How to make astrophysical jets?
MHD simulations of jet launching

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Questions?
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Abstract I present MHD simulations investigating the launching of astrophysical jets. Our simulations treat the time-dependent evolution of the accretion-ejection structure and the subsequent collimation of the disk wind into a high-velocity jet. Our setup considers various models for a physical (turbulent) magnetic diffusivity that is essential for the mass loading of the outflow. We find relatively high mass fluxes in the outflow, about 20-40% of the accretion rate.
Investigating disks of different magnetization (thereby taking advantage from the slow disk evolution over many 1000s of rotation periods), we find a general relation between the disk magnetization and the typical jet dynamical parameters. Our most recent simulations consider a mean-field accretion disk dynamo and the launching of outflows by a self-generated disk magnetic field.

1. Jet launching model setup

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.

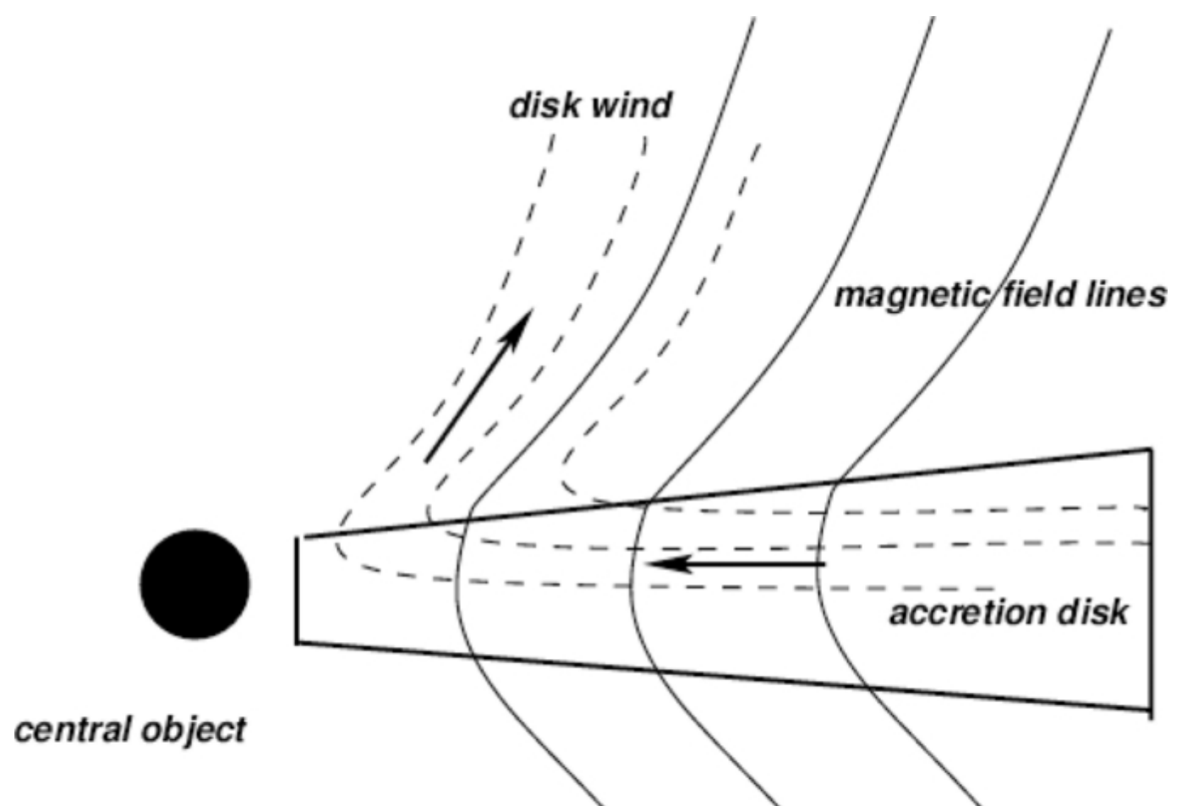

Fig.1. Schematic display of the outflow launching process from accretion disks. Matter (dashed lines) is accreted along the disk surrounding a central object and is loaded on to the magnetic field lines (solid lines). The emerging disk wind is further accelerated and collimated into a high-velocity beam.

