J. Astrophys. Astr. (2001) **22,** 283–292

Soft X-ray Variability of the Bright Quasar 3C273

Chulhee Kim *Department of Earth Science Education, Chonbuk National University, Korea.*
e-mail:chkim@astro.chonbuk.ac.kr

Received 2001 July 20; accepted 2001 November 2

Abstract. We present the results from ROSAT observations of 3C273 in the soft X-ray band. The light variation of 3C273 was investigated for three different energy bands of soft, medium, and hard. The maximum variability with a factor of 2 for 551 days was confirmed at all three different bands. This appears to be a periodic variation within the period of roughly 6 months. However, the short-term or micro variation was not so distinct and the light variation of each band did not show any correlation between them. The hardness ratio for hard and soft bands shows irregular variation but there was no correlation between them. There is no distinct variation of the photon index in the case of simple power law model fitting. For power law + free absorption model fitting, the average photon index (Γ) is 2.08.

Key words. Galaxies: individual (3C273), quasar—X-rays: galaxies.

1. Introduction

Bright quasar 3C273 ($z = 0.158$) is one of the most extensively observed extragalactic objects and has been tested by many theories of active galactic nuclei. Bowyer *et al*. (1970) detected X-rays from 3C273 for the first time. Turner *et al*. (1990) observed it with the EXOSAT and Ginga and they determined the photon index value of $1.40 < \Gamma < 1.55$ using the simple power law model. The fact that this value does not correlate with the flux variation in the 2–10 keV band region was also confirmed.

They also found the existence of soft excess below 1 keV from the analysis of the EXOSAT data and this was confirmed by Courvoisier *et al*. (1987); Masnou *et al*. (1992), and Wilkes & Elvis (1987) who analyzed the Einstein data. Furthermore, it was found that this soft component flux varies during a one week period. The existence of a soft excess component was again confirmed by Staubert (1992) from the analysis of the ROSAT and Ginga data.

Hence there has been no doubt about the existence of the soft excess component to 3C273, but there has been no agreement with the spectral model fitting to it. Based on the analysis of the Einstein data, it was argued that the broken power law or power law + black body model is better than other models. However it was reported that the black body, steep power law, or thermal bremsstrahlung model is good for the EXOSAT data.

Leach *et al*. (1995) analyzed the ROSAT PSPC data through 14 times of observations for 25 days and they found that the variations of the overall count rate is 20 per cent in

2d and the count rates, when split into hard (1.5–2.4 keV) and soft (0.1–0.3 keV) energy bands, are not correlated, showing that two physically distinct emission components are present. They also reported that the spectra are modelled best by a combination of two power laws with absorption at the galactic value, the spectral index of the softer power law ($\Gamma_{\rm soft}$) is 2.7 when the photon index ($\Gamma_{\rm hard}$) of the harder power law is fixed at 1.5, and there are small but significant variations in $\Gamma_{\rm soft}$ which do not correlate with the soft count rate.

Fan *et al* (2001) used a database of measurement of 110 years in the B-band in order to search periodicity of 3C273 and they argued the existence of periods of 2.0 years. By encouraging this discovery, we try to analyze the four ROSAT PSPC data sets of 3C273 which were not included in the investigation by Leach *et al*. (1995) in order to search any periodic long-term soft X-ray variation. We present the observation in section 2, an analysis and the results in section 3, and discussion and conclusion in section 4.

2. Observations and data analysis

The X-ray data described here are from observations carried out at four epochs between December 15th, 1991 and June 17th, 1993 using the X-ray telescope on board the ROSAT Observatory (Trümper 1983) with the position sensitive proportional counter (PSPC; Pfeffermann *et al*. 1987). The bandpass of the PSPC is $\sim$ 0.1–2.4 keV and the field of view was $\sim 2^\circ$ diameter. The energy resolution is $\Delta E/E = 0.43(E/0.93)^{-0.5}$ (FWHM) where the unit of E is keV. The spatial resolution at the central part is $\sim 25''$ (FWHM) (Hasinger *et al*. 1992). To eliminate the shadow effect due to the grid in front of the detector window, the satellite was wobbled at a period of $\sim$ 400 sec with a wobbling angle of $\sim 7'$–$8'$.

