THE EVOLUTION OF COMPACT DOUBLE RADIO SOURCES

R.L. Mutel
Department of Physics and Astronomy
University of Iowa
Iowa City, IA 52242 USA

R.B. Phillips
Haystack Observatory
Westford, MA 01886 USA

ABSTRACT. The evolution of compact double radio sources is discussed using a model due to Carvahlo (1985). We suggest that for doubles associated with active *galaxies*, there is a plausible evolutionary sequence from compact doubles to steep-spectrum compact sources to extended (D1) doubles.

Most well-studied central radio sources are characterized by asymmetric 'core-jet' morphologies. The projected sizes are typically tens of parsecs, but there is almost always extended arcsecond structure along the jet axis extending well beyond the parent galaxy (e.g., Antonucci 1985). This implies a *minimum* age $t \sim 10^{6.5}$ y for a deprojected size $l \sim 1$ Mpc and relativistic bulk flow for the entire lifetime of the jet.

By contrast, the compact double (CD) sources (Phillips and Mutel 1982) have overall sizes $\lesssim 1$ kpc., implying a much younger evolutionary state. Their observed properties have been discussed elsewhere (Hodges and Mutel 1987), and will only be summarized here: well separated double morphology with no arcsecond structure, self-absorbed synchrotron spectra for each component, low polarization and variability, optically identified with faint galaxies and empty fields (*never quasars*). The CD sources bear a striking resemblance to extended double sources, particularly the luminous, edge-brightened Fanaroff-Riley Class II (FRII, also known as D1) objects such as 3C33 or Cygnus-A. They are also similar to many 'steep-spectrum compact' (SSC) sources whose dominant structure is often double, but with linear separations of $1 - 10$ kpc. (Fanti, *et al.* 1985).

We have suggested that there is an evolutionary sequence connecting all three classes, *viz*, CD sources evolve into SSC sources, which eventually become extended doubles (Hodges and Mutel 1987). The lifetimes (and hence relative numbers) for each phase of evolution depend on the bulk expansion speed of the lobes. This is likely to be time variable, since the lobes pass through decreasing gas density as they move from near the galactic center to the intergalactic environment. If the lobes are pressure confined during the CD phase, the expansion speed is $v_{lobe} \sim 0.1c$ (Mutel, *et al.* 1985), implying a lifetime of $\tau \sim 10^4$ y.

Carvahlo (1985) has recently proposed a simple evolutionary model which is consistent with the hypothesis that CD sources are the progenitors of extended doubles. It is based on the model developed by Schueur (1974) in which the opposed radio lobes lose energy both by expansion and synchrotron radiation losses. The central engine supplies energy to the lobes at a constant rate until a characteristic time t_0, whence the lobe lu-

M. J. Reid and J. M. Moran (eds.), The Impact of VLBI on Astrophysics and Geophysics, 73–74.

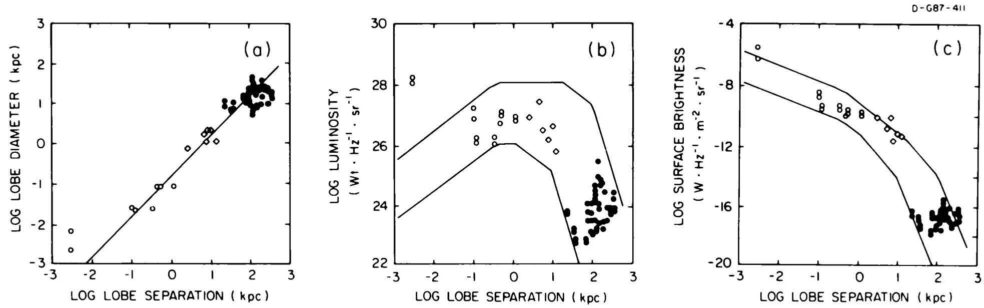

Figure 1 (a) Lobe diameter, (b) Radio luminosity, and (c) Surface brightness at 1.4 GHz of double radio sources as a function of lobe separation. The open circles (∘) refer to compact double (CD) sources, the diamonds (⋄) refer to steep spectrum compact (SSC) sources, and the filled circles (•) refer to Fanaroff-Riley Class II (edge-brightened or D1) doubles. The lines are predicted evolutionary tracks using the model of Carvahlo (1985).

minosity and energy density begins to decrease as e^{-t/t_0}. He compares the expected size, luminosity, energy density, and surface brightness of the radio lobes as a function of linear separation for the model versus a sample of CD and FRII sources. Carvahlo finds that the observed properties of CD and FRII sources are consistent with a lobe velocity of $v \sim 0.2c$ and a turn-off time of $t_0 \sim 10^5$ y.

We have applied this model to include the SSC sources as an intermediate state. An example of the lobe size, radio luminosity, and surface brightness as a function of overall size is given in figure 1. The relatively good fit suggests that at least some of the SSC sources (those with dominant double structure) could be the evolutionary successors of CD sources and progenitors of extended doubles. Additional supportive evidence derives from the spectral turnover frequencies in the three groups — there is a systematic decrease in average peak frequency as would be expected for synchrotron sources suffering radiation and expansion losses ($\nu_{peak} \propto B^{-3}t^{-2}$). A systematic analysis of the evolution of double radio sources should include a detailed statistical analysis of the evolution of the lobe properties, relative number densities, and spectral properties. Unfortunately, there are as yet no systematic surveys of either CD or SSC sources. Nevertheless, the initial results using a relatively simple physical model are encouraging.

REFERENCES

Antonucci, R.R.J. 1985, in *Active Galactic Nuclei*, ed. J.E. Dyson (Manchester University Press:Manchester), p. 98

Carvahlo, J.C. 1985, *M. N. R. A. S.*, **215**, 463.

Fanti, C., Fanti, R., Parma, P., Schilizzi, R.T., and van Breugel, W. 1985, *Astr. Ap.*, **143**, 292.

Hodges, M.W. and Mutel, R.L. 1987,in *Superluminal Radio Sources*, ed. J.A. Zensus and T.J. Pearson (Cambridge University Press:Cambridge), p. 168

Mutel, R.L., Hodges, M.W., and Phillips, R.B. 1985, *Ap. J.*, **290**, 86.

Phillips, R.B. and Mutel, R.L. 1982, *Astr. Ap.*, **106**, 21.

Scheuer, P.A.G. 1974, *M. N. R. A. S.*, **166**, 513.