Launching of two-component outflows in resistive MHD simulations

Miljenko Čemeljić 席門傑

ASIAA/TIARA Visiting Scholar

Star Formation Group Meeting, Jan 11, 2011, ASIAA, Taipei

Outline

-Introduction

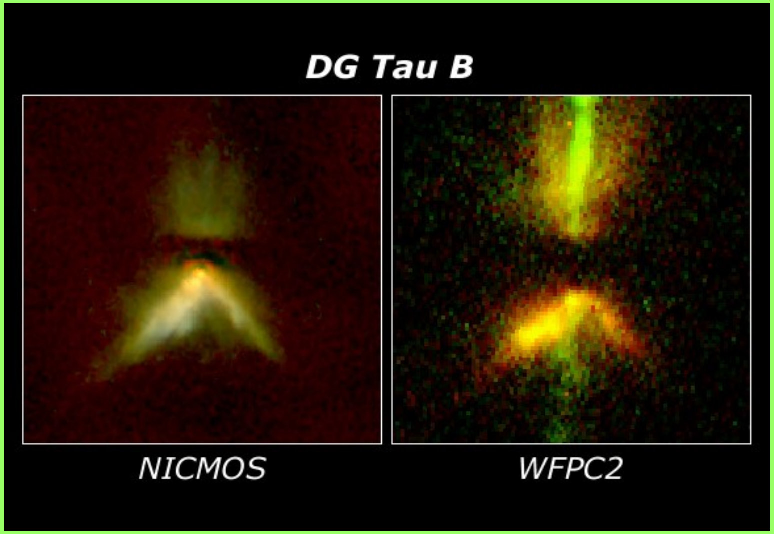
-Resistive MHD equations and simulations

-Simulations of star-disk system

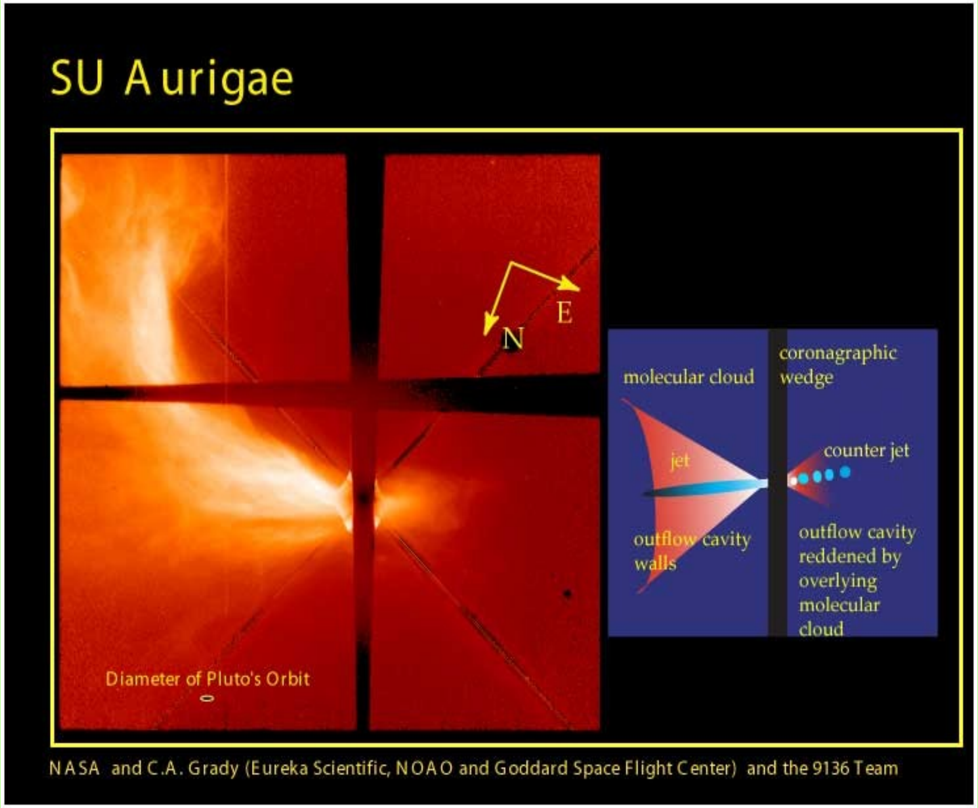
-Comparison of results with and without an accretion column

