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GAMMA-RAY AND X-RAY EMISSION FROM GAMMA-RAY-LOUD BLAZARS*

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We present a strong correlation of the gamma-ray (above 100 MeV) mean spectral indices α_γ and X-ray (1 keV) mean spectral indices α_X for 34 gamma-ray-loud blazars (16 BL Lac objects and 18 flat spectrum radio quasars). A strong correlation is also found between the gamma-ray flux densities F_γ and X-ray flux densities F_X in the low state for 47 blazars (17 BL Lac and 30 flat spectrum radio quasars). Possible correlation on the gamma-ray emission mechanism is discussed. We suggest that the main gamma-ray radiation mechanism is probably the synchrotron process. The gamma-ray emission may be somewhat different from that of BL Lac objects and flat spectrum radio quasars.

Keywords: BL Lacertae objects, general-γ-rays, general-X-rays, nonthermal
PACC: 9760L, 0420

I. INTRODUCTION

In recent years, one of the most important results of the energetic gamma-ray experiment telescope (EGRET) on the Compton gamma-ray observatory (CGRO) has been the discovery that blazars and flat spectrum radio quasars (FSRQs) are of strong γ-ray emission.[1] The most striking common properties of these EGRET detected blazars and FSRQs are as follows:[2] 1) the gamma-ray flux is dominant over the flux in other low-energy bands, and the gamma-ray luminosity above 100 MeV ranges from less than 3×10^{37} Js^{-1} to more than 10^{42} Js^{-1}, with the typical values in the range from 3×10^{40} Js^{-1} to 3×10^{41} Js^{-1}; 2) many of the sources are strongly variable in the γ-ray band on timescales from days to months, but large flux variability on short timescales of < 1 day has also been detected (see 0716+714, for instance, Cappi *et al.*[3]); 3) the redshifts are distributed over a wide range of values (0.31 to 2.28),[4] and the photon spectra in the EGRET energy (30 MeV to 30 GeV) are generally well represented by power laws with a wide range of photon spectral index (1.7 to 2.8). The other important results from the CGRO are that many relatively close active galaxies, especially Seyfeit galaxies and radio-quiet AGNs, have not been detected at photon energy $E >$ several MeV, and also some other notable blazars have not been detected yet.[5,6]

A variety of models have recently been proposed to explain the origin of the γ-ray emission, including synchrotron self-Compton,[7] inverse Compton on photons produced by the accretion disk,[8] or scattered by ambient material or reprocessed by the broad-line clouds,[9−13] synchrotron emission from ultrarelativistic electrons and positrons produced in a proton-induced cascade.[14−16] From these models it is clear that the γ-ray emission is from the jet. Observations suggest that most of the objects in the EGRET sample show superluminal motion, which yields also strong evidence that the γ-ray radiation from these objects comes from the relativistic jets and is strongly beamed. As the large number of proposed models indicates, there is no consensus yet on the dominant emission process. It is well known that the emission models might imply various relations among wavebands that can be used to distinguish among a variety of emission mechanisms observationally. Dondi and Ghisellini[17] have studied the correlations between γ-ray emission and the emission in radio, optical and X-rays in the form of luminosity for the entire sample of sources detected by EGRET. They found that the γ-ray luminosity is more correlated with the radio luminosity than with the optical or the X-ray luminosity. Xie *et al.*[18] found that the flux density correlation between

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the γ-ray emission and the infrared band is closer than that between the γ-ray emission and the optical or the X-ray band. Fan *et al.*[19] found that there is a correlation between the γ-ray emission and the high-frequency (1.3 mm, 230GHz) radio emission for maximum flux densities, other than between the γ-ray and the lower-frequency (5GHz) radio emissions.

These results show that the link between multi-waveband emissions is very important, owing to the strong correlation of luminosities with the redshift. Especially in samples which cover a wide range of distances, a correlation will appear in a luminosity plot, even though there is no correlation in the corresponding flux densities.[17−20] The correlations between flux densities are more important for the understanding of the emission mechanisms. The spectral index is correlated with flux densities, according to the definition about the spectral index. So, in this paper, we expand the spectral index with respect to flux densities and study the correlation of γ-ray mean spectral indices α_γ with X-ray mean spectral indices $\alpha_{\rm X}$, and X-ray versus γ-ray flux densities in detail. Here we will use the observed data for the X-rays and γ-rays, the sources are listed in table 1. In section II, we give the data and the correlation between the X-ray and γ-ray emissions, and in section III, there is a discussion.

