Astron. Astrophys. 330, 67–71 (1998)

ASTRONOMY AND ASTROPHYSICS

X-ray and optical study of the giant radio quasar 4C +74.26

W. Brinkmann[1], **C. Otani**[2], **S.J. Wagner**[3⋆], **and J. Siebert**[1]

[1] Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse, D-85740 Garching, Germany
[2] Cosmic Radiation Laboratory, RIKEN, Wako-shi, Saitama 351-01, Japan
[3] Landessternwarte, Königstuhl, D-69117 Heidelberg, Germany

Received 26 June 1997 / Accepted 15 September 1997

Abstract. We present the optical and X-ray study of the radio-loud quasar 4C +74.26. The ASCA spectrum is rather complex with indications of a reflection component, a neutral iron line and a warm absorber. The underlying power law has a photon index of $\Gamma = 2.03 \pm 0.09$. The soft X-ray flux in 1996 is nearly twice as high as that found in a ROSAT observation in 1993 without apparent spectral changes.

The X-ray data support the picture deduced from previous radio observations that 4C +74.26 is seen under a relative large angle ($\sim 45^o$) with respect to its jet axis. However, the rather unusual X-ray spectral properties might as well be a signature of the quasar's young evolutionary status.

No interaction between the quasar and the nearby $\sim$ 19 mag galaxy could be found in the optical images.

Key words: galaxies: active – quasars: general – quasars: individual 4C+74.26 – X-rays: general

1. Introduction

In a study of radio-loud extragalactic objects from the ROSAT All-Sky Survey (Brinkmann et al. 1995) the object RXJ20425+7505 was thought to be optically unidentified. Due to the large positional difference between the unresolved radio source and the X-ray source it became clear only later that the X-ray object is 4C +74.26, the largest known radio source associated with a quasar, a 10-arcmin double with a projected linear size of 1.6 Mpc (assuming $H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0$; Riley et al. 1988). The integrated 5GHz flux density is $\sim 0.81 \pm 0.2$ Jy, the core flux amounts to $\sim 0.37 \pm 0.1$ Jy and is variable. The 178 MHz radio luminosity places the source on the borderline between the classical double (FRII) sources and the more diffuse FRIs. However, its structure is clearly that of a FRII source. Only one other of the well known giant FRII sources (4C +34.47) is associated with a quasar, the others are galaxies.

VLA observations show a single jet which extends at least 400 kpc towards the bright spot in the southern lobe (Riley & Warner 1990) and VLBI observations (Pearson et al. 1992) reveal a one-sided parsec-scale jet well aligned with the kiloparsec-scale jet. If the asymmetry of the parsec-scale jet is attributed to Doppler boosting, the axis of the source must lie $\lesssim 49^o$ from the line of sight; i.e., the large extent of the radio source is **not** caused by the effect that the axis is almost perpendicular to the line of sight as expected from current unification schemes (cf. Orr & Browne 1982, Barthel 1989). On the other hand, the hot spot on the jet side is much brighter and more compact than on the opposite side. This can be naturally explained if the jet is intrinsically one sided, currently just 'feeding' that hot spot. If the asymmetry in the jets is due to Doppler boosting, this would imply that some radiation from the hot spots must also be beamed.

Optical follow up observations (Riley et al. 1988) revealed a typical quasar spectrum featuring strong broad Balmer emission lines (FWHM $\sim$ 7500 km s^{-1}), narrow forbidden lines of moderate equivalent width ($\sim$ 10Å), and a strong non-stellar continuum. The redshift of the object is z = 0.104 ± 0.001 and the spectrophotometry gives $m_v = 14.8 \pm 0.2$ for the continuum which indicates an absolute magnitude of $M_v \approx -24.7$. The quasar is surrounded by low-brightness extended optical emission and there is a 19-mag galaxy about 8 arcsec (i.e. 20 kpc) to the south-west which might be interacting with the quasar.

