Diffusion of magnetic field and outflows from star-disk magnetosphere

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Introduction

- Using the PLUTO code, I perform the long-lasting simulations of proto-stellar accretions disks, which reach a quasi-stationary state.
- With PLUTO we solve 2D axi-symmetric viscous & resistive MHD equations, with split field method and constrained transport for ensuring div B=0.
- We neglect Ohmic and viscous heating in the energy equation-we still include viscosity and resistivity in the equation of motion and in the induction equation.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

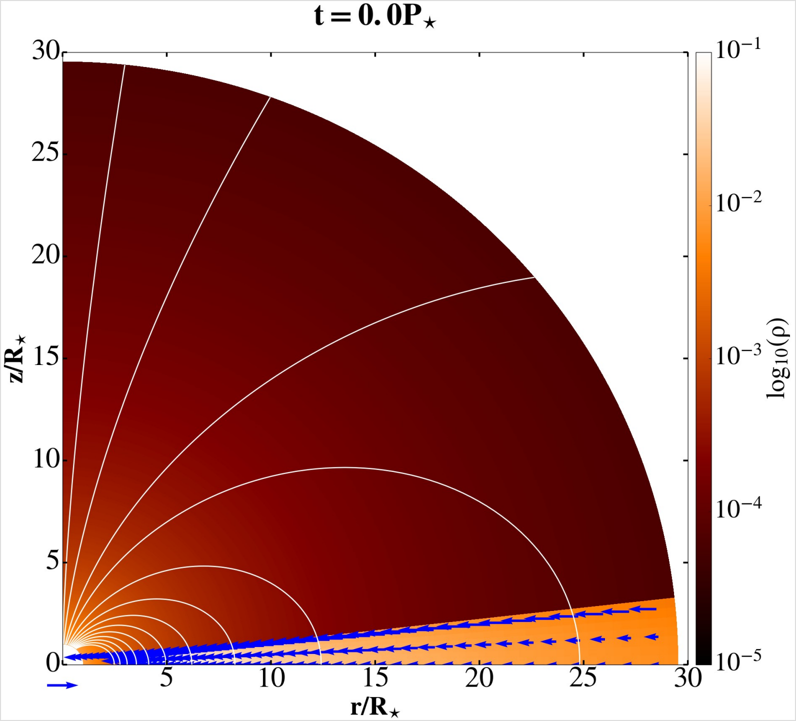
$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot \left[\rho \boldsymbol{u}\boldsymbol{u} + \left(P + \frac{\boldsymbol{B}\cdot\boldsymbol{B}}{8\pi}\right)\boldsymbol{I} - \frac{\boldsymbol{B}\boldsymbol{B}}{4\pi} - \boldsymbol{\tau}\right] = \rho \boldsymbol{g}$$

$$\frac{\partial E}{\partial t} + \nabla \cdot \left[\left(E + P + \frac{\boldsymbol{B}\cdot\boldsymbol{B}}{8\pi}\right)\boldsymbol{u} - \frac{(\boldsymbol{u}\cdot\boldsymbol{B})\,\boldsymbol{B}}{4\pi}\right] + \nabla \cdot \left[\eta_{\mathrm{m}}\boldsymbol{J}\times\boldsymbol{B}/4\pi - \boldsymbol{u}\cdot\boldsymbol{\tau}\right] = \rho \boldsymbol{g}\cdot\boldsymbol{u} - \Lambda_{\mathrm{cool}}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \times (\boldsymbol{B}\times\boldsymbol{u} + \eta_{\mathrm{m}}\boldsymbol{J}) = 0.$$

