

## LONG-TERM SOFT X-RAY VARIABILITY OF ACTIVE GALAXY MRK 841

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### ABSTRACT

We present an analysis of the soft X-ray emission of MRK 841 to investigate its long-term variation. The light variation of MRK 841 for three different energy bands of soft, medium, and hard values were studied. The maximum variability with a factor of 5 for about two years was confirmed at all three different bands. The light curves exhibit a gradual variation of brightness. In addition to a gradual variation, the short-term or micro variation was also confirmed with a factor of about two for all three different bands. The light variation of each band did not exhibit a correlation between them, but the flare event is strongest in the soft band. The hardness ratio for hard and soft bands shows irregular variation but there was no correlation between them. It was confirmed that there is a gradual decrease of the photon index. Results of our analysis are discussed within the framework of the accretion disk phenomenon.

*Key words :* galaxies: individual (Mrk 841)–galaxies: Seyfert–X-ray: galaxies

### I. INTRODUCTION

It is possible to investigate the region within a few light minutes to a few light days from the center of AGN with X-ray. In particular, light curve and spectral analysis of X-ray emission enable us to study accretion phenomena nearby super-massive black holes. Most of the investigations for X-ray variation have been concentrated on the study of relatively short-time scale using the data observed by an individual or a group.

However, detailed study for a time scale exceeding several months or one year with the combined data observed by different observers or different groups are rare. Leighly (1999a, 1999b) presented an analysis of 25 ASCA observations for 23 NLS1 (Narrow-Line Seyfert 1) galaxies and found that the variance is inversely correlated to the luminosity and is larger for NLS1 than for Seyfert 1 galaxies. Recently Grupe et al. (2001) presented the ROSAT All-Sky Survey (RASS, Voges et al. 1999) and the ROSAT Pointed Observations (PSPC and HRI) of a complete sample of 113 bright soft X-ray AGN in order to search X-ray transient AGN extreme cases of flux and spectral X-ray variability. They found amplitude variations typically by factors of 2-3 on time scales of years including three transients and one transient candidate.

However, parallel to the comprehensive study for many AGN at one time, the search of an individual galaxy with all data sets can play an important role in understanding the detailed process of variation, i.e. variation of X-ray properties for a long time scale. The periodic variation can be detected by searching all data sets. Hence we developed a project to study X-ray variability of active galaxies individually using the ROSAT

archive data. In fact, each active galaxy has its own characteristics different from others. As a first step we investigated 3C273 (Kim, 2001) and Mrk 926 (Kim & Boller, 2002), and we found signs of a periodic variation with the period of roughly one year for 3C273. For Mrk 926, a gradual decrease of brightness for a time scale of 36 months with the exception of single flare event superimposed on the gradual variation of brightness was confirmed. As a next target, we select Mrk 841 because Mrk 841 is one of four sources with the highest count rate ratio between the pointed and RASS observations by Grupe et al. (2001).

Mrk 841 (PG 1501+106, J2000 RA = 15<sup>h</sup>04<sup>m</sup>00.<sup>s</sup>, DEC = +10°26′24.0″; z=0.036) is a radio-quiet Seyfert 1 galaxy and one of representative UV excess galaxy. Arnaud et al. (1985) reported that Mrk 841 shows most distinct soft X-ray excess through the analysis of the EXOSAT data. On the other hand the existence of soft excess and exceptionally strong Fe K $\alpha$  were confirmed by George et al. (1993) which means that the reflection component is larger than that can be expected from the accretion disk. In addition it was reported that the variation of the power-law spectral index ( $\Gamma$ ) reached  $\approx$  0.6. It was also argued that the reflection model could be supported by these because these were interpreted as the result of the variation of relative contribution of continuum spectral component by the reflection.