The source is not an IRAS quasar but was found to be an IR emitter by Kobayashi et al. (1993). Its black body flux is 3.3×10^{-18} W cm$^{-2}\mu$m^{-1} at a fitted temperature of 1488 K. From the data a dust mass of 0.105 $M_\odot$ in grains of a=0.01μm was inferred.

In the ROSAT All-Sky Survey the object turned up as a relatively strong source with a count rate of $\sim$ 0.8 cts s^{-1}. A power law fit (assuming free absorption) resulted in a photon index of $\Gamma = 1.32^{+1.45}_{-0.88}$ with a column density of $N_H = 1.29^{+2.8}_{-1.1} \times 10^{21}$ cm^{-2}. Fixing the absorption to the Galactic value of $\sim 1.15 \times 10^{21}$ cm^{-2} (Dickey & Lockman 1990) an even flatter power law index of $\Gamma = 1.24^{+0.16}_{-0.17}$ was obtained (Schartel

Send offprint requests to: W. Brinkmann

⋆ Visiting astronomer at the German-Spanish Astronomical Centre, Calar Alto, operated by the Max-Planck-Institut für Astronomie, Heidelberg, jointly with the Spanish National Commission for Astronomy

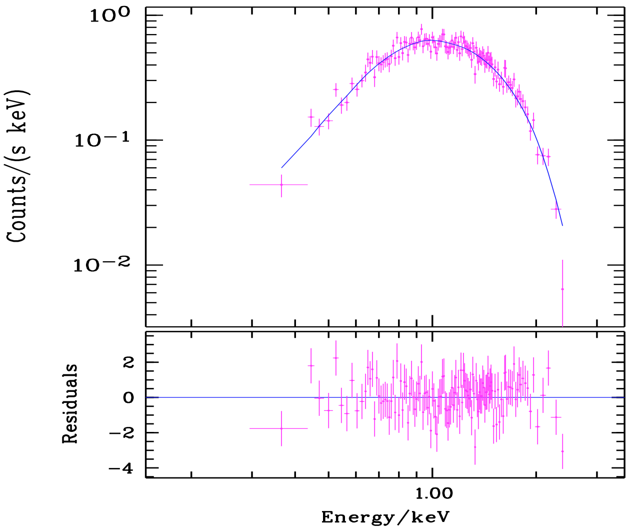

Fig. 1. ROSAT power law fit for 4C +74.26; top panel the folded spectrum, bottom panel the residuals.

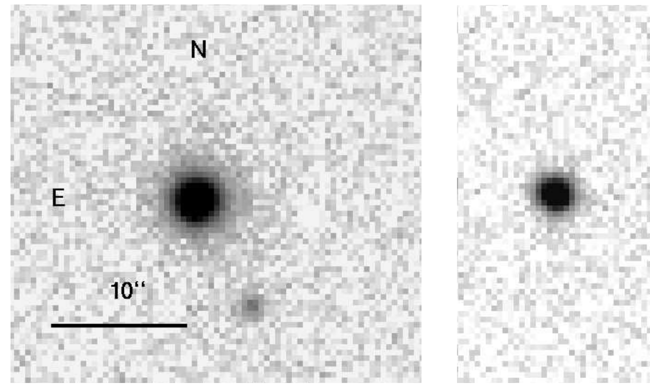

Fig. 2. Optical R - band CCD frame of 4C +74.26 and a close-by galaxy (left) and a stellar image from the same frame (right). While the comparison to the stellar PSF clearly illustrates the presence of extended wings around the quasar, no signs of interaction with the close-by (extended) galaxy was detected.

et al. 1996). These slopes are considerably flatter than usually found for radio-loud quasars ($\Gamma \sim 2.2$) in the ROSAT energy band: only less than about 5% of nearby radio-loud quasars show similarly flat power laws (Brinkmann et al. 1997).

