ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

Modelling the spectral energy distributions of the accretion disks of young stars with fossil magnetic field

D. Frol[1] and S. Khaibrakhmanov[1,2,3]

[1] Ural Federal University, 19 Mira, Ekaterinburg, 620002 Russia
[2] Saint-Petersburg University, 7-9 Universitetskaya Emb., St. Petersburg, 199034 Russia
[3] Chelyabinsk State University, 129 Br. Kashirinykh, Chelyabinsk, 454001 Russia

Abstract. This work focuses on the study of the thermal structure and observational appearance of the accretion discs of young stars that possess fossil magnetic fields. We analyse the influence of magnetohydrodynamics (MHD) effects on the disc temperature and its spectral energy distribution (SED). The simulations indicate that, with low accretion rates of $\dot{M} < 10^{-8}\,M_{\odot}/\text{yr}$, Ohmic heating leads to an increase in the disc temperature by 100 K near the inner boundary. This effect causes an increase in the radiation flux of the disc in the mid-infrared range.

Keywords: ISM: magnetic fields; accretion; accretion disks; magnetohydrodynamics (MHD)

DOI: 10.26119/VAK2024.054

1 Introduction

Accretion discs around young stars are thin rotating structures of gas and dust with sizes of about 100 AU to 1000 AU and mass of $0.001\,M_\odot$ to $0.1\,M_\odot$. The rate of mass accretion onto the star decreases from $10^{-6}\,M_\odot$/yr to $10^{-9}\,M_\odot$/yr during the evolution of these discs. Over time, such accretion discs can turn into protoplanetary discs, where the conditions are favourable for the formation of planets.

Analysis of the observational data allows us to state that accretion discs and protoplanetary discs of young stars have a large-scale magnetic field that may be of a fossil nature (Khaibrakhmanov 2024). Modern models suggest that MHD may impact the structure of accretion and protoplanetary discs of young stars (Khaibrakhmanov & Dudorov 2022).

In the present work, we study the conditions under which Ohmic heating affects the thermal structure of the disc. In order to study the observational appearance of the disks with magnetic field, we calculate the spectral energy distributions (SEDs) of the disks.

2 Model

The MHD model of Khaibrakhmanov & Dudorov (2022) is used to calculate the disc structure. A stationary geometrically thin and optically thick disc in magnetostatic and centrifugal equilibrium is considered. According to the model of Shakura & Sunyaev (1973), the angular momentum is assumed to be transported via turbulence. The magnetic field is calculated taking into account Ohmic and ambipolar diffusion, magnetic buoyancy, and the Hall effect. The influence of Ohmic heating on the thermal structure of the disc is taken into account (Khaibrakhmanov & Dudorov 2019). The main parameters of the model include the turbulence parameter, α, which relates to the efficiency of turbulence in the angular momentum transport, and the accretion rate $\dot{M}$.

The SED calculations use the model developed by Bertout et al. (1988), which assumes that the star and the disc emit radiation as black bodies of specified sizes. In the calculations, the disc was considered to have inner and outer radii of $R_{\rm in} = 0.1$ AU and $R_{\rm out} = 100$ AU, respectively.

The study focused on a typical representative of T Tau type stars of spectral class K7, with the following parameters: $M_\star = 1\,M_\odot$, $R_\star = 2\,R_\odot$, $T_{\rm eff} = 4000$ K, and $L_\star = 2\,L_\odot$. The young stellar object is assumed to be located at a distance of 140 pc from the Earth, with the plane of the disc oriented perpendicular to the line of sight. The algorithm for calculating the SED based on the given disc structure is implemented as a software package in Python.

3 Results

To study the effect of Ohmic heating on the disk thermal structure, two series of numerical simulations were performed:

1) taking into account viscous heating, heating by stellar radiation and cosmic rays,
2) taking into account Ohmic heating additionally. The turbulence parameter α and the accretion rate $\dot{M}$ were varied during the modelling process.

The simulations showed that for standard values of $\alpha = 0.01$ and $\dot{M} = 10^{-8}\,M_{\odot}/\mathrm{yr}$, the MHD effects do not influence the disk structure. The MHD heating rate is significantly lower than the viscous heating rate, meaning that the dissipation of currents does not have a notable impact on the thermal structure of the disc.

In Fig. 1a, b, the radial profiles of the effective temperature of the disk are plotted, as well as corresponding SEDs, for runs with $\alpha = 0.0001$ and $\dot{M} = 10^{-8}\,M_{\odot}/\mathrm{yr}$. Fig. 1a illustrates that the temperature in second run decreases monotonically from 800 K to 20 K as the distance r increases. The comparison of the temperature profiles (Fig. 1a) shows that, for Ohmic heating (line 1), there is a local temperature increase of about 100 K in the inner regions of the disk within the region from 0.2 AU to 0.8 AU.

