Resistive MHD simulations

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Outline

- Resistive MHD
- Research in Greece
- Research in Taiwan
- Teaching in Split
- Prospects

Equations of resistive MHD

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

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

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

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

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

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

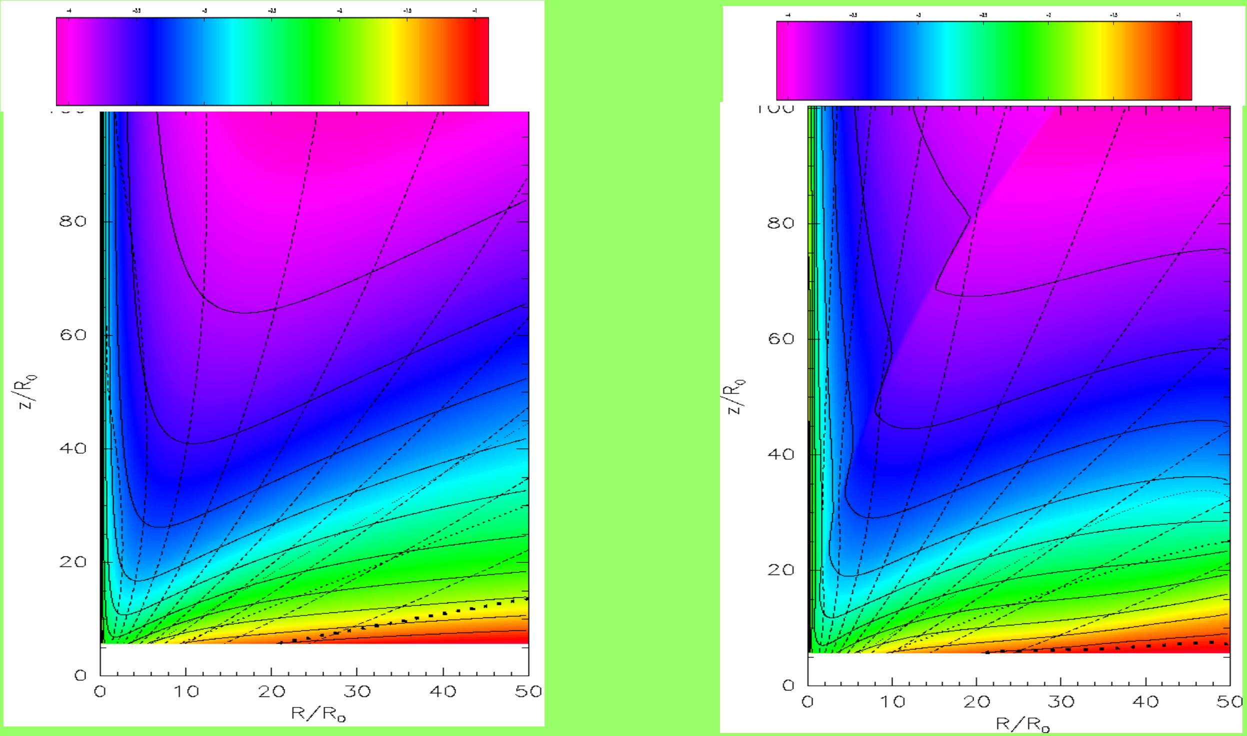
$$p = K\rho^{\gamma},\ e = \frac{p}{\gamma - 1},\ \gamma = \frac{5}{3}$$

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

Research in Greece

- Analytical solutions for radially self-similar MHD jet as initial conditions
- Ideal-MHD simulations, numerical resistivity
- Resistive-MHD simulations, two regimes identified
- Super-critical solutions