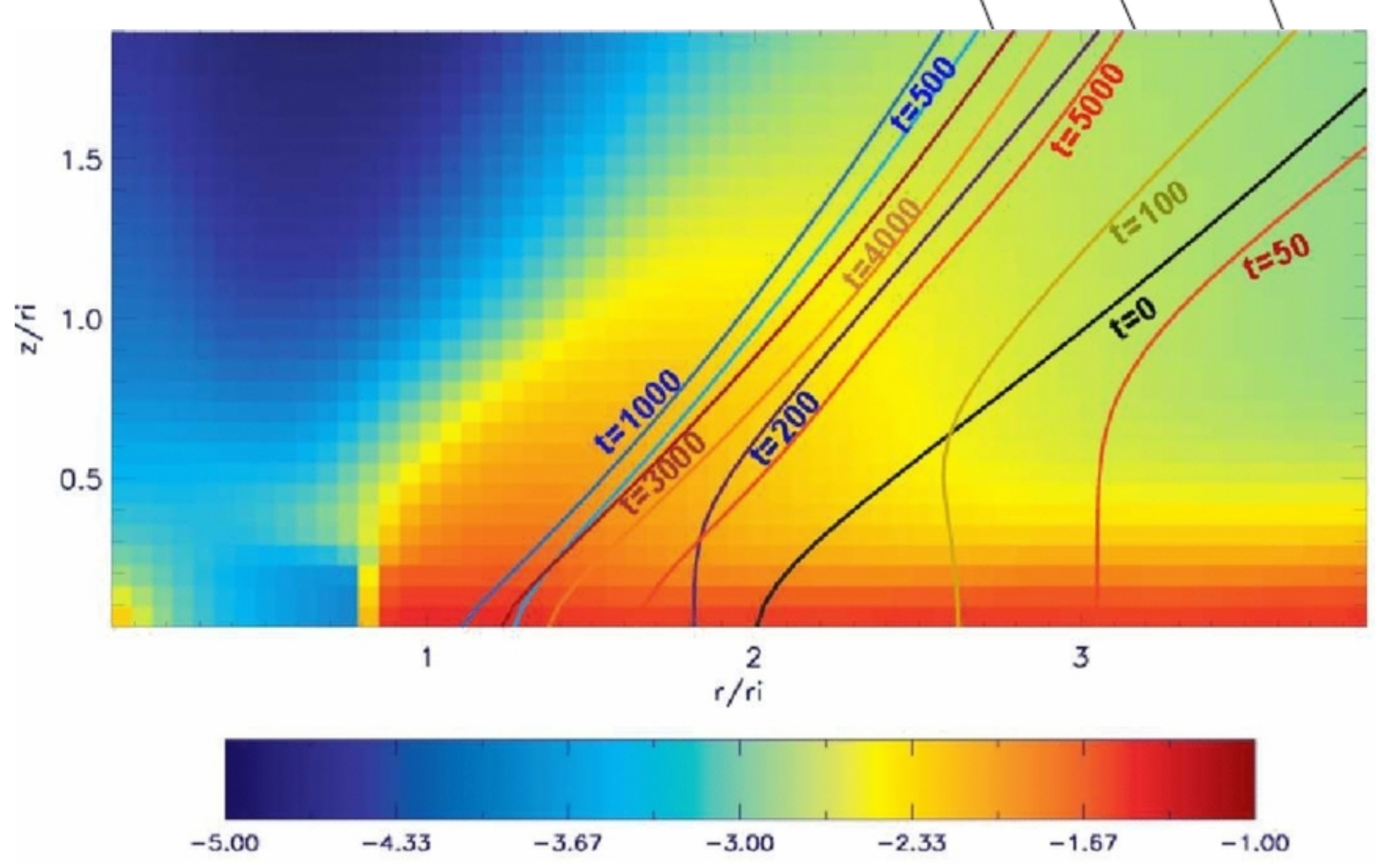

Fig.2. Diffusion and advection of magnetic flux. Shown is the evolution of the magnetic flux surface ψ = 0.1 for t = 0, 50, 100, 200, 500, 1000, 3000, 4000, 5000 (colored lines). This flux surface is initially rooted at (2, 0). Superimposed is the density distribution at t = 5000.

