6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

The effect of disk thickness on magnetic field transport

Ryoya Yamamoto[1], Shinsuke Takasao[1]
[1] Department of Earth and Space Science, Graduate School of Science, Osaka University
e-mail (speaker): ryoya@astro-osaka.jp

The global magnetic field threading an accretion disk is important for driving disk winds and jets. However, the mechanism that determines the global magnetic field distribution, or the magnetic flux transport, is still an open question. Previous 1D models of magnetic flux transport pointed out that the electric current produced by the radial component of the magnetic field, B_R, plays an important role in magnetic diffusion. As the electric current expressed as $J_\phi \propto B_R/H$ is larger in geometrically thin accretion disks, the accumulation of magnetic flux toward the center is difficult in such thin disks due to strong magnetic diffusion [1]. On the other hand, as the diffusion timescale is longer in a thicker disk, the accumulation of magnetic flux around the center occurs efficiently [2]. To reveal the origin of magnetically driven jets and winds, it is necessary to investigate flux transport in such thick disks.

We developed a code to simulate magnetic flux transport in 2D spherical coordinates with a small numerical cost, which enables us to investigate the effect of disk thickness for magnetic flux transport. The code uses the framework of the public MHD code Athena++ [3]. We focus on RIAF and supercritical accretion disk, which are representative of thick disks. To examine the magnetic flux transport in these two types of thick disks, we adopt the velocity field of the self-similar solution for RIAF [4] and the quasi-analytic solution of supercritical accretion disk [5], respectively, in our kinematic model. The magnetic diffusion coefficient is quantified by the magnetic Prandtl number defined as $P_m = \nu/\eta$. We take P_m as a free parameter. We compared the results of 2D simulations with those of the previous 1D models to reveal the condition under which the geometrical effects are significant.

Figure 1 shows the steady-state poloidal field structure for typical parameters. The left and right panels display the results of RIAF and supercritical accretion disk, respectively. Here, we adopted $P_m = 1$. The initially uniform vertical magnetic field is advected by accreting flows, which form the hourglass-shaped magnetic field structure.

Figure 2 shows the plot of the vertical component of the field, B_z, at the equatorial plane, in the case of $P_m = 2/3$. We found that for typical P_m which is around unity, the magnetic field strength in the 2D model is smaller than that in the 1D model. We found that the difference is more prominent in the slim region in the supercritical accretion disk with $H/R \approx 3$ than in the RIAF with $H/R \approx 0.5$. We also found that this difference is more prominent in the case of stronger magnetic diffusion (i.e., $P_m \lesssim 1$). These results indicated that the 1D approximation is violated in the thick disk. In this presentation, we will discuss the multidimensional effect on the magnetic flux transport and the possible applications to disks in X-ray binaries and AGNs.

References

[1] Lubow, S. H., Papaloizou, J. C. B., & Pringle, J. E. 1994a , MNRAS, 267, 235
[2] Begelman, M. C., & Armitage, P. J. 2014, ApJ, 782, L18
[3] Stone, J. M., Tomida, K., White, C. J., & Felker, K. G. 2020, ApJS, 249, 4
[4] Narayan R., & Yi I. 1994, ApJ, 428, L13
[5] Watarai, K. 2006, ApJ, 648, 523

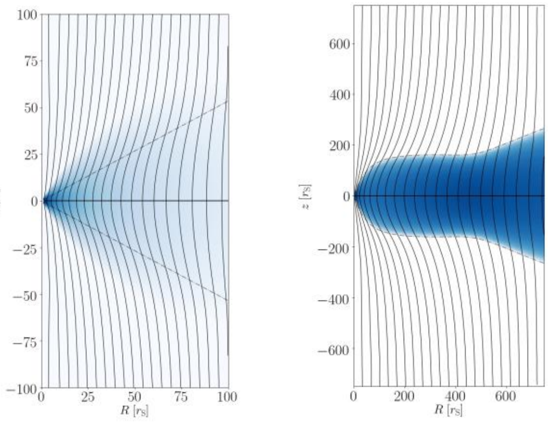

Figure 1.
The steady-state poloidal field structure. Left panel: RIAF. Right panel: supercritical accretion disk. The solid line represents the poloidal field structure, and the dashed line represents the location of the disk scale height. The blue color denotes the density distribution.

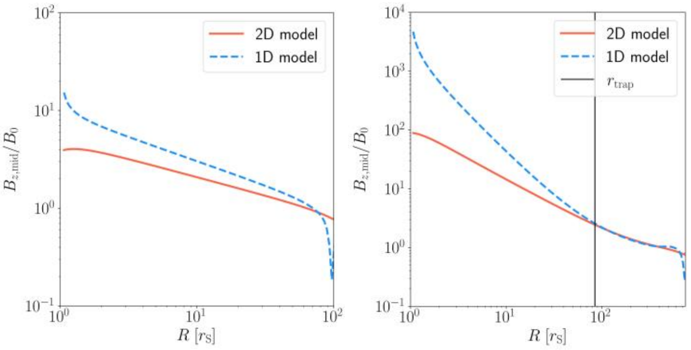

Figure 2.
The steady-state magnetic field strength at the equatorial plane of the disk. Left panel: RIAF. Right panel: supercritical accretion disk. The red line is the result of the 2D model, and the blue line is 1D model.