-Summary, Future work

Introduction-1



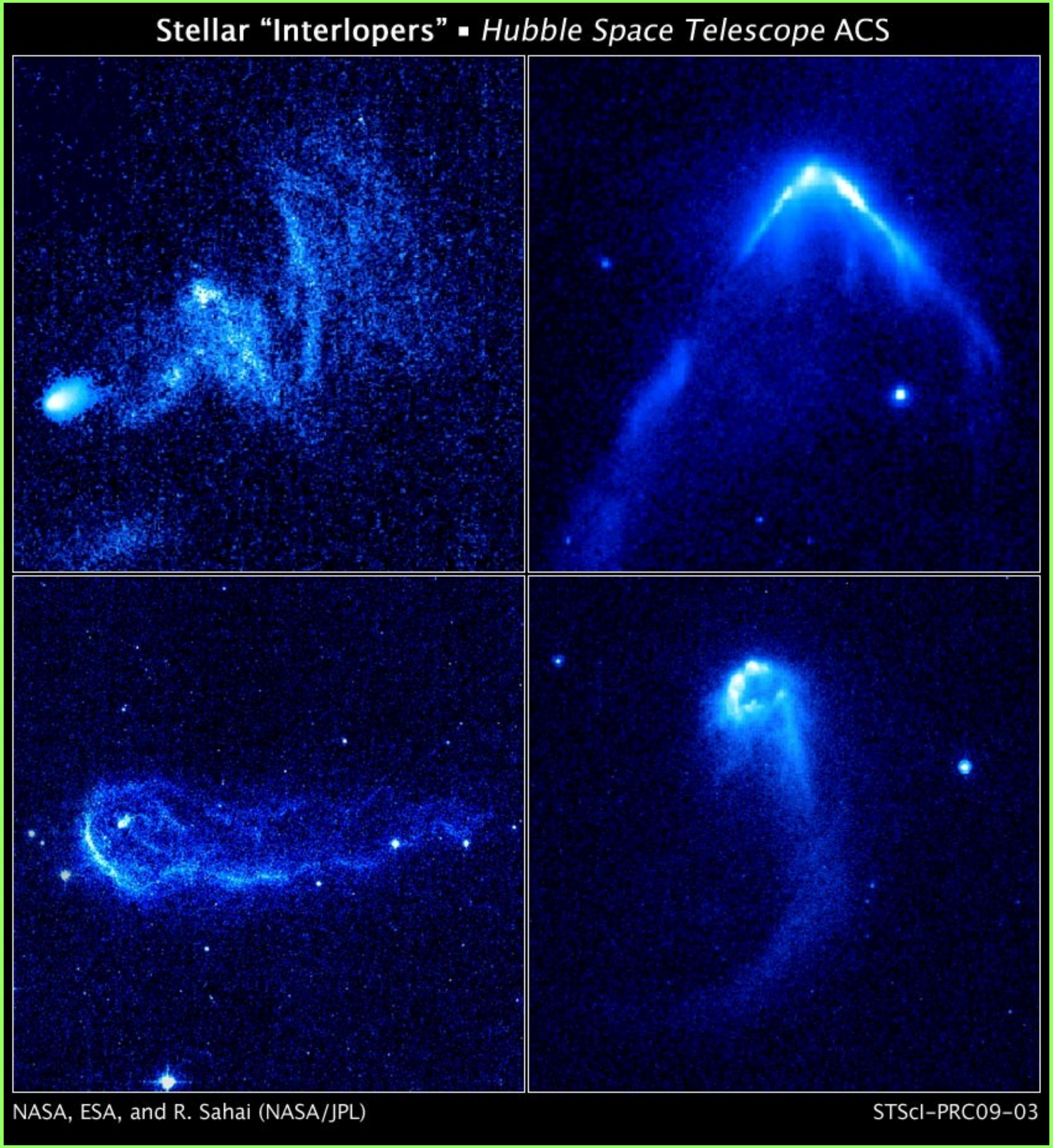
- outflows from Young Stellar Objects are usually shown as launched from the accretion disk, or as stellar wind+disk outflow.
- SU Aur is a 4 Myr old (de Warf et al. 1998), 1.9+/-0.1 solar mass star. The bipolar outflow reported here is the second collimated outflow detected in association with an isolated, several million year old intermediate-mass star. Given the small number of coronographic images of intermediate-mass stars, this result indicates that collimated outflows, similar to those routinely detected in association with lower mass T Tauri stars, appear to be common among their higher mass analogs and to persist for much of the star's pre-main sequence lifetime.



NASA and C.A. Grady (Eureka Scientific, NOAO and Goddard Space Flight Center) and the 9136 Team

Introduction-2

-stellar component can be well seen in young, runaway stars plowing through regions of dense interstellar gas, creating brilliant arrowhead structures and trailing tails of glowing gas. These arrowheads, or bow shocks, form when the stars' powerful stellar winds, streams of matter flowing from the stars, slam into surrounding dense gas. The phenomenon is similar to that seen when a speeding boat pushes through water on a lake.