2. Bipolar jets: launching from asymmetric disks

We perform simulations of the disk-jet interaction on a domain covering **both hemispheres**, 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 treat several setups, 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.
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 100 rotations. For a local diffusivity prescription the **outflow asymmetry is persistent for much longer time.**
We suggest that jet asymmetries can be generated intrinsically and maintained over long time by disk asymmetries and the standard launching mechanism.

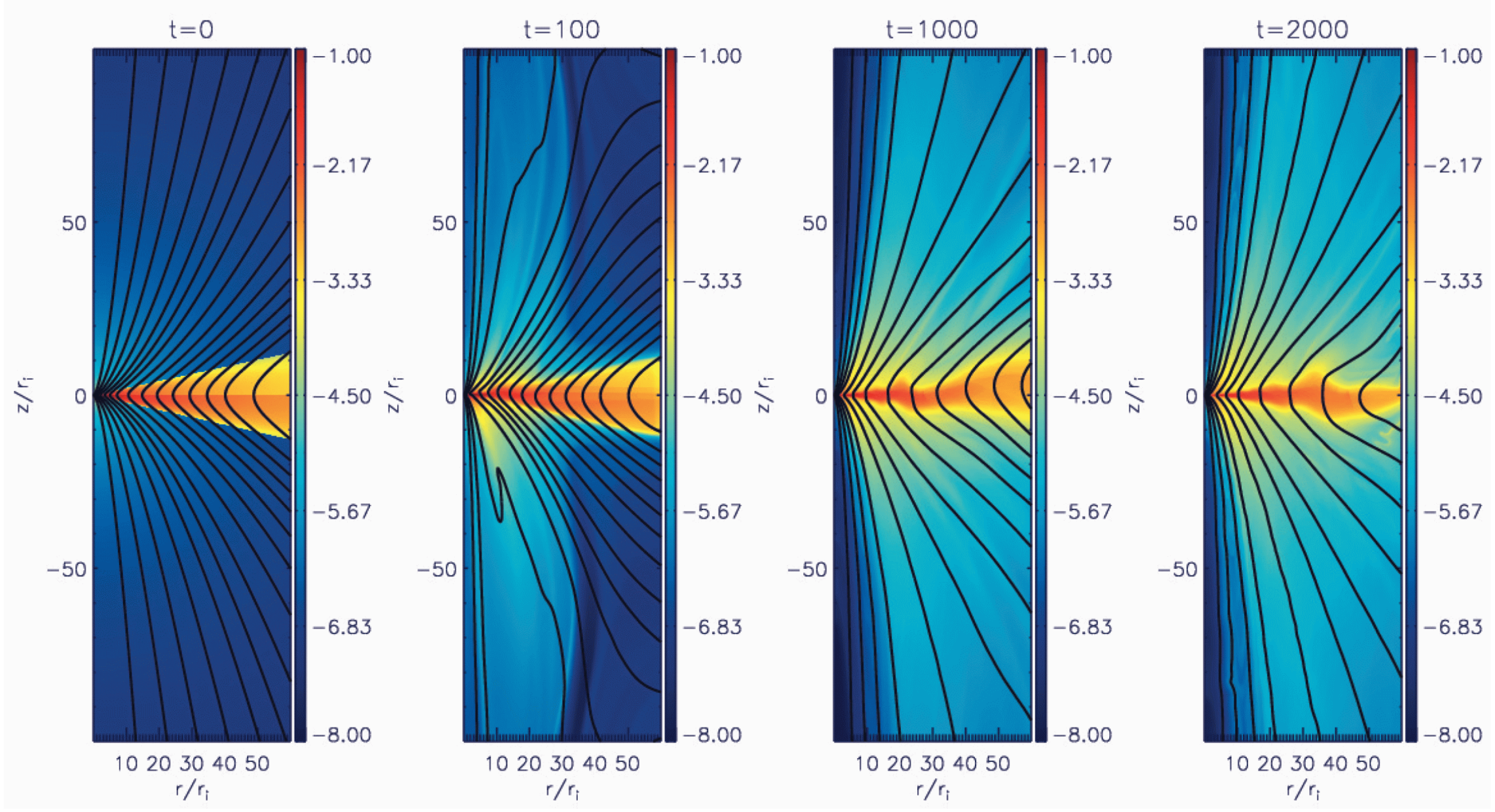

Fig.3. Time evolution of a bipolar jet-disk structure, applying a fixed-in-time diffusivity profile and evolving from an asymmetric initial state with different disk scale heights for the upper (h/r=0.15) and lower disk (h/r = 0.1). Shown are the mass density (colors) and the poloidal magnetic field (lines) for 2000 dynamical time steps.

