Resistivity and reconnection in magnetospheric launching of outflows

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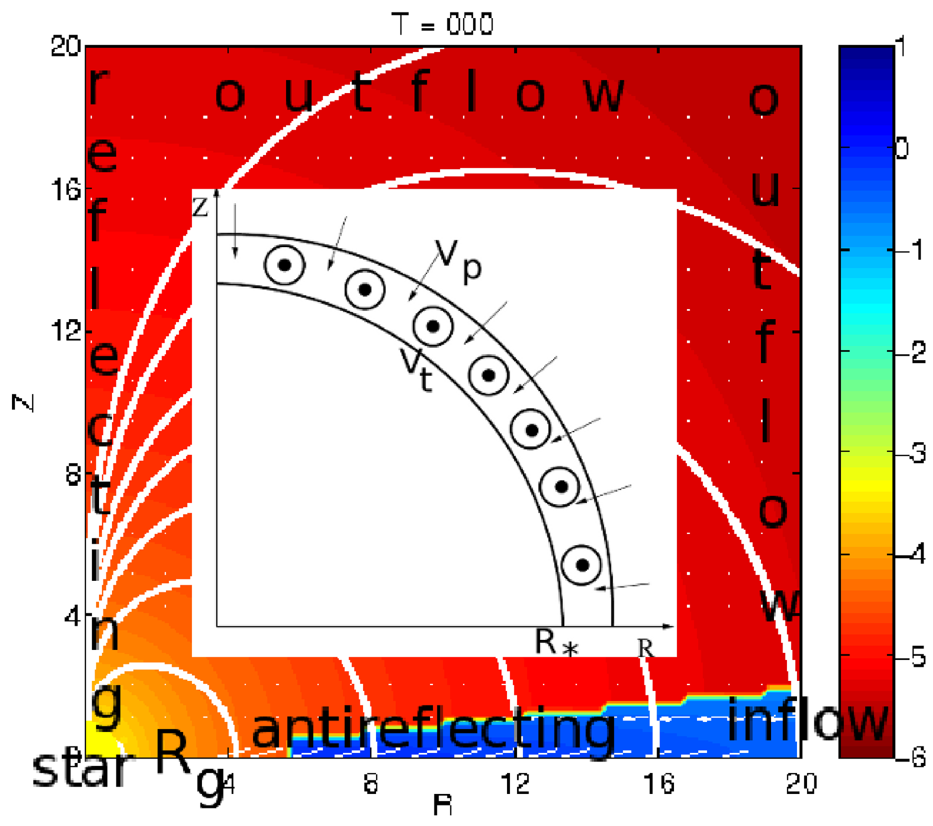
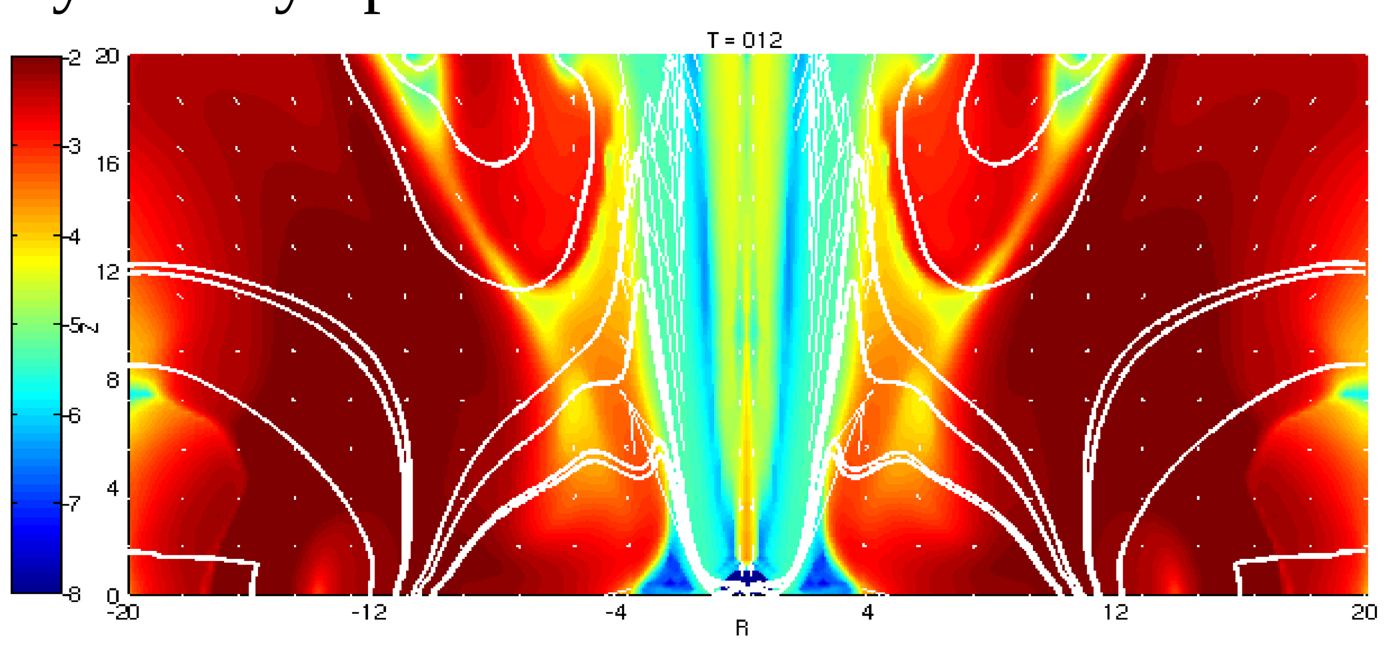
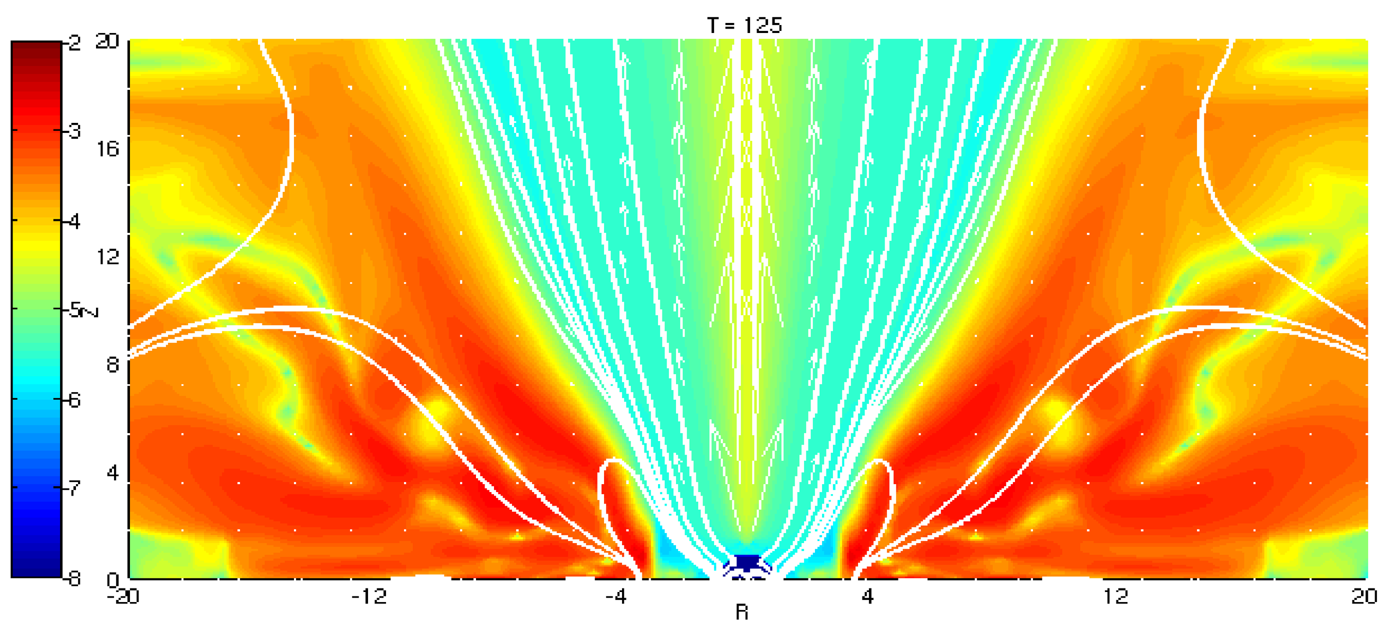
Viscosity and resistivity are dissipative processes which are the first introduced in the numerical simulations of non-ideal MHD in astrophysics. Their combination determines launching and shape of outflows from a central object surrounded by an accretion disk, but results are largely model dependent. We investigate the results for simplest, dipole stellar magnetic field in the purely resistive setup. Resistivity facilitates reconnection, so that the initial dipole can re-shape into the stellar and disk component, and provide channels for launching of outflows from the innermost vicinity of a star.

