Viscous-Resistive ADAF with a general Large-Scale Magnetic Field

Shahram Abbassi\(^1\,\,2\) • Amin Mosallanezhad\(^3\,\,4\)

Abstract We have studied the structure of hot accretion flow bathed in a general large-scale magnetic field. We have considered magnetic parameters \(\beta_{r,\phi,z} = \frac{c^2_{r,\phi,z}}{(2c^2_s)}\), where \(c^2_{r,\phi,z}\) are the Alfvén sound speeds in three direction of cylindrical coordinate \((r, \phi, z)\). The dominant mechanism of energy dissipation is assumed to be the magnetic diffusivity due to turbulence and viscosity in the accretion flow. Also, we adopt a more realistic model for kinematic viscosity \(\nu = \alpha c_s H\) with both \(c_s\) and \(H\) as a function of magnetic field. As a result in our model, the kinematic viscosity and magnetic diffusivity \(\eta = \eta_0 c_s H\) are not constant. In order to solve the integrated equations that govern the behavior of the accretion flow, a self-similar method is used. It is found that the existence of magnetic resistivity will increase the radial infall velocity as well as sound speed and vertical thickness of the disk. However, the rotational velocity of the disk decreases by the increase of magnetic resistivity. Moreover, we study the effect of three components of global magnetic field on the structure of the disk. We found out that the radial velocity and sound speed are Sub-Keplerian for all values of magnetic field, but the rotational velocity can be Super-Keplerian by the increase of toroidal magnetic field. Also, our numerical results show that all components of magnetic field can be important and have a considerable effect on velocities and vertical thickness of the disk.

Keywords accretion, accretion disks, magnetic field, magnetohydrodynamics:MHD

1 Introduction

The study of advection accretion flows around low luminosity black hole candidates and neutron stars is currently a very active field of research, both theoretically and observationally (for a review, see Narayan, Mahadevan & Quataert 1998). Observational evidence for the existence of low-luminosity black holes at the center of galaxies and in AGNs (Ho 1999) makes it necessary to revise theoretical models of the accretion discs. Thereby, the development of the subject of advection-dominated accretion flows (ADAFs) in recent years has led to global solutions of advection accretion discs around accreting black hole systems and neutron stars. In this case, viscously generated internal energy is not radiated away efficiently as the gas falls into the potential well of the central mass (as in standard thin disc models; Shakura & Sunyaev 1973). Instead, it is retained within the accreting gas and advected radially inward (Narayan & Yi 1994, hereafter NY1994) and might eventually be lost into the central object or, in contrast, a considerable portion of it might give rise to wind on to black holes and neutron stars (Blandford & Begelman 1999). By definition, ADAFs have very low radiative efficiency and as a consequence they can be considerably hotter than the gas flow in standard thin disc models (Narayan & Yi 1995a,b); therefore, they are ultra-dim for their accretion rates (Phinney 1981; Rees et al. 1982).

A notable problem arises when the accretion disc is threaded by a magnetic field. In the ADAF models, the temperature of the accretion disc is so high that the accreting materials are ionized. The magnetic field therefore plays an
important role in the dynamics of accretion flows. Some authors have tried to solve the magnetohydrodynamics (MHD) equations of magnetized ADAFs analytically. The effect of toroidal magnetic field on the disc were studied for example by Akizuki & Fukue 2006, Abbassi et al 2008, 2010 and Faghei 2012. Also Zhand & Dai 2008 have already considered global magnetic field on the disc. Ghanbari et al 2007, 2009 present the effect of viscous-resistive in ADAFs bathed in a dipole magnetic field. Resistive diffusion of magnetic field would be important in some systems, such as the protostellar discs (Stone et al. 2000; Fleming & Stone 2003), discs in dwarf nova systems (Gammie & Menou 1998), the discs around black holes (Kudoh & Kaburaki 1996), and Galactic center (Melia & Kowalenkov 2001; Kaburaki et al. 2010). In ADAF models, energy dissipation in the accretion flow can be assumed to be a result of turbulent viscosity and electrical resistivity. The Magnetic energy density of the flow must be dissipated by ohmic heating with a rate comparable to that of the viscous dissipation (Bisnovatyi-Kogan & Ruzmaikan 1974, Bisnovatyi-Kogan, Lovelace 1997). We argue that the ohmic and viscous dissipation must occur as a result of plasma instabilities. Bisnovatyi-Kogan, Lovelace 1997 point out that ohmic dissipation of magnetic energy density has an important role in heating process if accretion flows with condition of equipartition, $\varepsilon_{\text{mag}} \sim \varepsilon_{\text{kin}}$, where $\varepsilon_{\text{mag}}\xi\varepsilon_{\text{kin}}$ are the magnetic and kinetic energy density, respectively. In this regard, note that although Narayan & Yi (1995) assume an equipartition magnetic field, they do not consider the ohmic dissipation.

