Relaxation of initial conditions in MHD simulations of star-disk system

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Introduction

In numerical simulations, there is always transition between the initial conditions and time-evolved initial phase of the simulation. It is the *relaxation* of initial conditions. Depending on numerical methods used, relaxation can happen different ways.

What is a good relaxation?

- maintains appropriate initial conditions for time-evolved solutions

Resistive MHD equations

-in addition to physical resistivity, hydrostatic, viscous dissipation term could be added-but we investigate effects of resistivity

-we mimic viscosity with von Neumann-Richtmyer artificial viscosity, which is significant only for part of the flow with shocks-good for relaxation phase

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \quad (1)$$

$$\rho \left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} \right] + \nabla p + \rho \nabla \Phi - \frac{\boldsymbol{j} \times \boldsymbol{B}}{c} = 0 \quad (2)$$

$$\frac{\partial \boldsymbol{B}}{\partial t} - \nabla \times \left(\mathbf{v} \times \boldsymbol{B} - \frac{4\pi}{c} \eta \boldsymbol{j} \right) = 0 \quad (3)$$

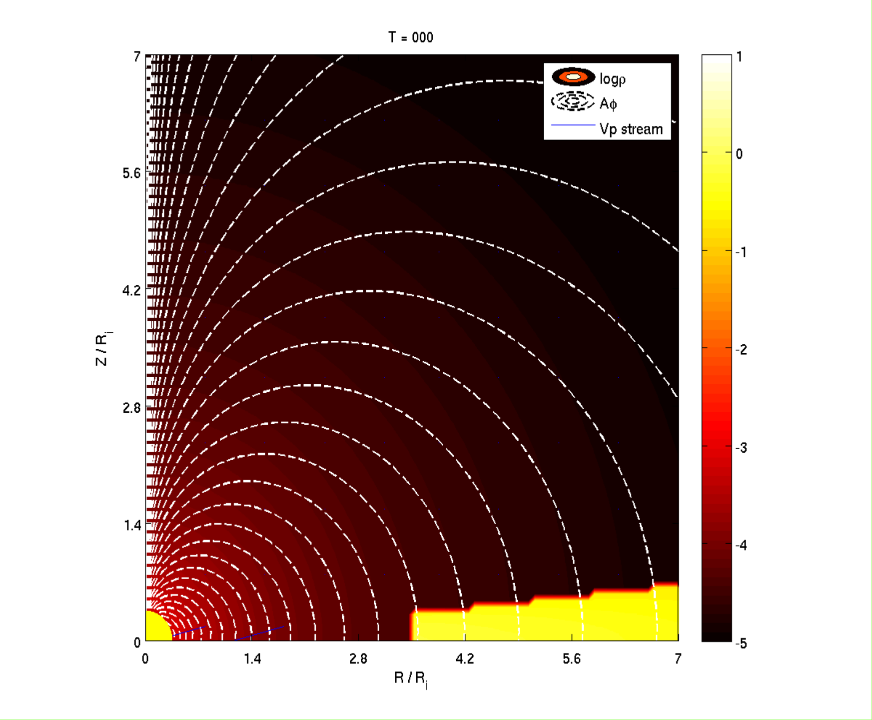
$$\rho \left[\frac{\partial e}{\partial t} + (\mathbf{v} \cdot \nabla) e \right] + p (\nabla \cdot \mathbf{v}) = 0 \quad (4)$$

