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Effects of Toroidal Magnetic Fields on the Thermal Instability of Thin Accretion Disks

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Abstract. The standard thin disk model predicts that when the accretion rate is moderately high, the disk is radiation–pressure-dominated and thermally unstable. However, observations indicate the opposite, namely the disk is quite stable. We present an explanation in this work by taking into account the role of the magnetic field which was ignored in the previous analysis.

Key words. Accretion—accretion disks—black hole physics—instabilities.

1. Introduction

The stability theory of the standard accretion disk model predicts that, when the luminosity of the disk is higher than $\sim 0.06 L_{\rm Edd}$, the innermost region of the disk will be both thermally and secularly unstable. However, in some luminous X-ray binaries the luminosity can even exceed $0.5 L_{\rm Edd}$ with little variability on the observed thermal time-scale. This result indeed challenges the standard disk theory.

We note that the behaviour of the toroidal magnetic field against a thermal perturbation may influence the disk stability. This has been partially supported by the MHD simulation of hot flows (Machida *et al.* 2006). In this work, we propose a parametric constraint on the relation between the perturbations of the mean toroidal magnetic field and the disk scale height about a thermal equilibrium state, i.e.,

$$\delta B_\varphi / B_\varphi = -n\,\delta H / H.$$

With this assumption, we obtain a general thermal instability criterion for magnetized thin disks, i.e.,

$$\Delta = 2 - 5\beta_{\rm gas} - 4(1+n)\beta_{\rm mag} - 6 f_{\rm adv} + 8 f_{\rm adv}\beta_{\rm gas} + (8+4n) f_{\rm adv}\beta_{\rm mag} > 0,$$

where $\beta_{\rm gas}$, $\beta_{\rm mag}$ and $f_{\rm adv}$ are the ratio of gas pressure to total pressure, the ratio of magnetic pressure to total pressure, and the advection factor, respectively.

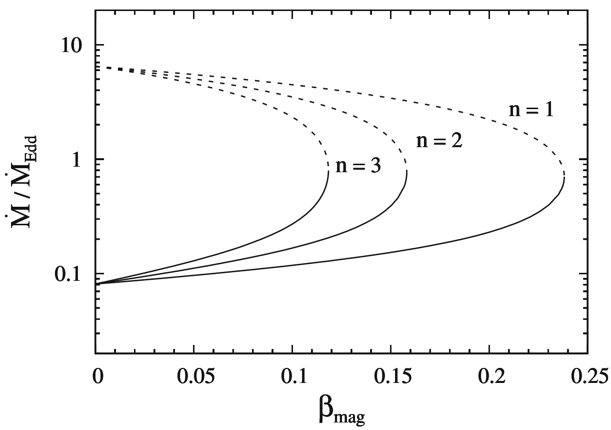

Figure 1. Thermal stability of the disk at $R = 10R_{\rm g}$ for different n.

2. Thermal stability of thin disks

In our study, we focus on $1 \le n \le 3$ since $n = 1$ corresponds to the conservation of toroidal magnetic flux per unit radius (Machida *et al.* 2006), and $n = 3$ corresponds to the conservation of the advection rate of toroidal magnetic flux (Oda *et al.* 2010). Figure 1 shows the stability of a thin disk for various $\dot{M}$ and $\beta_{\rm mag}$. Each curve is specified by a certain n, and represents the dividing line of the thermally unstable (inside) and stable (outside) parameter regions. The trend of each *solid* curve shows that the critical accretion rate increases with increasing $\beta_{\rm mag}$. When $\beta_{\rm mag}$ is large enough, e.g., exceeding a threshold of ~ 0.24 for the case of $n = 1$, the disk is thermally stable for any accretion rate. Larger the n parameter, lower the threshold turns.

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