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Kinematics of the parsec-scale jet of the blazar AO 0235+164

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Abstract. Radio interferometric maps of the blazar AO 0235+164 show the existence of a stationary core, and a compact jet composed of multiple receding components. In this work, we determined the structural characteristics of these jet components (core-component distance, position angle, flux density, etc.) using the statistical method for global optimization Cross-Entropy (CE). The images we analyzed were extracted from public databases, totaling 41 images at 15 GHz and 128 images at 43 GHz. Using criteria such as the value of the CE merit function, and mean residuals, we determined the optimum number of components in each map analyzed in this work. We found that jet components are distributed across all four quadrants on the plane of the sky, indicating a possible non-fixed jet orientation during the monitoring interval. The time evolution of the equatorial coordinates of the jet components were used to determine their respective speeds, ejection epochs, and mean position angles on the plane of the sky. We have identified more than 20 components in the jet of AO 0235+164, with their apparent speeds ranging roughly from 2c to 40c, and distributed across all four quadrants on the plane of the sky. From the kinematics of these jet components we could derive a lower limit of about 39 for its bulk jet Lorentz factor and an upper limit of approximately 42 degrees for its jet viewing angle.

Keywords. BL Lacertae objects: individual: AO 0235+164 — galaxies: active-galaxies: jets — methods: data analysis — radio continuum: galaxies — techniques: interferometric

1. Introduction

As usual in its active galactic nuclei (AGN) class, the BL Lac object AO 0235+164 exhibits violent variability across the electromagnetic spectrum on time-scales from hours to years (e.g., Raiteri *et al.* 2008; Ackermann *et al.* 2012).

Radio interferometric images of AO 0235+164 ($z = 0.94$ e.g., Cohen *et al.* (1987)) show a very compact source ($\lesssim$1 mas) with a stationary component identified as the core region and a few receding jet components (e.g., Chu *et al.* 1996; Jorstad *et al.* 2001; Lee *et al.* 2008; Lister *et al.* 2009; Kutkin *et al.* 2018).

2. Methodology and Results

We extended previous studies analyzing 128 43-GHz interferometric images obtained from the public archive VLBA-BU-BLAZAR Multi-Wavelength Monitoring Program (Jorstad & Marscher 2016; Jorstad *et al.* 2017), and 41 15-GHz maps gathered from the MOJAVE/2cm Survey Data Archive (Lister *et al.* 2009). Structural parameters of the elliptical Gaussian components were determined via Cross-Entropy global optimization techniques (e.g., Rubinstein 1997; Caproni *et al.* 2009, 2014, 2017).

We found that jet component motions are compatible with non-accelerated trajectories residing in all quadrants on the plane of sky. Their ejections coincide closely in time with flares seen in the core and gamma-ray light curves. The minimum value for the Lorentz factor was obtained from the maximum apparent speed, $\beta_{\rm app,max}$, determined in this work: $\gamma_{min} = \sqrt{1+\beta^2_{\rm app,max}} \geqslant 39.2 \pm 11.8$. The maximum jet viewing angle comes from the minimum apparent speed among jet components, $\beta_{\rm app,min}$, and taking the limit $\beta \to 1$, where β is the bulk jet speed: $\theta_{max} = \arccos\left[\left(\beta^2_{\rm app,min} - 1\right) / \left(\beta^2_{\rm app,min} + 1\right)\right] = 42\overset{\circ}{.}1 \pm 19\overset{\circ}{.}8$.

3. Conclusions

We were able to identify 27 components that have different apparent speeds, ranging from 2c to 40c. It allowed us to estimate a lower limit for the Lorentz factor (∼39), as well as an upper limit for the jet viewing angle (∼42°), in agreement with previous estimates (e.g., Zhang *et al.* 1998; Volv́ach *et al.* 2015).

We also found that the position angles of the jet components varied roughly from −10° to −345°. This very broad range indicates that the jet direction has not remained fixed over time. A possible explanation for such dispersion could be the jet precession phenomenon, which will be pursued in future work.

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