In order to investigate the long-term variation, we searched all the ROSAT PSPC archive data for 3C273. The selection criteria were first, observations should cover a long enough duration – at least more than one year – and, second, the count rate should be higher than about 10 (c/s) for more reliable timing and spectral analysing results. We selected four sources observed by different observers from 1991/12 to 1993/06 for about one and half years. 3C273 was at the center of the PSPC field of view during two of the observations. In the other two it was at different off-axis angles. We will refer to them as P1, P2, etc. The log of observations is presented in Table 1 where the source number, observation date, exposure time and count rate are given.

All data sets were analyzed using the MIDAS-EXSAS software package (Zimmermann *et al*. 1994). The imaging analysis, background subtraction and various detector corrections like vignetting and dead time corrections are included in data reduction. The source was extracted from a circular region of 1.5 arcmin. The background was computed in an annulus between 2.0 and 3.4 arcmin centered on the source cell. For the off-axis sources, a larger circular region was taken for source extraction and other nearby regions without faint sources instead of an annulus centered on the source were taken for the background subtraction.

3. Analysis and results

Because the typical X-ray spectra of AGNs show a distinct structural pattern caused by the soft excess, absorption by cold material in the host galaxy, and Kα line etc.,

Table 1. Log of ROSAT-PSPC observations.

Source name	Source number	Start time [UT]	End time [UT]	Exposure time (sec)	Count rate (cts/s)	Off-axis
P1	700191P	91/12/14/08:54:56	91/12/15/04:10:01	6140	14.64	no
P2	600242P	92/07/21/21:47:36	92/07/11/21:55:43	3078	31.05	yes
P3	600242P-1	92/12/24/15:31:36	92/12/26/22:16:59	24830	19.90	yes
P4	141509P	93/06/06/16:07:08	93/06/17/11:33:57	3330	26.63	no

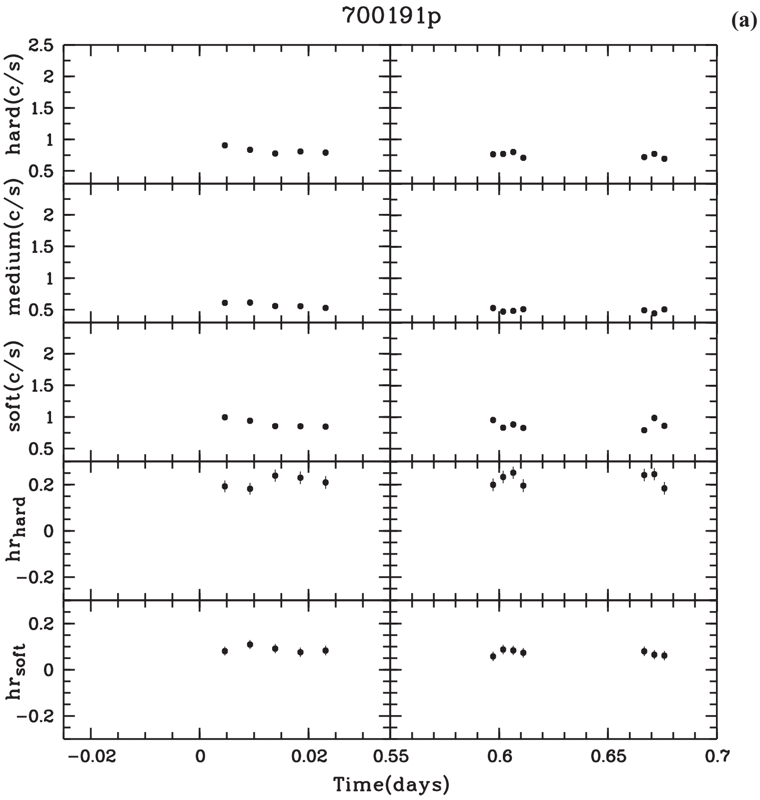

Figure 1(a–d). The X-ray light curves in the three X-ray bands (top three panels) and hardness ratios of 3C371. Note that the scale of X-axes is not the same for all observations.

it is necessary to investigate the light variation for different energy bands. Figure 1 shows the X-ray light curves for the three energy bands of soft, medium, and hard energy regions. These three bands correspond to channels 11–19, 52–69, and 132–201, respectively. Data were rebinned into 400 sec bins. Note that the scale of X-axes is different for each.

