Towards Parsec-Scale Jet Speed Measurements for the Full TeV Blazar Sample

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Abstract: We present new multi-epoch Very Long Baseline Array (VLBA) observations of TeV blazars drawn from our VLBA program to monitor all TeV-detected High-Frequency Peaked BL Lac Objects (HBLs) at the parsec scale. Many of these sources are faint in the radio (flux densities of a few millijanskys) so they have not been previously well observed with VLBI techniques by other surveys. Our previous measurements of apparent jet speeds in of order a dozen TeV HBLs showed apparent jet speeds that were subluminal or barely superluminal; suggesting jets with velocity structures at the parsec-scale. Here we present apparent jet speed measurements for eight new sources, which for the first time show a superluminal tail to the apparent speed distribution for the TeV HBLs.

The TeV Blazars:

- Detected by Cherenkov telescopes like H.E.S.S., MAGIC, and VERITAS.
- Most (46 of 61) belong to the HBL (High-frequency peaked BL Lac) class of blazar (TeVCat).
- SED modeling and TeV variability suggest Doppler factors approaching 100.
- However, VLBI observations and unification arguments suggest Doppler factors of a few (the "Doppler Crisis" for TeV blazars).

VLBA Observations of TeV HBLs:

- The goal of our project is to obtain parsec-scale kinematics **for all TeV HBLs**.
- Many are faint in the radio (as faint as 4 mJy), and not included in large surveys like MOJAVE.
- Previous observations of the brightest few showed slow apparent jet speeds (Tiet et al. 2012).
- Our 5-epoch series of observations of 20 TeV HBLs with the VLBA at 8 GHz recently concluded.
- Images and data available at the project website: www2.whititer.edu/facultypages/gpiner/research/archive/archive.html

Status of Jet Kinematics for the 46 TeV HBLs:

- **20** included in our current program. Results for 8 of these 20 are presented here. Results for the remaining 12 available later this year. First epoch VLBA results for all 20 published by Piner & Edwards (2014).
- **11** published previously by us (Tiet et al. 2012).
- **7** will have speeds through the MOJAVE program.
- **4** are too far south for the VLBA.
- **4** are recent detections which we will be proposing for.

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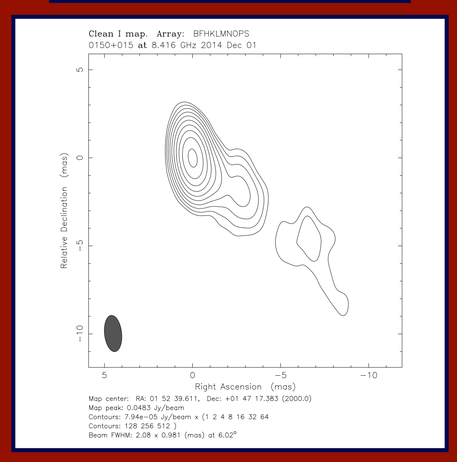

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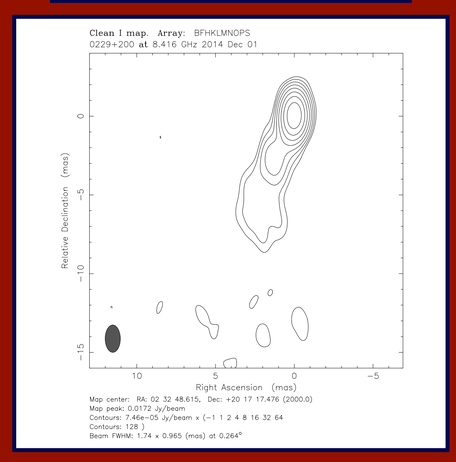

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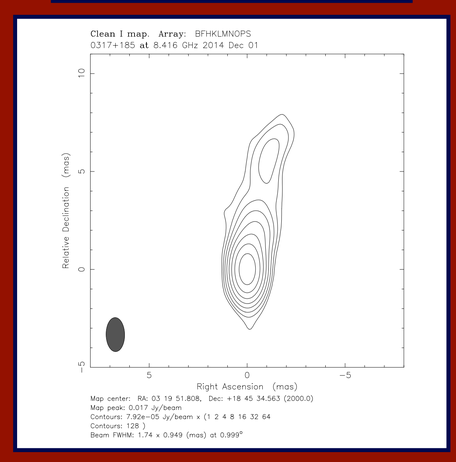

