Chin. J. Astron. Astrophys. Vol. 2 (2002), No. 3, 207–215
(*http://www.chjaa.org* or *http://chjaa.bao.ac.cn*)

Chinese Journal of
Astronomy and
Astrophysics

The Variability of Hardness Ratio 1 observed by ROSAT: Narrow-Line Seyfert 1 Galaxies versus Broad-Line Seyfert 1 Galaxies

Lin-Peng Cheng *, Jian-Yan Wei and Yong-Heng Zhao

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012

Received 2002 February 1; accepted 2002 April 15

Abstract We examined the correlation between the ROSAT Hardness Ratio 1 and Count Rates eight Narrow-line Seyfert 1 Galaxies (NLS1s) and 14 Broad-line Seyfert1 Galaxies (BLS1s). We found that six of the NLS1s show a positive HR1-CTs correlation, and seven of the BLS1s, a negative correlation. The other two NLS1s and seven BLS1s do not show any clear HR1-CTs correlation. Thus, the spectral behavior is statistically different for the NLS1s and BLS1s. The different behaviors can possibly be interpreted in terms of a stable 'soft excess' that is strong in NLS1s and weak in BLS1s, plus a power law component, common to both, which softens with increasing flux.

Key words: galaxies: Seyfert — galaxies: active — X-ray: galaxies

1 INTRODUCTION

Narrow-line Seyfert 1 galaxies (NLS1s), a peculiar group of AGNs, are characterized by their optical line properties: Hβ FWHM not larger than 2000 km s^{-1}, the [OIII]λ5007 Å to Hβ ratio less than 3, and UV-optical spectrum usually rich in high-ionization lines and Fe II emission multiplets (Osterbrock & Pogge 1985). From the ROSAT All-Sky Survey it was found that about half of the AGNs in soft X-ray selected samples are NLS1s (Grupe 1996); in addition, Boller et al. (1996) revealed that the soft X-ray spectra of the NLS1s are systematically steeper than those of Broad-line Seyfert 1 galaxies (BLS1s) and that an anti-correlation exists between the X-ray photon index and the FWHM of the Hβ line (Puchnarewicz et al. 1992; Laor et al. 1994; Wang et al. 1996), which provides strong evidence for a physical link of continuum emission and the dynamics of the broad line region. Moreover, it was discovered that NLS1s often show stronger X-ray variations than BLS1s (Boller et al. 1996; Leighly 1999a; Papadakis et al. 2001). Some ROSAT (0.1–2 keV) observations revealed dramatic variability with giant flares, with flux increases by a factor of 3–5, within about a day (Boller 1999 for recent review). Best individual examples are IRAS 13224–3809, the flux of which varies some 57 times in just 2d (Boller et al. 1997), PHL 1092 (Brandt et al. 1999) and PKS 0558–504 (Gliozzi et al. 2001;

---

* E-mail: clp@lamost.bao.ac.cn

Wang et al. 2001). In general, these features are interpreted as evidence for smaller black hole masses and higher accretion ratios relative to the Eddington accretion rate in the NLS1s.

Besides rapid and strong X-ray flux variability, NLS1s also display spectral variability. Spectral hardening during flux increases was noted in three ROSAT observations of MARK 766 by Leighly (1996). Page et al. (1999) further pointed out that the power law component of MARK 766 varied violently while the soft excess showed no detectable variability, and that the power law component became softer with increasing flux. A similar spectral variability of RX J0134.2–4258 was also reported by Grupe et al. (2000). Can the properties of MARK 766 be typical of NLS1s? To address the question about the variability of the soft excess and power law component, more NLS1s must be studied.

In this paper we report on the results of correlation analysis between Hardness Ratio 1 and Count Rates (HR1-CTs) for eight NLS1s and 14 BLS1s. The 22 objects were all observed with ROSAT/PSPC in pointing mode. In Sec. 2 we describe the observations and data reduction. The results are shown in Sec. 3. Section 4 contains our discussion and lastly we outline our conclusions in Sec. 5.

