2017: Disc, Dust & Jets

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& CAMK Summer Program Students
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Outline

- Introduction
- “Atlas” of solutions in Young Stellar Objects case
- Connection to observations: 2D model for 3D light curve
- Star-disk simulations for Millisecond pulsars
- Summer student projects:
  -Learning HARM, relativistic MHD code (L.Dickson, S.Mondal)
  -Dusty Disk in Young Stellar Objects (C. Turski)
- Axial and conical jets in YSO and NS cases
- Summary & Prospects

Introduction

- Using the PLUTO code, I perform long-lasting quasi-stationary simulations of stellar accretions disks.
- With PLUTO we solve 2D axi-symmetric viscous & resistive MHD equations, with split field method and constrained transport for ensuring div B=0.

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

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

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

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

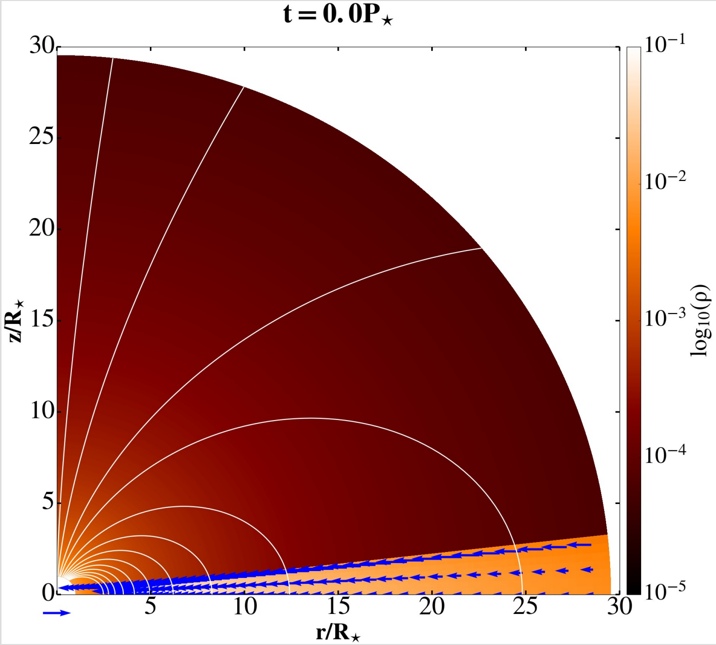
- We neglect Ohmic and viscous heating in the energy equation-we still include viscosity and resistivity in the equation of motion and in the induction equation.
- PLUTO is Newtonian code. I am currently learning to do also the relativistic simulations of the accretion disk, with codes HARM and COSMOS, to perform simulations in the relativistic regime, for the black hole accretion disk.

With 2 summer students, Lewis Dickson and Samaresh Mondal, we worked on setting the disk in HARM code. They learned to set and run the code on linux cluster. They also learned to visualize the results.

"Atlas" of solutions in Young Stellar Objects case

I completed the "atlas" of simulations of Young Stellar Objects with different magnetic field strenghts (0.25, 0.5, 0.75 and 1 kGauss) for the dipole stellar field. I performed 4x4x4=64 simulations and obtained quasi-stationary solutions with the realistic stellar rotation rates (2.3, 4.6, 6.9 and 9.2 days), with the resistivity coefficients of 0.1, 0.4, 0.7 and 1.0.

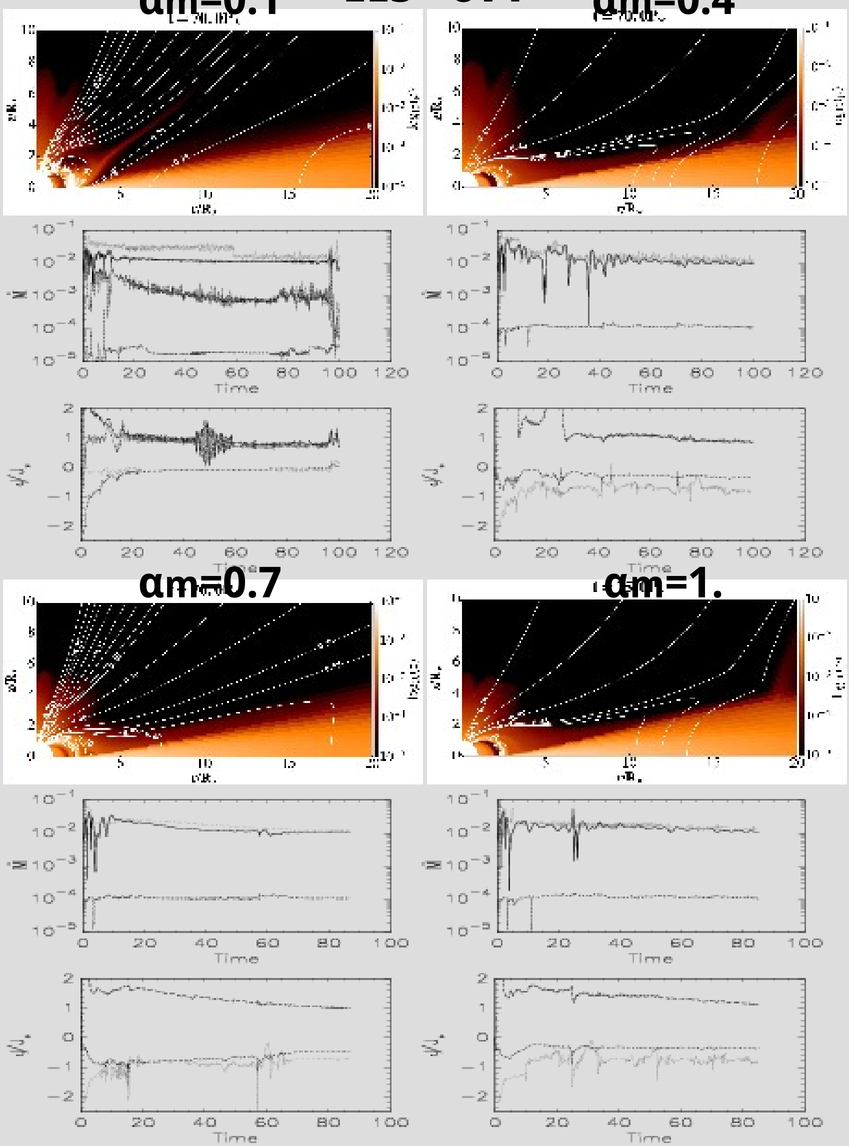
All the simulations start with the same initial and boundary conditions, a magnetic extension of Kluźniak & Kita disk:



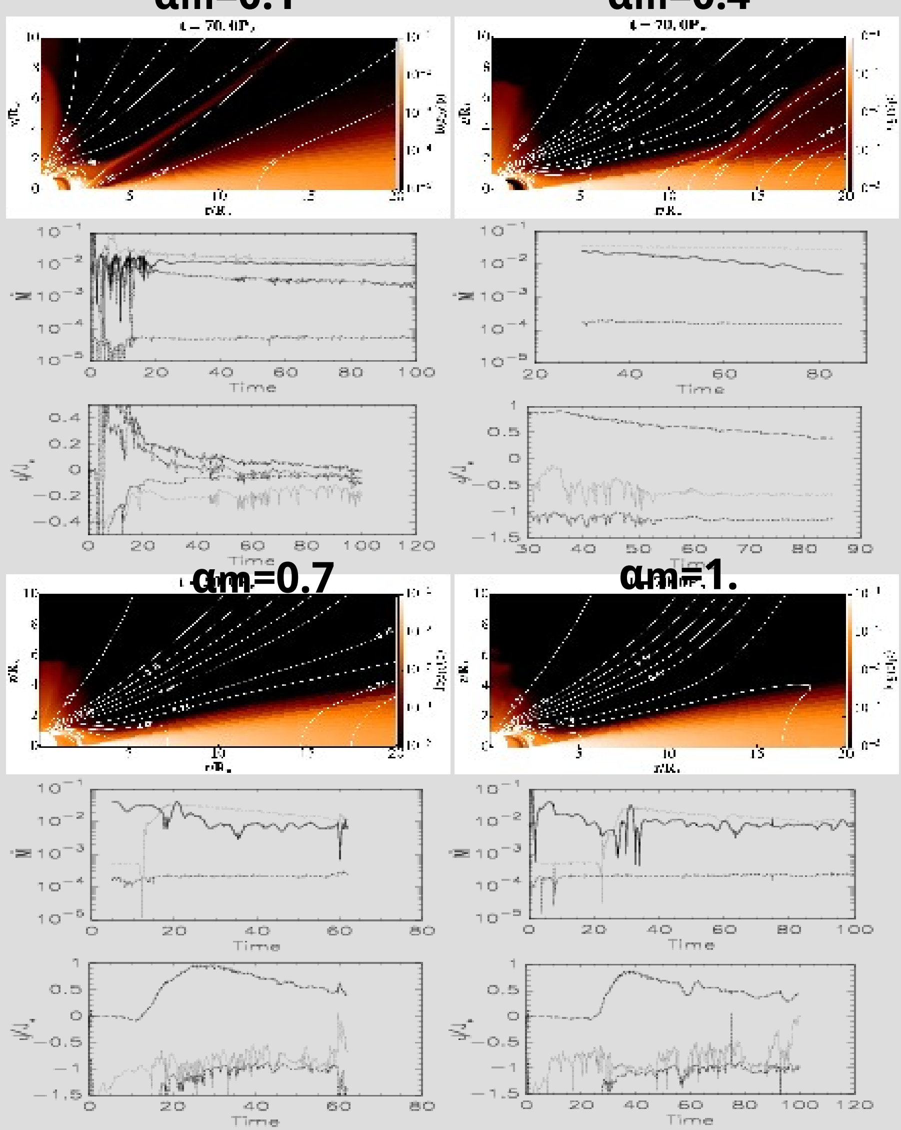
The results will be used for a study of trends in solutions for such systems. It is the first systematic study with magnetic star-disk numerical simulations where the disk quasi-stationarity is reached.

