Resistive simulations of magnetospheric interactions

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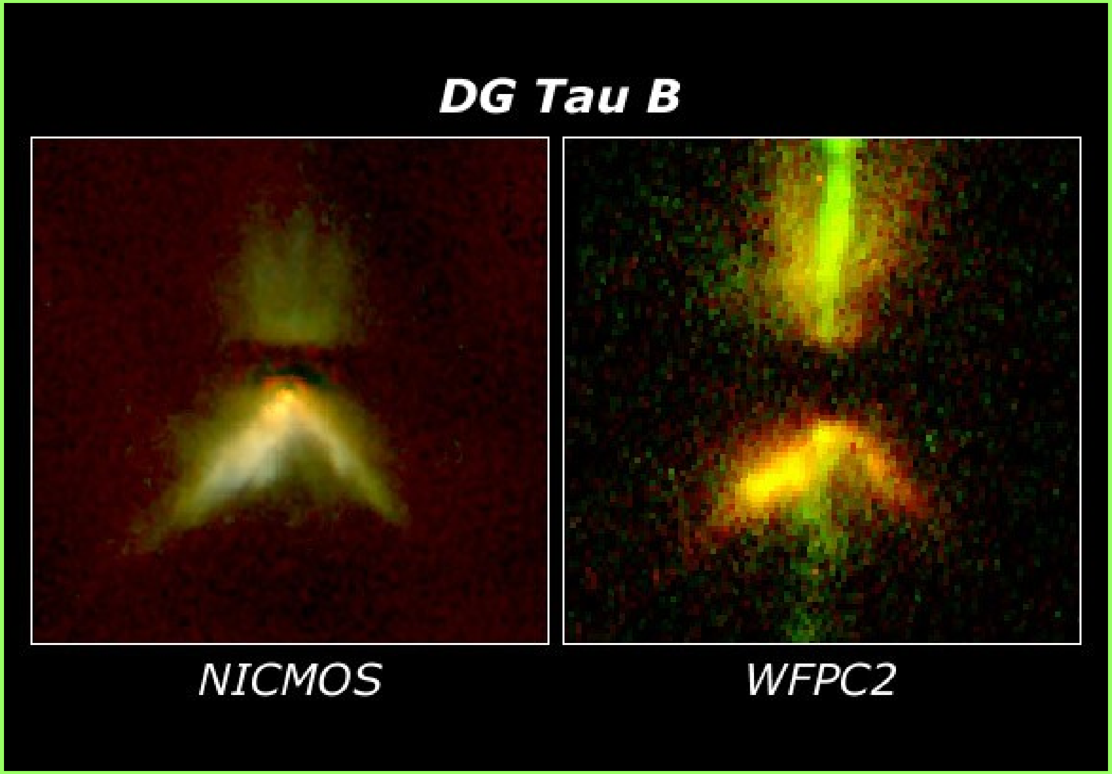
Outline

- Introduction
- Magnetospheric interactions
- Initial and boundary conditions
- Results for magnetospheric interactions
- Full 3D simulations setup
- Summary & Prospects

Young stellar objects



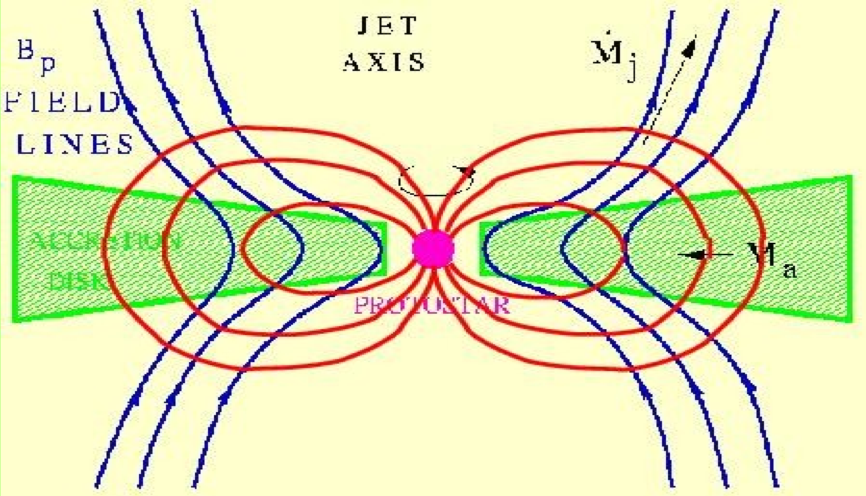
Comparison of the infrared NICMOS image of DG Tau B to the visible-light Wide Field and Planetary Camera 2 (WFPC2) image of the same object. WFPC2 highlights the jet emerging from the system, while NICMOS penetrates some of the dust near the star to more clearly outline the 50 billion-mile-long dust lane (the horizontal dark band, which indicates the presence of a large disk forming around the infant star). The young star itself appears as the bright red spot at the corner of the V-shaped nebula.

