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Proper motion and apparent contraction in the CSO J0650+6001

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Abstract. The evolutionary stage of a powerful radio source originated by an AGN is related to its linear size. In this context, compact symmetric objects (CSOs), which are powerful and intrinsically small radio sources, should represent a young stage in the individual radio source life. A decisive support to the genuine "youth" of this class of objects came from the determination of their hot spot separation rate, which provided kinematic ages of a few thousand years. Among the CSOs studied so far, the radio source J0650+6001 is the only object showing an apparent source contraction. No evidence of source expansion was found. A recent analysis of new multi-epoch VLBI observations of J0650+6001 has shown that the peculiar characteristics of this source may be related to Doppler beaming where the mildly relativistic jets are separating with an intrinsic velocity of $0.43c \pm 0.04c$ at an angle between 12° and 28° to the line of sight.

Key words. radio continuum: general – radiation mechanisms: non-thermal – quasars: individual: J0650+6001

1. Introduction

Powerful extragalactic radio sources hosted in elliptical galaxies represent only the 10 per cent of the population of active galactic nuclei (AGN). This suggests that the radio loudness is likely a transient period in the life of each AGN. The radio emission is associated with the presence of supersonic jets that originate in the central region of the AGN and propagate outwards. The linear size (LS) of the radio emission is related to the evolutionary stage (e.g. Fanti et al. 1995; Snellen et al. 2000). In this context, compact symmetric objects (CSO), with LS< 1 kpc, are young radio sources whose radio emission originated not long ago. Their main characteristic is the presence of a turnover between about 100 MHz and a few GHz in the synchrotron spectrum, likely due to synchrotron self-absorption (Snellen et al. 2000), although an additional contribution from free-free absorption has been found in the most compact (LS<20 pc) objects (Orienti & Dallacasa 2008a; Kameno et al. 2000).

Support to the genuinely youth of these radio sources came from the determination of both kinematic and radiative ages. The kinematic age is derived by means of parsec-scale resolution observations spanning several years. By comparing multi-epoch observations is possible to find changes in the source struc-

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ture, in particular we can determine at which rate the hot spots are increasing their separation. Assuming that the separation velocity $v_{\rm sep}$ is constant, the kinematic age $t_{\rm kin}$ is estimated as

$$t_{\rm kin} = {\rm LS} \cdot v_{\rm sep}^{-1}.$$

For the compact sources studied so far (LS<20 pc), the separation velocities are in the range $0.1c$-$0.4c$, corresponding to $t_{\rm kin}$ of a few thousand years (Polatidis & Conway 2003), i.e. much smaller than the ages derived for the extended (a few hundred kpc up to a few Mpc) radio galaxies which account for $10^7 - 10^8$ years (e.g. Lara et al. 2000).

The radiative ages are estimated by multifrequency observations able to constrain the break frequency $\nu_{\rm br}$ of the synchrotron radio spectrum. Once the magnetic field (H) is known, for example by assuming equipartition condition (Pacholczyk 1970), the radiative age $t_{\rm rad}$ can be easily computed by

$$t_{\rm rad} = {\rm const} \cdot \nu_{\rm br}^{1/2} H^{-3/2}.$$

The radiative ages derived in CSOs indicate ages of a few thousand years (Murgia 2003), in excellent agreement with the kinematic ages.

Among all the CSOs studied in this framework, the radio source J0650+6001 represents a peculiar case, being the only compact radio source apparently without evidence of expansion (Orienti & Dallacasa 2008a; Akujor et al. 1996).