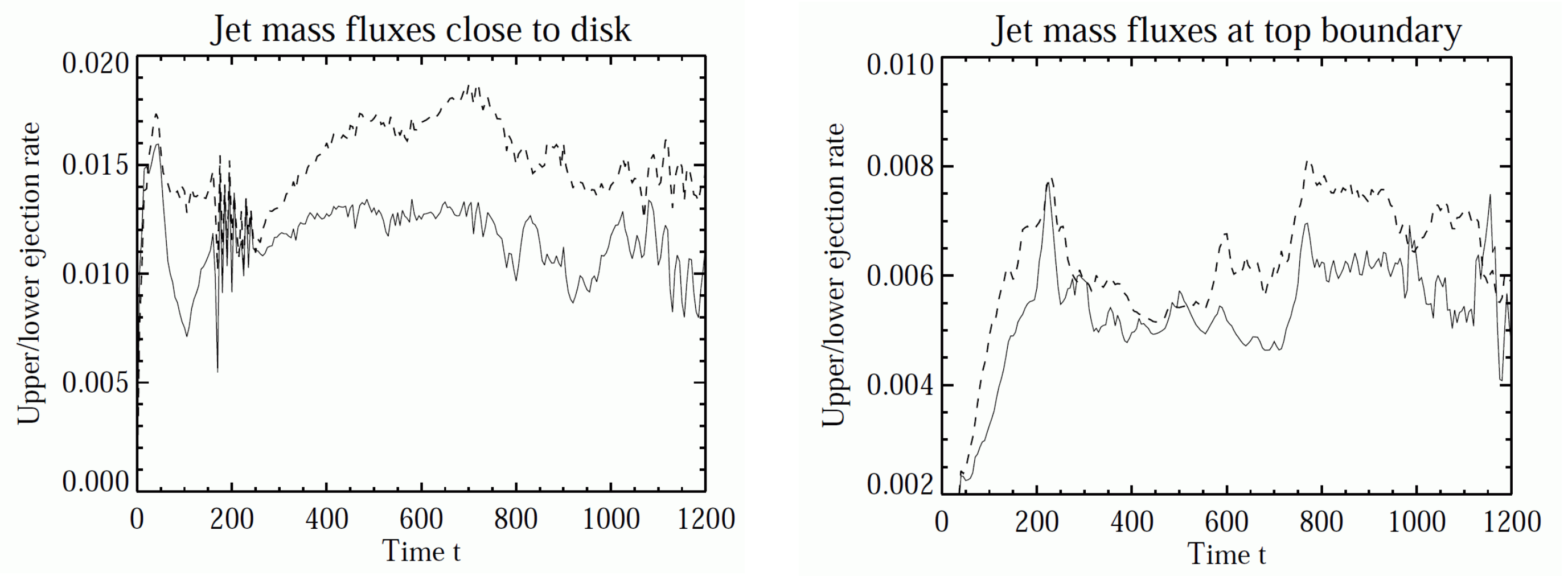

Fig.4. Jet mass flux evolution. Shown is the launching mass flux measured at three disk scale heights (left) and the asymptotic fluxes (right) integrated at z= +/- 50 from r= 2 to r=40.

3. Disk magnetization & jet properties

The disk-jet structure evolves into a quasi-steady state. However, due to mass loss out of the computational box (accretion and ejection) the disk structure changes slowly in time (on time scales much longer the the Keplerian time scale). This effect can be used to investigate for a **general relation** between disk **magnetization** (changing slowly as mentioned above) and the parameters of the **jet outflow** that is ejected, accelerated, collimated comparatively „instantaneously".
We find a relatively smooth relation over some orders of magnitude for the disk magnetization extending eaerlier results (Murphy et al. 2010).