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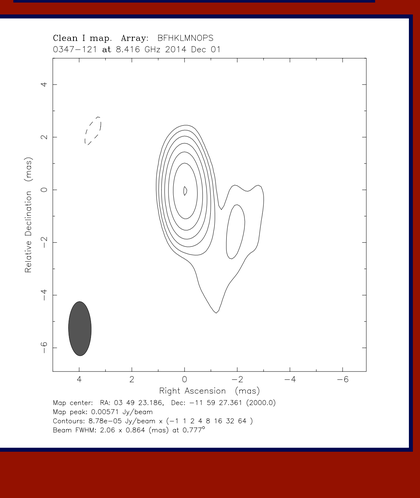

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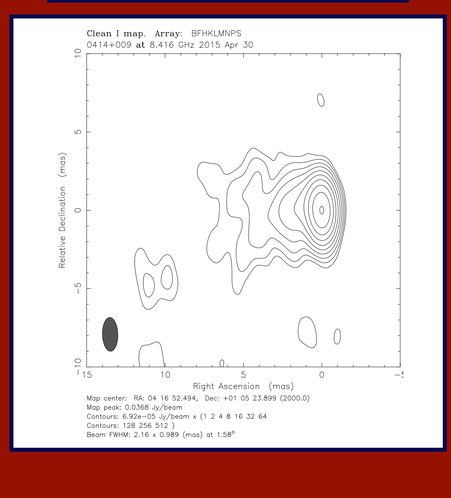

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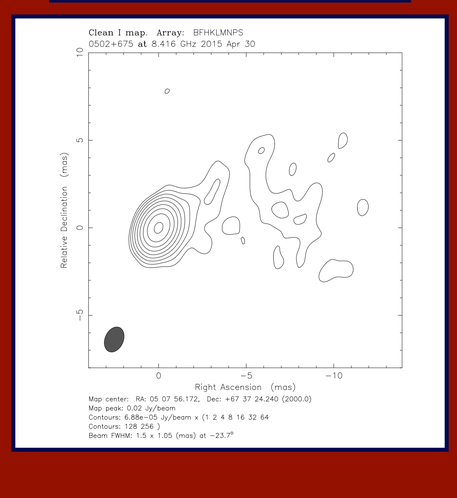
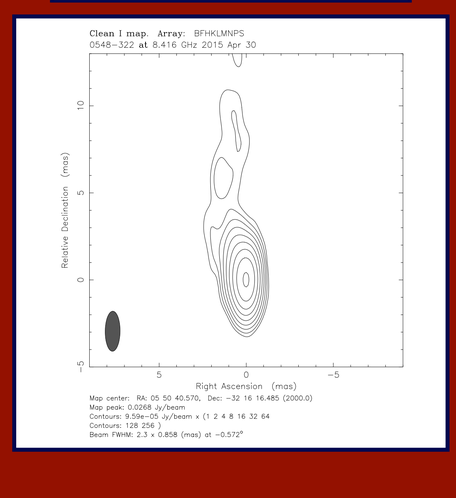
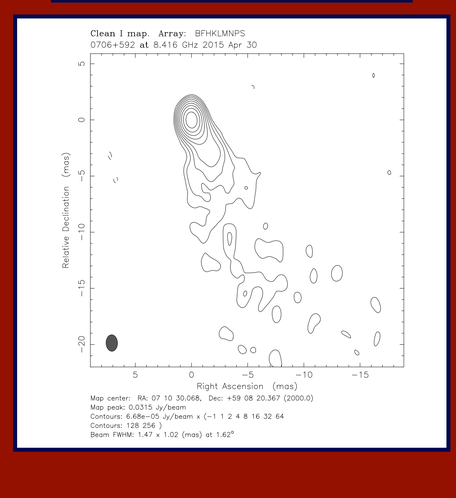


PKS 0548-322 (z=0.069)



RGB J0710+591 (z=0.125)