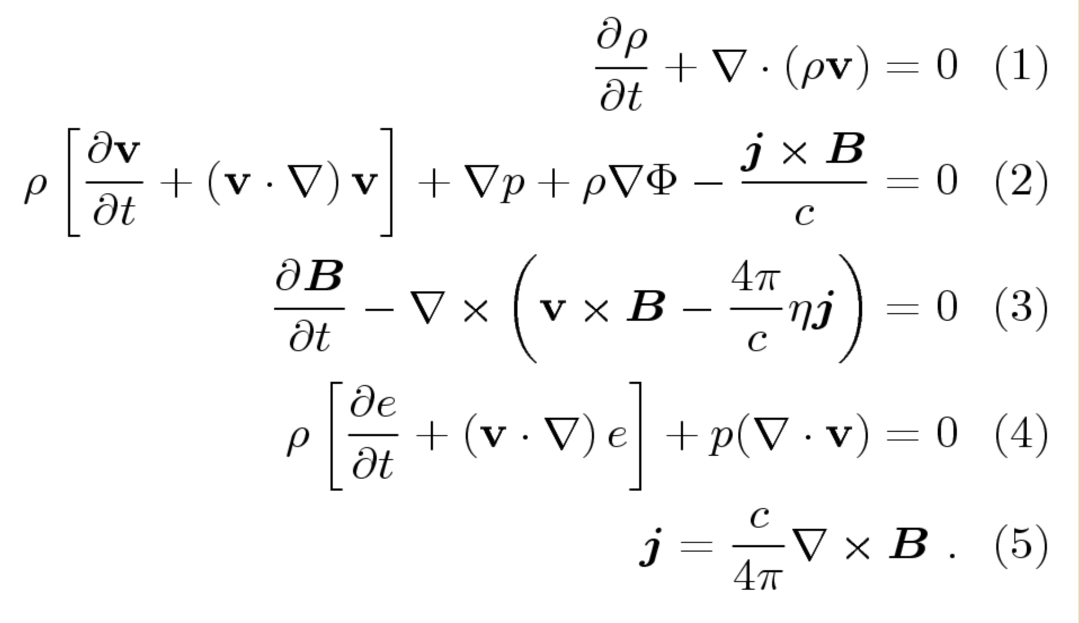
Resistive MHD equations

-ZEUS347 code

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

-mag. Prandtl number: Pr=viscosity/resistivity

-viscosity is included only as von Neumann-Richtmyer artificial viscosity, which is significant only for part of the flow with shocks- they are present especially during the relaxation phase. But still, caution, it is only numerical dissipation, not a physical model for viscosity.



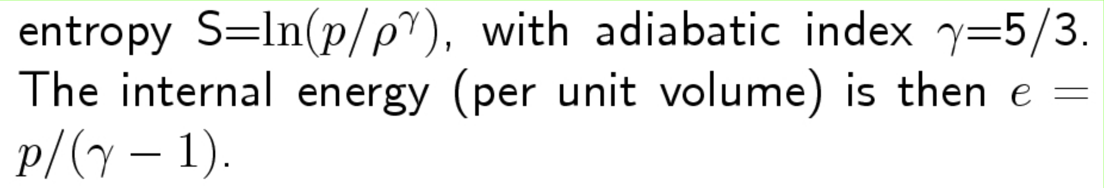
$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = 0 \quad (1)$$

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

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

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

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



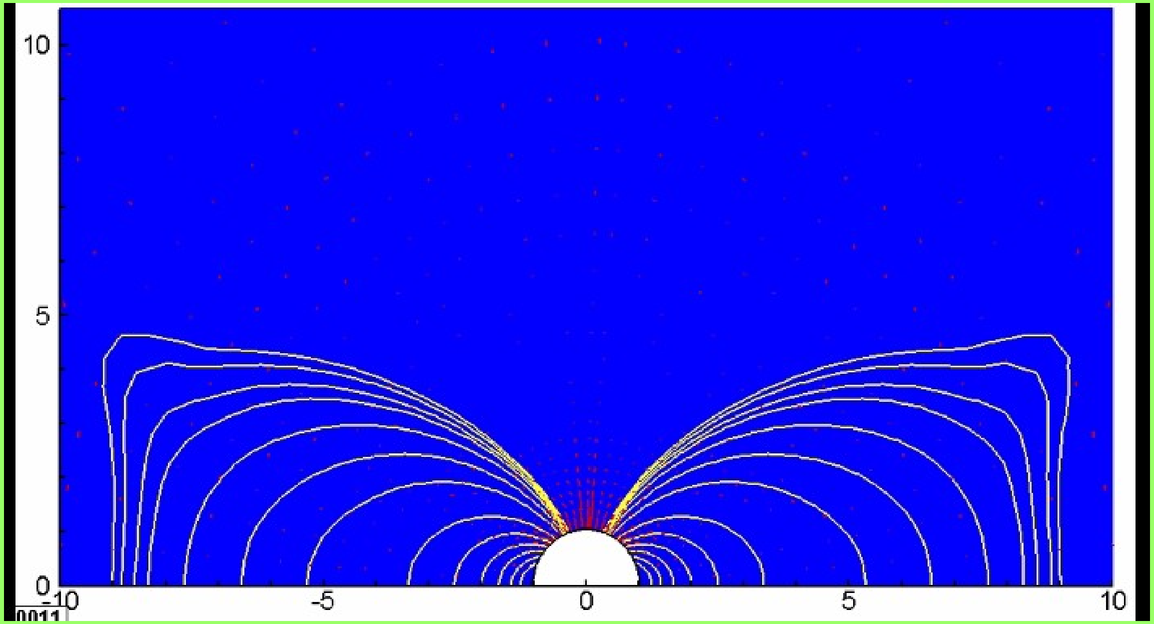
entropy S=$\ln(p/\rho^\gamma)$, with adiabatic index γ=5/3. The internal energy (per unit volume) is then $e = p/(\gamma-1)$.

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.

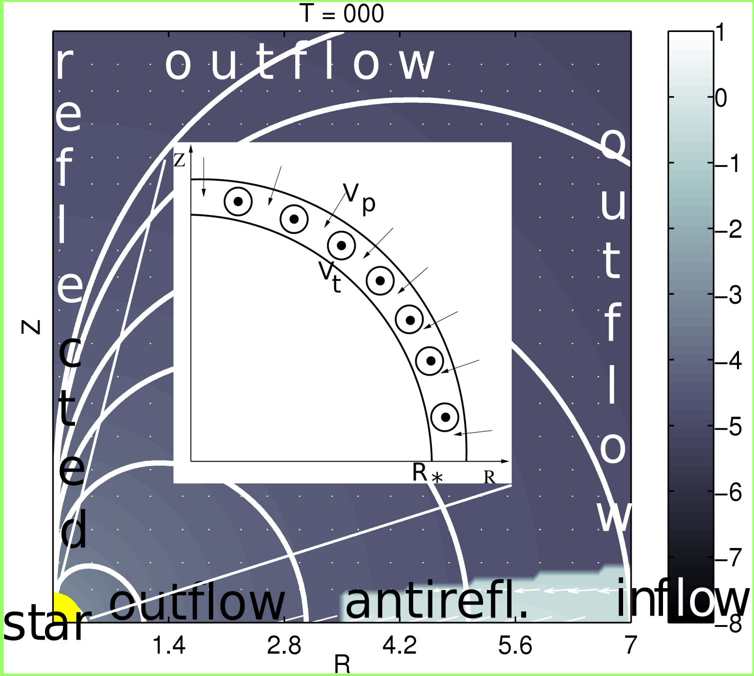
-but, do we really solve the same mathematical and physical problem?

