Astron. Astrophys. 336, L37–L40 (1998)

ASTRONOMY
AND
ASTROPHYSICS

LETTER

Letter to the Editor

Renewed Radio Activity of Age 370 years in the Extragalactic Source 0108+388

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Received 27 March 1998 / Accepted 23 June 1998

Abstract. We present the results of multi-epoch global VLBI observations of the Compact Symmetric Object (CSO) 0108+388 at 5 GHz. Analysis of data spread over 12 years shows strong evidence for an increase in the separation of the outer components at a rate of $0.197 \pm 0.026 h^{-1} c$. Given an overall size of 22.2 h^{-1} pc this implies a kinematic age of only 367 ± 48 yrs. This result strongly supports the idea that radio emission in Compact Symmetric Objects arises from recently activated radio sources. The presence of weak radio emission on kpc-scales in 0108+388 suggests recurrent activity in this source, and that we are observing it just as a new period of activity is beginning.

Key words: radio continuum: galaxies – galaxies: active – compact – evolution — jets – individual: 0108+388

1. Introduction

There exists a class of powerful radio sources consisting of high luminosity radio emission regions separated by less than 1 kpc and situated symmetrically about the centre of activity. Objects of this type were first described as 'Compact Doubles' by Phillips & Mutel (1982), but the more generic name of Compact Symmetric Objects (CSOs) was given by Wilkinson et al. (1994).

Three possible evolutionary scenarios of CSOs have been proposed: 1) they are old 'frustrated' sources, in which a dense environment doesn't allow them to grow (van Breugel et al. 1984); 2) they are young sources which will 'fizzle out' after a short lifetime (Readhead et al. 1994) or 3) they represent a very young stage in the evolution of large-sized classical radio sources (e.g. Fanti et al.1995, Readhead et al. 1996b, Begelman 1996, Owsianik & Conway 1998).

One archetypical CSO is the radio source 0108+388. This radio object is identified with a galaxy of m_V=22.0 mag at redshift z=0.669 (Lawrence et al. 1996). The radio flux density is weakly polarised ($0.30\% \pm 0.08\%$ at 4.8 GHz) and does not show significant variations (Aller et al. 1992). 0108+388 has a spectral turnover around 5 GHz, with spectral indices $\alpha^{22\mathrm{GHz}}_{5\mathrm{GHz}} = -1.27$ and $\alpha^{5\mathrm{GHz}}_{0.6\mathrm{GHz}} = 2.1$ ($S \propto \nu^{\alpha}$, Baum et al. 1990).

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2. Observations and imaging

There have been three epochs of global VLBI observations of 0108+388 at 5 GHz evenly spread over a period of 12 years. The first two epochs were made on 8th Dec 1982 with a global array of 5 telescopes and on 23rd Nov 1986 using multiple snapshots with 9 telescopes (Conway et al. 1994). Here we reanalyse these epochs and add new data from a multi-snapshot 10 station global VLBI observation made on 18th Sep 1994. The telescopes used included those from the European VLBI Network (EVN), the Very Long Baseline Array (VLBA), the Very Large Array (VLA) and Haystack Observatory.

The amplitude calibration, fringe-fitting, imaging and modelfitting were performed following the procedures described in Owsianik & Conway (1998). Fig. 1 shows the highest dynamic range image obtained from the third epoch data using DIFMAP (Shepherd et al. 1995), which was used as a starting point in remapping the other two epochs. Modelfitting of gaussian components to the visibility data was also carried out at each epoch using the 3rd epoch model as a starting model (see Table 1). In our modelfitting we allowed only the flux densities and positions of components to vary. The estimated models showed a good fit to the visibility data with total reduced χ^2 agreement factors of Q_{TOT}=1.158, Q_{TOT}=1.255 and Q_{TOT}=1.082 for epochs 1 to 3 respectively.

