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Confirmation of Apparent Speeds Exceeding 25c in the Jets of Three EGRET Blazars

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Abstract. We present multi-epoch Very Long Baseline Array (VLBA) observations at 22 and 43 GHz of the three EGRET blazars 0235+164, 0827+243, and 1406−076. These three blazars had been identified as potentially having apparent speeds exceeding 40c in the snapshot VLBA survey of EGRET blazars by Jorstad et al. (2001). Based on six epochs of full-track VLBA observations of each source during 2002 and 2003, we have measured apparent speeds of $31 \pm 6c$, $26 \pm 4c$, and $30 \pm 9c$ in the jets of 0235+164, 0827+243, and 1406−076, respectively (H_0=71 km s^{-1} Mpc^{-1}, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$). We therefore confirm the presence of ultra-relativistic pattern speeds in these three sources, with the implied lower limit to the bulk Lorentz factor from the observed apparent speeds being $\Gamma >\sim 25 - 30$, if the pattern speeds do not exceed the bulk apparent speed.

1. Introduction

Since the discovery of apparent superluminal motion in extragalactic jets with VLBI, there have been occasional reports of extremely fast apparent speeds, exceeding 25c or so (e.g., Jorstad et al. 2001; Kellermann et al. 2004). Because the apparent superluminal speed implies a lower limit to the Lorentz factor ($\Gamma_{min} > (1 + \beta_{app}^2)^{1/2}$), establishing the peak observed apparent speed establishes a Lorentz factor that must be reached but not greatly exceeded by jet acceleration models. Apparent speeds measured from sequences of VLBI images can be problematic, because there are sometimes ambiguities in component identifications. These important high-speed measurements should therefore be confirmed by multiple VLBI observations of the candidate sources. In this project, we monitored the three blazars 0235+164, 0827+243, and 1406−076, that had very high measured apparent speeds ($\sim 40c$) in the VLBA survey of EGRET blazars by Jorstad et al. (2001). Because we concentrated our observing time on these three sources, we were able to achieve image dynamic ranges about a factor of four higher than the images by Jorstad et al (2001).

2. Observations and Data Analysis

We observed the three blazars 0235+164, 0827+243, and 1406−076 each six times with the National Radio Astronomy Observatory's Very Long Baseline Array (VLBA) during 2002 and 2003. Each observation recorded six hours on-source per source. 0235+164 was observed at a frequency of 43 GHz, and 0827+243 and 1406−076 were observed at a frequency of 22 GHz, to match the frequencies used by Jorstad et al. (2001). Dual-circular polarization was recorded in each observation. Total intensity results are reported here; polarization analysis is in progress. The data were calibrated using standard routines from the AIPS software package, and imaging was done using standard CLEAN and self-calibration procedures from the DIFMAP software package. After imaging and self-calibration, the DIFMAP task "modelfit" was used to fit sequences of Gaussian models to the calibrated visibility data.

3. Results

Figure 1 shows separation versus time plots of the model component positions in these three sources. The apparent speeds measured from least-squares fits to the separation versus time are indicated on the figure. The peak apparent speeds in these three sources are $31\pm6c$, $26\pm4c$, and $30\pm9c$ for 0235+164, 0827+243, and 1406−076, respectively (H_0=71 km s^{-1} Mpc^{-1}, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$). The corresponding limits to the bulk Lorentz factor and angle to the line-of-sight (assuming these fastest measured pattern speeds are indicative of the bulk apparent speed of the jet, see Lister, these proceedings) are $\Gamma >\sim 25-30$, and $\theta <\sim 4^\circ$. Some specific results for the three individual sources are:

0235+164: ($z = 0.94$) This blazar has a short jet ($\sim$1 mas) to the north-northwest at 43 GHz. An additional component (C4, apparent speed $13\pm5c$) at a similar separation to C3 but a different position angle has not been shown on Figure 1.

0827+243: ($z = 0.94$) Rapid superluminal motion in an eastern jet feature (modeled by the Gaussian components C2, C3, and C4 in Figure 1) is very clear. This motion is shown in the mosaic of VLBA images in Figure 2.

1406−076: ($z = 1.49$) This source has a faint jet extending 10 mas to the west at 22 GHz. The fastest component is the 7 mJy component C4.

4. Conclusions

VLBI observers (e.g., Kellermann et al. 2004; Jorstad et al. 2005; Piner et al. 2004; this paper) seem to be reaching a consensus on the peak apparent speeds present in the relativistic jet population, at values of about $30c$. This then implies maximum bulk Lorentz factors of $\Gamma \approx 30$ on the parsec-scales sampled by VLBI imaging. This observational limit provides important constraints on models of jet acceleration — models should be able to produce a $\Gamma = 30$ jet, but should not produce jets with Lorentz factors much in excess of this unless significant deceleration occurs by VLBI scales.