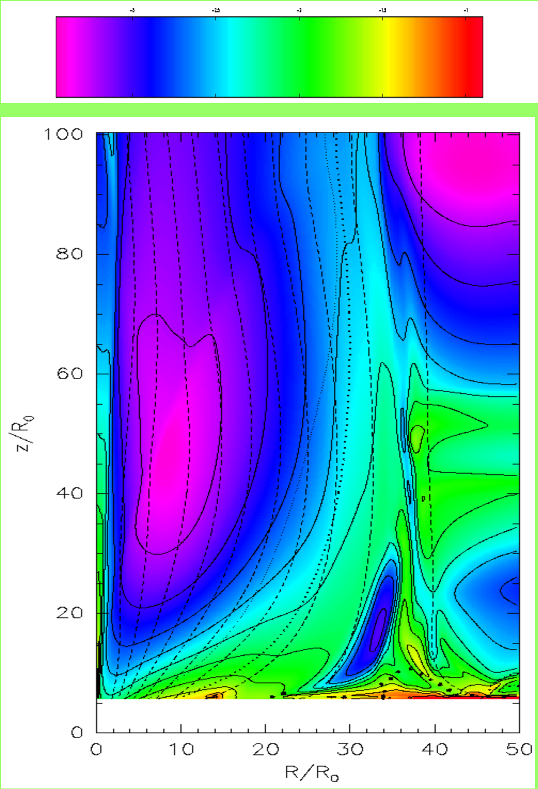
Initial state and low resistivity simulations



Left is initial state, right is the final, stationary state in low resistivity simulations. It does not differ significantly from the initial state, except for a shock introduced by modification near the axis of symmetry. **Very** well defined stationary state for final solution. Integrals of motion **smoothly** depart from initial condition for increasing resistivity.

High resistivity simulations

- Critical diffusivity
- Solution does not reach stationary state
- “Wing” sweeps quasi-periodically through the computational box
- New characteristic number Rb which, together with Rm, describes the influence of resistivity.



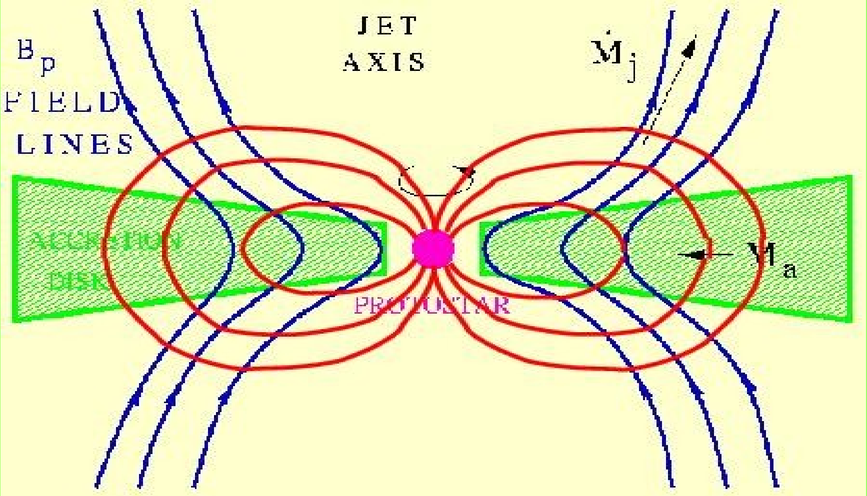
Solution for high resistivity simulations with critical surfaces depicted in dotted lines. It is not stationary, but quasi-periodical.

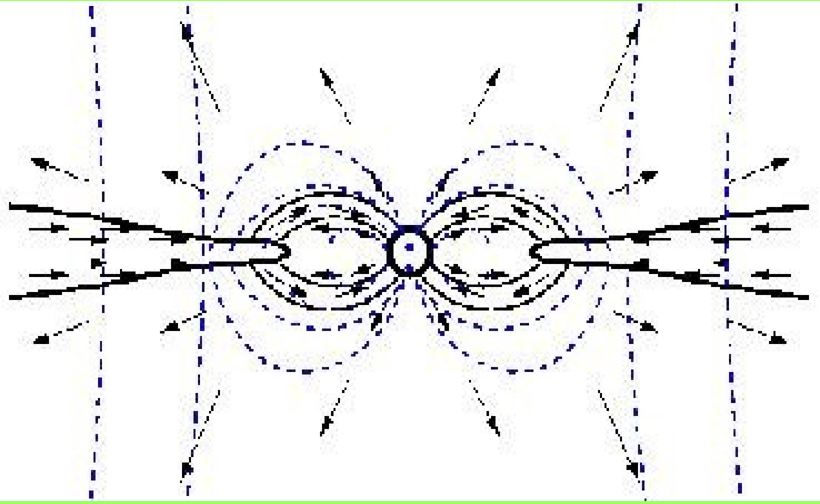
Research in Taiwan

- Star as a boundary, disk included in simulation, initially hydrostatic corona
- Various configurations of magnetic field
- Search for *robust* solutions
- *Transient* accretion funnels onto star
- Physical resistivity essential for reconnection to occur-weak outflows as condition for large scale outflows