Figure 1 does not exhibit any distinct short-term variation. However it can be seen that the count rate in the three different bands varies alternately for four data sets. Table 2 represents the mean count rate for different bands.

Table 2. Mean count rate for soft, medium, and hard band as well as the hardness ratio for four data sets.

	700191p	600242p	600242p-1	141509p
Hard(c/s)	0.8	1.2	0.7	1.2
Medium(c/s)	0.5	0.9	0.5	0.9
Soft(c/s)	0.9	2.0	1.3	2.0
hr_{hard}	0.2	0.2	0.2	0.2
hr_{soft}	0.1	−0.2	−0.2	−0.1

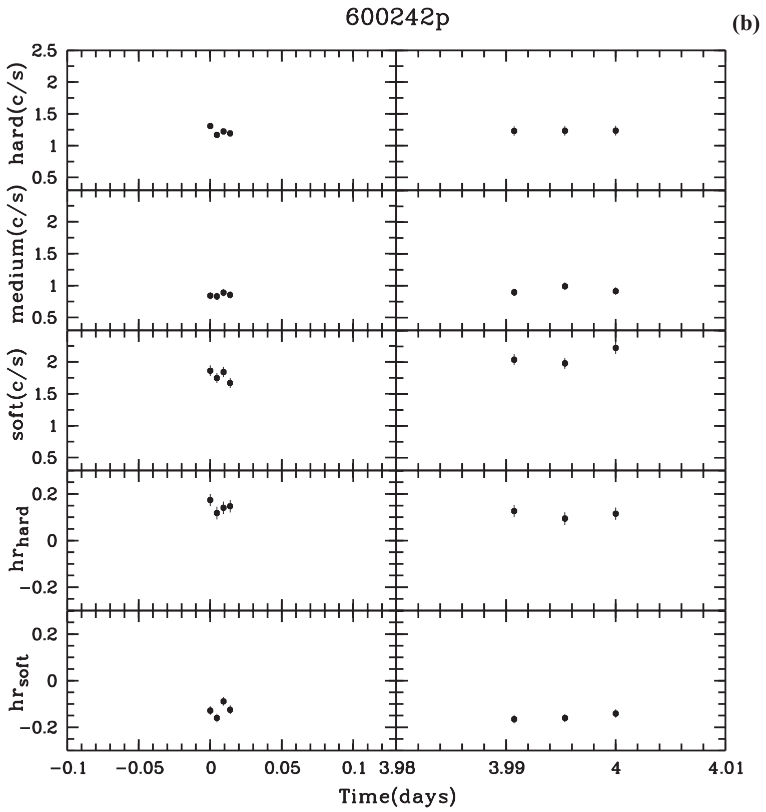

Figure 1(b). (*continued*)

The mean count rate for the hard band varies from 0.8 (c/s) in 700191p to 1.2 (c/s) in 600242p, then recovered to 0.7 (c/s) in 600242p-1. Again the count rate increased to 1.2 (c/s) in 141509p. For medium and soft bands, the light variation shows a similar pattern. Because the observation of four data sets carries out with crudely every half year interval, this alternate variation seems to be a periodic phenomenon. Also the amount of increment or decrement is largest for the soft band. And, in addition, the soft flux varies more largely than the hard flux especially for 600242p-1. A more detailed discussion will be given in the last section.

