session code: 8.26

Blazar Variability and Evolution in the GeV Regime

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Abstract

One of the most important problem of the blazar astrophysics is to understand the physical origin of the blazar sequence. In this study, we focus on the GeV gamma-ray variability of blazars and a evolution perspective we search the relation between the redshift and the variability amplitude of blazars for each blazar subclass. We analyzed the Fermi-LAT data of the TeV blazars and the bright AGNs (flux $\geq 5 \times 10^{-9}$ [cm^{-2} s^{-1}]) selected from the 2LAC (the 2nd LAT AGN catalog) data base. As a result, we found a hint of the correlation between the redshift and the variability amplitude in the FSRQs. Furthermore the BL Lacs which have relatively lower peak frequency of the synchrotron radiation and relatively lower redshift, have a tendency to have a smaller variability amplitude.

Introduction

The spectrum energy distribution (SED) of blazars has double peaks, one at lower energy ranges (radio to X-rays) and the others at higher energy ranges (X-rays to gamma rays).

Blazars are classified into two types; FSRQs and BL Lacs, according to a emission line. BL Lacs are moreover classified according to the first peak of their SED; They are called low-frequency peaked BL Lacs (LBLs), intermediate-frequency peaked BL Lacs (IBL) and high-frequency peaked BL Lacs (HBL) in order of increasing frequency.

(FSRQs have the lower first peak of SED than LBLs).

These peaks have anti-correlation between peak frequency and bolometric luminosity [1]. This relationship have been called the blazar sequence.

One of the most important probrem of the blazar astrophysics is to understand the physical origin of the blazar sequence.

We computed GeV gamma-ray variability (Fvar) of each classified blazars and investigated association between Fvar and blazar sequence.

We also obtained Fvar distribution for redshift due to derive the evolution of blazar.

Fvar (fractional rms variability amplitude)

Equation 1 shows the Fvar which is applied to calculate the variability amplitude considering the error. Fvar is often used in computation variability amplitude for each spectral band[2].

$$Fvar = \sqrt{\frac{S^2 - \overline{\sigma_{err}{}^2}}{\bar{x}^2}}$$

Eq.1 Fvar [3]

S^2: total variance of the light curve

$\overline{\sigma_{err}{}^2}$: mean square of flux error

$\bar{x}^2$: square of average flux

Data selection

We selected AGNs in 2LAC (the second LAT AGN catalog)[3] and TeVCat [4].

selection criteria were as follows

1. **It was decided which subclass was belonged to (HBL or IBL or LBL or FSRQ)**
2. **It had known redshift.**
3. **flux > 10^{-9} [cm^{-2} s^{-1}] in 2LAC.**

In this study, redshift and subclass was adopted in the 2LAC and TeVCat.

However, the redshift of PKS 1424+240 was referred to Furniss(2013) [5].

Name	redshift	Sub class	Name	Redshift	Sub class	Name	redshift	Sub class
NGC 1275	0.017559	FRI	S2 0109+22	0.265	IBL	PKS 0537-441	0.892	LBL
IC 310	0.0189	FRI	PKS 0301-243	0.266	HBL	AO 0235+164	0.94	LBL
Mrk 421	0.031	HBL	S5 0716+714	0.31	LBL	S 30218+357	0.944	blazar
Mrk 501	0.034	HBL	OT 081	0.322	LBL	OP 313	0.997249	FSRQ
1ES 2344+514	0.044	HBL	1ES 0502+675	0.341	HBL	PKS 0454-234	1.003	FSRQ
1ES 1959+650	0.048	HBL	PKS 1510-089	0.361	FSRQ	PKS 2201+171	1.076	FSRQ
AP Lib	0.049	LBL	3C 66A	0.41	IBL	PKS 0426-380	1.111	LBL
3C 371	0.051	IBL	4C +21.35	0.432	FSRQ	PKS B1908-201	1.119	FSRQ
BL Lacertae	0.0686	IBL	PG 1553+113	0.5	HBL	PKS 1551+130	1.30814	FSRQ
PKS 2005-489	0.071	HBL	GB 1310+487	0.501	FSRQ	PK S0244-470	1.385	FSRQ
RGB J0152+017	0.08	HBL	3C 279	0.536	FSRQ	PKS 2023-07	1.388	FSRQ
W Comae	0.102	IBL	MG2 J071354+1934	0.54	FSRQ	PKS 0402-362	1.417	FSRQ
1ES 1312-423	0.105	HBL	4C 31.03	0.603	FSRQ	PKS 0250-225	1.419	FSRQ
VER J0521+211	0.108	IBL	PKS 1424+240	≥0.6035	IBL	B2 1520+31	1.484	FSRQ
PKS 2155-304	0.116	HBL	S4 1849+67	0.657	FSRQ	PKS 2052-47	1.489	FSRQ
RGB J0710+591	0.125	HBL	4C +56.27	0.664	LBL	PKS 0215+015	1.721	FSRQ
1ES 1215+303	0.13	HBL	S5 1803+784	0.68	LBL	MG1 J123931+0443	1.76095	FSRQ
PKS 1717+177	0.137	LBL	Ton 599	0.724565	FSRQ	MG2 J101241+2439	1.805	FSRQ
1ES 0806+524	0.138	HBL	B2 0716+33	0.779	FSRQ	4C +38.41	1.81313	FSRQ
TXS 1055+567	0.14333	IBL	TXS 0106+612	0.785	FSRQ	PKS 0805-07	1.837	FSRQ
3C 273	0.158	FSRQ	B2 2234+28A	0.795	LBL	PKS 1502+106	1.83928	FSRQ
1ES 1218+304	0.182	HBL	PKS 0440-00	0.844	FSRQ	4C 01+02	2.099	FSRQ
OX 169	0.211	FSRQ	3C 454.3	0.859	FSRQ	S4 0917+44	2.18879	FSRQ
1ES1011+496	0.212	HBL	TXS 1920-211	0.874	FSRQ	PMN J1344-1723	2.506	FSRQ