II. CORRELATION OF γ-RAY EMISSION WITH X-RAY EMISSION

As a matter of fact, in view of the large variations in amplitude of the γ-ray and X-ray spectral indices with flux densities, simultaneous observations are necessary. Unfortunately, only a small number of EGRET sources have multi-waveband spectral indices and fluxes, and they are not simultaneous.[6] Because of lacking simultaneous multi-waveband data for EGRET sources, it is very useful to seek the state of the minimal flux in different multi-wavelength regions that have been reported for those objects in which flux variability has been measured.[21] Therefore, simultaneous observations should be adequate for a correlation analysis.[20] There is scarcity of such simultaneous observations. Thus, we can only choose the observed unweighted mean data for spectral indices in the γ-ray and X-ray bands to investigate the correlation between the γ-ray and X-ray emissions.

In this paper, we have collected 48 γ-ray-loud blazars with well-observed spectral index in γ-ray and X-ray bands. All of the relevant observed data of these blazars are listed in table 1. We give the IAU name (col. 1); other name and redshift z (col. 2); classification of the source (col. 3) (BL = Bl Lac object, HP = highly polarized quasar, LP = lowly polarized quasar, NP = no polarization measurements found, RQ = flat spectrum radio quasars), according to the criteria of, for example, Ghisellini *et al.*[22] and Mukherjee *et al.*[4] The X-ray spectral index ($\alpha_{\rm X}$) and γ-ray spectral index (α_γ)—the first entry is $\alpha_{\rm X}$ and the second is α_γ (col. 4); the references for the X-ray and γ-ray spectral indices (col. 5); 1 keV X-ray flux($F_{\rm X}$) in microjanskys—the first entry is the high-state flux and the second is low-state flux (col. 6); references for X-ray data (col. 7); γ-ray flux above 100 MeV (F_γ) in units of 10^{-7} photon cm^{-2} s^{-1}—the first entry is the high-state flux and the second is the low-state flux (col. 8); and references (col. 9). Reference numbers (1) to (43) for the table correspond to the references of papers Ref.[23] to Ref.[64].

Table 1. Blazar sample.

Source	Name Z	Class type	$\alpha_{\rm X}/\alpha_\gamma$	Reference	$F_{\rm X}$/uJy	Reference	F_γ	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	4C15.05	RQ	-0.32±0.06	31	0.06	20	5.28±2.64	38
0202+149	1.202	HP	2.5±0.1	1,37	0.35	31	0.87±0.28	38
	PKS	RQ	1.04±0.04	31	0.61	14	13.19±2.5	38
0208-512	1.003	HP	1.99±0.05	2	0.22	31	1.59±0.87	38
	3C66A	BL	1.49±0.04	31	1.25	31	3.42±0.43	32
0219+428	0.444	HP	2.01±0.14	21	0.16	26	1.52±0.41	32
	CTD	RQ	0.7	7	0.19	18	3.14±0.12	2
0234+285	1.213	HP	2.47± 0.26	2,21	0.09	31	1.09±0.44	2
	OD	BL	2.1±0.78	10,25,27,31	1.56±0.41	27	8.25 ±0.91	32
0235+164	0.940	HP	1.59±0.17	1,2.39	0.17	26	1.13±0.46	38
	CTA26	RQ	.....	...	0.10	31	18.6±0.76	38
0336-019	0.852	NP	.....	...	0.07	26	1.30±0.2	38

Table 1. (*Continued*)

