JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
29: S231 ~ S232, 1996

THE INSTABILITIES OF ACCRETION DISKS WITH RADIAL ADVECTION

XUE-BING WU
Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100080, China
and
Beijing Astronomical Observatory, Chinese Academy of Sciences, Beijing 100080, China

ABSTRACT

The local instabilities of accretion disks were extensively studied, with the considerations of radial advection, thermal diffusion and different disk geometry, dominated pressure and optical depth. Two inertial-acoustic modes in a geometrically thin, radiative cooling dominated disk depart from each other if very little advection is included. A geometrically slim, advection-dominated disk is found to be always stable if it is optically thin. However, if it is optically thick, the thermal diffusion has no effect on the stable viscous mode but has a significant contribution to enhance the thermal instability.

Key Words : accretion, accretion disks, instabilities

After the construction of standard α model (Shakura & Sunyaev 1973), the stability of geome- trically thin accretion disks has been extensively studied. In the standard α model, the viscous heating balances by radiative cooling. However, if the radiative cooling is not efficient, the advec- tion will be not negligible. Recently, the accretion disk models with advection have been studied when the disk is either optically thick or optically thin (Abramowicz et al. 1988; Narayan & Yi 1994; Abramowicz et al. 1995; Chen 1995). Although some of the stability properties of accre- tion disks with advection have been suggested in the previous research, the detailed stability analysis has not been well done. More recently, Kato, Abramowicz & Chen (1996) performed an analytic stability analysis to the advection-dominated disks by considering the local perturb-ations. They found the optically thick disks are still thermally unstable when the thermal diffusion is considered, while the optically thin disks are always stable. Stimulated by the above research, we have performed a detailed study to the local stability of accretion disks with advection and thermal diffusion (Wu & Li 1996). Different from the study of Kato et al. (1996), we discussed not only the stability of thermal mode, but also the viscous and inertial-acoustic modes.

We consider an axisymmetric, non-self-gravita-ting accretion disk and introduce the pseudo-Newtonian potential (Paczyński & Wiita 1980). Adopting a cylindrical system of coordinates, the vertical integrated time-dependent equations describing accretion flow are similar as those in Kato et al. (1996). The radial viscous force is included in the momentum equation and the radial advection, thermal diffusion are included in the energy conservative equation. For simplicity we assume the influences of radial viscous force and thermal diffusion on the disk equilibria are small, and adopt the self-similar disk equilibria obtained by Narayan & Yi (1994). The radial perturbations of some quantities are of the form $\delta Q \sim e^{i(\omega t-kr)}$, where k is the perturbation wavenumber. We follow the restric-tions given by the local approximation and the validity of the vertically integrated equations, which is well satisfied for a geometrically thin accretion disk but can be satisfied for a slim disk only when α is sufficiently small.

By deriving the perturbed equations and setting the determinants of the coefficients to zero, we can get a general dispersion relation:

$$a_1\tilde{\sigma}^4 + a_2\tilde{\sigma}^3 + a_3\tilde{\sigma}^2 + a_4\tilde{\sigma} + a_5 = 0, \qquad (1)$$

where $\tilde{\sigma} = \sigma/\Omega_k$, $\sigma = i(\omega - kV_r)$ and $a_i (i = 1, ..., 5)$ is the coefficients related to the disk parameters. The stability properties of two inertial-acoustic modes, thermal and viscous modes can be obtained by analyzing four kinds of solutions of the dispersion relation. The main results we have obtained can be summerized as following:

(1). Stability of optically thin disks: For a geometrically thin disk without advection, the thermal mode is unstable and the viscous mode is marginally stable in the long perturbation wavelength limit. However, in the short waveleng-th limit, the thermal and viscous modes are stable and the acoustic instability becomes impor-tant. For a geometrically thin disk with very little advection, the thermal and viscous modes are nearly the same as in the case without advec-tion but two acoustic modes are no longer complex conjugates. The inward propagating mode (I-mode) becomes stable while the outward propaga-ting one (O-mode) becomes more unstable. The departure of two acoustic modes becomes more significant as the increase of the value of q/m, where q is the ratio of advective to viscous dissipa-ted energy and m the Mach number. In a geometrically slim and advection-dominated disk, all four kinds of modes are stable. The thermal diffusion tends to make the disk more stable.

(2). Stability of optically thick disks: For a geometrically thin, gas pressure dominated disk without advection, the thermal and viscous modes are always stable. The acoustic modes are slightly unstable if without the thermal diffusion, but are stable if the thermal diffusion is considered. If very little advection is included in a geometrical-ly thin, gas pressure dominated disk, the thermal and viscous modes are always stable but two acoustic modes depart from each other. The O-mode becomes more unstable while the I-mode becomes stable. The inclusion of thermal diffusion does not change the instability of O-mode, although it decreases the growth rate of O-mode. For a geometrically thin, radiation pressure dominated disk without advection, the results is similar as those in Blumenthal, Yang & Lin (1984). The inclusion of thermal diffusion decreases the growth rate of acoustic modes but has very little effects on the thermal and viscous modes. The thermal and viscous instabilities are dominant for long wavelength perturbations but the acoustic instability is dominant for short wavelength perturbations. If very little advection is included in a geometrically thin, radiation pressure dominated disk, it leads to a significant departure of two acoustic modes but has nearly no effects on the thermal and viscous instabilities. The thermal diffusion tends to stabilize the acous-tic modes but does not alter the instability of I-mode. For a geometrically slim, radiation pressure and advection dominated disk, the thermal mode is only slightly unstable if without thermal diffu-sion. However, the inclusion of thermal diffusion has a significant role to enhance the thermal instability. The viscous mode is always stable and does not change even if the thermal diffusion is included. In addition, We note that in this case there are no self-consistent solutions correspond-ing to two acoustic modes in our local stability analyses, which is due to the local restrictions.

ACKNOWLEDGEMENTS

I am grateful to Prof. Q.B. Li for supervision, and Prof. S. Kato and Dr. X. Chen for helpful discussion on the advection and thermal diffusion.

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