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Line and Continuum Emission from the Outer Regions of a Self-Gravitating, Magnetized Accretion Disk[1]

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Abstract. We determine the variation with radius of the physical parameters (scale height, central density, and central temperature) of a stationary self-gravitating, magnetized accretion disk at radii larger than $10^2 R_G$. Our results are relevant in the context of line and continuum emission from the outer region of the disk. We have also studied the influence of self-gravitation and magnetic fields over typical radii, and have shown that the value of $R_{\rm BB}$ is larger than that computed by Collin-Souffrin & Dumont by a factor of about 4.7.

1. Introduction

Since the α-model of accretion disks was first suggested by Shakura & Sunyaev (1973), it has been widely used in various astrophysical studies. Shields (1977) showed that the broad-line emission can be induced in AGN by the illumination of an accretion disk at a distance of 10^3–10^4 gravitational radii. This possibility has been explored by Begelman & McKee (1983) and by Mardaljevic et al. (1988). Recently, Collin-Souffrin (1987), Collin-Souffrin & Dumont (1990, hereafter CS), and Dumont & Collin-Souffrin (1990a, 1990b) have done considerable work on the line and continuum radiation from the outer regions of accretion disks in AGN. This paper is devoted to the study of the radial outer-disk structure and typical radii, which are very important in the formation of both line and continuum emission. Our model differs from other studies mainly in considering both self-gravitation and magnetized accretion-disk structure.

2. Basic Equations

The basic equations are as follows:

$$\dot{M} = 2\pi H R n_c m_p V_r \tag{1}$$

$$V_r = \alpha C_s H/R \tag{2}$$

$$t_{r\phi} = \dot{M}\Omega/4\pi h. \tag{3}$$

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Using the conservation model of the magnetic flux (Sakimoto & Coroniti 1981), we have

$$t_{r\phi} = \Gamma H^2 m_p^2 n_c^2, \tag{4}$$

where $\Gamma = (2\pi G\alpha)^{-1}$. The gravitational energy release $D(R)$ is

$$D(R) = \frac{3GM\dot{M}}{4\pi R^3} \tag{5}$$

$$g = g_s + g_z = 2\pi G\Sigma_z + GM/R^2, \tag{6}$$

and defining

$$a^2 = g_s/g_z, \tag{7}$$

where g_s is due to self-gravitation and g_z due to the central gravitation. The pressure is given by

$$P = P_m + P_g = \frac{B^2}{8\pi} + \frac{n_c k T_c}{\mu}, \tag{8}$$

defining $\beta = P_g/P$, where P_g is the gas pressure, P_m the magnetic pressure, and μ is the mean molecular mass ($\mu = 0.65$ for an ionized gas with cosmic abundances). In the outer region of the disk, the gas pressure dominates, and H can thus be written

$$H(R) = 2\left(\frac{\beta k T_c}{\mu m_p}\right)^{1/2} R^{3/2}(GM)^{-1/2}(1+a^2)^{-1/2}. \tag{9}$$

The effective temperature T_{eff} corresponding to the gravitational energy release is given by

$$\sigma T_{eff}^4 = D(R), \tag{10}$$

and the central temperature is roughly

$$T_c = T_{eff}(0.75\tau)^{1/4}, \tag{11}$$

where τ is a mean vertical optical thickness (Frank et al. 1985). It is very important to use reasonable opacities, so we adopted different opacities for different regions as in the work by CS. From these basic eqs. (1)–(11), we then get the radial dependence of the central temperature T_c and central density n_c, and the scale height H. Table 1 summarizes the results obtained from the different regimes: it gives twice the scale height H_{10} (in units of 10^{10} cm), the central density n_{c15} (in units of $10^{15}\,\mathrm{cm}^{-3}$), the central temperature T_c, the column density, $N_{25} = (\pi/2)^{1/2} n_{c15} H_{10}$ (in units of $10^{25}\,\mathrm{cm}^{-2}$), and the mean optical thickness τ, as functions of the luminosity L_{44} (in units of 10^{44} ergs s^{-1}) and of ρ, the radius divided by $10^4 R_G = 10^4(2GM/c^2)$. These results are illustrated in Figs. 1–3 which display T_c, n_c, and H as functions of the radius ρ for the different regimes. An important quantity is the dimensionless radius ρ_{BB}, where the T_{eff} is equal to 10^4 K. It is given by

$$\rho_{\mathrm{BB}} = 14.3 \times 10^{-2}(1+a^2)^{-7/51}\beta^{8/17}\alpha^{16/17} f_\epsilon^{14/51} f_L^{2/3} L_{44}^{-2/3}. \tag{12}$$