Source	Name Z	Class type	α_X/α_γ	Reference	F_X/uJy	Reference	F_γ	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	PKS	RQ	-0.15	25	0.52±0.15	28	6.78±3.3	38
0420-014	0.915	HP	2.44±0.19	2	0.38	26	1.4±0.72	38
	PKS	RQ	.....	...	0.11±0.03	3	1.47±0.42	38
0454-234	1.009	HP	.....	...	0.085	26	1.4±0.4	40
	PKS	RQ	.....	...	0.195	14	2.28±0.74	38
0454-463	0.858	LP	.....	...	0.16	31	0.77±0.21	38
	4C2.19	RQ	.....	...	0.1	18	6.2±1.5	41
0458-020	2.286	HP	.....	...	0.04	26	1.10±0.20	2
	PKS	RQ	.....	...	0.35	14	2.88±1.15	38
0506-612	1.093	LP	.....	...	0.28	31	0.7±0.17	38
	PKS	BL	0.89±0.05	25,27,31	1.78	27	3.75±1.12	38
0521-365	0.055	HP	2.2± 0.4	1,37	0.68	26	1.4±0.4	41
	OQ147	RQ	0.54±0.29	31	0.65	31	30.76±3.46	38
0528+134	2.07	LP	2.53±0.07	1,2	0.19	20	2.29±1.23	38
	PKS	BL	1.16± 0.09	31	0.79±0.05	15	8.98±1.45	38
0537-441	0.896	HP	2.13± 0.16	1,2,4	0.20	29	1.74±0.41	37
	S5	BL	2.03±0.05	27,30,31	3.01	30	5±1.2	41
0716+714	0.3	HP	1.73±0.21	1,2,9	1.28	31	1.86±0.27	37
	PKS	BL	0.71	25	0.33	26	8.63	37
0735+178	0.424	HP	2.55±0.39	1,2	0.22±0.03	27	1.29±0.38	32
	OJ508	RQ	0.56±0.36	31	0.24	32	2.7±0.8	40
0804+499	1.433	HP	2.46±0.45	2,4	0.17	31	0.83±0.39	2
	OJ248	RQ	.....	...	0.34	31	6.81±1.44	2
0827+243	2.050	LP	.....	...	0.097	18	2.0±0.4	41
	OJ049	BL	2.26	25	1.07±0.3	25	1.9 ±0.57	37
0829+049	0.18	HP	2.30	2	0.19	26	1.4 ±0.5	41
	4C71.07	RQ	0.42±0.04	31	1.73±0.57	10	2.24±0.76	38
0836+710	2.172	LP	2.62±0.16	2	1.11	31	1.39±0.64	38
	OJ287	BL	1.45±0.18	31	2.16±0.15	33	2.9	42
0851+202	0.306	HP	2.03±0.35	2	0.62	31	1.22±0.4	2
		RQ	0.39±0.10	31	.....		3.21±0.98	38
0917+449	2.18		2.19±0.14	2	0.47	31	1.41±0.73	38
	4C55	RQ	1.17±0.14	31	.....		4.81±1.57	38
0954+556	0.901	HP	2.12±0.18	2	0.10	31	0.65±0.26	38
		BL	0.23±0.02	31	0.17	31	1.78±0.94	38
0954+658	0.368	HP	2.08±0.24	2	0.16±0.02	27	1.47±0.43	38
	MrK421	BL	2.14±0.07	31	36.13	31	4.94±0.76	32
1101+384	0.031	HP	1.50±0.12	2,24,41	10	19	1.57±0.24	32
	OM-146	RQ	.....	...	0.34	31	8.06±1.99	38
1127-145	1.187		.....	...	0.24	18	0.97±0.57	38
	4C29	RQ	0.86±0.15	31	0.8	34	22.84±5.48	32
1156+295	0.729	HP	1.98±0.36	1,2	0.62±0.06	33	2.12	32
	ON231	BL	1.79±0.05	25,31	0.21	3	2.84±0.92	43
1219+285	0.102	HP	1.73±0.18	2	0.03	16	0.69±0.02	43
	3C273	RQ	0.55±0.05	5,25,31,	12.05	25	4.65±0.45	37
1226+023	0.158	LP	2.62±0.30	2,4	11.15	25	2.1±0.26	41
	PKS	RQ	.....	...	0.10	18	1.34±0.4	38
1229-021	1.0448	LP	.....	...	0.08	31	0.9 ±0.4	38