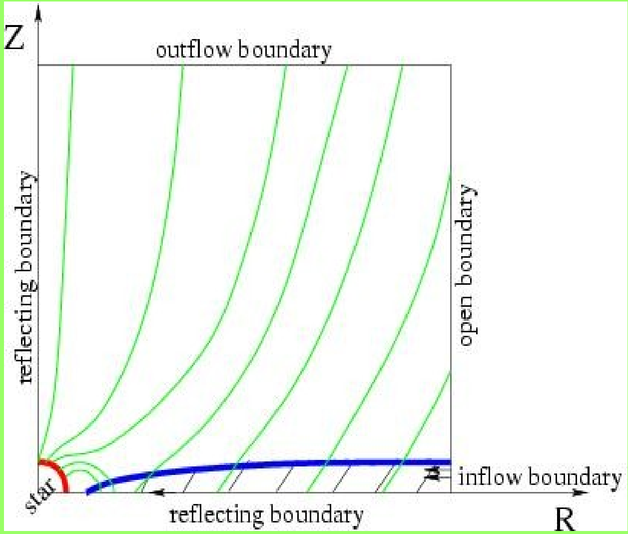
Simulations with dipole+open field

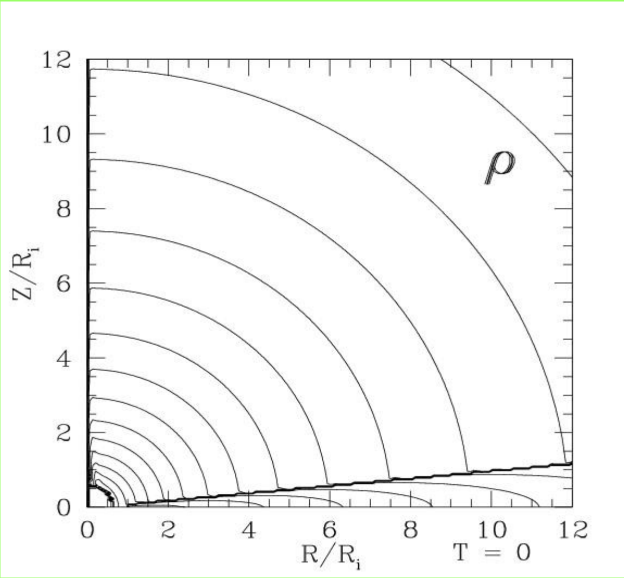
- Disk included in computational box in our simulations
- Nearest vicinity of the star
- **Interaction** of stellar magnetosphere & disk-new paradigm (previously: stellar wind; disk wind)



