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Two-dimensional MHD model of gas flow dynamics near a young star with a jet and a protoplanetary disk

V. V. Grigoryev, D. V. Dmitriev and T. V. Demidova

Crimean astrophysical observatory

Abstract. A numerical nonstationary two-dimensional MHD model of a protoplanetary disk near T Tauri star with a jet is developed. The model assumes consideration of pure gas ionization, optically thin cooling, anisotropic thermal conductivity and viscosity. The relaxation of gas-dynamic flows is analyzed. Based on the evolution of plasma flows, profiles of hydrogen spectral lines have been obtained.

Keywords. T Tau stars, protoplanetary disks, MHD, Radiative transfer

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1. The model

The two-dimensional model is implemented using the PLUTO package (Mignone et al. 2007), which allows solving the non-stationary MHD equations by the Godunov method. The equations are: mass continuity equation, motion equation (magnetic pressure, gravitational force, external forces and viscosity are included), energy equation (the same processes as in motion equation with optically thin cooling and thermal conductivity are included).

This equation system is closed by ideal gas equation, taking into account recombination processes by optically thin cooling, described in module SNEq (includes 16 different line emissions coming from some of the most common elements and the hydrogen ionization and recombination rate coefficients, see details in PLUTO documentation).

Viscosity is taken into account isotropically based on Shakura and Sunyaev (1976) model. Anisotropic thermal conductivity is taken into account in accordance with analytical formulas Balbus (1986), Cowie and McKee (1977).

Two-dimenstional grid ($(R,\theta) \in [0.35; 8]L_0 \times (0;\pi)$, 64×128 cells) is uniform on θ and logarithmic on R-direction, $L_0 = 4.2 \times 10^{11}$ cm $= 6R_\odot$, where $R_\odot$ — solar radius.

The initial conditions are the same as in Romanova et al. (2002), Type I. The outer boundary condition on $R \approx 0.23$ a.u. is outflow, in the border cells closest to the star a stellar atmosphere is modelled with a small thickness. The boundary conditions on θ satisfy the axisymmetry ones, but in the angle no more than 3.5° jet is modelled: matter is less dense than the corona of the disk, and it flies away from the star at a speed of no less than local escape velocity. The value 3.5° is chosen empirically and can be changed later.

2. Results

The plot Fig. 1 (left) shows the density at time $t = 38t_0$ ($t_0 \approx 2.5 \times 10^4$ s, $2\pi t_0$ is one orbital period at the distance L_0 from the center of the star). The matter of the disk has formed two accretion columns. Initially, they were formed by the corona material during about one period of rotation. These accretion columns enclose two hot bubbles that are

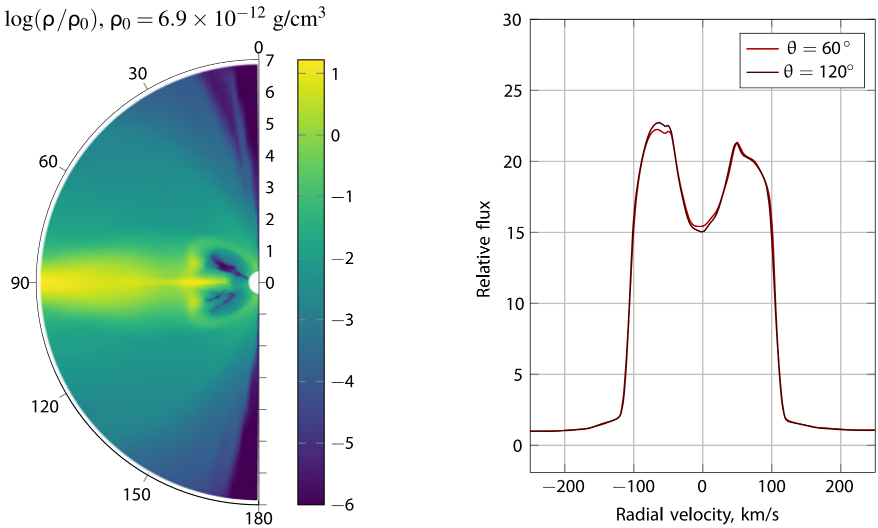

Figure 1. Left — density distribution at $t = 38t_0$. Right — emission in Br_γ at $t = 49.5t_0$.

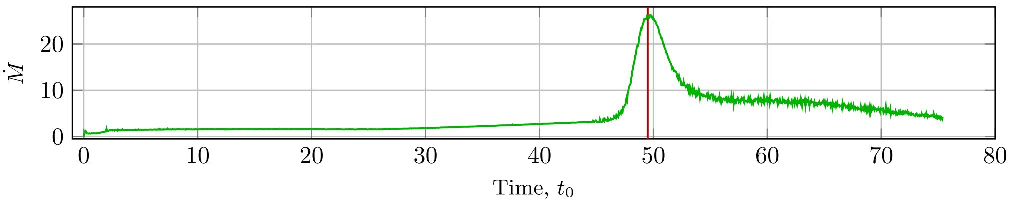

Figure 2. Accretion rate $\dot{M}$ in units 10^{-9} $M_\odot$/year during the simulation. $M_\odot = 2 \times 10^{33}$ g is solar mass.

part of the magnetosphere. Analysis of the dynamics shows unstable accretion rate (see Fig. 2) and variable equatorial radius of the magnetosphere, so there is no equilibrium yet.

To calculate hydrogen emission spectra we solve system of statistical equilibrium equations for a 15-level hydrogen atom (Grinin and Katysheva 1980). Sobolev (1960) approximation is used to solve radiation transfer in lines and find mean intensities. After solving statistical equilibrium equations for level populations we use ray-by-ray integration with Doppler line absorbtion core to find emergent transition line profile (Dmitriev et al. 2019). The spectral line Br_γ at the moment of maximum accretion rate is shown in Fig. 1 right.

Acknowledgements

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