Table 1. (*Continued*)

Source	Name Z	Class type	α_X/α_γ	Reference	F_X/uJy	Reference	F_γ	Reference
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	3C279	RQ	0.83±0.04	31	1.34±0.02	31	28.7±1.09	32
1253-055	0.538	HP	2.1±0.1	37,41	0.78	26	1.34±0.44	37
	OP+151	RQ	.....	...	0.65	18	1.28±0.81	38
1331+170	2.0838		.....	...	0.053	18	0.75±0.42	38
	PKS	RQ	0.52±0.16	25,31,33	0.84±0.7	33	2.7 ±0.6	36
1510-089	0.361	HP	2.47±0.21	2	0.44	26	1.8 ±0.7	41
	4C15	BL	.....	...	0.15	26	4.14±1.22	38
1604+159	0.357	HP	.....	...	0.12	16	1.71±0.92	38
	DA406	RQ	0.76±0.06	31	0.24	31	7.32±1.56	38
1611+343	1.404	LP	2.21±0.17	1,2	0.08	7	1.28±0.11	4
	4C38	RQ	0.53±0.08	31	0.42	31	10.54±0.94	37
1633+382	1.814	LP	2.15±0.09	1,2	0.08	13	1.36±0.34	2
	3C345	RQ	.....	...	8.3	27	2.5	21
1641+339	0.595	HP	.....	...	0.61±0.12	34	1.30±0.60	23
	Mkr501	BL	2.63±0.05	27	9.37±0.46	33	3.2±0.1.30	6
1652+398	0.033	HP	1.5±0.5	6	5.88	3	3.6	42
		RQ	.....	...	0.63	31	12.02±3.65	38
1730-130	0.902		.....	...	0.22	18	1.78±0.92	38
	4C51	RQ	0.7	7	0.16	31	5.10±2.76	38
1739+522	1.375	HP	2.42±0.23	2	0.1	13	1.61±0.85	38
	OT-68	RQ	.....	...	0.75	14	4.89 ±1.96	38
1741+380	1.054	HP	.....	...	0.61	31	1.76±0.47	38
	PKS	RQ	.....	...	0.38	14	9.94 ±3.24	38
1933-400	0.966	NP	.....	...	0.30	31	1.60±0.58	38
	PKS	BL	1.89± 0.05	31	5.30	31	6.3	39
2005-489	0.071	HP	2.2	4	2.21±0.02	31	1.8 ±0.5	41
	PKS	BL	1.43	25	1.22	25	2.442±1.02	38
2032+107	0.601	HP	2.16±0.27	2,8	0.10	31	1.34±0.77	38
	PKS	BL	1.61	25	16.47	25	4.25 ±1.36	39
2155-304	0.116	HP	1.53±0.25	2,9	5.98	25	2.62±1.20	38
	BL Lac	BL	1.34	25	4.32	25	7.81 ±3.83	22
2200+420	0.069	HP	1.9±0.28	35,47	0.53	3	1.84±0.97	38
	CTA102	RQ	0.7	7	0.75	18	5.16 ±1.5	17
2230+114	1.037	HP	2.45±0.14	2	0.30	15	0.74±0.40	17
	3C454	RQ	0.62±0.04	31	5.5±1.65	34	13.74±2.07	37
2251+158	0.859	HP	2.21±0.06	1,2	0.56	12	1.4 ±0.4	11
	PKS	BL	.....	...	0.15	36	2.7 ±0.4	36
2254+074	0.190	HP	.....	...	0.049	3	0.8	36

