TURBULENT GENERATION OF MAGNETIC FIELDS IN
ASTROPHYSICAL JETS

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Abstract. We consider evolution of the regular magnetic field in turbulent astrophysical jets. The observed lateral expansion of a jet is approximately described by a linear in coordinates regular velocity field (the Hubble flow). It is shown that in expanding turbulent jets with non-vanishing mean helicity of the turbulence temporal amplification and effective realignment of the regular magnetic field occurs with the field changing orientation from the transverse to the longitudinal one along the jet axis. The distance at which the realignment occurs depends on parameters of the jet, in particular, on the power of the central source. Estimates for the jet in a weak source 3C 31 favourably agree with observations.

1. Introduction

Turbulent jets are a widespread phenomenon in active astrophysical objects where they are most spectacular manifestations of activity both in Galactic (SS 433 – Margon, 1982; Sco X-1 – Fomalont et al., 1983; star formation regions – Snell et al., 1980; Bally and Lada, 1983; and probably in the galactic center – Brown et al., 1981) and extragalactic sources, radiogalaxies and quasars (see reviews by De Young (1984) and Begelman et al. (1984)). Very prominent they are in extended radio sources where jet lengths range from tens of kiloparsecs to few megaparsecs. The jets represent channels along which matter and energy are continiously supplied from a central source into extended remote radio source components. Free path lengths of particles within a jet exceed its radius but a considerable magnetic field ($\sim 10^{-5}$–$10^{-6}$ G) makes applicable the magnetohydrodynamical approximation (Blandford and Rees, 1978).
Magnetic field structure in the jets, as obtained from polarization observations, correlates with the source power (Bridle, 1982). In the jets that originate in powerful sources (whose total luminosity at 1.4 GHz exceeds $\sim 10^{25}$ W Hz$^{-1}$) magnetic fields are predominantly directed along the jet axis at all distances from the core. In weak sources the field, being longitudinal initially, changes a dominant orientation to the transverse one at some distance from the core.

According to the accepted models, hydrodynamic parameters of the jets are related to the power of the central sources. There are indications (e.g., Bridle and Perley, 1984) that the internal Mach numbers of jets grow with the source power and range from 1 to 10. The longitudinal velocity of the jet plasma also grows with the source power while the sound velocity is believed to be of the order of $v_s \approx 10^8$ cm s$^{-1}$. In addition, the inverse correspondence is observed between the source power and the rate of the jet transverse expansion. In weak sources this expansion occurs practically at all distances from the core while in powerful ones it is noticeable only at the jet end. This observation agrees with laboratory measurements of the expansion rates of turbulent jets at various Mach numbers $M$. The expansion rate declines with growth of $M$ (Lau, 1981).

It is often presumed that magnetic fields are created in central sources and advected into jets by plasma outflows. In this event the observed structure of the field could be explained on the premise of the frozen-in magnetic field: growth of the jet radius $r$ with distance from the core results in growth of the ratio of transverse field to the longitudinal one: $B_\perp/B_\parallel \propto r$ (Parker, 1979; Blandford and Rees, 1978).

However, the observed strengths of magnetic fields in jets cannot be explained if the magnetic flux is conserved (De Young, 1980). Magnetic fields of $10^{-5}$–$10^{-6}$ G strength in extended radio-emitting regions require unrealistically strong magnetic fields within the cores. The pressure of the required magnetic field exceeds, by several orders of magnitude, the thermal pressure of both interstellar and intergalactic medium. The observed brightness distributions along the jets in some radio sources (3C 31, 3C 449, 3C 296, etc.) also contradict the frozen-in concept (Fomalont et al., 1980; Scheuer, 1980; Birkinshaw et al., 1981). For instance, if magnetic field in 3C 31 is frozen-in, the surface brightness would drop by two orders of magnitude along the jet. Nothing of this kind is observed, the surface brightness decrement is described by only the factor of four (Fomalont et al., 1980). The observed picture implies amplification of the magnetic field along the jet or in situ acceleration of relativistic particles.

Here we consider the possibility of generation of the large-scale magnetic fields in the jets due to a joint action of helical turbulent plasma motions and a regular flow of the jet plasma, both of which distort and stretch a seed magnetic field advected into the jet from the core.

Helical turbulent hydromagnetic dynamo in jets and radiogalaxies has been numerically analyzed by De Young (1980) (see also Hughes and Allen, 1981). An additional factor of the regular velocity field can drastically change evolution of the magnetic field, specifically either strongly enhance the generation or suppress it by enhancement of dissipation. We show that very rapid, super-exponential growth of the field in time (or, which is the same, along the jet) may occur in astrophysical jets. However, in our model