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Research Note

Relation between γ-rays and emission lines for the γ-ray loud blazars

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Abstract. The relation between the γ-ray and the emission line luminosities for a sample of 36 γ-ray loud blazars is investigated; an apparent correlation between them, $L_\gamma \propto L_{Line}^{0.69\pm0.11}$, with a correlation coefficient $r = 0.741$ and a chance probability of $p = 1.9 \times 10^{-6}$, is found. It is found, however, that there is no intrinsic correlation between them: the apparent correlation is due to the redshift dependence in a flux-limited sample. Thus no evidence is found to support the argument that the upscattered soft photons are from the broad emission lines. Our analysis does not conflict with the SSC model. The disk-jet symbiosis and radio/γ-ray correlation found in the literature are also discussed. The radio/γ-ray correlation may be an apparent correlation caused by the boosting effect since both bands are strongly beamed.

Key words: galaxies: quasars: emission lines – galaxies: jets – galaxies: nuclei – galaxies: active

1. Introduction

In the third catalog of high-energy γ-ray sources, Hartman et al. (1999) listed 66 high-confidence identification blazars (i.e. flat-spectrum radio quasars (FSRQs) and BL Lac objects) which emit most of their bolometric luminosity in the γ-rays. Many of the γ-ray emitters also show superluminal components (Vermeulen & Cohen 1994, see also Fan et al. 1996) and very rapid γ-ray variability (von Montigny et al. 1995; Mattox et al. 1997; Mukherjee et al. 1997; Wehrle et al. 1998; Hartman et al. 1999). These facts strongly suggest that the γ-ray emission is from the jet of a blazar, and Doppler factors are derived for γ-ray loud blazars in the papers (Dondi & Ghisellini 1995; Cheng et al. 1999; Fan et al. 1999).

Models for γ-ray emission from AGNs are of two kinds: leptonic and hadronic. In the leptonic model, high energy γ-rays are produced by the inverse Compton scattering of high energy electrons in a soft photon field. The soft photons may be emitted from the nearby accretion disk (Dermer et al. 1992) or they may arise from disk radiation reprocessed in some region of AGNs (e.g. a broad emission line region; Sikora et al. 1994; Blandford & Levinson 1995; Xie et al. 1997, 1998); or they may come from the synchrotron emission in the jet (synchrotron self-Compton or SSC; Maraschi et al. 1992; Zdziarski & Krolik 1993; Bloom & Marscher 1996; Marscher & Travis 1996), or from a differential rotating flux tube near the inner edge of the accretion disk (Cheng et al. 1993). In the hadronic model, high energy γ-rays are produced by the synchrotron emission from ultrarelativistic electrons and positrons created in a proton-induced cascade (PIC; Mannheim & Biermann 1992; Mannheim 1993; Cheng & Ding 1994). There is no consensus yet on the dominant emission process. It is well known that the emission mechanisms might imply different relations between wave bands that can be used to choose between emission mechanisms. Such correlations have been discussed in many papers (Dondi & Ghisellini 1995; Mücke et al. 1997; Fan 1997a; Fan et al. 1998; Xie et al. 1997, 1998; Cheng et al. 2000). Fan (1997a) has investigated the correlation between the γ-ray band and lower energy bands by means of a multiple regression method, and proposed that the correlation between the γ-ray and the radio bands is probably due to the fact that both the γ-ray and the radio emissions are beamed. In this paper, we will discuss the relation between the γ-rays and the emission lines.

H_0 = 75 km s^{-1} Mpc^{-1} and q_0 = 0.5 are adopted.

