A&A 418, 907–911 (2004)
DOI: 10.1051/0004-6361:20035724

Astronomy & Astrophysics

1WGA J2223.7-0206: A Narrow-Line Quasi-Stellar Object in the *XMM-Newton* field of view of 3C 445*

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Received 21 November 2003 / Accepted 30 January 2004

Abstract. We report the discovery of a Narrow Line QSO located at about 1.3′ from the Broad Line Radio Galaxy 3C 445. The source, 1WGA J2223.7-0206, although already revealed by ROSAT, has never been optically identified previously. An *XMM-Newton* observation of 3C 445 has allowed, for the first time, an accurate X-ray spectral study of 1WGA J2223.7-0206, revealing an ultra-soft spectrum and fast flux variations typical of Narrow Line AGN. The 0.2–10 keV spectrum is well represented by a power law ($\Gamma = 2.5$) plus a black body component ($kT = 117$ eV) absorbed by Galactic $N_{\rm H}$. About 80% of the X-ray flux ($F_{0.2-10\ {\rm keV}} \sim 3 \times 10^{-13}$ erg cm^{-2} s^{-1}) is emitted below 2 keV. The 0.2−2 keV flux is observed to decrease by about a factor 1.6 in about 5000 s.
The optical observations, triggered by the X-ray study, confirm the Narrow Line AGN nature of this source. The continuum is blue with typical AGN emission lines, pointing to a redshift $z = 0.46$. The full width half maximum of H_β and the flux ratio [O III]/H_β are 2000 km s^{-1} and 0.21, respectively. The optical luminosity ($M_R = -23.2$) and the point-like appearance in the optical images identify 1WGA J2223.7-0206 as a Narrow Line QSO.
From the optical-UV-X-ray Spectral Energy Distribution we obtain a lower limit of the bolometric luminosity of 1WGA J2223.7-0206 ($L_{\rm bol} \geq 3 \times 10^{45}$ erg s^{-1}) implying, for accretion rates close to the Eddington limit, a black hole mass $M_{\rm BH} \geq 2 \times 10^7\ M_\odot$.

Key words. galaxies: quasars: individual: 1WGA J2223.7-0206 – X-rays: galaxies

1. Introduction

The Narrow Line (NL) type I AGN (Seyfert and QSO) are a class of objects which has focused the attention of the scientific community in the last years because of its unusual optical and X-ray properties. Their optical spectra have permitted lines which are slightly broader than the forbidden lines (i.e. full width at half maximum (*FWHMH*) $H_\beta \leq 2000$ km s^{-1}), a flux ratio O[III]$\lambda 5007/H_\beta < 3$ and a prominent Fe II bump (Osterbrock & Pogge 1985). In the X-ray range, they exhibit strong flux variability and very steep spectra (Boller et al. 1996; Forster & Halpern 1996; Molthagen et al. 1998; Dewangan et al. 2001). The most favored interpretation is that they represent an AGN class with very small black holes and very high accretion rates. Actually, emission lines of highly ionized iron, as expected to be produced by high accreting disks (Nayakshin & Kazanas 2001), have been discovered in several NL Seyfert 1 galaxies with ASCA and BeppoSAX (Pounds et al. 1995; Comastri et al. 1998; Turner et al. 1998; Leighly 1999; Gliozzi et al. 2001). Recently, Pounds et al. (2003a,b) have revealed several absorption lines in both *XMM-Newton* high and low resolution spectra, interpreted as signatures of a highly ionized wind. As suggested by King & Pounds (2003) AGN with very high accretion rates should be able to produce an outflowing photosphere.

In this paper, we present *XMM-Newton* and optical observations of the newly discovered NLQSO located only 1.3′ far away from the Broad Line Radio Galaxy 3C 445. This serendipitous source is included in the the WGA catalog (White et al. 1994) with the name 1WGA J2223.7-0206 and discussed in a ROSAT 3C 445 study of Sambruna et al. (1998). However no particular attention has been paid to it. Its faintness in the ROSAT band (about a factor 3 below 3C 445) assured a negligible contamination of the AGN spectrum.

Surprisingly enough, when *XMM-Newton* pointed the same field, the serendipitous source, this time clearly spatially resolved, appeared as bright as 3C 445 in the soft energy band (0.2–1 keV). As we will show in this paper, optical observations of 1WGA J2223.7-0206 indicate that the source is actually a quasar at $z = 0.46$ with spectral features typical of NL type I AGN. The presence of this peculiar AGN in the vicinity of 3C 445 should be taken into account when the X-ray

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* Based on observations obtained with *XMM-Newton*, an ESA science mission with instruments and contributions directly funded by ESA Member States and the USA (NASA), with the Bologna Astronomical Observatory in Loiano, Italy, and with the WHT telescope of the ING at La Palma, Spain.