In order to investigate the presence of any correlation between the hardness ratio and light variations, we calculated the hardness ratio of hr_{soft} and hr_{hard}. The hardness ratio is defined as equation (1) and (2) below where $band_1$, $band_2$, $band_3$, and $band_4$ are the count rates in channels 11–41, 52–201, 52–90, and 91–201 respectively.

$$hr_{\mathrm{soft}} = \frac{(band_2 - band_1)}{(band_2 + band_1)}, \tag{1}$$

$$hr_{\mathrm{hard}} = \frac{(band_4 - band_3)}{(band_4 + band_3)}. \tag{2}$$

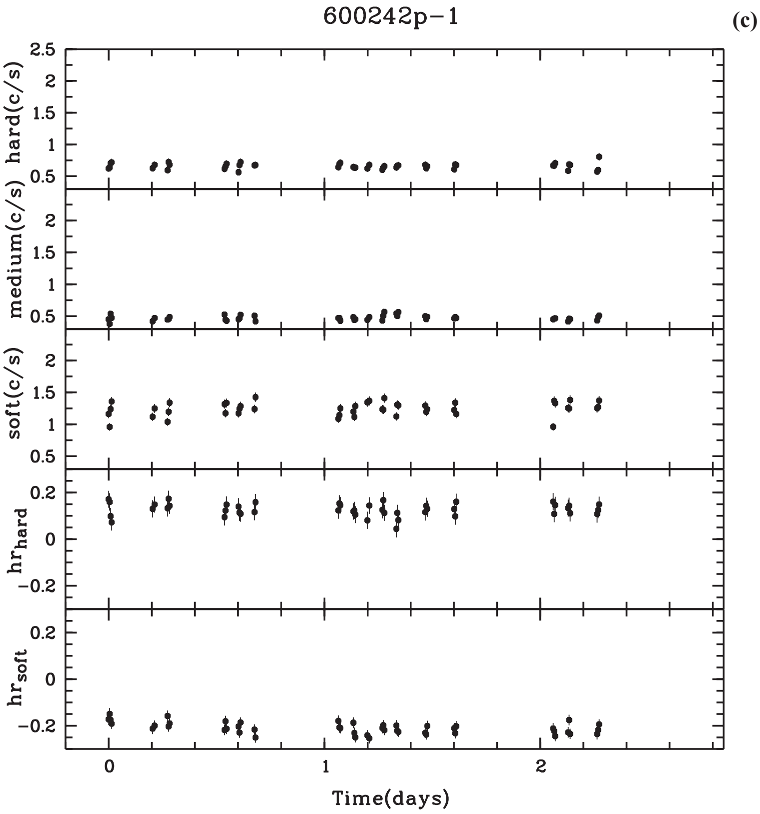

Figure 1(c). (*continued*)

The lower two panels for four data sets in Figs. 1 show $hr_{\rm soft}$ and $hr_{\rm hard}$ versus time. We can see that both $hr_{\rm soft}$ and $hr_{\rm hard}$ varied irregularly on short time scales. For all four data sets $hr_{\rm hard}$ varied from 0.14 to 0.22, but $hr_{\rm soft}$ varied strongly from 0.08 to -0.19. A variation in the hardness ratio exhibits spectral variability during the observations. However, any correlation between the hardness ratio and the light variation cannot be seen. Furthermore it was also found that there is no correlation between the variation of the $hr_{\rm soft}$ and $hr_{\rm hard}$.

The X-ray spectra of AGNs are complex (see Turner *et al*. 1993; Nandra & Pounds 1994; Page *et al*. 1999). The energy source below ~ 10 keV is composed of at least two parts, i.e., a power law component which reaches to the higher energy region (> 40 keV) and a soft X-ray component appearing in the lower (< 1.0 keV) energy region. The power law component seems to be produced in the hot corona surrounding the relativistic accretion disk (see Nandra *et al*. 1997).

For the spectral analysis we excluded bad PSPC channels 1–9 and 241–256 and the data were rebinned to have a S/N ratio of 8. A simple power-law + absorption model was fitted and the best-fit parameters are presented in Table 3. In Fig. 2, we show the observed spectra for all four sources with the best-fit model and residuals between the spectra and the model are shown in the lower panels of this figure. We can see from the χ^2 statistics that this model provides acceptable fits to all data sets except the spectrum of 600242p-1.

