Kinematics of Jets in Gamma-Ray Blazars

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Abstract. During the EGRET era some correlations between γ-ray and radio properties of blazars were discovered: the highest apparent speeds occur in γ-ray blazars and a connection exists between ejections of superluminal components and high states of γ-ray emission. We discuss the strategy of VLBA observations combined with GLAST data to test these findings.

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THE EGRET ERA OF BLAZAR MONITORING

Blazars, defined as quasars and BL Lac objects containing compact, variable radio sources with flat centimeter wave spectra, form the most numerous class of objects detected by EGRET [4]. One of the main characteristics of blazars is strong radio emission on parsec scales in the form of one-sided, highly relativistic jets (Fig. 1, *left*). Analyses of EGRET-detected blazars reveal a tight correlation between γ-ray flux and radio flux contained in the compact jets [3, 11, 6] and the highest apparent speeds in their jets among the radio sources [6, 8]. This suggests that the γ-ray emission takes place in the most compact, highly beamed region of the relativistic jet. Moreover, Jorstad et al. [7] found a statisticaly meaningful correlation between high γ-ray state and ejection of superluminal jet components, with the ejection preceeding a γ-ray flare. This implies that the γ-ray events occur in the superluminal knots at distances of several parsecs from the central engine. Comparison of the EGRET γ-ray and Metsähovi radio light curves allowed Lähteenmäki & Valtaoja [9] to conclude that the γ-ray emitting region responsible for the γ-ray variability in quasars is located, on average, $\sim$5 pc from the VLBI core.

The most popular model for the high energy emission in blazars is inverse Compton scattering of low energy photons (seed photons) by highly relativistic electrons up to X-ray and γ-ray energies. The seed photons can be either synchrotron photons from within the jet [the synchrotron-self-Compton, SSC, process, e.g., 1] or from the accretion disk or the broad-line region [the external radiation Compton, ERC, process, e.g., 2]. However, if the variable γ-ray emission is associated with superluminal knots, then the γ-rays originate well downstream from the accretion disk or the broad-line region and the SSC process should be responsible for the γ-ray production. In this case the Doppler and Lorentz factors of the γ-ray emission must be similar to those of the synchrotron radio emission and can be derived from the kinematics of the parsec-scale jets [5]. The latter requires high resolution Very Long Baseline Interferometric observations for which the Very Long Baseline Array (VLBA) is an ideal instrument. Such observations during operation of the Gamma-ray Large Area Space Telescope (GLAST) will confirm or reject the correlations. However, the success of this endeavor depends strongly on the methodology of the VLBA observations.

FREQUENCY OF EJECTION AND LIFETIME OF SUPERLUMINAL COMPONENTS

Jorstad et al. [5] have performed bimonthly monitoring from March 1998 to April 2001 of 15 active galactic nuclei (AGN) with the VLBA at 43 GHz. 13 objects in their sample are γ-ray blazars detected by EGRET. Figure 1 (*middle)* shows the distributions of the number of components emerging from the core per year, although none of the sources show periodicities in component ejections. Figure 1 (*right)* shows the distribution of lifetimes of components, ΔT, defined from the light curves as the time interval within which the flux of a component detected near the core decreases by factor of 2 from its maximum observed value. The time of separation of a superluminal component from the core, $T_\circ$, is estimated for 79 events. The uncertainty of $T_\circ$ depends on many factors, such as the brightness of a component, its speed, and trajectory; however, mainly it is determined by the number of epochs during which a component has been observed. Experience shows that the most accurate estimate of the time of separation (within a week) requires $\geq$6 epochs of observations of the same component. Such accuracy, needed for comparison with γ-ray light curves of

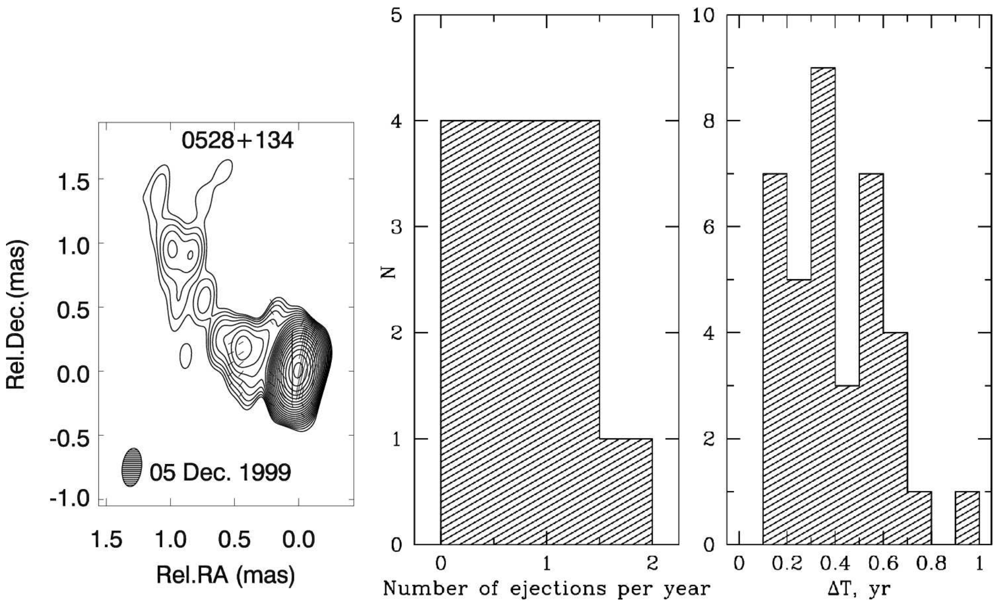

FIGURE 1. *Left:* 43 GHz image of the quasar 0528+134. The peak of the total intensity is 4.74 Jy/beam, the beam is indicated in the left bottom coner, the linear segments show direction of polarization. *Middle:* Distribution of number of ejections per year of 13 well-monitored blazars. *Right:* Distribution of lifetimes of superluminal components at 43 GHz.

blazars that possess variability on time scales ranging from hours to years [10], can only be obtained at present with the high-resolution imaging available with VLBI at 43 GHz.

Figure 1 shows that only 40% of sources in the sample undergo at least one ejection per year and only 35% of superluminal components have lifetimes at 43 GHz $\geq$0.5 yr. This means that to determine meaningful correlations between γ-ray and radio events (at least 10 superluminal ejections) within a one-year program $\sim$70 blazars with good γ-ray light curves should be monitored monthly with the high resolution of VLBI or $\sim$30 sources over 2 years. The latter is a reasonable task that can be performed with the coordinated efforts of GLAST and the VLBA.

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