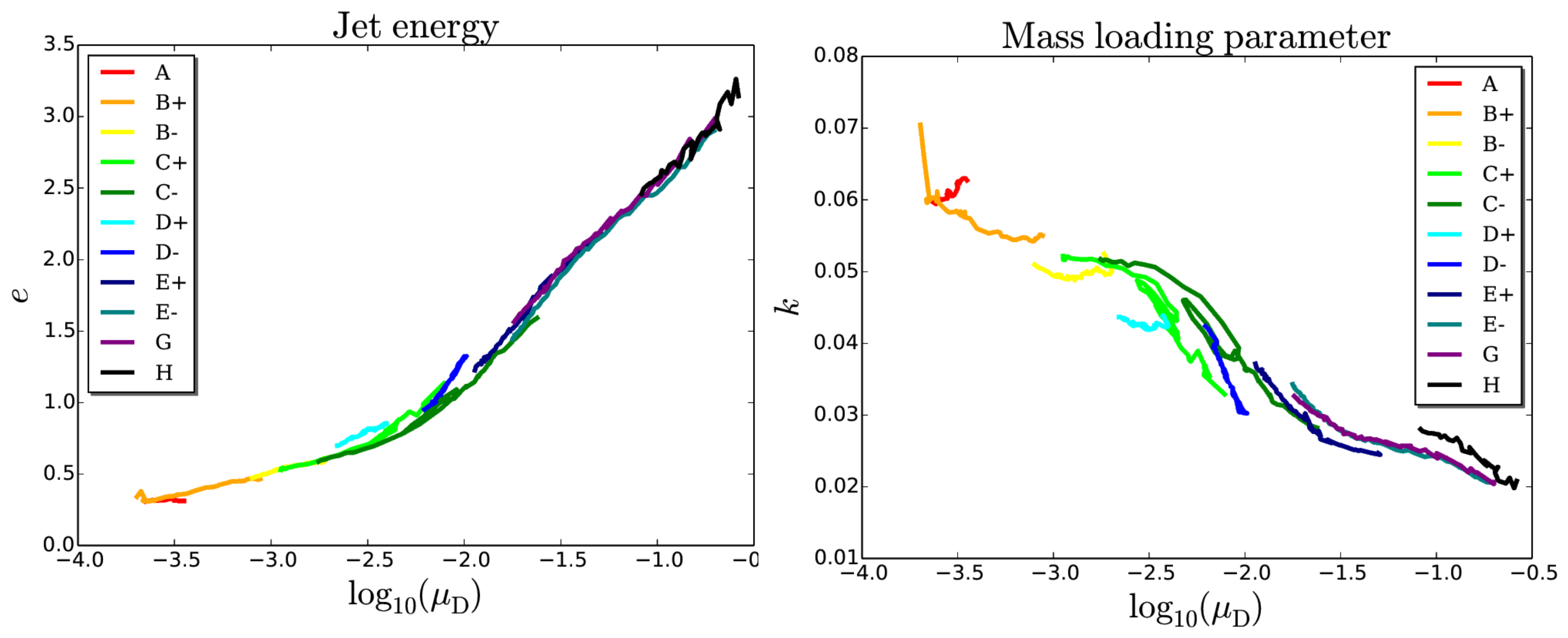

Fig.5. Jet energy ***e*** (left) and the mass loading parameter ***k*** (right) with respect to the disk magnetization μ_D. Each line represents the evolution from 700 to 10,000 time units of a single simulation starting from a different initial condition but evolving into a similar state.

