Launching & propagation of protostellar jets

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Questions?
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Abstract

We present resistive MHD simulations of jet launching and propagation using the PLUTO code. The main question we address is which kind of disks launch jets and which kind of disks do not? We investigate the jet-disk interaction applying different profiles of the disk magnetic diffusivity and derive the corresponding accretion and ejection rates for bipolar outflows. We determine the launching disk area of the fast component of protostellar jets. We further investigate numerically symmetry aspects of jet and counter jet. Finally, we present a model explaining the observationally indicated jet rotation by MHD shocks of the helical magnetic field in the propagating jet.

Jet launching from diffusive disks

We have studied how the magnitude and distribution of the magnetic diffusivity affects mass loading and jet acceleration. We apply a **magnetic diffusivity** based on α-prescription, but also investigate examples where the scale height of diffusivity is larger than that of the disk gas pressure. We further investigate how the ejection efficiency is governed by the magnetic field strength. Our simulations last for up to **5000 dynamical time scales** corresponding to 900 orbital periods of the inner disk.
We observe a continuous and robust outflow launched from the inner part of the disk, expanding into a collimated jet of super-fast magnetosonic speed. For long time scales, the disk internal dynamics change, as due to outflow ejection and disk accretion the disk mass decreases.
For magnetocentrifugally driven jets, we find that for (1) less diffusive disks, (2) a stronger magnetic field, (3) a low poloidal diffusivity, or (4) a lower numerical diffusivity, the **mass loading of the outflow increases** - resulting in more powerful jets with high-mass flux.
For **weak magnetization**, the outflow is driven by magnetic pressure gradient.
We consider in detail the advection and diffusion of magnetic flux within the disk and we find that the **disk and outflow magnetization may substantially change in time**. This may have severe impact on the launching and formation process—an initially highly magnetized disk may evolve into a disk of weak magnetization which cannot drive strong outflows.
We further investigate the jet asymptotic velocity and the jet rotational velocity in respect of the different launching scenarios. We find a **lower degree of jet collimation** than previous studies, most probably due to our revised outflow boundary condition.

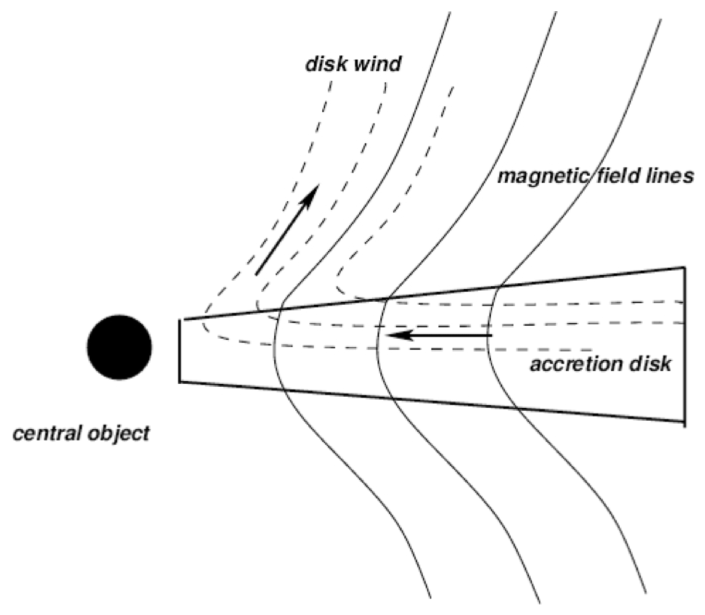

Fig.1. Schematic display of the outflow launching process from accretion disks. Matter (dashed lines) is accreted along the disk surrounding a central object and is loaded on to the magnetic field lines (solid lines). The emerging disk wind is further accelerated and collimated into a high-velocity beam.

