ASCA PV observations of the Seyfert 2 galaxy NGC 4388: the obscured nucleus and its X-ray emission

K. Iwasawa, A.C. Fabian, S. Ueno, H. Awaki, Y. Fukazawa, K. Matsushita and K. Makishima

1: Institute of Astronomy, Madingley Road, Cambridge CB3 0HA
2: Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-01, Japan
3: Department of Physics, the University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113, Japan

ABSTRACT

We present results on the Seyfert 2 galaxy NGC4388 in the Virgo cluster observed with ASCA during its performance verification (PV) phase. The 0.5–10 keV X-ray spectrum consists of multiple components; (1) a continuum component heavily absorbed by a column density $N_H \approx 4 \times 10^{23} \text{cm}^{-2}$ above 3 keV; (2) a strong 6.4 keV line (equivalent width $EW \sim 500 \text{ eV}$); (3) a weak flat continuum between 1 and 3 keV; and (4) excess soft X-ray emission below 1 keV. The detection of strong absorption for the hard X-ray component is firm evidence for an obscured active nucleus in this Seyfert 2 galaxy. The absorption corrected X-ray luminosity is about $2 \times 10^{42} \text{erg s}^{-1}$. This is the first time that the fluorescent iron-K line has been detected in this object; the large EW is a common property of classical Seyfert 2 nuclei. The flat spectrum in the intermediate energy range may be a scattered continuum from the central source. The soft X-ray emission below 1 keV can be thermal emission from a temperature $kT \approx 0.5 \text{ keV}$, consistent with the spatially extended emission observed by ROSAT HRI. However, the low abundance ($Z \sim 0.05Z_\odot$) and high mass flow rate required for the thermal model and an iron-K line stronger than expected from the obscuring torus model are puzzling. An alternative consistent solution can be obtained if the central source was a hundred times more luminous over than a thousand years ago. All the X-ray emission below 3 keV is then scattered radiation.

Key words:
nosity $L_X = 2 \times 10^{42}$ erg s$^{-1}$, is typical for a low luminosity Seyfert 1 galaxy.

The origin of weak soft X-ray emission seen from the source is, on the other hand, controversial. The soft X-ray luminosity, $L_{0.5–1.5 keV} = 1.5 \times 10^{40}$ erg s$^{-1}$, first detected by the Einstein Observatory (Forman et al 1979), is ~1 per cent of the absorption-corrected luminosity of the hard X-ray source and consistent with the possibility that the soft X-rays are scattered nuclear radiation. However, the ROSAT HRI image of NGC4388 shows the 0.1–2.4 keV emission to be clearly extended with a radius of 45 arcsec and luminosity $L_X \approx 3 \times 10^{40}$ erg s$^{-1}$ (Matt et al 1994; see also Fig. 1). The radial profile shows that half of the soft X-ray emission originate beyond the central 15 arcsec. Matt et al (1994) claim that the large extent is evidence against a scattering origin for the soft X-ray emission, since the X-ray luminosity of the central source implied by the hard X-ray observations is insufficient to photoionize the necessary column density. They propose as alternative explanations either thermal emission from a starburst or a collection of discrete sources. The ROSAT PSPC spectrum shows a steep spectral slope, $\Gamma = 2–3$ (Rush & Malkan 1996) which may be consistent with this interpretation. However, the spectral resolution of these instruments does not provide any conclusive evidence.

We report here the first ASCA results on NGC4388 (see Tanaka, Inoue & Holt 1994 for a brief discussion of the capabilities of ASCA). The superior spectral resolution of ASCA over the 0.5–10 keV band enables us to identify several different components in the spectrum.