Pound et al. (1994) obtained the similar results by George et al. (1993) and reported that results were more satisfying when the soft component was added on the reflection model. Nandra, et al. (1995) analyzed an extended ROSAT observation and reported the source is clearly variable on short time-scales with distinctive

changes in the hardness ratio. It was also confirmed that the data show that the continuum is particularly steep in the soft band. From the investigation with the ASCA data for 18 Seyfert 1 galaxies, Nandra et al. (1997) found a brightness variation whose time scale of variation reached a few minutes to a few hours for Mrk 841.

Piro, et al. (1997) tested the soft excess with black-body model, warm absorber model and reflection model but they argued all are not proper models. Hence the cause of soft excess for Mrk 841 has been uncertain.

Misaki, et al. (2001) examined a time behavior of the iron line in accordance with a spectral variability of Mrk 841 observed with ASCA. Recently Longinotti et al. (2004) have reported the variability of the iron K line in Mrk 841, and suggested that this could be possible by a flare inducing a hotspot in the inner disc. BeppoSAX observations of Mrk 841 were discussed by Bianchi, et al. (2001) and the soft excess was confirmed. Recently Petrucci (2007) observed Mrk 841 with XMM-Newton and confirmed the presence of a soft excess. In addition, it was also confirmed that the 0.5-3 keV soft X-ray flux decreased by a factor 3 between 2001 and 2005.

## II. OBSERVATION

Mrk 841 was observed with the ROSAT-PSPC on ten epochs between January 21, 1992 and February 10, 1993. Only PSPC data were downloaded from the archive because spectral analysis is not possible with the HRI data. In addition the RASS data (1RXS J150401.5+102620) observed in January 24, 1991 was included. For all cases Mrk 841 was at the center of the PSPC field of view, hence off-axis correction was not necessary. For all X-ray reduction and analysis tasks including the imaging analysis, background subtraction and various detector corrections like vignetting and dead time corrections the MIDAS-EXSAS software package of the MPE Garching (5th edition, Zimmermann et al. 1998) was used. All data was binned with 1000 seconds to investigate possible short-time variations.

## III. ANALYSIS AND RESULTS

To extract the light curves, the source region was enclosed in a circular region of 1.8 arc minutes radius. The background was computed in an annulus between 2.2 and 3.8 arc minutes radii centered on the source cell. Table 1 lists the source name, source number, observation date, exposure time and count rate from the archive data. The source name of 'R' in the first line is the RASS data and all others are the PSPC data. It is evident that the mean count rate was increased from 0.81 to 4.61 counts/s on the time scale of about 25 months by a factor of almost six. Figure 1 shows the light curve, and gradual increase of brightness for a time scale of about two years can be immediately