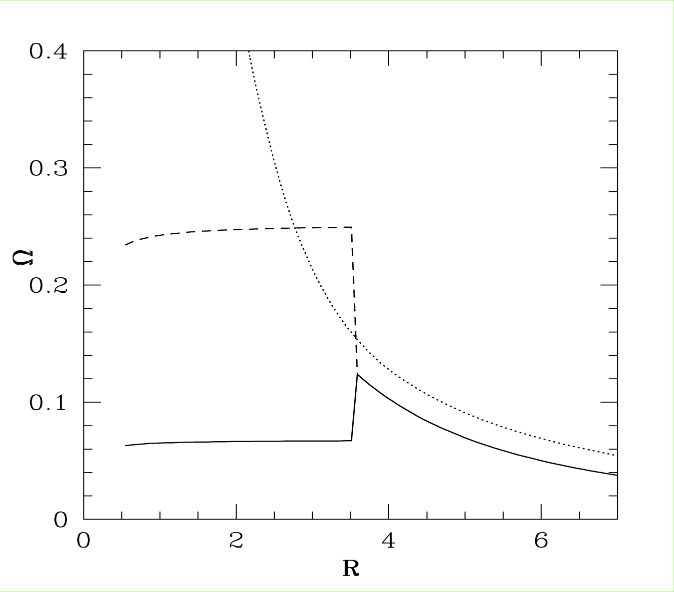
-simulations by Romanova et al., 2009. MOVIE 1



Straightforward setup

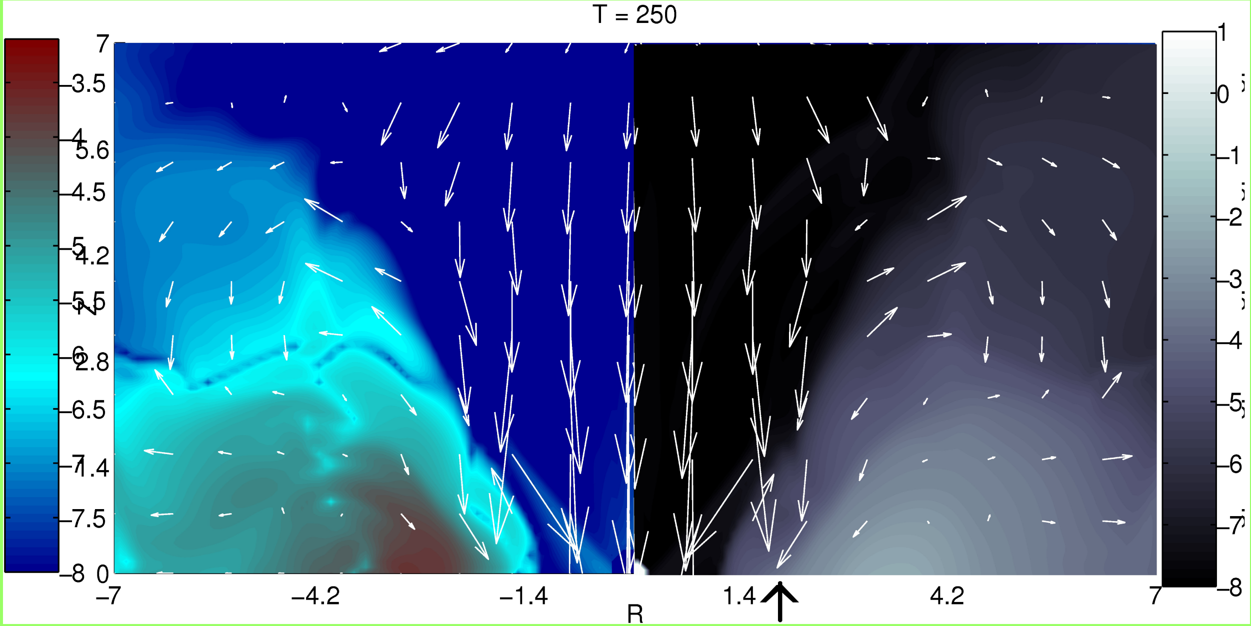
- the initial and boundary conditions when there is no “tricks” with matter in the disk. We set the initial and boundary conditions closest to “natural” ones, and search for solutions when code deals well with the relaxation. Stellar surface is set as an absorbing layer atop the star. In the right panel are shown the angular velocity profiles, solid line for slow, and dashed line for faster rotating star. The Keplerian profile is plotted in the dotted line.