Under some conditions, it is important that we consider the effect of resistivity on accretion flows. Kuwabara et al. (2000) showed the results of global magnetohydrodynamic (MHD) simulations of an accretion flow initially threaded by large-scale poloidal magnetic fields, including the effects of magnetic turbulent diffusivity. They found the importance of the strength of magnetic diffusivity when they studied it in magnetically driven mass accretion. They pointed out that the mass outflow depends on the strength of magnetic diffusivity, so that for a highly diffusive disc, no outflow takes place.

In this paper, we extend the work of Akizuki & Fukue 2006 and ghanbari et al. 2007, Ghanbari et al 2009 and Faghei 2012 by considering large-scale magnetic field with three components in cylindrical coordinates $(r, \varphi, z)$ in a viscous-resistive accretion disc, and investigate the role of non-constant magnetic diffusivity in the system. Ghanbari, Salehi & Abbassi (2007) have presented a set of self-similar solutions for two-dimensional (2D) viscous-resistive ADAFs in the presence of a dipolar magnetic field of the central accretor. They have shown that the presence of a magnetic field and its associated resistivity can considerably change the picture with regard to accretion flows. The paper is organized as follows. In section 2 we present the basic magnetohydrodynamics equations, which include the three components of magnetic field and magnetic resistivity. Self-similar equations are investigated in section 3 and the summary will come up in section 4.

2 Basic Equations

Since we are interested in analyzing the structure of a magnetized ADAF bathed in a global magnetic field, we consider a magnetic field in the disc with three components, $B_r, B_\varphi, B_z$, we suppose that the gaseous disc rotating around a compact object of mass $M$. Thus, for a steady axisymmetric accretion flow, i.e., $\partial/\partial t = \partial/\partial \varphi = 0$, we can write the standard equations in the cylindrical coordinates $(r, \varphi, z)$. We vertically integrated the flow equations and, all the physical variables become only function of the radial distance $r$. Moreover, we neglect the relativistic effects and Newtonian gravity in radial direction is considered. For conservation of energy, it is assumed the energy which is generated due to viscosity and resistivity dissipation are balanced by the radiation and advection cooling. Under these assumption, we can rewrite the MHD equation as (Zhang & Dai 2008). So the equation of continuity gives

$$\frac{1}{r} \frac{d}{dr} (r \Sigma v_r) = 2 \rho H, \quad (1)$$

where $\Sigma$ is the surface density at the cylindrical radius $r$, which is define as $\Sigma = 2 \rho H$, $v_r$ the radial infall velocity, $\rho$ the mass loss rate per unit volume, $H$ would be the disc half-thickness and $\rho$ is the density of the disc.

The equation of motion in the radial direction is

$$v_r \frac{d v_r}{dr} = \frac{v_\varphi^2}{r} - \frac{G M_s}{r^2} - \frac{1}{\Sigma} \frac{d}{dr} (\Sigma c_s^2) - \frac{1}{2 \Sigma} \frac{d}{dr} (\Sigma c_s^2 + \Sigma c_\varphi^2) - \frac{c_\varphi^2}{r}, \quad (2)$$

where $v_\varphi$ is the rotational velocity, $c_s$ the isothermal sound speed, which is define as $c_s^2 \equiv \rho_{\text{gas}}/\rho$, $p_{\text{gas}}$ being the gas pressure. Here, $c_r, c_\varphi$ and $c_z$ are Alfvén sound speeds in three direction of cylindrical coordinate and are defined as

$$c_{r,\varphi,z}^2 = \frac{B_r,\varphi,z}{4 \pi \rho} \quad (3)$$

The equation of angular momentum transfer can be written as

$$v_r \frac{d}{dr} (r v_\varphi) = \frac{1}{r^2 \Sigma} \frac{d}{dr} (r^2 \nu \Sigma \frac{d \Omega}{dr}) + \frac{c_r}{\sqrt{\Sigma}} \frac{d}{dr} \left( \sqrt{\Sigma} c_\varphi \right) + \frac{c_r c_\varphi}{r} \quad (4)$$
where $\Omega = (v_\varphi/r)$ is the angular velocity. Also, we assumed that only the $\varphi$-component of viscous stress tensor is important which is $\tau_\varphi = \mu \nabla^2 \varphi$, where $\mu = \nu \rho$ is the viscosity and $\nu$ is the kinematic coefficient of viscosity.