References for table 1:(1) Mattox *et al.* 1997; (2) Hartman *et al.* 1999; (3) Ghisellini *et al.* 1986; (4) Chiang *et al.* 1995; (5) Turner *et al.* 1990; (6) Katuoka *et al.* 1999; (7) Neumann *et al.* 1994; (8) Dingus *et al.* 1996; (9) Lin *et al.* 1995; (10) Sambruna *et al.* 1996;(11) Hartman *et al.* 1993; (12) Makino *et al* 1987; (13) Bloom *et al.* 1991; (14) Brinkmann *et al.* 1994; (15) Treves *et al.* 1993; (16) Giommi *et al.* 1995; (17) Mukherjee *et al.* 1997; (18) Wilkes *et al.* 1994; (19) Madejski & Schwartz 1983; (20) Bregman *et al.* 1985; (21) von Montigny *et al.* 1995; (22) Mattox *et al.* 1993; (23) von Montigny *et al.* 1993; (24) Lin *et al.* 1992; (25) Worrall & Wilkes 1990; (26) Ledden *et al.* 1985; (27) Urry *et al.* 1996; (28) Maraschi *et al.* 1986; (29) Wolter *et al.* 1994; (30) Cappi *et al.* 1994; (31) Comastri *et al.* 1997; (32) Thompsot *et al.* 1995; (33) Sambruna *et al.* 1994; (34) Makion *et al.* 1989; (35) Mattox *et al.* 1997; (36) Villata *et al.* 1997; (37) Thompson *et al.* 1996; (38) Mukherjee *et al.* 1999; (39) Lin *et al.* 1996; (40) Thompson *et al.* 1993;(41) Fichtel *et al.* 1994; (42) Shrade *et al.* 1994; (43) Thompson *et al.* 1996.

We choose the mean spectral index if there are more than one spectral indices available for the sources considered in the paper. For comparison, we also study the X-ray and γ-ray flux densities. We therefore choose the lowest fluxes (low state) and maximum fluxes (high state), irrespective of the data of observation for all γ-ray-loud blazars. From table 1, we can see that 34 γ-ray-loud blazars sources have γ-ray spectral index and X-ray spectral index for the unweighted mean data. All blazars (49 sources) have γ-ray fluxes in both high and low states. There are 47 blazars which have X-ray fluxes in both high and low states except for 0917+449 and 0954+556. We made the correlation analysis of spectral index. According to our analysis, the main results are as follows:

(1) There is a very strong correlation between X-ray spectral index ($\alpha_{\rm X}$) and γ-ray spectral index (α_γ) for the 34 objects. The linear regression equation is

$$\alpha_\gamma = (2.529\pm0.059) - (0.385\pm0.049)\alpha_{\rm X},$$

and we obtained a large correlation coefficient r=0.8091, with a chance probability of p=2 × 10^{-8}. Obviously, it is a strong correlation (see Fig 1.).

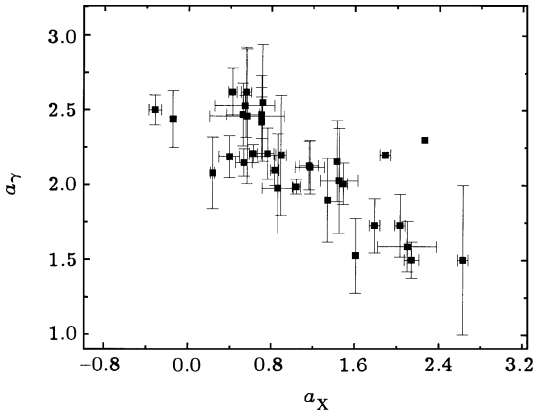


Fig.1. Correlation between $a_{\rm X}$ and a_γ.

(2) For 16 BL Lac sources, we find a significant correlation between the X-ray spectral index ($\alpha_{\rm X}$) and γ-ray spectral index (α_γ). The linear regression equation is

$$\alpha_\gamma = (2.46\pm0.13) - (0.355\pm0.082)\alpha_{\rm X}.$$

The correlation coefficient is r=0.75722, with a chance probability of p=1.9 × 10^{-4}. There is a weak correlation between X-ray spectral index ($\alpha_{\rm X}$) and γ-ray spectral index (α_γ) for 18 FSRQs sources. The correlation coefficient is r=0.54207, with a chance probability of p=2 × 10^{-2}.

(3) There is a strong correlation between F_γ and $F_{\rm X}$ flux densities in the low states for 47 objects. The linear regression equation is

$$\log F_\gamma = 2.44\text{–}0.8989\ \log F_{\rm X}.$$

The correlation coefficient is r=0.5950, with a chance probability p=1.4 × 10^{-7} (see Fig.2.). There is no correlation between F_γ and $F_{\rm X}$ flux densities in the high states.