2 THE OBSERVATIONS AND DATA REDUCTION

The data used in this paper are from ROSAT pointed observations of individual objects carried out during periods varying from days to years, using the X-ray telescope (XRT) on board the ROSAT observatory with PSPC on the focal plane (Trümper 1983). We picked out the AGNs from cross identification of the Véron (1991) AGN catalogue with the ROSAT pointed catalog. Using the ROSAT public archive of pointed observations, only sources with total X-ray photon counts greater than 1000 were selected to ensure the quality of the X-ray spectra. This yielded 214 AGNs. The data were processed for instrument corrections (such as vignetting and dead time effects) and background subtraction using the EXSAS/MIDAS software.

The light curve for each AGN was obtained from the original ROSAT observations with time binning of 400 seconds in three energy bands: 0.1–2.4 (total band), 0.1–0.4 (A band), 0.5–2.0 (B band) keV. Then, we picked out 22 Seyfert 1 galaxies or quasars from the set of 214 objects according to the following criteria: 1) For each source the ratio of maximal CTs to minimal CTs is greater than 2, which assures the range of CTs variability is large enough; 2) The data points are not too scarce (> 5) and are distributed in one diagram consecutively; 3) The HR1 error is small ($< 40\%$). These 22 sources are different type AGNs, eight are NLS1s, 14 are BLS1s/QSOs.

3 THE RESULTS OF HR1-CTs CORRELATIONS

All the X-ray count rates in the 0.1–2.4 keV band were taken from original ROSAT observations with time binning of 400 s. In addition, four energy bands are shown: A: 0.1–0.4 keV, B: 0.5–2.0 keV, C: 0.5–0.9 keV, D: 0.9–2.0 keV. The standard hardness ratios, HR1 and HR2, for ROSAT-PSPC data are defined as

$$HR1 = \frac{B - A}{B + A}, \qquad HR2 = \frac{C - D}{C + D}. \tag{1}$$

Of the four ROSAT bands, the "A" band is the most sensitive to the variability of the soft excess, and this will show up in a correlation between the HR1 and the count rates. To distinguish different trends in the individual objects we fit the data of each to a linear formula (HR1 =

a + b × CTs): if the slope b is a positive or negative value and its relative error is less than 50%, then we regard the object to show a positive or negative correlation; otherwise, random or no clear correlation. The results of the correlation analysis for the eight NLS1s and 14 BLS1s/QSOs are listed in Table 1 and plotted in Figs. 1–3. The results can be summarized as follows:

1. For the eight NLS1s in the sample, six of them, MCG–6-30-15, MARK 335, PG 1404+226, MARK 766, WAS 61 and NGC 4051, show a positive HR1-CTs correlation. Two of them, PG 1211+143 and TON S180 do not show any clear variation.

2. Seven of the 14 BLS1s, NGC 7469, MARK 841, NGC 5548, NGC 3031, GQ COM, 3C 273.0 and IV ZW 29, show a negative HR1-CTs correlation. The other seven objects show random variation.

Thus, the NLS1s, as a group, statistically show the trend of the spectrum becoming harder with increasing counts. And those BLS1s with a clear trend at all, present the opposite trend: their soft X-ray spectra become softer with increasing flux.

Table 1 Spectral variations of selected NLS1s and BLS1s

ROSAT Name (1RXPJ)	Other Name	RA (2000)	DEC (2000)	z	Type	HR1-CTs correlation
133554−3417.2	MCG–6-30-15	13 35 53.3	–34 17 48	0.008	S1n	Positive
000619+2012.4	MARK 335	00 06 19.4	20 12 11	0.025	S1n	Positive
140621+2223.7	PG 1404+226	14 06 22.1	22 23 42	0.098	S1n	Positive
121827+2948.8	MARK 766	12 18 26.6	29 48 46	0.012	S1n	Positive
124212+3317.0	WAS 61	12 42 11.3	33 17 06	0.045	S1n	Positive
120310+4431.9	NGC 4051	12 03 09.5	44 31 52	0.002	S1n	Positive
005719−2222.7	TON S180	00 57 19.0	–22 22 47	0.062	S1n	None
121417+1403.3	PG 1211+143	12 14 17.5	14 03 12	0.085	S1n	None
230316+0852.2	NGC 7469	23 03 15.5	08 52 26	0.017	Sy1.5	Negative
150401+1026.3	MARK 841	15 04 01.1	10 26 16	0.036	Sy1.5	Negative
141759+2508.2	NGC 5548	14 17 59.5	25 08 12	0.017	Sy1.5	Negative
095532+6903.9	NGC 3031	09 55 33.1	69 03 54	0.000	Sy1.5/S3b	Negative
120441+2754.0	GQ COM	12 04 42.0	27 54 11	0.165	Sy1.2	Negative
122906+0203.2	3C 273.0	12 29 06.6	02 03 08	0.158	Sy1.0	Negative
004215+4019.7	IV ZW 29	00 42 16.0	40 19 36	0.102	Sy1.0	Negative
122144+7518.6	MARK 205	12 21 44.3	75 18 39	0.070	Sy1.0	None
161357+6543.0	MARK 876	16 13 57.0	65 43 08	0.129	Sy1.0	None
132158−3104.2	K08.02	13 21 58.1	–31 04 10	0.045	Sy1.5	None
194240−1019.4	NGC 6814	19 42 40.5	–10 19 24	0.005	Sy1.5	None
121710+0711.5	NGC 4235	12 17 09.8	07 11 29	0.007	Sy1.2	None
092248+5120.8	Q 0919+515	09 22 46.9	51 20 39	0.161	Sy1.0	None
121920+0638.6	PG 1216+069	12 19 20.2	06 38 39	0.334	Q	None