“Atlas” of solutions in Young Stellar Objects case

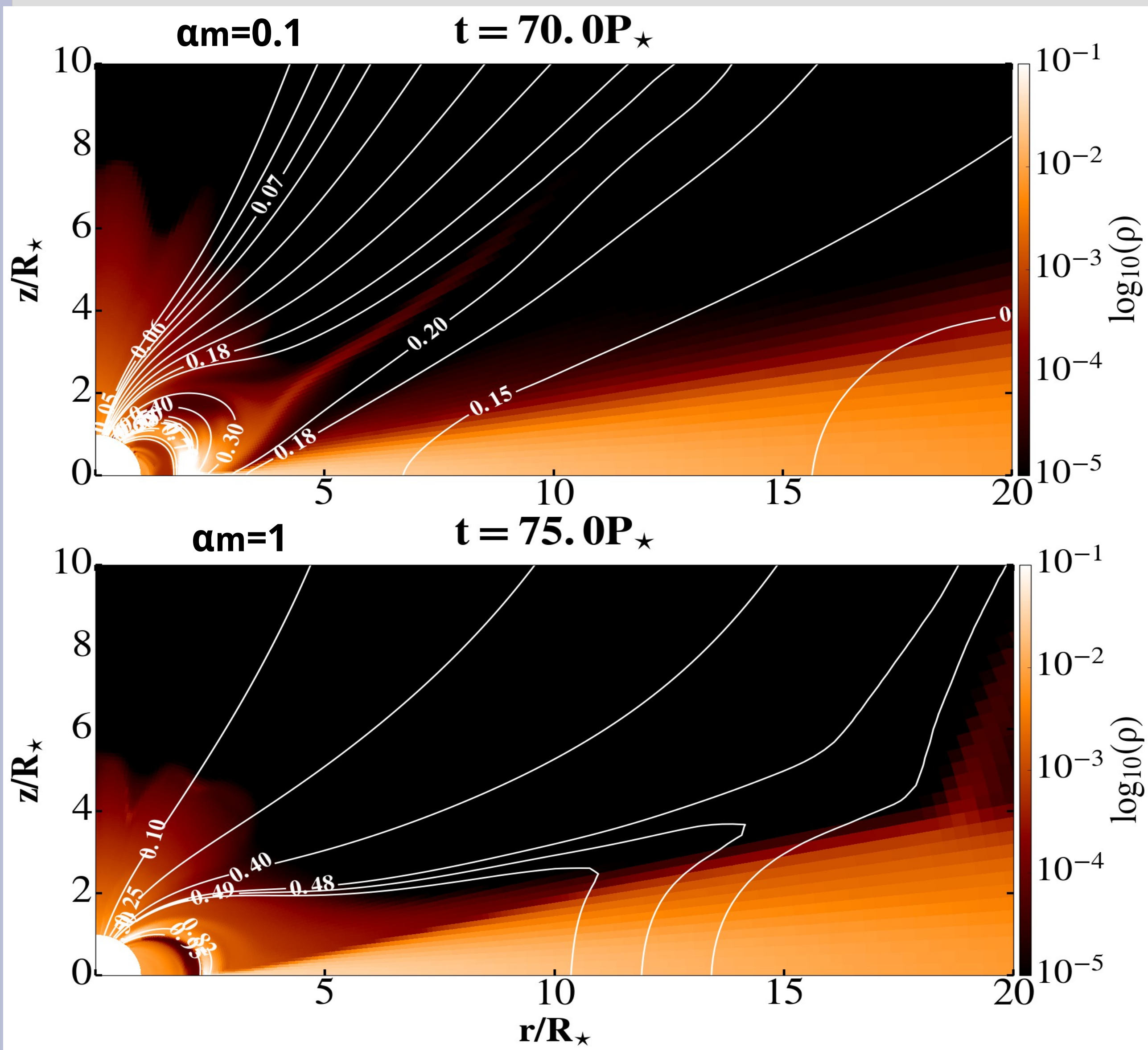
As a part of work in ANR “TOUPIES” project in France, I completed the “atlas” of simulations of Young Stellar Objects with different magnetic field strenghts B=0.25, 0.5, 0.75 and 1 kGauss of the dipole stellar field. I performed 4x4x4=64 simulations and obtained quasi-stationary solutions with realistic stellar rotation rates Ω_s=0.1 (P_s=2.3, 4.6, 6.9 and 9.2 days) giving R_{cor}=7.37,4.64,3.54,2.92, with the resistivity coefficients α_m= 0.1, 0.4, 0.7 and 1.0. I show here the solutions wih α_v=1 .



All the simulations start with the same initial and boundary conditions, the Kluźniak & Kita (2000) solution for the full 3D hydro-dynamical disk, with the added initially non-rotating corona and the stellar dipole field.
I repeated the results obtained by Romanova et al. (2009) and Zanni & Ferreira (2009,2013).

I performed a systematic study with magnetic star-disk numerical simulations where the disk quasi-stationarity is reached.

