The Parsec-Scale Structure of the Newer TeV Blazars

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Introduction and Background

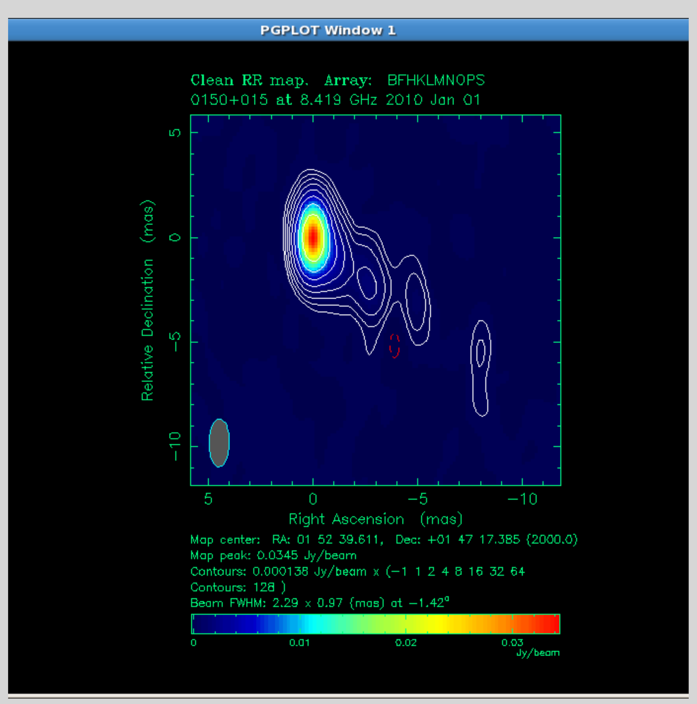
The current generation of ground-based TeV telescopes has now detected 55 AGN (tevcat.uchicago.edu). Most of these (41 of 55) belong to the class of high-frequency peaked BL Lac objects (HBLs), with synchrotron and inverse Compton spectra peaking in X-rays and high-energy gamma-rays, respectively. These TeV HBLs 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 jets directly on the parsec-scale is in the radio with VLBI. Most HBLs are relatively faint in the radio, so they are not well represented in other VLBI monitoring projects. We are taking advantage of both the rapidly growing TeV blazar source list and the upgraded sensitivity of the VLBA to begin a significant expansion of our previous work on the parsec-scale structure of TeV blazars. We have previously reported multi-epoch VLBI results for 11 TeV blazars (e.g., Tiet et al. 2012, Piner et al. 2010), and in this poster we present first-epoch VLBI observations of 10 new TeV blazars discovered during the years 2007 to 2009, several of which had never before been imaged with VLBI.