The hydrostatic balance in vertical direction is integrated to

$$\Omega^2 H^2 - \frac{1}{\sqrt{\Sigma}} \frac{d}{dr} \left( \sqrt{\Sigma} c_s^2 \right) H = c_s^2 + \frac{1}{2} \left( c_r^2 + c_\varphi^2 \right), \quad (5)$$

Now we can write the energy equation considering cooling and heating processes in an ADAF. Therefore the energy equation will be

$$\frac{\rho v_r}{\gamma - 1} \frac{dc_r^2}{dr} - v_r c_r^2 \frac{d\rho}{dr} = Q_+ - Q_- \quad \text{ (6)}$$

where $\gamma$ is the ratio of specific heats. In the right hand side of energy equation, $Q_+ = Q_{vis} + Q_B$ is the dissipation rate by viscosity $Q_{vis}$ and resistivity $Q_B$, and also $Q_- = Q_{rad}$ represent the energy lose through radiative cooling. For the right hand side of energy equation we can write

$$Q_{adv} = Q_+ - Q_- = f Q_+ \quad \text{ (7)}$$

Here, $Q_{adv}$ represents the advection transport of energy and is defined as the difference between the magneto-viscous heating rate and radiative cooling rate. We employ the advection parameter $f = 1 - \frac{Q_-}{Q_+}$ to measure the hight degree to which accretion flow is advection-dominated. When $f \sim 1$ the radiation can be neglected and accretion flow is advection dominated while in the case of small $f$, disc is in the radiation dominated case. Now the viscous and resistive heating rate are expressed as

$$Q_{vis} = \nu \rho r^2 \left( \frac{dJ}{dr} \right)^2 \quad \text{ (8)}$$

$$Q_B = \frac{\eta}{4\pi} |J|^2 \quad \text{ (9)}$$

where $J = \nabla \times B$ is the current density. We assume both the kinematic viscosity coefficient $\nu$ and the magnetic diffusivity $\eta$ have the same units and to be due to turbulence in the accretion flow. Bisnovatyi-Kogan & Lovelace 1997 have also shown that the flows have an equipartition magnetic field with the results that dissipation of magnetic energy at a rate comparable to that turbulence must occur by ohmic heating. They argue that this heating occurs as a result of plasma instabilities. Then, it is physically reasonable to express $\eta$ such as $\nu$ via the $\alpha$-prescription of Shakura & Sunyaev (1973) as follow (Bisnovatyi-Kogan & Rusmaikin 1976)

$$\nu = \alpha c_s H \quad \text{ (10)}$$

$$\eta = \eta_0 c_s H \quad \text{ (11)}$$

where, $\alpha$ and $\eta_0$ are the standard viscous parameter and the magnetic diffusivity parameter respectively. Also these parameters are assumed to be positive constant and less than unity ($\alpha, \eta_0 \leq 1$) (Compbell 1999; Kuwabara et al. 2000; King et al. 2007).

Finally since we consider a global magnetic field, the three components of induction equation can be written as:

$$\dot{B}_r = 0 \quad \text{ (12)}$$

$$\dot{B}_\varphi = \frac{d}{dr} \left[ (v_r B_r - v_\varphi B_\varphi) - \frac{\eta}{r} (r B_\varphi) \right] \quad \text{ (13)}$$

$$\dot{B}_z = -\frac{1}{r} \frac{d}{dr} \left[ r (v_r B_z + \frac{dB_z}{dr}) \right] \quad \text{ (14)}$$

where $\dot{B}_{r,\varphi,z}$ are the field scaping/creating rate due to magnetic instability or dynamo effect. Now we have a set of MHD equations that describe the structure of magnetized ADAFs. The solutions to these equations are strongly correlated to viscosity, resistivity, magnetic field strength $B_{r,\varphi,z}$ and the degree of advection $f$. We seek a self-similar solution for the above equations. In the next section we will present self-similar solutions to these equations.