Solution with 0.5 kG, Ω_s=0.1: α_m=0.1 and α_m=1

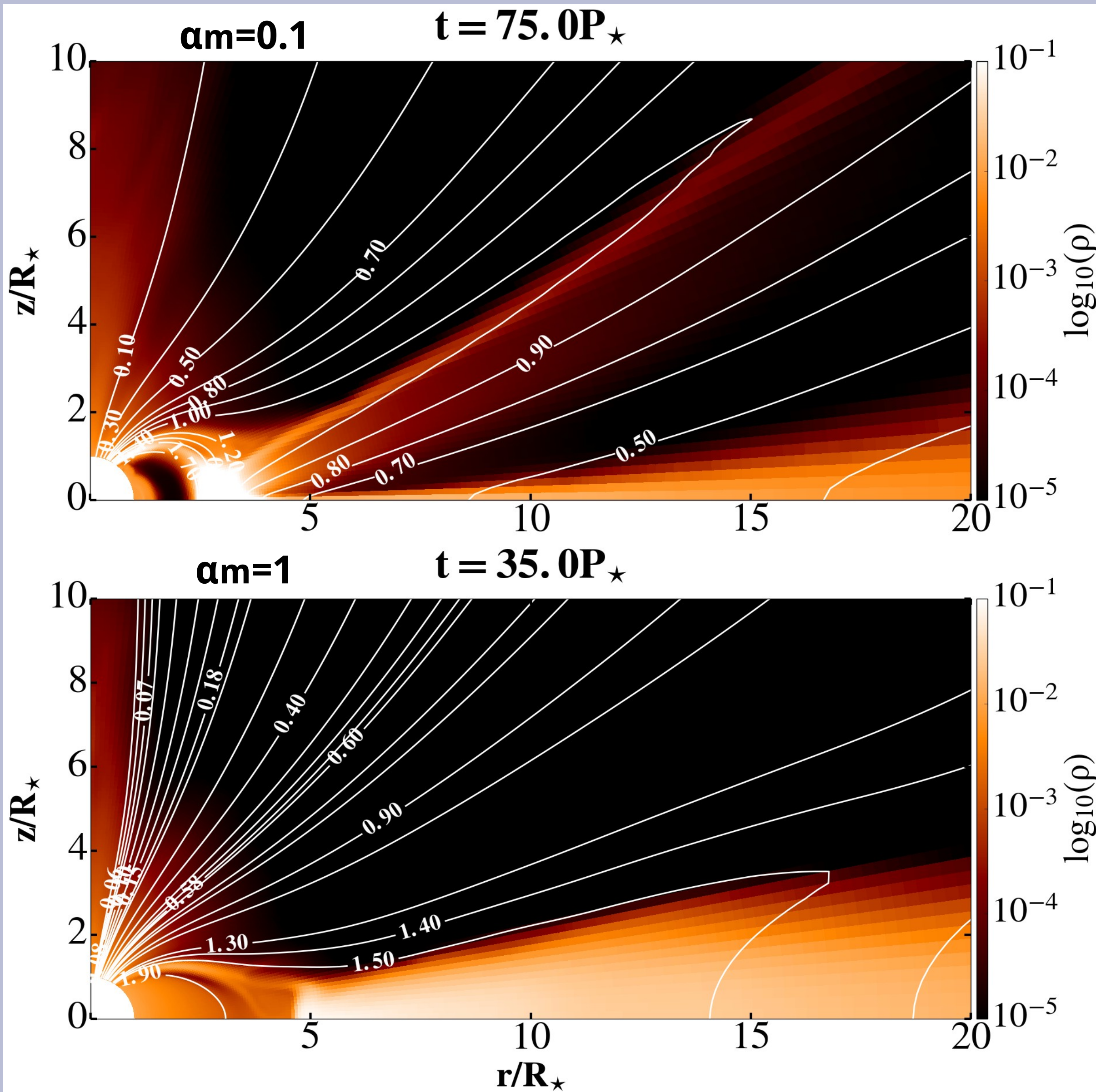


In my simulations I observe few types of solutions, which depend on the stellar rotation, strength of the magnetic field and amount of the resistivity in the simulation.

In all the simulations with α_m=0.1 a conical outflow is launched.

I investigate how far in the disk is the stellar magnetic field still connected with the disk. This determines the transport of the angular momentum in the system and if the star is spun up or slowed down.

Solution with 1. kG, Ω_s=0.2: α_m=0.1 and α_m=1



With larger magnetic field, the disk inner radius is pushed away from the star. This changes the geometry of solutions.

