Interacting Jets from a Binary Source

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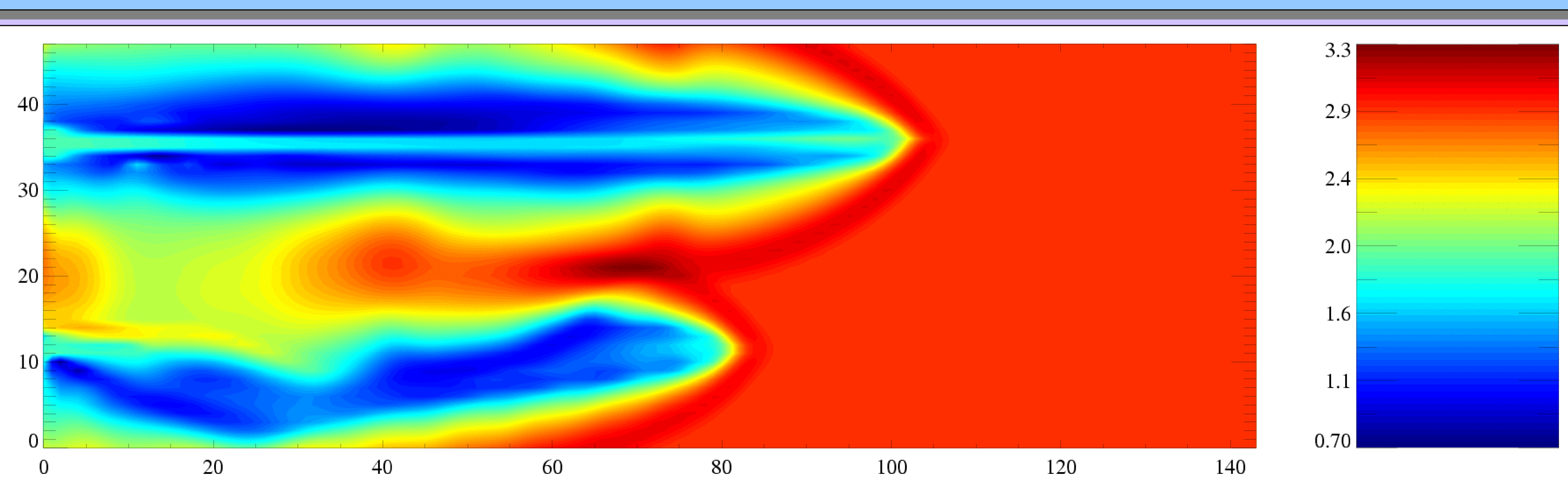
ABSTRACT

We investigate potential models that could explain why multiple proto-stellar systems predominantly show single jets. During their formation, stars most frequently produce energetic outflows and jets. However, binary jets have only been observed in a very small number of systems. We model numerically 3D binary jets for various outflow parameters. We also model the propagation of jets from a specific source, namely L1551 IRS 5, known to have two jets, using recent observations as constraints for simulations with a new MHD code. We examine their morphology and dynamics, and produce synthetic emission maps. We find that the two jets interfere up to the stage where one of them is almost destroyed or engulfed into the second one. We are able to reproduce some of the observational features of L1551 such as the bending of the secondary jet. While the effects of orbital motion are negligible over the jets dynamical timeline, their interaction has significant impact on their morphology.

INTRODUCTION

Most main sequence stars appear to be binaries or belonging to multiple systems. Therefore in their infancy they must have formed binary jets and outflows during the first stages of their formation. However, most of the time, observers find single jets. The question is then: why are most outflows not visibly binary outflows?