Positive: the HR1-CTS relation is positive; Negative: the HR1-CTS relation is negative; None: the HR1-CTS relation is random; S1n: Narrow-line Seyfert galaxy; Sy1.0 (1.2, 1.5, 2.0): Seyfert 1.0 (1.2, 1.5, 2.0); Q: Quasar; S3b: Seyfert 3 or liner with broad Balmer lines.

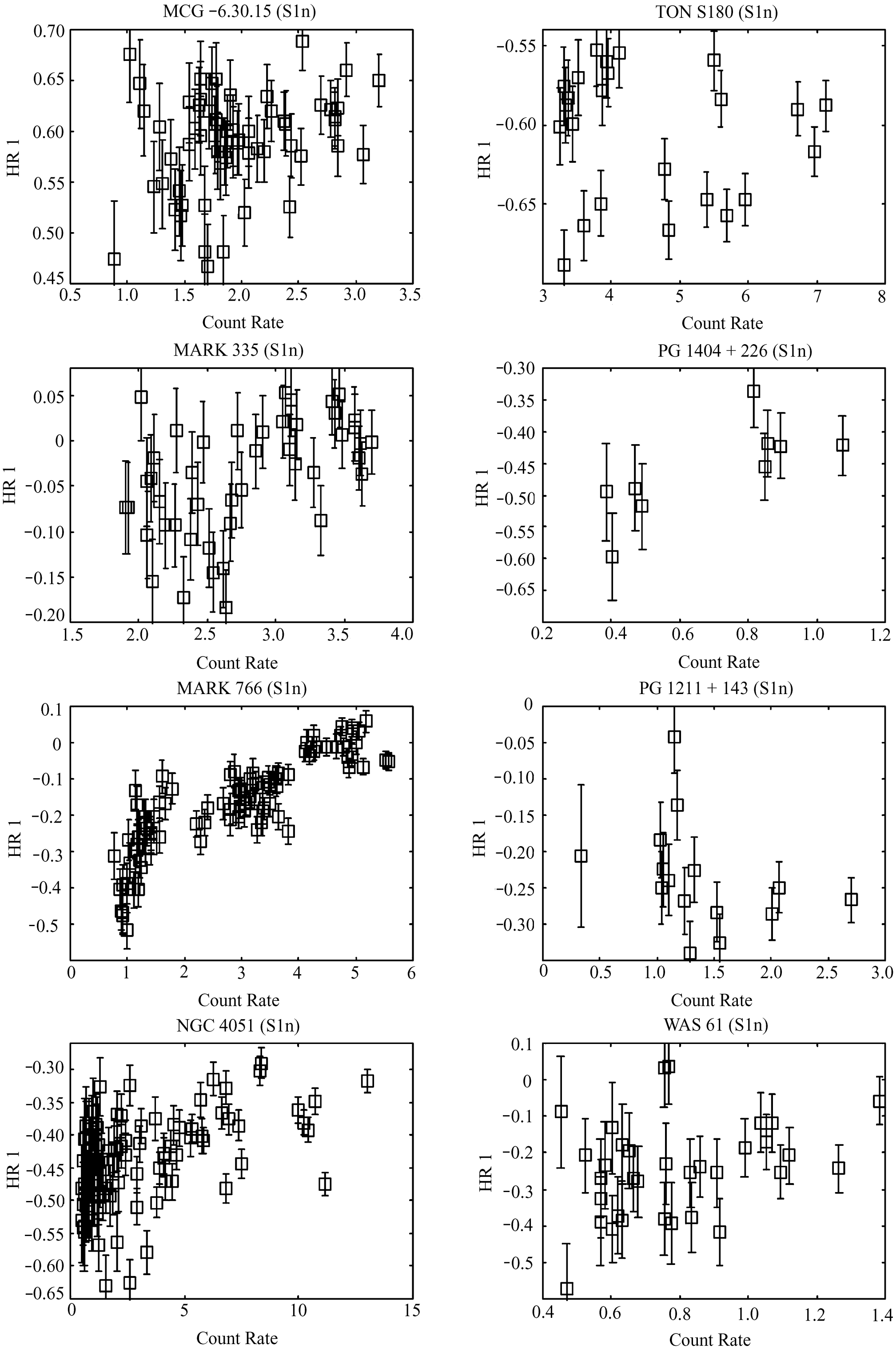
MCG −6.30.15 (S1n)
HR 1
0.70
0.65
0.60
0.55
0.50
0.45
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Count Rate
TON S180 (S1n)
−0.55
−0.60
−0.65
3
4
5
6
7
8
MARK 335 (S1n)
0.05
0
−0.05
−0.10
−0.15
−0.20
4.0
PG 1404 + 226 (S1n)
−0.30
−0.35
−0.40
−0.45
−0.50
−0.55
−0.60
−0.65
0.2
0.4
0.6
0.8
1.0
1.2
MARK 766 (S1n)
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
6
PG 1211 + 143 (S1n)
0
−0.05
−0.10
−0.15
−0.20
−0.25
−0.30
0
0.5
1.0
1.5
2.0
2.5
3.0
NGC 4051 (S1n)
−0.30
−0.35
−0.40
−0.45
−0.50
−0.55
−0.60
−0.65
0
5
10
15
WAS 61 (S1n)
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0.4
0.6
0.8
1.0
1.2
1.4