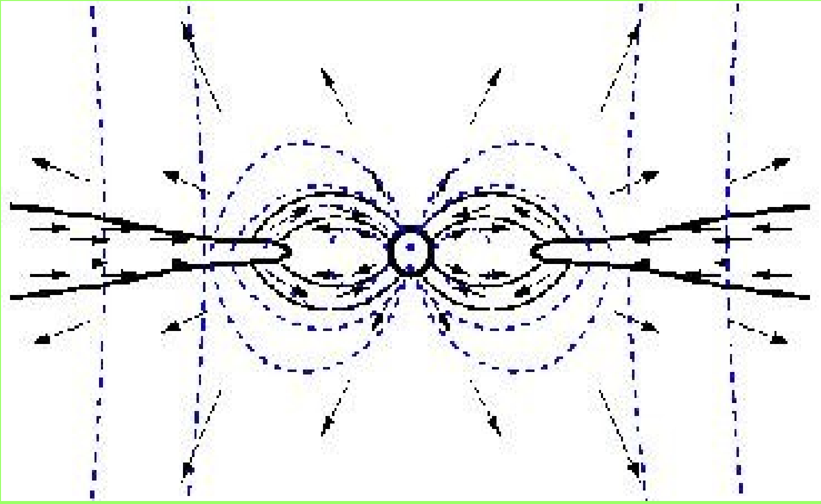
Introduction

- Protostellar outflows, accretion disk and excess of angular momentum of a star
- Numerical simulations: Disk as a boundary-axisymmetric 3D simulations=2.5D
- Disk included: 2.5D, next step is to do full 3D
- Stability of 2.5D results in 3D?

Simulations with dipole+open field

- Disk included in computational box in our simulations
- Nearest vicinity of the star
- **Interaction** of stellar magnetosphere & disk-new paradigm (previously: stellar wind; disk wind)





ZEUS-347 & ZEUS-MP1,2

- Time-dependent **resistive** MHD simulations
- Magnetic diffusivity included in induction and energy equations

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

$$\rho\left[\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\,\mathbf{u}\right] + \nabla p - \rho\nabla\left(\frac{GM}{\sqrt{r^2+z^2}}\right) - \frac{\mathbf{j}\times\mathbf{B}}{c} = 0$$

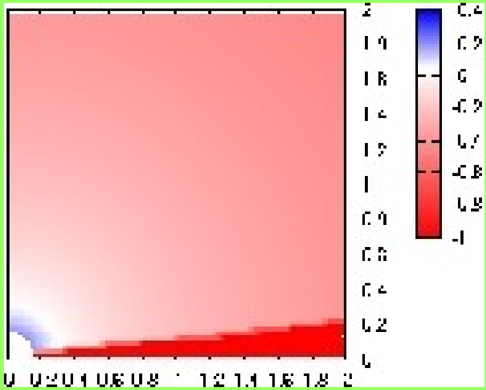
$$\frac{\partial \mathbf{B}}{\partial t} - \nabla\times\left(\mathbf{u}\times\mathbf{B} - \frac{c\mathbf{j}}{\sigma}\right) = 0$$

$$\rho\left[\frac{\partial e}{\partial t} + (\mathbf{u}\cdot\nabla)\,e\right] + p(\nabla\cdot\mathbf{u}) - \frac{\mathbf{j}^2}{\sigma} = \mathbf{0}$$

$$\nabla\cdot\mathbf{B} = \mathbf{0}$$

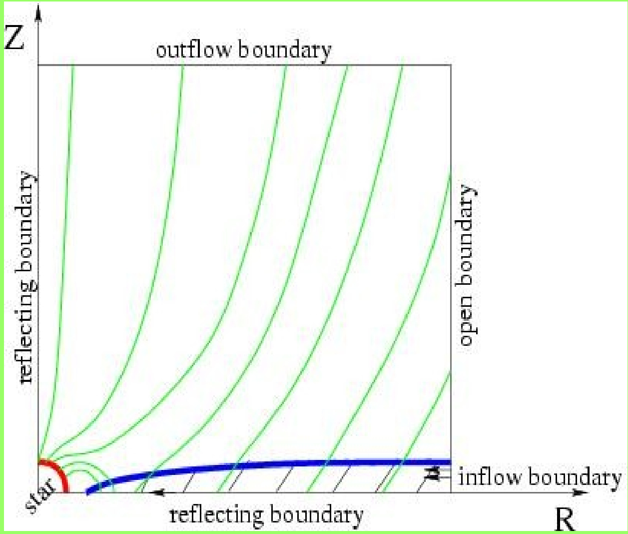
$$\frac{4\pi}{c}\mathbf{j} = \nabla\times\mathbf{B}$$

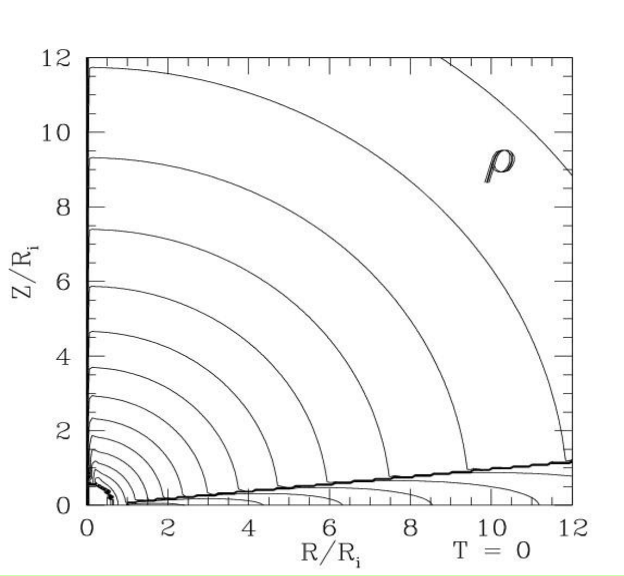
$$\frac{\partial \mathbf{B}}{\partial t} = \nabla\times(\mathbf{u}\times\mathbf{B}) + \eta\nabla^2\mathbf{B}, \quad \eta = \frac{c^2}{4\pi\sigma}$$