3. Results

3.1. Multi-Epoch Intercomparison

The image of the third epoch data of 0108+388 (Fig. 1) shows the pc-scale structure of the source at 5 GHz, which consists of two bright regions with embedded compact components at the leading edges, which we interpret as hotspots. The images and modelfits are consistent with those of Taylor et al. (1996) at

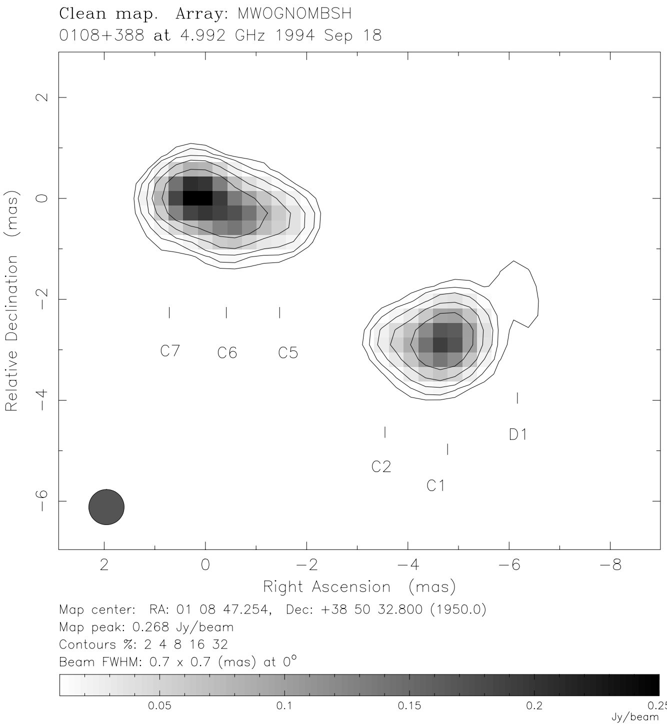

Fig. 1. Third epoch image of 0108+388 with the positions of components identified in gaussian modelfitting indicated. Rms noise=0.88 mJy beam^{-1}.

15 GHz, whose nomenclature we use in this paper. In addition at 15 GHz Taylor et al. (1996) found evidence for a Synchrotron Self-Absorbed (SSA) core region connected to the outer regions by jet-like structures. Due to its inverted spectrum we do not see this core component in our 5 GHz image.

Examining the visibility data we see clear evidence on the long baselines for structural changes in 0108+388 between epochs 2 and 3 (Fig. 2) which are explained by changes in component positions. Consistent differences are found on comparing the data from epochs 1 and 2 (Conway et al. 1994). Linear regression fits to the observed changes in the gaussian component separation between the three epochs of data give us estimates of relative component motions and associated errors. From this analysis we estimate an angular separation rate of components C1 and C7 of $9.27 \pm 1.21 \mu$as yr^{-1} corresponding to a velocity of $0.196 \pm 0.026 h^{-1} c$ (for q_0=0.5 and H_0=100 h kms^{-1} Mpc^{-1}). This result is consistent with earlier estimates based on two epoch data sets and shorter time baselines. Conway et al. (1994) found a velocity of 0.18 $h^{-1}c$ based on the first two 5 GHz epochs, which was cautiously claimed only as an upper limit. Taylor et al. (1996) also estimated $0.22 \pm 0.20 h^{-1} c$ by comparing 10 GHz and 15 GHz observations from 1984 and 1994.

We also found from our three epoch data that the C6-C7 separation increased at $0.088 \pm 0.018 h^{-1} c$. Finally we see evidence for motion in component C5, which is moving towards component C7 at a velocity of $0.942 \pm 0.151 h^{-1} c$. A motion of C5 relative to C7 with velocity of $0.92 \pm 0.20 h^{-1} c$ was also detected by Taylor et al. (1996).

Table 1. Gaussian model for the 3rd epoch of 0108+388

Comp.	S (Jy)	r (mas)	Θ (°)	a (mas)	b/a	Φ (°)
C7...	0.490	0.19	78.98	0.78	0.61	–87.75
C6...	0.253	0.78	–120.62	0.82	0.48	–62.53
C5...	0.063	1.64	–106.95	0.59	0.78	–16.34
C2...	0.045	4.72	–126.36	0.38	0.51	–90.00
C1...	0.422	5.51	–120.76	0.85	0.78	–45.52
D1...	0.030	6.52	–107.21	1.10	0.38	12.84

Parameters of the Gaussian components: S–flux density; r,Θ–polar coordinates, with polar angle measured from the North through East; a,b–major and minor axes of the FWHM contour; Φ–position angle of the major axis.