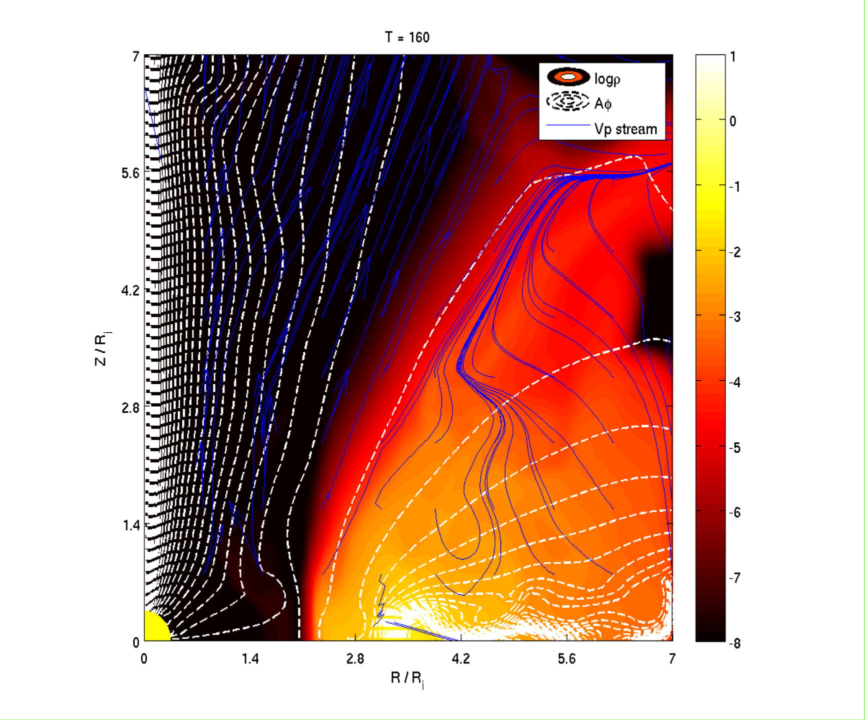
$$\boldsymbol{j} = \frac{c}{4\pi} \nabla \times \boldsymbol{B} \ . \quad (5)$$

entropy S$=\ln(p/\rho^{\gamma})$, with adiabatic index γ=5/3. The internal energy (per unit volume) is then $e = p/(\gamma - 1)$.

Straightforward simulations-time evolution

- the initial and end stage in simulation when there is no “tricks”. We set the initial and boundary conditions and leave the code to deal with physical and numerical instabilities, negative densities, large pressures... we decide to believe the code is doing it well.

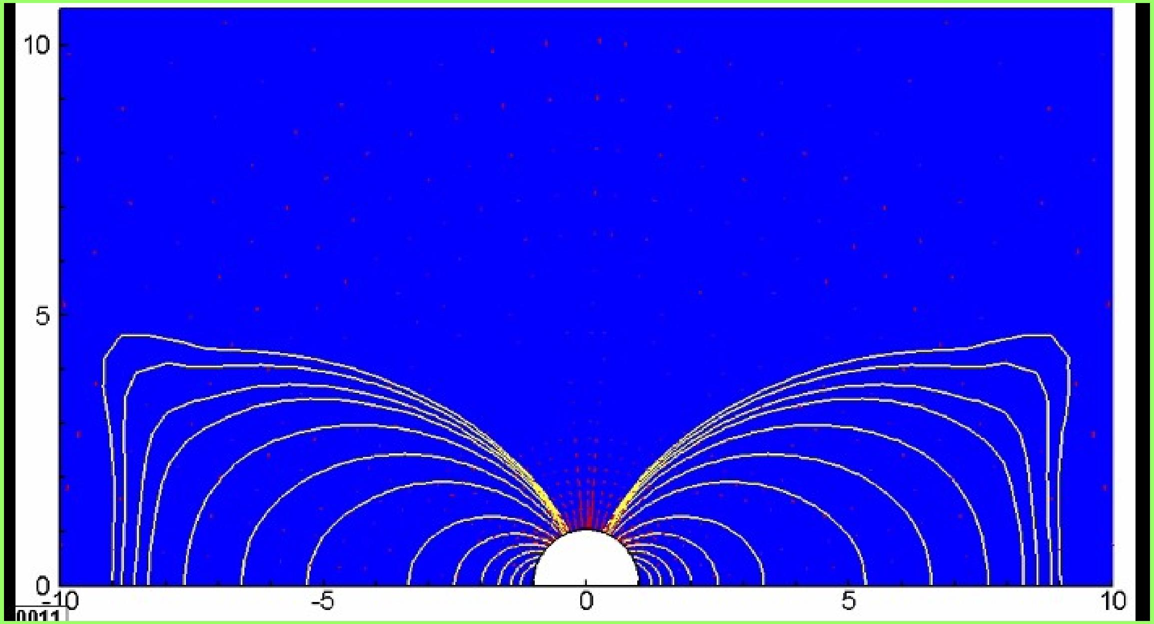




Smoothed initial conditions: slow introduction of matter

-if we start the simulation without the matter in the computational box, and then allow the matter to slowly enter the box, we avoid chaotic relaxation phase.