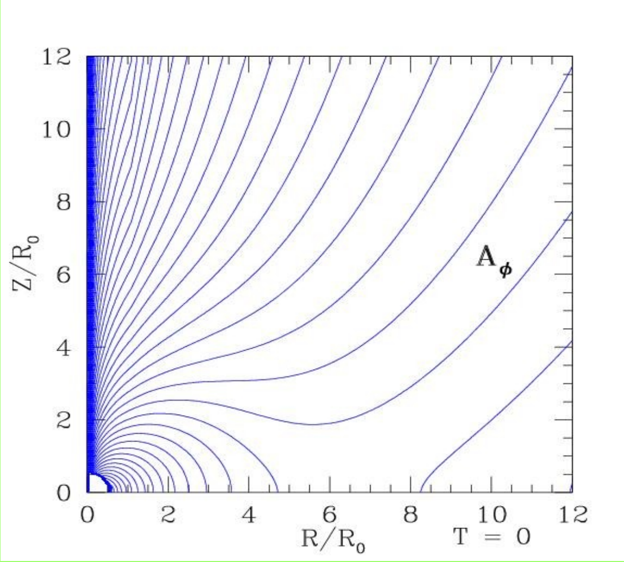


Boundary & initial conditions

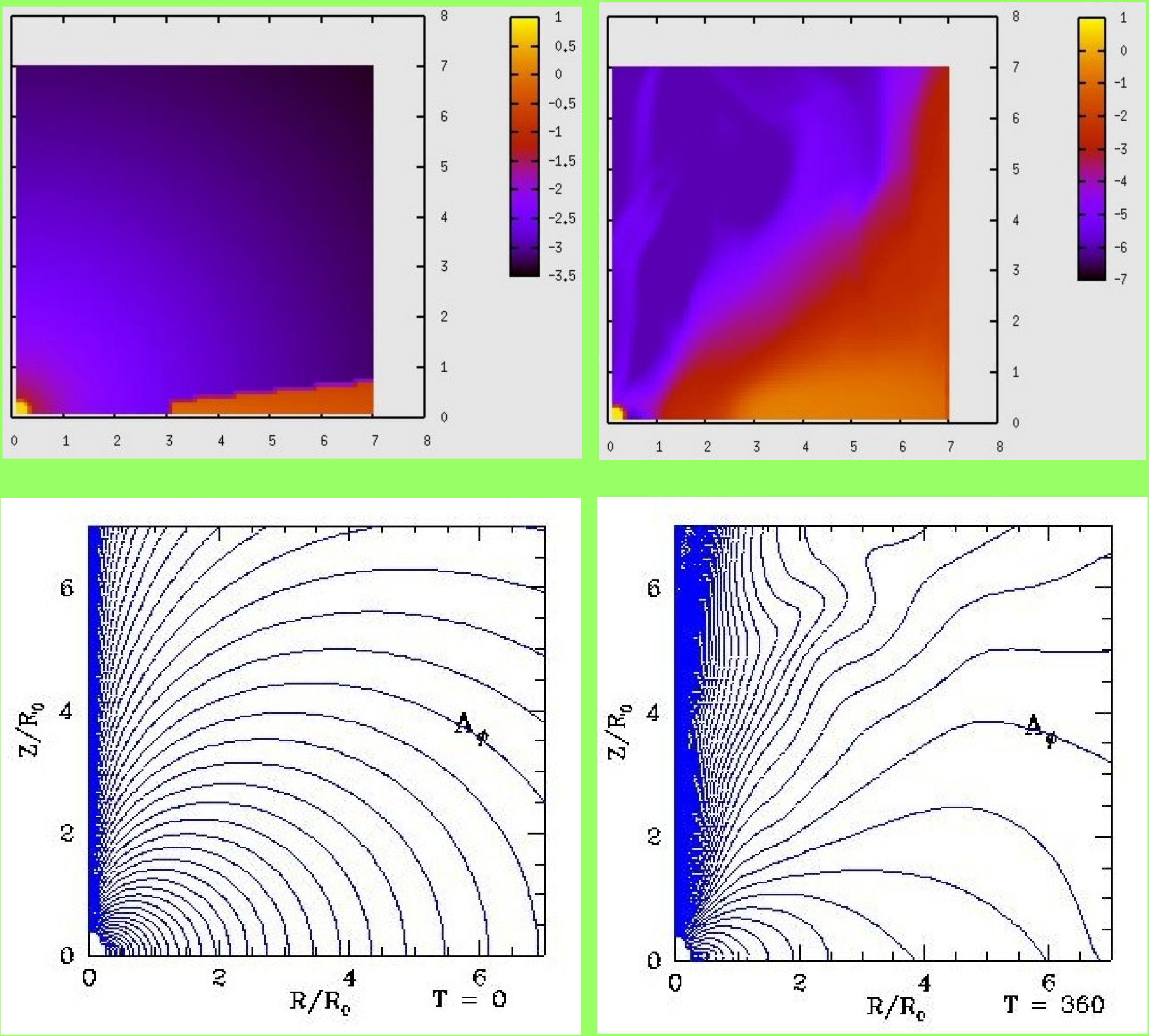


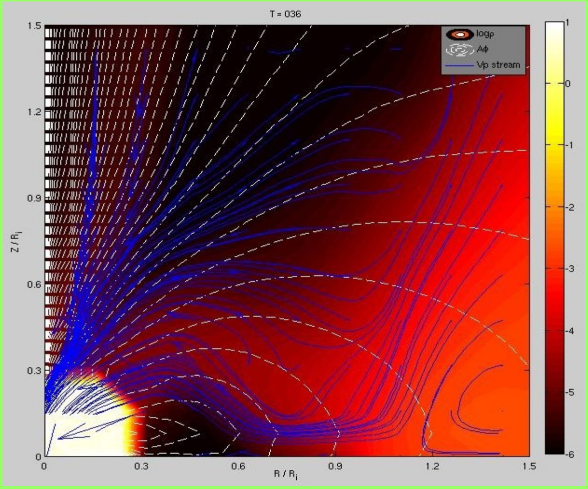


- Hydrostatic co-rotating corona above the disk, both resistive, in hydrostatic and magnetic forces balance
- Star as a boundary, in corrotation with disk at radius Rcorr
- Magnetic field as stellar dipole+large scale open field of the disk



