1977MNRAS.181..247G

Mon. Not. R. astr. Soc. (1977) **181**, 247–252

A study of the bridges in the radio galaxies 3C 132 and 3C 192 at metre and centimetre wavelengths

Gopal-Krishna *Radio Astronomy Centre, Tata Institute of Fundamental Research, PO Box 8, Ootacamund-643001, India*

Received 1977 May 2; in original form 1977 March 18

Summary. A comparison is made of the high-resolution observations of two double radio galaxies, namely 3C 132 and 3C 192, over a frequency range of more than 10:1. Each of these sources exhibits a wide bridge which accounts for about two-thirds of the total radio output and whose extent in the direction perpendicular to the source axis is found to remain unchanged over this large frequency range. In the case of 3C 132 the spectral break observed at centimetre wavelengths provides evidence for a deficiency of more energetic particles, possibly inside the bridge component. The role of radiative and adiabatic losses during evolution of the bridges is discussed. Using the continuous flow model, physical parameters are estimated for the two sources and for the intracluster medium in which they are embedded.

1 Introduction

In recent years much effort has been directed towards mapping powerful extragalactic radio sources with a resolution of a few seconds of arc over a wide range of frequencies. Many of these sources are distinguished by a pair of compact heads which are a few kiloparsecs in size and are located far away on opposite sides of the optical galaxy. In some cases only short tails are observed next to the heads but often the tails are long and may even form a continuous bridge of emission linking the two outer components. Recently, high-resolution observations of several double radio sources at widely separated frequencies have been compared for 3C 172 by Jenkins & Scheuer (1976) and for five other sources by Gopal-Krishna & Swarup (1977). It seems fairly clear that relative to compact heads, spectra of short tails are at most only marginally steeper but the bridges frequently, though not always, have steeper spectra. In some cases, such as 3C 215, although the total spectrum appears straight over the range 10–15 000 MHz (Véron, Véron & Witzel 1974; Genzel *et al.* 1976), high-resolution observations have shown that the spectrum of the bridge is much steeper than that of the compact heads (Gopal-Krishna & Swarup 1977). All these spectral data are consistent with the suggestion that fast particles escape from the compact heads into the region of the bridge (Hargrave & Ryle 1976) and in several sources, at least, the particles are contained within the bridge for a long enough time to have incurred severe energy losses.

Van der Laan & Perola (1969) have suggested that energetic particles leak out of radio sources in a time comparable to their radiative lifetimes. If the leakage occurs in a way such that the particles, soon after their injection into the bridge, acquire a bulk motion directed away from the axis of the bridge, the older particles which are responsible for the steeper spectrum of the bridge would develop a higher concentration in the outer parts and so the transverse width of the bridge would be greater at lower frequencies. Such observational evidence for bulk diffusion of particles, if any, is clearly of interest. But high-resolution maps at low frequencies are at present available for only a limited number of sources, for which lunar occultation observations have provided strip scans along a few position angles. In this paper, we consider two double radio galaxies, namely 3C 132 and 3C 192, whose occultations have provided strip scans at metre wavelengths not only along their main axes but also in the perpendicular directions. At centimetre wavelengths, Cambridge observations have revealed that each of these sources consists of two compact heads which are well aligned with respect to the optical galaxy and are connected by a bridge contributing at least two-thirds of the total emission. Such high contributions from the bridges reduce to a large extent the uncertainty in estimating their widths from strip scans.

