

PROCESSING OF A PROTOSTELLAR SYSTEM BY A BIPOLAR OUTFLOW

Kurt Liffman, Dept of Mathematics, Univ. of Melbourne, Parkville, Vic. 3052, Australia
James M. Stone, Dept of Astronomy, Univ. of Illinois, Urbana, IL. 61801, U.S.A.

Introduction In the last ten years, it has become evident that certain stars form bipolar outflows during their early evolution (1). These outflows are very energetic ($\sim 10^{47}$ ergs) and the force(s) required to drive them far exceeds the radiation pressure provided by the star, often by many orders of magnitude. The ubiquity and enormous power of these outflows suggests they may play an important part in the early evolution of the nebula material that surrounds protostars (2).

A popular, but controversial, mechanism for these outflows is the 'bead on the wire' magneto-hydrodynamic (MHD) model (3), which assumes that the outflows are formed by the magnetic field lines which are 'frozen' into the disk of material surrounding the protostar. The motion of ionized material that is caught by the field lines as the field lines orbit the protostar, can be likened to a bead on a wire, where the wire is held by one end at an angle to the horizontal and whirled around some point in space. If the angular velocity is high enough, the bead will move away from the center of rotation due to the application of centrifugal force. The movement of these ionized gases plus the infall of nebula material onto the protostar are the driving mechanisms for these outflows.

Method We have used a computer model to investigate how the outflows process material around a protostar. The model consists of two separate codes: an MHD code (written by J.M.S.) which models bipolar outflows, and an n-body code (written by K.L.) which takes the information provided by the MHD code and models the orbital motion and physical behaviour of material around a protostar/bipolar outflow system. Results from the codes are displayed in figures 2-5.

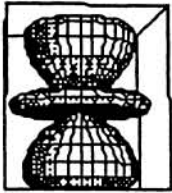


Fig. 1

In fig.1 we schematically depict the main features of a bipolar outflow: the outgoing lobes of gas and the central disk of material. Because of the inherent symmetry of the structure, it is convenient in subsequent figures to consider a cross section through the upper right hand quadrant

Our initial simulations (for a 0.1 solar mass protostar) suggest that a particle can be swept by wind pressure from the interior (within an astronomical unit (AU) of the protostar) to the outer regions of the nebula (figures 2 & 3). In the process the particle undergoes a series of temperature changes. The first is due to the initial drag of the outflowing gas, which tends to give a substantial heat impulse to the particle, the particle then moves into a less dense, but warmer region, where it is initially kept warm due to transfer of heat from the gas, but then cools as radiation effects dominate due to the decrease in gas density (figures 4 & 5). The history of the particles can then take on a number of different paths:- they can be blown away from the nebula; or they are too heavy to be moved and will stay in decreasing Keplerian orbits around the protostar;- they are blown away from the disk, but subsequently return, ram into disk material and are stopped;- they are blown away from the disk, but this time they pass through the disk, where they are subsequently hit by the other side of the symmetric gas outflow; and finally, they don't fall far enough to hit the disk and are caught in an 'up'draught again.

This model naturally leads to the following (tentative) conclusions:

The size of the particle swept up (s), will be a function of the wind speed (v), density of the gas (ρ_g), density of the particle (ρ_f), mass of the protostar (M), and distance of the particle from the protostar (r):

$$s \approx \frac{\rho_f v^2 r^2}{4\pi G M \rho_g}$$

The particles will be processed chemically (and perhaps isotopically) due to the change in thermal environments, and as the movement of the particle is somewhat dependent on its size, these chemical/isotopic effects may also be size dependent. Some of the particles would show signs of repeated processing.

BIPOLAR OUTFLOW PROCESSING Liffman K. and Stone J.M.

Denser particles fall out of the gas flow and onto the disk, before lighter particles. This being due to the smaller surface area to volume ratio. Thus implying size sorting as a function of distance away from the disk.

As the particles are moving at high speeds (~ 5 km/s), they should suffer some form of collisional effect(s) as the particles come into contact with the disk material. Also, as the particles would be newly processed, they would (appear to) be younger than the surrounding disk material.

