6.4 Future Work

6.4.1 Jets from Binary Protostars

The propagation and interaction of jets is a very broad area and contains several practical future research directions. There are still several outstanding problems with binary jets from young stars. An important question is whether the results based on observed quantities of LDN1551 IRS 5 can be generalised. A major requirement for further progress in direct simulation is a larger number of observational samples of binary jets. The number of observations remains low - approximately 10 sources. An observational search for binary jets in star forming regions would be able to add extra constraints to the model. In particular, a better constraint on the geometry of the magnetic field, which may be obtained using polarimetry, is desirable. While the best resolution available was used in this thesis along with modern adaptive grid techniques, resolution is still relatively low in three dimensions. A higher resolution study would give a more accurate quantitative estimate of the emission from the interaction region. Furthermore, in order to compare results with observations properly, it would be desirable to include a chemical network in the code, so emission maps for additional species, such as CO, could be produced. A future study could include the effects of precession as well as orbital motion. Precessing jets will have enhanced interaction and are likely to show increased dynamical instability.

Another open question concerns the production of X-rays from binary jets. As discussed in Chapter 4, the generation of X-rays from shocks in the case of L1551 IRS 5 requires velocities which are greater than those inferred from observations at other wavelengths. Imagining the binary jet system as a pair of mutually orbiting flux tubes, the probability of reconnection events occurring immediately springs to mind. For a physically meaningful study of reconnection processes within the binary jet, use of non-ideal MHD techniques such as e.g. Hall-MHD would be desirable. Some progress, however can be made studying using resistive MHD. As a preliminary step towards this, we have modelled 3D reconnection processes in a current sheet, over a range of perturbation modes. The purpose of the study is to constrain the large amount of thermal energy released in the reconnection process. For wave modes with $k > 1/a$, where k is the wave number and a is the current sheet thickness, along with the release of thermal energy, we observe in early simulations the formation of magnetic islands on the current sheet, which are usually associated with the tearing mode instability. Encouragingly, the critical value is in agreement with that found through the MHD analysis in the linear regime by Furth et al. (1963). Three-dimensional studies of the nonlinear regime are ongoing.

6.4.2 Jets in Evacuated Cavities

The evacuated cavity model for jet recollimation can be further enhanced by including a treatment of the magnetocentrifugal wind launching mechanism. This is a non-trivial problem, and necessitates the inclusion of gravity and magnetic field. An internal boundary is necessary around the gravitational source to prevent numerical difficulties when the radius approaches zero. Non-ideal effects such as resistivity are needed to allow accreting matter to slip through the magnetic field lines and gravitate towards the central object. Cooling is required within the disk to compensate for the effect of Joule heating, which tends to puff up the disk. Zanni et al. (2007) give a comprehensive treatment of the subject. We have performed such a simulation in order to calculate the size of the cavity generated by such a wind. We have also increased the domain of the simulation to study the long term evolution of the MHD wind model, examine the effects of boundary conditions on the jet collimation, and compare against observations of rotation in star formation jets. This required the use of a stretched grid in order to keep the simulation down to a manageable amount of computational time and data. The simulation also requires a greatly increased number of timesteps (an order of magnitude greater then in previous work), due to the much larger Keplerian rotation period in the outer edges of the disk. In Figure 6-1 a plot of the large-scale MHD disk wind simulation is shown. The bow shock, collimated disk wind and the disk itself are all present. The cavity formed may be clearly seen to the left of the image. It expands initially but then is recollimated along with the rest of the jet near to the bow shock. The simulation is still dynamically evolving and has not reached a quasi-stationary state yet. An important further study is to compare the results of the simulation to measurements of the jet rotation using Doppler gradients.