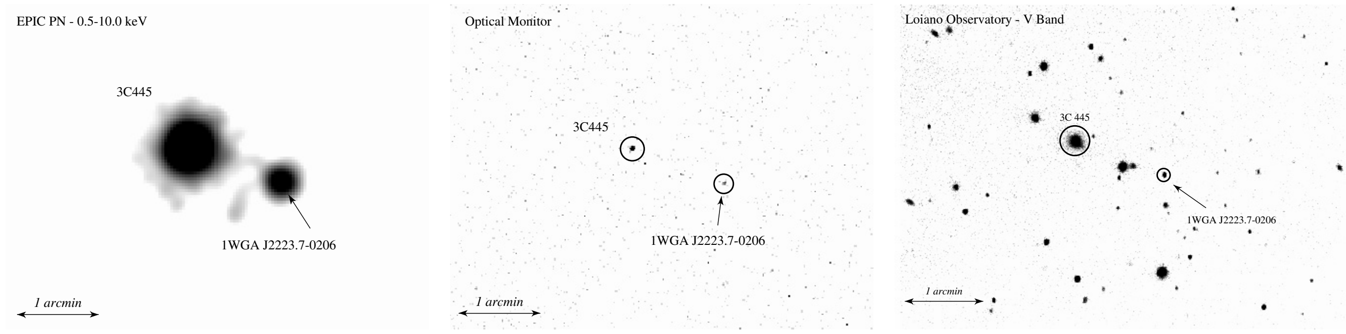

Fig. 1. EPIC-PN (*left panel*), OM/UVW2 (*middle panel*) and Loiano Observatory *V* band (*right panel*) images of 1WGA J2223.7-0206. The X-ray and Ultraviolet images are smoothed using a Gaussian filter with $\sigma = 2$ pixels (corresponding to 8″ and 1″ in the PN and OM, respectively).

spectra from previous and very poor spatial resolution satellites are interpreted.

Throughout the paper, luminosities are calculated assuming isotropic emission, a Hubble constant of $H_0 = 75$ km s^{-1} Mpc^{-1} and a deceleration parameter of $q_0 = 0.5$.

2. *XMM-Newton* observation

XMM–Newton observed 3C 445 on 2001 December 6 with the EPIC cameras MOS (Turner et al. 2001) and PN (Strüder et al. 2001) in small window mode for 20 ks.

A serendipitous source was detected in the PN image at coordinates α = 22:23:44.9, δ = −02:06:40 (J2000, position accuracy ∼4″) at ≈1.3′ from 3C 445 (see Fig. 1, left panel). It was not revealed by the MOS cameras, because of the smaller field of view. A rapid check of the WGA catalog allowed us to immediately identify it with the source 1WGA J2223.7-0206, detected by ROSAT at coordinates α = 22:23:44.7, δ = −02:06:33 (J2000, WGA position accuracy ∼13″).

Data from the Optical Monitor (OM, Mason et al. 2001) were also available (Fig. 1, middle panel). We got the mosaic image in the bands UVW2 (180−225 nm) and UVM2 (205−245 nm) from the standard pipeline. WGA J2223.7-0206 was detected in both bands at the coordinates α = 22:23:45.10 and δ = −02:06:41 (J2000, 0.9″ of error radius) with significance 14σ in UVW2 and 19σ in UVM2. UV magnitudes of $m_{\rm UVW2} = 17.4 \pm 0.1$ and $m_{\rm UVM2} = 17.8 \pm 0.1$ were obtained following the recent prescriptions of Chen (2003).

2.1. X-ray timing and spectral analysis

For the processing and screening of the data we followed the standard procedures described in Snowden et al. (2002). The XMM-SAS (5.4.1) software was utilized. Spectral and time analysis were performed with Xspec (11.2.0) and Xronos (5.19).