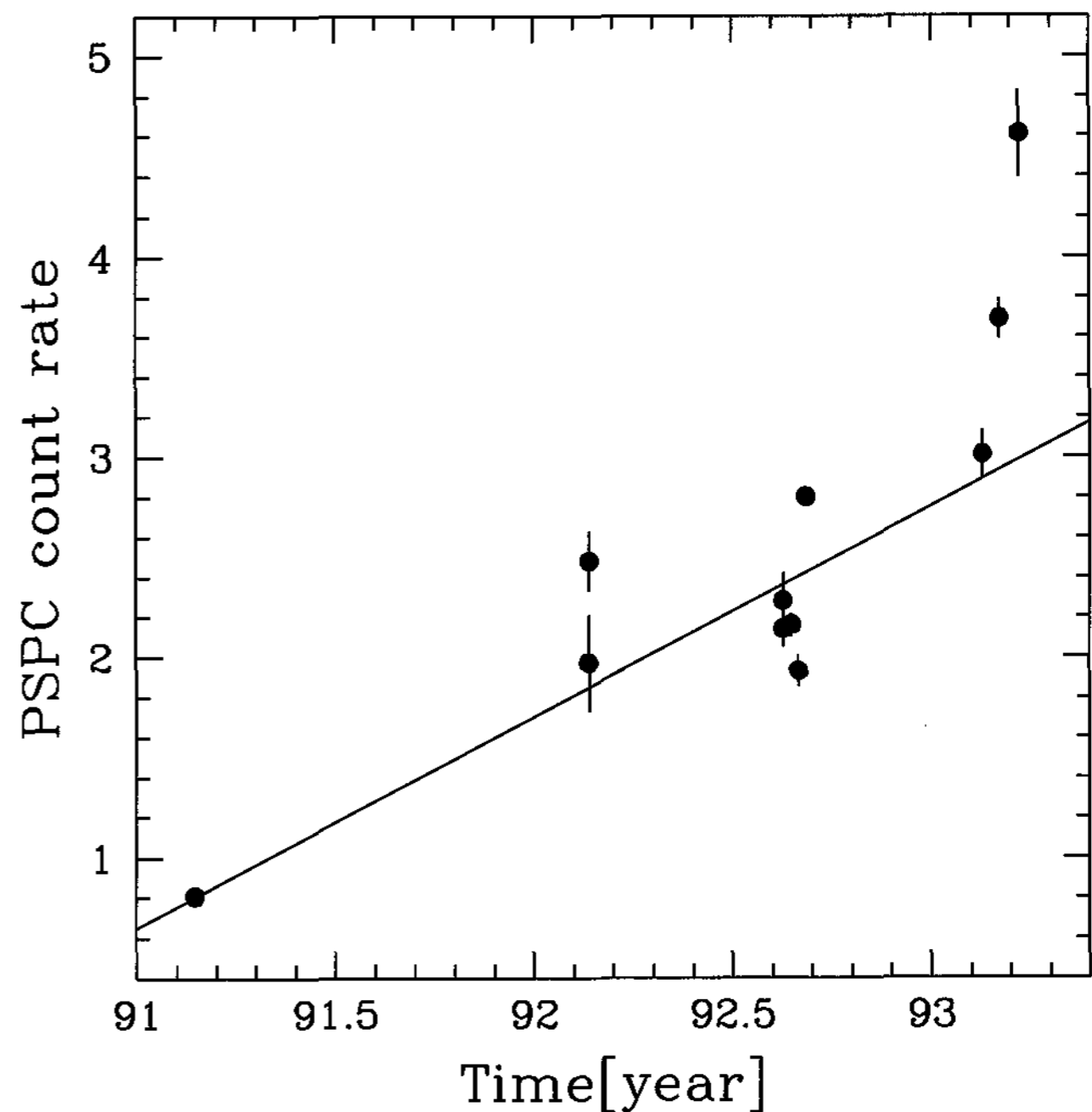


Fig. 1.— The X-ray light curves of Mrk 841.

confirmed.

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.

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

$$hr_{hard} = \frac{(band_4 - band_3)}{(band_4 + band_3)} \quad (2)$$

The fourth and fifth columns in Table 2 list the  $hr_{soft}$  and  $hr_{hard}$  and the fourth and fifth panels in Figure 2 show the hardness ratio versus time. We can see that there is no distinct variation for  $hr_{soft}$ , but a sign of slow decrement of brightness for  $hr_{hard}$  can be seen in a time scale greater than two years. The result of a weighted least-square fitting is presented in Figure 2, and the constant and the slope of a solid line are 5.36(1.63) and -0.057(0.017). The value in the parenthesis represents a 1- $\sigma$  error for a single interested parameter.