Further, the object was in the field of view of a 20 ks pointed PSPC observation on the cataclysmic variable VW Cep on June 23/24, 1993. The spectrum can be well fitted by a simple power law with cold absorption. The best fit obtained by leaving the absorption free (see Fig. 1) gives a power law index of Γ = 1.64 ± 0.26 (χ^2_{red} = 1.06). The fitted value for the absorption N_H = $(1.83 \pm 0.53) \times 10^{21}\mathrm{cm}^{-2}$ is, again, higher than the Galactic one.

With these spectral parameters 4C +74.26 has a moderate X-ray luminosity of $L_x \sim 4.7 \times 10^{44}$ erg s^{-1} in the 0.1 - 2.4 keV energy band. Unfortunately, the relatively high Galactic absorption and the narrow ROSAT energy band do not allow a more accurate determination of the power law slope and thus to study the amount and the physical state of the gas anticipated to cause the intrinsic absorption affecting the spectral fits.

In this paper we will present the spectral analysis of a 20 ks ASCA observation, providing excellent spectral information. In Sect. 2 we will first review the results of an optical observation of the quasar with the 3.5m telescope on Calar Alto. We will then present the spectral analysis for the ASCA data and will discuss the results in the framework of current unification theories in Sect. 4.

2. The optical observation

Direct imaging in the U, B, R, and I bands was carried out on July 8, 1994 with the prime focus camera of the 3.5m telescope on Calar Alto. The plate scale (0$''\!$.4/px) was well-matched to the 1$''\!$.0 seeing. The data confirm the existence of faint, extended, and slightly elongated wings surrounding the quasar (see Fig. 2). We do not, however, find any morphological indication for interaction of the quasar host galaxy with another, fainter (Δ m_R = 4.7) galaxy, 8$''$ to the south-west. If the latter source lies at the distance of 4C +74.26, its m_R = 20.2 correspond to M_R = -20.1.

Spectra of 4C +74.26 were taken on July 6, 1994 in the course of an identification programme of bright X-ray sources from the ROSAT All-Sky Survey at the 3.5m telescope of Calar Alto Observatory. We used a twin spectrograph to obtain simultaneous spectra in the blue and red channels. A 45 min integration was obtained with a 1$''\!$.4 wide slit placed along PA 40°. The red channel provided a dispersion of 72 Å /mm and a spatial scale of 26.8 μm/arcsec. The effective resolution was measured from the science frames using stellar profiles and night-sky lines to be 50 km/sec at [OI]λ6300 and $\lesssim$ 1$''\!$.9, respectively. In the blue channel the grating provided a dispersion of 72 Å / mm. Both channels were fed into TEK CCDs with 24 μm pixel size, which was well matched to the spectroscopic resolution (measured FWHM = 72 km/s at 4700 Å) but slightly under-sampled the spatial direction. Meteorologic conditions were reasonably good but failed to qualify as photometric. Nevertheless a 3 min integration of Feige 110 was secured to serve as a rough calibrator. Including slit-losses we assume the spectrophotometric accuracy to have errors of about 30 %. The frames were debiased and flat-fielded using standard procedures. Dispersion relations were derived from wavelength calibration lamps exposed prior and after the object integrations. To compensate for the slightly different illumination of the slit by the calibration lamps we corrected the zero-point offsets of the wavelength calibrations (Δ λ / λ $\leq$ 10^{-4}) by adjusting the scales to the observed wavelengths of night-sky emission-lines.

