Observed Properties of Jets in Young Radio Galaxies

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Abstract

Compact Symmetric Objects (CSOs) are a recently discovered class of radio galaxy thought to be quite young (age ∼1000 years). These compact (size < 1 kpc) radio sources are morphologically similar to classical double radio galaxies with lobes, hot-spots, jets and cores, but they inhabit a much denser environment. This dense environment can give rise to free-free and HI absorption of components, and may in some cases impact the shape of the source. VLBI studies can reveal the growth of the source, and motions in the jet. In a few cases, bidirectional motions are observed on either side of the core. I will review the properties of CSOs, paying particular attention to VLBA observations of jet motions and deflections.

Key words: galaxies: active, galaxies: nuclei, radio continuum: galaxies

1 Introduction

Compact symmetric objects (CSOs) comprise roughly 3% of flux-limited samples selected at high frequencies (Taylor, Readhead & Pearson, 1996; Peck & Taylor, 2000). Their defining characteristic is the presence of high luminosity radio components on both sides of a central engine on sub-kiloparsec scales. In most CSOs there is little or no extended emission present on kiloparsec scales. CSOs typically exhibit terminal hotspots which show no evidence of superluminal motion and are essentially free of relativistic beaming effects (Wilkinson et al., 1994). The primary jets are much brighter than the counterjets, and may exhibit some Doppler boosting. Other characteristics of CSOs are weak radio variability, low radio polarization, frequent presence of HI in absorption, and low core luminosities. Their hosts are elliptical galaxies (Readhead et al., 1996).

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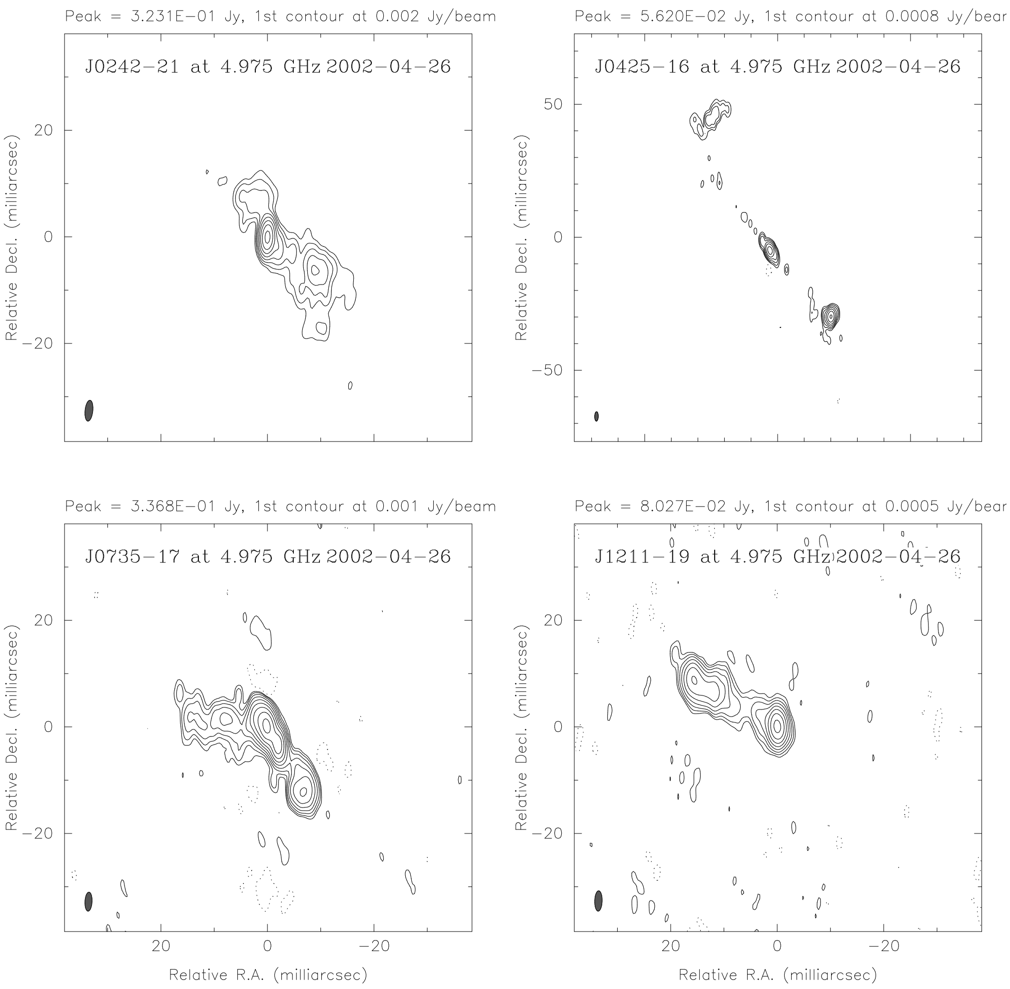

Fig. 1. A collection of recently discovered CSOs (Taylor & Peck, in preparation). The first contour level is given at the top of each plot and contours increase by factors of 2.

2 Recently Discovered CSOs

To identify CSOs it is necessary to have multi-frequency VLBI observations. In this way it is possible to identify the compact flat-spectrum core associated with the center of activity. In Fig. 1 we show a mosaic of 4 CSOs recently discovered with the Very Long Baseline Array (VLBA) telescope. These sources illustrate a range of morphologies. In all sources a compact central component can be identified, and oppositely directed jets are found to emerge from either side. These jets however, can be brighter or fainter than the core and can be straight or strongly bent. The observed velocities of jet components range from stationary to superluminal, with typical velocities of 1.2 c (Taylor et al., 2000). Frequently a reflection, or “S” symmetry is seen in the jets of CSOs.

