INTERACTING MULTIPLE JETS FROM BINARY SOURCES. G.C. Murphy, *(gmurphy@cp.dias.ie)*, T. Lery, *Dublin Institute for Advanced Studies, 5 Merrion Square, Dublin 2, Ireland*, S. O'Sullivan, *Department of Mathematical Physics, University College Dublin, Belfield, Dublin 4, Ireland*, D. S. Spicer, *NASA Goddard Space Flight Center, Greenbelt, Maryland, USA*.

1 Introduction

Observational evidence now strongly suggests that binary systems - sufficently well separated to form a disk around each protostar - will produce quadrupolar protostellar jets (Avery et al. 1990; Rodríguez et al. 2003; Gredel & Reipurth 1994; Rodríguez et al. 1998; Fridlund & Liseau 1998). On the other hand there are many well established multiple drivers of bipolar jets (XZ Tau, Sz 68, Z CMa, see Reipurth et al. (1993) for a listing). Either way, a numerical model of two jets from a double rotating source may help in understanding the morphology of interacting, high Mach number flows. Molecular outflows and jets are near-ubiquitous in the star formation process. There is also a large percentage of stars and protostars with companions. The question is then: why are most outflows not visibly binary outflows? Numerical modelling of binary jets can show that it is physically possible for them to not remain as binaries. We have modelled a pair of jets emitted from a double source - based on observations of a specific object, L1551 IRS 5 (HH154).

We present results from hypersonic highly collimated binary jet simulations in three dimensions. Using recent observational data, we model an existing binary jet with a new astrophysical MHD code and examine its shocked morphology and propagation dynamics.

2 Method

Athena is a new modular, parallel, shock-capturing, directionally split, AMR-based, multi-dimensional, staggered-mesh, higher-order Godunov astrophysical MHD code. Validation and verification tests have been run against the code to build confidence in its ability to form correct solutions. Athena uses PARAMESH (MacNeice et al. 2000) block-structured adaptive mesh refinement for high effective resolution in areas of physical interest. The solenoidal constraint is preserved using a staggered mesh. Simulations were carried out using Athena on a 64 node cluster of the so-called "Beowulf" type. Athena uses a MUSCL-type scheme (van Leer 1979) and the Roe-Balsara approximate MHD Riemann solver (Roe 1981; Roe & Balsara 1996).

We assumed a distance of 140 parsecs to the jets. We used observed values for the density, temperature and velocities. We assumed a sinusoidal variation of 30% in the velocity with a period of 8 years. The ambient medium is modelled with a uniform density ($\rho_a = 5 \times 10^3$ cm^{-3}) and temperature ($10^4 K$) and the jets are modelled with density $\rho_j = 0.1\rho_a$ and the same temperature and velocities of 90 and 300 km s^{-1} respectively (Liseau et al. 2005). We used a compromise figure of 300 km s^{-1} between the estimates of Liseau et al. (2005) and Hartigan et al. (2000). The Mach numbers of the jets are M=33 and M=110 respectively.

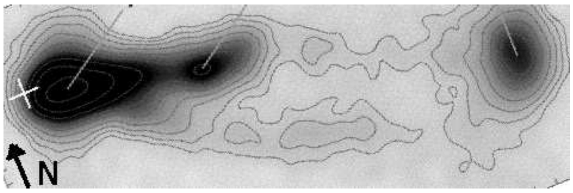

Figure 1: Continuum-subtracted Fe[II] λ1.644 μm image of the jets from L1551 IRS 5. The midpoint of the binary source is indicated by a cross. The image is 2" $\times$ 10" (280 $\times$ 1400 AU at a distance of 140 pc) (Image courtesy of Pyo et al. (2002))

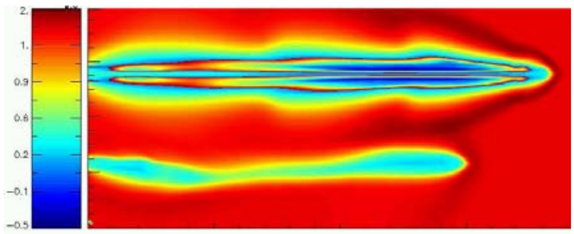

Figure 2: The twisted morphology of the southern (lower) jet is visible in this midplane colour density map of 3-D binary jet simulation at $t = 245$ years. The scale of the grid is 1500AU by 400AU The image has an effective resolution of 10 cells per jet radius.

3 Results

Figure 1 shows a continuum subtracted Fe[II] λ1.644 μm image of the jets from L1551 IRS 5. Figure 2 shows an HD model of the binary jet system. We were able to reproduce the twisted morphology of the L1551 IRS 5 outflow using jet interaction. The fast northern jet is lanched into the ambient medium at a time $t = 150$ years after the slow southern jet. Both jets are given a velocity variation at launch. The northern jet has a Mach number ~ 4 times higher than the slow southern jet and simply pushes it out of the way. This reproduces the observed kink at 4 arcseconds (560 AU at a distance of 140 pc) from the source (Itoh et al. 2000) - without the need for magnetic fields. There is no noticeable back reaction on the fast jet - possibly indicating that the estimated velocity is too high.

We have also explored effects of precession and source rotation and produced continuous and line emission maps (not shown here) to compare with observations of the L1551 IRS 5 jets (HH154). Using emission tracers of the density we are able to show jet interaction contributing to twisted morphology of the jets from L1551 IRS 5.

References

Avery, L. W., Hayashi, S. S., & White, G. J. 1990, ApJ, 357, 524

Fridlund, C. V. M. & Liseau, R. 1998, ApJ, 499, L75+

Gredel, R. & Reipurth, B. 1994, A&A, 289, L19

Hartigan, P., Morse, J., Palunas, P., Bally, J., & Devine, D. 2000, AJ, 119, 1872

Itoh, Y., Kaifu, N., Hayashi, M., et al. 2000, PASJ, 52, 81

Liseau, R., Fridlund, C. V. M., & Larsson, B. 2005, ApJ

MacNeice, P., Olson, K., Mobarry, C., de Fainchtein, R., & Packer, C. 2000, Computer Physics Communications, 126, 330

Pyo, T.-S., Hayashi, M., Kobayashi, N., et al. 2002, ApJ, 570, 724

Reipurth, B., Heathcote, S., Roth, M., Noriega-Crespo, A., & Raga, A. C. 1993, ApJ, 408, L49

Rodríguez, L. F., D'Alessio, P., Wilner, D. J., et al. 1998, Nature, 395, 355

Rodríguez, L. F., Porras, A., Claussen, M. J., et al. 2003, ApJ, 586, L137

Roe, P. L. 1981, Journal of Computational Physics, 43, 357

Roe, P. L. & Balsara, D. S. 1996, SIAM Journal on Applied Mathematics, 56, 57

van Leer, B. 1979, J. Comput. Phys., 135, 229