Jets at all Scales
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3D-MHD simulations of the evolution of magnetic fields in FR II radio sources

Martín Huarte-Espinosa[1,3], Martin Krause[4,5] and Paul Alexander[2,3]

[1]Department of Physics and Astronomy, University of Rochester 600 Wilson Boulevard, Rochester, NY, 14627-0171; [2]Astrophysics Group, Cavendish Laboratory, 19 J. J. Thomson Ave., Cambridge CB3 0HE, UK
emails: martinhe@pas.rochester.edu, pa@mrao.cam.ac.uk
[3]Kavli Institute for Cosmology Cambridge, Madingley Road, Cambridge CB3 0HA, UK;
[4]Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse, 85748 Garching, Germany. email: krause@mpe.mpg.de
[5]Universitätssternwarte München, Scheinerstr. 1, 81679 München, Germany

Abstract. 3D-MHD numerical simulations of bipolar, hypersonic, weakly magnetized jets and synthetic synchrotron observations are presented to study the structure and evolution of magnetic fields in FR II radio sources. The magnetic field setup in the jet is initially random. The power of the jets as well as the observational viewing angle are investigated. We find that synthetic polarization maps agree with observations and show that magnetic fields inside the sources are shaped by the jets' backflow. Polarimetry statistics correlates with time, the viewing angle and the jet-to-ambient density contrast. The magnetic structure inside thin elongated sources is more uniform than for ones with fatter cocoons. Jets increase the magnetic energy in cocoons, in proportion to the jet velocity. Both, filaments in synthetic emission maps and 3D magnetic power spectra suggest that turbulence develops in evolved sources.

Keywords. galaxies: active, jets, methods: numerical, polarization, MHD

1. Introduction

Fanaroff-Riley class II radio sources (FRIIs, Fanaroff & Riley 1974) are extragalactic, synchrotron in nature and show linear polarization fractions within 10–50% (Bridle & Perley 1984). Stokes parameters are used to infer the magnetic structure in these sources. Observed magnetic polarization vectors are generally parallel to the jets and to the lobe boundaries, and follow both flux intensity gradients perpendicularly and lines between multiple lobe hot spots (Bridle & Perley 1984). The linear polarization fraction in FRIIs is typically higher at jet edges than in their beams, and also at source edges than in the cocoons (Saikia & Salter 1988). The magnetic structure in FRIIs, as well as the way it evolves and relates to AGN jet properties, is not clear.

2. Model and methodology

The equations of ideal MHD are solved in 3D using the code Flash 3.1 (Fryxell B. *et al.* 2000), inside a cubic Cartesian domain with 200^3 fixed cells. The intra-cluster medium is implemented as a monoatomic ideal gas ($\gamma = 5/3$), a stratified King density profile (King 1972), magnetohydrostatic equilibrium with a central gravitational field and magnetic fields with a Kolmogorov turbulent structure, with a thermal-to-magnetic pressure ratio $\gtrsim 10$. Source terms are implemented in the equations to inject mass and x-momentum in a central cylinder which takes weak and random magnetic fields from

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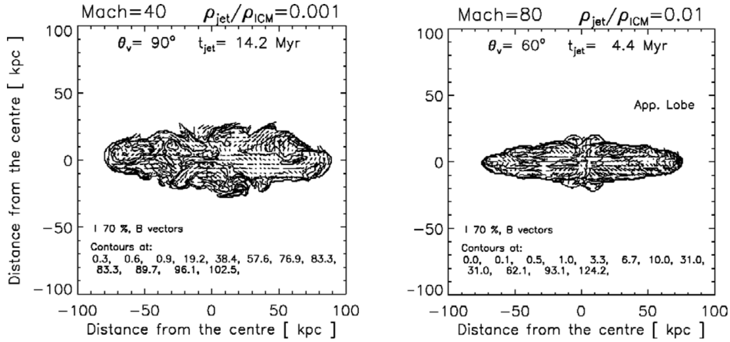

Figure 1. Synthetic polarization maps. Vectors follow the magnetic position angle and their length is proportional to the degree of linear polarization. Vectors are superimposed on contours of synchrotron emission (at 8 GHz) normalized to the mean emissivity. The initially random magnetic fields have been ordered by MHD processes. The left lobe in the right panel source is receding, yet beaming and light-travel effects are assumed to be negligible.

the innermost ambient medium. We investigate jet velocities with Mach=$\{40, 80, 130\}$ as well as $\eta = \rho_{\rm jet}/\rho_{\rm amb} = \{0.01, 0.001\}$.

3. Synthetic synchrotron emission

Synchrotron emission and Stokes parameters are calculated and integrated through the inflated model sources, along the line of sight. The density distribution of ultra-relativistic electrons is the product of the cocoon pressure and an incompressible tracer field injected with the jets. Synthetic polarization maps are produced for five model sources at different source expansion times, $t_{\rm jet}$, and for viewing angles $\theta_v = \{30°, 60°, 90°\}$ (e.g. Figure 1).

4. Conclusions

Jets injected with initial random magnetic fields develop ordered fields by MHD processes within the radio source. Filaments suggest that turbulence develops in evolved sources. Polarimetry statistics correlates with time, θ_v and η, but not so with $v_{\rm jet}$. Lighter jets show linear polarization degrees $\sim$39% at the end of the simulations, independently of θ_v. This agrees with observations better than for the heavier sources which show better, and more realistic, field alignment with the jets than lighter sources. Some initial order in the magnetic fields may be required to meet all the constraints at once. See Huarte-Espinosa, Krause & Alexander 2011a (in prep.) for details.

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