Fig. 3 gives the sky-subtracted spectrum of 4C +74.26 in both channels. Unfortunately the dichroic separating the blue and the red arm introduces a gap of about 20 Å with an uncertain flux calibration. This gap falls right on top of the red shifted [O III] λ 4959 line and on the red wing of H β. The centroids of the strongest emission lines and the widths of these features

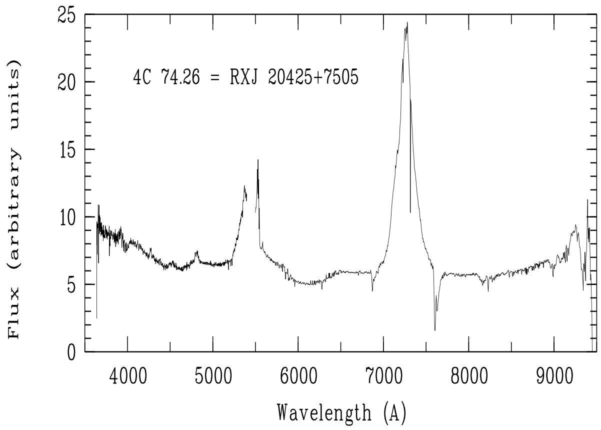

Fig. 3. Flux calibrated optical spectrum of the quasar associated with 4C +74.26 taken with the Calar Alto 3.5m; ordinate in arbitrary flux units, abscissa in Å

Table 1. Strongest optical emission lines in 4C +74.26

line		Velocity in km/s	FWHM in km/s	Eq. width in Å
[NeIII]	3869	31015	1200	19
Hδ	4101	31300	2000	26
Hγ	4340	31660	2000	51
$[OIII]$	4363	31010	1600	20
Hβ	4861	31400	(4700)	-
$[OIII]$	5007	31100	1500	20
HeI	5875	31560	5700	-
Hα	4861	31860	6270	680

are given in Table 1. The optical spectrum is not unusual for a radio-loud nearby quasar. The base of the lines have a fairly large width but the exact FWZI is difficult to estimate due to residual uncertainties in the flat-fielding and response calibration. The prominent red wing of H β does not permit a reliable estimate of the contribution of underlying [Fe II].

3. ASCA observations and data reduction

4C +74.26 was observed with ASCA (Tanaka et al. 1994) in 1996 from September 9, UT 14:52 to September 10, UT 03:00. The Solid-state imaging spectrometer (SIS) data were collected in 1 CCD faint mode. After applying standard screening criteria (i.e., removing Earth occultation and data with high background), the total effective exposure times were $\sim$ 21.5 ks for the SIS and $\sim$ 23.7 ks for the GIS (gas imaging spectrometer). The average background subtracted count rates were $\sim$ 0.54 s^{-1} for a SIS detector and $\sim$ 0.41 s^{-1} for a GIS detector.

Assuming a simple power law model (see Sect. 3.1) and fitting only the data in the ROSAT band we find that the source was nearly twice as bright compared to June 1993 during the ROSAT pointing. We tested the data for flux variations during the ASCA pointing but could not find any statistically significant variability during the observation.

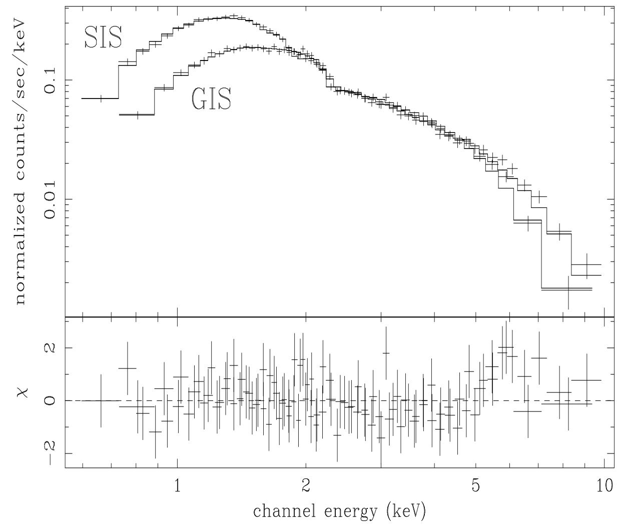

Fig. 4. Power law fit with free absorption to the combined GIS/SIS data. Top: Data and folded model; bottom: residuals.