Fig. 1

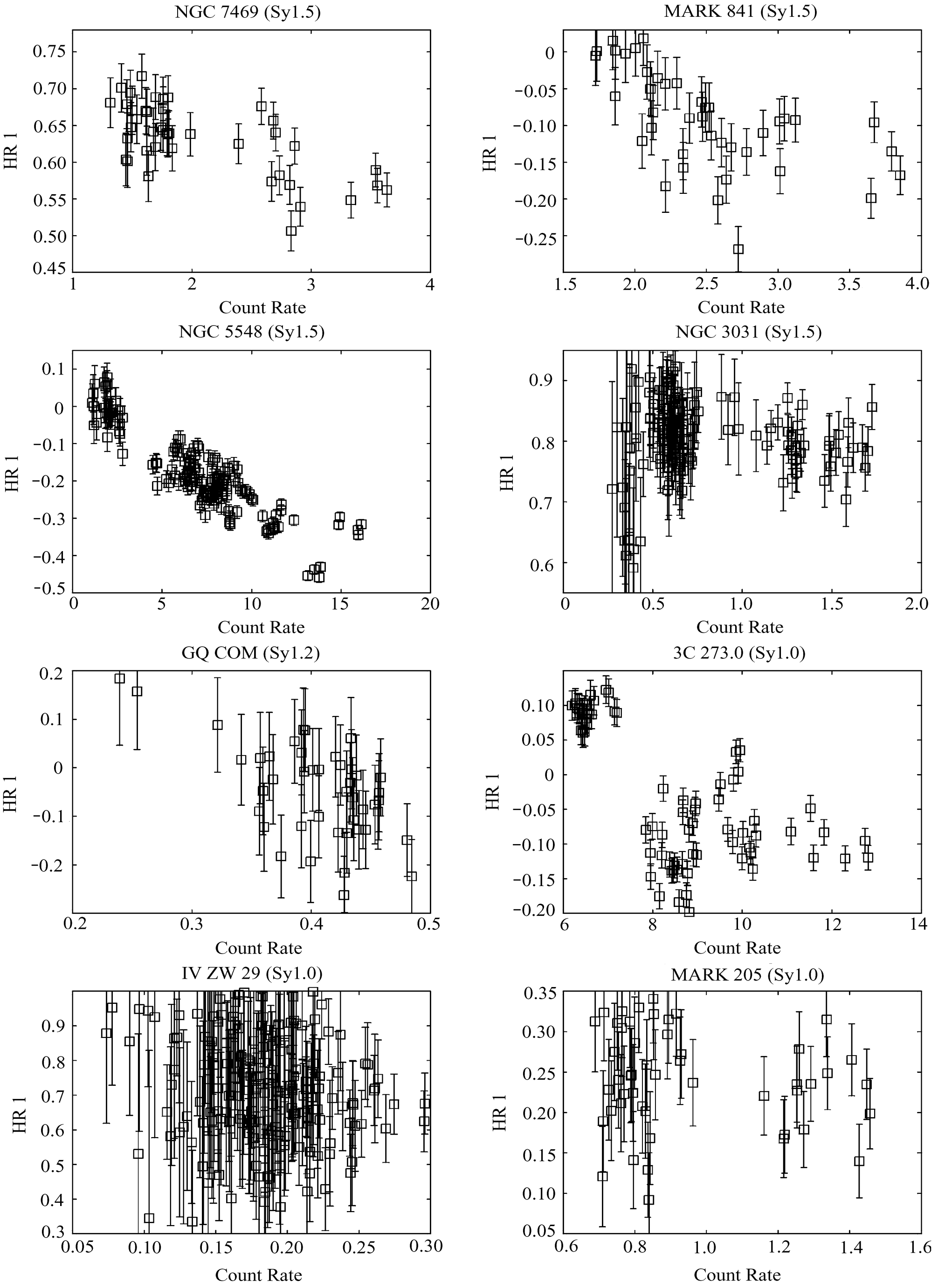
NGC 7469 (Sy1.5)
HR 1
0.75
0.70
0.65
0.60
0.55
0.50
0.45
1
2
3
4
Count Rate
MARK 841 (Sy1.5)
HR 1
0
−0.05
−0.10
−0.15
−0.20
−0.25
1.5
2.0
2.5
3.0
3.5
4.0
Count Rate
NGC 5548 (Sy1.5)
HR 1
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
5
10
15
20
Count Rate
NGC 3031 (Sy1.5)
HR 1
0.9
0.8
0.7
0.6
0
0.5
1.0
1.5
2.0
Count Rate
GQ COM (Sy1.2)
HR 1
0.2
0.1
0
-0.1
-0.2
0.2
0.3
0.4
0.5
Count Rate
3C 273.0 (Sy1.0)
HR 1
0.10
0.05
0
−0.05
−0.10
−0.15
−0.20
6
8
10
12
14
Count Rate
IV ZW 29 (Sy1.0)
HR 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.05
0.10
0.15
0.20
0.25
0.30
Count Rate
MARK 205 (Sy1.0)
HR 1
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.6
0.8
1.0
1.2
1.4
1.6
Count Rate