2 Results

The high-frequency maps of 3C 132 and 3C 192, shown in Figs 1 and 2, were obtained by

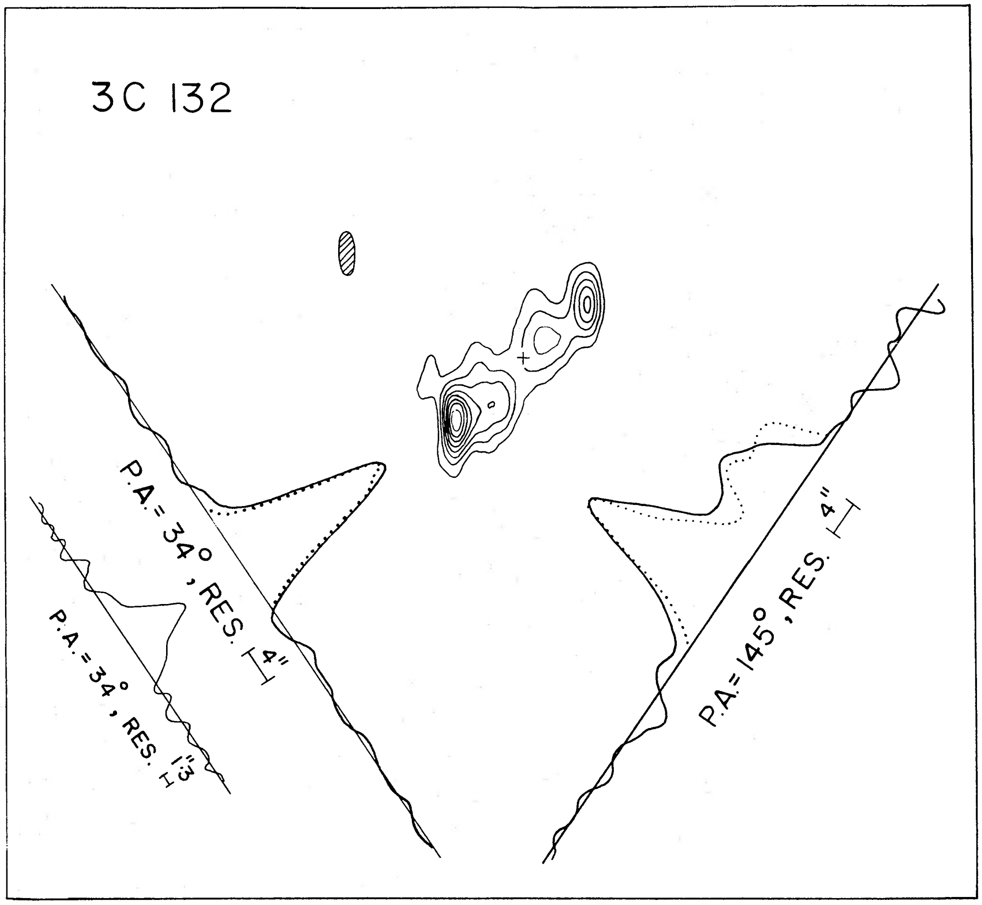

Figure 1. The solid and dotted profiles represent the strip brightness distributions for the indicated position angles at frequencies of 327 and 5000 MHz, respectively. For each position angle, the resolution of the two profiles is the same, as shown with a bar. The shaded ellipse represents the beamwidth of the 5000 MHz map shown in the middle. The cross marks the position of a cluster galaxy at a redshift of 0.2140 (Smith *et al.* 1976).

Jenkins, Pooley & Riley (1977) and Harris (1973), respectively. At lower frequencies, strip scans have been derived from lunar occultation observations of 3C 132 at 327 MHz (Joshi & Gopal-Krishna 1977) and of 3C 192 at 256 MHz (Taylor 1968). These are compared in Figs 1 and 2 with the scans derived by strip integration of the corresponding high-frequency maps. In all cases, of the two scans being compared, the one with higher resolution has been smoothed to the resolution of the other scan. Also, amplitudes of the two scans have been normalized to the same peak value. In order to make the flux densities resulting from contour integration of the two maps agree with the values quoted by the authors, the brightness temperature of the first contour was taken to be half of the given contour interval. But even if it were equal to the contour interval, the profiles shown in Figs 1 and 2 would not be significantly in error.