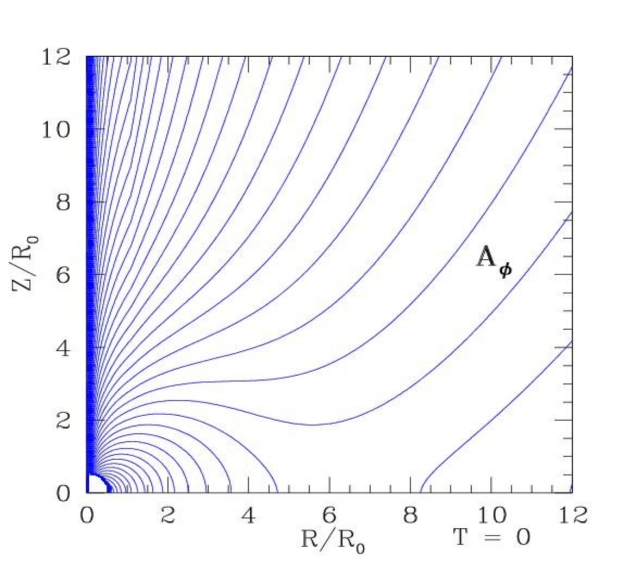
Initial magnetic diffusivity

Boundary & initial conditions

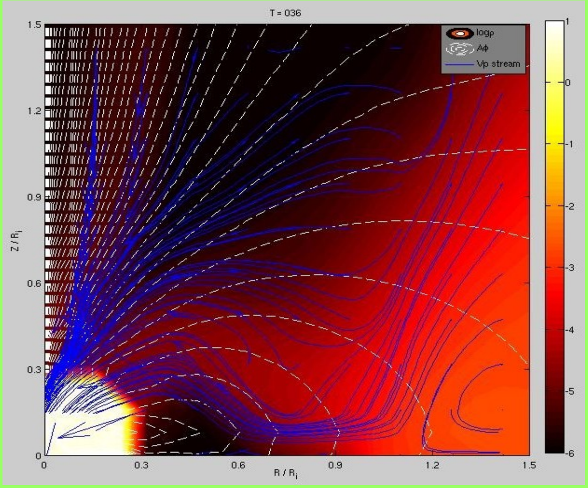




- Hydrostatic co-rotating corona above the disk, both resistive, in hydrostatic and magnetic forces balance
- Star as a boundary, in corrotation with disk at radius Rcorr
- Magnetic field as stellar dipole+large scale open field of the disk