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

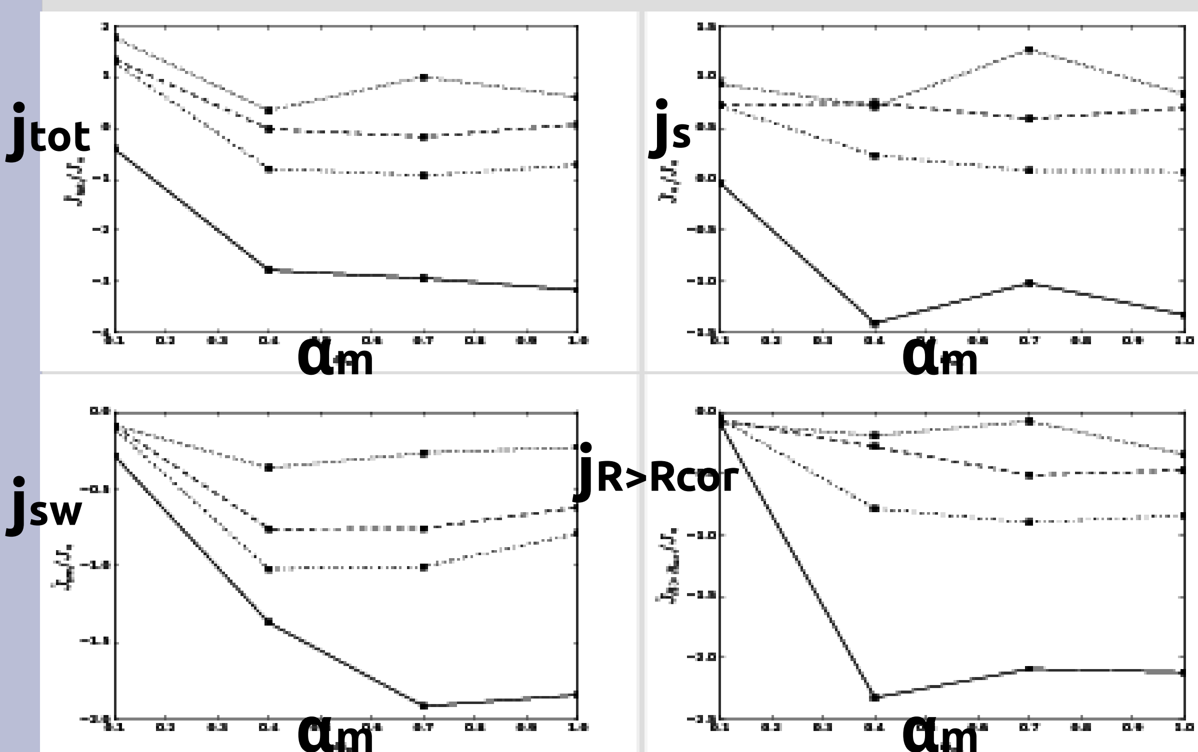
Ωs=0.1



Ωs=0.2

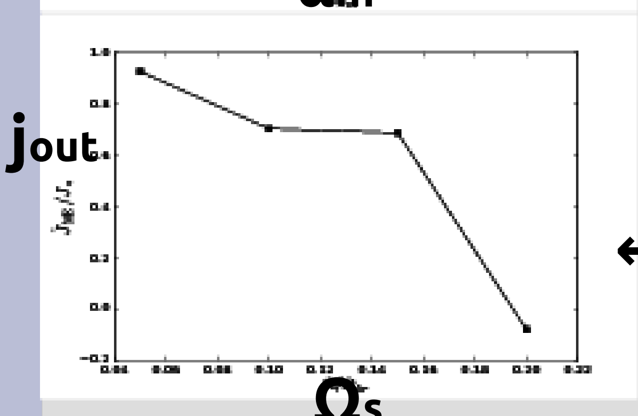


Trends in YSO solutions with B_{star}=0.5 kG



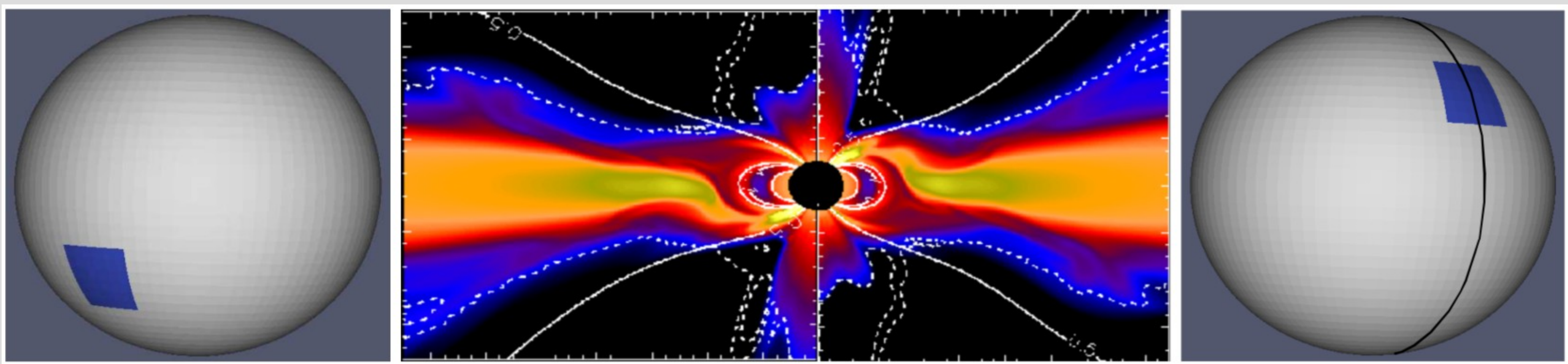
Shown is the average angular momentum flux change with resistivity (α_m) in various components of the system, normalized to the stellar angular momentum. Dotted, dashed, dot-dashed and solid lines represent fluxes in Ω_s=0.05, 0.1, 0.15 and 0.2 cases. We are interested in trends. Compared with observations,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

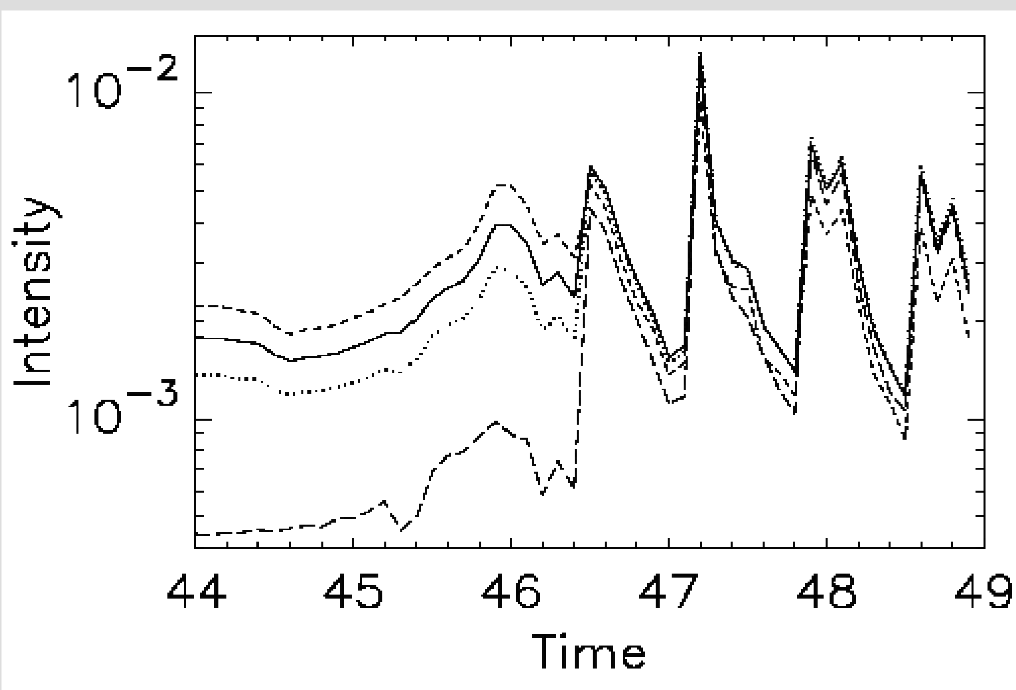
We are also working on the magnetic extension of the Kluźniak & Kita disk in the asymptotic approximation. Results presented here will be used to validate the results.