3.1. Power law fits

In Fig. 4 we show a simple power law fit to the combined SIS and GIS data. The photon index is Γ = 1.79 $\pm$ 0.02, the fitted absorption column density N_H = (2.32 $\pm$ 0.01) $\times$ 10^{21} cm^{-2}. Although the fit is acceptable with a reduced χ^2 = 0.61 it is obvious from the residuals that a simple power law is not a good representation of the data:

- the residuals show a pronounced broad band 'wavy' structure
- there is clear indication for an iron line structure around 6.5 keV in the quasar rest frame
- the obtained N_H value is by more than a factor of two higher than the Galactic value.

It should be noted that the above mentioned value for the Galactic column density is somewhat uncertain. There appears to be significant substructure in the IRAS 100 μm data and the region has a strong gradient across the field (Snowden, private communication). Using the SAO EINLINE database we obtain a slightly larger (interpolated) value of 1.31×10^{21} cm^{-2}, however, in fair agreement with the value obtained from the ROSAT analysis system.

We repeated the simple power law fit for energies less than $\sim$ 2 keV. In Fig. 5 we show the 1σ, 90%, and 99% confidence levels (for two free parameters) of the ROSAT and the ASCA fits. The ROSAT fits (left contour lines) give a slightly flatter power law and a lower N_H value, but the values are consistent with the ASCA fits within their mutual errors. This implies that the source has varied achromatically between the two observations, at least in the low energy band.

3.2. More component fits

The structure of the residuals suggests the presence of a reflection component in the spectrum. A red-shifted power law

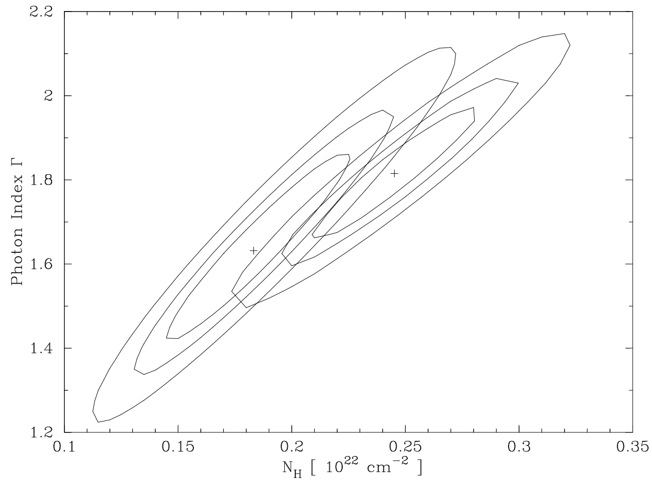

Fig. 5. Confidence contour levels for power law fits with free absorption to the ROSAT and the combined GIS/SIS ASCA (0.5 - 2 keV) data. The contours to the lower left in the figure are from the ROSAT data. Plotted are the 1σ, 90%, and 99% levels.

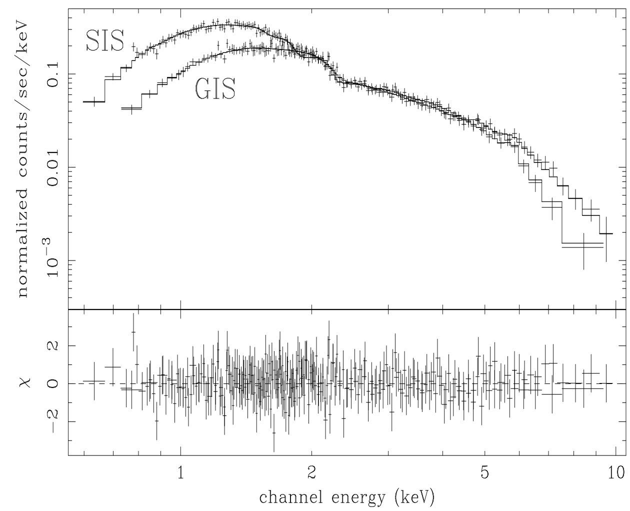

Fig. 6. Simultaneous fit of all four instruments with a power law plus cold reflection model and an additional Gaussian line. Cold absorption is fixed to the Galactic value, the warm absorber is left free. The data for both SIS detectors and both GIS detectors are combined.