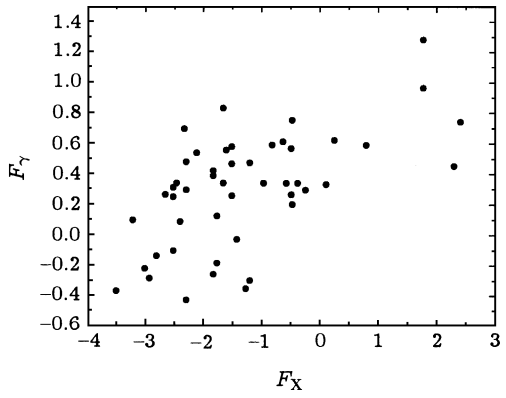


Fig.2. The correlation of flux densities between $F_{\rm X}$ and F_γ.

(4) There is a significant correlation between F_γ and $F_{\rm X}$ flux densities in low states for 17 BL Lac objects. The correlation coefficient is r=0.7036, with a chance probability p=7×10^{-4}.There is a weaker correlation between F_γ and $F_{\rm X}$ in low states for 30 FSRQs sources.

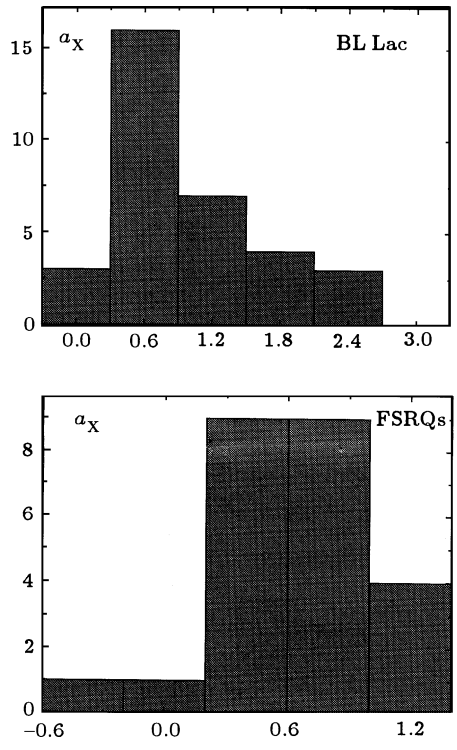


Fig.3. Histograms of the X-ray spectral indices for BL Lac objects and FSRQs.

(5) The range of measured values of the energy spectral indices is large, going from –0.32 to 2.6 for

X-ray band and from 1.5 to 2.63 for γ-ray band. We find a significantly different distribution of spectral indices between BL Lac objects and FSRQs, as can be clearly seen from the histogram shown in Figs.3 and 4. So, the γ-ray emission mechanism may be somewhat different for BL Lac objects and FSQRs.

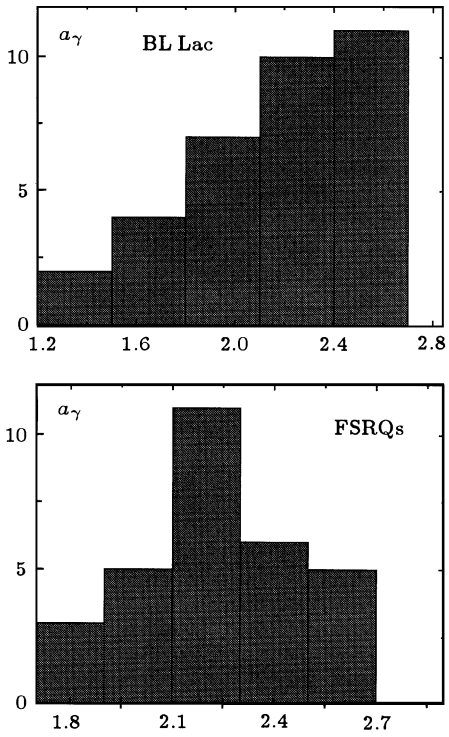


Fig.4. Histograms of the X-ray spectral indices for BL Lac objects and FSRQs.