3 Discussion

3.1 RELATIVE SPECTRA OF COMPACT AND EXTENDED COMPONENTS

From Fig. 1 it is seen that differences between the strip scans taken along the axis of 3C 132 at 327 and 5000 MHz are not much above the noise. Hence it is difficult to judge the signifi-

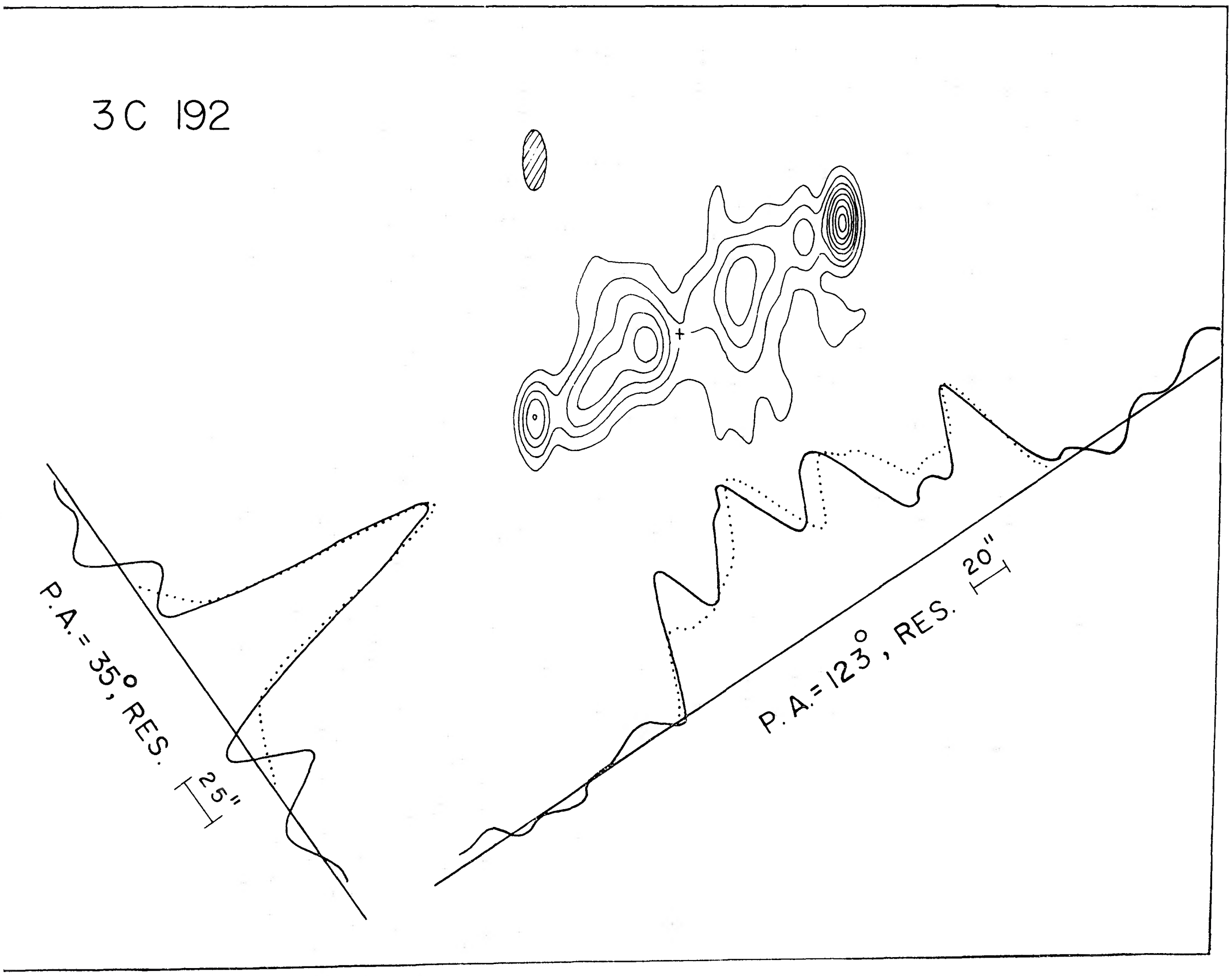

Figure 2. The solid and dotted profiles represent strip brightness distributions for the indicated position angles at frequencies of 256 and 2700 MHz, respectively. For each position angle the resolution of the two profiles is the same, as shown with a bar. The shaded ellipse represents the beamwidth of the 2700 MHz map shown in the middle. The cross marks the position of a cluster galaxy at a redshift of 0.0599 (Smith *et al.* 1976).