Magnetospheric accretion mechanism (MAEM)



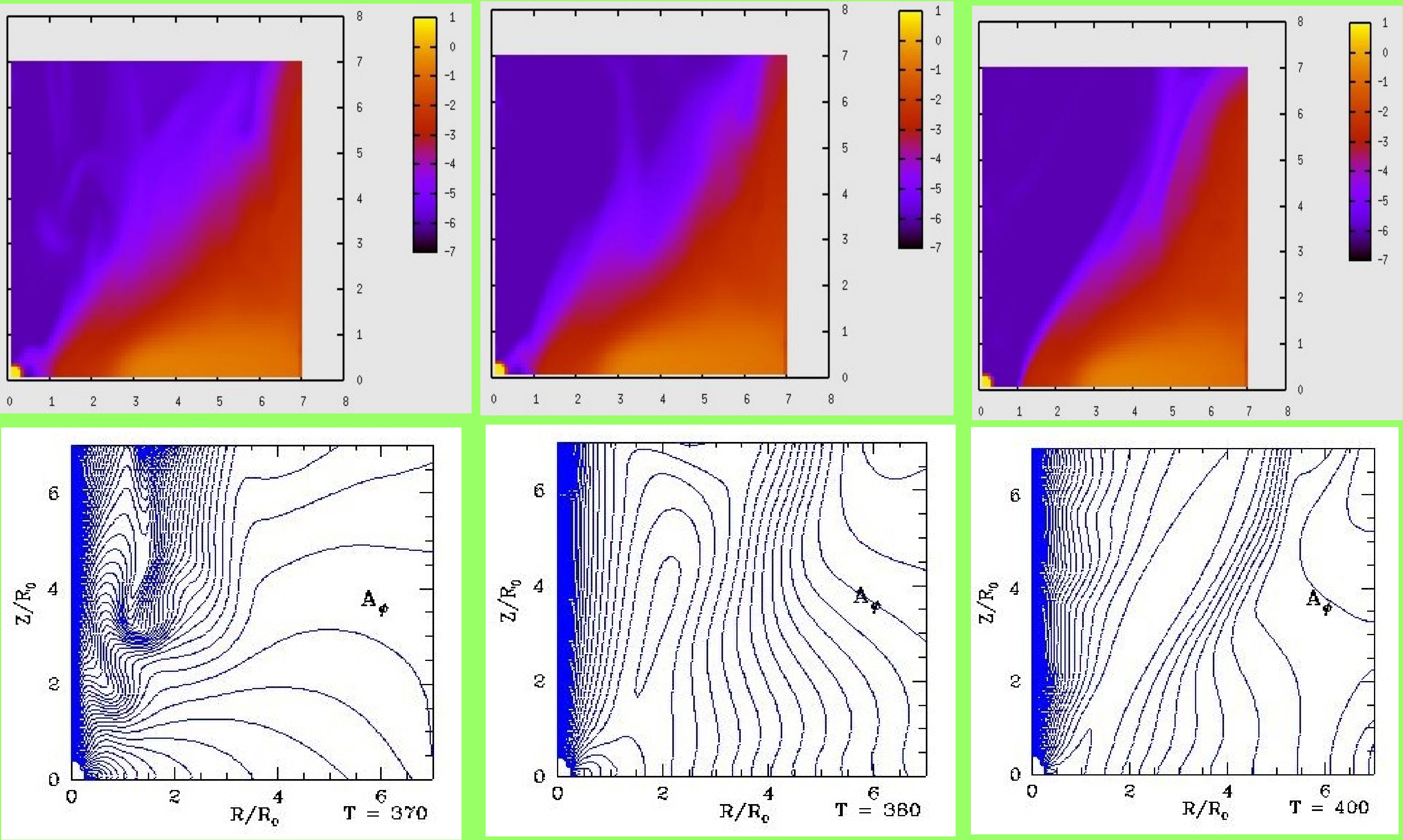


Zoom into the T=360 simulation

- star+disk, disk included
- stellar dipole magnetic field
- With lower diffusivity-reconnection does not occur-no funnel onto the star for less than 0.1 kGauss stellar field