TABLE 1.  
LOG OF ROSAT-PSPC OBSERVATIONS

SOURCE NAME	SOURCE NUMBER	START TIME [UT]	END TIME [UT]	EXPOSURE (SEC)	COUNT RATE (CTS/s)
R	1RXS	91/01/24/10:19:12	91/01/25/16:04:48	311	$0.81 \pm 0.05$
P1	700102P	92/01/21/05:38:51	92/01/21/15:38:59	2886	$2.48 \pm 0.15$
P2	700257P	92/01/20/04:02:51	92/01/26/03:12:05	16842	$1.97 \pm 0.24$
P3	700898P	92/07/16/03:59:51	92/07/16/06:09:55	2789	$2.28 \pm 0.14$
P4	700899P	92/07/16/07:14:07	92/07/16/09:24:59	3138	$2.14 \pm 0.09$
P5	700900P	92/07/24/08:03:17	92/07/24/10:19:27	3385	$2.16 \pm 0.06$
P6	700901P	92/07/30/14:00:54	92/07/30/16:17:21	3638	$1.93 \pm 0.08$
P7	700902P	92/08/07/00:34:15	92/08/07/01:27:05	2086	$2.80 \pm 0.05$
P8	700903P	93/01/17/00:34:10	93/01/17/01:17:11	2522	$3.01 \pm 0.12$
P9	700905P	93/02/02/07:19:19	93/02/02/09:22:28	2644	$3.69 \pm 0.10$
P10	700906P	93/02/10/04:56:33	93/02/10/06:53:45	2322	$4.61 \pm 0.22$

How could  $hr_{soft}$  show almost no variation during the fast increment of softer energy? This is somewhat difficult to understand because we expect the increment of  $hr_{soft}$  to be accompanied by the increment of softer energy. Decrement of  $hr_{hard}$  can be easily explained as relatively softer energy was increased during the flare event.

Light curve also shows the existence of two short-term variations for (P1, P2) and (P8–P10) respectively. In case of (P1–P2), on the time scale of about 4.75 days, the count rate was increased by a factor of almost two from 1.55 to 2.61 count/s. It seems that this short-term variance were superimposed on a gradual increase on a time scale of about two years. However, the variance of count rate was abruptly increased from 2.89 to 4.40 counts/s after 33 days,  $4.60 \times 10^{-2}$  count/s/day for (P8–P10) during 1993.

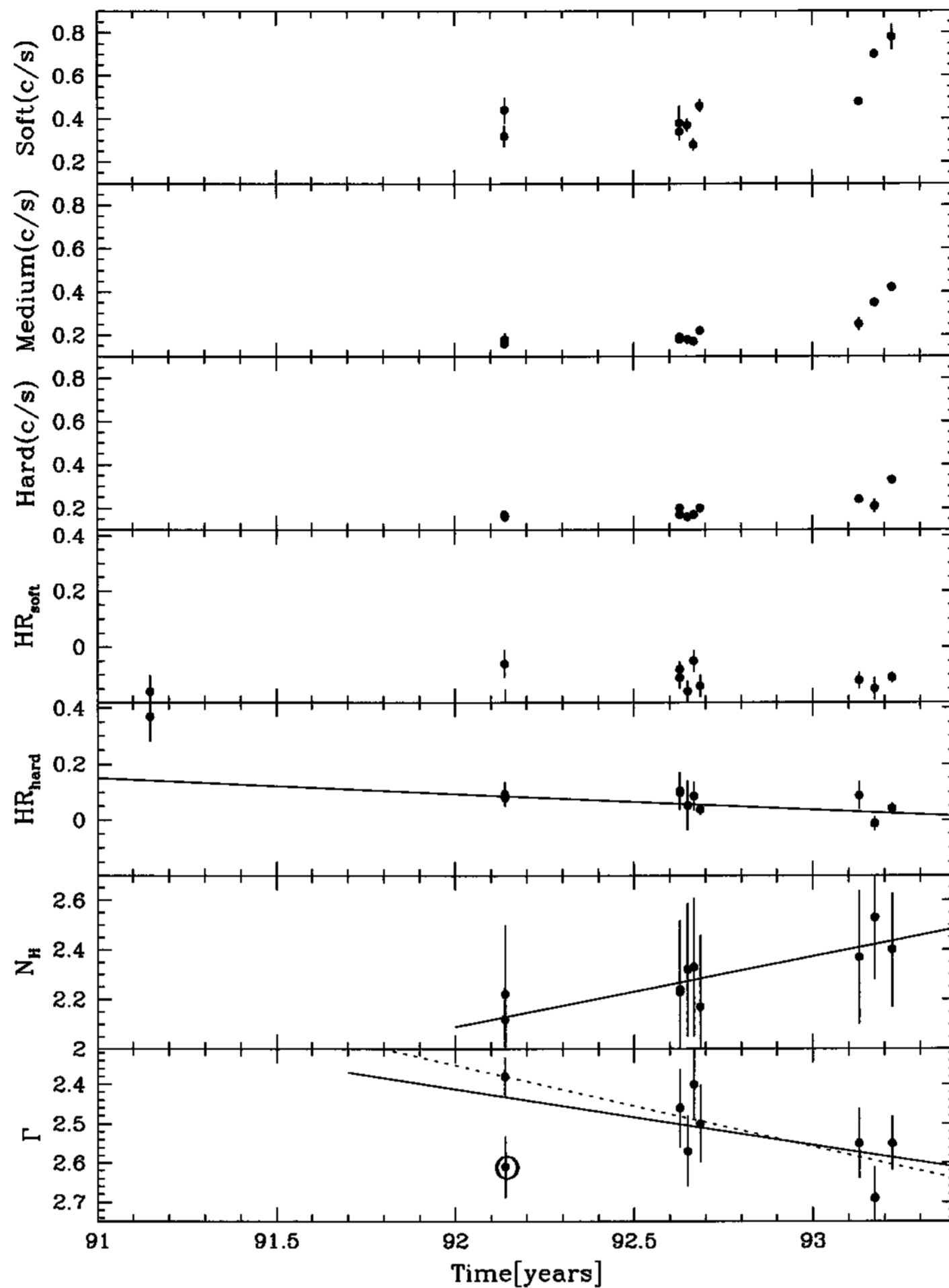
This pattern looks similar to the case of Mrk 926 (Kim & Boller 2002) where the light curve shows a gradual decrease of brightness for a time scales of 36 months with the exception of a single flare event superimposed on the gradual variation of brightness. Increasing rate of a gradual variation for Mrk 841 is about  $3.4 \times 10^{-3}$  count/s/day estimated with the line on Figure 1 which was drawn by a weighted least-square fitting with the  $const = -94.9$  (3.5), the  $slope = 1.0$  (0.04). The gradual decrease in the rate of Mrk 926 is about  $8.6 \times 10^{-4}$  count/s/day, and the increase in the rate of Mrk 841 is about four times faster than the decrease in the rate of Mrk 926.