cance of the apparent flattening of spectrum in the small region near the western edge. But the spectra of at least some parts of the bridge appear to be a little steeper than that of the eastern head, in view of the above two scans which show some excess emission at the lower frequency all over the bridge. For 3C 192, the strip scans taken along its main axis at 256 and 2700 MHz show very similar features (Fig. 2), as was also inferred by Harris (1973) from maps at 256, 1400, 2700 and 5000 MHz (considering the general agreement among these four maps, the small shift seen in Fig. 2 between the two profiles of the central region in the scan along the source axis does not seem real). Further, it may be noted that in both sources no significant change in transverse width of the bridge is observed over the large frequency range of more than 10 :1. The significance of this result is discussed later.

It may also be noted that, although the measured flux densities of 3C 192 (Véron *et al.* 1974) suggest a constant slope of -0.6 from about 178 MHz to about 10 GHz, the slope steepens to about -0.9 at low frequencies. If the excess emission at low frequencies is not due to some confusing sources, it probably arises from an extended halo surrounding 3C 192 (Kuril'chik 1973). The optical studies have shown that both 3C 192 and 3C 132 are located inside clusters (Smith, Spinrad & Smith 1976).

3.2 AGES OF THE TWO SOURCES

The spectra of these two sources are largely determined by the bridge components which account for about two-thirds of the total emission. The total spectrum of 3C 132 is known to remain straight up to ~10 GHz with a slope of -0.75 (Véron *et al.* 1974). But recent measurements by Genzel *et al.* (1976) at 15 GHz indicate that the slope steepens above 10 GHz by $\gtrsim 0.25$. We shall consider this steepening to arise mostly due to the bridge component, drawing an analogy from the case of Cygnus A (Hargrave & Ryle 1976) and a hint from the preceding discussion of the observations at 327 and 5000 MHz. Then a consideration of synchrotron losses and of inverse Compton losses due to the cosmic blackbody radiation (Rees & Setti 1968) gives an age of approximately 6×10^6 yr for the source 3C 132. The above consideration provides only an upper limit of 3×10^7 yr to the age of 3C 192, since its total spectrum shows no evidence for steepening at least up to 5 GHz (Véron *et al.* 1974; Fig. 2; van der Laan & Perola 1969). Combining these ages with the observed sizes of the sources, we obtain time-averaged velocities of the compact heads and also the rates at which the bridges expand laterally. These are given in Table 1.

3.3 THE PHYSICAL CONDITIONS

A strip scan taken normal to the axis of 3C 132 with a resolution of 1.3 arcsec at 327 MHz is also shown in Fig. 1. This profile consists of a peak due to the integrated response from the two heads, superimposed on a broader feature which corresponds to the bridge and has

Table 1. The derived physical parameters for the sources 3C 132 and 3C 192.

	3C 132 (Age $\sim 6 \times 10^6$ yr)			3C 192 (Age $< 3 \times 10^7$ yr)		
	Head	Bridge	External medium	Head	Bridge	External medium
Velocity of the advancing heads	$0.02c$			$> 0.01c$		
Velocity of lateral expansion		$0.01c$			$> 0.004c$	
Number density of protons (cm^{-3})	3×10^{-5}		2×10^{-4}	$< 7 \times 10^{-6}$		$< 1 \times 10^{-4}$
Temperature (K)			3×10^8			$> 5 \times 10^7$

an average width of ~ 8 arcsec. In comparison, the western head has a size of only ~ 1.4 arcsec, as given by Jenkins *et al.* (1977) (Fig. 1). From this map, nearly the same size is estimated for the eastern head which accounts for about a fifth of the total radio output from the source. Similarly, the size of the stronger western head of 3C 192 is only ~ 3 arcsec (Jenkins *et al.* 1977) which is almost 15 times smaller than the average width of the bridge estimated by Harris (1973). Thus it is seen that the bridges are an order of magnitude wider than the heads. This requires a rather high rate of energy transfer from the compact heads for replenishment against the severe adiabatic losses in the bridges.