Another important application of this model is outside the star formation regime, for micro-quasars and AGN jets. In the two-flow scenario, a classical MHD wind of the type shown in Figure 6-1 confines a highly relativistic electron-positron pair plasma beam (Henri & Pelletier 1991). The MHD outflow plays a dual role in the model. It provides a cavity in which the electron-positron beam can propagate. The outflow also prevents catastrophic Compton cooling from decelerating the electron-positron beam by reheating it through second-order Fermi mechanism thus allowing it to reach velocities approaching light speed (typically 92-99%, Renaud & Henri 1998). This acceleration mechanism can explain the apparently superluminal motions near black-hole X-ray binaries observed by Mirabel et al. (1992). See Mirabel & Rodríguez (1999) for a review of observations of galactic superluminal sources. The goal of this study is investigate the feedback between the two flows, in particular the effect of a strongly heated and episodic set of outburst on a collimating MHD wind. The MHD model is used to calculate the mean magnetic field and the radius of the inner cavity as a function of height. These constraints are then used to calculate the particle density and thermal energy of the plasma inside the cavity using a relativistic particle code (Saugé & Henri 2006). An internally consistent model for ejections from black-hole X-ray binaries will then be obtained.

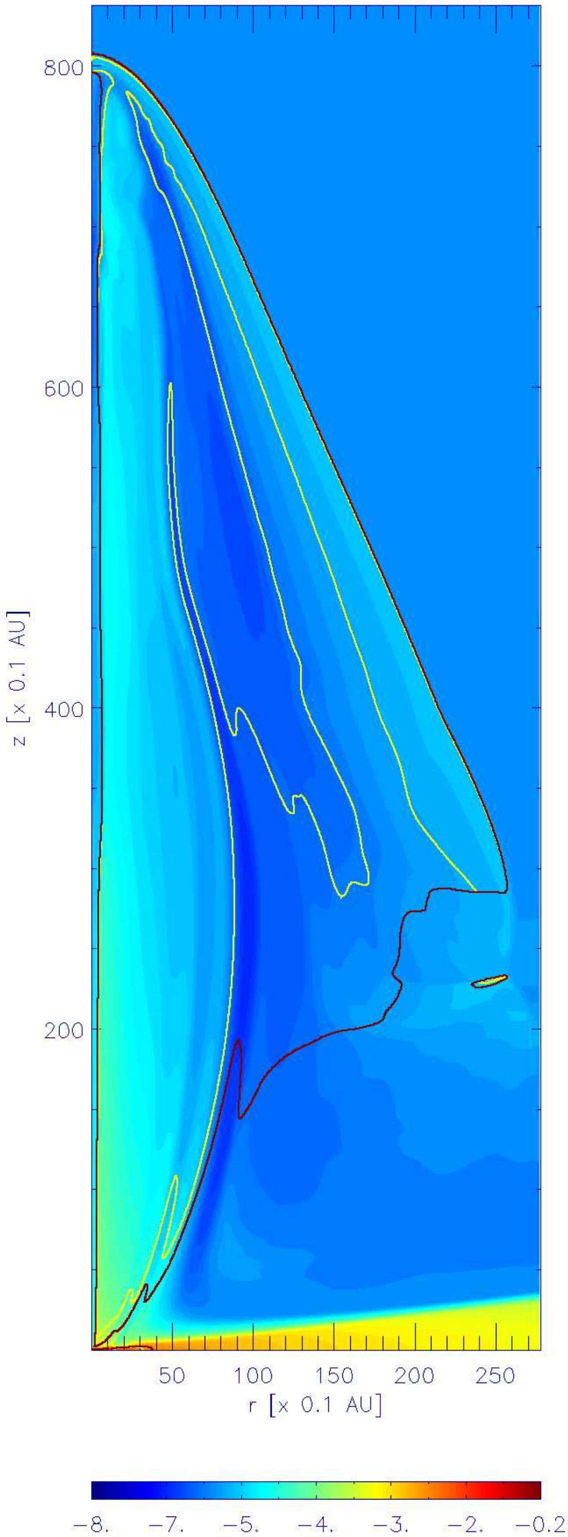

Figure 6-1: *Log density colourmap of axially symmetric MHD disk wind simulation at t=63. (Time units are Keplerian periods a the disk inner radius) As the disk wind moves upward from the disk it becomes collimated. The fast magnetosonic and Alfvén surfaces are plotted as yellow and black contours respectively.*