2. Correlation

2.1. Data

Since blazars are known to be strongly variable in γ-rays, we use both maximum and average γ-ray fluxes from Hartman et al. (1999). For the maximum fluxes, we use only those with significance level $(TS)^{1/2} \geq 3.0$. For the averages, we use the flux for the sum of all EGRET observation (denoted P1234 in Hartman et al. 1999); for the cases in which P1234 has only an upper limit, half of the (2σ) limit value was used. For the emission line information, we used the data listed in the paper by Cao & Jiang (1999) except for the marked items. The relevant data are listed in Table 1, where Column 1 gives the name of the source; Column 2, classification, FQ for flat spectrum radio quasar and BL for BL Lacertae object; Column 3, the redshift; Column. 4 and 5, the maximum and the average γ-ray flux in units of 10^{-8} photon cm^{-2} s^{-1} (the points with a $star$ are half the upper limit while those with a $dagger$ show a $3.0 < (TS)^{1/2} < 4.0$); Column 6, the γ-ray photon spectral index (from Hartman et al. 1999); Column 7, the flux of the emission line $logF_{\rm line}$ in units of erg cm^{-2} s^{-1}; Column 8 and 9, the maximum and the average γ-ray luminosities at 0.4 GeV in units of erg s^{-1}; Column 10, the luminosity of emission line in units of erg s^{-1}.

2.2. Result

The observed photons are converted to flux densities at E GeV as follows. Let

$$\frac{dN}{dE} = N_0 E^{-\alpha_{ph}} \quad (1)$$

where N_0 is the normalization and α_{ph} is the photon spectral index given in Column 6. Integrating the above relation from 100 MeV to 10 GeV and setting it equal the observed photon flux given in Column 4 or 5, we obtain N_0. We calculate the flux density at 0.4 GeV, since that is about the average energy of the photons. The flux density is k-corrected according to $f_\nu = f_\nu^{ob.}(1+z)^{\alpha-1}$, where α is the spectral index ($f_\nu \propto \nu^{-\alpha}$ and $\alpha = \alpha_{ph} - 1$). Adopting $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$, the distance at redshift z is $d_L = 2.48 \times 10^{28}(1+z-(1+z)^{1/2})$ cm. Assuming an isotropic emission, then the luminosities can be calculated.

When the linear regression analysis is performed (excluding 3C 273) for the maximum γ-luminosities, a correlation

$$\log L_\gamma = (0.71 \pm 0.12)\log L_{\rm Line} + 15.88 \pm 5.3$$

is found, with a correlation coefficient $r = 0.713$ and a chance probability $p = 4.9 \times 10^{-6}$. For the average γ-luminosities, a correlation is (excluding 3C 273 again)

$$\log L_\gamma = (0.69 \pm 0.11)\log L_{\rm Line} + 16.11 \pm 4.8$$

with a correlation coefficient $r = 0.741$ and a chance probability $p = 1.9 \times 10^{-6}$.

Fig. 1 shows the correlation for the average γ-luminosities; open circles are for flat spectrum radio quasars while the filled points for BL Lacertae objects. The solid line is the best fit.

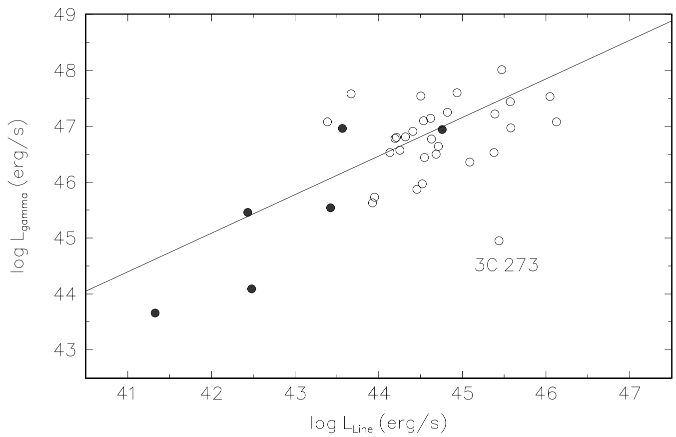

Fig. 1. The γ-ray luminosity vs. emission line luminosity using the average γ-ray flux. The open circles are for flat spectrum radio quasars and the filled points for BL Lacertae objects

3. Discussion

As mentioned above, other correlation investigations have been done for γ-ray loud blazars. It seems that the γ-rays are correlated with some lower energetic bands (Dondi & Ghiselini 1995; Fan 1997a; Fan et al. 1998; Xie et al. 1997, 1998; Cheng et al. 2000).