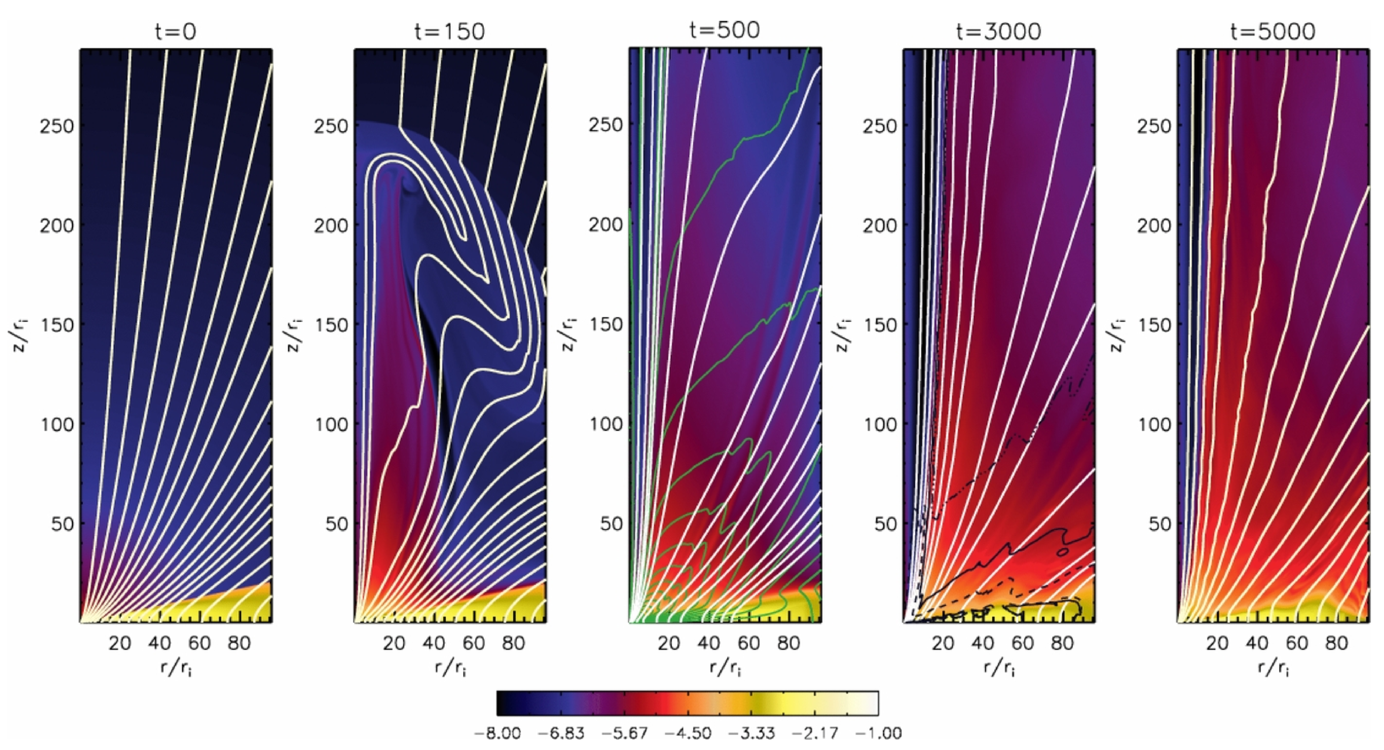

Fig.2. Time evolution if the jet-disk structure. Shown is the mass density (color) and the poloidal magnetic field (magnetic flux contours) for dynamical times t = 0,150,500,2000,5000. Dark lines indicate the slow-magnetosonic (dashed), Alfvén (solid), and fast-magnetosonic (dot-dashed) surfaces at t = 3000. Electric current lines are shown for t = 500 (green solid).