2 THE ASCA OBSERVATIONS AND DATA REDUCTION

2.1 Observations

NGC4388 was observed in two different pointings at adjacent elliptical galaxies in the Virgo cluster, M86 (NGC4406; ASCA results of this galaxy appear in Awaki et al 1994 and Matsushita et al 1994) and M84 (NGC4374) during the ASCA performance verification (PV) phase. These observations were carried out in series between 1993 July 3 and 4, each with an effective exposure time of about 20 ks. NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first observation, NGC4388 was off axis by 18 and 10 arcmin, respectively. In the first ob
The temperature of the ICM, significant emission from the intra-cluster medium (ICM). NGC4388 lies close to the core of the Virgo cluster there is because of the weakness of NGC4388 itself and the com-

Energy spectra were extracted from an elliptical-shaped re-

an excess above the diffuse emission spreading out from the M86 direction.

3.1 Spectral fitting

We have two SIS and four GIS spectra. Since the off-axis po-

NGC4388 is the only strong source in the energy band below 3 keV as 

3.1.1 The Hard X-ray components

As Fig. 4 and Fig. 5 show, a strong continuum excess is seen above 3 keV with a sharp emission line around 6.4 keV. This feature is identified as the K-shell fluorescence line from cold iron. The hard X-ray spectrum is well fitted by an absorbed power-law and a gaussian line. The photon-index and absorption column density depend on the precise spectral model chosen for the soft X-ray component (see later).

3.1.2 A Spectral model for the soft X-ray components

We first examined the SIS data below 3 keV, since the spec-

Table 1. The background-subtracted count rate in each detector. There is no SIS data in the first observation. NGC4388 is observed at off-axis angle ~ 18 arcmin in the first observation, and ~ 10 arcmin in the second observation. The effective area of the source-photon collected region of NGC4388 in the first observation is ~ 48 per cent of that in the second observation.

000 RAS, MNRAS 000, 000–000

3 RESULTS

* Awaki et al (1994) give a temperature of $kT = 0.79 \pm 0.01$ keV and abundance $Z = 0.45^{+0.12}_{-0.06}$Z⊙ for the total X-ray emission of M86 after fitting with a Raymond-Smith thermal spectrum model.
Figure 2. Full-band (0.7–10 keV) GIS image from the first observation, overlaid on the digital sky survey image in the optical band. X-ray emission was detected from three galaxies in the field of view; M86 (middle), M84 (right), and NGC4388 (below).

Figure 3. Projected images across M86 and NGC4388 in two energy bands; open circles with a dotted line: 0.7–3 keV; and filled squares with a solid line: 3–10 keV. 1 pixel corresponds to 0.25 arcmin.

Possible origins for the flat spectrum are; a) scattered nuclear continuum, b) part of the transmitted nuclear continuum, and c) a collection of high-mass X-ray binaries. These will be discussed in Section 4. In subsequent fits, the component is modelled by a power-law.

Thus a thermal spectrum plus a power-law can be an appropriate model for the soft X-ray spectrum. We use a Raymond-Smith thermal spectrum assuming only Galactic absorption, since this extended component may be free from
the intrinsic absorption of the host galaxy. The absorption for the power-law component remains a free parameter.

3.1.3 The spectrum of the whole energy band

The whole spectrum is fitted using the above two soft X-ray components in addition to the absorbed power-law plus a gaussian. The photon-index of the soft power-law component (PL$_2$) is not well constrained. Thus it is assumed to be identical to the hard power-law (PL$_1$). The GIS is less sensitive to the thermal component because of its poorer spectral resolution and limited efficiency below 1 keV. Constraints on the temperature and abundance are worse than those from the SIS data. The parameters of the thermal component are therefore fixed at the SIS-derived values, except for the normalization, when fitting the GIS spectra. The results are shown in Table 2, and the best-fit models for both detectors are shown in Fig. 4 and Fig. 5, respectively.

We detected strong absorption $N_H \approx 4 \times 10^{23} \text{cm}^{-2}$ for the hard X-ray component, with a relatively small uncertainty compared with previous measurement (see Table 2). The constraint on the photon index is weak owing to the limited energy range and strong absorption. The best-fit $\Gamma \approx 1.6$ is consistent with previous results (Hanson et al. 1990; Takano & Koyama 1991). A strong fluorescence iron K$\alpha$ line is found for the first time in this object. The equivalent width (EW) is quite large despite the relatively narrow line width. There is no evidence for the line broadening in the GIS data whereas there is weak evidence ($\sigma = 0.14^{+0.13}_{-0.06}$ keV) in the SIS data. When we assume that the PL$_2$ has an identical $\Gamma$ to the PL$_1$, some extra absorption, $N_H \approx (1 - 3) \times 10^{22} \text{cm}^{-2}$, is required (see Table 2).