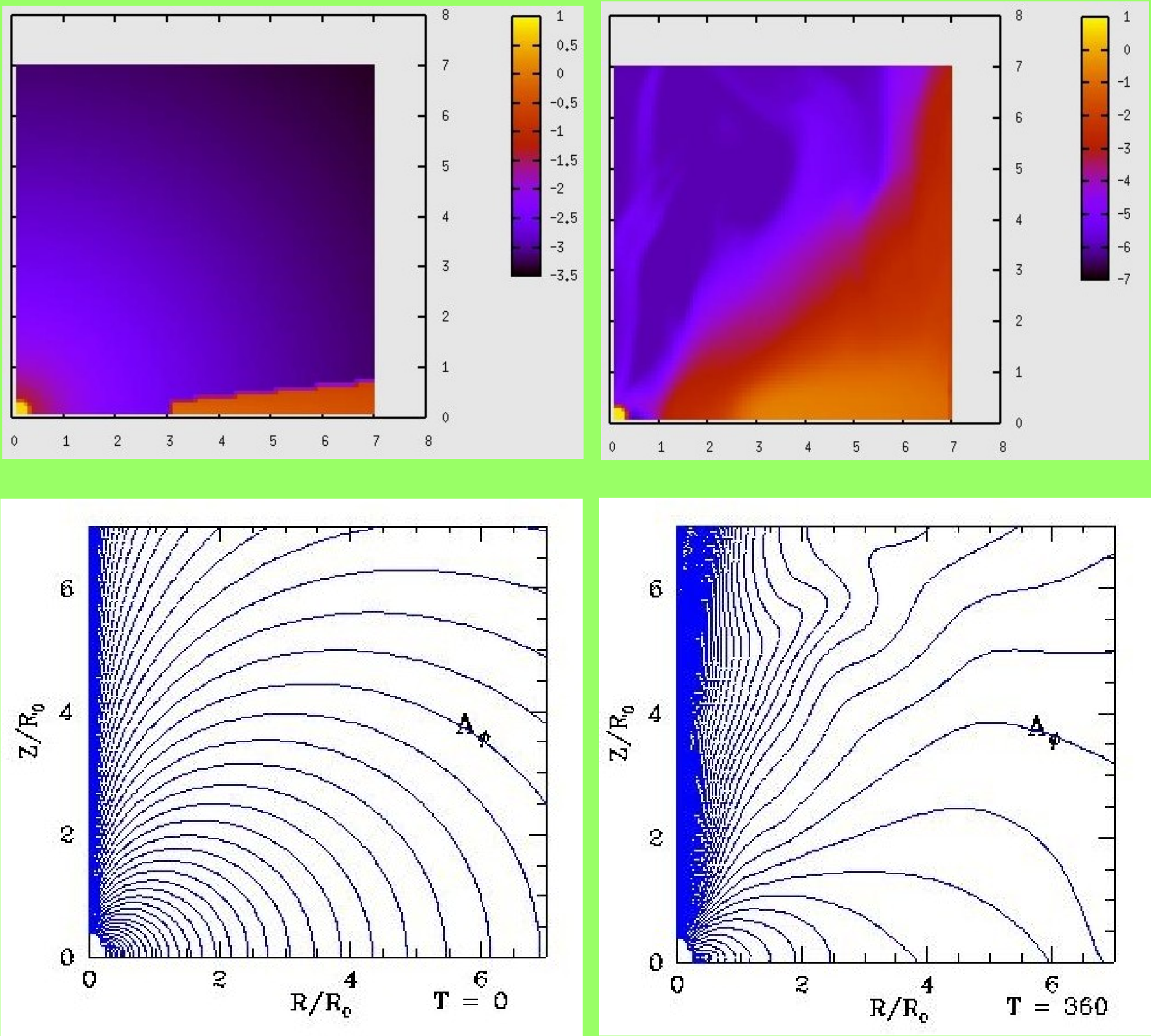


Magnetospheric accretion mechanism simulations



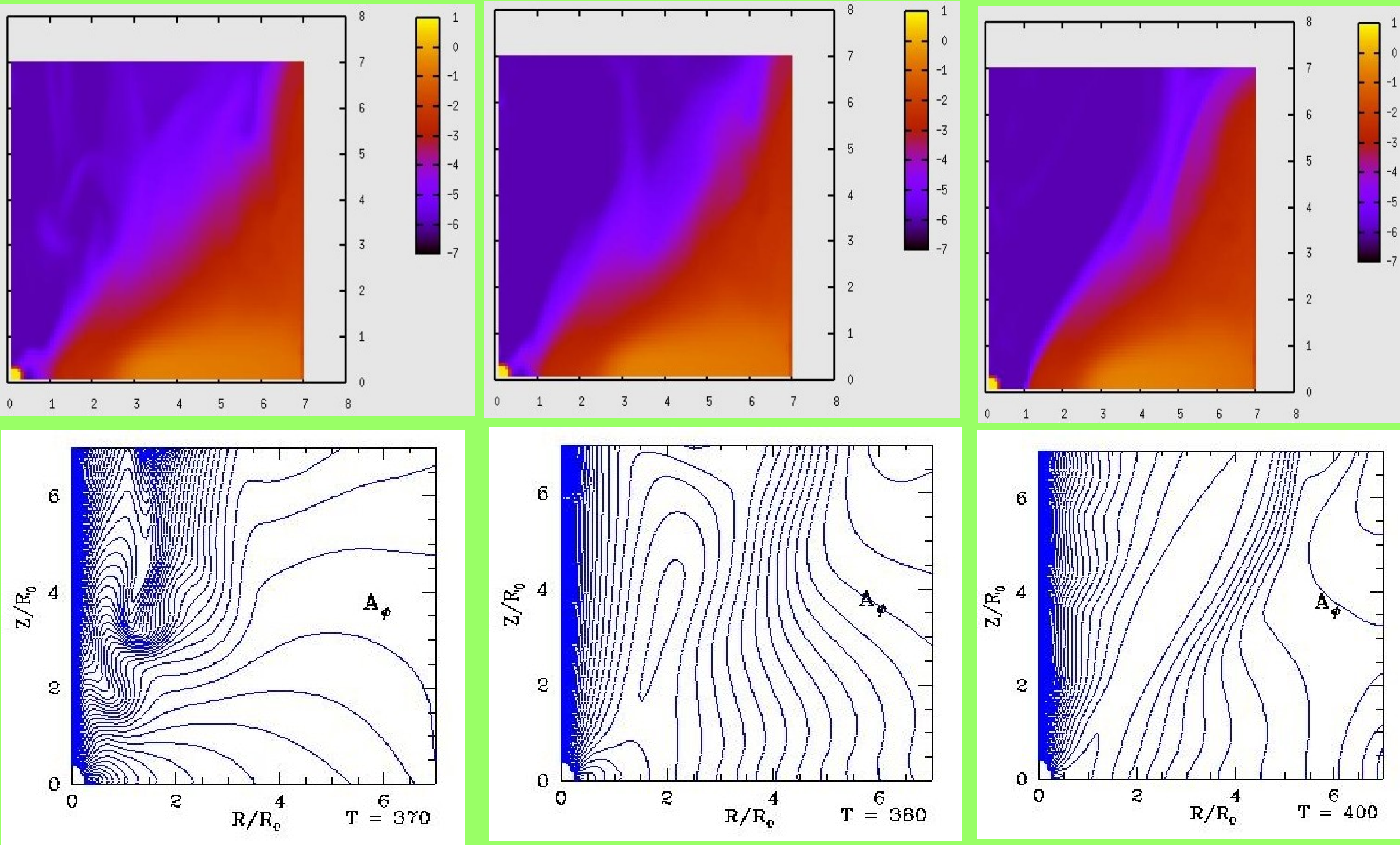
Zoom into the T=360 simulation

- Star+disk, disk included, star as a boundary condition
- Pure stellar dipole magnetic field ~10 Gauss
- With lower diffusivity- reconnection does not occur- no funnel onto the star form for less than few 100 Gauss stellar field.
- We seek fot the **robust** results, not fine-tuned.