2. The radio source J0650+6001

The radio source J0650+6001 is associated with a quasar at redshift $z = 0.455$[1] and it has an uncommon optical spectrum characterized by very weak broad lines and prominent narrow lines (Stickel & Kühr 1993). With its spectral peak occurring at 5.5 GHz (Orienti et al. 2007), J0650+6001 is part of the subpopulation of the CSO radio sources known as high frequency peakers (see Dallacasa et al. (2000) for a review on this class of objects). It has a very asymmetric triple radio structure (Fig. 1) dominated by the central and the southern component, whereas the northern component is very weak, and it accounts for only 1% of the total source flux density. The central component accounts for 60% of the total flux density, and it has a flat spectrum $\alpha_{5.0}^{8.4} = -0.05 \pm 0.15$ indicating that it hosts the source core. A jet-like structure emerges to the north of the core region in the direction of the northern component, which is located 20 pc away in PA 13°, with a spectral index $\alpha_{5.0}^{8.4} = 0.70 \pm 0.30$. The southern component is located at 16.2 pc in PA -146° from the central component, and it possesses a spectrum with $\alpha_{5.0}^{8.4} = 0.60 \pm 0.15$. With a flux density ratio $S_{\rm S}/S_{\rm N} \sim 30$, this source is one of the most asymmetric CSOs known so far.

[1] We assume H_0=0.71 km s^{-1} Mpc^{-1}, $\Omega_{\rm M}$=0.27 and Ω_Λ=0.73, in a flat Universe. At the redshift of the target, 1 arcsec=5.773 kpc. The spectral index is defined as $S(\nu) \propto \nu^{-\alpha}$.

3. Proper motion

The lack of source expansion made J0650+6001 a peculiar case among the population of CSOs. In fact, if these sources are young, changes in the position of the hot spots must be detectable by multi-epoch high resolution observations (Owsianik & Conway 1998). On the opposite, in J0650+6001 an unexpected apparent contraction has been reported by Akujor et al. (1996) between the central and the southern components.

The availability of other VLBI observations in addition to those considered in the previous study allowed a more accurate analysis of possible changes in the source structure. The comparison of the position of the northern and southern components showed that their separation has increased by 0.28±0.13 mas in about 15 years, i.e. the time baseline spanned by the available observations. This corresponds to an apparent separation velocity $v_{\rm s,a}$ of $0.39c$ $\pm 0.18c$, leading to a kinematic age of 360±170 years that confirms the genuine youth of this radio source (Orienti & Dallacasa 2010).

Furthermore, the multi-epoch analysis could confirm the decreasing distance between the central and the southern components, indi-