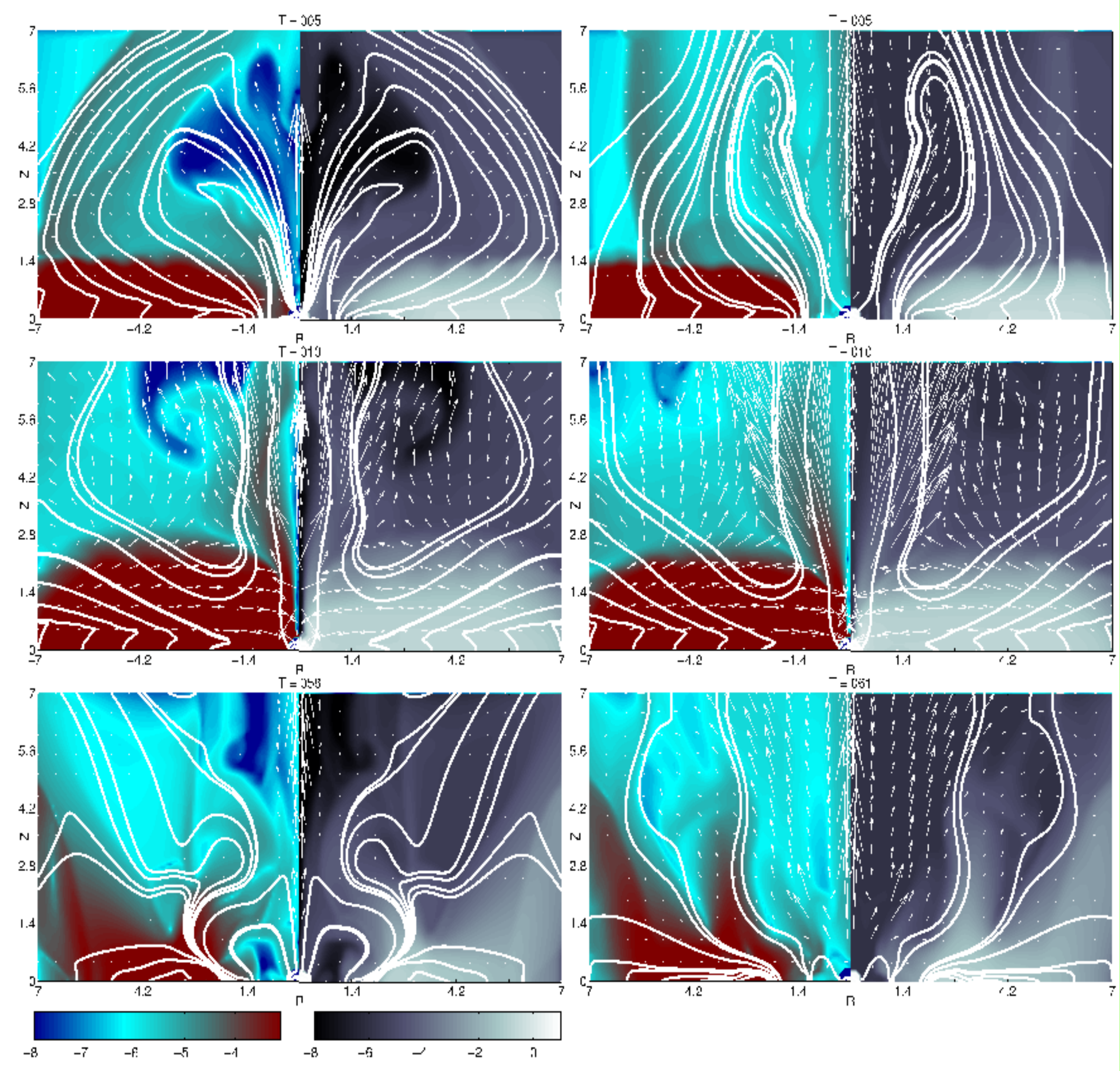
Time evolution of solutions without magnetic field

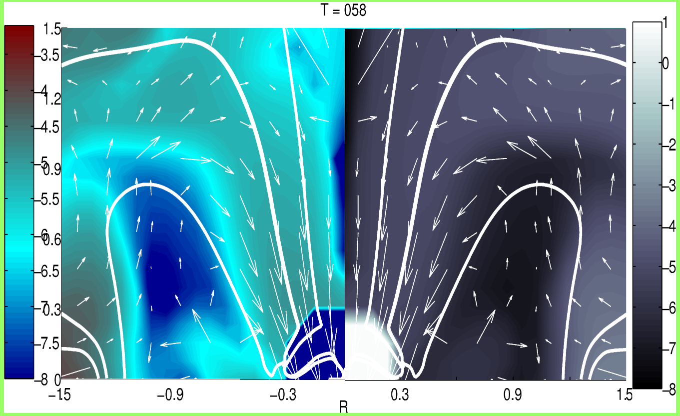
-after the relaxation, disk reaches quasi-stationary state, without outflows. Left half is the mass flux (rho*v) and right half is the density, both in logarithmic color grading. As we will see later, outflow(s) become visible in mass fluxes plots, in density plots, contrast between the disk and outflows is too large even for the logarithmic plots. MOVIE 2