4. Jets launched by a mean-field disk dynamo

We have implemented a **mean-field dymano** in the PLUTO code, in order to investigate jet launching by a magnetic field, self-generated by a disk dynamo. Dynamo action is concentrated to the inner disk in this model and considers a **turbulent dynamo-alpha** and a **turbulent disk magnetic diffusivity**. Figure 6 shows a **toy model** in which we switch off/on the dynamo action every 1000 dynamical time steps. When the dynamo is re-activated, a **new jet is ejected** leading to a series of **jet „knots".**

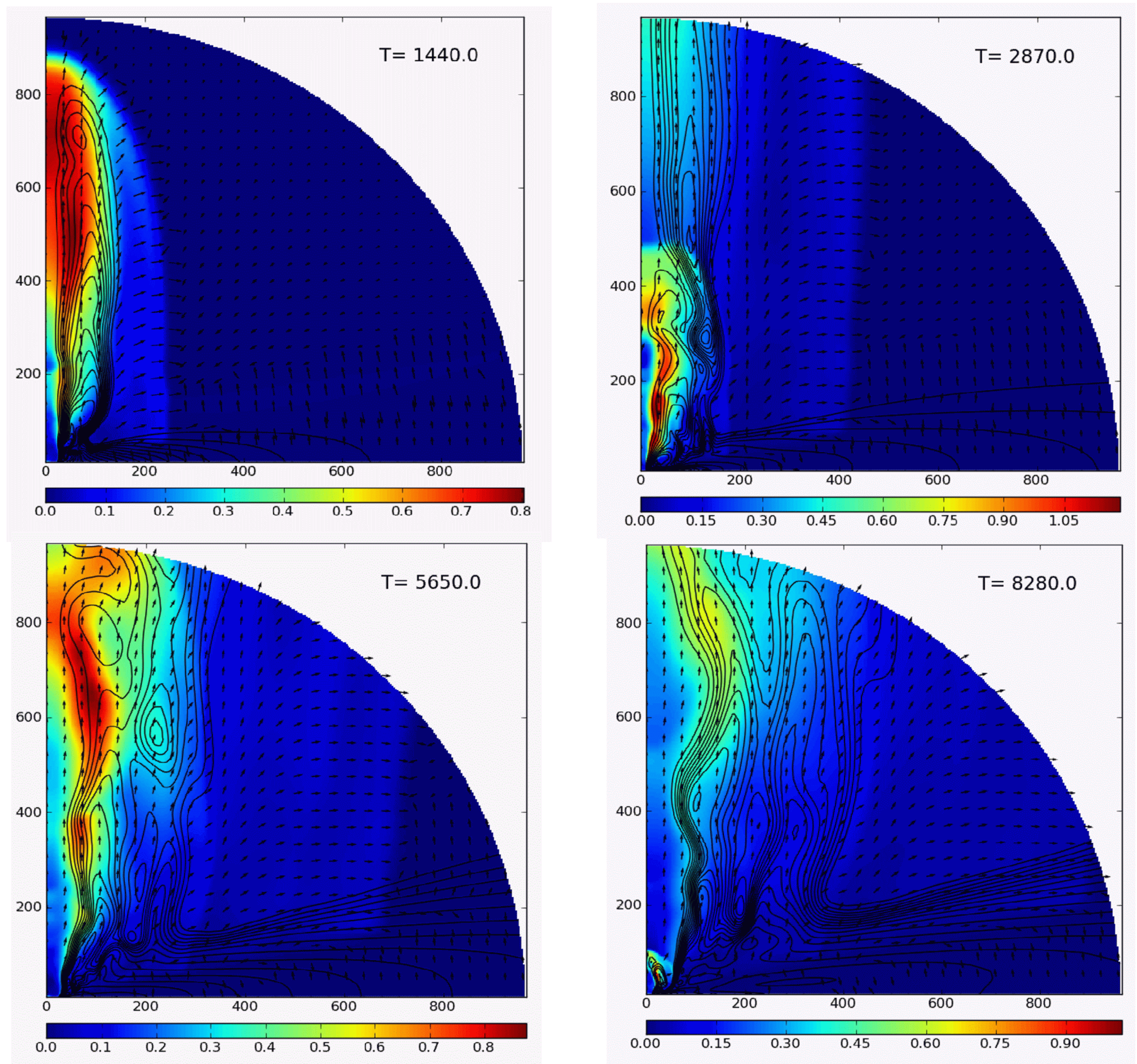

Fig.6. Episodic ejections of jet material following a toy model of disk mean-field dynamo that is switched on/off every 1000 dynamical time steps.

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