RELATIVISTIC MAGNETIC LOOPS IN DOUBLE RADIO SOURCES

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Abstract. A simple model for superluminal double radio sources is presented. A relativistic electron-positron beam drives the expansion of an elongated magnetic loop configuration. This is treated using basic conservation laws. Relativistically expanding radio components on a scale of parsecs result for plausible physical parameters.

1. Introduction

Very-long-baseline interferometry (VLBI) observations of compact extra-galactic radio sources have revealed that expanding structures with apparent separation speeds exceeding twice the speed of light are fairly common among strong sources (cf. Cohen et al., 1979). The theories advanced to explain this phenomenon have been reviewed and classified (Blandford et al., 1977). Theories of the 'ballistic' type involve a relativistic expansion of the source, with the apparent superluminal expansion being due to the emitting matter approaching the observer at a small angle to the line-of-sight. Although this requires the observer to be in a privileged angular position, Scheuer and Readhead (1977) have argued that the observational consequences of this provide an explanation of the large value of the ratio of radio-quiet to radio-loud quasars.

One method of driving the expansion and fueling the radio lobes is with a relativistic beam or jet. Jet-like structures are fairly common in giant radio sources (Rees, 1978), and theoretical models provide a number of processes for forming jets (Blandford and Rees, 1974; Lovelace et al., 1979). An alternative class of models involves the focused propagation of intense blast waves (cf. Marscher, 1978; Shapiro, 1980).

We present here a simple model for the dynamical evolution of a relativistic jet. The bulk motion is driven by a beam of relativistic particles which may have Lorentz factors much higher than that of the jet itself. The following section describes the general features of the model. Section 3 examines the jet dynamics, and Section 4 comments on some of the observational consequences of the model.

2. Description of the Model

The model assumes that the central object of the radio source emits two oppositely-directed collimated beams of relativistic particles which power the radio components.
Owing to relativistic beaming only one beam may be visible (Scheuer and Readhead, 1977). The origin of the collimated beams and the particle types are not important for the considerations of this paper, but we consider explicitly electron-positron beams, such as produced in the dynamo model (Lovelace et al., 1979), which are expected to have favourable stability properties (Lovelace et al., 1979; Kundt and Gopal-Krishna, 1980). The particle beam propagates within a channel delineated by a wall of inflowing cold matter. Accretion of matter with angular momentum leads to the formation of a vortex funnel about the rotation axis (Scott and Lovelace, 1982), and this provides a channel essentially clear of matter.

The particles of the beam stream outward along magnetic field lines within the channel. When the ratio of the energy density in the particles to that in the magnetic field, denoted by $\beta$, exceeds unity, the particles stretch the field lines. The resultant configuration of field lines consists of highly-elongated strands which double back on themselves, as depicted schematically in Figure 1. Qualitatively, this behaviour is suggested by the outward motion of coronal magnetic field loops above active regions of the Sun following large flares (cf. Priest, 1981).

The beam front, defined by the region in which the field lines double back, advances with a speed which depends on the parameter $\beta$. A tenuous cold medium ahead of the beam front will slow the front through ram pressure. The particle angular distribution, originally confined to a very narrow cone, broadens at the beam front as the particles impart forward momentum to the front. Thus synchrotron radiation from the beam particles becomes visible near the beam front. The resulting source of radiation moves, possibly at relativistic speeds.

![Fig. 1. Schematic drawing of beam, vortex funnel geometry. The region (a) may be occupied by a tenuous cold medium.](image-url)