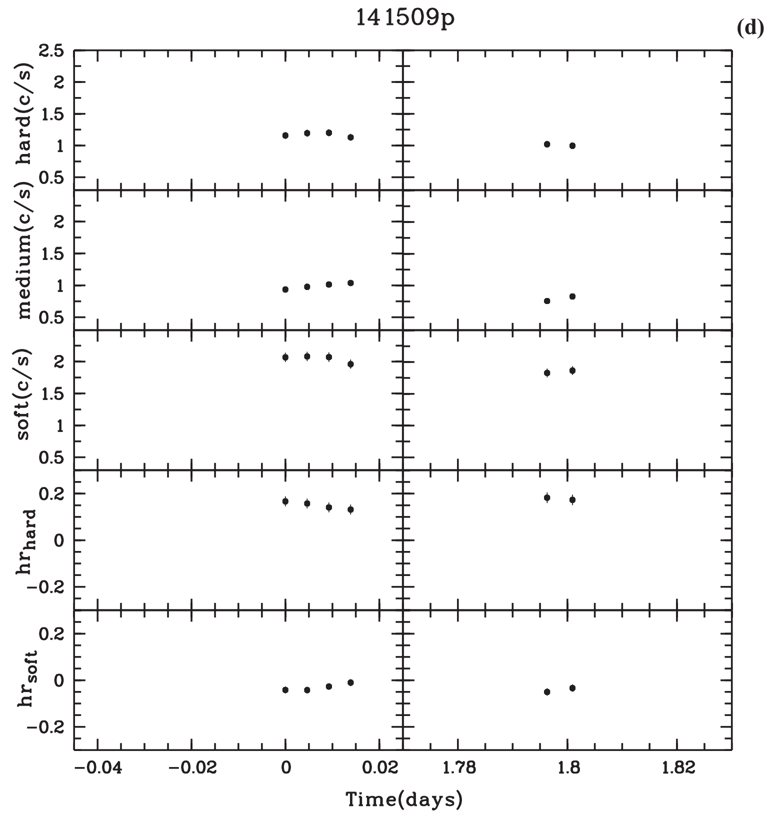

Figure 1(d). (*continued*)

The column density values of the hydrogen (N_H) along the line of sight to 3C273 are smaller than the Galactic value of $1.79 \times 10_{20}$ H-atom/cm^2 (Dicky & Lockman 1990). This lower N_H, i.e., "Negative N_H", implies a "soft excess" due to ionization. Residuals of this figure clearly show the existence of the "soft excess" and the soft emissions are variable. Because our main purpose is the investigation of the long-term variation, we did not try to apply other models for a better fit except a few models such as power law + fixed absorption, black body, exponential, thermal bremsstrahlung,

Table 3. Spectral fits to the spectra of 3C273: Power-law + absorption model.

Source name	γ^a	N^b	N_H^c	χ^2/d.o.f	L^d
P1	1.92 ± 0.04	1.85 ± 0.03	1.67 ± 0.10	1.16 ⁄198	1.03
P2	2.18 ± 0.05	2.81 ± 0.06	1.62 ± 0.12	1.62 ⁄174	2.00
P3	2.18 ± 0.05	1.57 ± 0.02	1.67 ± 0.05	4.40 ⁄206	1.23
P4	2.05 ± 0.04	2.86 ± 0.04	1.46 ± 0.09	1.15 ⁄190	1.78

[a]Photon index.
[b]Normalization at 1 ke V.
[c]Column density (N_H) 10^{20} H-atom/cm^2.
[d]Luminosity[10^{46} erg/s].