### 3 Self-Similar Solutions

In order to have a better understanding of the physical processes taking place in our discs, we seek self-similar solutions of the above equations. The self-similar method has a wide range of applications for the full set of MHD equations although it is unable to describe the global behavior of accretion flows since no boundary conditions have been taken into account. However, as long as we are not interested in the behavior of the flow near the boundaries, these solutions are still valid. In the self- similar model the velocities are assumed to be expressed as follow

$$v_r(r) = -c_1 \alpha \sqrt{\frac{GM_\ast}{r_0}} \left( \frac{r}{r_0} \right)^{-\frac{1}{2}} \quad \text{ (15)}$$

$$v_\varphi(r) = c_2 \sqrt{\frac{GM_\ast}{r_0}} \left( \frac{r}{r_0} \right)^{-\frac{1}{2}} \quad \text{ (16)}$$

$$c_s^2(r) = c_3 \left( \frac{GM_\ast}{r_0} \right) \left( \frac{r}{r_0} \right)^{-1} \quad \text{ (17)}$$

$$c_{r,\varphi,z}^2(r) = \frac{B_{r,\varphi,z}^2}{4\pi \rho} = 2\beta_{r,\varphi,z} c_3 \left( \frac{GM_\ast}{r_0} \right) \left( \frac{r}{r_0} \right)^{-1} \quad \text{ (18)}$$
where constants $c_1, c_2$ and $c_3$ are determined later from the main MHD equations. Also, $r_0$ are exploited to write the equation in non-dimensional form and the constants $\beta_r, \beta_\varphi, \beta_z$ measure the ratio of the magnetic pressure in three direction to the gas pressure, i.e., $\beta_{r,\varphi,z} = p_{\text{mag} r,\varphi,z}/p_{\text{gas}}$.

Assuming the surface density $\Sigma$ to be in the form of

$$\Sigma(r) = \Sigma_0\left(\frac{r}{r_0}\right)^s$$

(19)

where $\Sigma_0$ and $s$ are constant, we obtained, e.g.,

$$\dot{\rho} = \dot{\rho}_0\left(\frac{r}{r_0}\right)^{s-\frac{1}{2}}$$

(20)

$$\dot{B}_{r,\varphi,z} = \dot{B}_{r0,\varphi0,z0}\left(\frac{r}{r_0}\right)^{s+1/2}$$

(21)

where $\dot{\rho}$ and $\dot{B}_{r0,\varphi0,z0}$ are constants. The half-thickness of the disc still satisfies the relation $H \propto r$ and we can write

$$H(r) = c_4 r_0\left(\frac{r}{r_0}\right)$$

(22)

By substituting the above self-similar solutions in the continuity, momentum, angular momentum, hydrostatic balance and energy equation of the disc, we obtain the following system of dimensionless equations to be solved for $c_1, c_2, c_3$ and $c_4$:

$$\dot{\rho} = -\left(s + 1 \right)\frac{\alpha c_1 \Sigma_0}{2r_0^2 c_4} \sqrt{\frac{GM_p}{r}}$$

(23)

$$-\frac{1}{2} \alpha^2 c_1^2 = c_2^2 - 1 - \left[ (s - 1) + (s - 1) \beta_z + (s + 1) \beta_\varphi \right]c_3$$

(24)

$$-\frac{1}{2} \alpha c_1 c_2 = -\left( s + 1 \right) \frac{3}{2} \alpha c_2 \sqrt{c_3} c_4 + \left( s + 1 \right) c_3 \sqrt{\beta_r \beta_\varphi}$$

(25)

$$c_4 = \frac{1}{2} \left[ \sqrt{(s - 1)^2 \beta_r \beta_\varphi c_3^2 + 4(1 + \beta_r + \beta_\varphi)c_3} + (s - 1) \sqrt{\beta_r \beta_\varphi c_3} \right]$$

(26)

$$\left( \frac{1}{\gamma - 1} - (s - 1) \right) \alpha c_1 \sqrt{c_3} = \frac{9}{4} f \alpha c_2 c_4$$

$$+ \frac{1}{2} f \eta_0 c_3 c_4 \left[ \frac{2}{3} \beta_\varphi + (s - 2)^2 \beta_z \right]$$

(27)

If we solve the self-similar structure of the magnetic field escaping rate, we obtain

$$\dot{B}_{0r} = 0,$$

(28)

$$\dot{B}_{0\varphi} = \left( \frac{s - 3}{2} \right) \frac{GM_p}{r_0^{5/2}} \left\{ c_2 \sqrt{4 \pi \beta_r \beta_\varphi \Sigma_0 c_4} + \left( \alpha c_1 - \frac{s}{2} \eta_0 \sqrt{c_3} c_4 \right) \right\}$$