If the γ-rays result from up-scattering of emission line photons, a correlation between the γ-rays and the emission lines should be expected. In this paper, we found that the luminosities in the γ-rays are correlated with those of the emission lines. The correlation is better for the average γ-fluxes than for the maximum fluxes. Does the result favour the above argument?

When considering flux-limited samples, the use of luminosities instead of flux often introduces a redshift bias to the data, since the luminosities are strongly correlated with redshift. A correlation will be present in luminosity even there is no correlation in the corresponding flux density (Elvis et al. 1978). Feigelson & Berg (1983) show that if there is no intrinsic luminosity-luminosity correlation, no correlation will appear in the flux-flux relation even in the flux-limited samples (also see Mücke et al. 1997). Since the EGRET data certainly are flux-limited, we will discuss the luminosity relation further. First, we exclude the effect of redshift on the luminosity correlation; second, we consider the flux-flux relation.

To exclude the redshift effect, we use the method of Kendall & Stuart (1979). If r_{ij} is the correlation coefficient between x_i and x_j, in the case of three variables, the correlation between two of them, excluding the effect of the third one, is

$$r_{12,3} = \frac{r_{12} - r_{13}r_{23}}{(1-r_{13}^2)^{1/2}(1-r_{23}^2)^{1/2}}$$

From the data in Table 1, correlation coefficients, $r_{L_{Line}z} = 0.781$ and $r_{L_\gamma z} = 0.929$ can be obtained. The correlation coefficient between the γ-ray and the emission line luminosities, with the effect of the redshift excluded, is then $r_{L_{Line}L_\gamma,z} = 0.11$ and $p \sim 50\%$. Thus there is no evidence for intrinsic correlation between the γ-rays and the emission lines. If we only consider the flat spectrum radio quasars, a similar result is obtained.

Now we consider the flux-flux relation. When linear regression is performed on the > 100 MeV γ-ray flux and the emission line flux, there is no correlation between them. But if we exclude 3C 273, there is a tendency that the γ-ray flux increases with increasing emission line flux (see Fig. 2).

Therefore, we can say that, with the available data, there is no evidence of correlation between the γ-rays and the emission lines. Does that suggest that the up-scattered soft photons are not from the broad emission lines? This question will only be answered with better γ-ray data in the future. The reasons are:

Table 1. Observation data for γ-ray loud blazars

$Name$ (1)	Class (2)	z (3)	F_γ^{Max} (4)	$< F_\gamma >$ (5)	$\alpha_{\gamma,ph}$ (6)	logF$_{\rm Line}$ (7)	L_γ^{Max} (8)	$< L_\gamma >$ (9)	L_{Line} (10)
0208-512	FQ	1.003	134.1	85.5	2.23	-13.74[a]	47.78	47.583	43.67
0235+164	BL	0.940	65.1	25.9	1.85	-13.79	47.37	46.965	43.57
0336-019	FQ	0.852	177.6	15.1	1.84	-12.55	47.71	46.638	44.71
0414-189	FQ	1.536	49.5	4.5*	3.25	-13.62	47.84	46.798	44.21
0420-014	FQ	0.915	50.2	16.3	2.44	-12.70	47.26	46.771	44.63
0440-003	FQ	0.844	85.9	12.5	2.37	-13.00	47.41	46.573	44.25
0454-234	FQ	1.009	14.7	8.1	3.14	-13.29	46.79	46.532	44.13
0454-463	FQ	0.858	22.8	7.7	2.75	-12.18	46.83	46.359	45.09
0458-020	FQ	2.286	31.7	11.2	2.45	-13.28	48.05	47.599	44.94
0537-441	BL	0.896	91.1	25.3	2.41	-12.55	47.50	46.940	44.76
0836+710	FQ	2.172	33.4	10.2	2.62	-12.12	48.05	47.533	46.05
0851+202	BL	0.306	15.8	10.6	2.03	-12.88	45.72	45.543	43.43
0954+556	FQ	0.901	47.2	9.1	2.12	-12.63	47.21	46.498	44.69
0954+658	BL	0.368	15.5	6.0	2.08	-14.04	45.87	45.462	42.44
1101+384	BL	0.031	23.6	13.9	1.57	-12.94[b]	43.89	43.662	41.33
1222+216	FQ	0.435	48.1	13.9	2.28	-12.11[c]	46.51	45.967	44.52
1226+023	FQ	0.158	48.3	13.9	2.58	-10.27	45.49	44.946	45.43
1229-021	FQ	1.045	15.5	6.9	2.85	-12.08	46.88	46.526	45.38
1253-055	FQ	0.538	267.3	74.2	1.96	-12.42	47.47	46.912	44.08
1331+170	FQ	2.084	13.3	4.4	2.41	-12.00[d]	47.56	47.083	46.13
1334-127	FQ	0.539	11.8	5.5†	2.62	-12.88	46.06	45.733	43.95
1424-418	FQ	1.522	42.9	11.9	2.13	-13.2	47.69	47.136	44.62
1510-089	FQ	0.361	49.4	18.0	2.47	-12.00	46.31	45.870	44.46
1611+343	FQ	1.404	68.9	26.5	2.42	-12.17	47.85	47.436	45.57
1622-253	FQ	0.786	321.8	47.4	2.21	-13.80	47.91	47.082	43.39
1633+382	FQ	1.814	107.5	58.4	2.15	-12.52	48.27	48.008	45.47
1725+044	FQ	0.296	27.5	17.9	2.67	-12.35	45.82	45.633	43.93
1730-130	FQ	0.902	104.8	36.1	2.23	-12.78[e]	47.56	47.101	44.54
1739+522	FQ	1.375	26.9	18.2	2.42	-12.90	47.42	47.250	44.82
1741-038	FQ	1.054	48.7	11.7	2.42	-13.27	47.39	46.775	44.20
1936-155	FQ	1.657	55.0	3.7†	3.45	-13.90	47.99	46.813	44.32
2200+420	BL	0.069	39.9	11.1†	2.60	-12.49[f]	44.64	44.086	42.48
2230+114	FQ	1.037	51.6	19.2	2.45	-11.87	47.40	46.974	45.58
2251+158	FQ	0.859	116.1	53.7	2.21	-11.88	47.56	47.225	45.39
2320-035	FQ	1.411	38.2	3.0*	2.00	-13.20[g]	47.54	46.439	44.55
2351+456	FQ	1.992	42.8	14.3	2.38	-13.58	48.02	47.540	44.50

Notes: Col. 1, Name; Col. 2, Classification, FQ for flat spectrum radio quasar and BL for BL Lacertae object; Col. 3, the redshift; Col. 4, the maximum γ-ray flux in units of 10^{-8} photon cm^{-2} s^{-1}; Col. 5, the average γ-ray flux in units of 10^{-8} photon cm^{-2} s^{-1}, Col. 6, the photon spectral index; Col. 7, the flux of the emission line in units of erg cm^{-2} s^{-1}; Col. 8, the maximum γ-ray luminosity at 0.4 GeV in units of erg s^{-1}; Col. 9, the average γ-ray luminosity at 0.4 GeV in units of erg s^{-1}; Col. 10, the luminosity of emission line in units of erg s^{-1}.