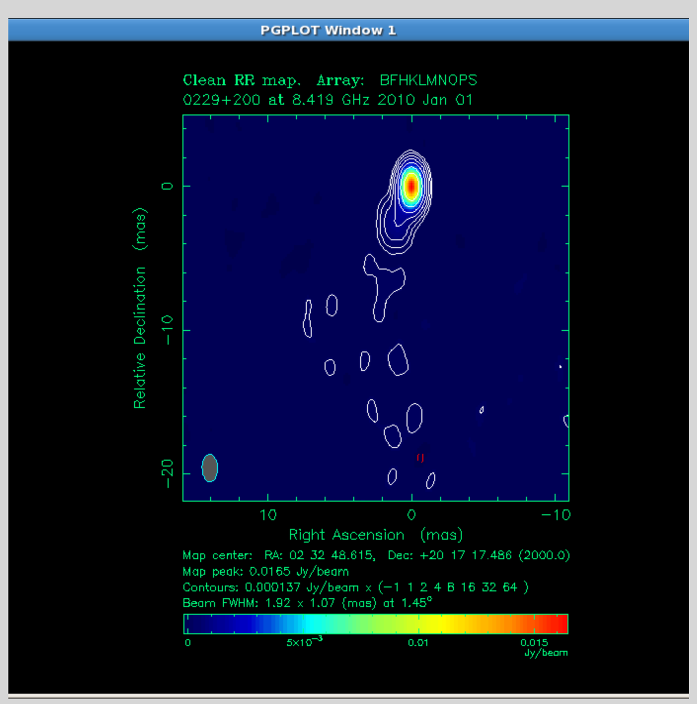
Observations

We observed these 10 new TeV blazars with the VLBA at one epoch each between 2009 and 2011, under observing codes BE055 and BE057. Observing frequencies ranged from 8 to 22 GHz, depending on source brightness. Earlier observations (BE055) used a data rate of 256 Mbps, while the later observations (BE057) used a higher data rate of 512 Mbps. The average observing time per epoch was five hours. Observations were done in phase-referencing mode for 7 of the 10 sources, both to aid in detection and to obtain precise mas-scale positions. Data were calibrated in AIPS, and imaged in Difmap.

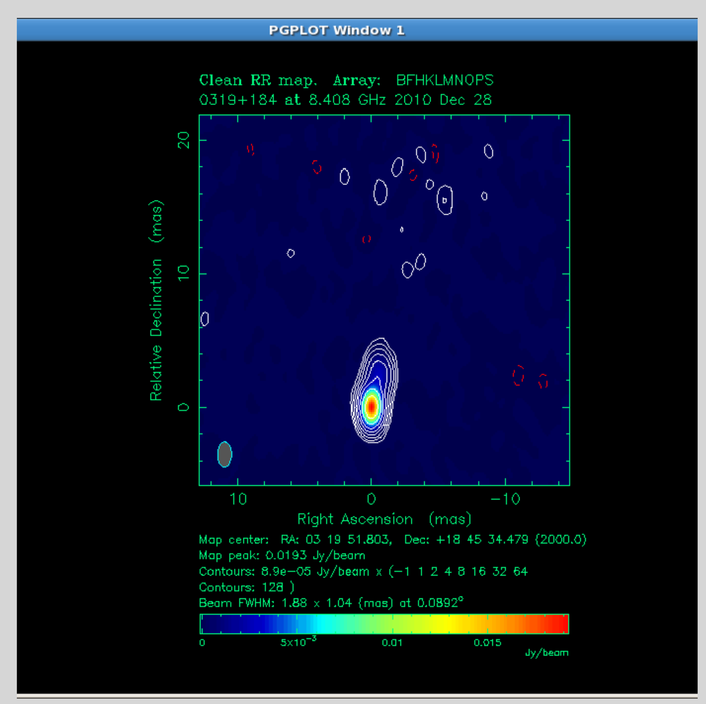
RGB J0152+017 (z=0.08)



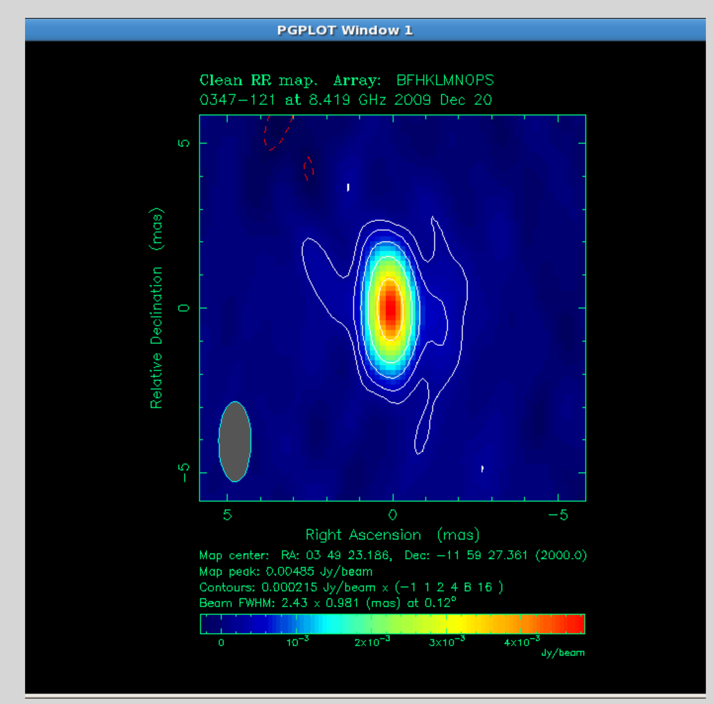
1ES 0229+200 (z=0.14)