This means that the soft X-ray spectrum around 2 keV is extremely flat.

3.1.4 X-ray fluxes

The observed fluxes are summarized in Table 3. The flux in the 3–10 keV band is slightly smaller than that observed by the SL2 XRT ($f_{3-10\text{keV}} = 2.0 \times 10^{-11} \text{erg cm}^{-2} \text{s}^{-1}$; Hanson et al. 1990). The soft X-ray flux is roughly consistent with previous measurements from the ROSAT PSPC ($f_{0.1-2\text{keV}} = 4.7 \times 10^{-13} \text{erg cm}^{-2} \text{s}^{-1}$; Rush & Malkan 1996) and the ROSAT HRI ($f_{0.1-2.4\text{keV}} = 5.8 \times 10^{-13} \text{erg cm}^{-2} \text{s}^{-1}$; Matt et al. 1994), extrapolating our best-fit model down to 0.1 keV, although the ROSAT flux depends on the assumed model.

4 DISCUSSION

4.1 The obscured nucleus

We find clear evidence for strong obscuration along the line of sight. The column density $N_H \approx 4 \times 10^{23} \text{cm}^{-2}$ implied from the ASCA spectrum is similar to those observed in some other classical Seyfert 2 galaxies (e.g., Awaki et al. 1991; Iwasawa et al. 1994). The photon index ($\Gamma \approx 1.6$) is also consistent with that of Seyfert galaxies. Our best-fit value can be justified by the fact that a SIGMA observation in the 40–150 keV band (Lebrun et al. 1992) is in agreement with an extrapolation of the result of Hanson et al. (1990), unless any extra component, e.g. Compton reflection component, has a significant contribution at the hard X-ray band (the
remote, Colina (1992) predicted that a UV luminosity, 
\( L_{\text{UV}} \), corresponding to a luminosity, \( L \), extended nebula. If NGC4388 has the ratio, as proposed in the unification scheme of Seyfert galaxies, even though deficits of HI and CO gas in this galaxy have been reported (Chamaraux, Balkowski, & Gerard 1980; Kenney & Young 1986), plenty of cold gas remains close to the central X-ray source. This can form an obscuring torus such as proposed in the unification scheme of Seyfert galaxies (e.g., Antonucci 1993). The anisotropic radio source extending perpendicular to the galaxy (Stone et al 1988; Hummel & Saikia 1991) and the conical high-ionization regions observed in the optical band (Pogge 1988; Colina et al 1987) are compatible with the idea of collimation of radiation by the torus. We note that the symmetrical axes of the torus and the stellar disk of NGC4388 are aligned as well as NGC4945 (Iwasawa et al 1993), while they are misaligned in most cases (e.g., NGC1068, Antonucci & Miller 1985; NGC5252, Tadhunter & Tsvetanov 1989).

An alternative source of the strong X-ray absorption is the interstellar medium in the nearly edge-on galaxy disk itself. Recent near-infrared imaging has revealed that this galaxy has a boxy bulge (McLeod & Rieke 1995). This and the dust lane crossing in front of the nucleus can be responsible for some or all of the absorption. In this case, the flat spectrum between 1 and 3 keV is possibly explained by transmission of scattered radiation from the central source seen through the stellar disk. Since the disk is tilted by \( \sim 18 \) degrees from being exactly edge-on, there may be less absorption along these lines of sight, so making a flat spectrum in the softer band in addition to the strongly absorbed component.

We note there will be some scattering in the obscuring medium with \( N_H \sim 4 \times 10^{23} \text{cm}^{-2} \) leading to a hard power-law component in the 1–3 keV band (Yaqoob 1996). This, however, is at least an order of magnitude fainter than the observed power-law in that band, unless the absorbing medium is partially ionized.