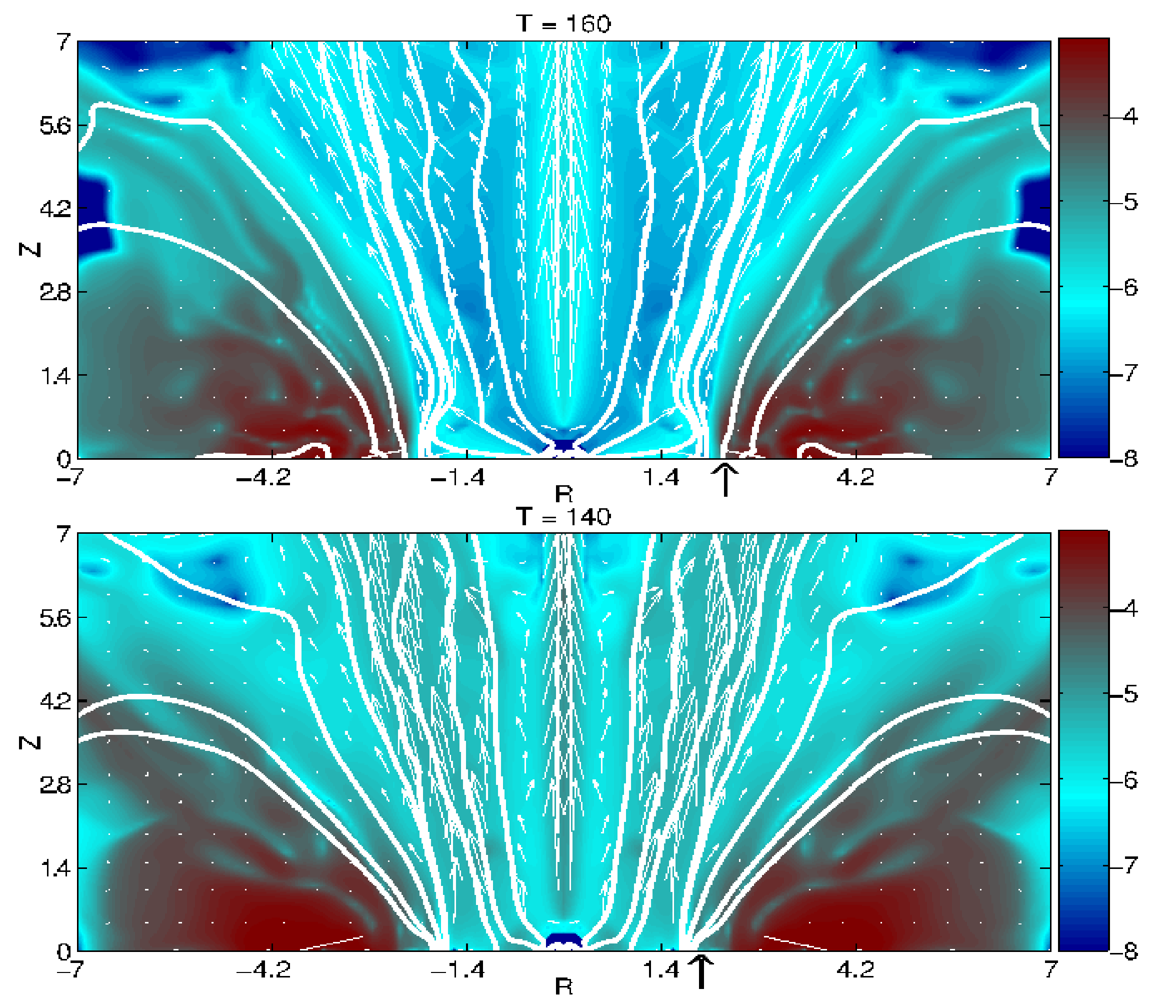
Time evolution in simulations S1,S2

-here I show first three stages in actual simulation, with disk initially 10 000 times denser than corona. Left column shows the case of slow, and right column the case of faster stellar rotation rate. I also show zoom into 3rd stage.





Final stages in simulations S1, S2

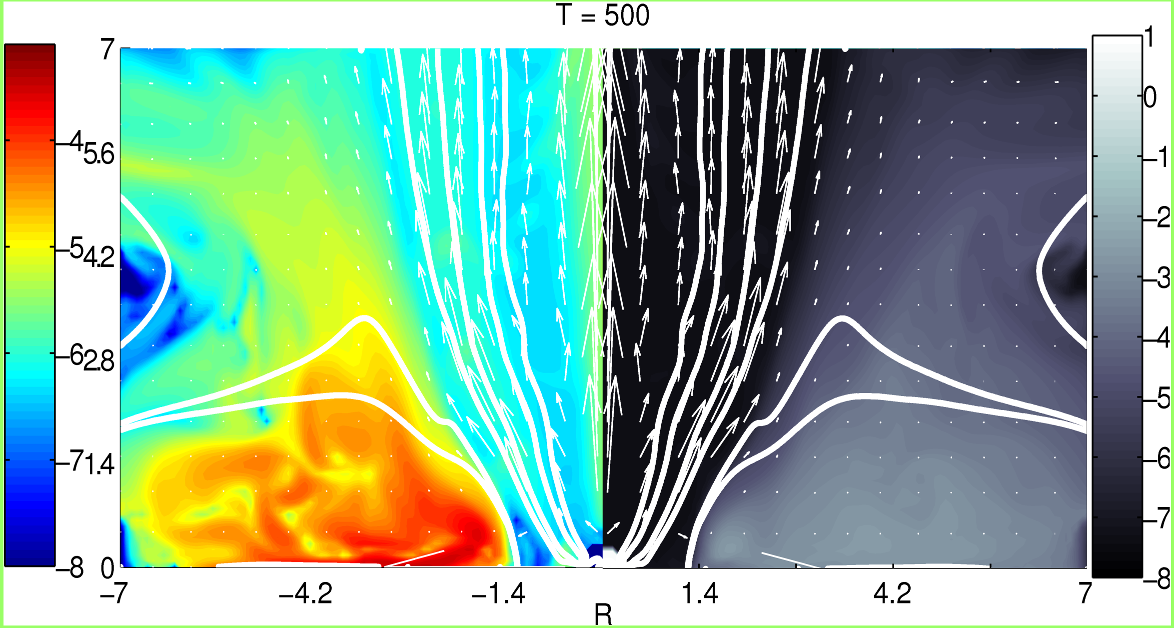


Solid lines show the poloidal magnetic field, and arrows show the poloidal velocity. The disk truncation radius is marked by an arrow. In the Top panel is shown the result in simulation S1, and in the Bottom panel in S2. A fast, light narrow axial outflow is formed above the star, and closer to the disk a slow, denser conical outflow with 40 deg opening angle in S1, and 20 deg in the simulation S2, when both outflows are more intensive.

