Three-dimensional models of astrophysical magnetohydrodynamical jets

by

Gareth Charles Murphy

Submitted to the Department of Physics
on 14 Sept, 2006 in fulfilment of the
requirements for the degree of
Doctor in Philosophy

Abstract

In the previous fifty years it has become clear that jets and outflows play a vital role in the formation of stars and compact objects. Jets from young stellar objects typically show Herbig-Haro knots and bow shocks. Additionally, it now appears that (1) most stars form in binaries, and (2) jets from young stars are multiple and episodic outflows. Several groups have carried out large-scale simulations of jets, but often assuming a uniform ambient medium and a single disk and star. In this thesis the problems associated with non-uniform media and binary systems are explored. In order to understand the role of jets in star formation the questions are asked: how do jets from binary stars behave? What is the effect of the prehistory of jets on their collimation, acceleration and morphology?

To answer these questions a parallel adaptive-grid magnetohydrodynamics code, Atlas, is modified to include optically thin atomic radiative cooling losses.The code is rigorously tested, with particular reference to the shock-capturing and the radiative cooling. The tests used include one-dimensional shock-tube tests, two-dimensional blast waves, double Mach reflection of a strong shock from a wedge, the overstable radiatively cooling shock, and the Orszag-Tang vortex. A comparison of the code with another code, PLUTO, for the type of jet problems solved in this thesis is also done. Using the code Atlas, the propagation of jets in complex environments is studied. The first ever simulations of binary jets are performed. Three aspects of the problem are studied, the effects of source orbiting, the effects of interaction, and the role of the magnetic field. It is shown that jets from binary stars can interact and the signature of the interaction is demonstrated. The negligible effect of source orbiting is demonstrated. A toroidal magnetic field is placed in the ambient environment and further accentuates the interaction. Following on from this work, the evolution of the jet when the environment is not uniform is studied. Simulations have been performed which track the evolution of a jet in an partially evacuated cavity. The parameter space of the problem is explored in axisymmetry. The strong effect of the cavity on the recollimation, the acceleration and the radiative cooling losses is demonstrated.

Finally, continuing the theme of the environment in which jets propagate, a study of the star-forming regions in the Galactic Plane was undertaken. Using the parallel and Grid computing methods acquired in the course of this thesis work, and observational data from star catalogues, a code was written to map dust extinction in the galactic plane, using the method of accumulated star counts. Star density and relative extinction maps of the Galactic Plane are created. The extinction maps are useful for observers to obtain realistic values of the opacity index, while the star density maps may be used (for example) to discover new clusters of stars.