plus cold reflection model[1] gave an acceptable fit to the data with a reduced χ^2 = 0.57. The photon index obtained was Γ = 1.97 $\pm$ 0.06, the solid angle subtended by the disk $2\pi \times (6.16 \pm 2.84)$, assuming an inclination of 45^o. However, this parameter proved to be rather insensitive to the chosen inclination and its absolute value as well as its large error implies that we cannot constrain the geometry and the nature of the reflector. The fitted absorption amounts to $N_H = (2.74 \pm 0.17) \times 10^{21}$ cm^{-2}.

Adding a Gaussian line to this model improves the fit with 97% significance (F-test). The line is narrow ($\sigma = 0.09 \pm 0.11$) but we cannot rule out a slightly broadened line. At an energy of $E_{rest} = 6.39 \pm 0.08$ keV in the rest frame of the quasar it indicates a relatively low ionization state of the iron. The line normalization of $(2.91 \pm 1.57) \times 10^{-2}$ gives an equivalent width of EW = 100 $\pm$ 40 eV. The parameters of the reflection model and the N_H value were very similar to the previous fits.

The fitted absorption column densities are generally a factor of two higher than the Galactic value, indicating extra absorption along the line of sight. Fixing the absorption to the Galactic value and adding an extra cold absorber gives a similarly acceptable fit but leaves some characteristic residuals at low energies.

The best fits were obtained by a red-shifted power law plus cold reflection model, with a Gaussian line added, absorbed by a fixed Galactic column density plus a warm absorber. We used a simple warm absorber model made from CLOUDY Ver. 90.01 (Ferland 1996). The assumed parameters were: a gas density $n = 10^9$ cm^{-3}, the distance from the source $R = 10^{17}$ cm, and a power law continuum with photon index Γ = 1.6 extending from 13.6 eV to 300 keV. The free parameters related to the warm absorber are its column density $N_{\rm W}$ and the ionization parameter ξ. In the model construction, the ionization parameter ξ was varied by changing the source luminosity. The fit is shown in Fig. 6 and the best fitting parameters are given in Table 1.

[1] for the model description and references see 'XSPEC User's Guide', version 8, NASA GSFC, Oct. 1994.

Table 2. Simultaneous fit of all four ASCA instruments with the XSPEC model: $phabs \times warmab \times (zprefl + zgauss)$; (see text for details).

model component	parameter	value	error
Galactic absorption	$N_H^{a)}$	1.31	fixed
warm column density	log N_w	21.549	$\pm$ 0.0799
ionisation parameter	log ξ	0.6522	$\pm$ 0.1687
power law index	Γ	2.0256	$\pm$ 0.0892
normalization	$\mathrm{norm}_{ref}^{b)}$	9.585	$\pm$ 0.783
disc inclination	Incl	45^o	fixed
solid angle	$\Omega/2\pi$	6.16	$\pm$ 2.84
line energy (keV)	$E_{l,rest}$	6.383	$\pm$ 0.0779
line intensity	$\mathrm{I}_{l,rest}^{c)}$	2.635	$\pm$ 1.51
line width (keV)	$\sigma_{l,rest}$	0.08372	$\pm$ 0.11
redshift	z	0.104	fixed
goodness-of-fit	χ^2_{red}	0.56	

a) in units of 10^{21} cm^{-2}
b) in units of 10^{-3}photons cm^{-2} s^{-1} keV^{-1} at 1 keV
c) in units of 10^{-5}photons cm^{-2} s^{-1} in the line

4. Summary

With regard to its luminosity 4C +74.26 is at all wavelengths only a moderately bright radio quasar. However, the object shows several peculiar properties which, altogether, make it rather unusual. 4C +74.26 is the largest of the only two known radio quasars amongst giant FRII sources with extremely large radio lobes. From the one-sidedness of the VLA jet Riley & Warner (1990) deduce a fairly large angle of $\sim 45^o$ between the jet axis and the line of sight, which is rather extreme for quasars.