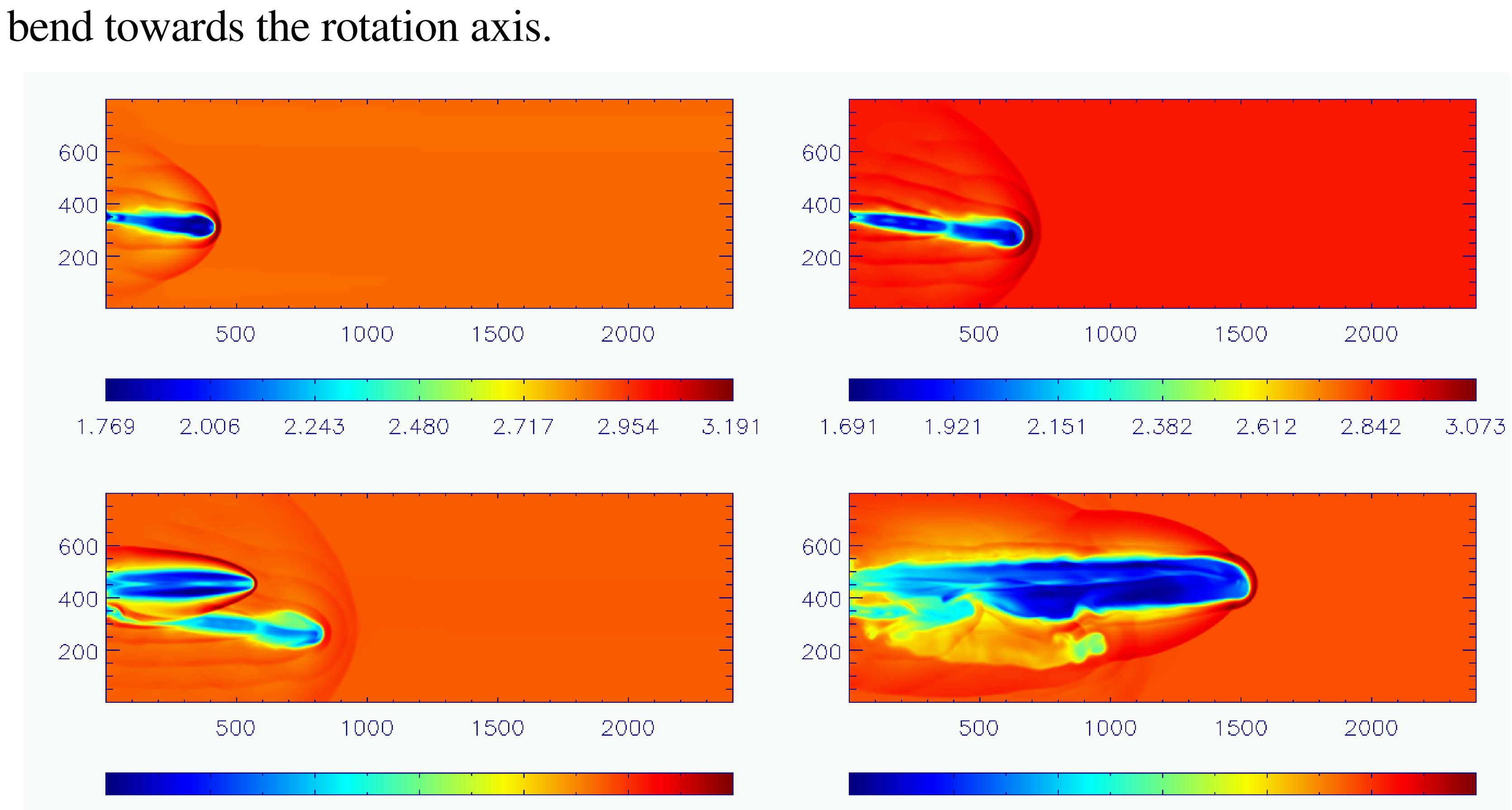
Several possibilities may resolve this problem. First, observations have shown in some cases that binary systems form a single disk around the protostar system and would consequently form only one jet. Another possibility is that the two jets interact and merge, or that one of them is destroyed. There are many multiple drivers of bipolar jets (XZ Tau, Sz 68, Z Cma etc). In any case, only a numerical model of two jets from a double rotating source may help in understanding the morphology of interacting, high Mach number flows. We have chosen to model a pair of jets emitted from a double source based on observations of a specific object, L1551 IRS 5 (HH154). We do so by using a new astrophysical AMR MHD code, ATLAS, and examine the corresponding shocked morphology and propagation dynamics. In order to show the jets interacting far from the source, we used a simplified model of parallel jets without a magnetic field, and a more complex model including angular separation and toroidal magnetic field closer to the binary source.



Density contour map of 3D HD binary jets at t = 245 years.
(1500AU by 400AU box with a resolution of 10 cells/jet radius)

3D MHD Simulations

Optical polarimetry observations (Scarrott 1988) show what appears to be a toroidal field surrounding the two jets from L1551 IRS 5. The toroidal field may have been created by the rotation of the large circumbinary disk. Such a field could have a significant effect on the dynamics and may cause the initially angularly separated outflows to change their direction. We used a toroidal magnetic field strength of 0.01 mG. The figure below shows the time evolution of the jets moving into an environment with a toroidal magnetic field. The Lorentz force causes the jets which have an initial angular separation of 10 degrees to bend towards the rotation axis.



Time evolution of MHD binary jets at t=125,155,170 years. The images shown are 2D cuts midplane cuts through the 3D grid.

