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Connection Between Superluminal Ejections and γ-Ray Flares in Blazars

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Abstract

We examine the coincidence of times of high γ-ray flux and epochs of zero separation of superluminal components from the core in EGRET blazars based on our 1993.9–1997.6 VLBA monitoring program at 22 and 43 GHz. In 19 cases of γ-ray flares for which sufficient VLBA data exist, 10 of the flares fall within 1σ uncertainty of the extrapolated epoch of zero separation from the core of a superluminal radio component. The number expected by random chance ≤ 3 at 95% confidence. Although there are a small number of cases in which the γ-ray flux was low at the extrapolated epoch of ejection, these can be explained by accelerations or decelerations in the proper motions, as expected, for example, in bent jets.

1 Introduction

We have completed a program of monitoring of the milliarcsecond-scale structure of γ-ray bright blazars (42 sources) with the VLBA at 22 and 43 GHz during the period from November 1993 to July 1997. We have determined velocities of jet components in 33 sources and compare the epochs of zero separation from the (presumed stationary) core with the γ-ray light curves obtained from the 3rd EGRET catalog (Hartman et al. 1999) in order to determine whether γ-ray flares are associated with major energetic disturbances that propagate down the jet.

2 Detections of Gamma-Ray Flares

One of the most difficult aspects of the analysis is to detect a γ-ray flare because the light curves are very sparse. For this purpose we have determined the average γ-ray flux of every source as a weighted average value of all measurements, including the upper limits to the flux, with weight equal to $1/\sigma$, where σ is an error of the measurement; in the case of an upper limit σ is equal to the value of the upper limit itself. We assume that a γ-ray flare is detected if the flux measurement exceeds the average flux value by a factor of 1.9 or more and if the uncertainty in the measurement is less than the deviation of the measurement from the average value. In 29 cases the VLBA data are contemporaneous with the γ-ray observations; in 19 of these 29 cases a γ-ray flare is detected.

3 Discussion

3.1 Positive Detections

In 10 of these 19 cases the epochs of zero separation coincide, to within the 1-σ uncertainties, with the times of the γ-ray flares. (For 0458−020, the coincidence is within the 2-σ uncertainty. For both 1222+216 and 1226+023 there are only two epochs of VLBA observations; in these cases we assume that the 1-σ uncertainties = 0.2 yr, similar to those of many other objects). These results are presented in Table 1, where the first column gives the name of the source, the second - redshift, the third - the ratio of the peak γ-ray flux to the average flux, the fourth - the time of the γ-ray flare, the fifth - the epoch of zero separation, and the sixth - the apparent speed (H_0 = 100 h km s^{-1} Mpc^{-1}, q_0=0.1)

Seven sources (0234+285, 0446+112, 0917+449, 0954+658, 1606+106, 1611+343, and 1739+522) can be classified as inactive γ-ray blazars since they do not show significant variability during the γ-ray observations. No disturbances that propagate down the jet are seen in any of these sources during the period covered by our VLBA observations.

3.2 Marginal Detections

In the case of five additional sources (0420−014, 0716+714, 1253−055, 1406−076, and 1908−201) there is a hint of an association between γ-ray variability and ejection of superluminal jet components. For 0420−014, 1253−055, and 1406−076 the time of ejection of a component differs from the time of a γ-ray flare by less than the 3-σ uncertainties of the

Table 1: Epochs of Zero Separation and Times of Peak γ-Ray Flux

Name	z	Factor of γ-ray flare	Time of separation	Epoch of zero	β_{app}h
0336−019	0.852	5.3	1995.266	1995.2±0.1	5.8±0.5
0440−003	0.844	3.0	1994.632	1994.7±0.2	8.5±0.8
0458−020	2.286	3.2	1994.212	1994.0±0.1	9.0±0.8
0528+134	2.06	4.0	1993.233	1993.2±1.6	24±14
				1993.4±0.7	15±6
0836+710	2.17	1.9	1992.197	1992.1±0.2	14±1
1222+216	0.435	2.3	1992.984	∼1993.1	∼8.5
1226+023	0.158	2.2	1993.899	∼1994.2	∼3.0
1622−253	0.786	1.9	1995.460	1995.7±0.2	17.5±1.1
		2.0	1995.729		
1622−297	0.815	3.4	1995.441	1995.2±0.2	16.0±0.8
		4.7	1995.460		
		3.9	1995.482		
		3.5	1995.482		
1730−130	0.902	2.2	1995.510	1995.5±0.2	6.1±2.1

times of zero separation. For 0716+714 and 1908−201 the times of zero separation correspond to less significant increases (by factors of 1.4 and 1.3, respectively) over the mean γ-ray fluxes.

3.3 Negative Detections

For four sources (0219+428, 0851+202, 1510−089, 2230+114) γ-ray flares were not detected, but we can follow moving components and in three cases even multiple knots. The γ-ray measurements nearest in time to the zero separations correspond to low levels of γ-ray flux. However, because of the sparseness of the γ-ray light curves, such non-correspondence can be explained if the time scale of a high γ-ray state is of the same order as or less than the typical 1-σ uncertainty of the epoch of zero separation ($\sim$0.2 yr). If we assume that γ-ray flares are associated with ejections of superluminal jet components, then it is more challenging to explain the absence of moving knots connected with γ-ray flares in four sources (0827+243, 1127-145, 1219+285, and 1633+382), since if components were ejected they should have been detected by our VLBA observations. Nevertheless, there are possible explanations of such non-correspondence: the marginal significance of the γ-ray flare in 0827+243, two different possible cross-epoch identifications of components in 1219+285, and possible deceleration of a component in 1633+382).

3.4 Statistical Simulations

We have generated 10^6 samples of random epochs of zero core-knot separations over a 5-year period of γ-ray observations to define the probability of random coincidences between 19 fixed epochs of γ-ray flares and ejections of superluminal jet components. A coincidence was recorded if the difference between the epoch of a γ-ray flare and an epoch of zero separation was equal to or less than 0.2 yr. The results are presented in Fig. 1, which shows that in a sample of 19 events the number of chance coincidences ≤ 3 at the 95% confidence level. If the number of coincidences ≥ 5 the γ-ray flares and superluminal ejections are associated with each other at the 99.9% confidence level.

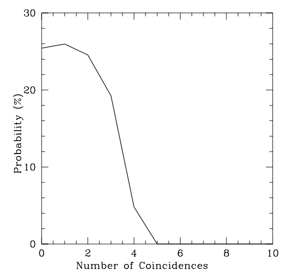

Figure 1: Probability of random coincidences between γ-ray flares and epochs of zero separation.

4 Conclusion

It is very striking that, despite the sparse character of the γ-ray light curves and uncertainties of epochs of zero separation of about 0.2 yr, 50% of the γ-ray flares are associated with the ejection of superluminal jet components. This implies that the γ-ray high states are not, in general, merely very short-timescale peaks of constantly fluctuating γ-ray emission, but rather correspond to major disturbances in bulk Lorentz factor and/or flow energy of the relativistic jet.

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References

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