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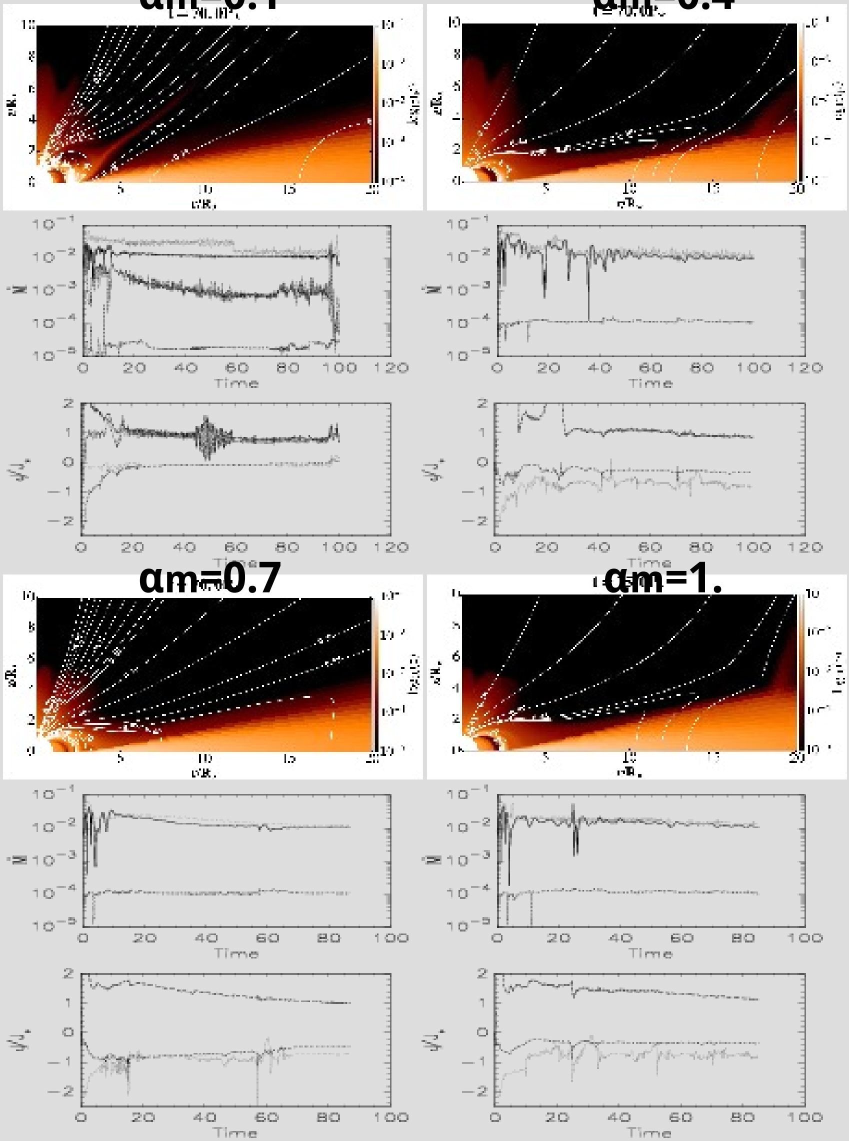
Part of the “atlas” of solutions in B_s=0.5 kG case