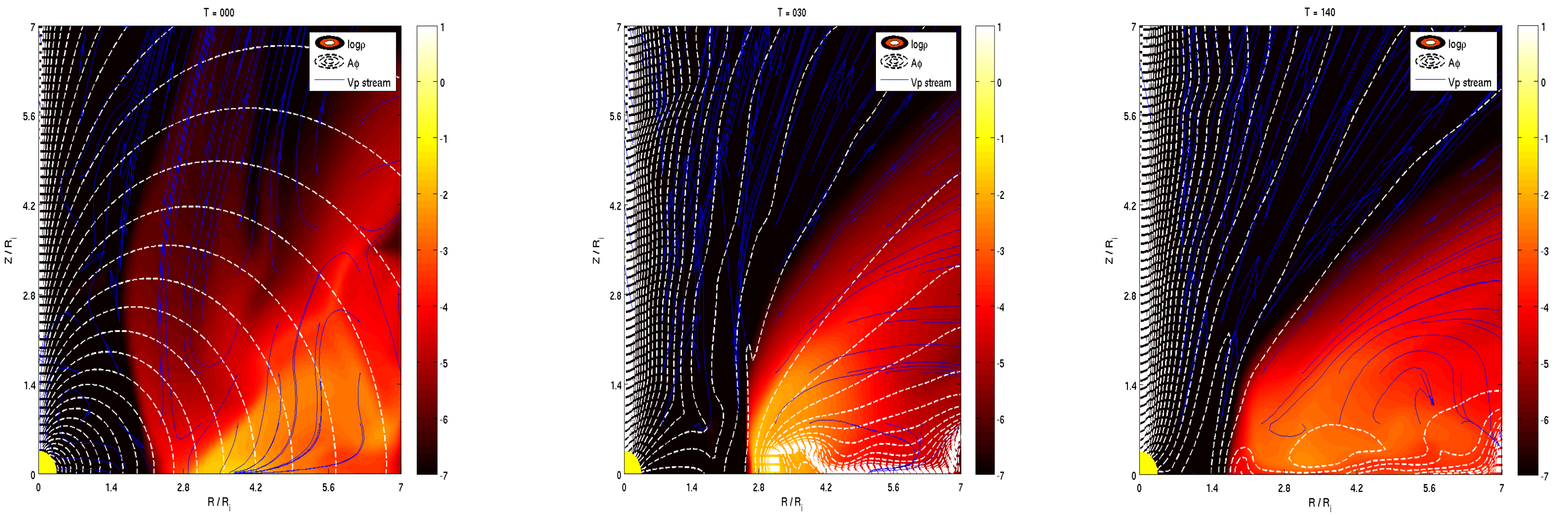
-but, do we really solve the same mathematical and physical problem?



Smoothed initial conditions: slow increasing of B

-we leave the code to deal with HD relaxation, as it shows to be good with it (in simulations without/with small B), but we gradually increase the magnetic field, reaching the magnitude we want in few steps.

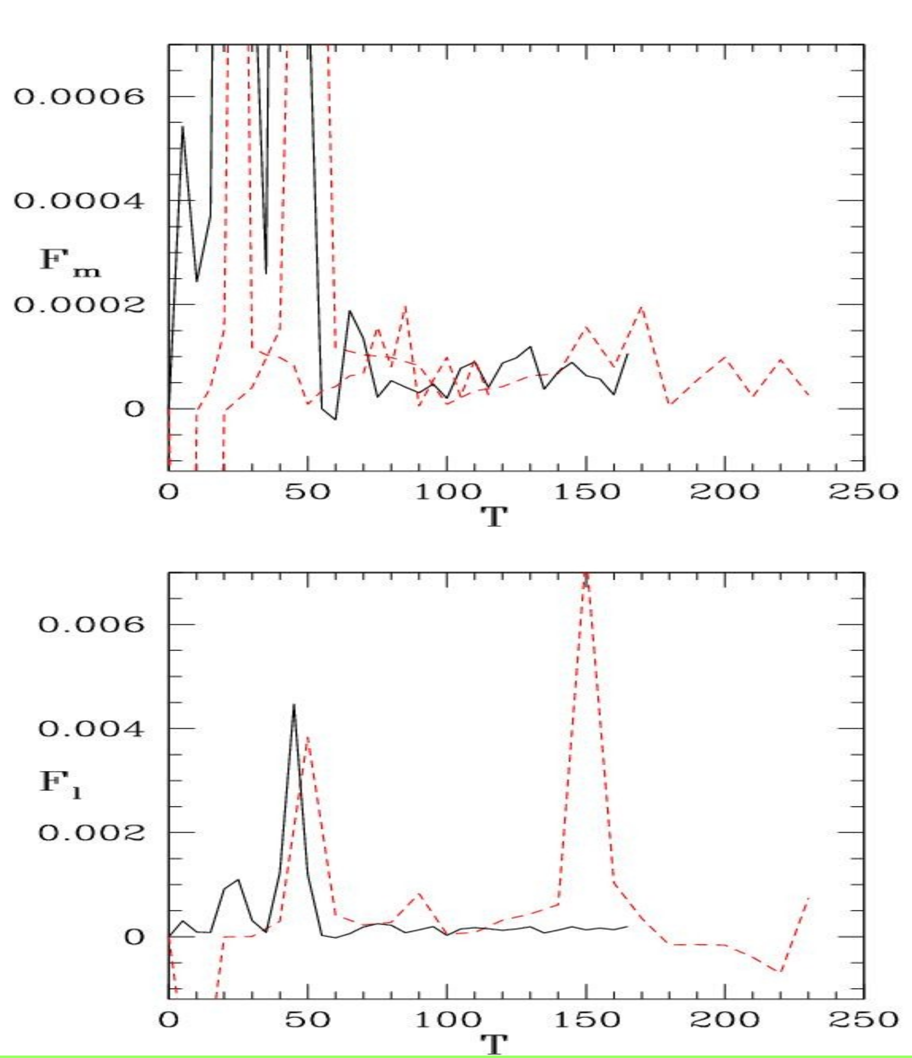
-should be more realistic, but there is no guarantee. Has to be checked carefully.