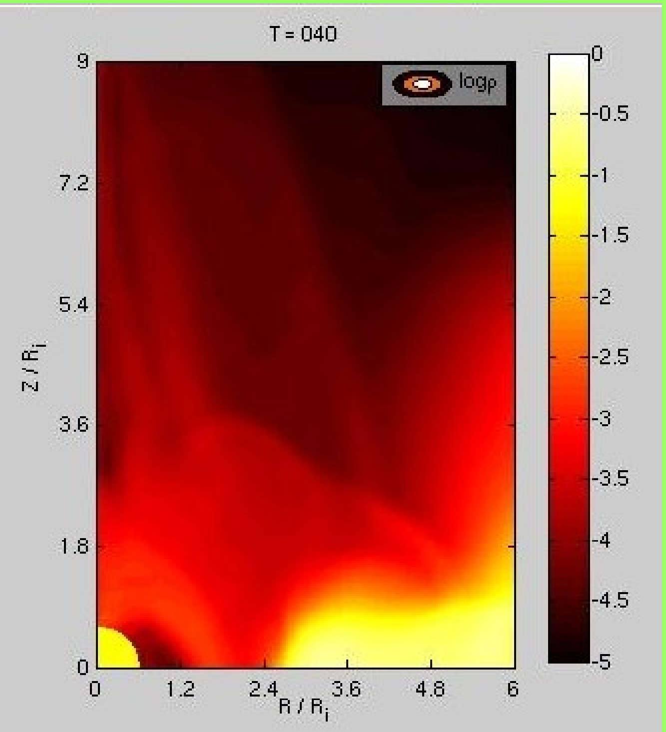
Density (top) and magnetic field lines (bottom) for initial and evolved state when R_corr=R_in.

Magnetospheric accretion mechanism simulations-robust results



Further evolution, showing reconnection and re-shaping of the field. Without mag. diffusivity reconnection does not occur and simulations fail.

- Cemeljic, Shang & Chiang, 2008, in preparation



Our results in 2.5D

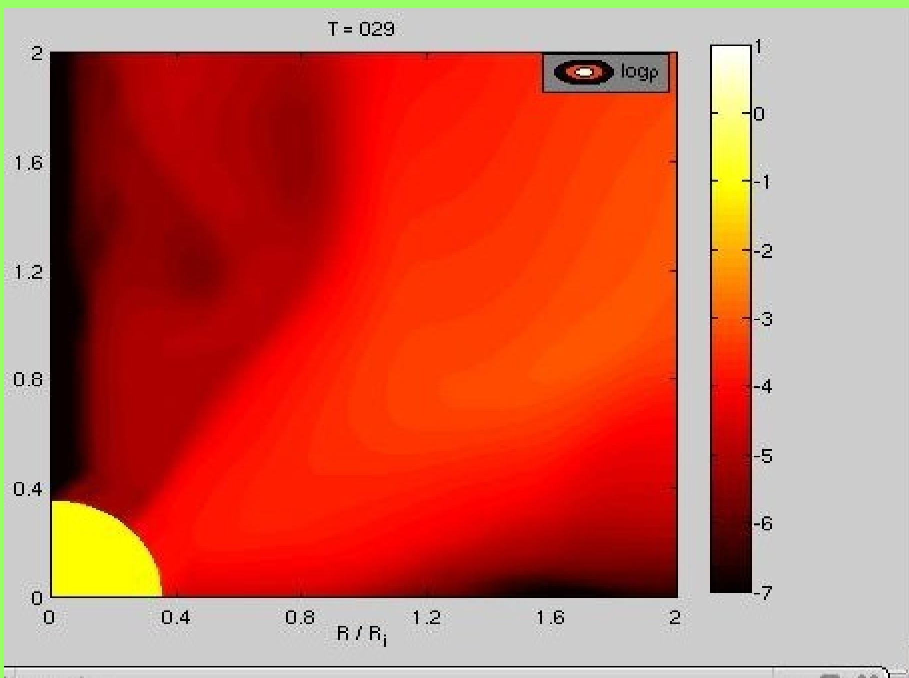
Animation of results for different times.

