Origins: From the Protosun to the First Steps of Life
Proceedings IAU Symposium No. 345, 2018
B. G. Elmegreen, L. Viktor Tóth & M. Güdel, eds.

doi:10.1017/S1743921319001443

Large-scale magnetic field of the accretion disks of T Tauri stars

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Abstract. The large-scale magnetic field in the accretion disks of young stars is investigated. Main features of our magnetohydrodynamical (MHD) model of the accretion disks and typical simulation results are presented. We discuss the role of MHD effects, ionization structure, magnetic field geometry and strength of the accretion disks.

Keywords. Accretion, accretion disks, instabilities, MHD, ISM: magnetic fields

1. Introduction

Stars with accretion disks born with large-scale magnetic field, according to theory of fossil magnetic field (see Dudorov & Khaibrakhmanov 2015). Efficiency of angular momentum transport mechanisms in the accretion disks depends on the strength and geometry of the magnetic field (see Papaloizou & Lin 1995), which are still poorly known.

In this paper, we present an MHD model of the accretion disks of young stars developed by Dudorov & Khaibrakhmanov (2014), Khaibrakhmanov *et al.* (2017). We calculate the strength and geometry of the magnetic field in the accretion disks of T Tauri stars and make synthetic polarization maps of the dust continuum emission to predict the appearance of the disks with magnetic field.

2. Model description

We consider a stationary geometrically thin and optically thick disk of a T Tauri star. The disk's inner boundary $r_{\rm in}$ is the stellar magnetosphere, the outer boundary is the contact boundary with the ISM. Disk vertical structure is calculated assuming hydrostatic equilibrium. The model includes equations of Shakura & Sunyaev (1973), induction equation taking into account Ohmic diffusion (OD) and ambipolar diffusion (AD), magnetic buoyancy and the Hall effect, equations of thermal and collisional ionization taking into account cosmic rays, X-rays, radionuclides, radiative recombinations and recombinations on dust grains. In the present work, we additionally include dissociative recombinations, charge transfer reactions and grain charges following Tassis & Mouschovias (2005). Evaporation of dust grains is included in the model.

Below we discuss the results of simulation for stellar mass $M = 1\,M_\odot$, accretion rate $\dot{M} = 3\times 10^{-8}\,M_\odot\,{\rm yr}^{-1}$, turbulence parameter $\alpha = 0.01$, dust grain radius $0.5\,\mu$m. Other parameters are adopted according to Khaibrakhmanov *et al.* (2017).

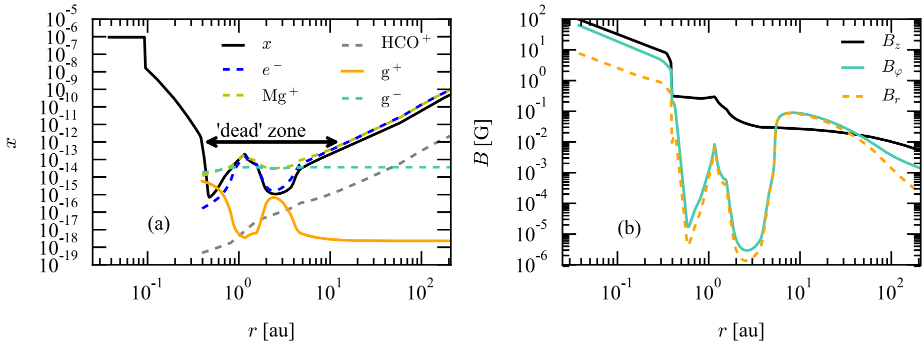

Figure 1. Panel (a): radial profiles of fractional abundances of the charged species (x is the ionization fraction). Panel (b): radial profiels of magnetic field components.

3. Results and discussion

In Fig. 1(a) we plot radial profiels of the fractional abundances of charged species and of the total ionization fraction x. The profile of the ionization fraction is non-monotonic. Thermal ionization operates, and magnetic field is frozen into gas at $r < 0.5$ au. The region of low ionization fraction, $x < 10^{-12}$ ('dead' zone) is located at $0.5 < r < 30$ au. The small peak $x \sim 10^{-12}$ near $r \approx 1$ au is due to evaporation of dust grain mantles. The ionization fraction is high due to cosmic rays ionization at $r > 30$ au. Electrons, metal ions and negatively charged grains are the main charge carriers inside the 'dead' zone.

In Fig. 1(b) we plot the radial profiels of the magnetic field components. The magnetic field geometry is quasi-azimuthal at $r < 0.5$ au. Magnetic buoyancy hinders growth of B_φ in this region. The magnetic field is quasi-uniform due to OD inside the 'dead' zone. It is quasi-radial near the borders of the 'dead' zone due to the Hall effect. AD hinders growth of B_r outside the 'dead' zone, and the magnetic field geometry is quasi-azimuthal. The upper boundary of the 'dead' zone is determined by AD and lies below the disk's surface. Surface density of the active layer above the 'dead' zone is of $5 - 10\,\mathrm{g\,cm^{-2}}$.

Magnetic field strength is characterized by plasma $\beta \sim 10 - 100$ near the inner boundary of the disk, $\beta \sim 10^{-5}$ at $r = 3\,$au, and $\beta \sim 1 - 10$ near the outer boundary (240 au).

We made the synthetic maps of polarized continuum dust emission using the accretion disk structure. It is considered that the polarization comes from dust grains alignment with the magnetic field direction in the disk (see details in Khaibrakhmanov *et al.* 2017). The polarization maps shows that the 'dead' zones can be observed as regions with lowest polarization degree in the polarization maps.

Acknowledgements

This investigation is supported by Russian Foundation for Basic Research (project 18-02-01067) and by the Ministry of Science and High Education (the basic part of the State assignment, RK no. AAAA-A17-117030310283-7).

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