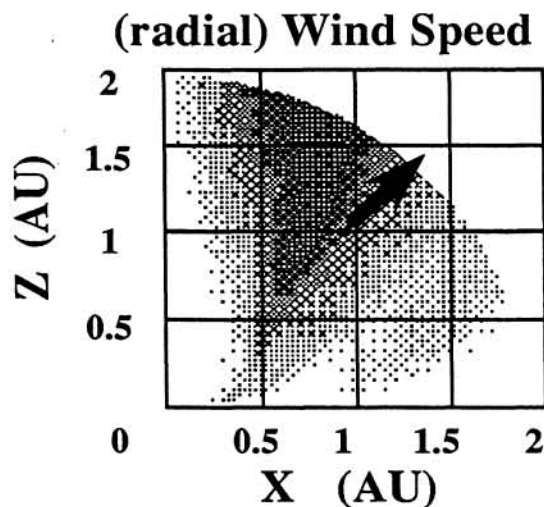


Fig. 2.

Grey areas showing gas moving away from the protostar (located at the origin). Gas speeds range from 0.1 - 20 km/s

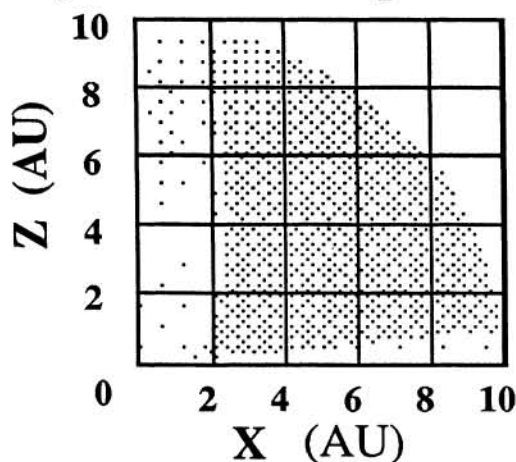
Bipolar Wind Temperature

Fig. 4

A vertical cross section showing the gas temperature as a function of distance. The darker sections correspond to hot gas ($10^3 - 10^4$ K), & whiter regions to cold gas (10-100 K).

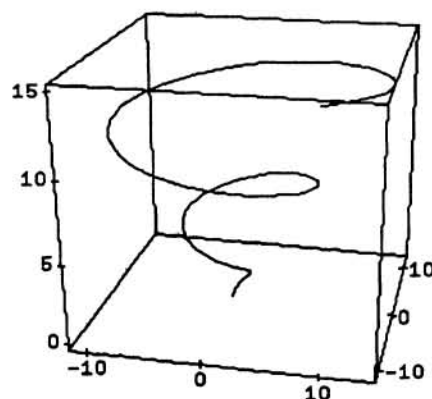


Fig. 3.

Schematic depiction of the path travelled by a microgram particle caught in a bipolar outflow.

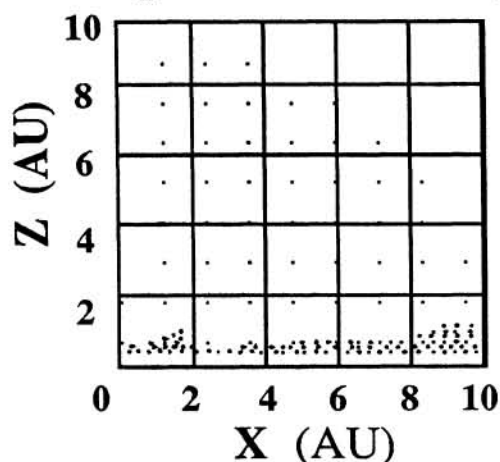
Bipolar Wind Density

Fig. 5

The high density region ($\sim 10^{-14}$ g/cm³) corresponds to the area in lower part of the figure. The rest of the outflow has a density of $\sim 10^{-17}$ g/cm³

References: (1) Lada C.J. (1985) Ann. Rev. Astron. Ap. 23, 267-317; (2) Skinner, W.R., LPSC XXI Abs. 1166-1169; (3) Blanford, R.D., and Payne, D.G., Mon. Not. R. astr. Soc. (1982) 199, 883-903.