Ⅲ. DISCUSSION

The EGRET-detected AGNs share many common properties: all are flat spectrum radio-loud sources, and almost all are core-dominated, a large fraction of them are superluminal.[6] The most striking common properties of these EGRET-detected AGNs are the large fraction of the bolometric power in the γ-ray band and the rapid time variability, which ranges from as short as a few days to several months in the high-energy γ-ray emission. Some of them are known to be Bl Lac objects, and others are recognized as OVV and/or HPQ quasars. It is necessary to study this class of EGRET-detected AGNs together in order to understand the γ-ray emission mechanism of individual sources. Using the entire sample of these EGRET-detected sources, Dondi and Ghisellini[17] found that all of them require relativistic bulk motion in order to be transparent to the γ-ray emission. We find a very strong correlation between γ-ray and X-ray unweighted mean spectral indices. A strong correlation is also found between the γ-ray flux densities F_γ and X-ray flux densities $F_{\rm X}$ in the low states for 47 blazars (17 BL Lac and 30 flat spectrum radio quasars). These results support a synchrotron self-Compton origin for the high-energy γ-ray emission. Since the beaming effect may smear out a possible correlation between the intrinsic fluxes,[20] thus, the significant correlation between F_γ and $F_{\rm X}$ shows that the relativistic Doppler factor for γ-ray bands must be close to the relativistic Doppler factor for X-ray bands. That is, the γ-ray and X-ray emission regions are co-spatial, and it is possible to interpret the γ-ray emission as being directly related to the X-ray radiation.

Finally, our conclusions are as follows. (1) The synchrotron self-Compton radiation is the main mechanism of γ-ray emission. (2) Compton scattering of the radiation from hot circumnuclear dust by beamed ultra-relativistic electrons is likely to be an important complementary mechanism. (3) The γ-ray emission mechanism may be somewhat different for BL Lac objects and FSQRs .

References

[1] Fichtel C E *et al* 1994 *Astrophys. J. Suppl.* **94** 551

[2] von Montigny C *et al* 1995a *Astrophys. J.* **440** 96

[3] Cappi M, Comasti A *et al* 1994 *Mon. Not. R. Astron. Soc.* **271** 438

[4] Mukherjee D L, Bertsch S D and Bloom B L *et al* 1999 *Astrophys. J.* **516** 221

[5] Dermer C D and Gehrels N 1995 *Astrophys. J.* **447** 103

[6] von Montigny C *et al* 1995b *Astrophys. J.* **440** 525

[7] Maraschi L, Ghisellini G and Celotti A 1992 *Astrophys. J.* **397** L5

[8] Dermer C, Shchlickeiser R and Mastichiadis A 1992 *Astronom. Astrophys.* **256** L27

[9] Sikora M, Begelman M C and Rees M J 1994 *Astrophys. J.* **421** 153

[10] Sikora M, Begelman M C and Rees M J 1993 in Friedlander M, Geherels N, Macomb D J (eds) *AIP Conf. Proc.* 280 *Compton Gamma-ray Observatory* (New York: AIP) p 512

[11] Blandford R D 1993 in Friedlander M, Geherels N, Macomb D J (eds) *AIP Conf. Proc.* 280 *Compton Gamma-ray Observatory* (New York: AIP) p 533