In the case of Mrk 841, it is not clear whether the short-term variation for (P8–P10) is a similar flare event as in Mrk 926 because there was no further PSPC observation. However, a hint can be obtained from the HRI data observed from August 1 to 8 in 1995 with the exposure time of 2699 seconds. HRI count rates can be converted into the effective PSPC count rates using the W3PINMS program of NASA's Goddard Space Flight Center (version 2.7, 1999). Converted value is

3.30 count/sec by Grupe et al. (2001) which is much less than 4.87 count/sec, highest brightness in P10. If this is correct, then there is a strong possibility that the abrupt variation for (P8–P10) is a flare event as in Mrk 926.

Because the typical X-ray spectra of AGN show a distinct structural pattern caused by the soft excess, absorption by cold material in the host galaxy, and  $K\alpha$  line etc, it is necessary to investigate the light variation for different energy bands of soft, medium, and hard energy regions. In particular, we are interested in the variation of brightness before and after as well as during the flare event and the gradual variation for different energy bands. Hence, we ascertained the mean count rates for the three energy bands in Table 2. The first three columns in Table 2 list the mean count rates for the three energy bands. The upper three panels in Figure 2 reveal the X-ray light curves for three different bands. These three bands correspond to channels 11–19, 52–69, and 132–201, respectively. Data were rebinned into 1000 seconds bins except 2000 seconds for P2. For two cases of (P1, P2) and (P3–P7), brightness variation is not so distinct for all three different bands. However, the brightness increment is highest for the soft band and lowest for the hard band in case of (P8–P10). Variation difference is also highest for the soft band which means that the possible flare event in Mrk 841 is caused by mainly increment of the soft band energy.

