

MHD SIMULATIONS OF JET-LAUNCHING FROM DIFFUSIVE MAGNETIZED ACCRETION DISKS

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Abstract. We investigate the launching process of jets from accretion disks by means of axisymmetric MHD simulations. Here, we present results of numerical MHD simulations investigating how magnetic diffusivity and numerical resolution may affect the ejection-to-accretion fraction and the asymptotic outflow structure.

1 Introduction

Astrophysical jets and outflows are a common phenomenon in the universe. They are observed over a wide range of luminosity and spatial scale – originating from young stellar objects (YSO), micro-quasars, active galactic nuclei (AGN), and most probably also in gamma ray bursts. Jets can be understood as channels along which mass, momentum, energy, and magnetic flux are transported through the ambient medium – either the interstellar or the intergalactic medium. The most powerful jets emerge from active galactic nuclei (AGNs) while the jets associated with low-mass young stellar objects have much lower energy.

The seminal model of jet formation applies steady-state MHD solutions for an axisymmetric, magneto-centrifugally driven outflow from a Keplerian disk threaded by a large scale magnetic field [Blandford & Payne \(1982\)](#). For the (cold) outflow to be launched, the poloidal magnetic field lines must be inclined less than 60° with respect to the plane of the accretion disk.

This model has been further applied within the steady-state approach ([Fendt & Camenzind 1996](#); [Pudritz & Norman 1983](#)), and simulations of jet-launching from the disk surface ([Fendt & Cemeljic 2002](#); [Fendt 2006](#); [Ouyed & Pudritz 1997](#); [Porth & Fendt 2010](#)), or considering also taking into account the disk evolution ([Casse & Keppens 2002](#); [Zanni *et al.* 2007](#)). Our simulation presented here also consider the latter approach, a disk wind accelerated by the magneto-centrifugal

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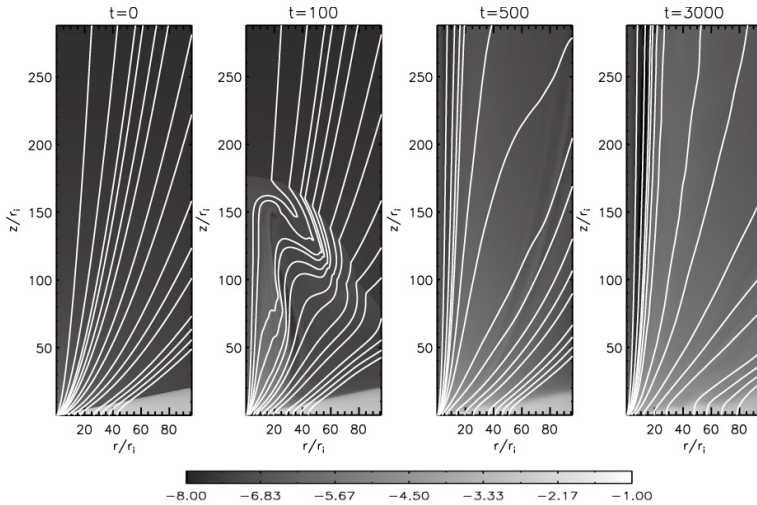


Fig. 1. Snapshots of MHD jet formation. Shown is the evolution of the mass density (color coding) and the poloidal magnetic field (contours of poloidal magnetic flux) for the dynamical time steps $t = 0, 500, 1000, 3000$.

driving mechanism, with material lifted from the disk midplane into the outflow. In particular, we present a time-dependent simulation of the outflow launching from a diffusive magnetized accretion disk for which we take into account the evolution of the underlying accretion process.

2 Model setup

We model the MHD jet launching from a slightly sub-Keplerian thin disk initially in pressure equilibrium with a non-rotating corona. The density contrast between the disk and corona is $\delta = 10^{-4}$. We prescribe the initial configuration of accretion disk following the approach of [Casse & Keppens \(2002\)](#) and [Zanni *et al.* \(2007\)](#). The magnetic diffusivity η_m plays an essential role in driving the accretion process. Turbulent magnetic diffusivity allows matter to steadily diffuse across the field line. The magnetic torque $F_\phi = J_z B_r - J_r B_z$ brakes the disk. The outflow carries out both the angular momentum and mechanical energy of the plasma ([Ferreira & Pelletier 1993](#)). This is an efficient way of removing the angular momentum from the disk. Magnetic diffusivity allows for an equilibrium between advection of magnetic flux with the accretion flow and diffusive outwards. Inside the disk, we prescribe the anisotropic magnetic diffusivity as

$$\eta_m = \alpha v_A(r)|_{z=0} H(r) \exp\left(-2 \frac{z^2}{H_\eta(r)^2}\right), \quad (2.1)$$

where α is diffusivity coefficient, v_A the initial Alfvén speed measured at the midplane, H is the disk's thermal scale height, and H_η is the scale height regarding