### 4.2 The iron K line

A strong iron Kα emission line is detected at 6.4 keV. The large equivalent width (\( EW = 440 - 730 \) eV) of the 6.4 keV line is one of the signatures of reprocessing in cold matter. Various calculations of X-ray spectra emerging from a central power-law source surrounded by a torus do predict a large EW (Awaki et al 1991; Krolik, Madau & Życki 1994; Ghisellini, Haardt & Matt 1994). However, the observed EW is larger than the value (\( EW \sim 300 \) eV) expected from the work of Awaki et al (1991) with \( N_H \sim 4 \times 10^{21} \text{cm}^{-2} \), taking an opening angle of the torus of about 1/3, as deduced from the optical extended nebula (Pogge 1988). The excess EW could be due to an enhanced iron abundance.

Although the present data cannot provide any meaningful restriction on the depth of any iron K absorption edge at 7.1 keV, and hence on the iron abundance, a deep edge due to a supersolar abundance of iron could partly explain the flat hard X-ray spectra, found in some Ginga Seyfert 2...
spectra (Awaki et al. 1991; Smith & Done 1996), especially when the column density exceeds \( N_H \sim 10^{22} \text{cm}^{-2} \).

A similar iron K line feature has been found in ASCA spectra of another Seyfert 2 galaxy Mrk 3 (Iwasawa et al. 1994). Mrk 3 showed a significant intensity change of the iron K line in response to the continuum variation between two observations of 3.6 yr apart. This fact suggests that the line is produced within \( \sim 1 \text{ pc} \) from the central source. We do not of course detect any variability within the present one-day observing run of NGC4388 and therefore cannot obtain any constraint about the line emitting region from this observation.

### 4.3 The scattered continuum

There is a flat spectral component detected in the intermediate energy range between the hard component and the thermal component. Such a flat component has been observed in ASCA spectra of Seyfert 2 galaxies NGC1068 (Ueno et al. 1994) and NGC6552 (Fukazawa et al. 1994), and the eclipse spectrum of X-ray binary Vela X-1 (Nagase et al. 1994). These are considered to be scattered continuum of the central source. It is therefore plausible that this component in NGC4388 is also scattered radiation from the central obscured source, although the possibility that it is radiation from the central source escaping through a partially covering absorber as mentioned in Section 3.1.2. is also viable.

As the broad H\( \alpha \) detected from the off-nuclear region (Shield & Filippenko 1988; 1996) suggests, scattered light may be observed in the optical band. However, spectropolarimetry in the optical blue band does not detect any such broad-line region (Kay 1994).

One can expect that several emission lines produced in the photoionized gas or cold gas which is responsible for the scattering would be observable on the X-ray continuum, as seen in the ASCA spectra of Mrk 3 (Iwasawa et al. 1994) and NGC6552 (Fukazawa et al. 1994; Reynolds et al. 1994). It is, however, hard to detect such lines in our data, because of poorer statistics and contamination by the thermal emission. The detected absorption column density of a few times \( 10^{22} \text{cm}^{-2} \) imposed on the power-law is consistent with the narrow-line region reddening \( E(B-V) \sim 0.5 \text{ mag} \) deduced from the [S\( II \)] doublet (Malkan 1983), although a recent estimate of the reddening from Pa\( \beta \)/H\( \beta \) = 1.1 gives a greater value, \( E(B-V) \sim 1 \text{ mag} \) than this (Ruiz et al. 1994).

We do however detect a marginally significant iron line due to hydrogenic iron in the SIS spectrum at 6.9 \( \pm 0.1 \) keV of equivalent width 194 \( \pm 118 \) eV against the absorbed hard continuum or 4.7 \( \pm 2.9 \) keV against an extrapolation of the scattered continuum. The strength of this line is difficult to predict as it is probably due to resonant scattering of the continuum (Matt, Brandt & Fabian 1996), but it does corroborate the scattering hypothesis. To be so highly ionized, the scattering medium is probably within a pc of the nucleus for the observed X-ray luminosity of the central source.