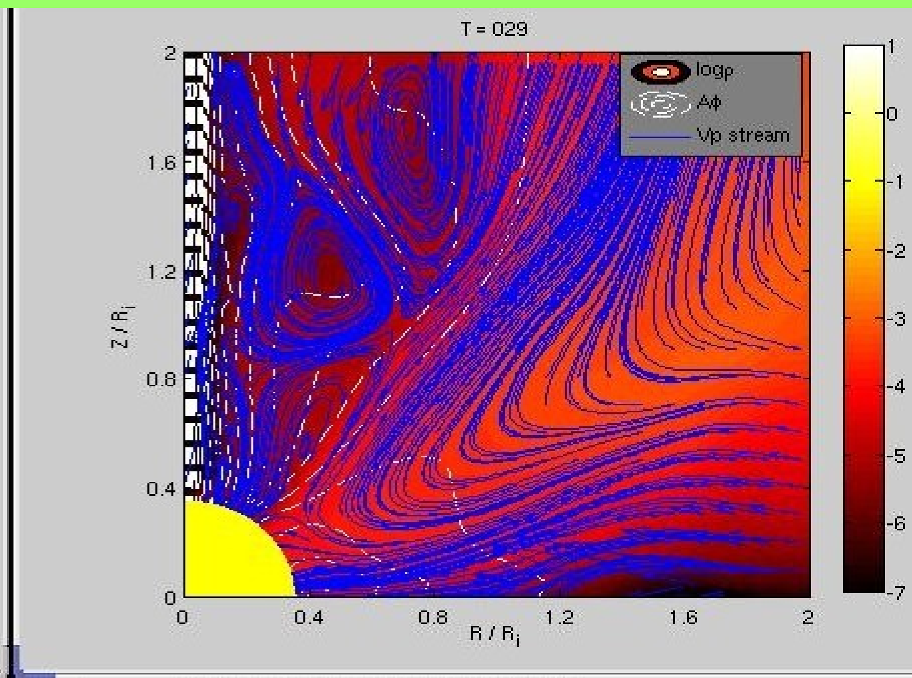
-**transient** funnels (accretion columns) of matter infalling onto the star-for larger magnetic fields

-results dependent on strength of magnetic field

-we obtain outflows of low mass flow rate, but these are needed to enable more massive outflows at larger heights above the disk and larger radii

