Doubling the Sample of Jet Speed Measurements for the TeV Blazars

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Introduction and Background

The new generation of ground-based TeV gamma-ray telescopes has now detected 48 AGN (tevcat.uchicago.edu). Most of these (29 out of 48) belong to the class of high-frequency peaked BL Lac objects (HBLs), with synchrotron and inverse Compton spectra peaking in the X-ray and high-energy gamma-rays. They display remarkable variability in their gamma-ray emission on time scales of minutes (e.g., Aharonian et al. 2007), suggesting extremely high Lorentz factors of about 50 in their relativistic jets (e.g., Begelman et al. 2008).

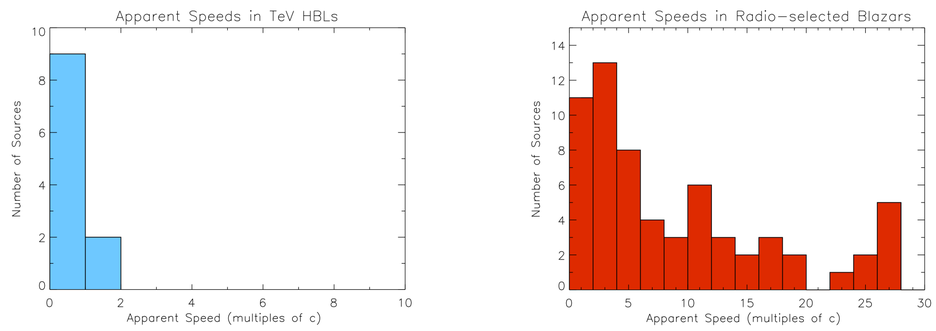
The only way to image these relativistic jets directly on the parsec-scale is in the radio with VLBI. Most HBLs are relatively faint in the radio, so they are not included in other VLBI monitoring projects. We are currently studying the parsec-scale structures of the TeV HBLs with multi-epoch VLBI imaging. Our results for six of these TeV blazars have already been reported (Piner et al. 2010); here we present multi-epoch VLBI observations of an additional five TeV blazars discovered during 2006.

Observations

We observed the five TeV blazars 1ES 1101-232, Markarian 180, 1ES 1218+304, PG 1553+113, and H 2356-309 at five epochs each from 2006 to 2009 with the NRAO Very Long Baseline Array (VLBA), at frequencies from 5 to 22 GHz. Most observations recorded three hours of data per source, at 256 Mbps. Polarization observations were made of Markarian 180 and PG 1553+113 at the first epoch. Data were calibrated in AIPS, and imaged in Difmap. We fit Gaussian components to the visibility data after imaging; the positions of the Gaussian components were then used to measure the apparent jet speeds.

Results

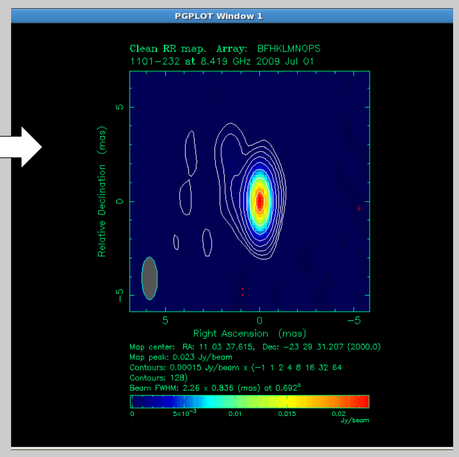
We measured apparent speeds for 10 different jet components in these five blazars, approximately doubling the number of TeV blazars for which multi-epoch parsec-scale structural information is available. The apparent speeds were all low, ranging from 0 to 1*c*, in contrast to radio and GeV-selected blazar samples, which have typical apparent jet speeds of several *c* (e.g., Piner et al. 2007). This trend was previously noted for the first six TeV blazars studied with the VLBA (Piner et al. 2010), now these additional five TeV blazars confirm and statistically strengthen that earlier result.



Distribution of peak apparent jet speeds in the 11 TeV HBLs studied to date, compared with peak apparent jet speeds in a radio-selected blazar sample (Piner et al. 2011, in preparation). The distributions differ at >99.99% confidence.

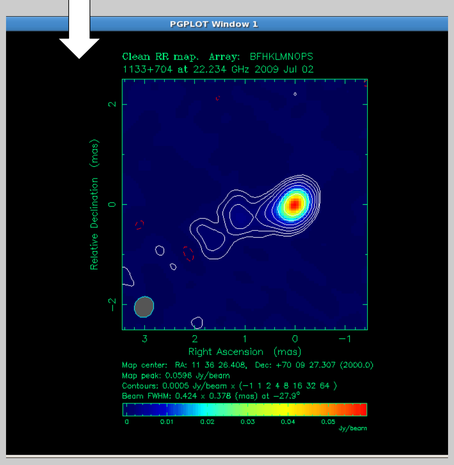
1ES 1101-232 (*z*=0.186)

Observations were made at 5 and 8 GHz. The structure consists of a 25 mJy core, and a short jet extension to the northeast that is modeled as a single 5 mJy component.



