Resistive MHD Simulations of Star-Disk-Jet System

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Abstract

Stellar magnetosphere and accretion disk interact, and a result should be outflow launched from the innermost vicinity of a protostellar object. We simulated physical conditions in this region by resistive MHD simulations. Outflows resembling the observed ones do not happen in the closest vicinity, except for quasi-stationary funnel flows onto the star, but could occur at few tens of stellar radii above the star. Numerical simulations we performed using our resistive version of ZEUS-3D code, ZEUS347.

Key words: methods: numerical — processes: MHD — stars: formation

1. Introduction

Astrophysical jets are often present phenomena in both stellar and galactic scale. In our numerical simulations, we investigate the interaction of protostellar magnetic field with the large scale magnetic field of the circumstellar disk. Numerical simulations of the ideal MHD jet propagation with the disk as a boundary condition have been presented in Ustyugova et al. 1995. They were also studied, in various setups, in the papers by Ouyed & Pudritz (1997a,b) and in the resistive MHD setup in Fendt & Čemeljić (2002).

Simulations involving the underlying disk have been firstly presented for short lasting simulations in Shibata & Uchida (1985). After success of Casse & Keppens (2002) to simulate the jet launched from resistive disk around the protostar during more periods (few tens) of rotations, more investigations on the effects of resistivity have been done (Zanni et al., 2004; 2007). Our setup extends the setup of Casse & Keppens (2002) (see also Čemeljić & Fendt, 2004) for a case when also the stellar magnetosphere is included in the simulations. A star has been included as a rotating sink boundary for the matter, emulating the stellar accretion.

2. Problem setup

We solved the resistive MHD equations using the ZEUS347 code in the axisymmetry option in cylindrical coordinates. In the time evolution of energy equation we neglected the Ohmic part.

The energy of initial state was computed by the polytropic equation of state $p=K\rho^\gamma$ with $\gamma=5/3$, when the internal energy (per unit volume) is defined as $e=p/(\gamma-1)$. Our simulations presented here have been done in a resolution $R\times Z=$...
Fig. 3. Computational box in our simulations. Initial setup for a disk-star simulation. Density shown in color grading.

Fig. 4. For the close vicinity of a star, solutions with the funnel of matter from the disk onto the star are expected. Conditions for such solutions and their stability are still under investigation.

Fig. 5. After a few ten rotations at the inner disk radius, the new equilibrium is established. Such configuration could, at larger distances from the protostar, feed a collimated outflow. In this simulation, shown after T=40 rotations, the inner disk radius initially was R_{in}=3.

(320×320) grid cells. The physical scale has been typically R×Z=(10×10) stellar radii. Simulations in smaller and larger resolutions and scales have also been performed.

The initial disk corona in a hydrostatic equilibrium, co-rotating with the underlying disk, has been set. The central star was considered as a (rotating or non-rotating) sink for matter inflowing from the disk. The disk itself has been given as rotating with the slightly sub-Keplerian rotation profile. Sketch of our model is shown in Fig. 1. In the most general setup the magnetic field has been set as a stellar dipole combined with split-monopole large scale field, threading the disk, as shown in Fig. 2. For the investigation of the innermost part of the magnetosphere, we also considered only the stellar dipole field case.

The magnetic diffusivity is essential for lifting of the matter from the disk, and it has been introduced with a Gaussian profile, depending on height above the disk equator. It has been parametrized by the local Alfvén velocity, and it was effectively zero outside the disk.

3. Results

In our simulations here we present the results for innermost part of the star-disk system. A magnetic field configuration determines the time evolution of initial configuration. In Fig. 3 shown is the initial density distribution in our computational box. Following in Fig. 4 is the solution after few rotations at the inner disk radius. Our results are comparable with these of Romanova et al. (2002) and Long et al. (2005), when an infall onto the star is observed.

The disk setup is still much simplified, representing rather a clump of matter in a hydrostatic balance than an accretion disk. However, we can study the interaction of such disk and star, through the difference in the rotation rates and magnetic field configurations of stellar and disk fields. A perspective of fully 3D simulations for such systems closes us to more realistic theoretical investigations of a star-disk interaction.

References