RBS 0413 (z=0.19)



1ES 0347-121 (z=0.185)



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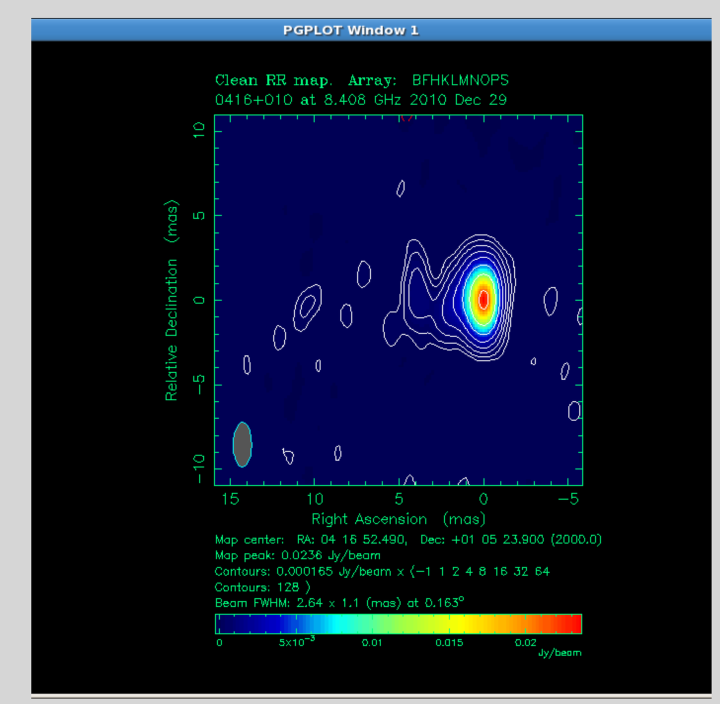
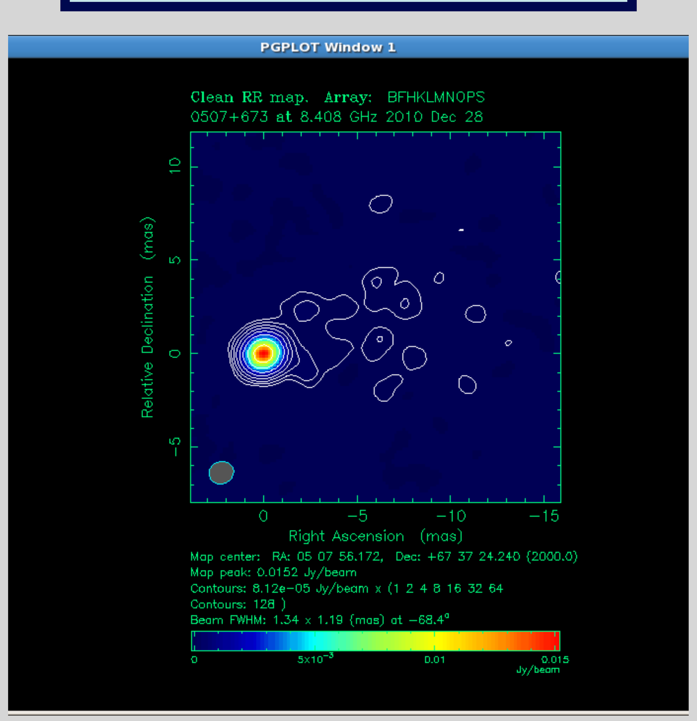
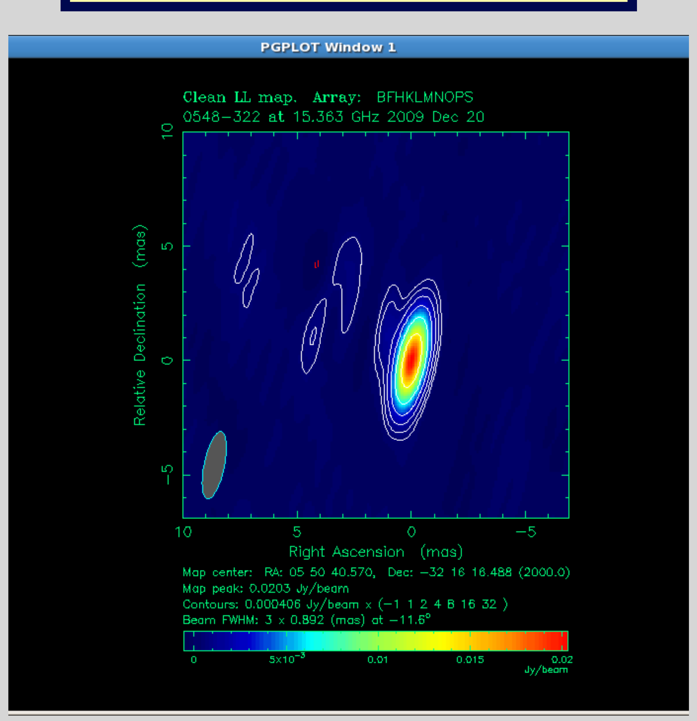