Comparison of results

-we compare the mass and angular momentum fluxes

SLOW INFLOW OF MATTER



GRADUAL INCREASE OF B

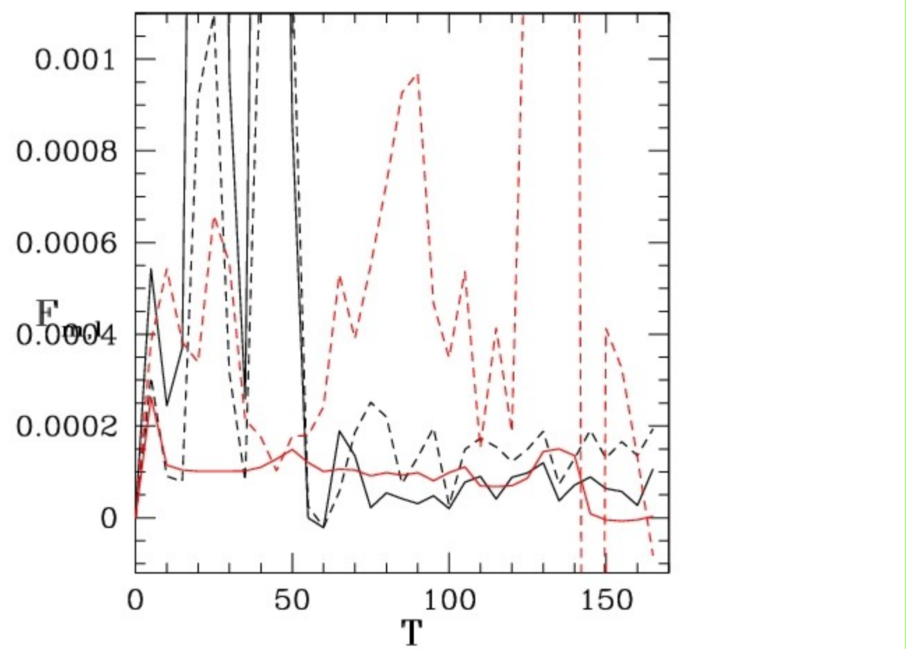


Fig. 1.— Comparison plots for mass (F_m) (solid lines) and angular momentum (F_l) fluxes (dashed lines) for typical simulation from paper, with B_*=100G for the case with usual evolution (black) and evolution when B_* has been gradually increased from 0 to 100 Gauss, in order-of-magnitude steps (red).

Dangers of too nice methods

-star-disk magnetospheric interaction is complicated problem, not easy to disentangle physical and numerical effects. We have to ensure the result is realistic.

-even in ideal MHD simulations, there is always some numerical resistivity and viscosity, hence results will depend on resolution. It might happen, because of dissipation effects which smooth-out the numerical problems and instabilities, that coarser grid gives more realistic results.

-relaxation phase of simulation might define the effective initial conditions (this what remains of initial conditions after the relaxation) to be quite different than we would expect from our initial and boundary conditions

-needed to consult results with different relaxation processes