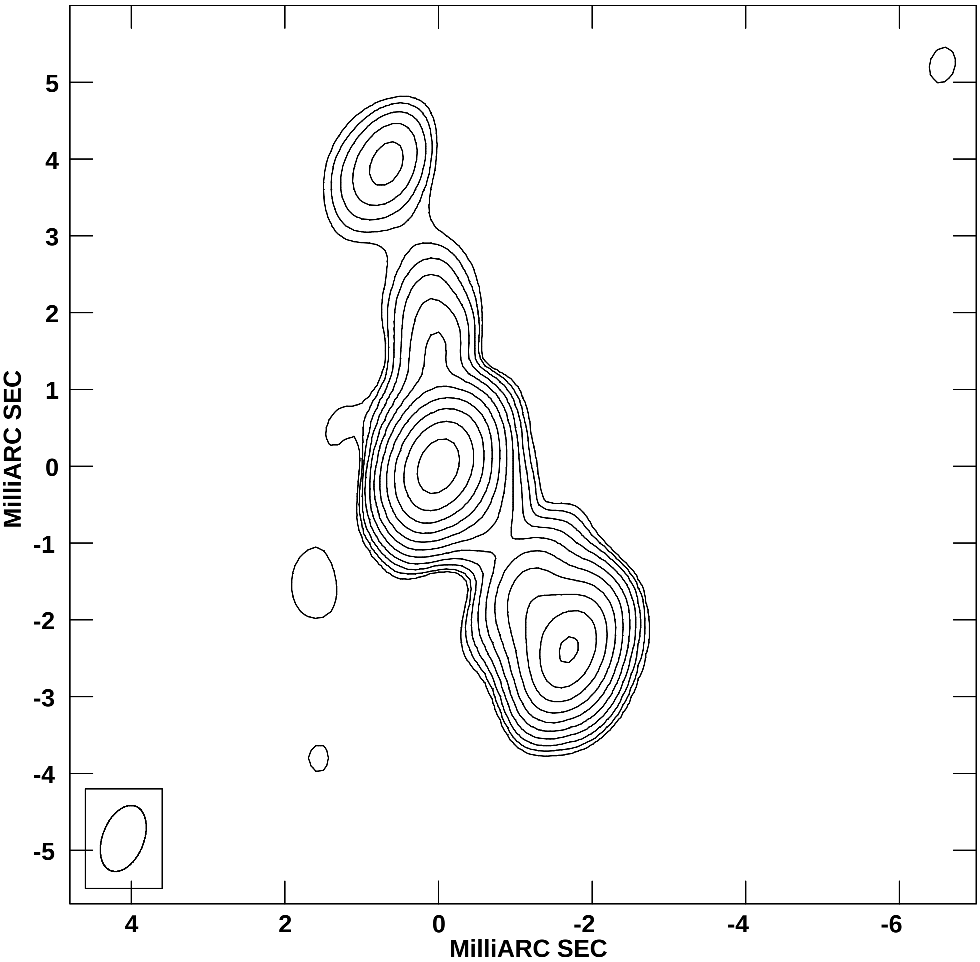

Fig. 1. VLBI image at 8.4 GHz of J0650+6001. The peak flux density is 491 mJy/beam. The first contour intensity is 0.3 mJy and it corresponds to three times the off-source noise level measured on the image plane. Contour levels increase by a factor 2. Adapted from Orienti & Dallacasa (2010).

cating an apparent contraction velocity $v_{c,a} = 0.37c \pm 0.02c$ (Orienti & Dallacasa 2010).

4. Variability

To study the flux density behaviour of J0650+6001, the 5-GHz light-curve has been constructed on the basis of available VLA data spanning a period of almost 18 years. At 5 GHz, i.e. in the optically-thick part of the spectrum, the source flux density steadily increased during the time interval considered (Fig. 2). Flux density variability is not commonly found in young radio sources (O'Dea 1998). However, the presence of variability in the optically thick part of the spectrum may indicate that the source is adiabatically expanding (Orienti & Dallacasa 2008b). To check whether the variability is associated with a particular source component we compared multi-