The spectrum and the light curve of the source were extracted using a circle of 15″ radius to take into account any

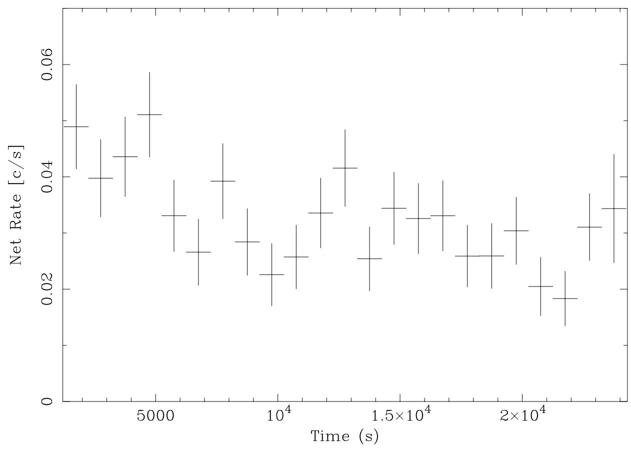

Fig. 2. EPIC-PN light-curve of 1WGA J2223.7-0206 in the energy band 0.2−2 keV. Background subtracted source count in 1000 s bin and associated 1σ errors are shown

possible 3C 445 contamination. The background was estimated in an annular region of inner circle radius 15″ and width 25″[1].

The spectrum was rebinned so that each energy bin contained a minimum of 25 photons and it was fitted in the 0.2−10 keV energy range. The appropriate photon redistribution matrix and ancillary file were created with the `rmfgen` and `arfgen` tasks of XMM-SAS.

Fast variability occurred during the observation. The source was in a higher activity state during the first 5000 s of the observation and then it decreased of about 40% (Fig. 2). A standard χ^2 test assures that constant emission can be ruled out at a level of confidence >99.99%.

As the two spectra, extracted before and after the flux drop, did not display any significant change of shape, we performed the spectral analysis on the entire observation.

A simple absorbed power law did not give a satisfactory fit to the data. The fit was poor (χ^2 = 62 for 49 degrees of freedom (d.o.f.)) and an inspection of the residuals showed an excess of emission at low energy. When a black body model was added, the χ^2 value became better (χ^2 = 47 for 47 d.o.f.) implying a significant improvement ($P_{\rm F_{test}}$ = 99.2%). As the acceptable

[1] We also extracted a background spectrum from a region free of sources using a circle of 40″ radius. The spectral fit results using a background from a circle or an annulus were completely consistent.

Table 1. EPIC-PN best fit spectral (rest frame) parameters. Column density was fixed to the Galactic value $N_{\rm H}^{\rm Gal} = 5.0 \times 10^{20}$ cm^{-2}.

Γ	kT [eV]	$f^a_{\rm PL}$ [2–10 keV]	$f^a_{\rm PL}$ [0.2–2 keV]	$f^a_{\rm BB}$ [0.2–2 keV]
2.4 ± 0.2	117 ± 21	0.7 ± 0.1	2.2 ± 0.4	1.1 ± 0.5

^{a} In units of 10^{-13} erg cm^{-2} s^{-1}.

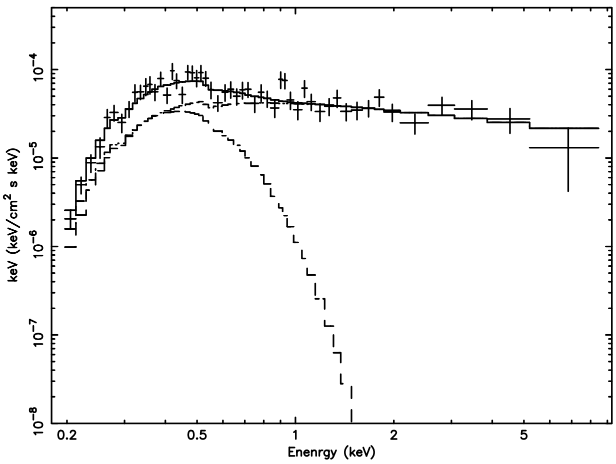

Fig. 3. The EPIC-PN observed spectrum of 1WGA J2223.7-0206. The best fit is a power law plus a blackbody model absorbed by Galactic column density.

range of $N_{\rm H}$ was consistent with the Galactic line of sight value ($N_{\rm H} = 5.0 \times 10^{20}$ cm^{-2}; Dickey & Lockman 1990), we fixed the column density to the Galactic value in order to reduce the fit uncertainties. The best fit parameters are listed in Table 1. The source is extremely soft with ~80% of the radiation emitted below 2 keV (see also Fig. 3). The intrinsic luminosity (i.e. corrected for the absorption column along the line of sight) in the rest frame is 2.3×10^{44} erg s^{-1} in the 0.2–10 keV band (see below for the distance determination).