Ω_s=0.1

αm=0.1 αm=0.4

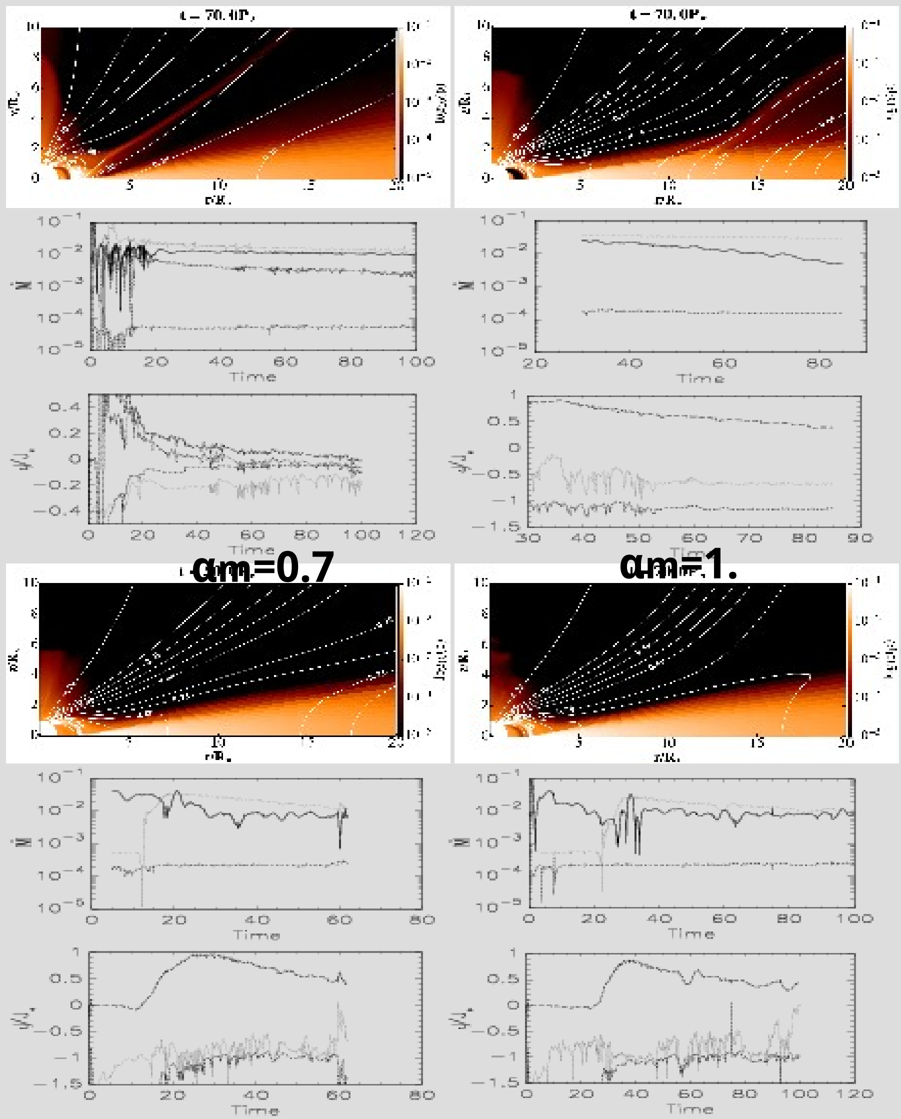
αm=0.7 αm=1.



Ω_s=0.2

αm=0.1 αm=0.4

αm=0.7 αm=1.



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