Time evolution in solutions without accretion column onto the star

-simulations performed with even more realistic density contrast between the disk and the corona (100 000 times denser disk than the corona) than previously. It shows that it is even simpler to run longer lasting runs for more realistic setup.

-during the relaxation part of initial disk is swept out and new equilibrium is reached. Animation shows mass fluxes, where establishing of the quasi-stationary outflows is visible. MOVIE 3



Solutions without accretion column onto the star-velocities along the outflows

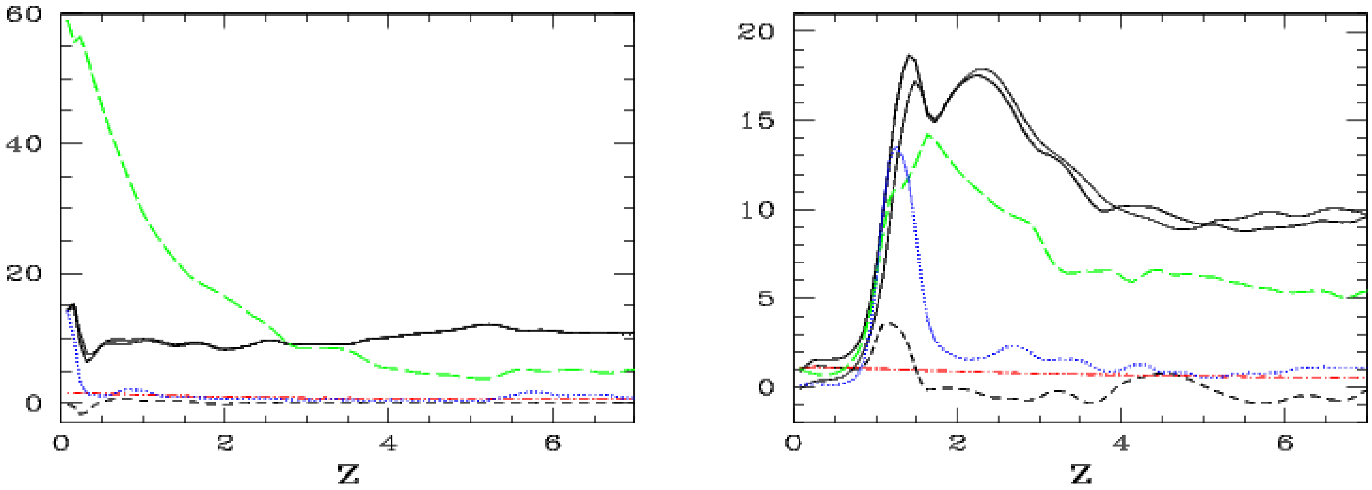
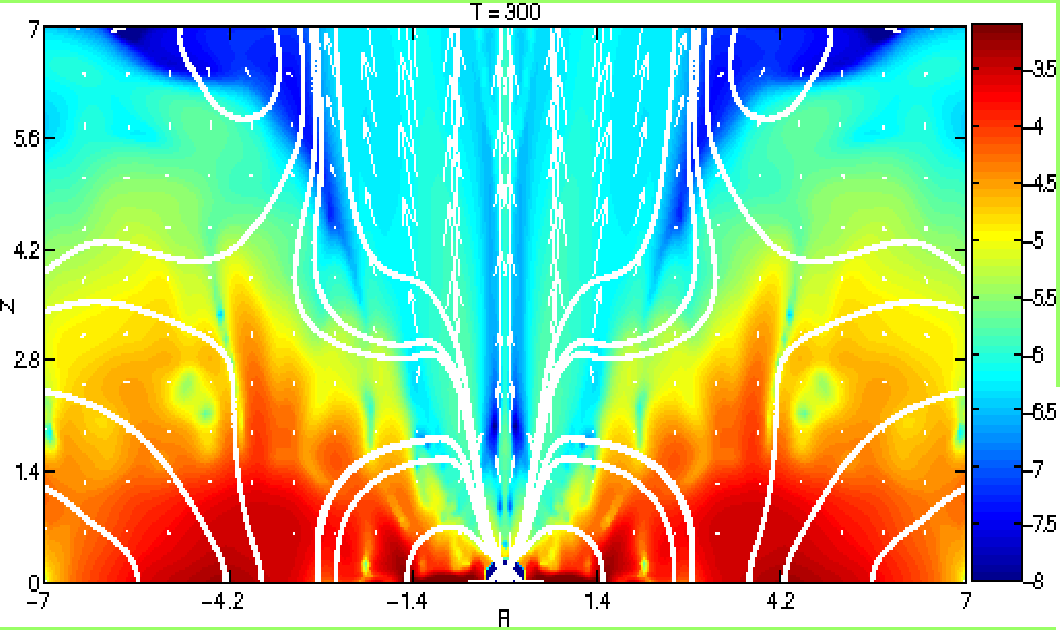