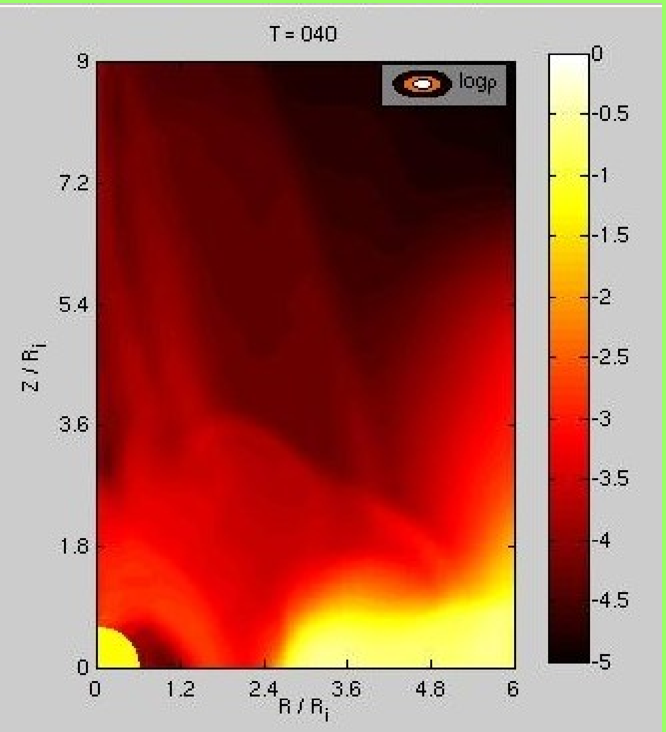
Density (top) and magnetic field lines (bottom) for initial and evolved state when R_corr=R_in.

Implications for magnetospheric accretion mechanism simulations



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

- Cemeljic, Shang & Chiang, 2008, in preparation



Our results in 2.5D

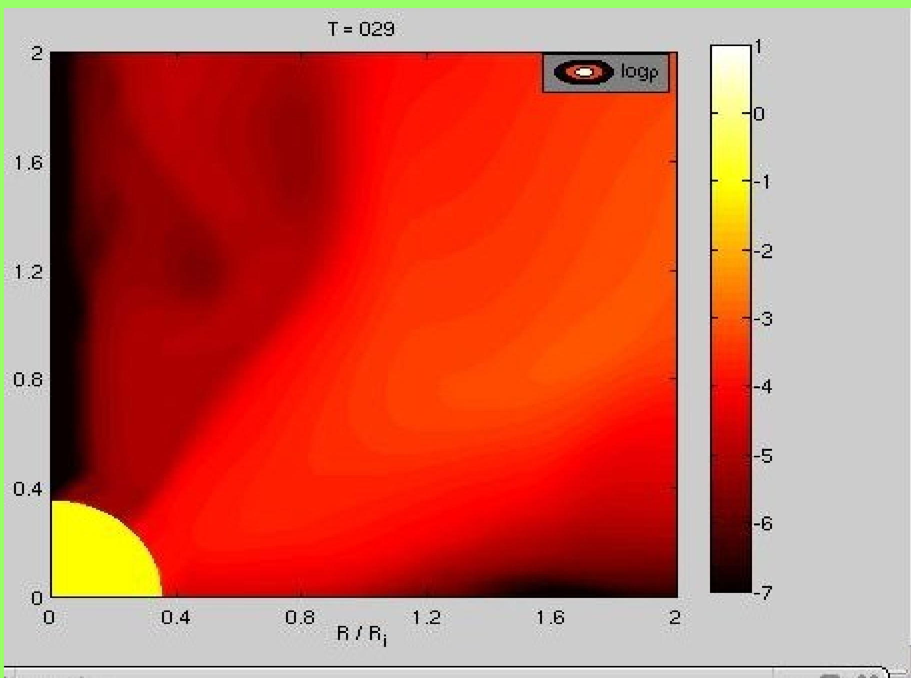
Animation of results for different times.