In Fig. 1b, we plot the SEDs of the star (grey line) and the disc (dashed and dotted lines). The black body SED of the star has a maximum at a wavelength of 10 μm. The SED of the disc for solution (2) shows two maxima at wavelengths of 100 μm and 2 mm, with the first peak representing the inner region of the disc and the second peak corresponding to its periphery. The increase in local temperature within the temperature profile has an effect on the SED, resulting in an increase in the emission flux from the disc associated with Ohmic heating (1). Fig. 1b shows the difference between lines 1 and 2 in the region from 20 μm to 1 mm.

Temperature profiles and SEDs for $\alpha = 0.01$ and $\dot{M} = 10^{-9}\,M_{\odot}/\mathrm{yr}$ are plotted in Fig. 1c, d. For a lower than standard accretion rate, a local temperature increase of 100 K is observed for the solution (3) in the regions from 0.1 AU to 0.2 AU. This temperature increase caused by Ohmic heating leads to an increase in the radiation flux of the disc in the region from about 20 μm to 1 mm.

4 Summary

It has been demonstrated that Ohmic heating affects the disc temperature and its spectral shape, especially with low turbulence parameters (less than $\alpha = 0.01$) and low accretion rates (less than $\dot{M} = 10^{-8}\,M_{\odot}/\mathrm{yr}$). The disks with a small accretion rate are usually at the final stages of their evolution. The study of SED objects with

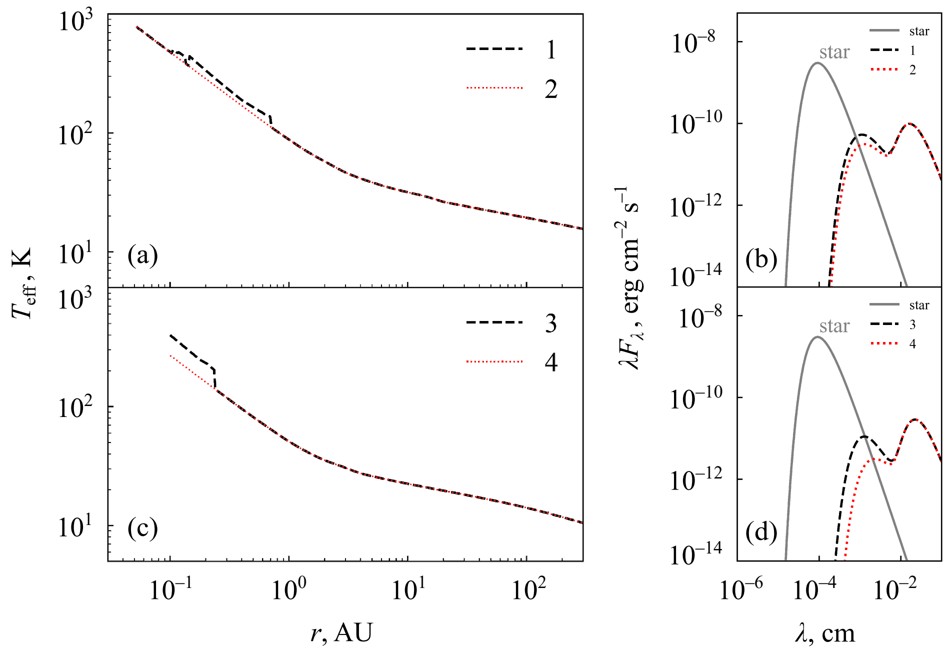

Fig. 1. Left panel: radial profile of the effective temperature of the disc, right panel: spectral energy distributions of the star and protoplanetary disc. The lines corresponding to the solutions considering Ohmic heating are labelled by numbers 1 and 3, without it by numbers 2 and 4. Upper panels: $\alpha = 0.0001$ and $\dot{M} = 10^{-8}\,M_\odot$/yr. Lower panels: $\alpha = 0.01$ and $\dot{M} = 10^{-9}\,M_\odot$/yr.

these characteristics can serve as an important tool to analyse the influence of MHD effects on their structure and evolution.

Funding

This work was financially supported by the Ministry of Education and Science of the Russian Federation (project No. FEUZ-2020-0038).

References

Bertout C., Basri G., Bouvier J., 1988, Astrophysical Journal, 330, p. 350
Khaibrakhmanov S. 2024, Astronomical and Astrophysical Transactions, 34, 2, p. 139
Khaibrakhmanov S. and Dudorov A., 2019, Magnetohydrodynamics, 55, 1/2, p. 65
Khaibrakhmanov S. and Dudorov A., 2022, Astronomy Reports, 66, 10, p. 872
Shakura N. and Sunyaev R. 1973, Astronomy & Astrophysics, 24, p. 337