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

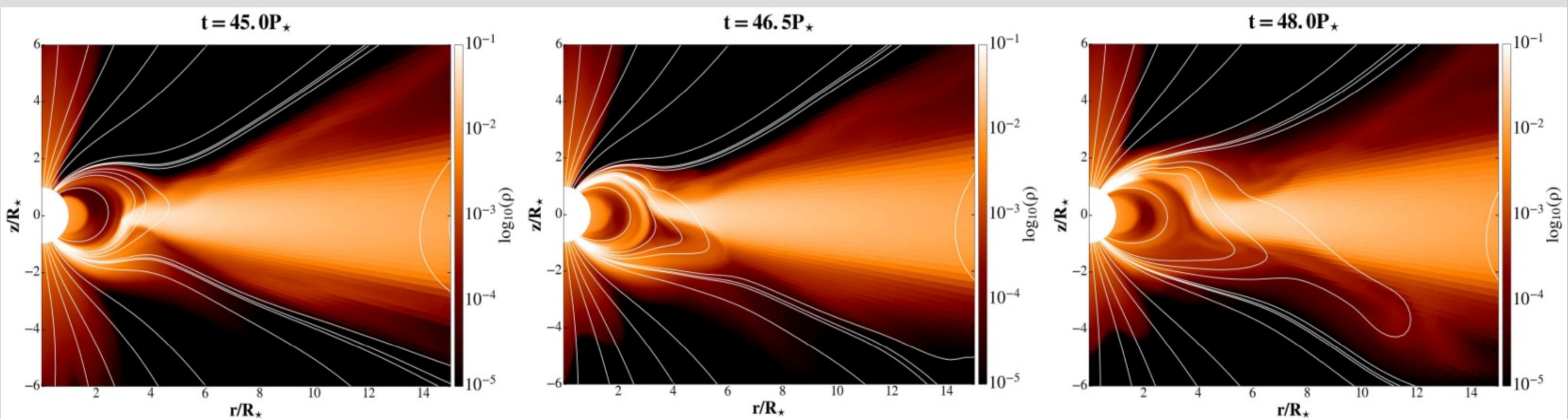
Connection to observations: 2D model for 3D light curve

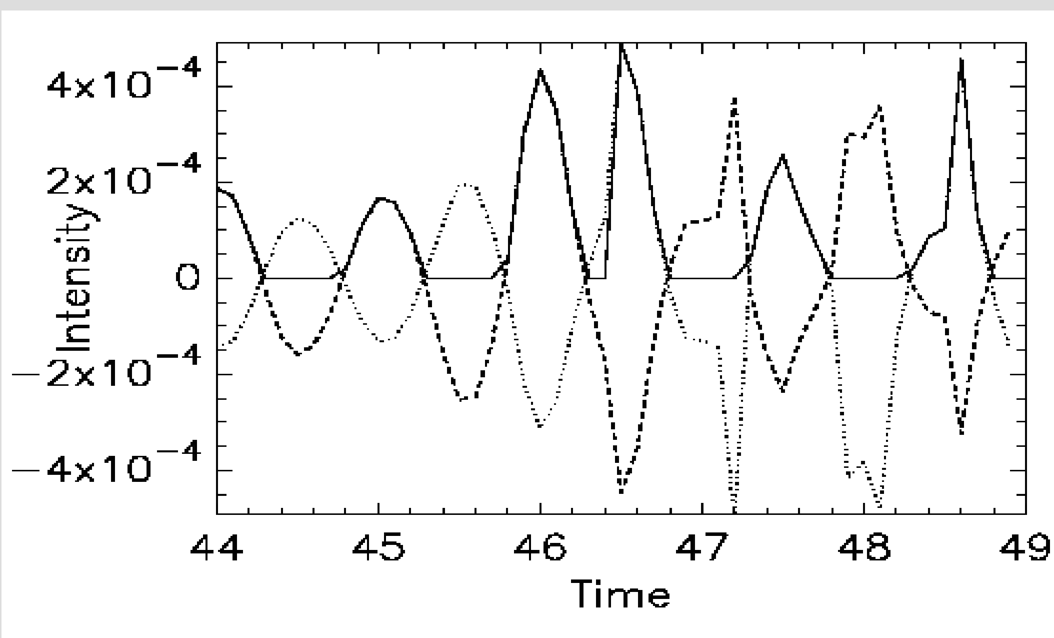




The emission integrated along the stellar rim one grid cell thick in the azimuthal direction. The solid, dotted, long-dashed and short-dashed lines represent the intensities for an observer positioned at a co-latitudinal angle θ =15, 30, 60 and 165 degrees, respectively.

Connection to observations: 2D model for 3D light curve





The dotted and dashed lines show the intensity for modeled hot spots as seen from the co-latitude angles of θ =15 and θ =165 degrees. Intensity is negative when the spot is not visible from a given position. In solid line is shown the total intensity for an observer with θ =165. Switching of the accretion column from the southern to northern hemisphere produces a phase shift in the observed intensity peak as the star rotates.