* Half value of the upper limit

† $3.0 < (TS)^{1/2} < 4.0$

[a] Scarpa & Falomo (1997) [b] Morganti et al. (1992); [c] Stockton & MacKenty (1987); [d] Baker et al. (1994), Gondhalekar et al. (1986) [e] Junkkarinen (1984); [f] Vermeulen et al. (1995); [g] Baldwin et al. (1989)

1) the γ-ray flux densities used here are based on photon fluxes and photon spectral indices both of which have substantial errors, leading to possible significant errors in the flux densities; 2) most of the EGRET-detected blazars are detected only in a flaring state, while most of the optical spectra were taken in non-flaring states. These facts should dilute any intrinsic luminosity-luminosity correlation.

Our analysis does not conflict with the SSC model, as seen from the following discussion. Observations indicate that the γ-rays are strongly beamed. But the X-ray emissions seem not to be strongly beamed (Fan 1997b). If the emission is boosted in the form as showed in our previous paper (Fan et al. 1993, also see Fan 1999), then the emissions in neither the X-ray nor the optical bands are so strongly beamed as the radio bands. This implies that we can not expect close correlation between γ-ray and X-ray/optical bands for the observation data. Nevertheless, we can expect a correlation between the observed radio and the γ-rays since they both are strongly beamed (Fan 1997a; Fan et al. 1998).

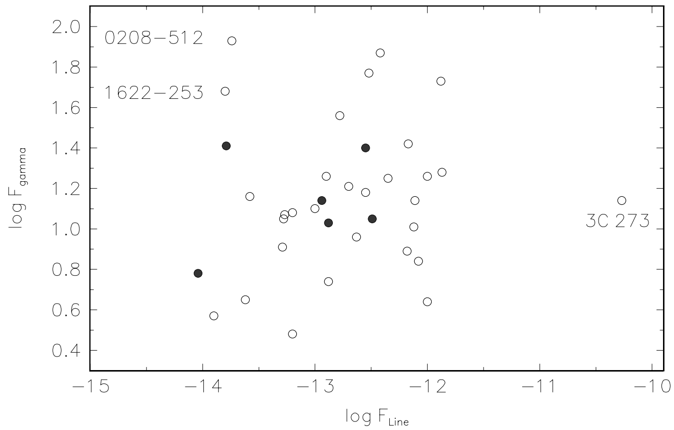

Fig. 2. The maximim γ-ray flux vs. the emission line flux. The open circles are for flat spectrum radio quasars and the filled points for BL Lacertae objects

If the SSC model is correct, we should expect a correlation for the corrected(intrinsic) γ-ray and optical data when the Doppler factors (boosting factors) are known. Conversely, the Doppler factor can be estimated using the SSC model.

In AGNs, the power is generated through accretion, and then extracted from the disk/black hole rotational energy and converted into the kinetic power in the jet (e.g., Blandford & Znajek 1977). Therefore, there is a possible disk-jet symbiosis in AGNs, and some tests have been performed (e.g. Rawlings & Saunders 1991; Falcke et al. 1995; Celotti et al. 1997; Serjeant et al. 1998; Cao & Jiang 1999). In those papers, the radio luminosity is taken to represent the jet and the emission line luminosity or optical luminosity is taken to represent the disk. Correlation is found to exist between those luminosities, and regarded as evidence of the disk-jet symbiosis.

If a correlation between γ-rays and emission lines is found to exist with more data in the future, it may support a disk-jet symbiosis. In this case, the γ-ray emissions could be taken to represent the jet, and the correlation with the emission line could be taken as the confirmation of the disk-jet symbiosis. However, this correlation gives no signature of the γ-ray emission mechanism. Therefore, the relation does not conflict the SSC model.

In this paper, a possible relation between the γ-ray emission and emission lines is investigated and discussed for a 36-blazar sample. The apparent luminosity correlation between the γ-rays and the emission lines is found to be entirely due to the effect of the redshift. There is no intrinsic correlation between the two luminosities, and thus no evidence to support the argument that the up-scattered photons are from the broad emission lines. The claimed radio and γ-ray correlation is most likely from the fact that the both emissions are strongly beamed, and we can not expect correlation between the γ-ray and other bands.

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