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A New Approach in Modeling the Large Scale Structure of Magnetically Dominated Astrophysical Jets[1]

HUI LI, Los Alamos National Laboratory

Formation of supermassive black holes ($\sim 10^8 M_\odot$) at the centers of massive galaxies leads to the release of significant amount of gravitational energies, part of which comes out in magnetic fields mixed with highly energetic plasmas. Powerful astrophysical jets and giant radio lobes from extra-galactic radio galaxies are examples of such processes, as revealed by multi-wavelength observations. Magnetic fields are believed to play an important role in determining the overall structure of astrophysical jets, though many fundamental questions remain. We will give a brief overview of the different approaches in modeling these jets. We will describe a new global model of the electromagnetic structure of the jets/helixes using a semi-analytical theory, motivated both by models of the astrophysical accretion disk dynamo and by helicity injection experiments (such as spheromak) in laboratory experiments. In this model, the poloidal current forms a closed circuit, with the central poloidal current producing a collimated magnetic helix in the middle and the return current around an expanded "lobe". The size of the lobe is determined by the balance between the toroidal magnetic pressure produced by the central poloidal current and the surrounding plasma pressure. We will present global 3-D ideal magnetohydrodynamics simulations of the formation, propagation, and termination of large scale magnetic jets, confirming the basic theoretical framework. This global solution is also subject to the 3-D Kink instability, which increases the inductance of the magnetic structure and causes current filamentation in the lobe, giving some resemblance to the observed inhomogeneities in astrophysical lobes. This instability, however, does not completely disrupt the propagation of the magnetic helix, partly because the dynamic expansion of the helix relaxes the pinch $q(r, z)$ profile on a fast timescale. The magnetic field lines become chaotic, as shown by their Poincare plots. This has important implications on the energetic particle acceleration and transport since these particles may be the primary contributor to the extragalactic cosmic rays, including the ultra-high energy cosmic rays. Comparisons between our 3-D MHD simulations will also be made with laboratory experiments studying the jet formation.

[1]In collaboration with S. Colgate, J. Finn, K. Fowler, G. Lapenta, S. Li, M. Nakamura.