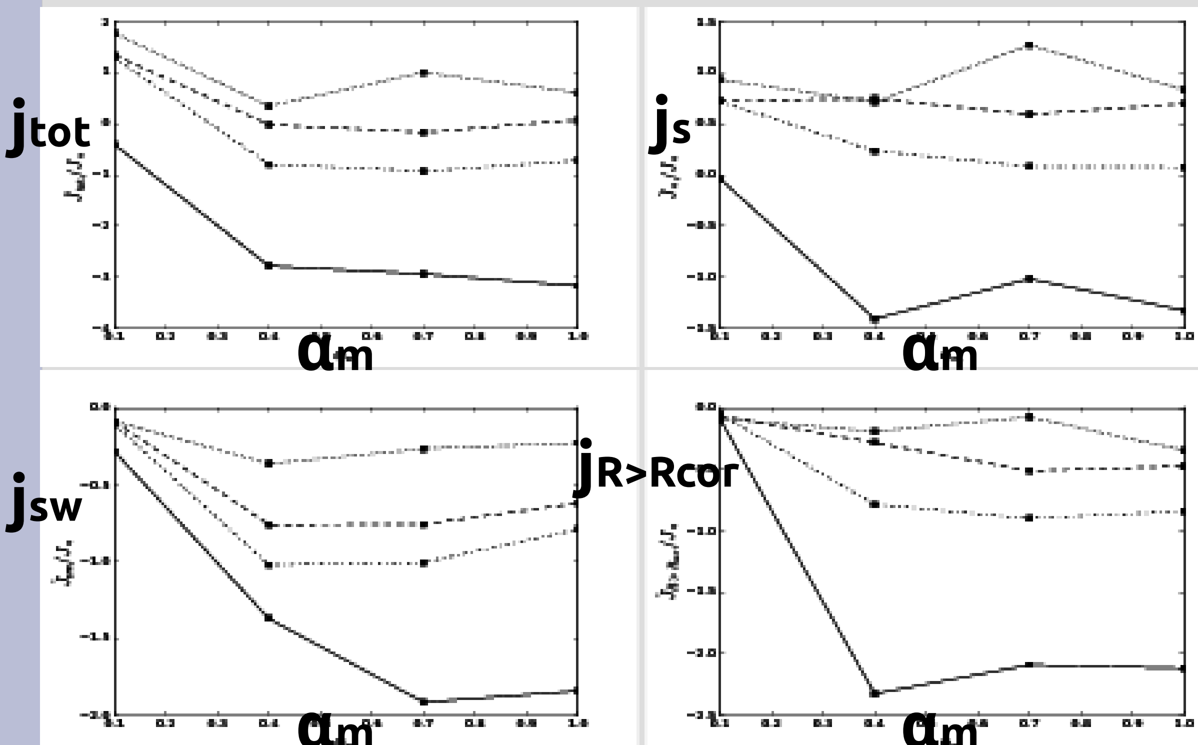
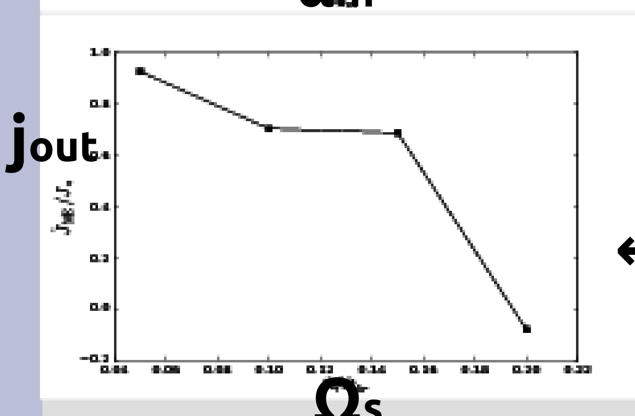
Trends in YSO solutions with B_{star}=0.5 kG-preliminary results