We note that a reasonable fit to the whole SIS spectrum can be obtained with a partially-covered power-law spectrum, with a gaussian line at 6.4 keV and an edge at 0.9 keV. This last feature could be due to a oxygen warm absorber, such as is commonly observed in the spectra of Seyfert 1 galaxies, along the line of sight to the scattering medium. This model is rejected because the ROSAT HRI image shows that the scattering medium is much more extended than can be plausibly ionized by the central source (Matt et al. 1994).

Other explanations for the flat spectrum are transmission through the edge-on stellar disk, as discussed in the previous section, and a population of high mass X-ray binaries. This last possibility is unlikely given the expected massive star population in the galaxy. The ratio of far infrared luminosity to blue luminosity can be an indicator of relative excess of young population (O stars and high mass X-ray binaries; David et al. 1992). Since this ratio in NGC4388, \( L_{\text{FIR}}/L_{\odot} = 1.5 \), is a factor of 10 lower than in M82, it is unlikely that an intensive starburst like that in M82 is taking place in NGC4388. A collection of X-ray binaries is expected to emit a much smaller X-ray luminosity than that observed (\( L_X \approx 5 \times 10^{40} \text{ erg s}^{-1} \)).

### 4.4 The extended thermal emission

The ASCA spectrum, combined with the extended image (Fig. 1) resolved by the ROSAT HRI (Matt et al. 1994), provides evidence that the soft X-ray emission below 1keV is of thermal origin. Such thermal emission has been observed in the ASCA spectra of other nearby spiral galaxies which contain an obscured Seyfert nucleus (e.g., NGC1068, Ueno et al. 1994; NGC4258, Makishima et al. 1994). The temperature is \( kT = 0.47 \pm 0.18 \text{ keV} \) and the abundance is extremely low (\( Z = 0.053^{0.035}_{0.027} \odot Z_\odot \)). The 0.5–3 keV luminosity of this thermal emission is \( L_X = (1.4 \pm 0.3) \times 10^{40} \text{ erg s}^{-1} \), consistent with the Einstein IPC measurement (Forman et al. 1979).

Our spectral fits shows most of the observed X-rays below 1.5 keV come from the thermal component (see Fig. 4 and Fig. 5). This is compatible with the fact that most of the X-ray emission detected by the ROSAT HRI is extended over the nucleus (Matt et al. 1994), taking account for the ROSAT bandpass.

The extended thermal gas could be the stripped interstellar medium of the galaxy. Starburst activity is not strong in NGC4388, as discussed in Section 4.3, but consistent with that in normal galaxies with respect to the \( L_X/L_\text{FIR} \) correlation (David et al. 1992). NGC4388 is known to be located close to the Virgo cluster core, and to move at high velocity of 1311 km s\(^{-1}\) relative to the cluster (Corbin et al. 1988) in the deep cluster potential. The deficiency of HI and CO in this galaxy has been explained in terms of ram-pressure stripping by interaction with the Virgo ICM (Chamaraux et al. 1986). Since this ratio in NGC4388, \( L_{\text{FIR}}/L_{\text{X}} \approx 1 \), consistent with the 

Finally, we note that at the radius of the thermal component (1.4–4.5 kpc, Matt et al. 1994) the gas density is only \( \sim 0.2 \text{ cm}^{-3} \), assuming bremsstrahlung emission since the abundance is so low, and any scattered X-ray emission will be negligible. The bremsstrahlung emission from any scattering medium at a temperature \( > 10^6 \text{ K} \) would swamp
the scattered flux. The radiative cooling time of the gas is \(\sim 10^5\) yr and the recombination time (of say highly ionized oxygen) is \(< 10^4\) yr. The flow time at a velocity of 300 km s\(^{-1}\) is \(\sim 10^7\) yr. The gas may therefore be due to an outburst in the last ten million yr, or a more general wind from the nuclear regions. The mass flow rate is then about \(\dot{M} \sim 100 v_{300} R_2^2 M_\odot\) yr\(^{-1}\) where \(v_{300}\) is a wind velocity in unit of 300 km s\(^{-1}\) and \(R_2\) is the radius of the thermal emission region in units of 2 kpc, which is at the highest end of the values for superwind galaxies (\(\dot{M} \sim 1-100 M_\odot\) yr\(^{-1}\), Heckman, Armus & Miley 1991). This large mass injection is unlikely for NGC4388 since it shows no evidence for a strong starburst such as in superwind galaxies. The low measured abundance (though error is rather large) is also puzzling. It is however measured mainly for iron-L in our spectrum. As the abundance of iron is usually lower than that of other elements in starburst galaxies, the low abundance may not be unusual if the thermal emission is produced through a recent starburst.