3.2. Source orientation and true velocity of the components

Since at 5 GHz we were unable to detect the core component, we cannot measure the individual motions of C1 and C7 relative to the core. However, we can constrain the hotspot advance speeds and the overall orientation of the source using the observed total separation rate between C1 and C7 and the ‘arm-length ratio’ of 1.3 measured at 15 GHz (Taylor et al. 1996). Assuming both hotspots have the same advance speed β_{hot} through the surrounding medium and assuming this velocity has remained constant over the lifetime of the source then the apparent source asymmetry must be due to light travel time effects. Given this, the measured ‘arm-length ratio’ provides the constraint that $\beta_{hot} \cos\theta = 0.13$, where θ is the angle between the jet axis and the line of sight. The apparent separation velocity v_{sep} of C1 and C7 is connected to β_{hot} and θ by the relation:

$$v_{sep} = \frac{2c\beta_{hot} \sin\theta}{1 - \beta_{hot}^2 \cos^2\theta}\,, \quad (1)$$

where v_{sep} depends on H_0 and q_0 as well as the measured angular rate of separation. From our two constraints, for a given choice of h and q_0 we can solve uniquely for both θ and β_{hot}. For $q_0 = 0.5$ and $h = 0.5$ we find $\theta = 56° \pm 11°$ and $\beta_{hot} = 0.23 \pm 0.02$, for q_0=0.5 and $h = 1.0$ then $\theta = 36.6° \pm 6°$ and $\beta_{hot} = 0.16 \pm 0.01$.

For the jet component C5, given its apparent motion relative to C7 and the ‘arm-length ratio’, we can estimate its apparent motion relative to the core. If we assume that C5 has the same θ as the hotspots then for a given q_0 and h we can derive the true velocity β_{jet} of C5. Alternatively we can assume that $\beta_{jet} < 1$ and constrain the allowed cosmological parameters. For $q_0 = 0.5$, we find solutions with $\beta_{jet} < 1$ only for values of Hubble constant greater than $H_0 = 54 \pm 6$ kms^{-1} Mpc^{-1} while for $q_0 = 0$ a larger lower limit to the Hubble constant ($H_0 = 80 \pm 8$ kms^{-1} Mpc^{-1}) is required. In most jets it appears that $\gamma > 2$ so that $\beta_{jet} > 0.9$ (Taylor & Vermeulen 1997). Therefore for a given q_0 the best estimate of H_0 is close to the lower limits given above (e.g. $H_0 = 54$ kms^{-1} Mpc^{-1} for $q_0 = 0.5$).

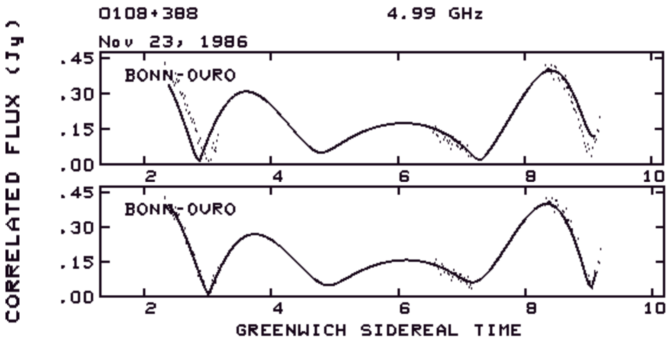

Fig. 2. Temporal changes in visibility data from 0108+388 at 5 GHz. *Top*: Third epoch model plotted against the second epoch data, *Bottom*: the same second epoch data with the best fitting model from gaussian modelfitting after allowing component positions to change.

3.3. Physical parameters of the source

Dividing the distance between C1 and C7 by their observed separation rate we estimate that the pc-scale source would have had zero size 367 ± 48 yrs ago (measured in the source frame). This implies that the pc-scale structure of 0108+388 is very young. Furthermore, from the measured angular expansion rate and using the arguments given in Sect. 3.2 we estimate a minimum physical advance speed of the hotspots in 0108+388 of $0.16c$. Combining this with our estimation of the internal pressures of the hotspots (1.14×10^{-4}dyne cm^{-2}) from equipartition arguments and given ram pressure confinement of the hotspots we derive an upper limit on the external density of 2.1 cm^{-3}.