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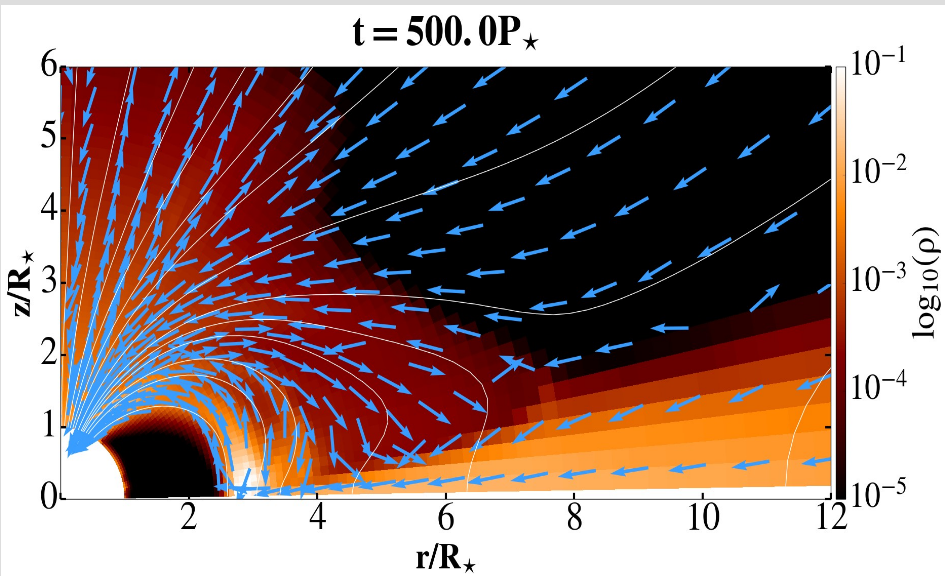
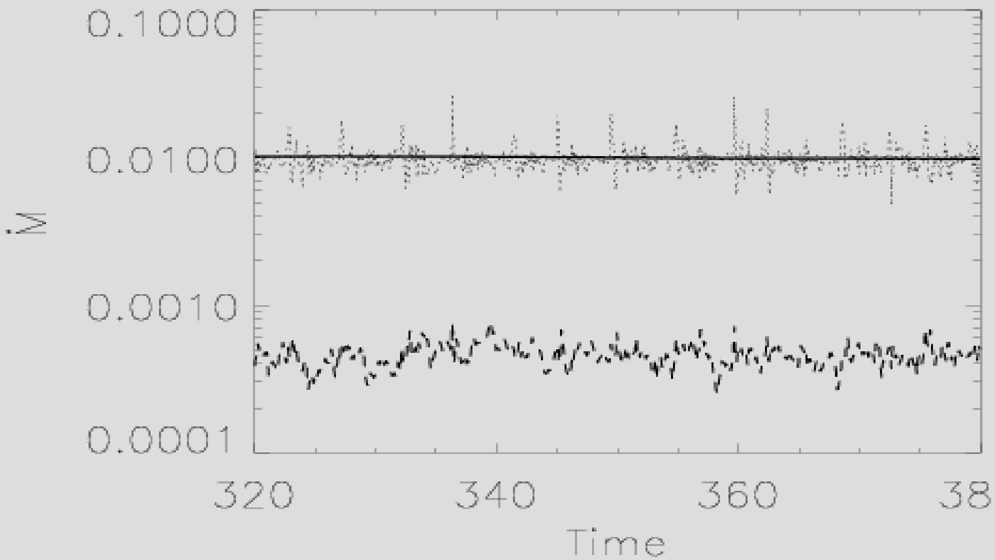
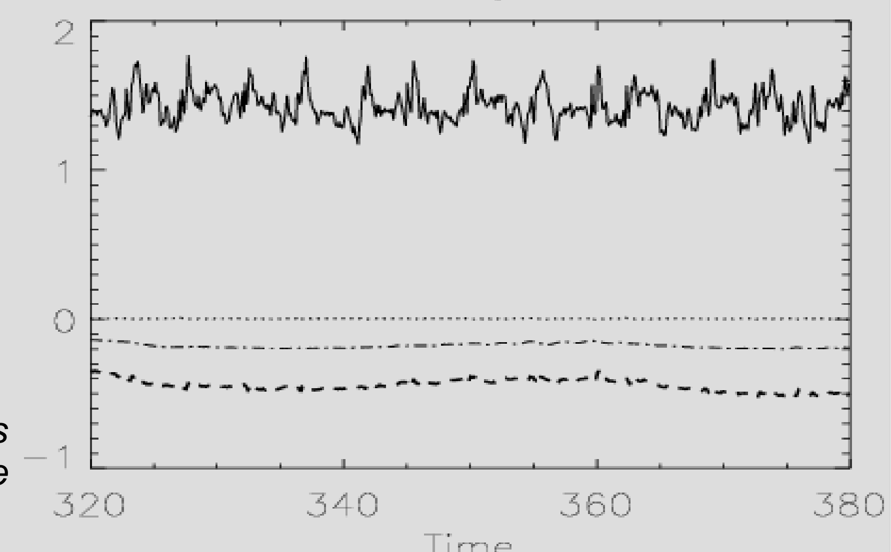
Star-disk simulations of millisecond pulsars



Zoom into the central part of the system after 500 pulsar rotations to visualize the accretion column and the magnetic field lines connected to the disk beyond the corotation radius Rcor=4.65 Rs.