Fig. 2

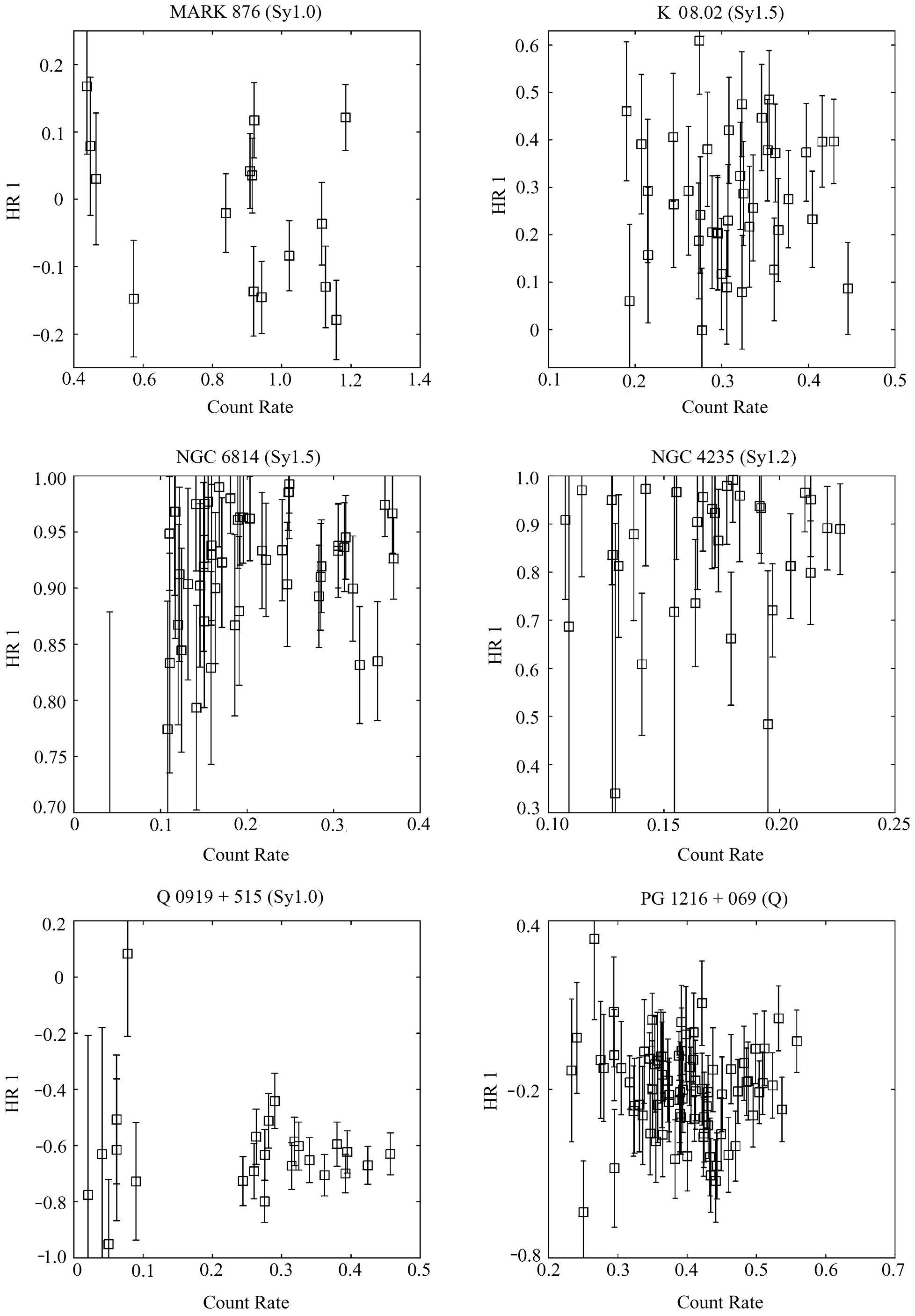
MARK 876 (Sy1.0)
HR 1
0.2
0.1
0
-0.1
-0.2
0.4
0.6
0.8
1.0
1.2
1.4
Count Rate
K 08.02 (Sy1.5)
HR 1
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
Count Rate
NGC 6814 (Sy1.5)
HR 1
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0
0.1
0.2
0.3
0.4
Count Rate
NGC 4235 (Sy1.2)
HR 1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.10
0.15
0.20
0.25
Count Rate
Q 0919 + 515 (Sy1.0)
HR 1
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
0
0.1
0.2
0.3
0.4
0.5
Count Rate
PG 1216 + 069 (Q)
HR 1
0.4
-0.2
-0.8
0.2
0.3
0.4
0.5
0.6
0.7
Count Rate

Fig. 3

In addition, we note that there exist some individual points in the HR1-CTs plot of several NLS1s including NGC 4051 and WAS 61, where a very high value of HR1 goes with a low count, contrary to the statement above. A sudden fading of the soft excess or a violent enhancement of the power law component might interpret this hardening in the low state, but a detailed analysis beyond the scope of this paper would be necessary.