Initial and boundary conditions We set innermost region of a star-disk system, with RxZ=(90x90)grid cells=0.2x0.2 AU. Disk is initially in a slightly sub-Keplerian rotation, with a rotating, hydrostatic corona and dipole magnetic field centred at the origin. Resistivity nearby the equatorial plane is set constant, and higher in corona and disk with $\eta \sim \rho^{(1/3)}$. In both cases it is few orders of magnitude larger than microscopic value. We solve resistive MHD equations with our resistive version of the ZEUS-3D code in 2D axisymmetry option.

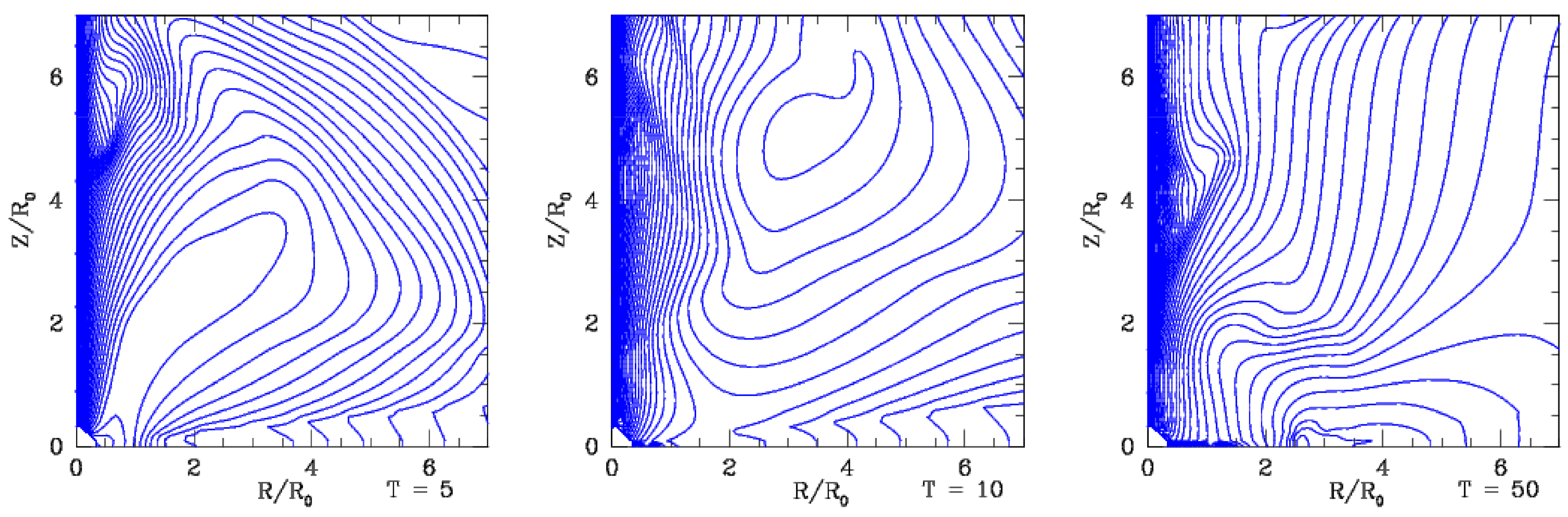


Setup of initial and boundary conditions, with inserted panel showing magnification of stellar surface in sketch drawing. In logarithmic color grading is shown the density, solid lines show the poloidal magnetic field of a stellar dipole, and vectors the velocity. Along the axis of symmetry and the disk equatorial plane, appropriate reflecting conditions are imposed. Outer boundaries are defined as open, except for a disk outer boundary, where inflow into the disk is defined, to mimic accretion from the part of the disk outside the domain. Star is set as a rotating absorbing boundary condition (with a constant rotation rate) inside the computational box, enclosing the origin.