4.5 A consistent solution for NGC4388

We have identified several problems in the interpretation of the X-ray data of NGC4388: a) the large soft X-ray extent, if thermal, means a large mass loss rate from the bulge which can only plausibly last a few million yr, b) a thermal model requires a very low abundance in the extended gas and c) the iron line is high for the observed obscuration (and in the case of an iron line from reflection assuming that the solid angle irradiated and the opening angle for the emerging radiation, which reduces the predicted level of polarization. Further spectropolarimetric observations of a wider region are required.

5 SUMMARY

We find from the ASCA observations that the spectrum of the Seyfert 2 galaxy NGC4388 has many components. The hard X-ray emission is strongly absorbed, and a strong iron K line (\(\text{EW} \approx 440-730\) eV) is found at 6.4 keV. The hard continuum has a photon index \(\Gamma \approx 1.6\) and is absorbed by a column density \(N_H \approx 4 \times 10^{23}\) cm\(^{-2}\). Evidence for a thermal spectrum is found in the soft X-ray band, which can be identified with the spatially extended emission observed by ROSAT HRI (Matt et al 1994). A flat spectrum joins these two components in the band around 2 keV. It may be the scattered continuum of the obscured central source. However, several difficulties still remain: (1) an extremely low abundance is required for the thermal emission model; (2) an unlikely high mass flow rate is required to explain the soft X-ray extent; and (3) the iron-K line stronger than expected from the torus model, with the observed column density. These can be overcome if the central source was a hundred times brighter a thousand or more years ago. All the soft X-ray emission below 3 keV can then be due to the continuum scattered in a partially ionized medium irradiated by the luminous source. The iron K line produced by gas in the bulge and disk in the galaxy then remains strong, because of the larger size. This will be tested by a detailed imaging spectroscopy with future missions like AXAF and Astro-E.

ACKNOWLEDGEMENTS

We thank all the members of the ASCA PV team, Giorgio Matt and David White for useful discussion and Niel Brandt for helping to make the ROSAT HRI image. The optical image of NGC4388 was obtained through the Sky View facility operated by HEASARC at NASA/GSFC. This research has made use of data obtained through the High Energy Astrophysics Science Archive Research Center Online Service, provided by the NASA-Goddard Space Flight Center. ACF
and KI thank the Royal Society and PPARC, respectively for support.