Table 1: Analyzed blazar list.

Data analysis

We analyzed the Fermi LAT data between 4th Aug. 2008 and 9th June 2014, using the UNBINNED likelihood analysis package of ScienceTools-v9r33p0 with the P7REP_SOURCE_V15 post-launch instrument response function.

We selected events of energy between 100 MeV and 300 GeV within 10 degrees of the position of each sources.

The spectra of target AGNs were fitted to the log-parabolic

$dN/dE = N_0(E/100\mathrm{MeV})^{-\{\alpha+\beta\log(E/100\mathrm{MeV})\}}$, $N_0[\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{MeV}^{-1}]$.

N_0 was flux normalization, α and β were photon index parameter. If β equal zero, the log-parabolic spectrum becomes same meaning as Power-Law spectrum.

Background sources were used the spectra listed in 2FGL (the second Fermi Gamma-ray LAT) catalog. The analysis details were described in Tsujimoto et al (2014)[6].

We used TS > 9.0 (> 3σ) and α > 0.01 to compute Fvar.

First step, we made 30 days bin light curves (shortest time scale in this study).

Second step, if calculated Fvar was not required some criteria(upper limit rate ≤ 0.6 light curve had significant variation in χ^2test (> 2σ significant)), we adopted more long separate time (bin size) light curves (60 days, 90 days, 150 days, and 300 days).

Light curve (0.1 GeV < E < 300 GeV), 30 days bin.

Mrk 421 (z = 0.031)

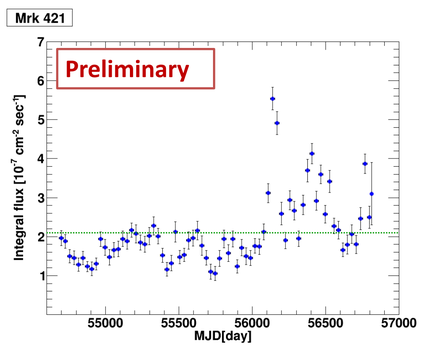

Fig.1, Mrk 421

- Subclass: HBL
- Fvar = 42.63 ± 1.28 %
- Average flux = (2.06 ± 0.36) × 10^{-7} cm^{-2} s^{-1}

S3 0218+357 (z = 0.944)

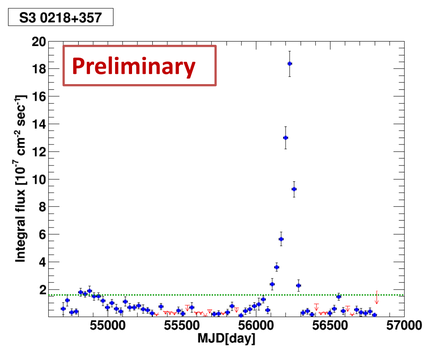

Fig.2, S3 0218+357

- Subclass: Uncertain
- Fvar = 198.05 ± 2.78 %
- Average flux = (1.59 ± 0.30) × 10^{-7} cm^{-2} s^{-1}

PKS 0454-234 (z = 1.003)

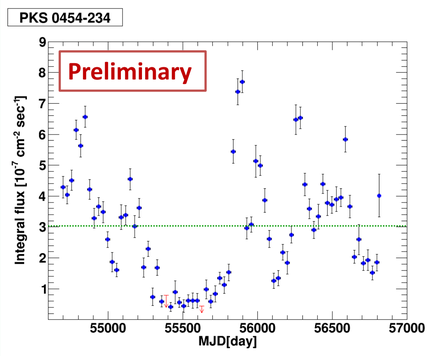

Fig.3, PKS 0454-234

- Subclass: FSRQ
- Fvar = 59.92 ± 1.28 %
- Average flux = (3.03 ± 0.31) × 10^{-7} cm^{-2} s^{-1}