This value was derived assuming Doppler boosting at relatively modest speeds ($\gtrsim 0.5$c). If the jets are highly relativistic this angle could be as much as 70^o, which would be well outside the commonly assumed 'quasar cone'. The core dominance R = log(l_{core}/l_{extd}) is about $R \sim 0$, consistent with the above estimates of a moderately beamed radio source. The quasar seems to be young: Saripalli et al. (1996) determine a maximum age of $\sim 3 \times 10^7$ years from the fact, that the axial ratios of the lobes at 2.8 cm do not differ significantly from those at other wavelengths.

The quasar has a rather complex X-ray spectrum with excess absorption and indications for a re-processing of the initial X-ray spectrum in a surrounding warm material, as well as a relatively strong iron line. From the properties of the radio jet it appears that the inclination angle of the accretion disk is near 45 degrees. In that case, we would expect a broad ($\sigma \gtrsim 0.5$ keV) iron line feature as seen in MCG-6-30-15 (Tanaka et al. 1995) if the line emitting region is concentrated around the innermost part of the accretion disk (Fabian et al. 1995). The detection of a rather narrow iron line suggests that the line is emitted in the outer parts of the disk or the putative molecular torus which may be the IR emitter. The initial power law is relatively flat for a radio-loud quasar, but not well constrained due to the complexity of the spectrum. Further, the soft X-ray flux varies considerably, at least by a factor of two on time scales of years.

Summarizing, we can say that 4C +74.26 is energetically not an outstanding radio-loud quasar, but it shows unusual properties at all wavelengths. The question whether these are related to the young evolutionary status of the quasar or whether the quasar is seen under special geometrical conditions is of great importance for our understanding of the evolution of quasars and radio-loud unification schemes.

Acknowledgements. WB thanks the Cosmic Radiation Laboratory for hospitality where part of the research was done in the framework of the RIKEN - MPG exchange program. CO acknowledges the support from the Special Postdoctoral Researchers Program of RIKEN and thanks the ISAS/MPE Inter-Research Center Cooperative Program for funding his visit to MPE. SW thanks H. Bock and the Calar Alto staff for effective help during the observations and acknowledges partial help by the DFG (through SFB 328). We also thank G. Ferland for providing the Cloudy code.

References

Barthel P.D., 1989, ApJ 336, 319
Brinkmann W., Siebert J., Reich W., et al. 1995, A&AS 109, 147
Brinkmann W., Yuan W., Siebert J., 1997, A&A 319, 413
Dickey J.M., Lockman F.J., 1990, ARA&A 28, 215
Fabian A.C., Nandra K., Reynolds C.S., et al., 1995, MNRAS 277, L11
Ferland G.J., 1996, Univ. Kentucky, Dept. Phys. Astr. Internal Report
Kobayashi Y., Sato S., Yamashita T., Shiba H., Takami H., 1993, ApJ 404, 94
Orr M.J.L., Browne I.W.A., 1982, MNRAS 200, 1067
Pearson T.J., Blundell K.M., Riley J.M., Warner P.J., 1992, MNRAS 259, 13p
Riley J.M., Warner P.J., 1990, MNRAS 246, 1p
Riley J.M., Warner P.J., Rawlings S., et al., 1988, MNRAS 236, 13p
Saripalli L., Mack K.-H., Klein U., Strom R., Singal A.K., 1996, A&A 306, 708
Schartel N., Walter R., Fink H.H., Trümper J., 1996, A&A 307, 33
Tanaka Y., Inoue H., Holt S.S., 1994, PASJ 46, L37
Tanaka Y., Nandra K., Fabian A.C., et al., 1995, Nat 375, 659

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.