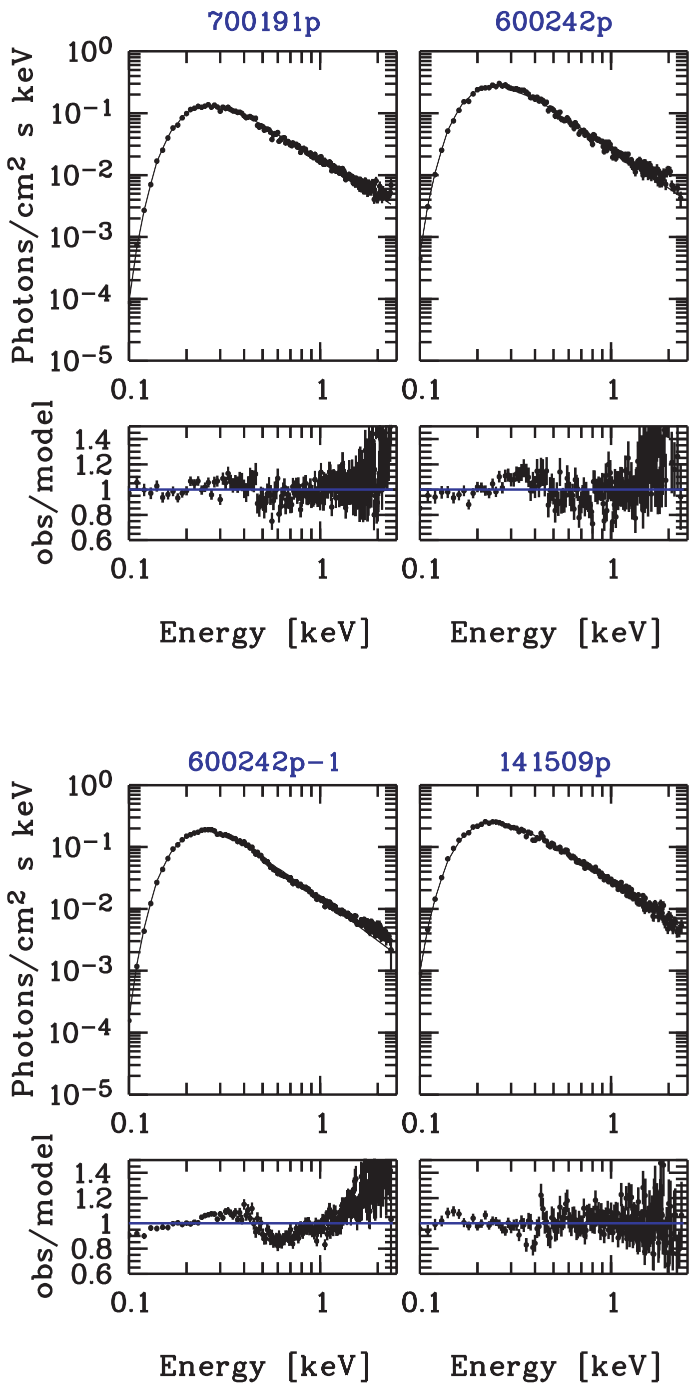

Figure 2. Observed spectra of 3C371 along with the best-fit model (power law + absorption). Residuals between the spectrum and the model are shown in the lower panels.

and power law + exponential. From the χ^2 statistics for these models, it was found that the simple power-law + absorption model gives the best fit.

The photon index varies from $\Gamma = 1.92$–2.18 which is not much different from 2.1 by Leach, *et al*. (1995). However this value is different from $\Gamma = 1.4$–1.55 from the EXOSAT ME and Ginga spectra for 2–10 keV band (Turner *et al*. 1990), and also $\Gamma = 1.3$ from the Einstein spectra for 0.2–3.5 keV band (Wilkes & Elvis 1987). This difference can be understood by the fact that the spectral slope of AGNs is flatter as the band is towards hard X-ray.

Using the relation of Schmidt & Green (1986), assuming $H_0 = 50$ km/s/Mpc and $q_0 = 0.5$, the luminosity of 3C273 was determined. The result is given in Table 3 and again light variation is evident.

4. Discussion and conclusions

In order to search for short- and/or long-term variations and spectral properties of 3C273, we have examined the soft X-ray emissions using hardness ratios and spectral analysis of four ROSAT data sets. It was found that light variation for all three different bands during 551 days was in the order of two, but short-term or micro variation was not confirmed. Interestingly light increment alternates with light decrement and the amount of variation is almost the same. It would be difficult to say that this is a periodic phenomenon occurring about every six months because the total number of data sets is only four. However this is different from the gradual decrease in X-ray brightness over about three years detected in Mrk 926 by Kim & Boller (2002).

