Intrinsic anisotropy of gamma-ray emission from blazar jets?

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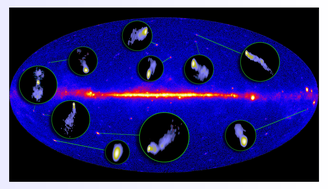
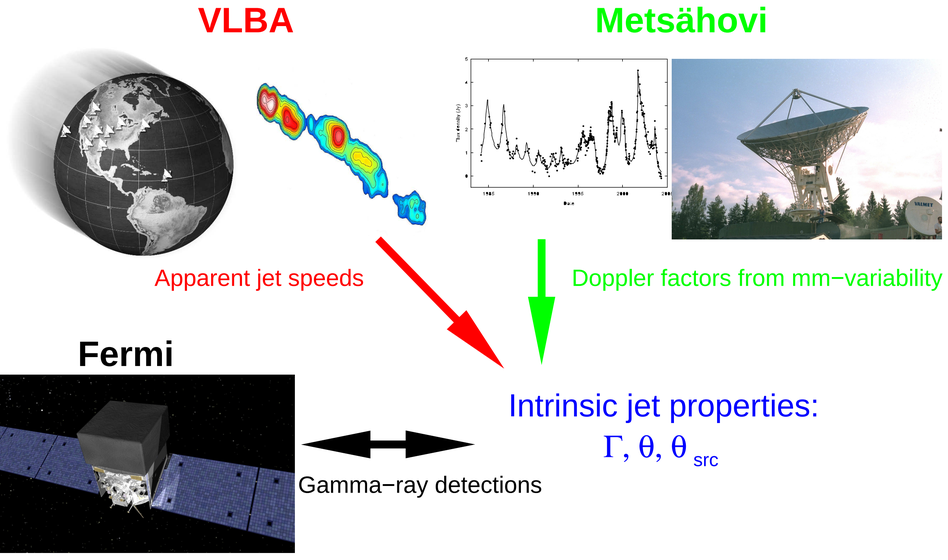


The analysis of combined radio and *Fermi* LAT data shows that the γ-ray bright blazars have higher variability Doppler factors than γ-ray weak ones. We also find a hint that γ-ray emission from blazars may be anisotropic in the comoving frame of the jet.

There is both observational evidence and theoretical arguments which strongly suggest that the MeV–GeV γ-rays from active galactic nuclei (AGN) originate in relativistic jets, but the exact mechanism of γ-ray production is poorly understood. Here we report an analysis of intrinsic jet properties of a sample of blazars detected by the Fermi Gamma-ray Space Telescope during its first three months of science operations. By combining high-resolution VLBI images and millimeter-wavelength flux density monitoring data of 62 blazars, we have estimated their jet Doppler factors, Lorentz factors, and viewing angles in the observer's frame and in the frame comoving with the jet. The analysis shows that, in addition to having on average higher variability Doppler factors, the sources detected by the Fermi LAT have a distribution of jet rest-frame viewing angles that is significantly narrower than that of the γ-ray weak sources and is centered at $\sim 75^\circ$ from the jet axis. The lack of γ-ray bright sources at small comoving frame viewing angles hints that γ-ray emission from blazars may be intrinsically anisotropic. This warrants further investigation with a larger sample.

The Metsähovi-MOJAVE sample and the analysis



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- Measurements of the apparent jet speeds from the MOJAVE program and mm-wavelength variability data from the Metsähovi AGN monitoring are used to derive the intrinsic jet properties – Doppler factor (δ), Lorentz factor (Γ), and the viewing angle in the observer's frame (θ) and in the rest-frame of the jet ($\theta_{\rm src} = \arccos\left(\frac{\cos\theta-\beta}{1-\beta\cos\theta}\right)$) – for a blazar sample. The obtained values are compared with the γ-ray detections from the LAT 3-month source list (Abdo et al. 2009a,b).
- A flux-density-limited sample of 135 compact extragalactic radio sources, mostly blazars, are monitored with the VLBA by the MOJAVE program (Lister et al. 2009).
- The Metsähovi Radio Observatory's long-term AGN flux monitoring program at mm-wavelengths has been used to estimate the Doppler beaming factors of 87 AGN by applying the light-travel time argument (Hovatta et al. 2009).
- There are 62 blazars in the flux-density-limited MOJAVE sample (at galactic latitude $|b| \geq 10^\circ$) for which variability Doppler factors have been measured (Metsähovi-MOJAVE sample; MM). The sample contains 48 quasars and 14 BL Lac objects, out of which 23 are associated with bright LAT sources from the 3-month list.