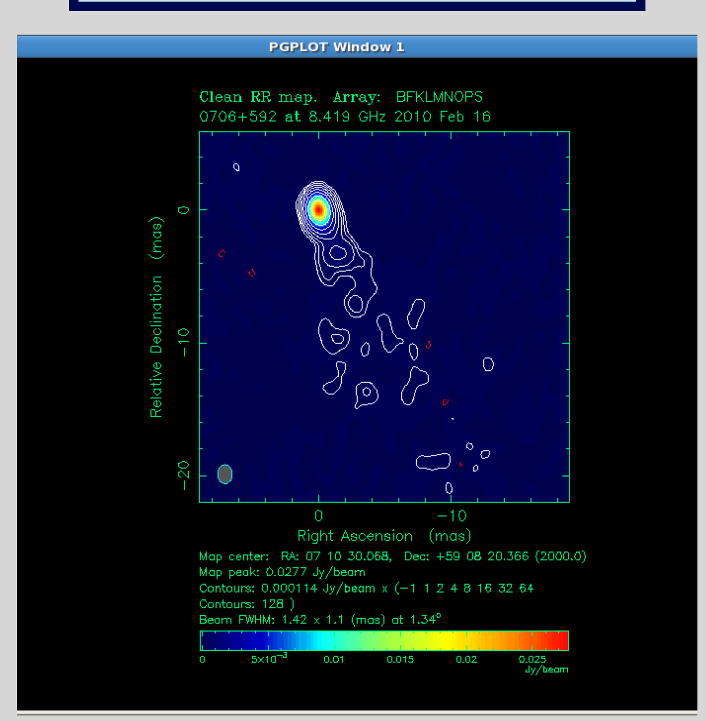
1ES 0502+675 (z=0.314)