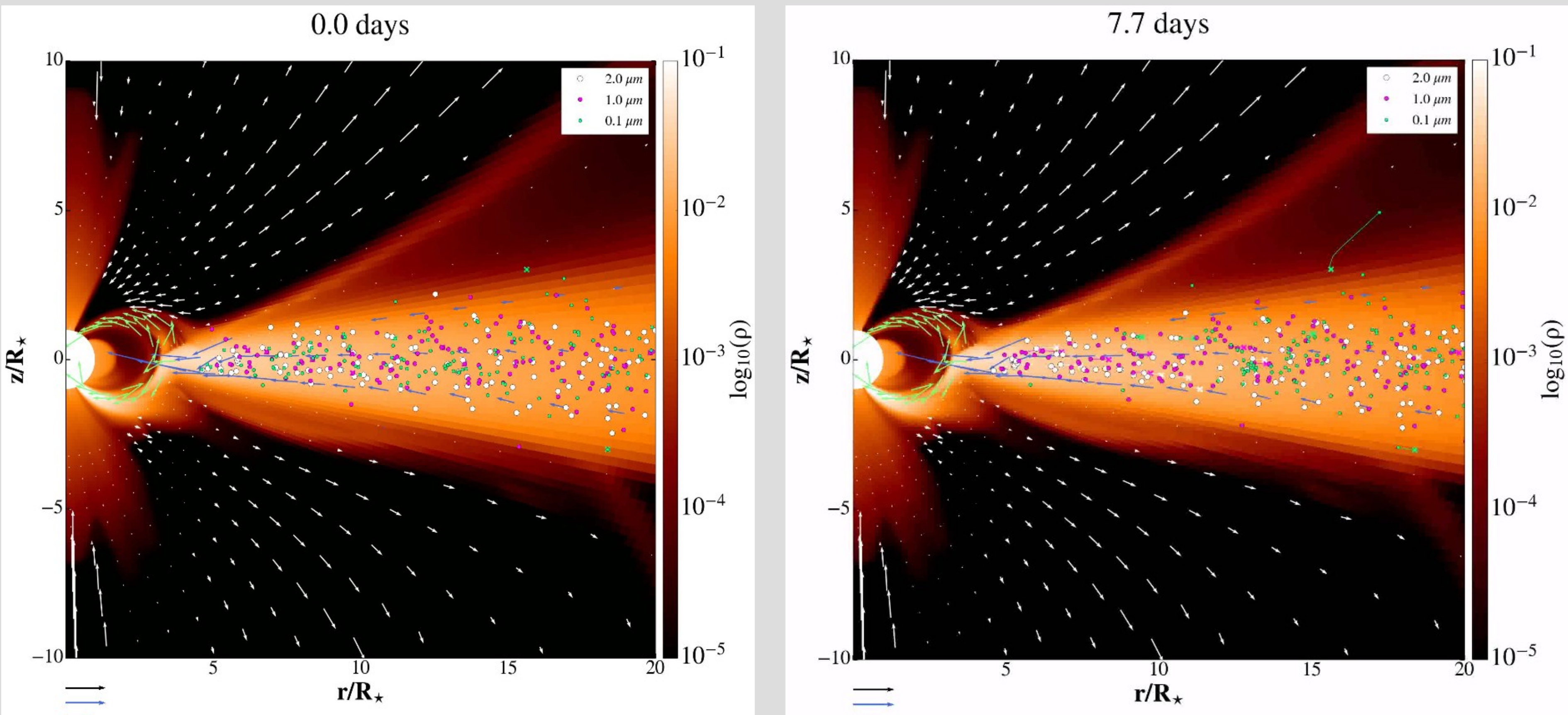


Right top panel: Mass flux in time. Dotted and solid lines show the flux onto the star and through the disk at R=12. Dashed line shows the mass flux in the stellar wind. Right bottom panel: Angular momentum flux in time. Dotted and dot-dashed lines show the negligible kinetic flux and the stellar wind flux. Solid and dashed lines show the flux from the matter falling onto the star from the disk inside the Rcor and beyond Rcor. Negative flux slows down the star.



Dusty disk in Young Stellar Objects

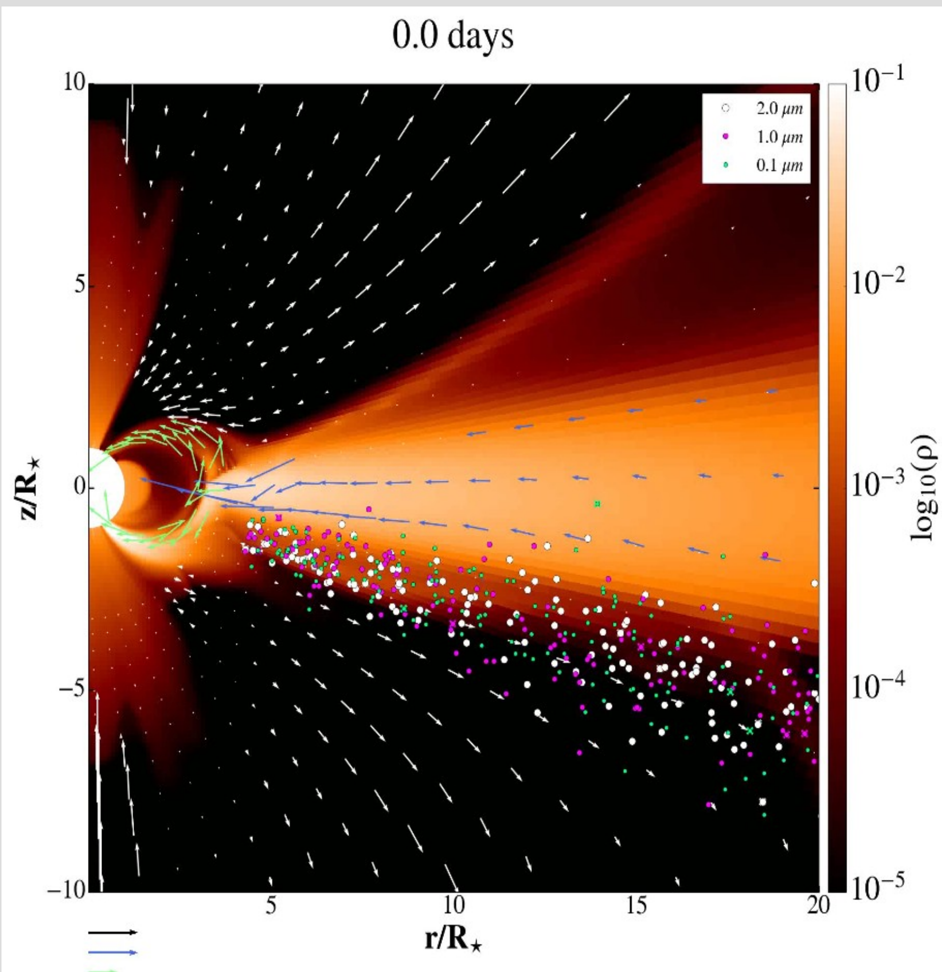
In a Summer Program project Cezary Turski wrote the Python script for post-processing of the quasi-stationary results in my solutions. He added the dust particles and computed their movement in and above the disk as a background. The results will be used to improve the model of dust distribution in the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