In addition, spectral variability was searched for the studies of correlations between the spectral and variability parameters. The X-ray spectra of AGN are complex (see Page et al. 1999; Nandra & Pounds 1994; Turner et al. 1993). The energy spectrum below  $\sim 10$  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) region. The power law component seems to be produced in the hot corona



**Fig. 2.**— The X-ray light curves in the three X-ray bands (top three panels), hardness ratios,  $N_H$  column density, and photon index of Mrk 841.

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 was rebinned to have a S/N ratio of 5. A simple 'power-law + absorption model' was fitted and the best-fit parameters of column density ( $N_H$ ) and photon index ( $\Gamma$ ) are presented in the last two columns of Table 2. The column density value of the hydrogen ( $N_H$ ) along the line of sight to Mrk 841 is  $2.2 \times 10^{20}$  H-atom/cm<sup>2</sup> (Dicky & Lockman 1990). For (P1,P2), the column density of Mrk 841 is comparable to that of galactic value which means that there is almost no absorption by Mrk 841 itself towards this galaxy. In the lower two panels of Figure 2, we show the column density and the photon index. Using the relation of Schmidt & Green (1986), assuming  $H_0=50$ km/s/Mpc and  $q_0=0.5$ , the luminos-

ity of Mrk 841 was determined. The result is given in the last column on Table 2 and again light variation is evident.

In Figure 2, it is evident that the photon index is increasing over time. A solid line and a dotted line are the results of a weighted least-square fitting with and without a data point marked with 'o'. For two cases, the constants and the slopes are  $[-10.65(5.51), 0.14(0.06)]$ , and  $[-16.55(5.97), 0.20(0.06)]$  respectively. The increment of photon index can be easily understood by the fact that the spectral slope of AGN is flatter as the band is towards hard X-ray, i.e. as the soft band energy increases the steepness increases. This phenomenon is caused by the increasing effect of the soft component, which is a source of blackbody radiation. On the other hand, if column density is increasing, absorption effect by neutral hydrogen is also increasing.

TABLE 2.  
MEAN COUNT RATE FOR SOFT, MEDIUM, HARD BAND, AND HARDNESS RATIO  
AS WELL AS THE  $N_H$  COLUMN DENSITY, PHOTON INDEX, AND LUMINOSITY.

Source	Soft	Medium	Hard	$hr_{soft}$	$hr_{hard}$	$N_H^a$	$\Gamma^b$	$L^d$	$\chi^2/d.o.f$
R <sup>c</sup>				-0.16 ± .06	0.37 ± .09				
P1	0.44 ± .06	0.18 ± .03	0.16 ± .02	-0.21 ± .06	0.079 ± .013	2.22 ± .28	2.61 ± .09	2.74	1.00/113
P2	0.32 ± .05	0.16 ± .02	0.17 ± .02	-0.06 ± .05	0.093 ± .045	2.12 ± .13	2.39 ± .05	1.62	0.88/181
P3	0.38 ± .08	0.19 ± .01	0.20 ± .01	-0.11 ± .04	0.104 ± .067	2.24 ± .28	2.47 ± .10	2.01	0.73/113
P4	0.34 ± .03	0.18 ± .01	0.17 ± .01	-0.08 ± .03	0.098 ± .062	2.23 ± .27	2.46 ± .09	1.86	1.02/121
P5	0.37 ± .03	0.18 ± .02	0.16 ± .01	-0.16 ± .04	0.051 ± .090	2.32 ± .27	2.57 ± .09	1.99	1.08/119
P6	0.28 ± .03	0.17 ± .02	0.17 ± .01	-0.05 ± .04	0.086 ± .051	2.33 ± .28	2.40 ± .09	1.71	0.89/126
P7	0.46 ± .03	0.22 ± .01	0.20 ± .02	-0.14 ± .04	0.038 ± .019	2.17 ± .29	2.50 ± .10	2.40	1.33/103
P8	0.48 ± .02	0.25 ± .03	0.24 ± .01	-0.12 ± .03	0.087 ± .050	2.37 ± .27	2.55 ± .09	2.79	0.95/122
P9	0.70 ± .02	0.35 ± .02	0.21 ± .03	-0.15 ± .04	-0.013 ± .025	2.53 ± .25	2.69 ± .08	3.81	1.60/130
P10	0.78 ± .06	0.42 ± .02	0.33 ± .01	-0.11 ± .02	0.041 ± .020	2.40 ± .23	2.56 ± .07	4.33	1.07/140

