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Evolution of the parsec-scale jet in 3C 345

F. K. Schinzel[1]†, A. P. Lobanov[1], J. A. Zensus[1], G. B. Taylor[2], S. Jorstad[3] and A. Marscher[3]

[1]Max-Planck-Institut für Radioastronomie,
Auf dem Hügel 69, 53121 Bonn, Germany
email: schinzel@mpifr.de

[2]Dept. of Physics & Astronomy, University of New Mexico,
Albuquerque NM, 87131, USA

[3]Institute for Astrophysical Research, Boston University,
725 Commonwealth Avenue, Boston, MA 02215, USA

Abstract. The $16^{\rm m}$ quasar 3C 345 is one of the best examples of an AGN showing structural and flux variability on parsec scales around a compact unresolved radio core. It has been observed from radio to γ-ray wavebands with a special focus on Very Long Baseline Interferometry (VLBI) observations in the range 1-100 GHz that cover a period of over 30 years. The complex pc-scale jet of 3C 345 exemplifies an archetypal "superluminal" jet with helical substructure. Existing VLBI observations of 3C 345 form an unprecedented database enabling a unique insight into the long-term evolution of the pc-scale radio emission. Here we present the latest results from our ongoing long-term VLBI monitoring of 3C 345, focusing on the morphological, kinematic, and spectral evolution of the pc-scale jet. Special attention will be given to the recent onset of a new period of high activity in the source that has been manifesting itself since 2008 from radio through γ-rays. Recent VLBI and high energy observations to study the relation between the radio emission and the production of high energy photons in 3C 345 are combined.

Keywords. galaxies: active, quasars: individual (3C 345), galaxies: jets

1. Introduction

The $16^{\rm m}$ quasar 3C 345 has been observed at radio wavelengths for over 30 years, in particular with VLBI. The source still continues to be of special interest due to its complex, helical parsec-scale jet around a compact unresolved radio core and its pronounced multi-wavelength variability. A likely 8-10 year periodicity of the high activity phases in 3C 345 has been identified (Lobanov & Zensus 1999). Measurements of nuclear opacity and magnetic field strength (Lobanov 1998) yield a total mass for the central engine of $(4.0 \pm 2.4) \cdot 10^9$ $M_\odot$.

3C 345 is known as a prominent variable source at high energies up to the X-ray band and only recently it was clearly identified as γ-ray source by the Large Area Telescope (LAT) aboard the *Fermi* satellite (Atwood *et al.* 2009, Schinzel *et al.* 2010a). This enabled continuous monitoring of γ-ray emission originating from the vicinity of 3C 345.

We have analyzed VLBI observations of the last three decades in order to understand the physics of the relativistic outflow and dynamics of central regions in 3C 345. After the launch of *Fermi*, a dense monthly VLBI monitoring was performed to study the new active period of 3C 345 and the combination of radio and γ-ray obserations of 3C 345 provide the opportunity to locate the sites of γ-ray emission and to study emission mechanisms.

† Member of the International Max Planck Research School (IMPRS) for Astronomy and Astrophysics at the Universities of Bonn and Cologne.

2. Results

The VLBI data collected on the pc-scale jet in 3C 345 revealed 19 bright features over a period of 30 years. Their brightness distribution was represented by Gaussian modelfits used for analysis of the kinematics and emission evolution of the features detected. At 15 GHz, the jet trajectories of such features were traceable up to a distance of 8 mas from the VLBI core. The pc-scale jet is initially directed westward, at a position angle of almost 90°. The individual jet features trace a common channel of ~ 1 mas in width within a distance of ~ 5 mas from the core, beyond this distance the jet sharply turns north-ward. The component position angles measured at 0.5 mas radial separation from the VLBI core at 15 GHz offered an initial way to represent deviations from the 90° position angle. We saw no clear periodic trends like it was claimed in the past, but we saw long- and short-term variability of jet ejection angles on scales from 10 years to just a few years. A behavior like this might be expected for a helical, precessing jet.

Apparent speeds were determined for all jet features. After an accelaration phase, for a separation of > 0.7 mas, a constant characteristic speed of $\beta_{\rm app} \approx 12.2$ c is reached. With the exception of two features that showed an apparent speed of about 15.8 c.

A new moving emission region was detected on June 16, 2008, followed by detections of another new feature on January 24, 2009, and a third one on July 27, 2009. During 2009, the jet (average flux density: 3.6 Jy), at a distance of $\leqslant 0.3$ mas from the VLBI core, was brighter than the core (average flux density: 1.5 Jy) by a factor of 2.4. All newly ejected jet features showed similar apparent acceleration from $\sim 2-10$ c over a distance of 0.2 mas.

The γ-ray emission from 3C 345 was identified, based on correlations found between the optical and radio variability and major γ-ray events observed by *Fermi*/LAT in October 2009 (Schinzel *et al.* 2010a). A rising underlying trend in the γ-ray emission similar to the one in radio was observed, which suggests the γ-ray emission to originate over a distance of up to 10 pc. Out of six γ-ray events identified (2008–2010), two were associated with a new feature passing the 43 GHz VLBI core and one with a feature in the jet at a distance of 0.2 mas from the VLBI core, which showed a rapid multi-wavelength flare mid 2009. (Schinzel *et al.* 2010b).

3. Conclusions

Harvesting this unprecedented database on 3C 345 is going to give a unique insight into the long-term evolution of the pc radio emission and will further our understanding of the underlying physics of jet emission. We have observed that γ-rays are produced over large distances in the pc-scale radio jet, further constraining γ-ray emission scenarios of blazar jets.

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