Jet properties of γ-ray blazars

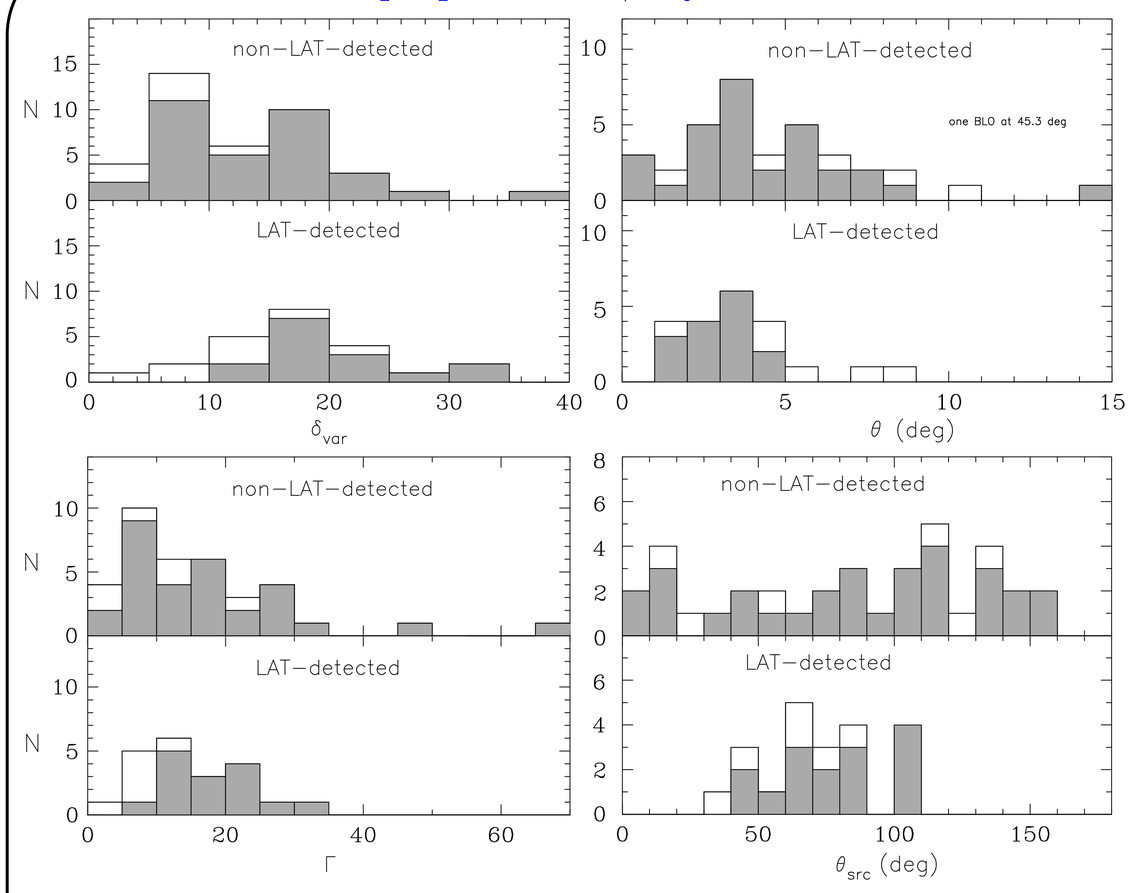

Fig. 1. *Doppler factor (Top left), Lorentz factor (Bottom left), observer's frame viewing angle (Top right) and jet rest-frame viewing angle (Bottom right) distributions in the Metsähovi-MOJAVE sample. In each panel, the upper sub-panel shows the distribution for the non-LAT-detected blazars and the lower sub-panel for the LAT-detected ones. Quasars are denoted by shaded boxes, BL Lacs by unshaded.*

