ELECTROMAGNETIC JETS DRIVEN BY ACCRETION DISKS

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ABSTRACT. As a model of ionized jets from young stars, an analytic solution has been derived from the resistive MHD equations. The essence of our model and an outline of the calculation are presented.

1. INTRODUCTION

Mundt and his coworkers discovered the optical jets from T-Tauri stars and low luminosity IR sources (Mundt *et al.* 1983, Mundt and Fried 1983). The jets have typical lengths of $2 \sim 4\times10^{16}$ cm and are moving at high velocities ($\lesssim$400 km/sec). Their collimations are very high (the opening angles are $5° \sim 10°$). These features of the jets are clearly distinct from those of relatively large scale and low velocity bipolar flows observed in CO line emission. Although the molecular flows and the ionized jets coexist in some cases, it is believed that the latter phenomenon corresponds to a somewhat later phase in the star formation processes than the former.

Associated with the molecular flows in star forming regions, self-gravitating disks are often found around central objects. Recently, it has pointed out that such disks show a hierarchical structure (e.g. Rodríguez 1987, and papers cited therein). When the central objects become sufficiently massive and compact they begin to controle the inner disks, by their own gravity. Nearly Keplerian, inner disks may thus be formed.

We propose a model in which the ionized jets are driven by these compact Keplerian disks threaded by the magnetic field lines. A schematical view of the circumstances under consideration is given in Figure 1. Overall field lines are nearly uniform and parallel to the molecular flows. Young stars, however, are assumed to have already acquired their own magnetic dipole moments. We do not discuss here the driving mechanism for the molecular flows which, as a whole, are more massive and energetic than the ionized jets.

2. ELECTRODYNAMICAL EFFECTS ON JETS

As one of the authors has shown (Kaburaki 1986), an accretion disk in a magnetic field acts as a dynamo and drives a poloidal current which flows in the disk inward toward the central object (in case of parallel rotation, i.e. when the magnetic dipole moment is parallel to the angular momentum vector of the disk). Near the inner edge of the disk where the plasma is fairly dense, the current turns its direction to the upper and lower halves of the polar axis and returns to a distant region as a line current along each axis. This current system results in an azimuthal magnetic field of the form $B_\phi \sim 1/r \sin\theta$, where r is the radial distance from the center and θ is the colatitude. At the inner edge of the disk $|B_\phi|$ is comparable to or larger than the original dipole field. Because of the slow decrease with r and $(\sin\theta)^{-1}$ dependence of B_ϕ, it is always the dominant component of the magnetic field especially near the polar axis. As a next order approximation, we add to the line current a poloidal current distribution $\mathbf{j}_p$ in order to take into account the return current which successively leaves the axis and flows toward the accretion disk. The dominant Lorentz force acting on the current near the axis is $\mathbf{j}_p \times \mathbf{B}_\phi$. As can be seen in Figure 2, this force has, at the same time, the effects to accelerate the plasma radially and to pinch it in the θ-direction. The former effect guarantees the long travel distances of the ionized jets and the latter does the sharp collimations. The reversal of the magnetic dipole moment does not affect the above result since in such a case both $\mathbf{j}_p$ and $\mathbf{B}_\phi$ change their signs.

3. METHOD OF CALCULATION AND RESULTS

Under the assumptions of steadiness and axisymmetry we derive a jet solution from the resistive MHD equations. For simplicity, the electrical conductivity is regarded as a constant. Our discussion is restricted to a region near the polar axis where $\sin\theta \cong \theta \ll 1$.

We decompose the magnetic field as $\mathbf{B} = \mathbf{B}_0 + \mathbf{b}$. Here $\mathbf{B}_0$ represents the young star's magnetic field which is deformed by the action of a compact accretion disk, and therefore is a known quantity. On the other hand, $\mathbf{b}$ represents the deformation caused by the formation of a jet. Since the jet is controlled by the accretion disk, it is natural to require that $|b_\phi| \ll |B_{\phi 0}|$ as a physical restriction. There is, however, no such restriction on the poloidal components: i.e. we may have $|\mathbf{b}_p| \gg |\mathbf{B}_{po}|$. In the mathematical treatment we do not use any approximation which is based on the relative size of $\mathbf{B}_o$ and $\mathbf{b}$. Rather, the perturbational expansion is performed with $\sin\theta$ being a small quantity. From the continuity requirement for the physical quantities on the polar axis, v_θ, v_ϕ, b_θ, b_ϕ, j_θ and j_ϕ are assumed to be functions $\sim 0(\sin\theta)$. All other quantities (v_r, b_r, j_r, ρ, p and T) are regarded as of order unity. Under these conditions, only the terms that are of the lowest order in $\sin\theta$ are retained in each component of the resistive MHD equations.

Since there is no space to describe in detail the derivation of the solution (it will appear elsewhere in the near future), only the results are summarized below. There is a solution in which the radial velocity is kept constant from the bottom of the jet where it reaches the thermal speed there. The electromagnetic force accelerates the plasma which comes into the jet region from the surroundings owing to the pinch effect. In this sense, the jet may be considered as a thermal wind which is highly collimated and maintained for a long range by the magnetic field. The high temperature at the root of a jet which is inferred from the observations based on this model could be explained by the impact of accreting matter on the stellar surface (the roots of the jets seem to be very close to the central stars, e.g. Strom 1987). The magnetic lines of force would guide the matter from the accretion disk to the polar region where the jet is formed. The temperature in a jet is assumed to be isothermal in any cross-section at arbitrary r, but it should decrease slightly faster than r^{-1} in order to maintain a sufficiently long jet. The density and $b\phi$ decreases slower than r^{-2} but faster than r^{-1}. The condition $|b\phi| << |B\phi o|$ requires $p << B^2\phi o/2\pi$ at the root. The poloidal component of the magnetic field is amplified by a factor, R_J, since a jet stretches the field lines as it travels through them. Here R_J is the magnetic Reynolds number characterizing the jet and is usually very large compared with unity.

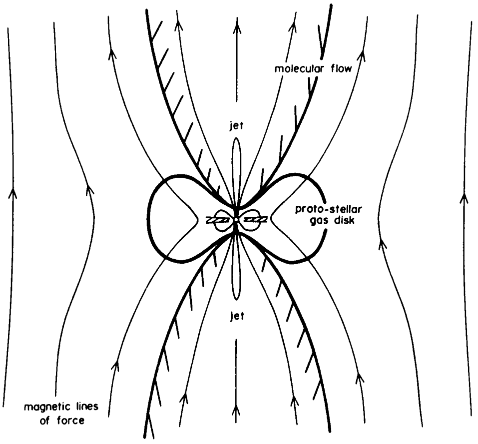

Fig. 1. A schematic picture of the regions of bipolar flows from young stars.

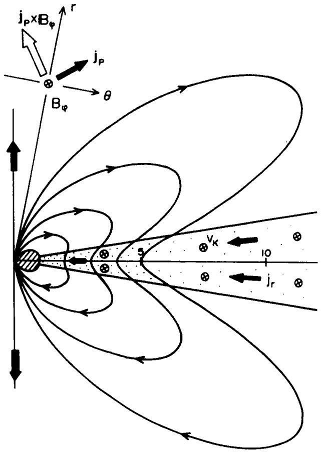

Fig. 2. Current system driven by a compact accretion disk and the Lorentz force in the jet region.

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