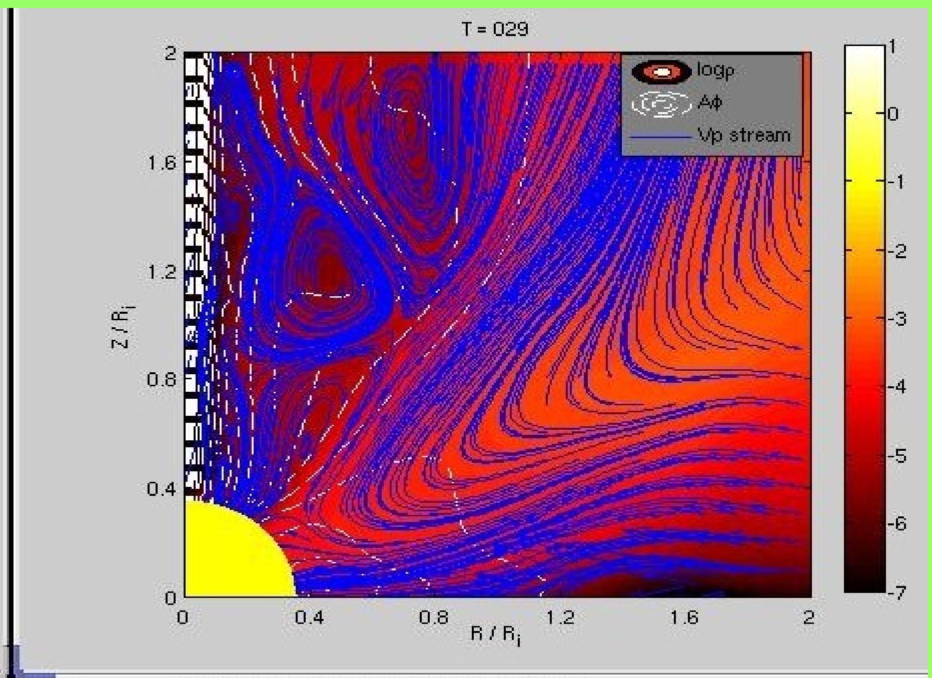
-**transient** funnels (accretion columns) of matter infalling onto the star-for larger magnetic fields

-results dependent on strength of magnetic field

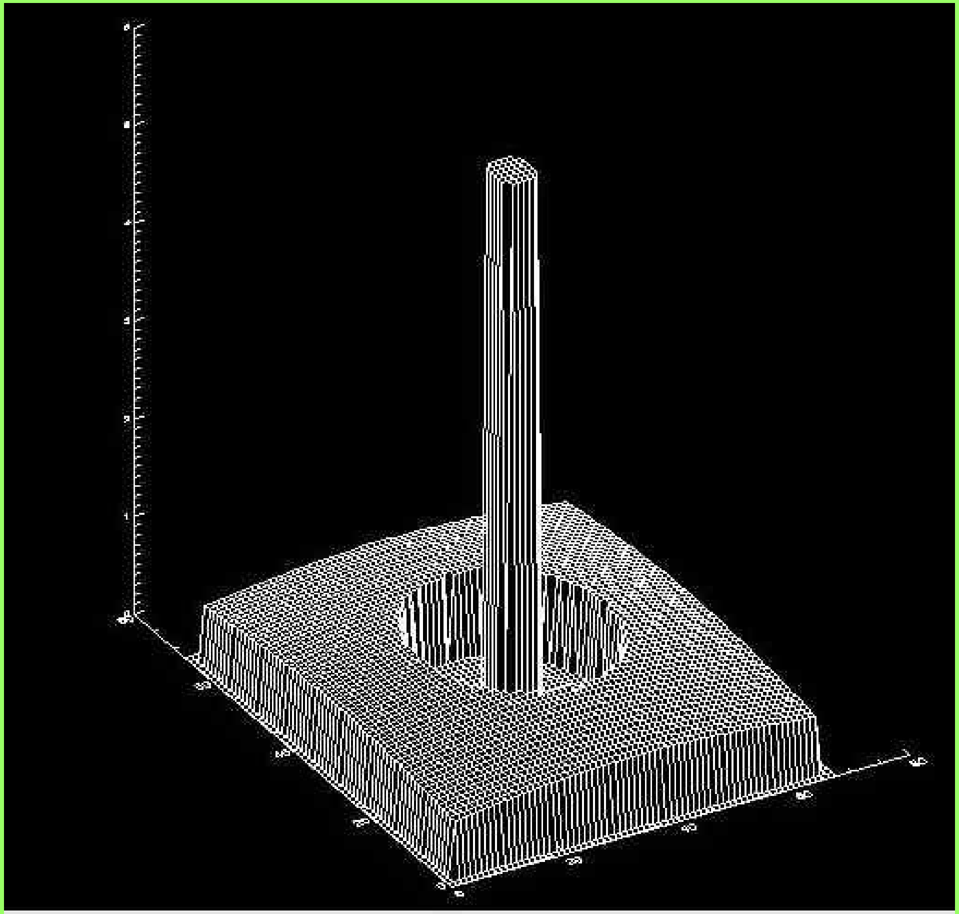
-we obtain outflows of low mass flow rate, but these are needed to enable more massive outflows at larger heights above the disk and larger radii