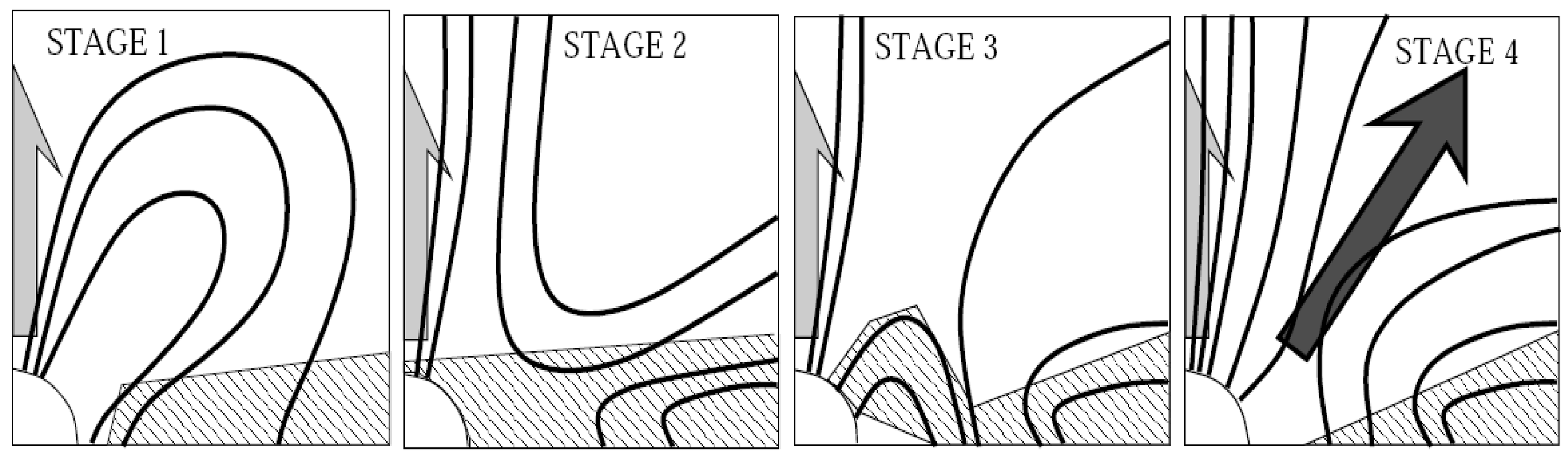




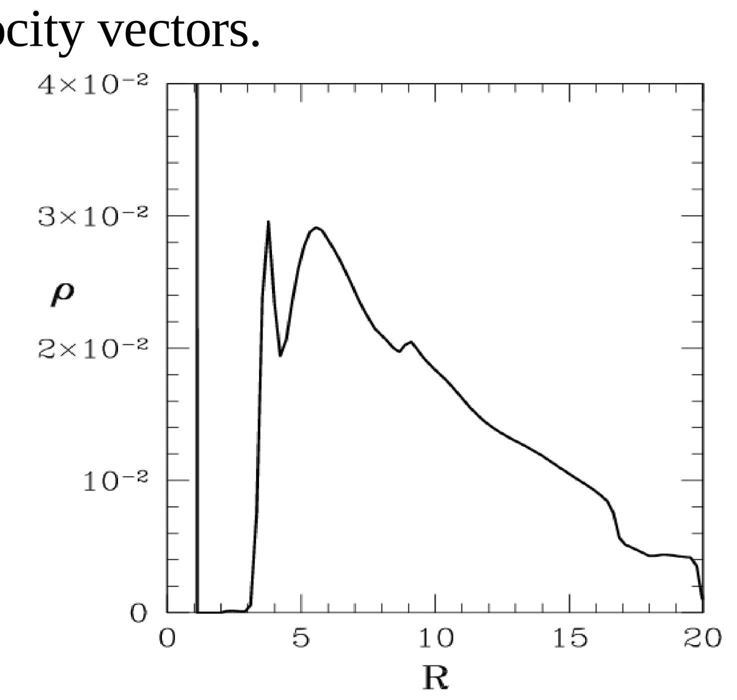
Two snapshots in simulation where the reconnection takes place. The magnetic field is of the order of 100 G. At T=12, during the relaxation from the initial conditions, reconnection enables opening of the initial dipole magnetic field lines, and at later time T=125, ongoing reconnection helps in launching the wide conical outflow. The transient axial outflow is probably numerical artefact, with mass flux many orders of magnitude smaller than the observed outflows. The wider, conical part of the outflow loads more mass into the outflow, but is still 2 orders of magnitude smaller than observed outflows. In logarithmic color grading is shown the poloidal mass flux. The solid lines show poloidal magnetic field lines, arrows show poloidal velocity vectors.

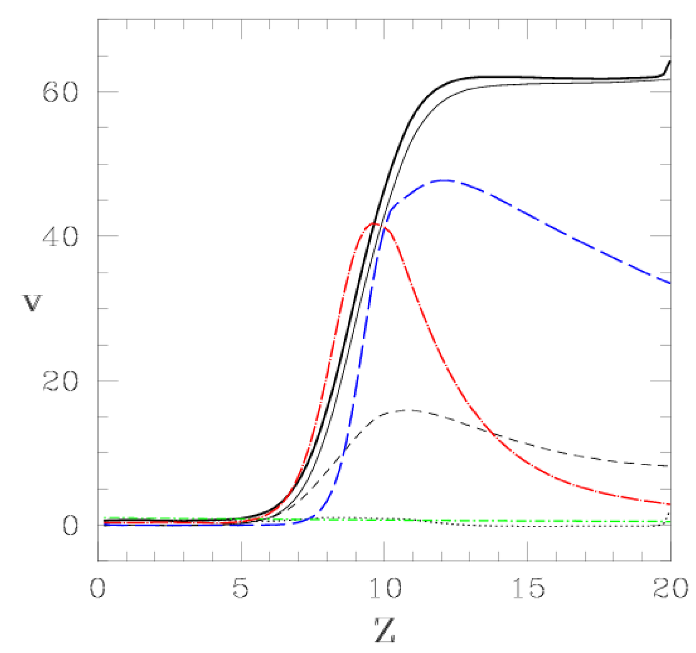


Poloidal magnetic field lines for the different timesteps. Initial stages in the simulation are related to the reshaping of the magnetic field, because of reconnection. In our simulations resistivity facilitates reconnection, so that in effect result depends on resistivity in the magnetosphere.



All simulations of star-disk interaction in our setup go through four stages: 1) relaxation with pinching of magnetic field inwards, 2) reconnection and opening of the stellar dipole, 3) narrowing of the disk gap with formation of transient funnel flow onto the stellar surface, 4) final stage of equilibrium of magnetic and disk ram pressure, with ongoing reconnection along the neutral line, with two low-mass outflows, one axial and another conical. The first two stages are related to relaxation from the initial conditions, and the last two can repeat many times during the simulation, if the quasi-stationary state is not reached.





Left panel shows the density along the disk equator at T=125. In the right panel are shown velocity components along the conical outflow at R=5 at the same time. In black thin solid, dotted, short dashed and thick lines are plotted components in Z, R and toroidal direction, and total velocity, respectively.The dashed green line shows Alfven velocity, the red dot-dash line the escape velocity, and the dotted blue line shows the sound speed.

Conclusions: Reconnection enables reshaping of magnetic field in our simulation. It is essential during the relaxation from initial conditions, for opening of the stellar dipole, and later in the simulation as a part of the launching mechanism.