SWEEPING-MAGNETIC-TWIST MECHANISM AND MOLECULAR BIPOLAR FLOWS

Kazunari SHIBATA[1] and Yutaka UCHIDA[2]

1. Department of Earth Science, Aichi University of Education
2. Tokyo Astronomical Observatory, University of Tokyo

Uchida and Shibata have proposed the "sweeping-magnetic-twist" mechanism for the formation of astrophysical jets in relation to the accretion disks (disks around protostars, around black hole in the center of active galactic nuclei, and so on) in which a jet is accelerated by the $j \times B$ force in the relaxing magnetic twist created in the winding-up of the poloidal magnetic field by the rotation of the contracting disk (Uchida and Shibata 1985a, b; Shibata and Uchida 1986a, b; Uchida *et al.* 1985). In this mechanism, a jet is collimated also by the $j \times B$ force due to the large scale poloidal magnetic field whose footpoints are squeezed in the contracting disk. The main mechanism involved is different from that of centrifugal wind models (Blandford and Payne 1982, Pudritz and Norman 1983) and worked out independently, but the centrifugal effect itself is automatically built-in.

By using the non-steady 2.5-dimensional axisymmetric MHD numerical simulations, we have studied the detailed dynamical processes in the formation of jets by the "sweeping-magnetic-twist" mechanism, and have applied the results to the molecular bipolar flows in star forming regions (Uchida and Shibata 1985a, b; Shibata and Uchida 1985, 1986b). Simulations are performed on the assumption of (1) axisymmetry with respect to the rotation axis of the disk, (2) ideal MHD (adiabatic, frozen), (3) in a gravitational potential due to a point mass (self-gravity of the disk is not included). The initial magnetic field is assumed to be uniform and parallel to the rotation axis of the disk whose rotation velocity is equal to or smaller than the Keplerian value. Outside the disk, a hot tenuous corona is assumed to exist. The formulation was made in a non-dimensional scale-free representation, and thus similarity is expected if the initial situation in the relative coordinate r/L is similar, and if the set of non-dimensional coefficients of that equation, $R_1 \equiv (v_s/v_k)^2$, $R_2 \equiv (v_A/v_k)^2$, $R_3 \equiv (v_\varphi/v_k)^2$ and the ratio of the coronal and disk temperatures ($= R_4$) is the same, where v_s, v_A, v_k and v_φ are initial sound, Alfven, Kepler, and rotational velocities at a reference point in the disk. In the following, we show the results with parameters in the range suitable for the proto-stellar disk from which our jet (molecular bipolar flow) emanates ($R_1=10^{-3}-10^{-2}$, $R_2=10^{-3}-10^{-2}$, $R_3=0.6-1.0$, $R_4=100-400$).

The following dynamical processes are found in the numerical simulations : When the initial rotation velocity of the disk is equal to the Kepler value, the disk first pulls the field lines to the azimuthal direction, generating the torsional Alfven waves which propagate along the poloidal field lines. Consequently the disk loses angular momentum, and starts contraction toward the inner region, pulling the field lines with it. As the disk contracts to the inner and inner region, the magnetic field is more and more tightly twisted. When the magnetic twist becomes sufficiently large, the gas in the surface layers of the disk starts to be accelerated perpendicularly to the disk by the $j\times B$ force producing a helically driven jet with a hollow cylindrical shape. The velocity of the jet is of the order of the local Alfven velocity.

