Galaxies and Their Constituents at the Highest Angular Resolutions
IAU Symposium, Vol. 205, 2001
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VLBI Observations of Extragalactic TeV Gamma-ray Sources

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Abstract. VLBI observations of reported TeV gamma-ray sources are described and the inferences that can be drawn on the jet behaviour between the TeV variability-scale and the VLBI parsec-scale discussed.

1. Introduction, Observations and Discussion

TeV gamma-rays are detected using the ground-based Cherenkov technique (see, e.g., the review by Catanese and Weekes 1999). Only low redshift ($z < 0.2$) sources are expected to be detected at TeV energies due to absorption by the infra-red background for more distant sources — TeV gamma-ray astronomy thus allows the intergalactic infra-red background to be studied. With the current sensitivity of TeV gamma ray telescopes there are two established extragalactic TeV sources: Mkn 421 ($z = 0.031$) and Mkn 501 ($z = 0.034$). Detections of four other AGN have been reported but have yet to be confirmed: 1ES 2344+514 ($z = 0.044$), PKS 2155−304 ($z = 0.116$) and 3C 66A ($z = 0.444?$) (see Catanese and Weekes 1999 and references therein) and 1ES 1959+650 ($z = 0.047$) (Nishiyama et al. 1999).

The size of the emission region implied by the hour-scale variability observed in the TeV emission from Mkn421 and Mkn501 is typically 100 times smaller than that probed by Very Long Baseline Interferometry observations. However, VLBI parsec-scale imaging provides the only direct information on the jet being ejected from the core. We are undertaking multi-epoch VLBI observations of reported TeV gamma-ray sources to study their milli-arcsecond (mas) scale structure and component motions, and to determine whether TeV activity signals the emergence of a new parsec-scale jet component. In addition, we are (together with Travis Rector, NOAO) comparing the mas-scale morphology with the arcsecond-scale structure to track the jets on the larger scale (Edwards et al. 2000a).

Combination of multi-epoch VLBI observations of Mkn 421 and Mkn 501 have revealed that the jet components in these sources display sub-luminal apparent motions (Piner et al. 1999; Edwards et al. 2000b) in contrast to GeV gamma-ray (EGRET detected) sources, which tend to show more super-luminal motions than AGN with similar radio properties (Kellermann et al. 2000).

We have undertaken multi-epoch observations with the Very Long Baseline Array of 1ES 2344+514, PKS 2155−304 and 1ES 1959+650, and preliminary results indicate the jet components are either sub-luminal or marginally superluminal (Piner et al. 2000; Edwards et al. 2000a; Edwards et al. 2000c). 3C 66A has not been included in our observing program to date. The often quoted value for the redshift of 3C 66a of 0.444 is uncertain (Hewitt & Burbidge 1993). VLBI observations by Marscher & Marchenko (1997) revealed apparent speeds, assuming a redshift of 0.444, of 12 to 16c within 1 mas of the core and 5.6c beyond 2 mas ($H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$). However, should the redshift be confirmed, the claimed detection of TeV gamma-rays must be considered suspect: conversely, should TeV emission be confirmed, the redshift of 0.444 is unlikely to be correct and thus these apparent speeds will need to be revised.

Despite Doppler factors of greater than ~10 inferred from short-timescale TeV variability and correlated TeV and X-ray emission (Catanese and Weekes 1999), on the parsec-scale TeV blazars appear to show much slower motions than EGRET-detected sources.

A small angle to the line-of-sight of the jets appears unlikely. An intriguing possibility is that most of the energy and momentum is lost close to the base of the jet, where the X-ray and TeV emission occurs (Marscher 1999). As protons do not lose energy as quickly, if the deceleration of TeV blazar jets is confirmed, it will be a strong argument in favour of electron-positron jets in these sources.

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