(29)

$$\dot{B}_{0z} = \left( \frac{s - 1}{2} \right) \frac{GM_p}{r_0^{5/2}} \sqrt{4 \pi \beta_r \beta_\varphi \Sigma_0 c_4} \times$$

$$\left\{ \alpha c_1 - \left( \frac{s - 2}{2} \right) \eta_0 \sqrt{c_3} c_4 \right\}$$

(30)

It is evident from the above equations that for $s = -1/2$ there is no mass loss while it is present for the case where $s > -1/2$. On the other hands, the toroidal component of escape and creation of magnetic fields balance one another for $s = 3$ and also for $z$-component of field creating / escaping rate (eq. (26)) they balance for $s = 1$. Although outflow is one of the most important processes in accretion theory, (see Narayan & Yi 1995; Blandford & Begelman 1999; Stone & Pringle & Begelman 1999 and also some recent work like Xie & Yuan 2008; Ohnaga & Mineshige 2011), however in our model we choose a self-similar solution in which $\dot{\rho} = 0$, $(s = -1/2)$ thus ignoring the effect of wind and outflow on the structure of the disc.

Without magnetic resistivity and magnetic field, $\eta = \beta_r = \beta_\varphi = \beta_z = 0$, the equations and their similarity solutions are reduced to the standard ADAFs solution (Narayan & Yi 1994). Also without resistivity they are reduced to Zhang & Dai 2008.

Now, we can do a parametric study considering our input parameters. The parameters of our model are the standard viscose parameter $\alpha$, the magnetic diffusivity parameter $\eta_0$, the advection parameter $f$, the radio of the specific heats $\gamma$ and the degree of magnetic pressure to the gas pressure in three dimensions of cylindrical coordinate, $\beta_r, \beta_\varphi$ and $\beta_z$. Figure [1] shows how the coefficients $\alpha c_1 (= -v_r/v_K)$, $c_2 (= v_\varphi/v_K)$, $\sqrt{c_3}(= c_s/v_K)$ and $c_4 (= H/r)$ depend on the magnetic parameter in radial direction $\beta_r$ for several values of magnetic diffusivity parameter $\eta_0$, i.e., $\eta_0 = 0$ (dotted line), $\eta_0 = 0.05$ (dashed line) and $\eta_0 = 0.1$ (solid line), corresponding to $\alpha = 0.1$, $\gamma = 4/3$, $\beta_\varphi = \beta_z = 1.0$ and $f = 1.0$ (fully advection). radial velocity is shown in the upper-left panel. In ADAFs the radial velocity is generally less than free fall velocity on a point mass, but it becomes larger if the magnetic parameter $\beta_r$ is increased. Also, we can see that the radial flows of the accretion materials become larger by the increase of resistivity parameter $\eta_0$. The upper right panel of figure [1] displays the ratio of the rotational velocity to the Keplerian one. As it can seen, the rotational velocity slightly shifts up when the magnetic parameter $\beta_r$ increases. Although the increase of resistivity parameter $\eta_0$ will decrease the rotational velocity. Moreover, the down left and right panels of figure [1] display the ratio of the sound
speed to the Keplerian velocity and the vertical thickness of the disc respectively. As the magnetic parameter $\beta_r$ become large, the isothermal sound speed of the flow decreases but vertical thickness of the disc has a different behavior between $\beta_r < 1$ and $\beta_r > 1$. When $\beta_r$ is below unity, the vertical thickness is reducing. On the other hand, for $\beta_r > 1$ the thickness is increasing. It means that there is a minimum near $\beta_r \sim 1$. Also, by adding the magnetic diffusivity parameter, the sound speed and vertical thickness will increase.