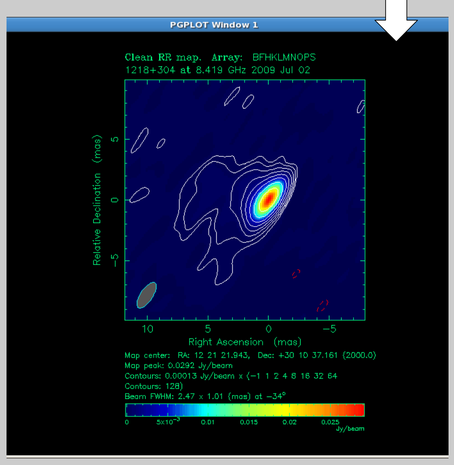
Markarian 180 (*z*=0.045)

Observations were made at 22 GHz. A jet extends several mas to the east from a 40 mJy core. The jet is modeled by four Gaussian components at most epochs. Polarization observations were done at the first epoch, and show that the core is 4% polarized with the electric vector position angle aligned with the jet.



1ES 1218+304 (*z*=0.182)

Observations were made at 5 and 8 GHz. There is a broad jet extending 10 mas to the east from a 25 mJy core. The inner 3 mas of the jet are modeled as two stationary Gaussian components.

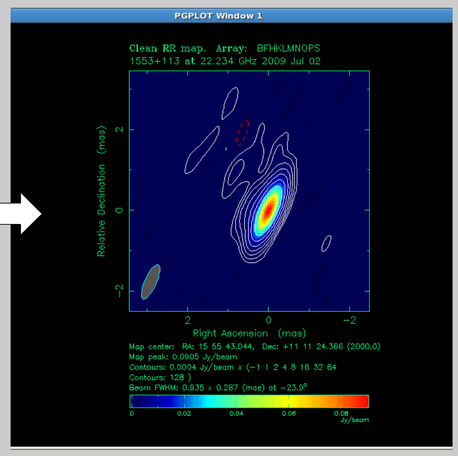


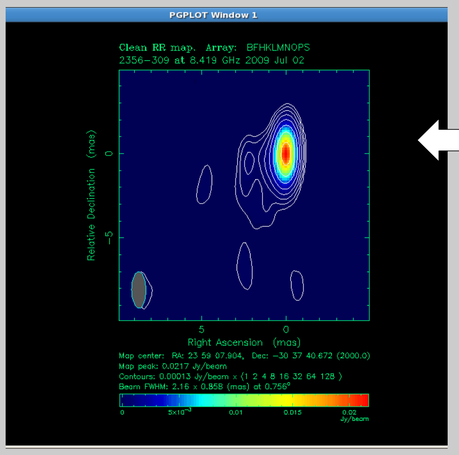
Discussion

The preponderance of subluminal apparent speeds suggests that the Lorentz factor is relatively low in the parsec-scale radio jets of these sources (Γ~ 2-3), in contrast to the high Lorentz factors that are required to explain their TeV gamma-ray emission. This implies that the relativistic jets of the TeV HBLs are *structured*, with a Lorentz factor gradient either along the jet (so that the jet decelerates by the parsec scale, e.g., Georganopoulos & Kazanas 2003) or transverse to the jet (a fast spine surrounded by a slower layer, e.g., Ghisellini et al. 2005), or both. The existence of limb brightening in the VLBI images of the nearest TeV blazars (Piner et al. 2009; 2010) supplies additional evidence that transverse structures exist in these jets.

PG 1553+113 (*z*=0.5)

Observations were made at 22 GHz. This source is compact at 22 GHz, with a ~100 mJy core and a short jet to the northeast that can be modeled as a single ~25 mJy component about 0.2 mas from the core. A single epoch of polarization observations showed the core to be 3% polarized with the electric vector position angle aligned with the jet.





H 2356-309 (*z*=0.165)

Observations were made at 5 and 8 GHz. There is a 20 mJy core and a jet extending several mas to the southeast that is modeled by two components.

Acknowledgements

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References

Aharonian, F., et al. 2007, ApJ, 664, L71
Begelman, M. C., et al. 2008, MNRAS, 384, L19
Georganopoulos, M., & Kazanas, D. 2003, ApJ, 594, L27
Ghisellini, G., et al. 2005, A&A, 432, 401
Piner, B. G., et al. 2007, AJ, 133, 2357
Piner, B. G., et al. 2009, ApJ, 690, L31
Piner, B. G., et al. 2010, ApJ, 723, 1150