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Supermassive binary black hole system in the quasar 3C 345

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Abstract. Most of active galactic nuclei (AGN) present a remarkable variety of signs pointing toward periodical processes determining the observed properties of this class of extragalactic objects. It is expected that these processes must be taking place in the very center of an active galaxy, thereby being related to the core of the AGN. We propose here the hypothesis that most of the AGN contain supermassive binary black hole systems, in which the orbital motion and precession are ultimately responsible for the observed broad–band emission variations, as well as for the morphological and kinematic properties of the radio emission on parsec scales. We apply this scenario to the archetypical quasar 3C 345, and show that our model explains the observed variations of radio and optical emission from the quasar, and reproduces the structural variations observed in the parsec–jet of this object.

1. Introduction

In a growing number of cases, explanation of the observed nuclear variability and structural changes in parsec–scale jets is linked to the presence of supermassive binary black hole (BBH) systems in the centers of AGN. The BBH model postulates that an accretion disk (AD) exists around at least one of the two black holes (typically, around the more massive one), and the resulting variability and structural changes are determined by the dynamic properties of the the disk itself and the BBH–AD system (this includes the disk and black hole precession, orbital motion, passages of the secondary component through the AD). The observed helical trajectories of jet components is a strong indication of precession or perturbation of the jet. The dynamics and emission of such perturbed outflows have been recently explained in the framework of the two–fluid model (Sol, Pelletier & Asseo 1989, hereafter SPA89) describing the structure and emission of the jet in terms of an ultra-relativistic electron–positron ($e^{\pm}$) beam with $\Gamma_b \approx 10$ surrounded by a slower, electron–proton ($e^{-}p$) jet moving at a speed $\beta_j \approx 0.4\,c$. In this paper, we combine the dynamics of the BBH–AD system and the two–fluid model to construct a single framework for explaining optical flaring activity, kinematic properties and internal structure of the compact parsec–scale jets. We use the combined model to describe the quasar 3C 345 during a strong flare in 1992 that resulted in appearance of a new superluminal jet component C7. The model explains the observed optical variability, the trajectory and flux density evolution of radio emission from C7, and the overall structure of the compact jet in 3C 345.

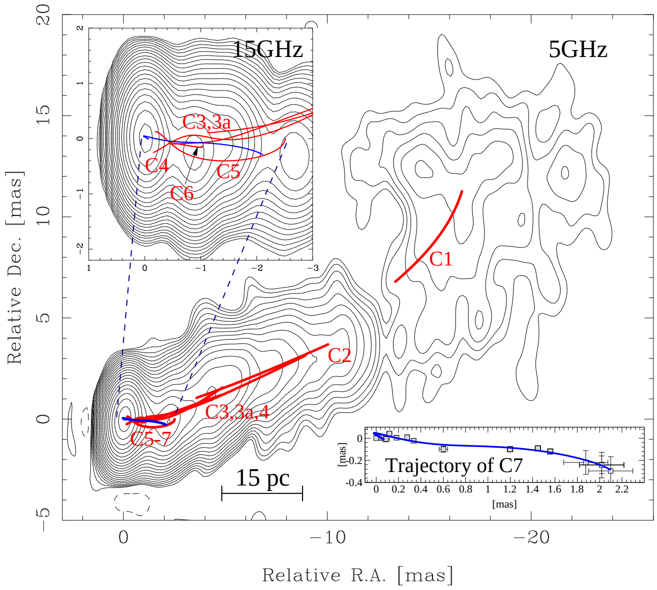

Fig. 1. Parsec-scale jet in 3C 345 at 5 and 15 GHz. Contours are drawn at -1,1,$\sqrt{2}$,2,... of the lowest contour (2.5 mJy/beam, in both images). Solid lines mark the trajectories of superluminal features C1–C7 identified in the jet based on measurements from 1979–1998 VLBI monitoring data (Zensus et al. 1995, Lobanov 1996, Ros et al. 1999 and references therein). The positions of C7 measured at 22 GHz are shown in the inset.

2. The BBH model

We adopt the two–fluid description of the outflow, and assume that a condensation of relativistic plasma injected into the beam in the vicinity of the black hole M_1 moves at a constant speed characterized by its bulk Lorentz factor Γ_b and follows the magnetic field lines. The perturbation of the magnetic field propagates at the Alfvénic speed $V_A = B(4\pi m_e n_b)^{-0.5}$. The observed trajectory of the perturbed region is determined by the precession of the accretion disk (Roland, Teyssier & Roos 1994) and orbital motion in the binary system (Laskar & Robutel 1995). We apply this description to fitting the optical light curve of 3C 345 and the observed trajectory of the enhanced emission region C7 (Figure 1) identified in the parsec–scale jet in this quasar.