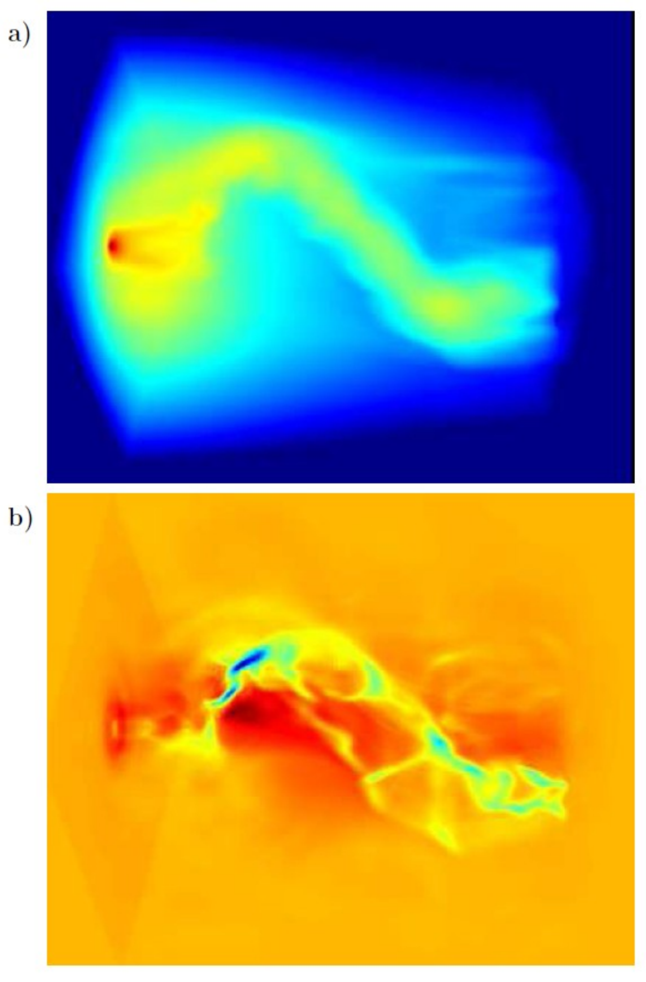
Zoom closer to star in one of solutions





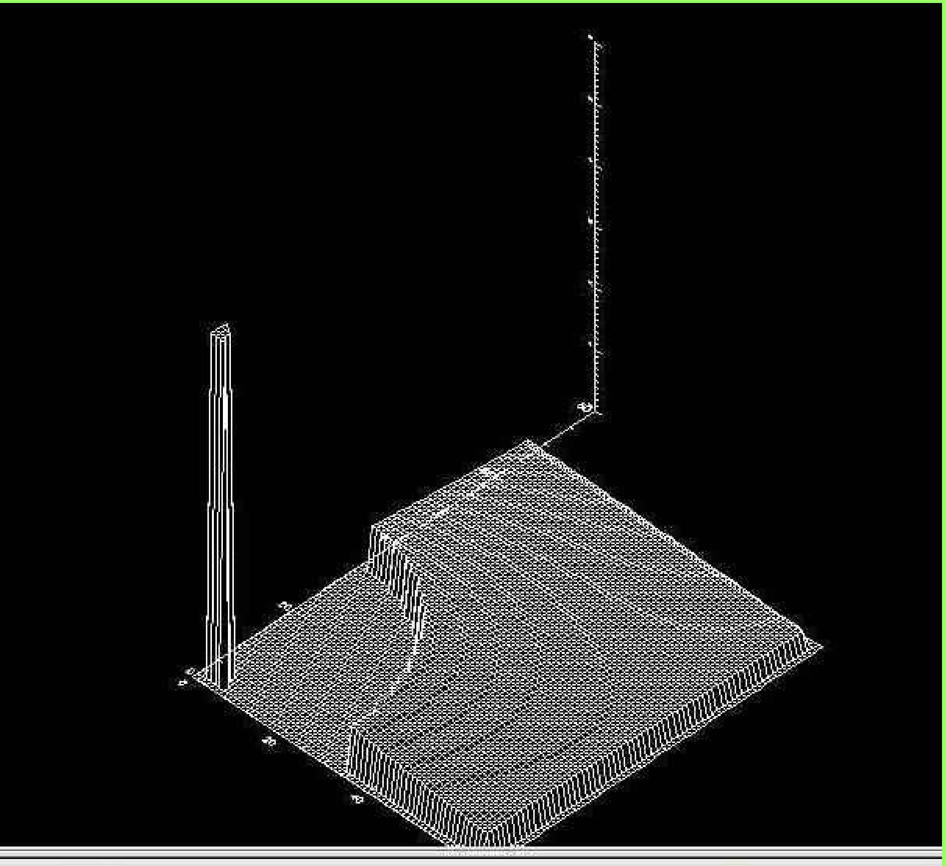
Simulations in 3D

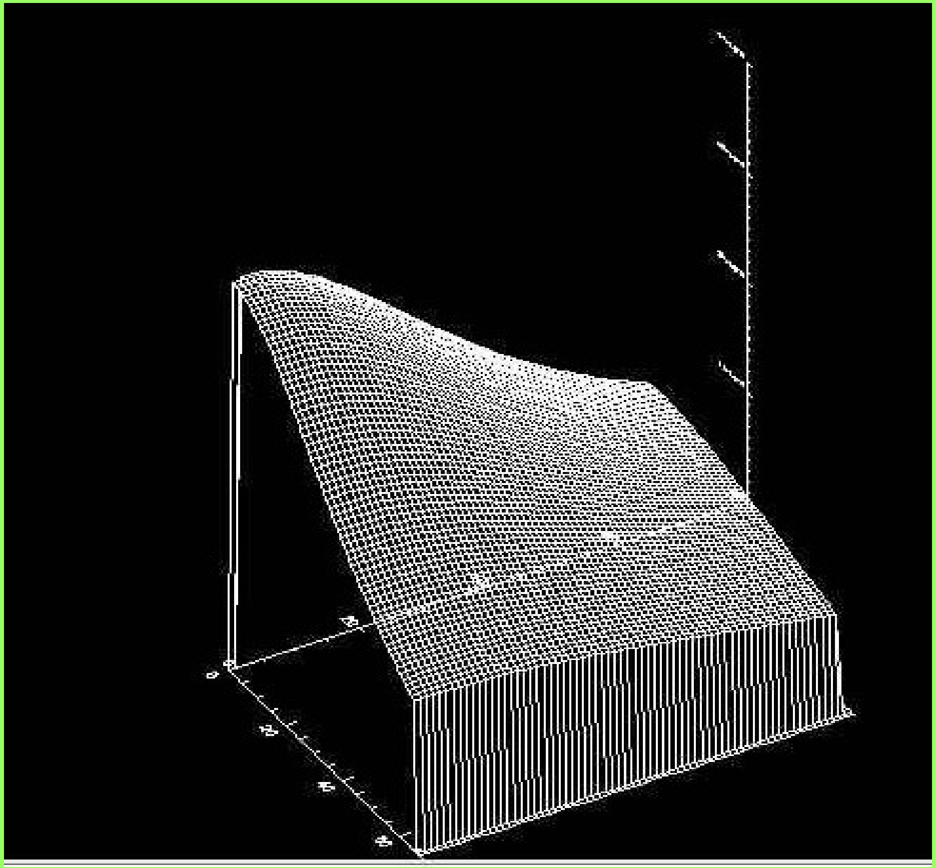
Ouyed, Clarke & Pudritz (2003)



- Disk as a boundary condition only
- Corkscrew or wobbling solutions found, not destroyed by non-axisymmetric (m=1) modes
- Self-regulatory mechanism found, maintaining the flow sub-Alfvenic=more stable

Our setup in 3D – 1st step (extension)