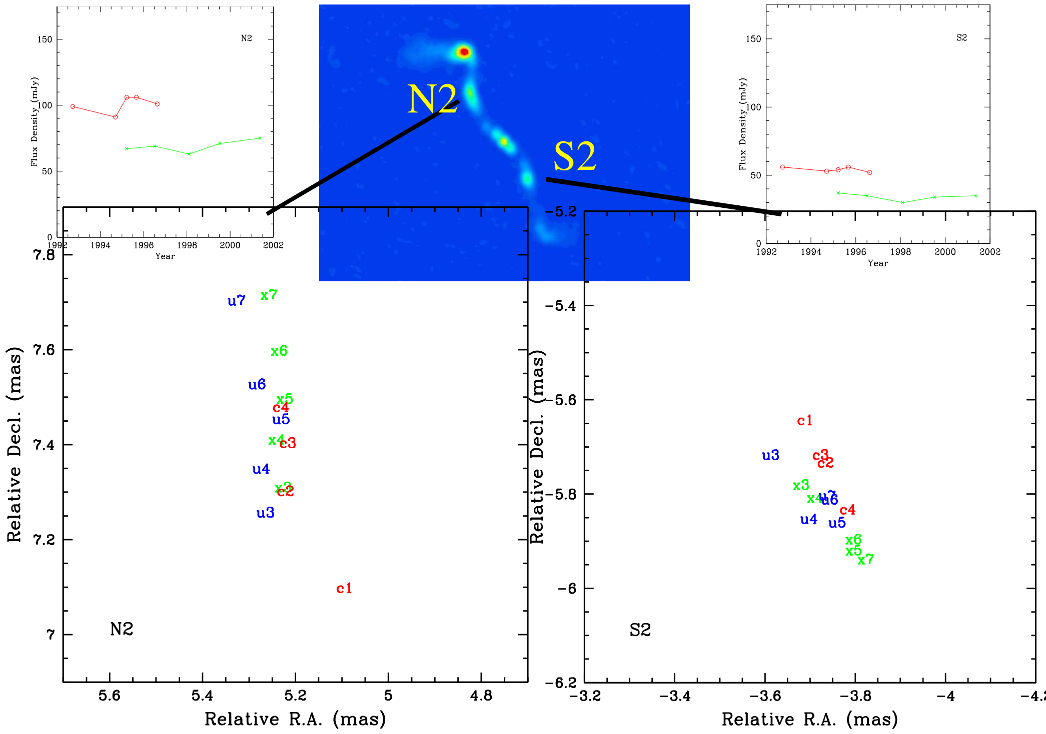

Fig. 2. Light curves (top panels) and trajectories (bottom panels) for the N2/S2 pair of jet components of the CSO 1946+708. In the bottom panels each frequency is denoted by a code (c = 5 GHz, x = 8 GHz, and u = 15 GHz) and a number corresponding to the epoch (1 = 1992 Sep.; 2 = 1994 Sep.; 3 = 1995 Mar. or Sep.; 4 = 1996 Jul. or Aug.; 5 = 1998 Feb.; 6 = 1999 Jul.; 7 = 2001 May).

3 1946+708: Ongoing Study of a Bidirectional Jet

The CSO 1946+708 is an exceptionally interesting source to study with VLBI techniques. It possesses twin, "S" symmetric, bidirectional jets with components that move rapidly (0.4 - 1.4c towards the hot spots on either side of the nucleus. A corkscrew model such as has been used to explain the precessing jets of SS433 (Hjellming & Johnston, 1981) with a period of 5700 years provides a reasonably good fit to the source morphology. Taylor & Vermeulen (1997) asserted that CSOs provide a unique opportunity to determine the Hubble constant directly. Their analysis stemmed from the fact that a direct measure of the distance to an object can be obtained by observing angular motion in it, if the intrinsic linear velocity can be ascertained independently. Based on five epochs of observations of the CSO 1946+708 at 5 GHz Taylor & Vermeulen placed a lower limit on H_0 of 37 and suggested that further multi-frequency observations should improve this constraint. Such data at several additional epochs have been obtained at 8 and 15 GHz over the past 6 years.

In Fig. 2 we show the almost 10 years of monitoring at 5, 8 and 15 GHz of the N2/S2 pair of components in 1946+708. These components are nearly reflection symmetric in the Northern and Southern jets and are paired under the assumption that they were emitted in a common outburst (Taylor & Vermeulen, 1997). Both components have been fairly stable in flux density over the past 10 years of observations. In the stonger N2 component we see some evidence for jet components following curved trajectories. This curved motion argues against a purely ballistic model such as was used by (Taylor & Vermeulen, 1997), and underpinns their determination of H_0. Also, according to the simple ballistic model the velocity ratios, arm-length ratios and flux ratios of components should be simply related, whereas they disagree by factors up to 2.

The next step in the analysis of the jet components in 1946+708 will be to use a relativistic helical jet model. Hopefully this model will do a better job reproducing the observed component trajectories, and changes in brightness. Regardless of the kinematic model used, it is worth pointing out that since the jet components are not strongly Doppler boosted they must be intrinsically more luminous than jet components in typical assymetric sources. This could be another consequence of a higher density environment.

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