Shown is the average angular momentum flux change with resistivity (α_m) in various components of the system, normalized to the stellar angular momentum. Dotted, dashed, dot-dashed and solid lines represent fluxes in Ω_s=0.05, 0.1, 0.15 and 0.2 cases. We are interested in trends. Compared with observations, this will be used to improve the stellar models.

We are also working on the magnetic extension of the Kluźniak & Kita disk in the asymptotic approximation. Results from the "Atlas" will be used to validate the results.

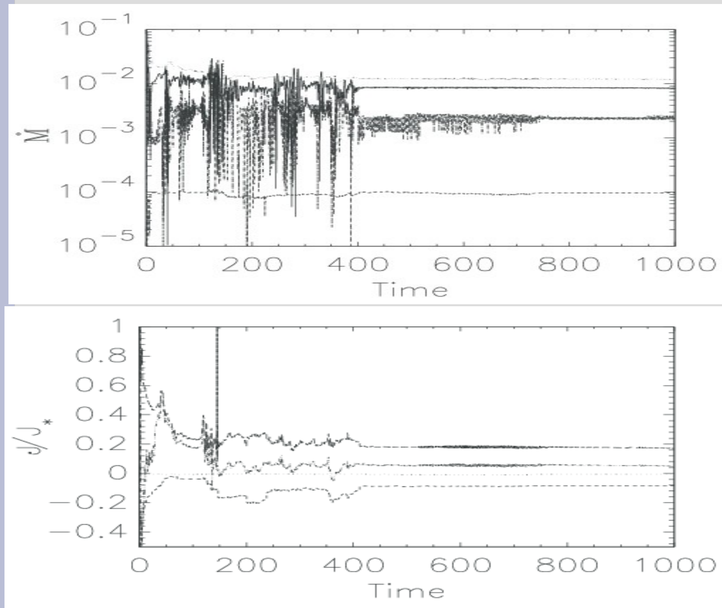


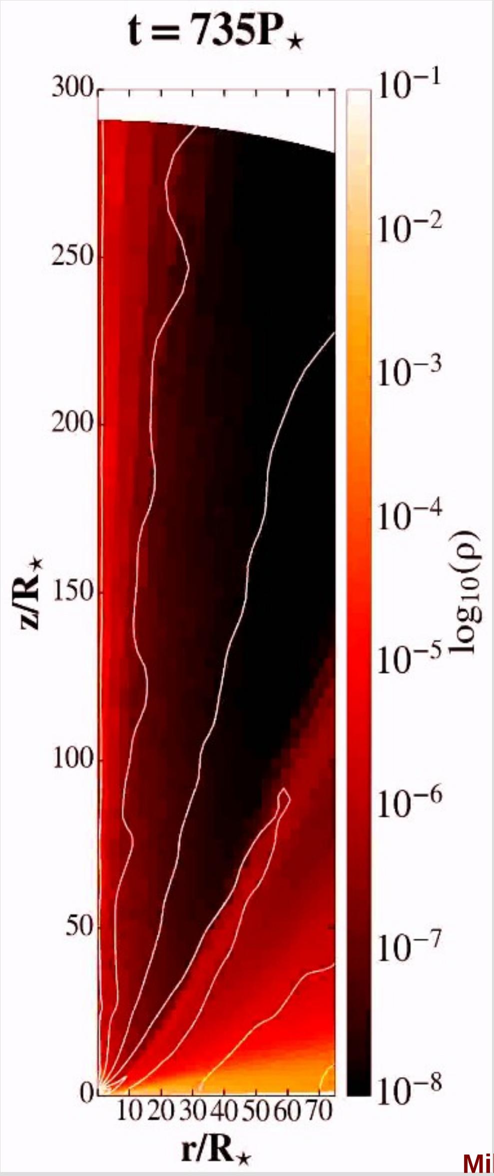
←-- Here is shown angular momentum flux change with Ω_s, in the case with conical outflow (with α_m=0.1).

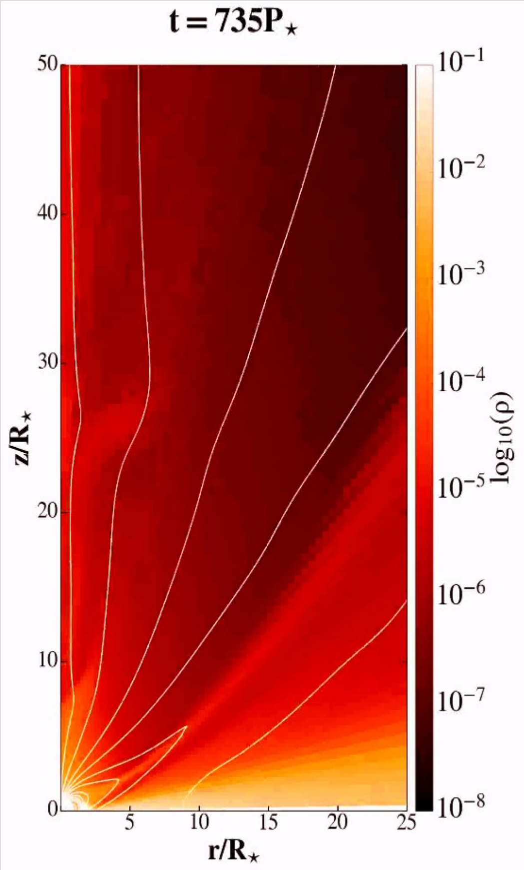
The jet launching

I also obtained a continuous launching of an axial jet from the star-disk magnetosphere.

The axial jet and the conical outflow are launched after the relaxation from the initial conditions. They are similar to the results in Romanova et al. (2009) and Zanni & Ferreira (2013).