In figure 2 behavior of the coefficients $\alpha c_1$, $c_2$, $c_3$ and $c_4$ versus toroidal magnetic field $B_{\phi}$ ($\beta_{\phi}$) are shown for different values of $\eta_0$. From the upper-left panels of figure 2 we can see that for $\beta_{\phi} = 0 - 10$, the radial infall velocity is sub-Keplerian, and that becomes larger by increasing of resistivity parameter $\eta_0$. In addition, when the toroidal magnetic field becomes stronger, the radial velocity of accretion materials increases. The upper-right panel in figure 2 display the rotational velocity of accretion disc. We see that for the given advection parameter $f(= 1.0)$ and $\beta_r = \beta_z = 1.0$, the rotational velocity increase as the toroidal magnetic field become stronger. The considerable matter about this panel is that, when the toroidal magnetic field is very strong, the rotational velocity will be Super-Keplerian (i.e., $\beta_{\phi} > 7$). Also as the magnetic diffusivity parameter $\eta_0$ increases, the rotational velocity of the disc decrease. The raise of viscose torque by adding $\eta_0$ and $\beta_{\phi}$ parameters generate a large negative torque in angular momentum equation and cause the angular velocity of the flow decreases and materials accretes with large speed. Two down-panels of figure 2 show the behavior of sound speed and vertical thickness of the accretion disc respectively. As it can be seen from these panels, by the increase of magnetic diffusivity ($\eta_0$) from 0 – 0.1 the isothermal sound speed as well as vertical speed increase. Although we see that when the toroidal magnetic field increase, at first, the diagrams decrease and then increase. It means that there is a minimum in two panels.

In figure 3 we have plotted the coefficients $c_i$s with $z$-component of magnetic field for diffractions values of $\eta_0$. We first find out a strong $z$-component of magnetic field ($\beta_z$) leads to an decrease of the infall velocity $v_r$, rotational velocity $v_{\phi}$, isothermal sound speed $c_s$ and vertical thickness of the disc $H/r$, which means that a strong magnetic pressure in the vertical direction prevents the disc matter from being accreted, and decreases the effect of gas pressure as accretion proceeds. Although it is shown from all four panels of figure 3 the magnetic diffusivity increases $c_i$s except $c_2$ (the rotational velocity).
4 Summery and Dissussion

In this paper we studied the influence of the resistivity on the dynamics of advection dominated accretion flows in the presence of global magnetic field. Some approximations were made in order to simplify the main equations. We assumed an axially symmetric, static disc and the $\alpha$-prescription is used for the kinematic coefficient of viscosity ($\nu = \alpha c_s H$) and the magnetic diffusivity ($\eta = \eta_0 c_s H$). Also we ignored the self-gravity and the relativistic effects.

We have extended Akizuki & Fukue 2006 and Zhang & Dai 2008 self-similar solutions to present dynamical structure of advection dominated accretion flow by considering a three component magnetic field and magnetic diffusivity. We have accounted for this possibility by allowing input parameters $\alpha$, $\eta_0$, $\beta_r$, $\beta_\phi$, $\beta_z$, $f$ to vary in our solutions.

First, we have shown that the physical quantities of the disk are sensitive to the magnetic diffusivity parament $\eta_0$. We found out the magnetic resistivity increase the radial infall velocity $v_r$, the isothermal sound speed $c_s$ and the vertical thickness of the disk $H/r$. On the other hand, our numerical results shown that when the magnetic diffusivity parameter raise up, the rotational velocity of the disk $|v_\phi|$ decrease.

Also we have shown that the strong magnetic filed in the radial direction increase $v_r$, $|v_\phi|$ and $H/r$ although $c_s$ will be decrease which are satisfied with the results were presented by Zhang & Dai 2008. Also when the toroidal magnetic field become stronger, our physical quantities $v_r$, $|v_\phi|$, $c_s$ and $H/r$ increase (see, e.g., Akizuki & Fukue 2006; Abbas et al 2008, 2010; Bu & Yuan & Xie 2009). Moreover according to Zhang & Dai 2008, a large vertical magnetic field prevents the disk from being accreted and decrease effect of the gas pressure.

Although our preliminary self-similar solutions are too simplified, they clearly improve our understanding of the physics of ADAFs around a black hole. In order to have a realistic picture of an accretion flow a global solution is needed rather than the self-similar one. In our future studies we intend to investigate the effect of wind and thermal conduction on the observational appearance and properties of a hot magnetized flow.

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Fig. 2  Numerical coefficient $c_i$ as a function of magnetic parameter $\beta_\phi$ for several values of $\eta_0$. The dotted, dashed and solid lines correspond to $\eta_0 = 0.0, 0.05$ and $0.1$ respectively. Parameters are set as $s = -0.5$ (no wind), $\alpha = 0.1$, $\beta_r = \beta_z = 1$ and $f = 1$. 
Fig. 3  Numerical coefficient $c_i$s as a function of magnetic parameter \(\beta_z\) for several values of $\eta_0$. The dotted, dashed and solid lines correspond to $\eta_0 = 0.0, 0.05$ and 0.1 respectively. Parameters are set as $s = -0.5$ (no wind), $\alpha = 0.1$, $\beta_r = \beta_\phi = 1$ and $f = 1$. 