REFERENCES

Antonucci R.R.J., 1993, ARAA, 31, 473
Antonucci R.R.J., Miller J.S., 1985, ApJ, 297, 621
Awaki H., et al, 1994, PASJ, 46, L65
Awaki H., Koyama K., Inoue H., Halpern J.P., 1991, PASJ, 43, 195
Böhringer H., Briel U.G., Schwarz R.A., Voges W., Hartner G., Trümper J., 1994, Nat, 368, 828
Brandt W.N., Fabian A.C., Pounds K.A., 1996, MNRAS, 278, 326
Chamaraux P., Balkowski C., Gerald E., 1980, A&A, 83, 5
Colina L., 1992, ApJ, 386, 59
Colina L., Fricke K.J., Kolatschny W., Perryman M.A.C., 1987, A&A, 186, 39
Corbin M.R., Baldwin J.A., Wilson A.S., 1988, ApJ, 334, 584
David L.P., Forman C., Jones W., 1992 ApJ, 388, 82
Fabian A.C., 1977, Nat, 269, 672
Filippenko A.V., Sargent W.L.W., 1985, ApJS, 57, 503
Forman W., Schwartz J., Jones D., Liller W., Fabian A.C., 1979, ApJ, 234, L27
Fukazawa Y. et al 1994, PASJ, 46, L141
Giovanelli R., Haynes M.P., 1983, AJ, 88, 881
Ghisellini G., Haardt F., Matt G., 1994, MNRAS, 267, 743
Hanson C.G., Skinner G.K., Eyles C.J., Wilmore A.P., 1990, MNRAS, 242, 262
Heckman T.M., Armus L., Miley G.K., 1991, ApJS, 74, 833
Hummel E., Saikia D.J., 1991, A&A, 249, 43
Iwasawa K., Yaqoob T., Awaki H., Ogasaka Y., 1994, PASJ, 46, L167
Iwasawa K., Koyama K., Awaki H., Kunieda H., Makishima K., Tsuru T., Ohashi Y., Nakai N., 1993, ApJ, 409, 155
Kay L.E., 1994, ApJ, 430, 196
Kenney J.D., Young J.S., 1986, ApJ, 301, L13
Koyama K., Takano S., Tawara Y., 1991, Nat, 339, 603
Krolik J.H., Madan P., Życki P.T., 1994, ApJ, 420 L57
Lebrun F., et al 1992, A&A, 264, 22
Makishima K., Fujimoto R., Ishisaki Y., Kii T., Loewenstein R., Mushotzky R., Serlemitsos P., Sonobe T., Tashiro M., Yaqoob Y., 1994, PASJ, 46, L77
Malkan M.A., 1983, ApJ, 264, L1
Matsushita K. et al, 1994, ApJ, 436, L41
Matt G., Piro L., Antonelli L.A., Fink H.H., Meurs E.J.A., Perola G.C., 1994, A&A, 292, L13
Matt G., Brandt W.N., Fabian A.C., 1996, MNRAS, 280, 823
McLeod K.K., Rieke G.H., ApJ, 441, 96
Nagase F., Zylstra G., Sonobe T., Kotani T., Inoue H., Woo J., 1994, ApJ, 436, L1
Otani C., et al 1996, PASJ, 48, 211
Phillips M.M., Malin D.F., 1982, MNRAS, 199, 905
Phillips M.M., Charles P.A., Baldwin J.A., 1983, ApJ, 266, 485
Pogge R.W., 1988, ApJ, 332, 702
Rangarajan F.V.N., White D.A., Ebeling H., Fabian A.C., 1995, MNRAS, 277, 1047
Reynolds C.S., Fabian A.C., Makishima K., Fukazawa Y., Tamura T., 1994, MNRAS, L55
Ruiz M., Rieke G.H., Schmidt G.D., 1994, ApJ, 423, 608
Rush B, Malkan M.A, 1996, AJ, in press
Sandage A., Tammann G.A., 1984, Nat, 307, 326
Shields J.C., Filippenko A.V., 1988, ApJ, 332, L55
Shields J.C., Filippenko A.V., 1996, A&A, 311, 393 (RN)
Smith D.A., Done C., 1996, MNRAS, 280, 355
Stone J.L., Wilson A.S., Ward M.J., 1988, ApJ, 330, 105
Tadhunter C., Tsvetanov Z., 1989, Nat, 341, 422

© 0000 RAS, MNRAS 000, 000–000

Takano S., Koyama K., 1991, PASJ, 43, 1
Ueno S., Mushotzky R.F., Koyama K., Iwasawa K., Awaki H., Hayashi I., 1994, PASJ, 46, L71
Weaver K.A., Nousek J., Yaqoob T., Mushotzky R.F., Makino F., Otani C., 1996, ApJ, 458, 160
White D.A., Fabian A.C., Forman W., Jones C., Stern C., 1991, ApJ, 375, 35
Wilson A.S., Elvis M., Lawrence A., Bland-Hawthorn J, 1992, ApJ, 391, L75
Yaqoob T., 1996, ApJ, in press