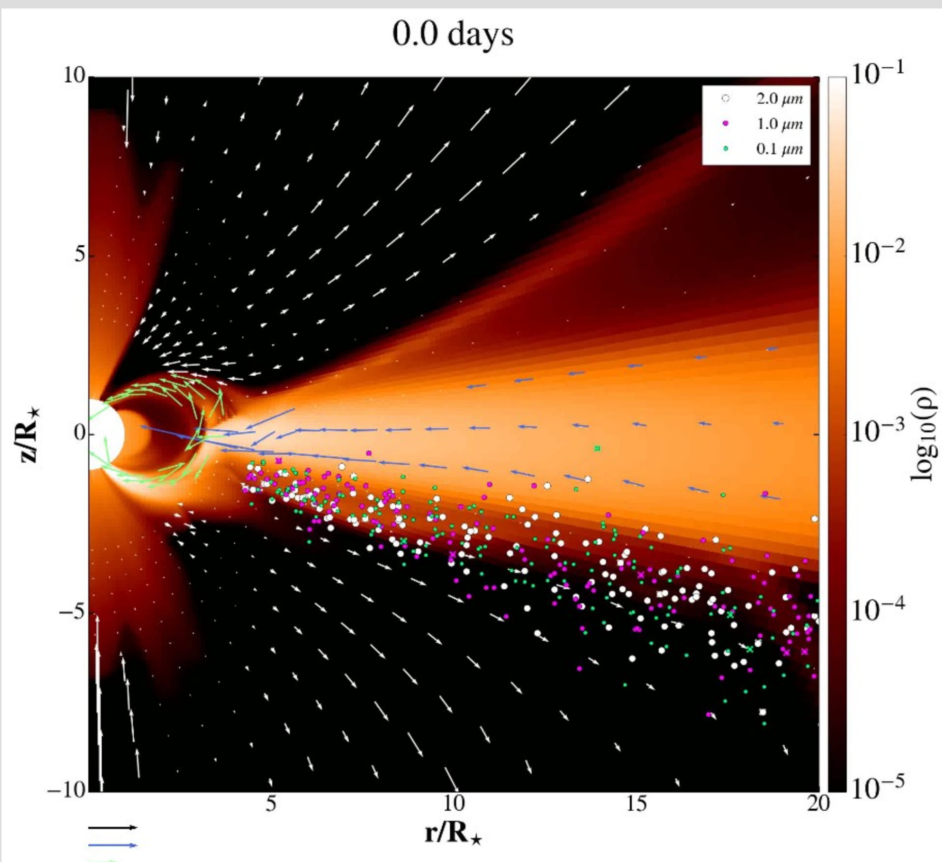


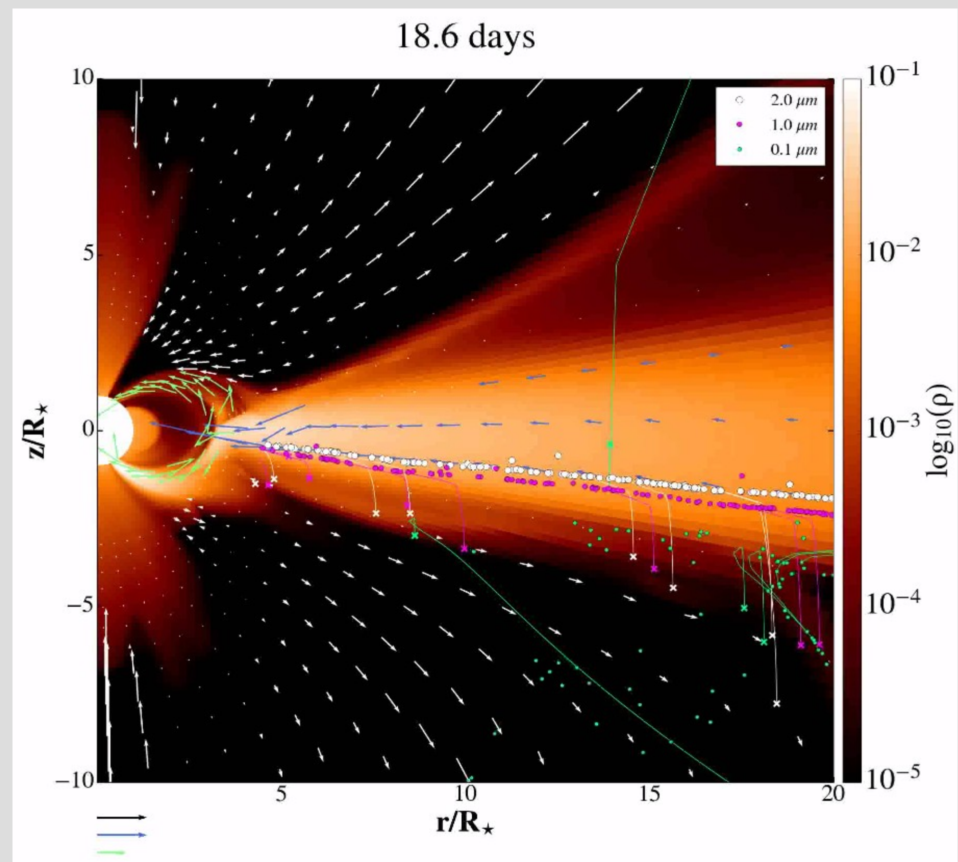


Zoom into the launching region.

Dusty disk in Young Stellar Objects

In a Summer Program project C. Turski wrote the Python script for post-processing of the quasi-stationary results in my solutions in full meridional plane. He added the dust particles and computed their movement in and above the disk as a background. The results will be used to improve the model of dust distribution in the disk-collaboration with D.Vinković.





Summary & Prospects

-"Atlas" of solutions in Young Stellar Objects case completed, analysis in progress

-Portion of parameter space with conical outflows indicated

-I obtained axial and conical jets in star-disk magnetospheric simulations with the stable accretion column – *further investigation.*

-In a post-processing of the results, we add the dust to the solutions, and observe its motion to study the dust distribution.