 314, 759

Giacconi, R., Rosati, P., Tozzi, P., et al. 2001, ApJ, 551, 624

Gilli, R., Salvati, M., & Hasinger, G. 2001, A&A, 366, 407

Gilli, R., Comastri, A., & Hasinger, G. 2007, A&A, 463, 79

Hasinger, G., Altieri, B., Arnaud, M., et al. 2001, A&A, 365, L45

Hewett, P. C., Warren, S. J., Leggett, S. K., & Hodgkin, S. T. 2006, MNRAS, 367, 454

Ichikawa, T., Suzuki, R., Tokoku, C., et al. 2006, in Ground-based and Airborne Instrumentation for Astronomy, ed. I. S. McLean, & M. Iye, Proc. SPIE, 6290, 6269/16

Koekemoer, A. M., Alexander, D. M., Bauer, F. E., et al. 2004, ApJ, 600, L123

Lehmann, I., Hasinger, G., Schmidt, M., et al. 2001, A&A, 371, 833

Maccacaro, T., Perola, G. C., & Elvis, M. 1982, ApJ, 257, 47

Maccacaro, T., Gioia, I. M., Wolter, A., Zamorani, G., & Stocke, J. T. 1988, ApJ, 326, 680

MacKenty, J. W., Maíz-Apellániz, J., Pickens, C. E., Norman, C. A., & Walborn, N. R. 2000, AJ, 120, 3007

Maiolino, R. 2002, in Issues in Unification of Active Galactic Nuclei, ed. R. Maiolino, A. Marconi, & N. Nagar, ASP Conf. Ser., 258, 15

Maiolino, R., Marconi, A., & Oliva, E. 2001a, A&A, 365, 37

Maiolino, R., Marconi, A., Salvati, M., et al. 2001b, A&A, 365, 28

Martínez-Sansigre, A., Rawlings, S., Lacy, M., et al. 2006, MNRAS, 370, 1479

McLeod, K. K., & Rieke, G. H. 1995, ApJ, 454, L77

Mignoli, M., Pozzetti, L., Comastri, A., et al. 2004, A&A, 418, 827

Mushotzky, R. F., Cowie, L. L., Barger, A. J., & Arnaud, K. A. 2000, Nature, 404, 459

Netzer, H., Shemmer, O., Maiolino, R., et al. 2004, ApJ, 614, 558

Oke, J. B., & Gunn, J. E. 1983, ApJ, 266, 713

Panessa, F., Bassani, L., Cappi, M., et al. 2006, A&A, 455, 173

Pei, Y. C. 1992, ApJ, 395, 130

Polletta, M., Tajer, M., Maraschi, L., et al. 2007, ApJ, 663, 81

Polletta, M., Weedman, D., Hönig, S., et al. 2008, ApJ, 675, 960

Predehl, P., & Schmitt, J. H. M. M. 1995, A&A, 293, 889

Rigby, J. R., Rieke, G. H., Donley, J. L., Alonso-Herrero, A., & Pérez-González, P. G. 2006, ApJ, 645, 115

Setti, G., & Woltjer, L. 1989, A&A, 224, L21

Severgnini, P., Caccianiga, A., Braits, V., et al. 2006, A&A, 451, 859

Saida, L., Granato, G. L., Bressan, A., & Danese, L. 1998, ApJ, 509, 103

Spergel, D. N., Verde, L., Peiris, H. V., et al. 2003, ApJS, 148, 175

Sulentic, J. W., Sturpe, G. M., Marziani, P., et al. 2004, A&A, 423, 121

Sutherland, W., & Saunders, W. 1992, MNRAS, 259, 413

Vanden Berk, D. E., Shen, J., Yip, C.-W., et al. 2006, AJ, 131, 84

Ward, M. J., Done, C., Fabian, A. C., Tennant, A. F., & Shawer, R. A. 1988, ApJ, 324, 767

Watson, M. G., Schröder, A. C., Fyfe, D., et al. 2008, ArXiv e-prints, 807

Willott, C. J., Simpson, C., Almaini, O., et al. 2004, ApJ, 610, 140

Yuan, M. J., & Wills, B. J. 2003, ApJ, 593, L11

Zakamska, N. L., Strauss, M. A., Krolik, J. H., et al. 2003, AJ, 126, 2125

Zakamska, N. L., Strauss, M. A., Heckman, T. M., Ivezic, Ž., & Krolik, J. H. 2004, AJ, 128, 1002