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ORIGINAL ARTICLE

Hot accretion flow with ordered magnetic field, outflow, and saturated conduction

Kazem Faghei

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Abstract The importance of thermal conduction on hot accretion flow is confirmed by observations of hot gas that surrounds Sgr A* and a few other nearby galactic nuclei. On the other hand, the existence of outflow in accretion flows is confirmed by observations and magnetohydrodynamic (MHD) simulations. In this research, we study the influence of both thermal conduction and outflow on hot accretion flows with ordered magnetic field. Since the inner regions of hot accretion flows are, in many cases, collisionless with an electron mean free path due to Coulomb collision larger than the radius, we use a saturated form of thermal conduction, as is appropriate for weakly collisional systems. We also consider the influence of outflow on accretion flow as a sink for mass, and the radial and the angular momentum, and energy taken away from or deposited into the inflow by outflow. The magnetic field is assumed to have a toroidal component and a vertical component as well as a stochastic component. We use a radially self-similar method to solve the integrated equations that govern the behavior of such accretion flows. The solutions show that with an ordered magnetic field, both the surface density and the sound speed decrease, while the radial and angular velocities increase. We found that a hot accretion flow with thermal conduction rotates more quickly and accretes more slowly than that without thermal conduction. Moreover, thermal conduction reduces the influences of the ordered magnetic field on the angular velocities and the sound speed. The study of this model with the magnitude of outflow parameters implies that the gas temperature decreases due to mass, angular momentum, and energy loss. This property of outflow decreases for high thermal conduction.

K. Faghei (✉)
School of Physics, Damghan University, Damghan, Iran
e-mail: kfaghei@du.ac.ir

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1 Introduction

Accretion onto a black hole can occur through at least two different regimes: (1) a standard thin accretion disk (Shakura and Sunyaev 1973), and (2) an advection-dominated accretion flow (ADAF; Ichimaru 1977; Narayan and Yi 1994). Most observational features of black hole accretion systems can be successfully explained by the standard thin accretion disk model (Shakura and Sunyaev 1973). The ultraviolet/optical continuum emission observed in luminous quasars is usually attributed to thermal radiation from the standard disks surrounding the massive black holes in quasars (see, e.g., Sun and Malkan 1989). However, the standard disk model cannot explain the spectral energy distributions (SED) of many sources, such as Sgr A*, the supermassive black hole located at our Galactic Center. To understand such systems, the ADAF model was introduced. In ADAF models, the radiation time scale is much longer than the accretion time scale, so most of the dissipated energy is stored in the gas as thermal energy rather than being radiated away. The energy is advected into the horizon of the black hole; thus, the efficiency of ADAF is generally extremely low (Yuan 2010).

Accretion flows in active galactic nuclei are probably associated with winds/outflows. Observational evidence for winds has been given in some research works (e.g., Pounds et al. 2003; Reeves et al. 2003; Tombesi et al. 2010, 2011). One of the best examples comes from Sgr A*. Marrone et al. (2006) suggested that the accretion rate of Sgr A* at small radii, much smaller than the Bondi radius, must be low, below $10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$, whereas Baganoff et al. (2003)