Given our estimates of the age and the jet thrust (found by dividing the internal pressure in each hotspot by its area) we can compare the mechanical luminosity required to drive the hotspots forward with the radio luminosity and jet power. For an age of 367 yrs the combined mechanical luminosity of the two hotspots is $1.17 \times 10^{44} h^{-17/7}$ ergs^{-1}, while the observed radio luminosity of the two hotspots is about $7.76 \times 10^{43} h^{-2}$ ergs^{-1}. Following the arguments used in Readhead et al. (1996a) the upper limit on the total power supplied by the jets is $1.37 \times 10^{45} h^{-10/7}$ ergs^{-1}. A lower limit on the total jet power can be obtained by adding together the radio power and mechanical work. The total jet luminosity is (for $h = 0.54$) then in the range 7.89×10^{44} ergs^{-1} to 3.29×10^{45} ergs^{-1} and the efficiency of conversion of the jet energy to radio emission is between 8% and 34%. In contrast, for classical FRII radio galaxies upper limits on the hotspot radiative efficiencies are only of the order of a few percent (Owsianik & Conway 1998).

4. Discussion

From three epoch observations we find strong evidence for an increase in separation of the two outer pc-scale components of 0108+388 (C1 and C7) at a velocity of $0.197 \pm 0.026 h^{-1} c$. These outer components have all the properties expected of hotspots in a CSO (in contrast for instance to being knots in a two sided jet): the two components lie at the extremities of the pc-scale structure, have simple SSA spectra and are connected via jets to a core (Taylor et al. 1996). Given their identification as hotspots the measured separation rate of components C1 and C7 implies that the pc-scale source in 0108+388 is very young, i.e. 367 ± 48 yrs.

Recent results from other CSOs suggest that they are also very young radio sources (e.g. Fanti et al. 1995, Readhead et al. 1996b, Owsianik & Conway 1998). The evidence therefore suggests that CSOs are not in general ‘frustrated’ slowly growing sources within a dense environment but are instead fairly rapidly ($\sim 0.2c$) growing sources. There are then several possibilities for the subsequent evolution of CSOs. The simplest possibility is that they evolve via a Compact Steep Spectrum phase into classical double radio sources (FRIs or FRIIs). Given their fairly rapid expansion rate the sources would only be expected to spend a short time in their CSO phase. In order to explain the large fraction of CSOs in flux limited samples there must be a strong negative luminosity evolution with increasing source size (e.g. Readhead et al. 1996b). If such luminosity evolution occurs the ‘population problem’ for CSOs is explained because CSOs then evolve into much weaker, more numerous sources. Such negative luminosity evolution is expected in theory (e.g. Begelman 1996), and evolution of just the amount required is found if we compare the efficiency of radio production in CSOs and classical radio double sources (e.g. Readhead et al. 1996a, Owsianik & Conway 1998).

Another way to explain the large population of CSOs is via recurrent activity in these sources (e.g. O’Dea & Baum 1997, Reynolds & Begelman 1997). In this model the sources are quite old but the activity occurs in short bursts. Every time the activity restarts the jet must propagate again from the nucleus to the kpc working surface. Hence the sources appear as Compact Symmetric Objects (size < 1 kpc) for a significant fraction of their lifetime. The source 0108+388 appears to be a good candidate for such recurrent activity, since in this source Baum et al. (1990) have detected weak extended emission $\sim 20''$ ($\sim 78 h^{-1}$ kpc) to the East of the nucleus.

The fact that we see kpc-scale structure only on one side of 0108+388 might be understood as a natural consequence of intermittent activity in the nucleus (although Baum et al. 1990 discuss other possibilities). If the on-off cycle is short then separate regions of activity (light grey areas in Fig. 3) will propagate out towards the kpc-scale hotspots. Due to light travel time effects we are viewing the far side of the source at an earlier time than the near side. It may be that we are viewing the Eastern, near side kpc-scale hotspot at a time when it is being supplied by jet material and the Western, far side kpc-scale hotspot while unsupplied. Such an unsupplied hotspot fades very fast as electrons diffuse to regions of lower density and magnetic field and radiate inefficiently. Given the size of the Eastern hotspot at the lowest 5 GHz contour (Baum et al. 1990), the fact that the Western hotspot is not detected at this contour and assuming an electron backflow velocity of $0.1c$, we calculate that the Eastern hotspot must have been left unsupplied for at least of $2 \times 10^5 h^{-1}$ yrs, providing a lower limit on the on-off cycle time.