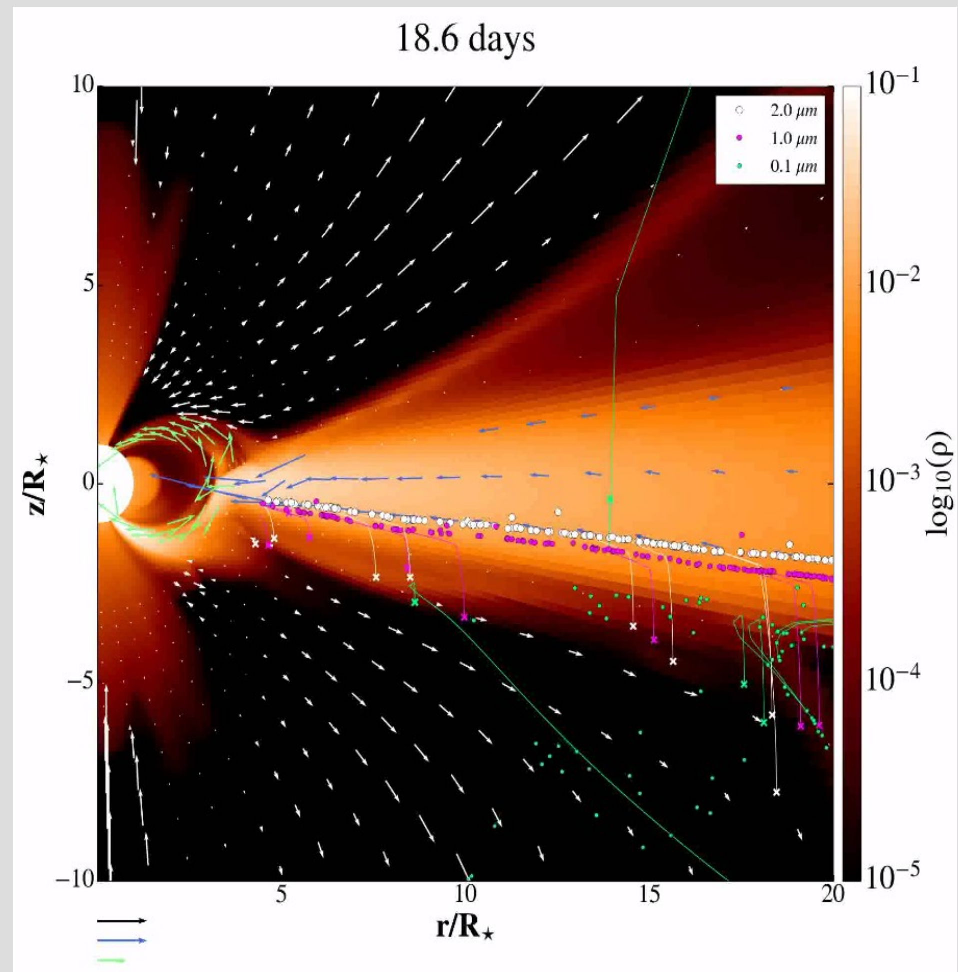


Random distribution of dust particles in the disk.

Dusty disk in Young Stellar Objects

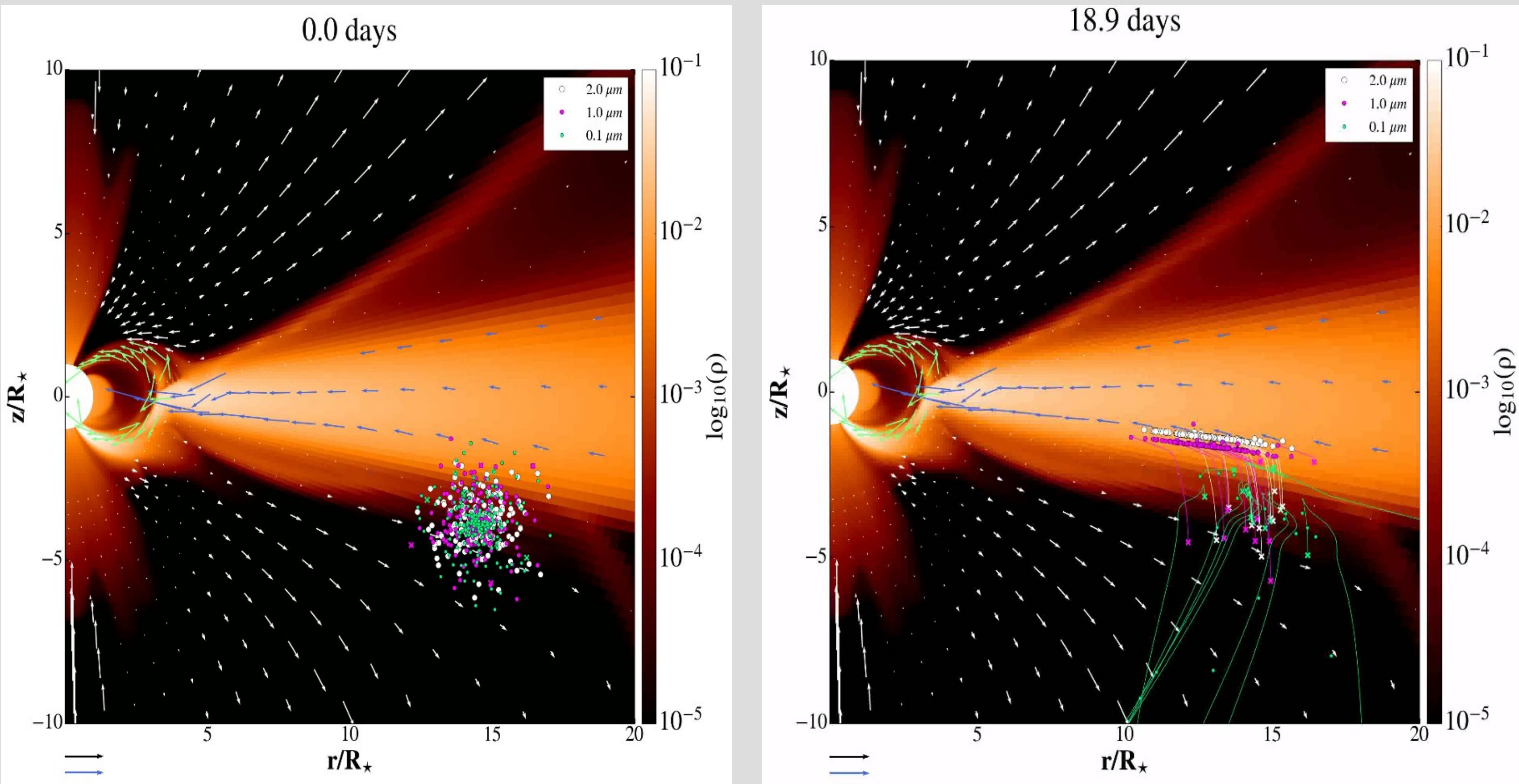
We can investigate also the results of the impact of the disk with another material which does not influence the disk.