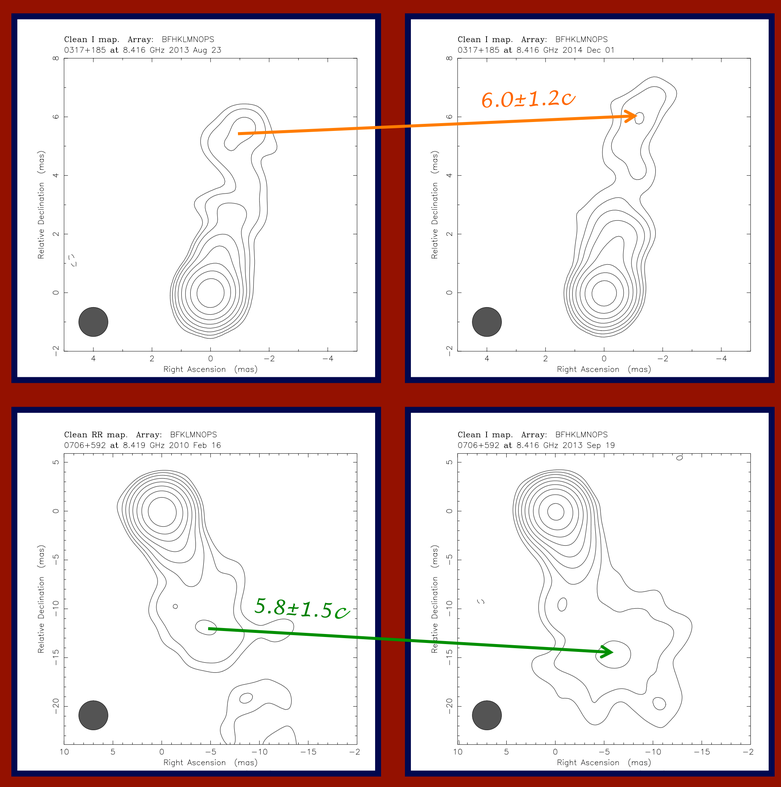


Current Results on Jet Speeds:

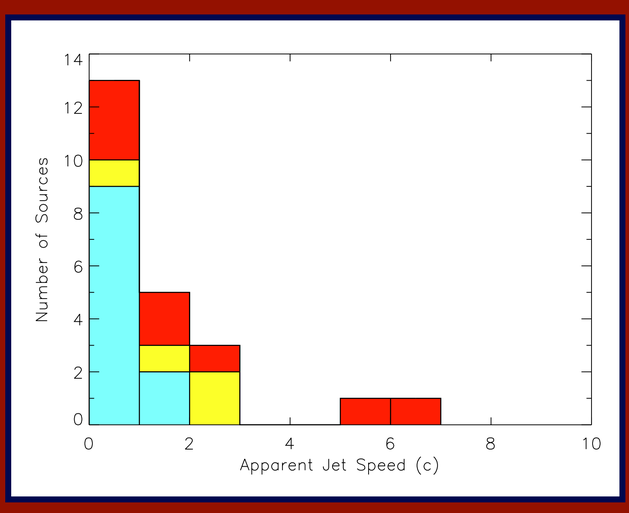
- Previous work showed an absence of superluminal components.
- Interpreted as evidence for velocity structures in the jets, possibly a fast spine producing high-energy emission and a slower layer producing the radio emission.
- Our current work (with 8 new sources) now shows a mildly superluminal tail to the speed distribution for the first time.
- This is expected if we are selecting some sources closer to the critical angle for the layer, possibly due to a somewhat smaller Doppler factor in the spine.

An explanation of the "Doppler Crisis" in HBLs?

- Selection in X-ray or TeV gamma-rays favors rare high-synchrotron peak sources, drawn from the low end of the luminosity function where the source density is largest (Giommi et al. 2012).
- Thus, HBLs have intrinsically weak jets resulting from inefficient accretion modes in low-luminosity FR I parent objects (LERGs).
- Weak jets favor the interaction of the jet walls with the external medium, forming a slow layer.
- Radiative interaction between the spine and the layer eventually decelerates the spine.



Visible superluminal motions in the jets of the two fastest TeV HBLs.



Peak jet speeds in 23 of the 46 TeV HBLs. Blue sources are from our previous work, red are from this work, and yellow are from MOJAVE.

References:
Giommi et al., 2012, MNRAS, 420, 2899
Piner & Edwards, 2014, ApJ, 797, 25
Tiet, Piner, & Edwards, 2012, arXiv:1205.2399