The long-term variation is difficult to explain. One possibility is a change in the accretion rate which is expected to occur on a time scale of the radial infall of matter onto the central masssive black hole. The infall time scale of the order of months to years can be estimated (see Kim & Boller 2002). If the alternate variation in 3C273 is periodic, the plausible explanation can, therefore, be a periodic accretion rate variation. In order to confirm this as well as the periodicity of 3C273, observation of this object for a longer time for multi-wavelength bands is absolutely required.

On the other hand the variation of the soft hardness ratio is evident from 0.08 to -0.19, but this variation does not show any correlation with that of brightness. However soft hardness varies from 0.08, -0.15, -0.19, to -0.05 for four sources in Table 2, but the photon index varies from 1.92, 2.18, 2.18, to 2.05 in Table 3, i.e., variation of soft hardness ratio is the reverse of that of the photon index. Similar variation pattern can be seen for hard hardness ratio, but the amount of variation is much smaller. However the meaning of this is not so evident.

Because photon index is an indicator of a soft excess, a variation of soft hardness ratio reflects a physical and/or morphological variation in the original source of a soft excess. If the soft excess is due to the most promising mechanism of the thermal radiation from the accretion disk surrounding a super massive blackhole (see Arnaud *et al*. 1985; Ross, Fabian & Mineshige 1992), variation of the soft hardness ratio can be understood as a variation of thermal radiation output caused by a variation of the amount of gas infalling on the accretion disk. However because the soft hardness ratio does not correlate with the variation of brightness, the variation of infalling gas on the accretion disk is too small to have an effect on the change of brightness.

Acknowledgements

CK thanks Prof. J. Trümper for the kind hospitality at the Max-Planck-Institut für Extraterrestrische Physik and Dr. Thomas Boller for his assistance and close collaboration. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Arnaud, K. *et al*. 1985, *MNRAS*, **217**, 105.
Bowyer, C. S., Lampton, M., Mack, J., de Mendonca, F. 1970, *Ap. J.*, **161**, L1.
Courvoisier, T. J. -L, *et al*. 1987, *A& A*, **176**, 197.
Dicky, J. M., Lockman F. J., 1990, *Ann. Rev. Astron.*, **28**, 215.
Fan, J. H., Romero, G. E., and Lin, R. G., 2001, *Acta Astronomical Sinica*, **42**, 9.
Hasinger, G., Turner, T. J., George, I. M., Boese, G. 1992, Legacy 2 (OGIP Calibration Memo CAL/ROS/92-001), 77
Leach, C. M., McHardy, I. M., Papadakis, I. E. 1995, *MNRAS*, **272**, 221L.
Kim, Chulhee, Boller, Th. 2002, *Ap & SS* (accepted)
Masnou, J. L., Wilkes, B. J., Elvis, M., McDowell, J. C., Arnaud, K. A. 1992. *A& A*, **253**, 35.
Nandra, K., Pounds, K. A. 1994, *MNRAS*, **268**, 405.
Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J., Yaqoob, T., 1997, *ApJ*, **477**, 602.
Pfeffermann, E., *et al*. 1987, *Proc. SPIE*, **733**, 519.
Page, M. J., Carrera, F. J., Mittaz, J. P. D., Mason K. O. 1999, *MNRAS*, **305**, 775.
Ross, R. R., Fabian, A. C., Minesshige, S. 1992, *MNRAS*, **258**, 189.
Schmidt, M, Green, R. F. (1986) *Ap. J*, **269**, 352.
Staubert, R. 1992, in *MPE report no. 235*, W. Brinkmann & J. Trümper (eds)
Turner, T. J., George, I. M., Mushotzky, R. F. 1993, *Ap. J*, **412**, 72.
Turner, M. J. L, Williams, O. R., Courvoisier, T. J. -L. *et al*. 1990, *MNRAS*, **244**, 310.
Trümper, J. 1983, *Adv. Space Res.* **2**, 241.
Wilkes, B. J., Elvis, M., 1987, *Ap. J*, **323**, 243.
Zimmermann, H. U. *et al*. 1994, *EXSAS Users' Guide, MPE Report*.