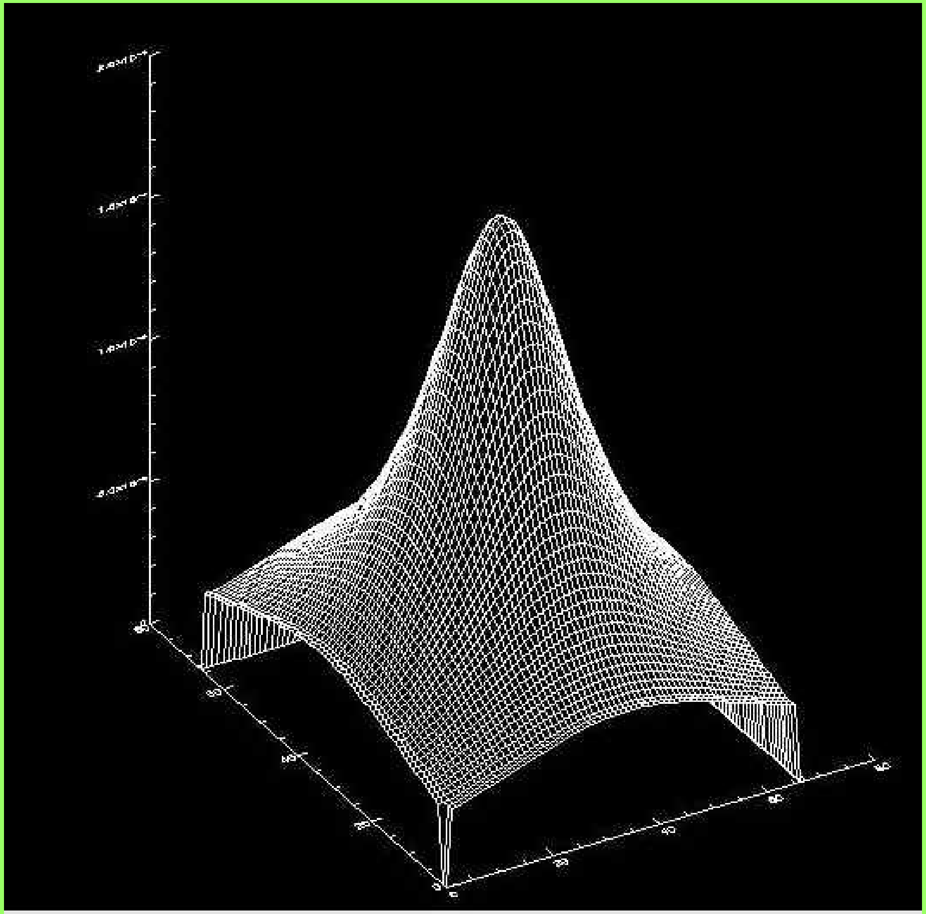
Zoom closer to star in one of solutions





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.

Teaching: Modern Astrophysics I

- Macroscopic description of radiation
- Radiation transport
- Spectral lines
- Equation of state of stellar matter
- Nuclear reactions in stars
- Observations of stars
- Stellar evolution
- Stellar models
- Stellar pulsations
- Degenerate stellar remnants
- Black holes
- Binary stars

Summary-1

- Self-similar analytical solutions modified and used as initial condition
- Two regimes of solution recognised: low and high resistivity case
- Low resistivity: stationary solution
- Super-critical solution: periodical?
- Prospects: astrophysical implications?

Summary-2

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

Summary-3

- Course in astrophysics
- In Croatia & in Croatian
- Next postdoc... more permanent job needed
- Europe? Asia?
- Research & Teaching