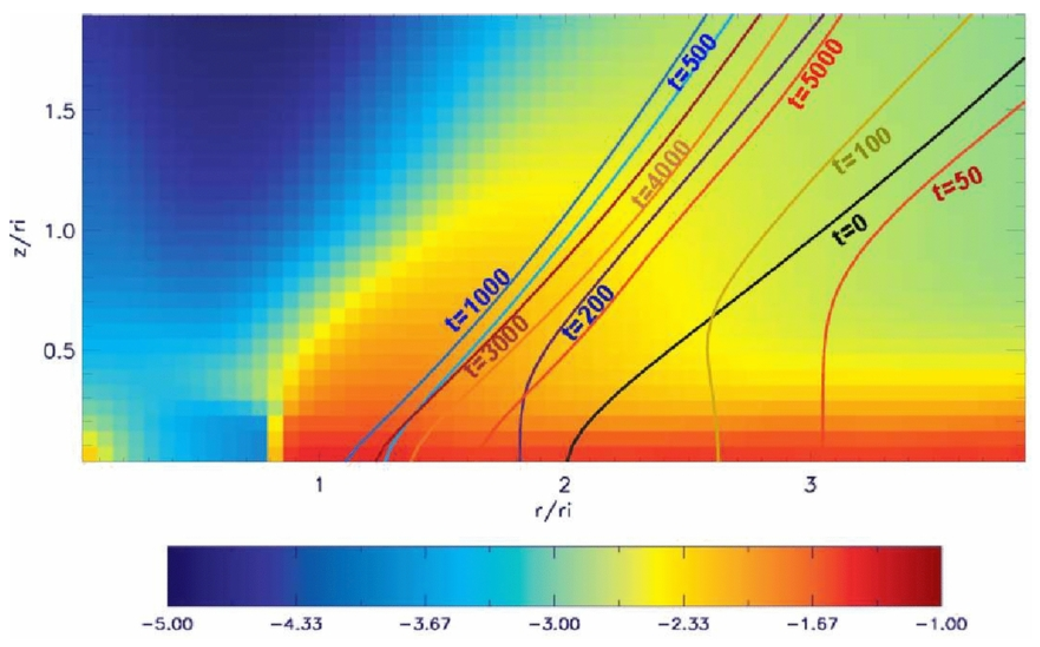

Fig.3. Diffusion and advection of magnetic flux. Shown is the evolution of the magnetic flux surface ψ = 0.1 for t = 0, 50, 100, 200, 500, 1000, 3000, 4000, 5000 (colored lines). This flux surface is initially rooted at (2, 0). Superimposed is the density distribution at t = 5000.

Bipolar jets - launching from asymmetric disks

We have performed simulations of the disk-jet interaction on a computational domain covering **both hemispheres,** in particular addressing the question of an intrinsically **asymmetric origin of jet / counter-jet systems**.
We disturb the hemispheric **disk** symmetry, and investigate the subsequent evolution of the outflow. We investigate several models, such as asymmetric disks with (initially) different thermal scale height in each hemisphere, and symmetric disks into which a local disturbance is injected in one hemisphere.
In these simulations we consider **global and local diffusivity models**.
The disk evolution first leads to substantial **warping.** The disk asymmetry results in **asymmetric outflows** with mass fluxes differing by 10-30 %.
For a global diffusivity (constant in space & time) model the outflow asymmetry deceases after several hundred rotations. For a local diffusivity prescription the **outflow asymmetry is persistent for much longer time.**
Our results suggest that jet asymmetries can indeed be generated intrinsically and maintained over long time by disk asymmetries and the standard launching mechanism. The numerically derived parameters agree with few observed objects, however, it is too early to apply our models to individual sources.