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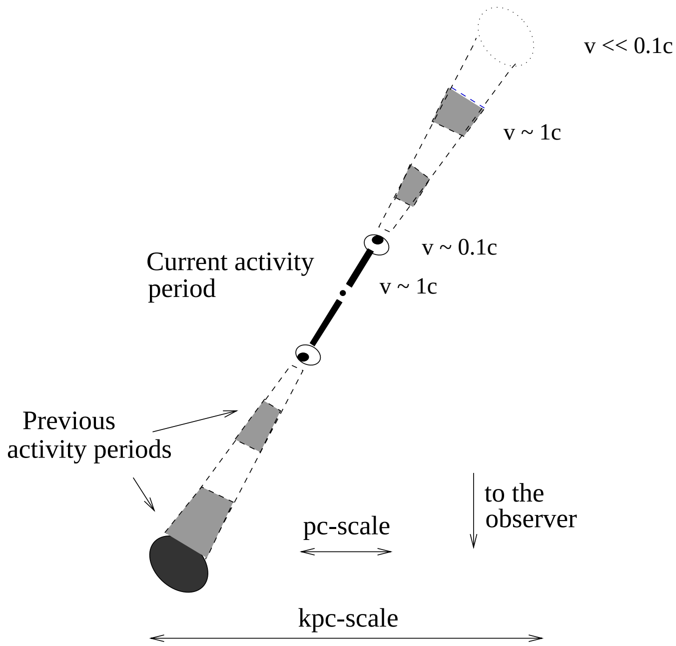

Fig. 3. Diagram illustrating a possible explanation of the extended emission in 0108+388. *Light grey* areas represent material emitted from the central engine in previous periods of activity which propagates through a low density cocoon. *Dark grey* areas represent working surfaces against high density circumnuclear and IGM gas from which we get significant radio emission on pc- and kpc-scales respectively.

An approximate upper limit to the cycle time can be set by considering the effects of light travel time and jet propagation. We first note that in the proposed model (see Fig. 3) the kpc-scale hotspots advance with low average speed (v$<< 0.1c$) through the relatively dense IGM or intercluster gas; hence the observed projected distances to the two kpc-scale hotspots are expected to be approximately the same. From the measured distance of the Eastern kpc-scale hotspot from the core and the estimated angle to the line of sight (see Sect 3.2), we can calculate that this hotspot is viewed $5 \times 10^5 h^{-1}$ yrs earlier than the Western kpc-scale hotspot. The regions of jet activity (light grey areas in Fig. 3) are assumed to propagate out at high speed through the low density radio cocoon. Relativistic velocities for this material are consistent with the detection of a possible weak kpc-scale jet feature on the Eastern side of the source (Baum et al. 1990). If the on-off cycle time was long compared to the light travel time difference then we would most likely observe either both kpc-scale hotspots supplied or unsupplied. To have a high probability of seeing only one hotspot supplied we require that the lengths of the periods of activity must be comparable or shorter to the light travel time (see Fig. 3); hence we can estimate an upper limit on the cycle time of about $10^6 h^{-1}$yrs.

We conclude that the pc-scale structure in 0108+388 is very young, but that activity in this source may be intermittent. In this case we are probably viewing 0108+388 just as a new phase of high radio-efficiency activity in the central engine has begun. Our results imply that at least some CSOs are recurrent sources. In contrast other CSOs (e.g. 0710+439 and 2352+495) apparently show no extended emission or signs of recurrent activity, so the CSO population may contain a mixture of intermittent and non-intermittent sources.

Acknowledgements. IO acknowledges support from EU grant (ERB-CIPDCT940087), OSO and S. Batory Foundation. AGP acknowledges support from the European Commission's TMR programme, Access to Large-Scale Facilities, under contract number ERBFMGECT950012

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