Table 1. Parameters of the BBH model applied to 3C 345.

Parameter	
Primary BH mass, M_1	$1.5 \cdot 10^9 \mathrm{M}_\odot$
Secondary BH mass, M_2	$1.0 \cdot 10^9 \mathrm{M}_\odot$
Orbital major axis, a_{maj}	0.64 pc (0.13 mas)
Orbital eccentricity, e	0.1
Orbital period, T_{orb}	170 yrs (8.5 yrs)
Precession period, T_{prec}	2500 yrs (125 yrs)
Beam Lorentz factor, Γ_{b}	3.5
Jet viewing angle, θ_{j}	8°
Precession angle, Ω_{prec}	1.2°
Alfvén speed, V_{a}	$0.05\,c$

Note: Brackets denote values measured in the observer's frame.

3. Properties of the BBH system in 3C 345

The results of applying the BBH model to 3C 345 are shown in Figure 2. The parameters of the model are listed in Table 1. The model explains well the optical variability and the observed trajectory and emission of the jet component C7. It is remarkable that both the observed light curve and trajectory would require neither a compressed magnetic field, nor helical geometry induced by Kelvin-Helmholtz instability. The main factors responsible for the observed behavior of C7 are now the orbital motion in the binary black hole system and the precession of the accretion disk, while the beam can in principle remain a quasi-stationary and homogeneous outflow on spatial scales of up to $\sim$ 50 pc. Such a beam is not disrupted by Kelvin–Helmholtz instability for as long as $B_{\mathrm{beam}} \gtrsim 50$ mG (Pelletier & Roland 1989), and it does no suffer from substantial inverse Compton and synchrotron losses on parsec scales (SPA89). In this case, even the observed morphology of the compact jet can be reconstructed from the BBH model, assuming that the radio emitting plasma moves along the magnetic field lines and has a slowly decaying comoving emissivity along the beam (Lobanov & Roland 2002).

4. Conclusions

The BBH model presented here provides a good account of the observed properties of the radio and optical emission in the quasar 3C 345 on parsec scales. One of the most intriguing implications of the model is the possibility to relax some of the most stringent requirements for the physical conditions of relativistic plasma in extragalactic jets. In the paradigm outlined by the model, the extragalactic jets start off as undisturbed, magnetized flows, and develop shocks and instabilities rather gradually, on scales of 10–1000 parsecs. This scenario, although being drastically different from the commonly accepted scheme, may provide a better explanation for the observed morphological, kinematic, and emission properties of compact extragalactic jets.

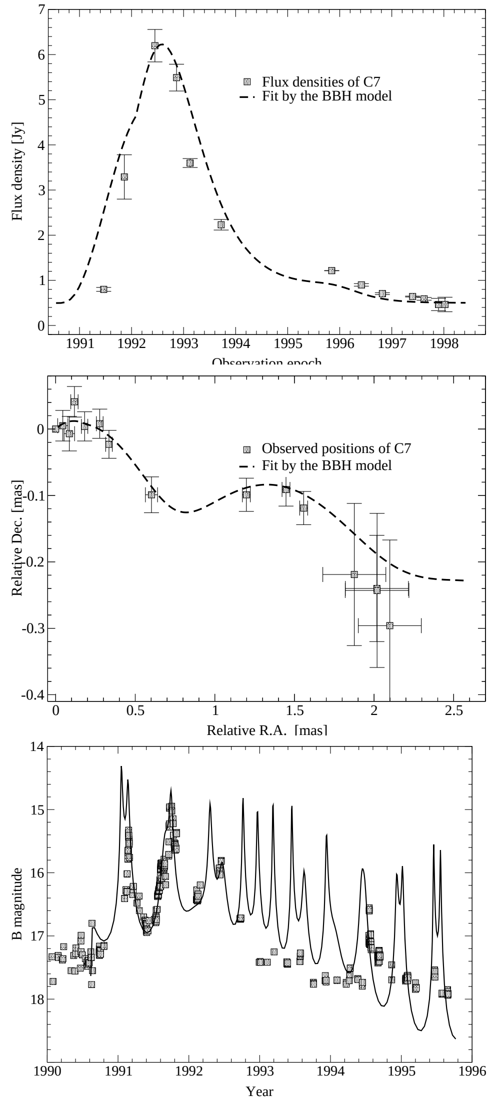

Fig. 2. Radio flux density at 22 GHz (top) and two–dimensional trajectory (middle) of the component C7. The dashed line is the best fit by the BBH model. Optical variability in 3C 345 (bottom). Solid line shows the optical light curve resulting from a flare in 1990.6. Individual peaks result from the orbital motion in the BBH system with a period of $\approx$ 170 years. The basic parameters of the model are given in Table 1.

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