Acknowledgements

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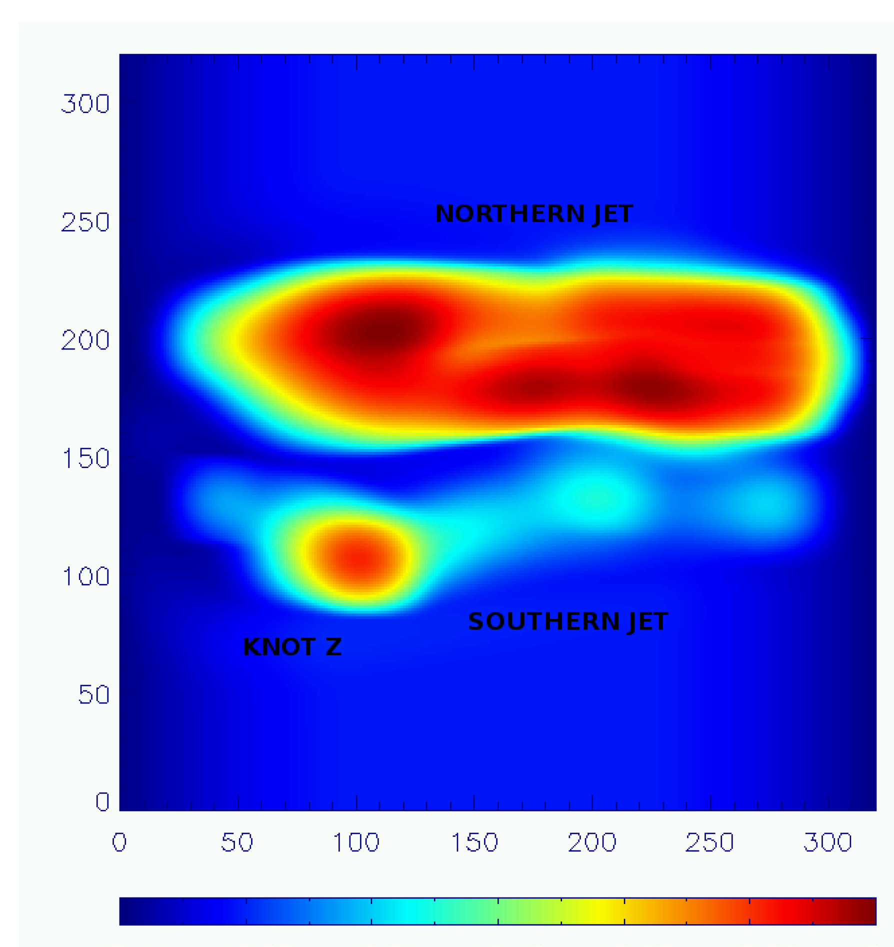
3D HD Simulations

We have produced 3-dimensional pure hydro-dynamical (HD) simulations of interacting binary jets. We have studied the parameter space of the jet properties in order to see their influence on the interaction. Pure HD can reproduce binary jet characteristics.

We show here solutions that reproduce the twisted morphology of observed jets by allowing the bow shock of the fastest jet to strike the beam of the other jet midway through its propagation. We begin by making the simplifying assumptions that the magnetic field can be neglected and that the jets are parallel. We assumed a distance of 140 parsecs to the pulsating 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 (n = 5,000 cm^{-3}) and temperature (100K). The jets are modelled with density n=500 cm^{-3}, temperature (10,000K) and velocities of 65 and 300 km/s respectively (Liseau et al. 2005). We used a compromise figure of 300 km/s between the estimates of Liseau et al. (2005) and Hartigan et al. (2000). The Mach numbers of the jets are M=21 and M=60 respectively. We are able to reproduce the twisted morphology of the L1551 IRS 5 outflow. The fast northern jet is launched into the ambient medium at a time t = 150 years. Both jets are given a velocity variation at launch. The northern jet has a Mach number ~3 times higher than the slow jet. This reproduces the observed kink at 4 arcseconds (560 AU at a distance of 140 pc) from the source (Itoh et al. 2000).

SYNTHETIC OBSERVATIONS



Synthetic [OI]λ6300 emission map derived from the physical parameters of our simulation in the hydrodynamic case to be compared with corresponding HST observations of the L1551 IRS 5 jet (HH154) The image shows the northern and southern jets at a time t=190 years. Knot Z indicates the point where the bow shock of the northern jet collides with the beam of the southern jet.

CONCLUSIONS

- We can reproduce the kink and bending of the secondary jet and the knotty structure of the two components as observed for L1551 IRS 5.
- Over a long time-scale, we see precession induced by the orbital motion of the source. On the short lifetime of the jets from L1551, this effect is negligible.
- If the jets are not strictly parallel, as in most observed cases, we show that the magnetic field can help the collimation and refocusing of both the jets. In fact the toroidal field affects the motion of the southern jet; and this magnetically driven change in direction together with the interaction of the bow shock of the fast jet with the beam of the slow jet contribute to the distinctive morphology.
- We have produced emission maps which can be compared with observations. We show that the interacting jet kink structure is apparent in the synthetic observations.

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