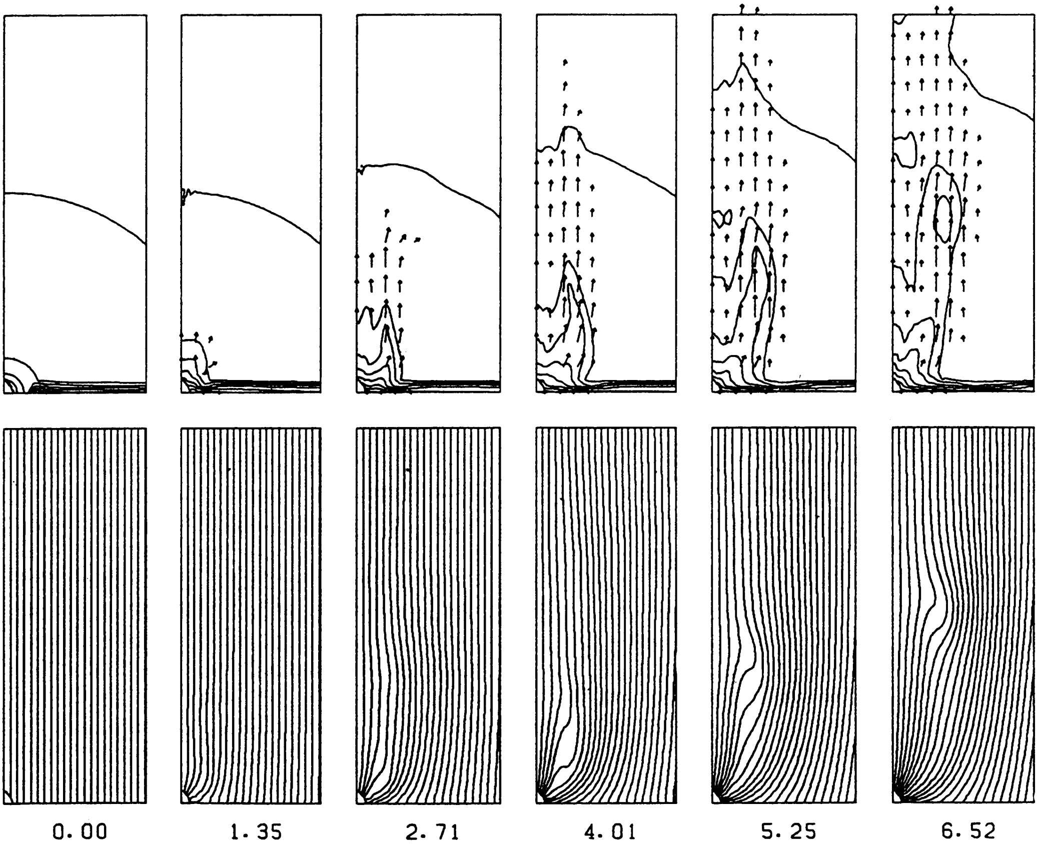

Fig. 1. (a) Poloidal velocity field overlaid on the contour map of density (log ρ). (b) Poloidal magnetic field lines. (for $R_1 = 3\times10^{-3}$, $R_2 = 2\times10^{-3}$, $R_3 = 0.6$, $R_4=100$).

The kinetic energy of a jet derives itself from the gravitational potential energy released in the contraction of the disk through the action of the helically twisted magnetic field, and the rate of conversion of energy is about 10 percent. Since the angular momentum loss of the disk becomes more significant due to the production of the jet, the disk can continue to contract toward the center.

Figure 1 shows an example of the flows in the simulation, and shows well the characteristics of hollow cylindrical shell structure and the collimation of the flow by the large scale poloidal magnetic field. [Note that the model is not to the exact scaling to be compared directly with the observed molecular bipolar flows. This is because it is not possible to make simulations covering three orders of magnitude. Further theoretical study about the global behavior of the flow by using 1.5-dimensional MHD simulations is now in progress to supplement this (Shibata *et al.* in preparation 1986)] . Characteristic features (hollow cylindrical structure and the helical motion of the flow) predicted by this idealized MHD model, however, have actually been observed in the L1551 molecular flow (Uchida *et al.* 1987).

In contrast to the case of the cold molecular flow, our proposed picture on the origin of the optical (or ionized) small scale jets (Mundt and Fried 1983) is that they are created near the surface of the protostar by the "magnetically buffered accretion" (Uchida and Shibata 1984), in which the jet is accelerated by the recoiling shock produced in the final accretion of the matter, and is collimated also by the poloidal magnetic field.

References

Blandford, R.D. and Payne, D.G.: 1982, *Monthly Notices Roy. Astron. Soc.*, **199**, 883.

Mundt, R. and Fried, J.W.: 1983, *Astrophys. J. Letters*, **274**, L83.

Pudritz, R.E. and Norman, C.A.: 1983, *Astrophys. J.*, **274**, 677.

Shibata, K. and Uchida, Y.: 1985, *Publ. Astron. Soc. Japan*, **37**, 31.

Shibata, K. and Uchida, Y.: 1986a, *Astrophys. Space Sci.*, in press.

Shibata, K. and Uchida, Y.: 1986b, *Publ. Astron. Soc. Japan*, submitted.

Uchida, Y. and Shibata, K.: 1984, Publ. *Astron. Soc. Japan*, **36**, 105.

Uchida, Y. and Shibata, K.: 1985a, *Proc. IAU Symp.* No. 105, 287.

Uchida, Y. and Shibata, K.: 1985b, *Publ. Astron. Soc. Japan*, **37**, 515.

Uchida, Y., Shibata, K. and Sofue, Y.: 1985, *Nature*, **317**, 699.

Uchida, Y., Kaifu, N., Shibata, K., Hayashi, S. and Hasegawa, T.: 1987, in these proceedings.