[12] Blandfrod R D and Levinson A 1995 *Astrophys. J.* **441** 79

[13] Xie G Z, Zhang Y H and Fan J H 1997 *Astrophys. J.* **477** 114

[14] Mannheim K and Biermann P L 1992 *Astronom. Astrophys.* **253** L21

[15] Mannheim K 1993 *Phy. Rev.* D **84** 4208
[16] Cheng K S and Ding W K Y 1994 *Astronom. Astrophys.* **288** 97
[17] Dondi L and Ghisellini G 1995 *Mon. Not. R. Astron. Soc.* **237** 583
[18] Xie G Z, Zhang X and Bai J M *et al* 1998 *Astrophys. J.* **508** 180
[19] Fan J H and Xie G Z *et al* 1998 *Astronom. Astrophys.* **338** 27
[20] Mucke A *et al* 1997 *Astronom. Astrophys.* **320** 33
[21] Burbidge G *et al* 1987 *Astronom. J.* **93** 1
[22] Ghisellini G and Maraschi L 1993 *Astrophys. J.* **407** 65
[23] Bloom S D *et al* 1991 *Astrophys. J.* **336** 16
[24] Bregman J N *et al* 1985 *Astrophys. J.* **291** 505
[25] Brinkmann W, Siebert J and Boller T 1994 *Astronom. Astrophys.* **281** 355
[26] Chiang J *et al* 1995 *Astrophys. J.* **452** 156
[27] Comastri A *et al* 1997 *Astrophys. J.* **480** 534
[28] Dingus B L *et al* 1996 *Astrophys. J.* **467** 589
[29] Ghisellini G and Maraschi L 1986 *Astrophys. J.* **310** 317
[30] Giommi P, Ansari S G and Micol A 1995 *Astronom. Astrophys. Suppl.* **109** 267
[31] Hartman R C *et al* 1993 *Astrophys. J.* **407** L41
[32] Hartman R C *et al* 1999 *Astrophys. J.* **515** 32
[33] Kakuoka J *et al* 1999 *Astrophys. J.* **514** 620
[34] Ledden J E *et al* 1985 *Astrophys. J.* **298** 630
[35] Lin Y C *et al* 1996 *Astrophys. J. Suppl.* **105** 331
[36] Lin Y C *et al* 1992 *Astrophys. J.* **401** L61
[37] Lin Y C *et al* 1995 *Astrophys. J.* **442** 96
[38] Makino K 1989 *Proc. 23rd ESLAB Symp ESA SP*-295 p 803
[39] Wolter A *et al* 1994 *Astrophys. J.* **433** 29
[40] Maraschi L *et al* 1992 *Astrophys. J.* **397** L5
[41] Mattox J R *et al* 1993 *Astrophys. J.* **410** 609
[42] Mattox J R *et al* 1997 *Astrophys. J.* **481** 95
[43] Mattox J R, Wanger S J and Malkan M *et al* 1997 *Astrophys. J.* **443** 578
[44] Madau P G and Persic M 1987 *Mon. Not. R. Astron. Soc.* **224** 257
[45] Madejski G M and Schwartz D A 1983 *Astrophys. J.* **275** 467
[46] Makino F *et al* 1987 *Astrophys. J.* **313** 662
[47] Maraschi L *et al* 1986 *Astrophys. J.* **310** 325
[48] Mukherjee R *et al* 1997 *Astrophys. J.* **490** 116
[49] Neumann M *et al* 1994 *Astronom. Astrophys.* **106** 303
[50] Sambruna R M *et al* 1996 *Astrophys. J.* **463** 444
[51] Sambruna R M *et al* 1994 *Astrophys. J.* **434** 468
[52] Shrade C R *et al* 1994 *Astronom. J.* **107** 904
[53] Macomb D J *et al* 1993 in *AIP Conf. Proc.* 281 *Compton Gamma-ray Observatory* (New York: AIP) p 598
[54] Thompson D J *et al* 1995 *Astrophys. J. Suppl.* **101** 259
[55] Thompson D J *et al* 1996 *Astrophys. J. Suppl.* **107** 227
[56] Thompson D J *et al* 1993 *Astrophys. J.* **415** L13
[57] Thompson D J *et al* 1993 *Astrophys. J.* **410** 87
[58] Treves A *et al* 1993 *Astrophys. J.* **406** 447
[59] Turher M J L *et al* 1990 *Mon. Not. R. Astron. Soc.* **244** 310
[60] Urry C M *et al* 1996 *Astrophys. J.* **436** 424
[61] von Montigny C *et al* 1993 in *AIP Conf. Proc.* 281 *Compton Gamma-ray Observatory* (New York: AIP) p 543
[62] Villata M *et al* 1997 *Astronom. Astrophys.* **121** 119
[63] Wilkes B J *et al* 1994 *Astrophys. J.* **92** 53
[64] Worral D M *et al* 1990 *Astrophys. J.* **360** 390