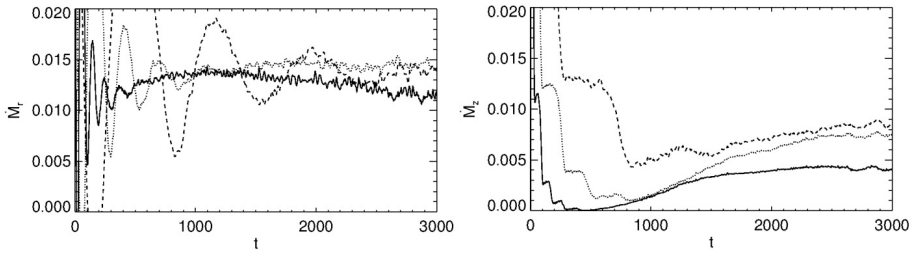


Fig. 2. Mass flux evolution. Shown is the evolution of the accretion rate (*left panel*) and ejection rate (*right panel*), for the presented simulation with $r_1 = 1$, $r_2 = 5$ (solid line), 10 (dotted line), 20 (dashed line).

the disk diffusivity. The initial magnetic field is prescribed by the magnetic flux function

$$\psi(r, z) = \frac{3}{4} B_{z,0} r_0^2 \left(\frac{r}{r_0}\right)^{3/4} \frac{m^{5/4}}{(m^2 + (z/r)^2)^{5/8}}. \tag{2.2}$$

where m determines field line inclination (Zanni *et al.* 2007). We solve the resistive MHD equations for the disk-jet structure using the MHD code PLUTO (Mignone *et al.* 2007). An internal boundary is imposed within the central part of the disk – a sink – to i) hide the singularity at the origin, and to ii) absorb the accreting plasma from the disk. At the outer boundary of the domain, we impose a modified outflow boundary condition (Porth & Fendt 2010) to avoid any artificial collimation.

3 Results and discussion

Here we present results of simulations applying the following set of parameters, $m = 0.4$, plasma- $\beta = 20$, $\epsilon = H/r = 0.1$. We observe a continuous and robust outflow formed from the inner part of the disk (Fig. 1). Our simulation reaches a quasi steady state at $t = 3000$ and super-Alfvénic outflow velocities. In order to measure the mass flux loaded from the disk into the outflow, we adopt a control volume as a sector with two surfaces perpendicular to the equator at $r = r_1$ and $r = r_2$, and the two other surfaces being the disk mid plane and a surface which is parallel to the initial disk surface. Comparing the mass flux evolution in radial and vertical direction, we find an efficient accretion process in the disk (*cf.* Fig. 2). Depending on the radial position, a different period of time is required to establish dynamical equilibrium of inflow (accretion) and outflow (jet). Accretion establishes first at smaller radii and then spreads out to the larger radii. Higher accretion rates corresponding to larger radii imply that part of the accreting plasma is loaded into the outflow. About 30–40% of the accreting plasma is diverted into the outflow. We have also performed runs with different diffusivity scale height H_η . We find that this may affect the outflow structure considerably, as a lower diffusive scale height results in a more filamentary outflow. We also studied the aspect numerical resolution. We find that with increasing resolution,

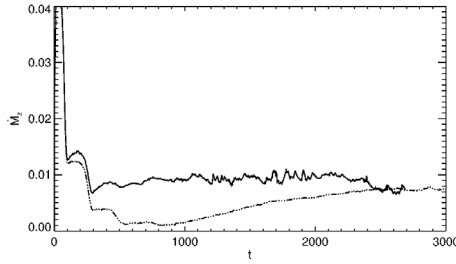


Fig. 3. Resolution comparison. Shown is the ejection rate evolution for presented simulation (solid line) and one with 3 times higher resolution (3dots-dashed line) for $r_1 = 1$ and $r_2 = 10$.

the ejection-to-the accretion ratio in general increases (*cf.* Fig. 3), indicating a more efficient mass loading in the launching process. As for higher resolution – thus decreasing numerical diffusivity – the coupling between the plasma and the field line decreases, the foot points of the field lines are further advected inward. The subsequent faster rotation induces a stronger B_ϕ leading to a stronger toroidal magnetic field pressure gradient, and finally a higher ejection rate.

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References

- Blandford, R.D., & Payne, D.G., 1982, MNRAS, 199, 883
 Casse, F., & Keppens, R., 2002, ApJ, 581, 988
 Fendt, C., & Camenzind, M., 1996, A&A, 313, 591
 Fendt, C., & Cemeljic, M., 2002, A&A, 395, 1045
 Fendt, C., 2006, ApJ, 651, 272
 Ferreira, J., & Pelletier, G., 1993, A&A, 276, 625
 Mignone, A., Bodo, G., Massaglia, S., *et al.*, 2007, ApJS, 170, 228
 Ouyed, R., & Pudritz, R.E., 1997, ApJ, 482, 712
 Porth, O., & Fendt, C., 2010, ApJ, 709, 1100
 Pudritz, R.E., & Norman, C.A., 1983, ApJ, 274, 677
 Zanni, C., Ferrari, A., Rosner, R., *et al.*, 2007, A&A, 469, 811