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Position Angle Changes of Inner-Jets in a Sample of Blazars

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Abstract. We have carried out the Gaussian model-fitting to 15 GHz VLBA cores for a sample of blazars from the MOJAVE database, analysed the correlations in the model-fitted parameters and studied the variability properties for different group of sources. We found that the Fermi LAT-detected blazars have on an average higher position angle changes of cores than the non-LAT detected blazars, and that the LAT-detected ones are associated with more variable cores in flux density.

Key words. Active galactic nuclei: blazars—radio continuum: variability—γ-ray: Fermi-LAT.

1. Model-fit and statistical analysis

We compiled a sample of 104 blazars that have been monitored for more than 10 years with VLBA at 15 GHz till the end of 2011 and have at least 15 epoch data sets with good time coverage, from the MOJAVE database (Lister *et al.* 2009). The 104 blazars all show prominent core-jet features in the 15 GHz VLBA images. We fitted to the 'core' component the natural-weighed 15 GHz VLBA images for each blazar, with a 2-dimensional elliptical Gaussian model in the AIPS task 'JMFIT', to get the Position Angle (PA) of the major axis of the elliptic Gaussian component, the Integrated Fux-density (IF) of the Gaussian component, and the deconvoluted major and minor axes scales of the Gaussian component. We considered that the core component of the 15 GHz VLBA image is an 'inner-jet' rather than a true core, and the inner-jet could be modelled with an elliptical Gaussian component with its major axis being along the inner-jet orientation or the inner-jet ridge-line on average, thus reflecting the inner-jet position angle. As demonstrated by Liu *et al.* (2012), the model-fitted position angles of cores are not correlated at all with the position angles of the VLBA restoring beams.

We defined ΔPA as the difference between the median and minimum of PA, and used it as a measure of the position angle changes of the inner-jet. It is expected that the Gaussian model-fitted PA of the inner-jet could be arbitrary when the minor/major ratio of the Gaussian component is close to unity, but this error in PA cannot be properly estimated by the model-fit task itself (see Condon 1997). To test this, we defined an average ratio, R, of the minor/major for each blazar core, and found a positive correlation between ΔPA and R for $\Delta\text{PA} > 25°$ which supports that the error in the model-fitted PA of the core is proportional to the minor/major ratio of the core. In the regime of smaller ΔPA and/or smaller R, this effect is not significant, e.g., there seems to be no significant correlation between ΔPA and R for $\Delta\text{PA} < 25°$. For simplicity, we divided the 104 sources into group 1 (G1) for $\Delta\text{PA} < 25°$ and group 2 (G2) for $\Delta\text{PA} > 25°$ (G1 and G2, respectively as shown in Fig. 1), and we only considered group 1 in the following, since group 2 could have relatively larger errors of inner-jet position angles. G1 contains 57 quasars and 21 BL Lac objects, out of which 58 blazars are Fermi LAT-detected and 20 are not. To analyse possible correlation between IF and PA for G1, we defined that a significant linear correlation should have an absolute value of linear correlation coefficient >0.40 at a confidence of $>95\%$. About 25% (20 out of 78) blazars showed significant linear correlations between IF and PA. The details are shown in Table 1. The columns are: (1) source type, (2) source count, and (3),(4) number (fraction) of sources having positive and negative correlations between IF and PA, and a $+$ or $-$ sign indicates a positive or a negative correlation, respectively. Non-ballistic counter-clockwise (or clockwise) helical jet models based mainly on the geometric beaming effect could respectively explain the positive correlation (or negative correlation) between IF and PA of inner-jets of the blazars (see Liu *et al*. 2012).

We also studied the long-term variability of the parameters PA and IF. The distributions of ΔPA for quasars, BL Lacs, the LAT-detected and non-LAT detected are shown in Fig. 2(left). The Gaussian or Lorentzian function fitting was used to fit the histogram distribution to get the peak value. The Kolmogorov–Smirnov (K–S) tests for 57 quasars and 21 BL Lacs suggest that the two distributions are not significantly different; there appears to be a peak at higher ΔPA in the BL Lacs than

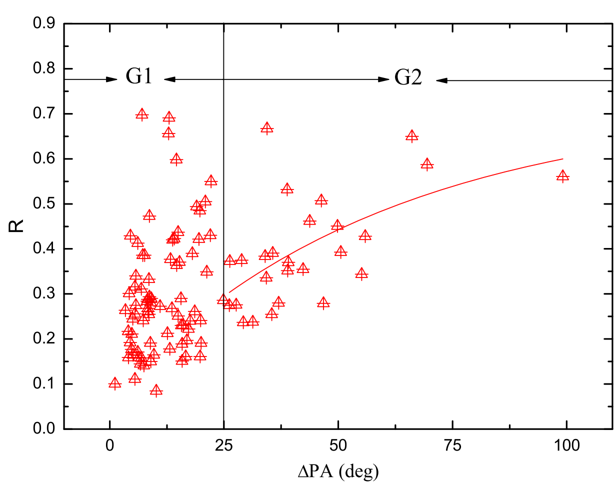

Figure 1. Relationship between the average of the minor/major axis ratio, R, and the position angle changes of inner-jet, ΔPA. A positive correlation between R and ΔPA appears in $\Delta\text{PA} > 25°$ for group G2, and there is no correlation in $\Delta\text{PA} < 25°$ for group G1.