Taking Einstein–de Sitter model with $H = 50$ km/(s Mpc) and making no allowance for the possible presence of relativistic protrons, the estimated equipartition magnetic field is $\sim 7 \times 10^{-5}$ G for both heads in 3C 132. The value is $\sim 5 \times 10^{-5}$ G for the western and $\approx 3 \times 10^{-5}$ G for the eastern head of 3C 192. Similarly, magnetic fields in the bridges of 3C 132 and 3C192 are estimated to be $\sim 2 \times 10^{-5}$ and $\sim 5 \times 10^{-6}$ G, respectively. Thus, for the equipartition condition, energy densities, u_{B}, in the bridges of the two sources are 10–70 times smaller than those within the heads, u_{H}. If it is assumed that during the continuous flow of energy from the heads into the adiabatically expanding bridge the ratio of energy densities, $u_{\mathrm{H}}/u_{\mathrm{B}}$, in the two regions remains unchanged, the total amount of energy supplied into the bridge would have been $(u_{\mathrm{H}}/u_{\mathrm{B}})^{1/4}$ times its present energy content. By combining this total energy with the age of the source, deduced from its spectral curvature, it is possible to determine the rate at which energy escapes from the compact heads into the bridge. Following the above approach, Hargrave & McEllin (1975) have shown for five sources that relativistic electrons are required to escape out of the heads at speeds $\gtrsim 0.5c$. The escape velocities estimated similarly for particles in the heads of 3C 132 and 3C 192 are $0.1c$ and $> 0.1c$, respectively. Assuming that these values represent the generalized sound speeds, the matter densities in the compact heads are determined as given in Table 1. Also, temperature and density are estimated for the intracluster medium around these sources, assuming that ram pressure due to the medium balances the internal pressure of the heads and the bridges are contained due to thermal pressure of the medium (Table 1). Definite values of the parameters could be obtained only for 3C 132. As seen from Table 1, an external medium with a temperature exceeding 10^7–10^8(K) is required in this model for containing the bridges, even if the particles escape from the heads into the bridges at rates several times smaller than those estimated above. For a few sources, Hargrave & McEllin (1975) have shown that in the above model the required velocities of escape of particles from the heads are several times higher than the generalized sound speeds within the heads, as estimated from the minimum energy densities and the matter densities inferred from depolarization data. It would be interesting to observe this effect in some more sources.

Conclusions

To summarize, the transverse widths of the bridges in 3C 132 and 3C 192 are found to remain unchanged over frequencies from a few hundred to a few thousand megahertz. This would be expected even if an outward diffusion of energetic particles occurs inside the bridges, because the spectra of the bridges in the above frequency range are not appreciably steeper than those of the compact heads, indicating that energy losses for the particles radiating at centimetre wavelengths are yet not heavy. The spectrum of 3C 132 does become quite steep above ~ 10 GHz but maps of this source at such high frequencies are not yet available. It would be of interest to measure the transverse dimensions of bridges at frequencies in the range over which their spectra show appreciable curvature. Also, it would be desirable to confirm the possible halo around 3C 192 at decametre wavelengths. Such observations may be useful for understanding the diffusion of energetic particles, which is linked with the question of their leakage from radio sources.

Acknowledgments

I am grateful to Drs C. J. Jenkins, G. G. Pooley and J. M. Riley for communicating the results of their observations of 3C 132 at 5 GHz, prior to publication. I also thank Professor G. Swarup for his critical reading of the manuscript and valuable comments.

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