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Rising magnetic flux tubes as a source of IR-variability of the accretion disks of young stars

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Abstract. We investigate dynamics of slender magnetic flux tubes (MFT) in the accretion disks of young stars. Simulations show that MFT rise from the disk and can accelerate to 20-30 km/s causing periodic outflows. Magnetic field of the disk counteracts the buoyancy, and the MFT oscillate near the disk's surface with periods of 10-100 days. We demonstrate that rising and oscillating MFT can cause the IR-variability of the accretion disks of young stars.

Keywords. Accretion, accretion disks, instabilities, MHD, ISM: jets and outflows, ISM: magnetic fields, infrared: ISM

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1. Introduction

Young stars with accretion disks born with large-scale magnetic field, according to theory of fossil magnetic field (see Dudorov & Khaibrakhmanov 2015). We developed an MHD model of the accretion disks with magnetic field (Dudorov & Khaibrakhmanov 2014, Khaibrakhmanov *et al.* 2017). Simulations have shown that Ohmic dissipation and ambipolar diffusion limit generation of the magnetic field in regions of low ionization fraction. In the regions where ionization fraction is high, magnetic field is frozen in gas, and generation of strong toroidal magnetic field is possible. Runaway growth of the magnetic field can be limited by magnetic buoyancy instability. This instability leads to formation of slender magnetic flux tubes (MFT, see Parker 1979), that rise from the disk and carry away the excess of magnetic flux (see Khaibrakhmanov & Dudorov 2017). In this work, we present our model of MFT dynamics in the accretion disks of young stars (see details in Khaibrakhmanov *et al.* 2018; Dudorov *et al.* 2019).

2. Model description

We consider geometrically thin, optically thick accretion disk in hydrostatic equilibrium. Vertically stratified polytropic disk is considered. We investigate the dynamics of the unit length cylindrical MFT as a part of magnetic flux ring. Dynamics of slender MFT in the z-direction under the action of buoyant and drag forces is investigated. Turbulent drag is considered inside the disk, and aerodynamic drag above the disk. Heat exchange between the MFT and external gas is calculated in frame of radiative diffusion approximation.

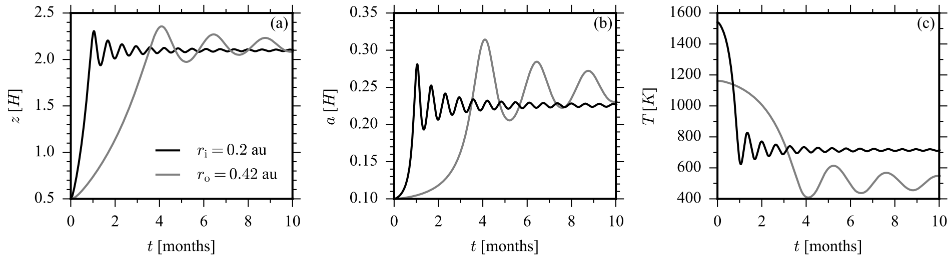

Figure 1. Dependences of z-coordinate (panel (a)), radius (panel (b)) and temperature (panel (c)) of the MFT in the disk of star J11092266-7634320 from Chameleon I cluster. Two representative distances are considered (0.2 au and 0.42 au). H is the scale height of the disk.

3. Results and discussion

In absence of exernal magnetic field, the MFT rapidly accelerates, then rises with slowly increasing velocity, decelerates a little and acquires nearly steady velocity above the surface of the disk. The MFT with stronger magnetic field move faster. The MFT with plasma beta of 0.01 can reach velocity up to $20-30$ km s^{-1}. The MFT expands during rise. We conclude that rising MFT form outflowing magnetized corona of the disk.

External magnetic field changes dynamics of the MFT. The MFT rise from the disc and then oscillate near its surface, where intensities of external and internal magnetic fields are equal, and the buoyant force vanishes. The oscillations periods are of 10-100 days depending on the magnetic field strength. Ultimately the oscillations decay. The MFT pulsates during the oscillations. It also exhibits temperature oscillations.

We apply our numerical results for interpretation of IR-variability of T Tauri stars from Chameleon I cluster found by Flaherty, *et al.* (2016). As an example, in Fig. 1 we plot dependences of z-coordinate, radius and temperature on time for the MFT in the disk of star J11092266-7634320. Fig. 1 shows that radius and temperature of MFT experience oscillations at height $z \sim 2.1\,H$ decaying in time, where H is the scale height. Maximal temperature variations are of 200 K. Corresponding periods are 1 and 4 months at $r = 0.2$ au and 0.42 au, respectively. The MFT has large optical depth in IR range, therefore their temperature variations should appear as variability of the IR-brightness of the disk. Observed IR-variability period for star J11092266-7634320 (32 days) can be explained by oscillating MFT with initial plasma beta 1 and radius $0.1\,H$.

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