3. Optical observations

The inspection of the Red Digitized Sky Survey II[2] shows, within the *XMM-Newton* error box for 1WGA J2223.7-0206, one single and relatively bright object. Indeed this source is also present in the USNO-A2.0 catalog[3] as an $R \sim 18.1$, $B \sim 18.6$ object with identification number U0825_19648565. We thus considered it as the optical counterpart of 1WGA J2223.7-0206 and started an optical spectrophotometric campaign in order to find out its nature.

3.1. Spectroscopy

Optical medium-resolution spectra of 1WGA J2223.7-0206 within the *XMM-Newton* error circle (4″) were acquired on 2003 June 19 with the 4.2 m William Herschel Telescope (WHT) located at the Roque de Los Muchachos Observatory in La Palma, Canary Islands (Spain). The WHT was equipped with ISIS, which carried on its red arm a 4k×4k MARCONI2 CCD. The spectra were obtained under a seeing of about 1″ using Grating R158R, nominally covering an unvignetted spectral range between 4200 and 8800 Å. The use of a 1″ slit width secured a spectral dispersion of 1.7 Å/pix. In total, two 15-min spectra were acquired between 04:13 and 04:44 UT.

Spectra, after correction for flat-field, bias and cosmic-ray rejection, were background subtracted and optimally extracted (Horne 1986) using IRAF[4].

Copper-argon lamps were used for wavelength calibration; the spectra were then flux-calibrated by using the spectrophotometric standard HD 192281 (Massey et al. 1988) and finally averaged together. Correction for slit losses was also applied to the continuum by checking the flux calibration against the optical photometry collected in the *UBVRI* bands (see next subsection). Wavelength calibration was instead checked by using the positions of background night sky lines: the error was 0.1 Å.

Finally, the averaged spectrum was corrected for the foreground Galactic absorption along the direction of the source assuming a color excess $E(B-V) = 0.082$ mag, evaluated using the Galactic dust infrared maps by Schlegel et al. (1998). The reddening value obtained is consistent with the X-ray absorption column and with the measured interstellar hydrogen column (Dickey & Lockman 1990) for an average gas-to-dust ratio (Predehl & Schmitt 1995).

The averaged optical spectrum acquired with WHT (Fig. 4) shows a blue continuum over which a number of emission features are superimposed. These can readily be identified with typical AGN lines, such as Balmer lines (H_β, H_γ, H_δ), [O III] λ5007, [O II] λ3727, and possibly the [Ne III] λ3969/H_ζ blend, are detected. All these lines point to a redshift $z = 0.460$ for the source.

Prominent Fe II bumps at around 4500 Å and 5200 Å (the latter one falling on the telluric absorption band at 7600 Å) are also detected at wavelengths consistent with the above redshift determination. Table 2 reports full width at half maxima (*FWHM*s), equivalent widths (*EW*s) and fluxes of the detected emission lines.

The *FWHM* of H_β (2000 km s^{-1}) and the [O III]/Hβ flux ratio (0.21), measured from the optical spectrum, are typical of

[2] Available at `http://archive.eso.org/dss/dss/`

[3] Available at `http://archive.eso.org/skycat/servers/usnoa`

[4] IRAF is the Image Analysis and Reduction Facility made available to the astronomical community by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under contract with the US National Science Foundation. STSDAS is distributed by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under NASA contract NAS 5–26555.

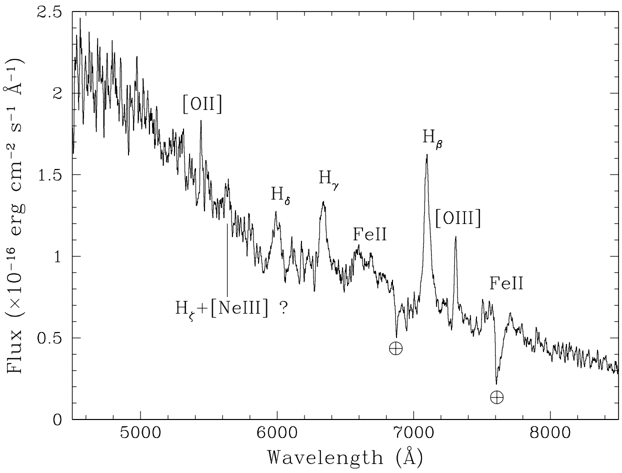

Fig. 4. Average optical spectrum of 1WGA J2223.7-0206 obtained with the WHT at La Palma. The main emission features are labeled. The symbol ⊕ indicates atmospheric telluric features.

