Use of Multiwaveband Polarization and Light Curves to Identify Sites of Gamma-Ray Emission in Blazar Jets

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Abstract. We describe how the combination of VLBA and optical polarization monitoring identifies the site on the VLBA images where the variable optical emission occurs. Correlation between the optical and X-ray and/or γ -ray light curves then establishes an association of the emission across the electromagnetic spectrum with a particular feature on the images. Application of this technique to blazars monitored by GLAST will allow us to construct multiwaveband emission maps of their compact relativistic jets.

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LIGHT CURVES, IMAGES, AND POLARIZATION AS PROBES OF BLAZAR JETS

Studies of continuum variability in blazars have the potential of probing relativistic jets on the smallest angular scales. The goal is to explore the dynamics and other physical conditions such as the formation of shocks, turbulence, and processes by which electrons gain and lose energy. However, the method used in isolation provides timescales, not maps, so while the sizes of the sites of variable emission can be inferred, without further information their locations in the jet cannot. This point has been emphasized by the recent observation of X-ray variability on timescales of months in M87 [2], with a new knot appearing and moving at an apparently superluminal speed, more than 120 pc from the nucleus [1].

Very Long Baseline Interferometry (VLBI) provides images of the emission, but only at wavelengths longer than a few mm. In order to provide the information necessary for making a multiwaveband emission map, we therefore need to provide a connection between features on the VLBI images and events seen in the light curves at shorter wavelengths. While correlations of light curves of the individual features seen on the VLBI images with changes in the flux at shorter wavelengths can in principle provide this information, in practice cross-wavelength time lags, multiplicity of flares, and variations that are seen only over a few decades of wavelengths render the method ineffective except in isolated cases. However, if variations in total flux are combined with polarization information, a much more robust procedure emerges. Here we describe a program that combines Very Long Baseline Array (VLBA) observations with multiwaveband flux and polarization monitoring of blazars, with the potential of providing the time sequences of multiwaveband emission maps that can provide rigorous tests of theoretical models.

Similarity between mm-wave and optical polarization electric vector position angle (EVPA) provides a robust method for locating regions that emit at both wavebands [see 3]. If simultaneous variations in mm-wave and optical EVPA track each other, we can associate the variable optical emission with a specific feature on the 43 GHz VLBA images. Our pilot program started in 2005 suggests that this connection is not only possible, but actually is common. That is, the variable optical emission is often co-spatial with either the core or a superluminally moving knot that is near the core and subsequently separates from the core on 43 GHz VLBA images. We have observed this in a few blazars in which the optical EVPA and the EVPA of a compact component in the 43 GHz images track each other remarkably well. Two examples are shown in Figure 1.

EXTENSION TO HIGH-ENERGY EMISSION

Polarization can currently be measured only at radio, mm/submm, near-IR, and optical wavelengths. Inclusion of other wavebands in the emission maps can be accomplished through correlations of light curves at these wavebands with those at wavelengths at which polarization observations are possible. For example, if γ -ray and optical flux vary



FIGURE 1. Left 4 panels: Sequences of VLBA images (left: I, right: P with polarization sticks) at 43 GHz of 3C 279 and PKS 1510–089. Knots can be identified by their distinct EVPAs. Contours in the I maps are in factors of $\sqrt{2}$ starting from 0.25% ×11.9 Jy/beam & 0.6% ×1.13 Jy/beam for 3C 279 & PKS 1510–089, respectively, while in the P maps the contours are in factors of 2 starting from 3% ×0.443 Jy/beam for 3C 279 and 3% ×0.061 Jy/beam for PKS 1510–089. *Rightmost panel:* Comparison of time variations of polarization of knots on the VLBA images with optical polarization for the source as a whole (circles connected by solid lines). X's connected by dotted lines: VLBI core (A2 in 3C 279, A in 1510–089); triangles connected by dashed lines: moving knot B; for 3C 279 only, stars connected by dash-dot lines: feature A1, which first appears upstream of the core. A sharp increase in optical % polarization (top panels) suggests the appearance of a new knot. Correspondence of the EVPA (bottom panels) across wavebands indicates that the same component is involved. The optical EVPA tends to fluctuate by tens of degrees about a mean value. Taking this into account, we associate the flare in optical polarization in 3C 279 near JD 2453480 with knot A1, while the optical polarization outburst near JD 2453480 in 1510–089 appears to be connected with superluminal knot B, evident during the 1st 3 epochs of the VLBA images before another event dominates in the optical. For reference, JD 2453500 is 9 May 2005.

simultaneously, we can identify the high-energy emission with the feature on the VLBA image that has the same polarization direction as seen in the optical.

In two radio galaxies, 3C 120 and 3C 111, the appearance of new superluminal knots in the jet follows by 2–4 months a dip in the flux X-rays coming from the accretion disk/corona region [4, 5]. If these objects are strong enough γ -ray emitters to measure variability with GLAST, we can use relative timing of X-ray, γ -ray, optical, and mm-wave events to determine how far from the black hole the γ -ray emission originates. We will then have a complete emission map of the synchrotron and high-energy emission from near the black hole out to the radio jet.

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