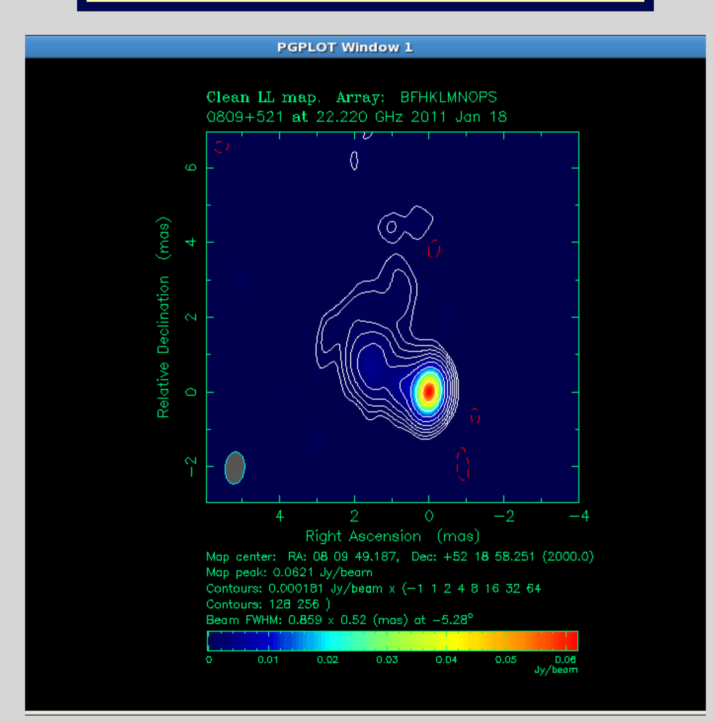
PKS 0548-322 (z=0.069)



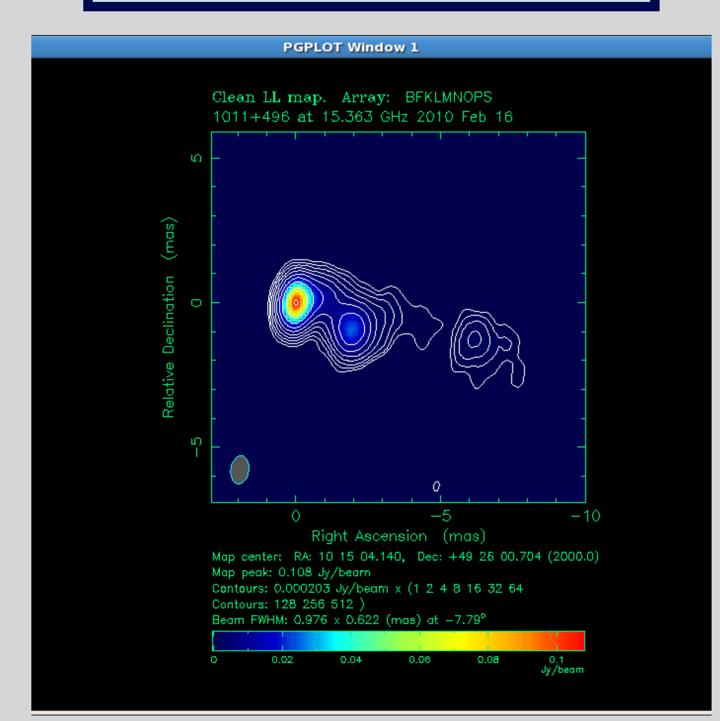
RGB J0710+591 (z=0.125)



1ES 0806+524 (z=0.138)