Table 2. *FWHM*s, *EW*s and fluxes of the emission lines detected in the optical spectrum of 1WGA J2223.7-0206. Line *FWHM*s (km s^{-1}) are intrinsic, i.e. corrected assuming an instrumental broadening of 200 km s^{-1}; *EW*s (Å) are reported in the source rest frame; flux values are expressed in units of 10^{-15} erg s^{-1} cm^{-2} and are corrected for the Galactic foreground absorption.

Line	*FWHM*	*EW*	Flux
[O II] λ3727	460 ± 150	4 ± 1	0.6 ± 0.2
H_δ	3300 ± 500	19 ± 6	2.4 ± 0.7
H_γ	1700 ± 400	16 ± 4	2.0 ± 0.5
H_β	2000 ± 200	46 ± 8	4.7 ± 0.6
[O III] λ5007	700 ± 100	10 ± 2	1.0 ± 0.2

NL type 1 AGN according to the criteria coded by Osterbrock & Pogge (1985).

3.2. Photometry

Optical photometry was acquired in Loiano (Italy) with the Bologna Astronomical Observatory 1.52 m "G.D. Cassini" telescope plus BFOSC, on 2003 August 1 (*U* and *R* bands), 2 (*B* and *I* bands) and 3 (*V* band), under an average seeing of 3″, 2″ and 2″, respectively. The Cassini telescope was equipped with a 1300 × 1340 pixels EEV CCD. This detector, with a scale of 0.″58/pix, secured a field of 12.′6 × 12.′6.

Images were corrected for bias and flat-field in the usual fashion and calibrated using the PG 1633+099 and PG 2213-006 fields (Landolt 1992); the calibration accuracy was better than 3% in all bands. The source (see Fig. 1, right panel) was well detected in all optical filters. It also showed no significant extension with respect to star-like objects in the field. Therefore, standard Point Spread Function (PSF) fitting was chosen as photometry method, and to this aim we used the *DAOPHOT II* image data analysis package PSF-fitting algorithm (Stetson 1987) running within MIDAS[5].

Optical fluxes, computed using the tables by Fukugita et al. (1995) are listed in Table 3, along with those in the UV and X-rays. Dereddening for optical and UV fluxes was applied assuming the extinction law by Cardelli et al. (1989). The X-ray flux density was corrected for the Galactic absorption.

Table 3. Observed optical-UV-X-ray flux densities of 1WGA J2223.7-0206. Optical-UV data are corrected for Galactic reddening by using A_λ/A_V given by Cardelli et al. (1989) and $E(B-V) = 0.082$. The flux density at 1 keV is corrected for the Galactic extinction assuming a column density $N_H = 5.0 \times 10^{20}$ cm^{-2}.

Instrument	ν (Hz)	Flux (μJy)
Loiano/*UBVRI*	8.21×10^{14}	109 ± 11
	6.74×10^{14}	141 ± 7
	5.45×10^{14}	190 ± 6
	4.55×10^{14}	151 ± 9
	3.72×10^{14}	182 ± 5
XMM-Newton/OM	1.33×10^{15}	570 ± 30
	1.48×10^{15}	650 ± 60
XMM-Newton/PN	2.42×10^{17}	0.030 ± 0.004

4. Discussion

Our observations show that the source 1WGA J2223.7-0206, located at about 1.3′ from the bright radio Galaxy 3C 445, is an AGN at redshift $z = 0.46$. It is a quasar as attested by its optical point-like aspect and its high luminosity both in the optical ($M_R = -23.2$) and X-ray ($L_{0.2-10\ \mathrm{keV}} = 2.3 \times 10^{44}$ erg s^{-1}) bands.

More interesting, both the optical and X-ray spectra indicate that 1WGA J2223.7-0206 is a NL QSO. The *FWHM* of H_β (2000 km s^{-1}), the [O III]/H_β flux ratio (0.21) and the relatively strong Fe II emission conform with the NL type I classification. The X-ray spectrum of 1WGA J2223.7-0206 is very soft as observed in most of the NL type I AGN (Boller et al. 1996; Leighly 1999). The steep power law ($\Gamma = 2.5$) necessary to reproduce the hard X-ray continuum was not sufficient to fit the soft emission below 1 keV. PN data need an extra component that, if we choose to model it with a black body emission, requires a temperature of $kT = 117$ eV. Similar black body values characterize the NL QSOs studied by ROSAT and ASCA (Forster & Halpern 1996; Molthagen et al. 1997; Ulrich et al. 1999; Komossa et al. 2000; Dewangan et al. 2001).

