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# Axisymmetric MHD Simulations of Stellar Magnetosphere/Accretion Disk Interaction

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**Abstract.**
The evolution of the inner disk region of magnetized accreting systems is studied by means of numerical simulations. Two different initial magnetic field topologies are studied: a pure dipole field which threads the disk continuously and a dipole field excluded from the disk by surface currents. When present, the Balbus-Hawley (BH) instability provides efficient angular momentum transport, and accretion is equatorial. Otherwise, magnetic coupling between the disk and star surfaces as the dominant mechanism for transport and nonequatorial accretion results. In all of the simulations, low density, collimated disk-driven winds lead to mass loss.

## 1. Introduction

The current work consists of time-dependent, nonlinear, axisymmetric MHD simulations of the interaction between a magnetized star and a Keplerian disk. Specifically, it summarizes the results for two initial configurations: Model 1 depicts a dipolar stellar field which threads the disk continuously, and Model 2 examines the case where the dipolar stellar field is excluded from the disk by surface screening currents. In this model, the stellar field topology bends inwards (toward the star) at the equator (the component of the magnetic field normal to the disk being completely cancelled by the field of the disk surface currents, leaving only a component parallel to the disk surface). (See Ghosh & Lamb (1979) and Aly (1980) for analytical descriptions of similar topologies.)

## 2. Results

A number of exploratory simulations are performed by varying the field strength and the disk density (Miller & Stone, 1996). In Model 2, resistivity is added to allow the field to penetrate the disk and control the size of the interaction region. The evolution is computed by solution of the equations of ideal magnetohydrodynamics with resistivity, assuming equatorial and axisymmetry. We use free flow boundary conditions at the outer boundary of the disk and magnetosphere. A hard stellar surface is assumed at the inner radial boundary. The midplane disk density is uniform in r and Gaussian in $\hat{z}$. The magnetosphere and stellar magnetic field are in solid body rotation at the stellar velocity. The density of the magnetosphere is $\approx 10^{-2}\rho_{disk}$; it is in pressure balance with the disk.



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In Model I, for all values of $R_c$ (corotation radius), density, and magnetic field strength used, angular momentum transfer is so efficient that the ram pressure of the accreting material is able to easily overcome the equatorial magnetic pressure and thus accrete onto the equator of the star. This transport is provided either by magnetic coupling between the disk and star or by the BH instability (or both). We find no combination of the input parameters such that polar accretion results. In all cases, reconnection events develop at large radii in the magnetospheric region, suggesting the formation of a wind.

Resistivity controls the evolution of Model II. Because the initial state is not in radial force balance, a large resistivity is required to allow the field to diffuse into the disk, alleviating the radial magnetic tension force at the inner edge. However, a small resistivity is needed to ensure the field remains sufficiently coupled to the disk material to provide angular momentum transport once it has entered the disk. The optimum choice is to have the magnetic Reynolds number, $R_m, \approx 1$.

Nonequatorial accretion ($\theta \approx 10^o - 20^o$ above the equator) is achieved with this value of the resistivity for relatively weak fields. In these simulations, the accreting plasma moves with subkeplerian speeds and does not follow the field lines, but, instead, areas of high magnetic field strengths. Accretion takes place at a single hot spot on the stellar surface and appears to be steady. If the field is frozen into the stellar surface, episodic outflows originate at the hot spot and move radially out from the star. As in Model I, winds are also suggested during the evolution.

## 3. Discussion

In both models, small values of the resistivity are needed to allow sufficient coupling between the field and the disk for angular momentum transport to occur via magnetic instabilities. When such coupling exists, this transport, driven by either the BH instability or magnetic braking, dominates the evolution. The occurrence of nonequatorial accretion is highly dependent on both the initial configuration and the diffusion rate of the field into the disk (i.e., the value of the resistivity). For the purely dipolar field with negligible resistivity, we find no combination of the input parameters which will result in polar accretion. For the dipole field screened from the disk, a value of $R_m \approx 1$ results in nonequatorial accretion which does not follow the field lines. None of the simulations result in dynamical flow (i.e., $v \approx v_{kep}$) of material along the field lines from the midplane of the disk to the stellar poles. In both scenarios, reconnection events are present in the field lines at large radii, suggestive of the formation of a disk driven wind. In Model II, the winds appear to be collimated in the polar direction and radially directed outflows occur.

## References

Aly, J.J., 1980, A&A, 86, 192.

Ghosh, P., & Lamb, F.K., 1979, Ap.J., 232, 259.

Miller, K., & Stone, J., 1996, in preparation.

https://doi.org/10.1017/S0252921100043888 Published online by Cambridge University Press