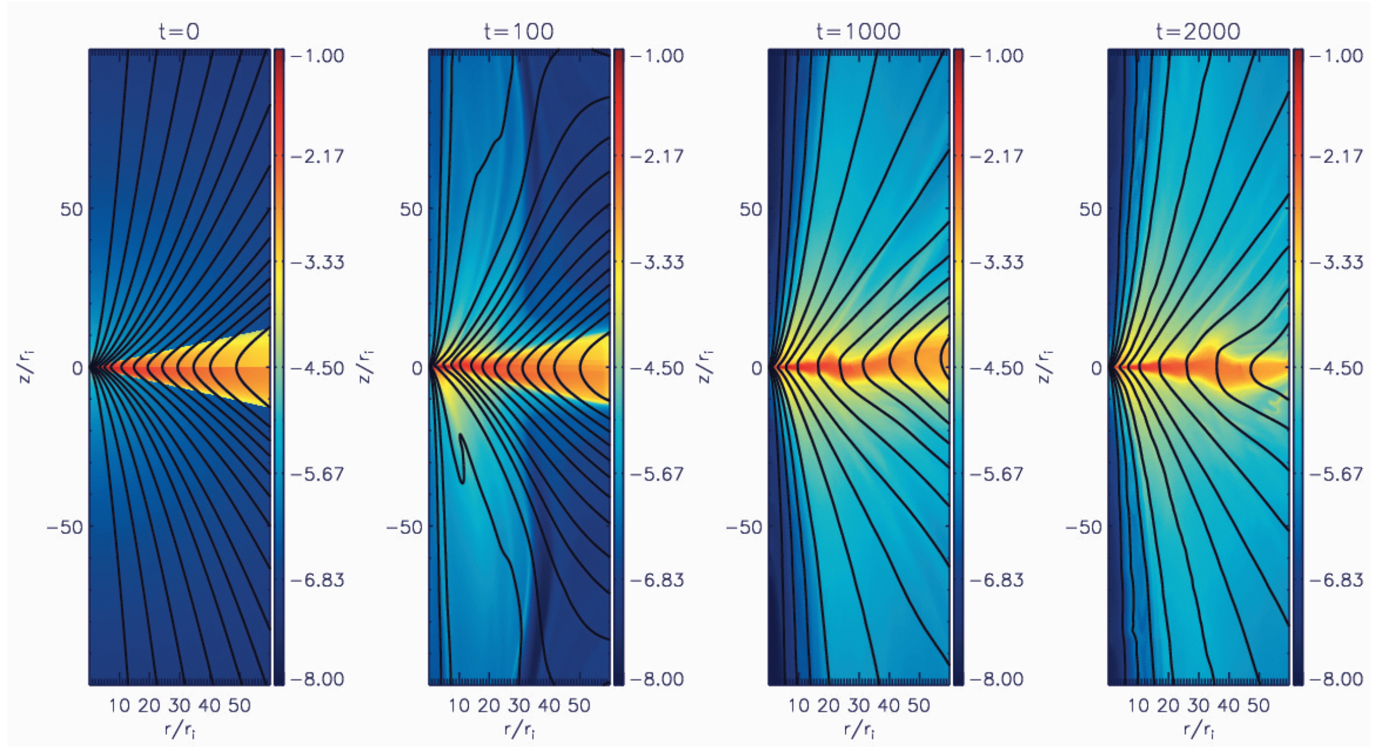

Fig.4. Time evolution of a bipolar jet-disk structure, applying a fixed-in-time diffusivity profile and evolving from an asymmetric initial state with different disk scale heights for the upper and lower disk, $(h/r)_{up} = 0.15$ and $(h/r)_{down} = 0.1$. Shown are the mass density (colors) and the poloidal magnetic field (lines) for 2000 dynamical time steps.