Dusty disk in Young Stellar Objects

A case of an impact with a more compact distribution of particles.

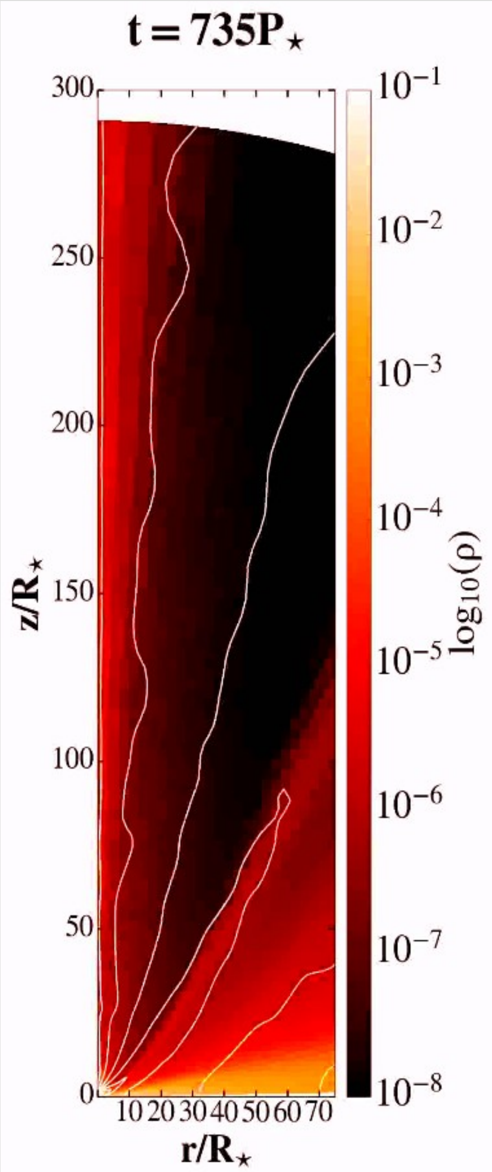


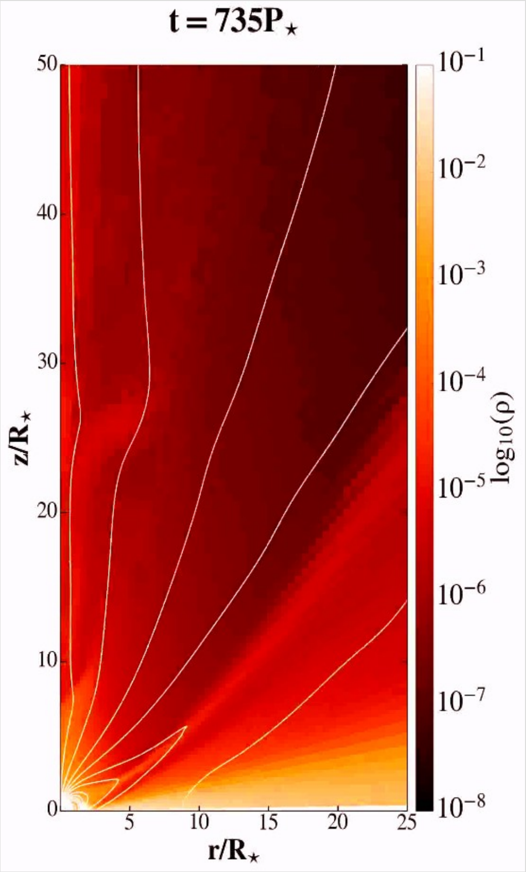
The axial jet launching

After the 15 years of work on numerical simulations of accretion disk, I obtained a stable launching of axial jet from the star-disk magnetosphere.

The axial jet and the conical outflow are obtained. They are similar to the result in Romanova et al. (2009).

This will be investigated further.





Zoom into the launching region.

Summary & Prospects

-I made an “Atlas” of solutions in Young Stellar Objects case.

-2D model for 3D light curve developed, to help connecting models and observations – *paper to be submitted.*

-I performed long-lasting star-disk simulations for millisecond pulsars -*published in conference proceedings, paper in draft.*

-Summer student projects:
    -Learning HARM, relativistic MHD code (L.Dickson, S.Mondal).
    -Dusty Disk in Young Stellar Objects (C. Turski) - *paper in draft.*

-I finally obtained axial (and conical) jets in YSO and NS cases – *further investigation.*