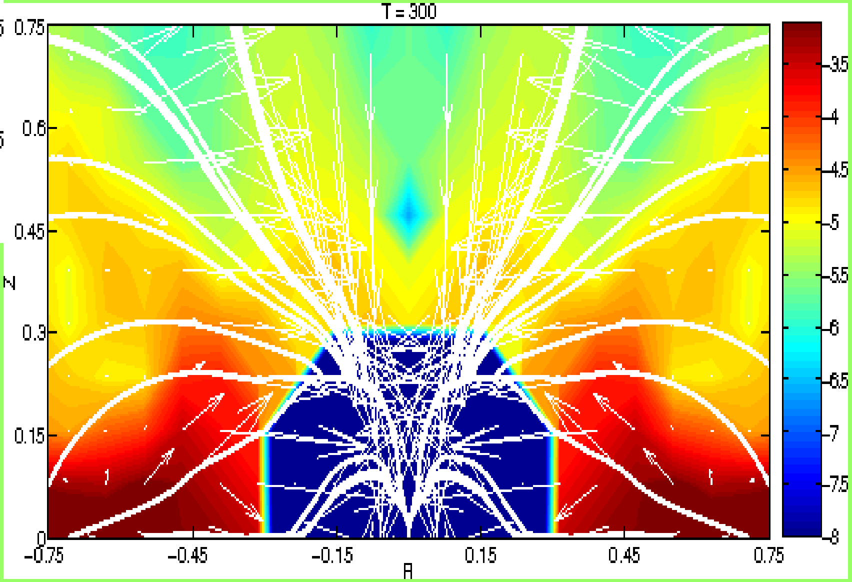
FIG. 3.— Velocities in slices along the axial outflow at $R = 0.8$, and along the conical outflow at $R = 1.5$, respectively. In solid thick (black) line shown is the total velocity, a sum of the poloidal (solid thin black line) and toroidal (dashed thin black line) velocity components. Thick dashed (green) line depicts the Alfvén velocity, and (red) dot-dash line depicts the escape velocity. In dotted (blue) line depicted is the sound speed.

Time evolution in solutions with accretion column onto the star

- In this case, with a bit larger artificial viscosity than in previous runs, but with physical resistivity in the corona still large (so that Pr<1), magnetic field finds balance with disk mater closer to the star, and accretion column forms. MOVIE 4, MOVIE 5

- in the panel below is still at T=300 and zoom closer to the star at the same time.





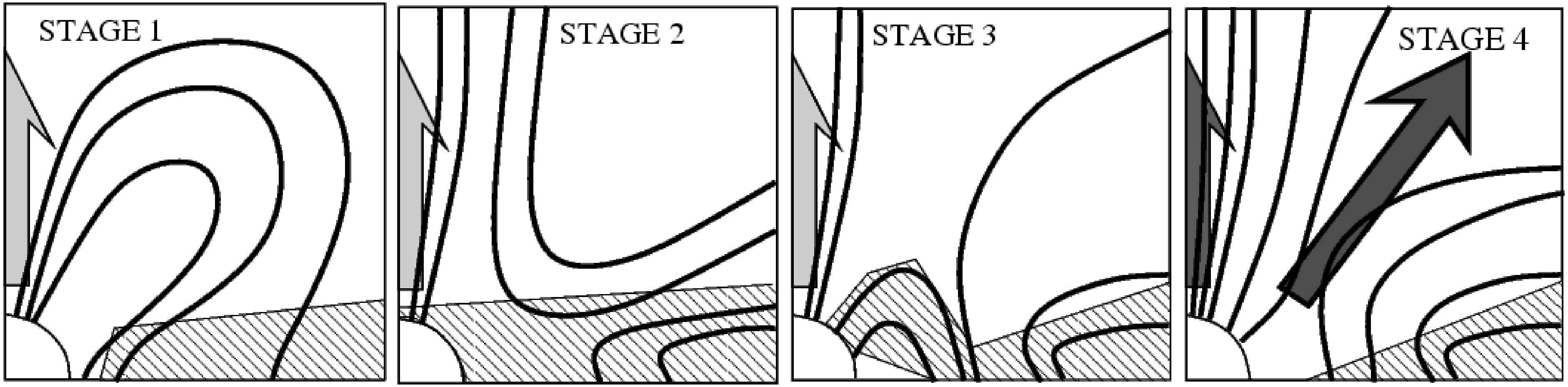
Evolution in star-disk interaction

-Stage one: The initial stellar dipole gets pinched during the relaxation, when matter flushes in toward the central star.

-Stage two: the magnetic fieldlines are open after reconnection, and disk matter can reach the surface of the star.

-Stage three: the disk matter retracts and a funnel flow forms from the disk inner radius and accretes matter onto the star. This stage can become a final stage, in some setups.

-Stage four: the system reaches a quasi-steady state, settling into a configuration consisting of open stellar field and field footed in the disk.



The arrows indicate the directions of the matter outflow. In the first three stages, the axial component is strongly episodic (marked with gray shadow), on and off many times into the quasi-stationary state.

Summary, Future work

-I obtained 2-component outflows from the star-disk system with only physical resistivity included.

-yes, I did obtain, finally, the quasi-stationary accretion column onto the star

-In the previous talk at SF meeting I was presenting “full 3D” as a“future work”

Yes, but... maybe we can learn a bit more from 2D axisymmetric?

Current setup I am working at is complete R_Z halfplane, in cylindrical coordinates. Results... my next SF meeting presentation.