Redshift vs. Fvar

Fvar distribution for redshift

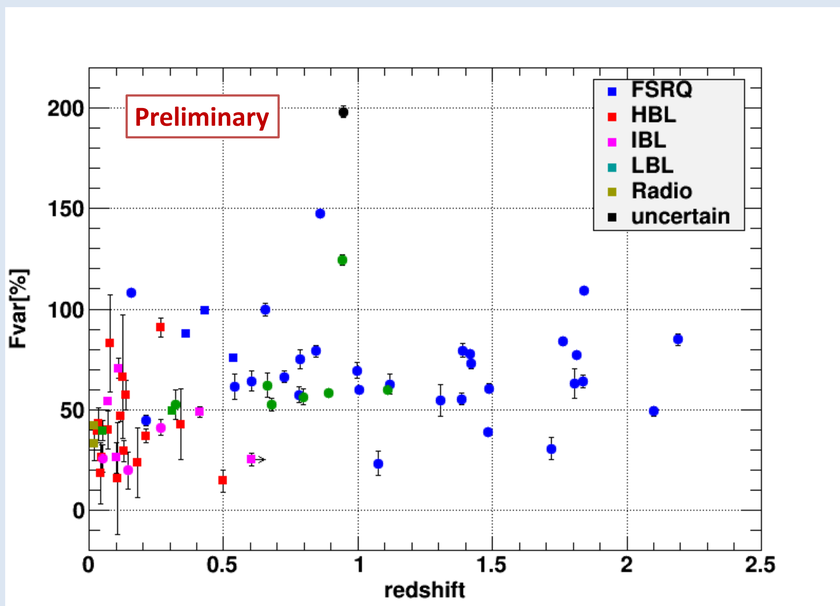

Fig.4 redshift vs. Fvar

(Large Fvar → Large variability amplitude of the GeV gamma-ray LC.)

- GeV gamma ray from FSRQs could be detected at high redshift(z>0.5) and have the large Fvar.
- In addition, HBL and IBL assemble in z < 0.5.
- Therefore blazar subclass seems to change along the increasing redshift.

- Peculiar features were as follows;
- S3 0218+357 shows the extreme large Fvar.
- PKS 0301-243 has the large Fvar for HBLs and also AO 0234+164 has large Fvar for LBLs.

Fvar histogram

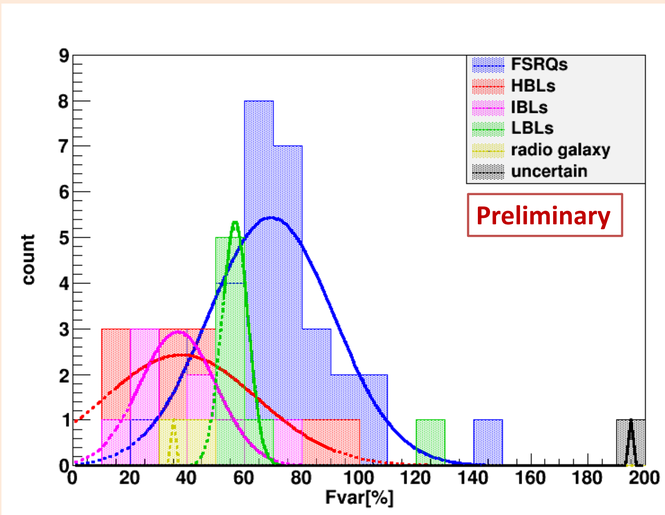

Fig.5 Fvar histogram

- A bin of the histogram is 10%.
- Solid lines show the Gaussian fitting of the each histogram and dash lines extrapolate fitting curve.
- HBLs and IBLs has the similar distribution and also FSRQs and LBLs.

discussion

Results

- Fvar and subclass are potentially-correlated, and blazar subclass seems to change along the increasing redshift (fig.4).
- HBLs and IBLs are distributed with z < 0.5, in contrast to the FSRQ distribution (fig.4 and 5).
- The first peak of SED tend to be lower frequency with the increasing Fvar (fig.5).

However (some problems)

- The synchronizing of redshift and Fvar might be caused by observing effect.
- There is a possibility that peak of Fvar histogram became large value because low level flux sources are could not calculate Fvar.
- Some AGN redshifts have large margin of errors.
- This study could not considered the short time scale variability (< 30 days). If the short time scale variability occurred, Its Fvar become larger than our results.
- We selected the bright AGN and TeV gamma-ray sources. Therefore, our sample might contain selection effects.
- Fvar values are changed if log-parabola and power-low spectra are used as the fitting function.

Conclusion

- Fvar and subclass are potentially-correlated, and blazar subclass seems to change along the increasing redshift.
- HBLs and IBLs are distributed with z < 0.5, in contrast to the FSRQ distribution.
- The first peak of SED tend to be lower frequency with the increasing Fvar.

Reference

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[3] Fermi-LAT Collaboration, ApJ, 743, (2011) 171
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[6] S. Tsujimoto, et al, JPS conference proceedings, 1, (2014) 013106