If we let a^2, β, α, f_ϵ, f_L, $L_{44} \approx 1$, then

$$\rho_{\rm BB} \approx 12.9 \times 10^{-2} \tag{13}$$

and

$$R_{\rm BB} \approx 1.29 \times 10^3 R_g. \tag{14}$$

Table 1.

Quantity	Regime A	C	E	D	F
Opacity ($\mathrm{cm^2\,g^{-1}}$)	0.4	0.001	1	1	1
T_c (K)	572[a]	27.6[a]	906[a]	1400	7000
N_{25} ($\mathrm{cm^{-2}}$)	2.61[b]	0.573[b]	3.28[b]	4.08[c]	9.13[c]
H_{10} (cm)	0.35[d]	0.072[d]	0.44[d]	0.55[e]	1.23[e]
n_{c15} ($\mathrm{cm^{-3}}$)	5.94[f]	5.94[f]	5.94[f]	5.94[f]	5.94[f]
τ	3.496[g]	0.0019[g]	10.97[g]	...	< 1

[a] $\beta(1+a^2)^{-1/4}\alpha^{5/2}f_\epsilon^{1/2}f_L^{3/2}L_{44}^{-3/2}\rho^{-9/4}$

[b] $\beta(1+a^2)^{-1/8}\alpha^{13/4}f_\epsilon^{1/4}f_L^{7/4}L_{44}^{-7/4}\rho^{-21/8}$

[c] $\beta^{1/2}\alpha^2 f_L L_{44}^{-1}\rho^{-3/2}$

[d] $\beta f_\epsilon^{1/4}f_L^{-1/4}L_{44}^{1/4}\alpha^{5/4}\rho^{3/8}(1+a^2)^{-5/8}$

[e] $\beta^{1/2}(1+a^2)^{-1/2}f_L^{-1}L_{44}\rho^{3/2}$

[f] $\alpha^2(1+a^2)^{1/2}f_L^2 L_{44}^{-2}\rho^{-3}$

[g] $\beta(1+a^2)^{-1/8}\alpha^{13/4}f_\epsilon^{1/4}f_L^{7/4}L_{44}^{-7/4}\rho^{-21/8}$

3. Conclusions

As Table 1 and Fig. 1 show, our main results are very similar to those of CS, but our value of $R_{\rm BB}$ is greater than that of CS $R_{\rm BB}$ by a factor of about 4.7. In the region 10^3–$10^4 R_g$, several AGNs display double-peaked broad lines (cf. Hure et al. 1994). Equation (14) shows that $R_{\rm BB}$ is just in this region, so $\rho_{\rm BB}$ will play an important role in line formation. This result is different to the results of CS, because we have considered both self-gravitation and magnetic fields in our model.

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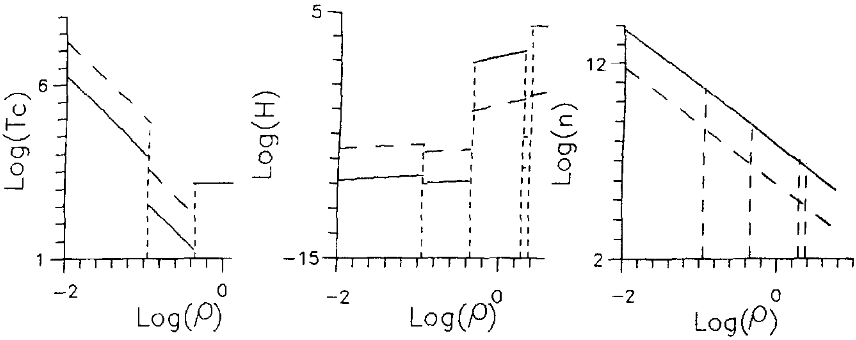

Figure 1. The dashed line corresponds to $a = 0$ and the solid line to $a = 10$.

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