Table 1. Statistics of correlations of IF vs. PA in G1.

(1)	(2)	(3)	(4)
Class	N	Positive corr.	Negative corr.
Blazars	78	+12 (15%)	−8 (10%)
Quasars	57	+8 (14%)	−8 (14%)
BL Lacs	21	+4 (19%)	−0 (0%)

in the quasars, but not significantly. The K–S tests for 58 LAT-detected and 20 non-LAT non-detected indicate a low probability ($p = 0.012$) for these two samples being drawn from the same parent population. It shows that the source distribution peaks at ΔPA of $12.3 \pm 0.8°$ in the LAT-detected sources being higher than the peak of ΔPA ($8.0 \pm 0.1°$) in non-LAT detected ones, which suggests that the γ-ray blazars mostly have a larger ΔPA of inner-jet than the non-γ-ray blazars.

Source counts vs. the 'relative variability of IF' (defined as long-term rms-variation divided by the mean of IF) are displayed in Fig. 2(right). The K–S tests for

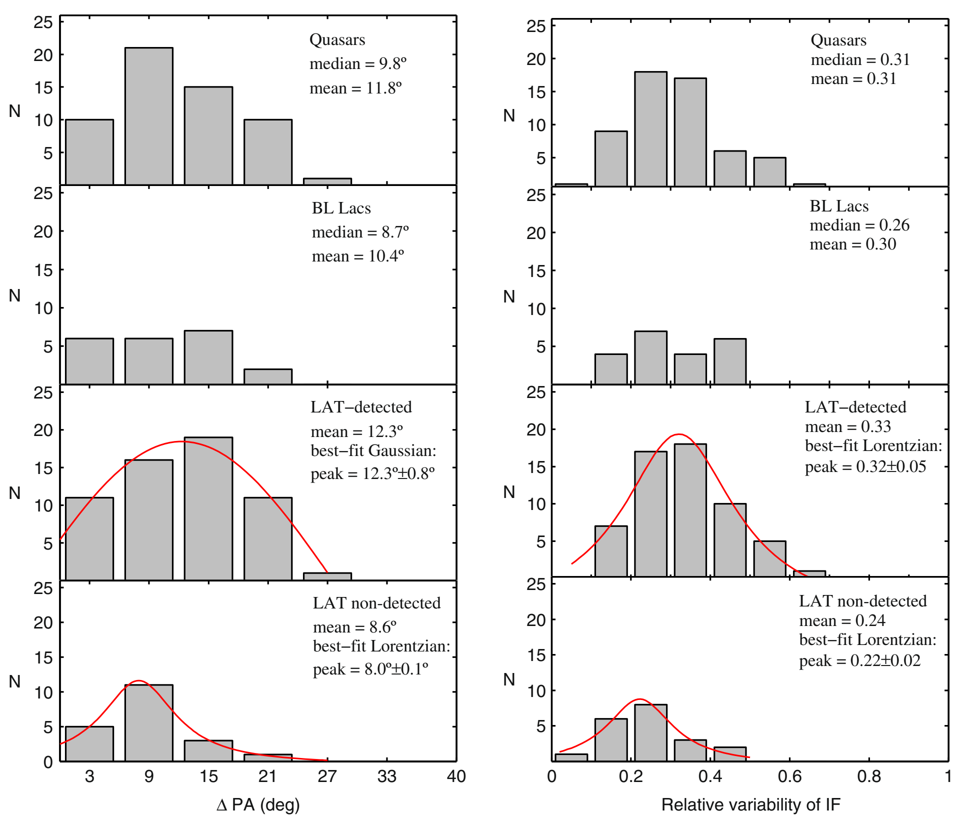

Figure 2. *Left*: Distributions of ΔPA for 57 quasars, 21 BL Lacs, 58 LAT-detected and 20 LAT non-detected, respectively from top to bottom panel. *Right*: Distributions of the relative variability (from 0 to 100%) of the intergrated flux density (IF) for 57 quasars, 21 BL Lacs, 58 LAT-detected and 20 LAT non-detected, respectively from top to bottom panel.

57 quasars and 21 BL Lacs suggest that the two distributions are not significantly different. The K–S tests for 58 LAT-detected and 20 LAT non-detected indicate a low probability ($p = 0.005$) for these two samples being drawn from the same parent population. It displays that the source distribution peaks at the relative variability of 0.32 ± 0.05 in the LAT-detected sources, which is higher than the peak of 0.22 ± 0.02 in the relative variability of the non-LAT detected sources, suggesting that the γ-ray blazars mostly have a larger relative variability of inner-jet than the non-γ-ray blazars.

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