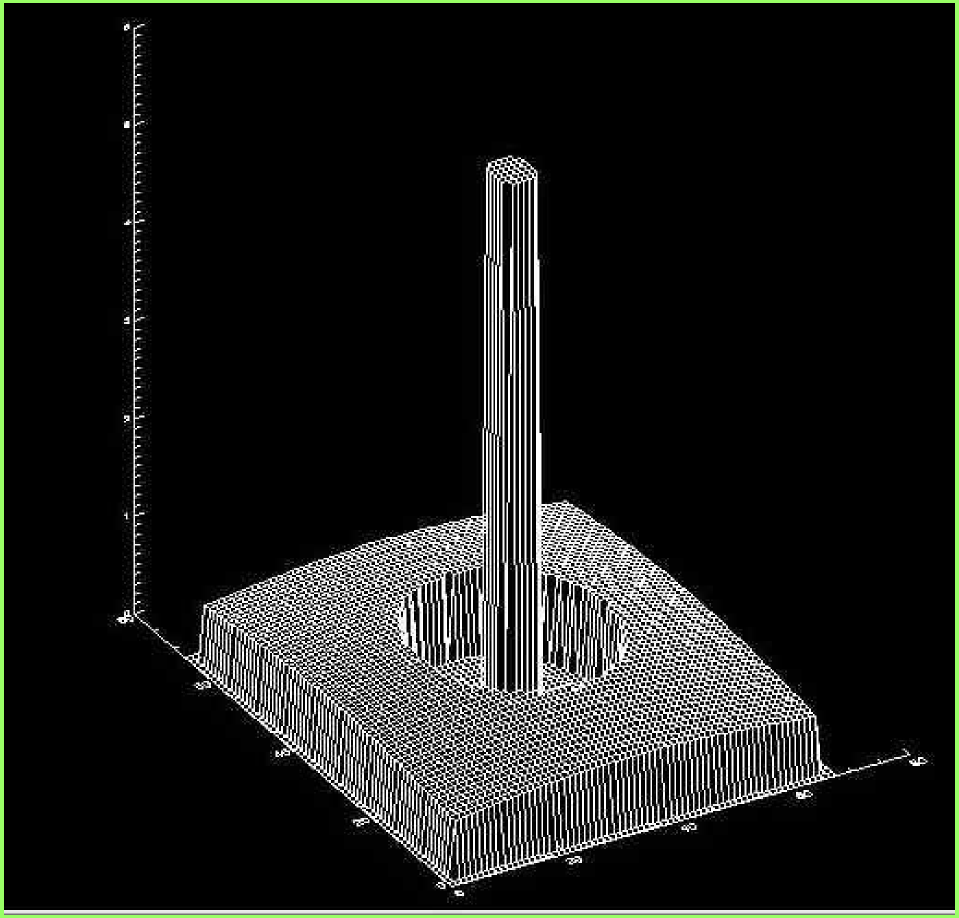


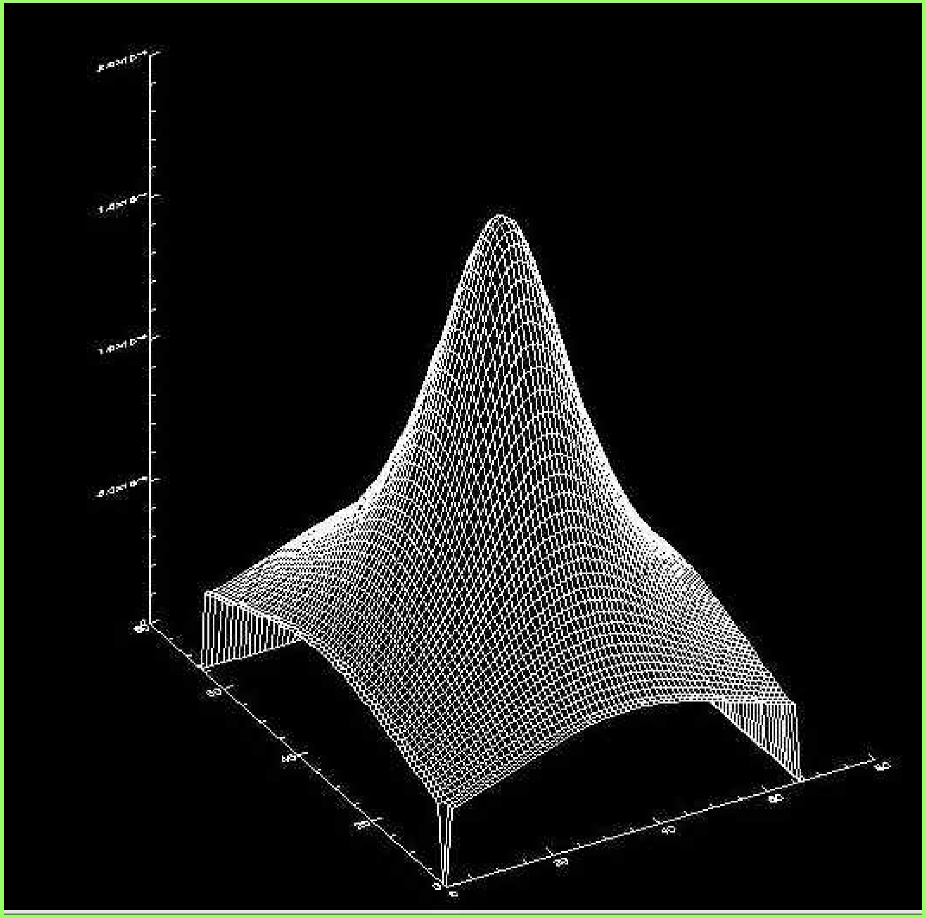
- Star+disk

Corona above (star+disk)

We seek for full 3D numerical simulations (with the disk included) to confirm the stability of the 2.5D solutions for outflows and disk. Therefore, parallel simulations are needed.

Our setup in 3D (extension+shifted)





• Star+disk

Corona above (star+disk)

The accretion disk stability is problem in itself. Also, the boundary condition effects in various coordinate systems need to be studied, if the disk is not enclosed completely in the computational box.

Summary

- Study for the close vicinity of the star
- Magnetic fields from simple to more complicated, in 2.5 D
- Motivation: search for robust results
- Prospects: -to consistently include accretion disk in full 3D and to investigate stability to small perturbations