Star-disk magnetospheric interaction with non-dipolar stellar field

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Abstract

In our study we investigate non-dipolar geometries of stellar magnetic field. We perform resistive and viscous magneto-hydrodynamical simulations of a star-disk system and compare the results for the dipole, quadrupole and octupole stellar magnetic fields.

Introduction

Mass in the accretion disk around a star can behave in different ways: it can fall directly at the equator of a star or form an accretion column at a higher latitude, but it can also escape from the vicinity of a star in the form of stellar wind and a conical or axial outflow. Which scenario is realized in our simulations depends on free parameters such as resistivity, viscosity, and stellar rotation rate, but it also depends on the geometry and strength of the stellar magnetic field. In the simulations presented in [1] was investigated the interaction between a thin accretion disk and a rotating stellar surface with the dipolar stellar magnetic field. Here we extend this research to the non-dipolar fields.

Numerical Setup

We use the PLUTO v.4.1 code (Mignone et al. 2007 [3]) to perform 2D-axisymmetric star-disk simulations in a half of the latitudinal plane. The resolution is $R \times \theta = [217 \times 100]$ grid cells with the maximal radius of 30 stellar radii, in a logarithmically stretched radial grid and uniform co-latitudinal grid in spherical coordinates. The initial disk is set following Kluzniak & Kita (2000) [2] purely hydro-dynamical solution, onto which we add the stellar magnetic field. The viscosity and resistivity in the disk are parameterized by the Shakura-Sunyaev prescription as $\alpha c^2/\Omega$, so that the magnetic Prandtl number $P_m = 3\alpha_v / 2\alpha_m$. Our setup is detailed in [1].

Simulation parameters

In all the cases we perform simulations with the same free parameters of the stellar magnetic field strength, viscosity and resistivity anomalous coefficients and the stellar rotation rates (we are interested in the slowly rotating stars, up to 0.2 $\Omega_\star/\Omega_{br}$). We will compare the resulting mass accretion rates and angular momentum transports onto the star and into various components of the flow.

$B_\star$ (kG)	[0.25, 0.5, 0.75, 1.]
α_v	[0.1, 0.4, 0.7, 1.0]
α_m	[0.1, 0.4, 0.7, 1.0]
$\Omega_\star/\Omega_{br}$	[0.05, 0.1, 0.15, 0.2]

Results: Dipole, Octupole and Quadrupole stellar field

In the cases of dipole and octupole magnetic field an accretion column is formed, with the mass accreting onto the star along the magnetic field lines. Because of the difference in the field geometry, the footpoint of the magnetic field lines is closer to the stellar equator in the octupole case than in the dipole case. Such a configuration enhances the stability of the runs. In the quadrupole case, the matter flows directly onto the stellar equator, similar to the purely hydrodynamic case. In the figures, color shows the density in logaritmic color grading, solid white lines show the poloidal magnetic field lines, and arrows show the velocity in the disk and corona, normalized to the Keplerian velocity at the stelar equatorial surface. Since the disk is about 100 times denser than the corona, velocity in the disk is much smaller. We multiplied the velocity in the disk and in the corona with different factors so that the vectors would be better visible.

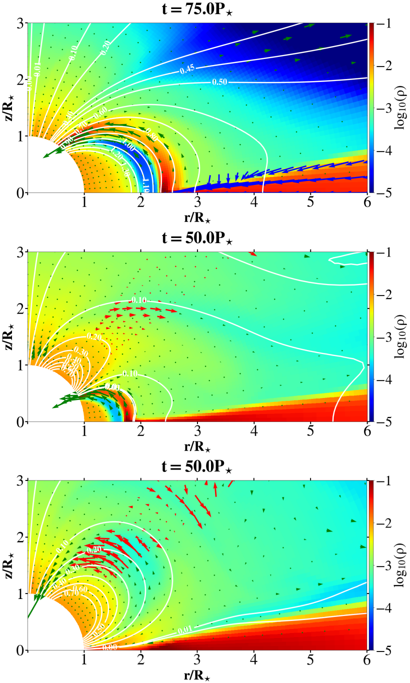

Figure: Zoom into the vicinity of the star in quasi-stationary results in our simulations with 0.5 kG stellar field, $\alpha_v = 1$, $\alpha_m = 1$ and stellar rotation rate $\Omega = 0.1\Omega_{br}$. Shown are the cases with the dipole, octupole and quadrupole stellar fields, in the top to bottom panels. The density is shown in the logarithmic color grading, poloidal magnetic field lines are shown with white solid lines, and vectors of poloidal velocity are multiplied with the factors 15 (in the disk) and 3 (in the corona) for better visibility.

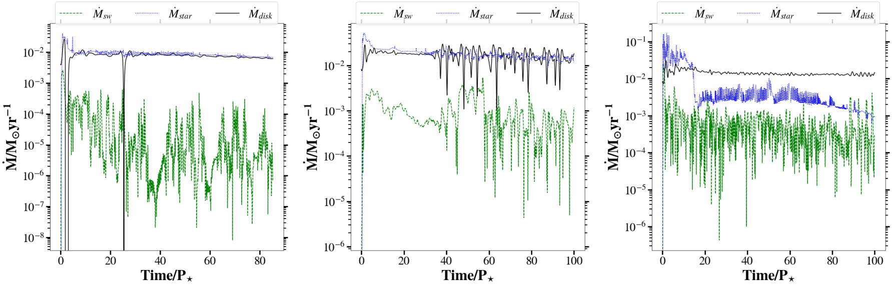

Figure: Mass fluxes $\dot{M} = \rho v_p$: across the disk at $R = 10R_\star$ ($\dot{M}_{disk}$), at $R_\star$ onto the star ($\dot{M}_{star}$) and into the stellar wind ($\dot{M}_{SW}$) for the dipole, octupole and quadrupole. In all the cases, runs reach quasi-stationarity after the brief initial relaxation.

Conclusions

Difference in the geometry of magnetic field in our simulations result in the different evolution of the star-disk magnetospheric interaction. With the dipole and octupole stellar magnetic field, material from the disk is lifted above the equatorial plane, and an accretion column is formed. The footpoint of the magnetic field lines in the column is closer to the stellar pole in the dipole case, and shifts towards the equatorial plane in the octupole case, to reach this plane in the quadrupole case. In the quadrupole case, the matter flows directly onto the stellar equator, similar to the purely hydrodynamic case. With the column positioned closer to the equatorial plane, runs tend to be more stable and reach the quasi-stationarity easier than in the cases with the stellar dipole field.

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