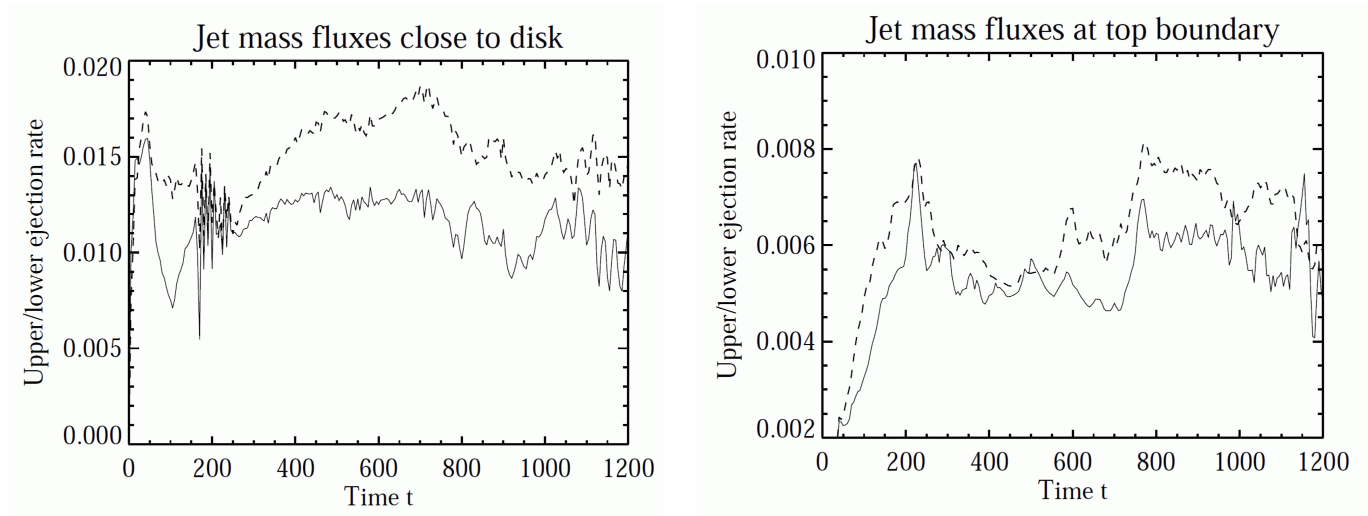

Fig.5. Jet mass flux evolution. Shown is the launching mass flux measured at three disk scale heights (left) and the asymptotic fluxes (right) integrated at z= +/- 50 from r= 2 to r=40.

Jet rotation by helical MHD shocks

Shock compression of a helical magnetic field results in a toroidal Lorentz force component that will accelerate the jet material in the toroidal direction. This process **transforms magnetic angular momentum carried along the jet into kinetic angular momentum (rotation)**. In our setup, the jet is injected into the ambient gas with no rotation. We apply different dynamical parameters for jet propagation such as the jet internal Alfvén Mach number and fast magnetosonic Mach number, the density contrast of the jet to the ambient medium, and the external sonic Mach number of the jet. The mechanism we suggest should work for jet **internal shocks** or **external shocks** between the jet and the ambient gas (entrainment). For typical parameter values for protostellar jets, the numerically derived rotation feature is consistent with the observations, i.e., a rotation speed 0.1%-1% of the jet bulk velocity.

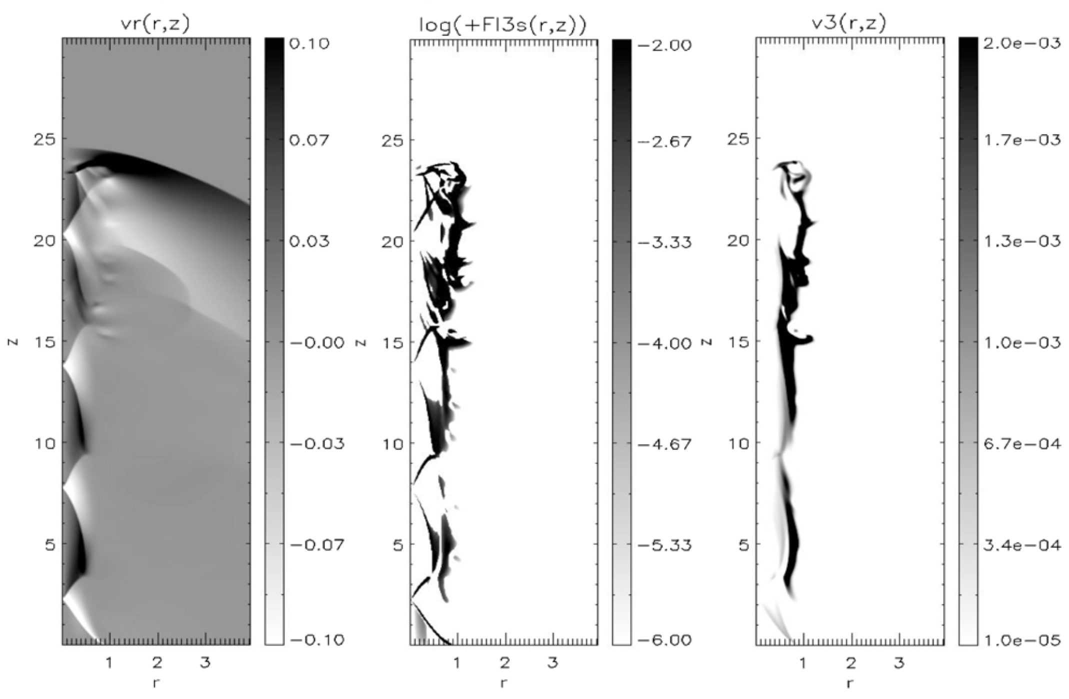

Fig.6. Shown are the density distribution (left), the positive specific toroidal Lorentz force (middle), and the positive toroidal velocity component (right) at dynamical time t = 50.

References:

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