4 DISCUSSION: POSSIBLE INTERPRETATION OF THE SPECTRAL VARIABILITY

In general, the spectra of AGNs in the soft X-ray band below 2.0 keV contain two main components: a non-thermal power law emission which extends to the hard X-ray band and a soft excess (typically $< 0.5\,\mathrm{keV}$). The soft excess may be a thermal emission at the high energy tail of the Big Blue Bump (BBB), which is considered to be the thermal emission from a hot accretion disk. The extreme soft excess of NLS1s compared to BLS1s gives the first impression that their violent variability may be from the soft excess. If the variability is mainly from the soft excess, then NLS1s at brighter states will show softer spectra. Furthermore, if the variability is mainly from the power law excess, then NLS1s at brighter states may show a harder spectrum, since the soft excess usually dominates the soft band under 0.5 keV. Thus, the spectral variability of the NLS1s can be used to check the origin of the variability.

As shown in Section 3, the NLS1s indicate a different spectral shape variability from the BLS1s in the sense that, for the NLS1s, the flux of the soft component (A energy band) changes less rapidly than the hard component (B energy band), while for the BLS1s, it is just the opposite. Although a detailed description of the variability of the two components requires the fitting of the spectra with a power law component, a soft excess component, and a neutral absorbing column, a possible explanation for the different behaviors can be made now and is presented below.

If the violent variability of NLS1s is mainly from the soft excess, the ROSAT A band (0.1–0.4 keV) will be expected to change more than the B band (0.5–2.0 keV), and hence a negative HR1-CTs correlation will be expected. The statistically positive HR1-CTs correlation of NLS1s shown above would therefore imply that the soft X-ray variability of NLS1s mainly comes from the power law component, and not from the soft excess. This is in agreement with the result from the detailed analyses of MARK 766 by Page et al. (1999) and of RX J0134.2–4258 by Grupe et al. (2000): these authors found that the power law component was more variable than the soft excess.

What is the spectral behavior of the power law component? Do NLS1s and BLS1s follow the same rule? The results on the BLS1s are better to answer the first question since the power law component generally dominated the soft X-ray emission of BLS1s. We have shown that the spectra of all the seven BLS1s that do show a clear HR1-CTs correlation become softer with increasing flux. For these BLS1s it is likely that their power law components get softer when they are brighter. Our simple analysis of the HR1-CTs correlation of NLS1s could not clarify this issue directly. Detailed study of Mark 766 by Page et al. (1999) revealed that the power law component becomes softer when it gets brighter, while variability of the soft excess and neutral absorbing column is not detected. That the power law component becomes softer as it gets brighter was also found in the cases of NGC 4051, MCG–6-30-15 and RX J0134.2–4258 (Matsuoka et al. 1990; Kunieda et al. 1992; Pounds et al. 1986; Papadakis & Lawrence 1995; Grupe et al. 2000). Therefore, if MARK 766, NGC 4051 and MCG–6-30-15 are typical of NLS1s, the power law components of both NLS1s and BLS1s might vary in the same way. This implies that the power law components of both NLS1s and BLS1s possibly have the same kind of physical origin. In fact, two popular models for the power law X-ray component of radio quiet Seyfert galaxies, both of which are based on Compton upscattering of UV or soft X-ray photons from an accretion disk or optically thin plasma, predict that in the variation of a single source the power law slope is softer as the power law flux becomes higher (Done & Fabian 1989; Torricelli-Ciamponi & Courvoisier 1995), and this is entirely consistent with what we have found.

As shown in MARK 766, NGC 4051 and MCG–6-30-15, it is very interesting to note that, although the power law component becomes softer, the entire spectrum get harder with increasing flux. We suggest here that some properties of the soft excess possibly take charge of the difference of spectral variability between the NLS1s and BLS1s. We assume that, for both NLS1s and BLS1s, the power law component gets softer with increasing flux, and that the soft excess remains nearly stable throughout the whole observations. For typical NLS1s, the A band is dominated by the giant thermal soft excess, and the B band is dominated by the power law component. The increase of the power law component will change the B band relatively more than that of A band, since the A band is dominated by the stable soft excess. Therefore, although the increase of the power component makes the power law component softer, a harder spectrum emerges when the power law component is combined with the soft excess. For typical BLS1s, the total spectrum is dominated by the power law component, and so behaves just like the power law component by itself. For the NLS1s and those BLS1s without a clear HR1-CTs correlation, we guess that they possess marginal soft excesses. Further detailed spectral fit will confirm if our assumption is reasonable and will give a clearer interpretation of the different spectral shape variability between the NLS1s and BLS1s.