<sup>a</sup>Column density ( $N_H$ ) [ $10^{20}$  H-atom/ $cm^2$ ]

<sup>b</sup>Photon index

<sup>c</sup>RASS, 1RXS J150401.5+102620

<sup>d</sup>Luminosity [ $10^{44}$ ergs $^{-1}$ ]

<sup>d</sup>The energy range is defined in 0.1-2.4 Kev.

Although the error bars are larger in Figure 2, it seems there is an overall increasing tendency for  $N_H$ . The constant and slope of a weighted least-square fitting are -23.81(16.40), 0.28(0.17). Although error of the slope is large, there is a possibility that the inclination looks more or less real. Then how can we explain the increment of column density under significant flux rising? Naturally the gas column could be reduced if the photoionization rate could be increased by the stronger continuum from the rising flux. There is no way except a possibility that the increasing amount of accretion material. Thus, the gradual increase in brightness and the flare event cause by the gradual and abruptly increasing of gas on accretion disk. This gas can block out harder band photons or photons produced by power-law component. In addition, if the amount of infalling neutral H is over the amount of photoionized H, the increasing gas column following the increasing flux can be explained. Another instance occurs if the accretion rate is almost constant, which means that the activity of black-body component should be strengthened due to unknown black hole phenomena during the gradual increment of brightness and flare event.

#### IV. DISCUSSION AND CONCLUSION

X-ray variability can be explained by the changes in the absorption column or intrinsic causes such as changes in the accretion rate or relativistic beaming effects (e.g. Boller et al., 1997). The changes in the absorption column can be possible by the changes of accretion rate, which is expected to occur on a time scale of the radial infall of matter onto the central massive black hole. In this sense variability can be mainly due

to changes of accretion rate except relativistic beaming effects. If the distribution of  $N_H$  is not uniform which causes the changes in absorption column, relatively short-term variation can be easily explained.

However, long-term variation is difficult to explain. In the case of Mrk 841, the main source of the gradual increase with a flare event is the increase of soft-band energy. It has been widely accepted that the soft X-ray emission is explained by Compton scattering of thermal UV disk photons by a hot electron layer above the accretion disk. If the increase of luminosity is due to increasing of accretion rate, the infall time scale of the order of months to years can be estimated (see Kim & Boller, 2001). If we assume that gradual variation is crudely linear and if we exclude two data sets of P9 and P10 corresponding to a flare event, then the luminosity increment is approximately  $3 \times 10^{36}$  erg/s/s for about two years. This value can be compared with the  $2.4 \times 10^{36}$  erg/s/s for Mrk 926 (Paper I). Luminosity of two galaxies is not much different, but the gradual variance presents the opposite case of increment for Mrk 841 and decrement for Mrk 926. If the variability is due to the changes of accretion rate for a long time scale, it seems that the variation of accretion rate is same during gradual increase and decrease.

On the other hand the variation of the soft hardness ratio is not so evident for long-time scale in Mrk 841. Because the 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 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. Hence it is difficult to understand how brightness, especially that in the soft energy band can be increased without changing soft hardness ratio. Was infalling matter enough to increase brightness but not enough to change soft hardness ratio? Or was the soft excess not due to the thermal radiation from the accretion disk but rather due to a different mechanism such as absorption or reflection by the photo-ionized plasma? What is the most promising mechanism which can explain both increase of the brightness without changing the soft hardness ratio, regardless increase or decrease of brightness? In order to answer these questions it is necessary to investigate the light curve and spectral analysis for other different type of AGN.

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