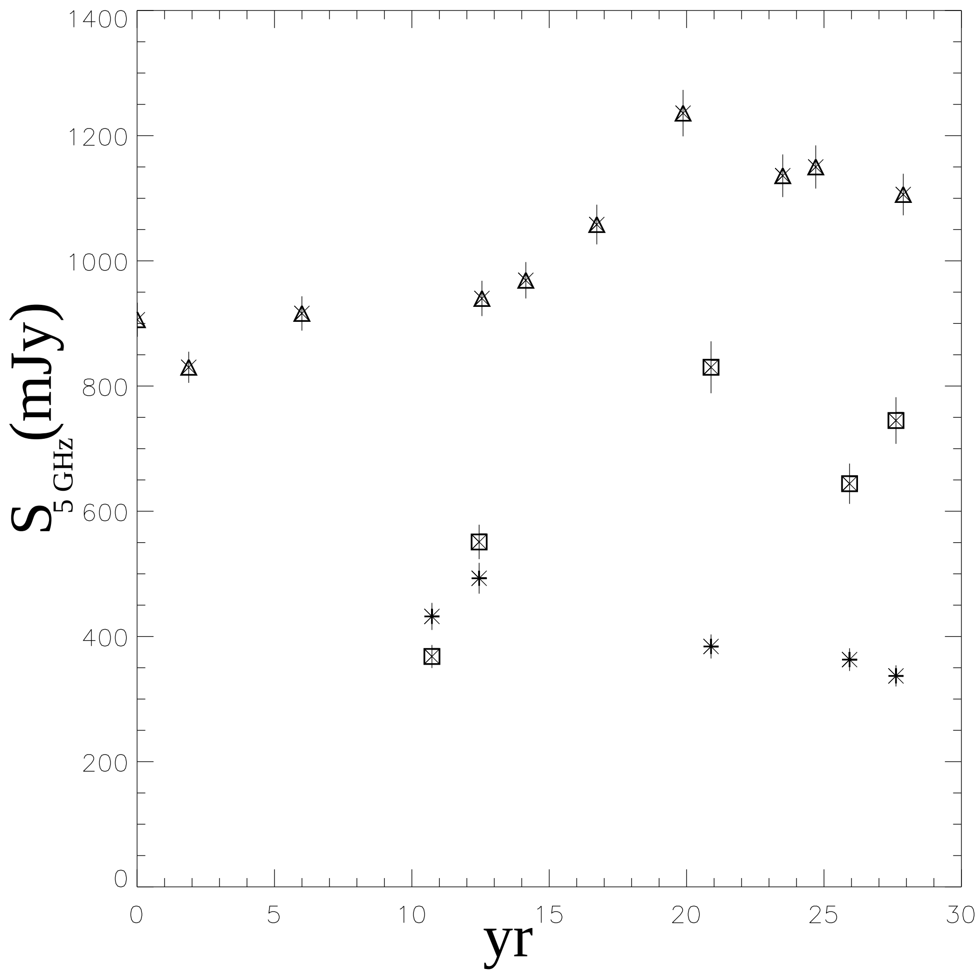

Fig. 2. 5-GHz light-curve of J0650+6001. Triangles indicate the source total flux density from VLA data, while squares and crosses refer to VLBI flux density of the central and southern component respectively. Adapted from Orienti & Dallacasa (2010).

epoch high resolution VLBI data at 5 GHz. An increasing flux density is observed only for the central component, while the southern one is almost constant (Fig. 2).

5. Discussion

The peculiar morphological characteristics of J0650+6001, together with the apparent contraction between the central and southern components, makes this source a study case among the CSO population. A possible explanation may arise from Doppler boosting effects. J0650+6001 is associated with a quasar, suggesting that projection effects may play an important role. If this interpretation is correct, the highly asymmetric structure and the apparent contraction may be explained assuming that the southern and the northern components are the preceding and the receding jet respectively, oriented at small angle to the line of sight. The flux density ratio between the outer components is thus related to both the intrinsic jet speed $v_{\rm s,i}$ and its orientation θ by

$$\frac{S_{\rm S}}{S_{\rm N}} = \left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{3+\alpha} \quad (1)$$

where $\beta = v/c$, and c is the speed of light. Furthermore, the intrinsic jet speed and the source orientation can be derived by means of the apparent separation velocity:

$$\beta_{\rm s,a} = \frac{\beta_{\rm s,i}\sin\theta}{1-\beta_{\rm s,i}\cos\theta} \ . \quad (2)$$

The possible ($\beta_{\rm s,i}$-θ) combination are then derived by comparing the results from Eq. 1 and 2. We obtain that $\beta_{\rm s,i}$= 0.43±0.04 and θ ranges between 12° and 28° (Orienti & Dallacasa 2010).

In this beaming model, the apparent contraction observed can be explained assuming that a compact component, likely a knot in the jet, is moving towards the southern component with $\beta_{\rm c,a}$ = 0.37±0.02 (see Sect. 3). Using Eq. 2, and assuming the same orientation as derived above, we find that this knot is moving toward south with a mildly relativistic intrinsic velocity $\beta_{\rm c,i}$ = 0.66±0.03. From these values we can derive the Doppler factor δ of the jet knot

$$\delta = \frac{1}{\Gamma(1-\beta_{\rm c,i}\cos\theta)} \ ,$$

where Γ is the Lorentz factor, and we find $\delta \sim 2$. This is consistent with both the flux density variability and the uncommonly high flux density shown by the central component, usually weak in CSO sources, that is explained by beaming effects enhancing the intrinsic luminosity.

6. Conclusions

In VLBI images the compact symmetric object J0650+6001 shows a peculiar asymmetric triple radio structure where the outer components are misaligned with respect to the central flat-spectrum region. From multi-epoch observations we found that the outer regions are increasing their separation with an apparent velocity $\beta_{\rm s,a}$= 0.39±0.18, corresponding to a source kinematic age of 360±170 yr. Assuming that the flux asymmetries are due to Doppler boosting effects, we find that the jets are mildly relativistic and oriented with small angle to the line sight. On the other hand, the central and the southern components are reducing their distance with an apparent contraction speed $\beta_{\rm c,a}$= 0.37±0.02, suggesting that the central component is dominated by a knot in the jet that is moving towards the southern one.

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