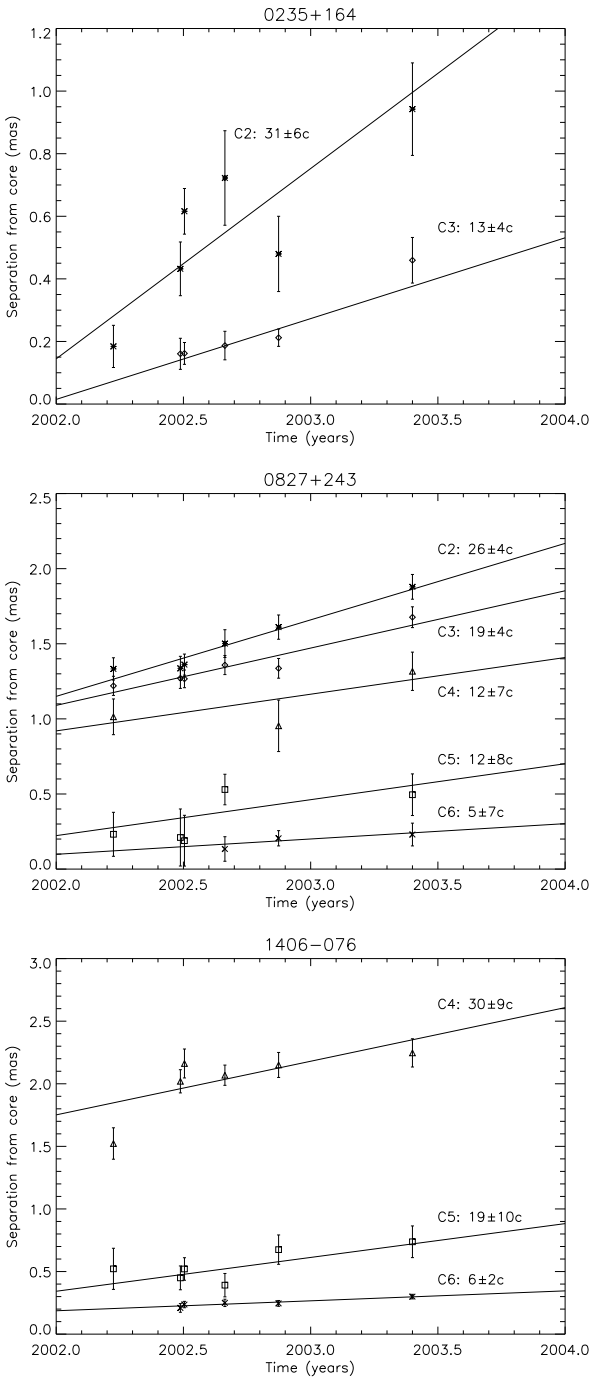

Figure 1. Distances from the core of Gaussian component centers as a function of time. The lines are the least-squares fits to outward motion with constant speed. Fitted apparent speeds are shown next to these lines, for H_0=71 km s^{-1} Mpc^{-1}, $\Omega_m = 0.27$, and $\Omega_\Lambda = 0.73$

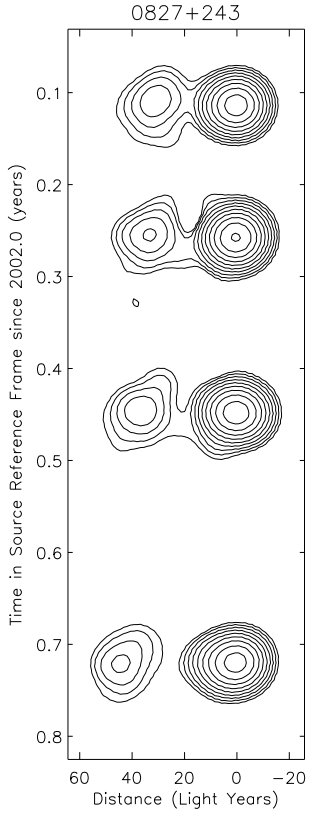

Figure 2. Mosaic of images of 0827+243 at 22 GHz. The bright feature moves approximately 15 light-years in 0.6 years (source-frame), for an apparent speed of about 25 c. Only four of the six epochs are shown to prevent overlapping of images. Images have been rotated 25° clockwise, and restored with a circular 0.5 mas beam. Model component C3 is at the center of the bright jet feature.

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