The main statistical results regarding the differences between the LAT-detected and non-LAT-detected sources:

- The LAT-detected blazars have significantly higher variability Doppler factors than non-LAT-detected blazars: the mean $\delta_{\rm var}$ is 17 ± 2 for the γ-ray bright blazars (20 ± 2 for quasars) and 12 ± 2 for the γ-ray weak ones (13 ± 2 for quasars). The difference is significant at the level of $p < 0.01$ according to a one-sided Student's t-test. The same is true for quasars alone.
- The distribution of the viewing angles in the comoving frame of the jet is significantly narrower for the LAT-detected blazars than for the non-LAT-detected blazars. The comoving fluid frame viewing angles of γ-ray bright blazars have a range of $40 - 110^\circ$, while the γ-ray weak blazars have an almost uniform distribution from 0 to 160°. An Anderson-Darling two-sample test gives a probability of $p = 0.02$ that both samples are drawn from the same parent distribution and rejects this null hypothesis.
- The observer's frame viewing angle distributions of LAT-detected and non-LAT-detected quasars are drawn from the same parent distribution at a probability of only $p = 0.04$ according to an Anderson-Darling test.

Discussion

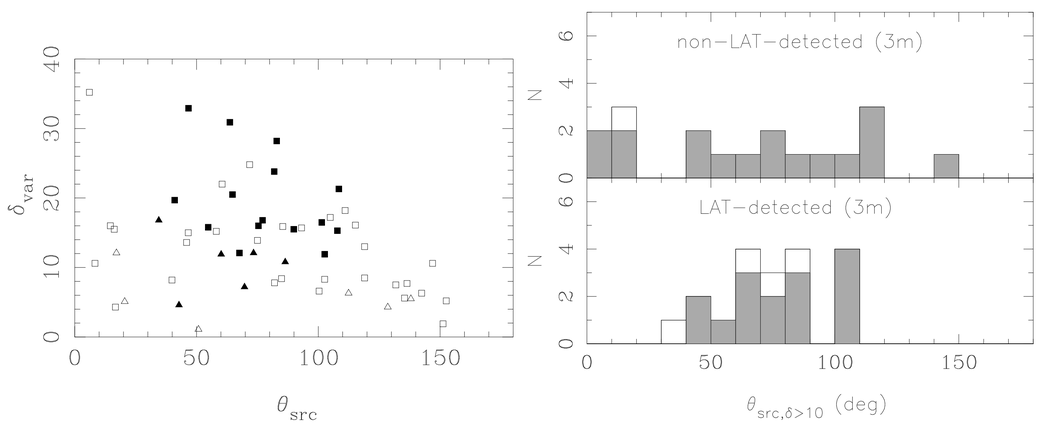

Fig. 2. *(Left:) Variability Doppler factors vs. comoving frame viewing angles in the MM sample. Squares and triangles denote quasars and BL Lacs, respectively. Filled symbols are LAT-detected sources. (Right:) Distributions of $\theta_{\rm src}$ after removing sources with a Doppler factor less than 10.*

- The lack of LAT-detected blazars at *large* comoving frame viewing angles is well explained by the γ-ray bright sources having higher Doppler factors than other blazars (see Fig. 2).
- Beaming cannot explain the lack of γ-ray bright sources at *small* comoving frame viewing angles. If the difference seen in the distributions is real, it hints of a possible intrinsic anisotropy of the γ-ray emission in the comoving frame of the jet.
- If the γ-ray emission were intrinsically anisotropic that would have important consequences for the γ-ray emission models of blazars, since it is inconsistent with their typical simplifying assumptions.
- Unfortunately, the simple detection/non-detection γ-ray data used in this analysis does not allow a firm conclusion to be drawn about the significance of the lack of LAT-detected sources at small comoving frame viewing angles if beaming is taken into account (see Fig. 2). Further investigation of a larger sample with γ-ray luminosity data is needed.

References

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Acknowledgments

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