In addition, for those objects with detected warm absorbers such as NGC 5548 and NGC 7469, the spectral shape variability could be due to a change in the warm absorber; however, a detailed examination is needed to fit the spectra and then to analyze the variability of the warm absorber. This is beyond the scope of this paper.

5 CONCLUSIONS

We have presented an analysis of spectral shape variability of 22 Seyfert 1 galaxies in terms of the HR1-CTs correlation and found that six NLS1s display a positive HR1-CTs correlation in the sense that their spectra harden as the overall flux increases, while seven BLS1s show a negative correlation, opposite to the NLS1s. All the other objects do not show any evident HR1-CTs correlation. From the spectral analysis results of MARK 766 and RX J0134.2–4258, we are led to a very probable explanation: the different spectral behaviors with increasing flux can be due to a stable soft excess below 0.5 keV that is strong in NLS1s and weak in BLS1s, plus a variable power law component common to both, that softens when the flux increases. This interpretation supports the BBB origin of the soft excess and the power law originating in the Compton upscattering of UV or soft X-ray photons in an accretion disk or optically thin plasma. Thus, the distinct spectral variation trends might be characteristic of BLS1s and NLS1s.

Acknowledgements We thank Dr. Luo Ali for helping us with data reduction and some software applications. Supports under Chinese NSF (19973014), the Pandeng Project, and the 973 Project (NKBRSF G19990754) are also gratefully acknowledged.

References

Boller Th., Brandt W. N., Fink H. H., 1996, A&A, 305, 53

Boller Th., Brandt W. N., Fabian A. C., Fink H. H., 1997, MNRAS, 289, 393

Boller Th., Invited talk presented at the Joint MPE, AIP, ESO workshop on NLS1s, Bad Honnef, Dec. 1999 (astro-ph/0005127)

Brandt W. N., Boller Th., Fabian A. C., Ruszkowski M., 1999, MNRAS, 303, L53

Done C., Fabian A. C., 1989, MNRAS, 240, 81

Gliozzi M., Brinkmann W., O'Brien P. T., Reeves J. N., Pounds K. A., Trifoglio M., Gianotti F., 2001, A&A, 365, L128

Grupe D., 1996, PhD thesis, Univ. Gottingen

Grupe D., Leighly K. M., Thomas H.-C., Laurent-Muehleisen S. A., 2000, A&A, 356, 11

Kunieda H., Hayakawa S., Tawara Y., Koyama K., Tsuruta S., Leighly K. M., 1992, ApJ, 384, 482

Laor A., Fiore F., Elvis M., Wilkes B. J., McDowell J. C., 1994, ApJ, 435, 611

Leighly K. M., Mushotzky R. F., Yaqoob T., Kunieda H., Edelson R., 1996, ApJ, 469, L147

Leighly K. M., 1999a, ApJS, 125, 297

Matsuoka M., Piro L., Yamauchi M., Murakami T., 1990, ApJ, 361, 440

Osterbrock D. E., Pogge R. W., 1985, ApJ, 297, 166

Page M. J., Carrera F. J., Mittaz J. P. D., Mason K. O., 1999, MNRAS, 305, 775

Papadakis I. E., Lawrence A., 1995, MNRAS, 272, 161

Papadakis I. E., Brinkmann W., Negoro H., Detsis E., Papamastorakis I., Gliozzi M., 2000, preprint (astro-ph/0012317)

Pounds K. A., Turner T. J., Warwick R. S., 1986, MNRAS, 221, 7

Puchnarewicz E. M., Mason K. O., Cordova F. A. et al. 1992, MNRAS, 256, 589

Torricelli-Ciamponi G., Courvoisier T. J. -L., 1995 A&A, 296, 651

Trümper J., 1983, Adv. Space Res., 4, 241

Véron-Cetty M. P., Véron P., 1991, A Catalogue of Quasars and Active Galactic Nuclei, 5th ed. (ESO, Garching near Munich)

Wang T. G., Brinkmann W., Bergeron J., 1996, A&A, 309, 81

Wang T. G., Matsuoka M., Kubo H., Mihara T., Negoro H., 2001, ApJ, 554, 233