Forster & Halpern (1996) discovered a clear correlation between the soft X-ray luminosity and the spectral slope in a large sample of NL type I objects observed with ROSAT. If we consider a broken power law to model the PN data, the fit formally acceptable ($\chi^2 = 52$ for 49 d.o.f.) yields the following spectral parameters: $\Gamma_{\mathrm{soft}} = 3.0^{+0.3}_{-0.1}$, $\Gamma_{\mathrm{hard}} = 2.3^{+0.4}_{-0.2}$ with an energy break at 1.1 keV. Our source parameters are in perfect agreement with

[5] MIDAS (Munich Image Data Analysis System) is developed, distributed and maintained by ESO (European Southern Observatory) and is available at `http://www.eso.org/projects/esomidas`

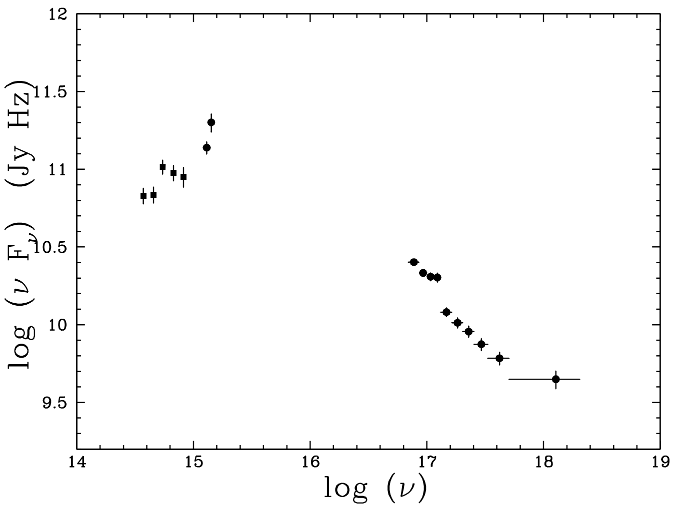

Fig. 5. Optical-UV-X-ray spectral energy distribution of 1WGA J2223.7-0206 in the observer frame. A strong UV-soft X-ray bump is clearly visible.

that correlation. An object with the same intrinsic soft luminosity of 1WGA J2223.7-0206 $L_{0.1-2\ \mathrm{keV}} \sim 10^{45}$ erg s^{-1} (assuming $H_0 = 50$ and $q_0 = 0$ to meet the cosmological assumptions of the authors) is expected to have a soft spectral slope of about 3, as actually observed.

Finally, the rapid change of the X-ray flux, rather common in ultra-soft AGN (Boller et al. 1996; Leighly 1999), is another hint in favour of its NL classification.

The ultra soft nature of 1WGA J2223.7-0206 becomes much more evident when the optical UV and X-ray data are combined to produce a Spectral Energy Distribution (SED). Unfortunately, neither radio nor infrared counterparts were found for this source.

In Fig. 5, the presence of a very prominent UV-soft-X-ray bump is unequivocal, taking also into account that the X-ray and the UV data are simultaneous. From Fig. 5, it is also evident that the thermal model used to parameterize the X-ray excess can not reproduce the entire UV bump, that is more intense and broad. On the other hand, it is well known that a black body emission is a very rough assumption. Plausible interpretations assume inverse-Compton scattering of cold disk photons by a warm/hot atmosphere (Janiuk et al. 2001; Vaughan et al. 2002) or high accretion slim disk characterized by a multicolour black body emission (Mineshinge et al. 2000).

A lower limit of the bolometric luminosity $L_{\mathrm{bol}} \geq L \sim 3 \times 10^{45}$ erg s^{-1} can be directly estimated from Fig. 5, using only the optical-UV-X data, implying a 0.2–10 keV X-ray contribute to the total luminosity less than 7%. The bulk of the emission occurs between 10^{15} and 10^{17} Hz. By using simple arguments (uniform accretion at the Eddington limit), we deduce a lower limit to the mass of the central supermassive object of $2 \times 10^7\ M_\odot$.

Acknowledgements. The authors wish to thank Natalia Auricchio, Ivan Bruni, Elisabetta Maiorano and Andrea Simoncelli for the help and assistance with the observations made in Loiano. The staff of the Service Observing Programme at WHT is gratefully acknowledged. This research has made use of the SIMBAD database and of the VizieR catalogue service, both operated at CDS, Strasbourg, France. We are also greateful to he ASI for partial support of this research under grant ASI I/R/069/02.

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