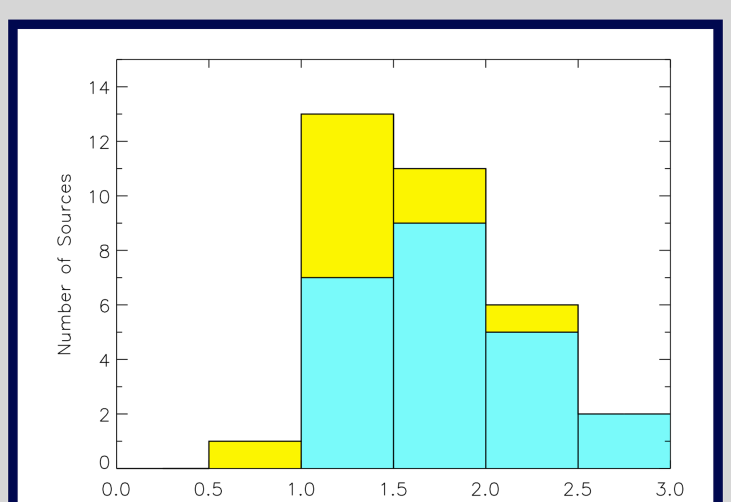


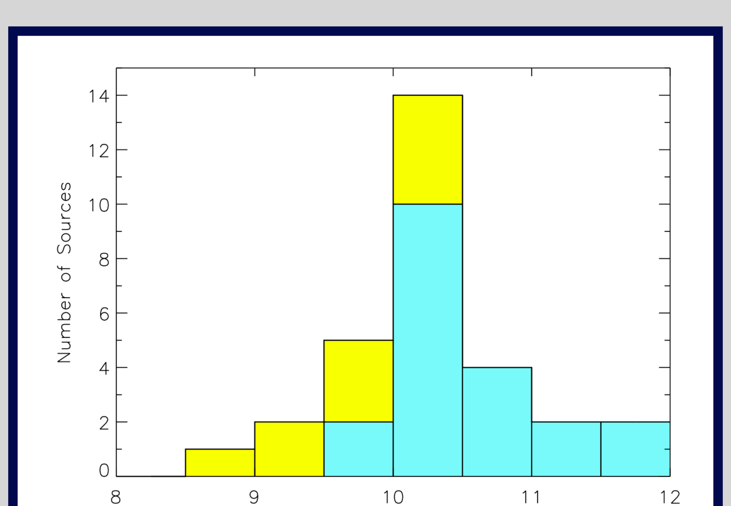
1ES 1011+496 (z=0.212)



Results

All 10 sources were successfully detected and imaged, the VLBA images are shown above. Precise mas-scale positions were obtained by phase referencing for those sources with uncertain positions. All 10 sources show a one-sided core-jet structure; these were modeled as a core and from one to four circular Gaussian jet components. Several sources show a collimated limb-brightened region, followed by low surface brightness extended emission with a much broader opening angle beyond a few mas from the core, reminiscent of the similar parsec-scale morphology of Markarian 421 and Markarian 501. Core flux densities range from 5 to 106 mJy with a median of 22 mJy. Most VLBI core components were partially resolved, and best-fit Gaussian brightness temperatures range from 8×10^{8} K to 3×10^{10} K, with a median brightness temperature of 8×10^{9} K.





Distribution of VLBI core flux density and brightness temperature for 33 TeV HBLs observed with VLBI at at least a single epoch. The ten new sources from this poster are shown in yellow.

Discussion

The brightness temperatures of the radio cores of the newer TeV blazars do not require large Doppler factors to avoid either the inverse Compton or the equipartition limits; however, their one-sidedness does suggest at least mild Doppler boosting. This agrees with our previous kinematic results on 11 other TeV blazars that showed only subluminal apparent speeds, and implied modest values of the Doppler and Lorentz factors. These results contrast with the high Lorentz factors invoked to explain the TeV gamma-ray emission. This implies that the jets of the TeV HBLs are probably structured, with velocity structures either along the jet (decelerating jet), transverse to the jet (spine-sheath), or both. Limb brightening in VLBI images of the nearest TeV blazars (Piner et al. 2009, 2010) may also be evidence for transverse velocity structures. These results support an emerging unification scheme for radio-loud AGN, where blazars are divided into two populations based on accretion mode, and where these populations differ in their jet velocity structures (Meyer et al. 2011). We are now beginning multi-epoch monitoring of these 10 sources, as well as using the upgraded VLBA to obtain both first-epoch images of new TeV HBLs discovered after 2010, and deep high-frequency images of brighter TeV HBLs to investigate jet velocity structures.

References

Aharonian, F., et al. 2007, ApJ, 664, L71; Begelman, M. C., et al. 2008, MNRAS, 384, L19; Meyer, E. T., et al. 2011, ApJ, 740, 98; Piner, B. G., et al. 2009, ApJ, 690, L31; Piner, B. G., et al. 2010, ApJ, 723, 1150; Tiet, V. C., et al. 2012, arXiv:1205.2399