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ORIGINAL ARTICLE

Dynamical friction in an isentropic gas

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Abstract When a gravitating object moves across a given mass distribution, it creates an overdense wake behind it. Here, we performed an analytical study of the structure of the flow far from object when the flow is isentropic and the object moves subsonically within it. We show that the dynamical friction force is the main drag force on the object and by using a perturbation theory, we obtain the density, velocity and pressure of the perturbed flow far from the mass. We derive the expression of the dynamical friction force in an isentropic flow and show its dependence on the Mach number of the flow and on the adiabatic index. We find that the dynamical friction force becomes lower as the adiabatic index increases. We show analytically that the wakes are less dense in our isentropic case in comparison to the isothermal ones.

Keywords Hydrodynamics · ISM: general · Galaxies: kinematics and dynamics · Stars: kinematics

1 Introduction

The motion of a gravitating mass across a given distribution of matter creates an overdense wake behind it. In turn, this overdense region interacts gravitationally with the moving object causing it to lose momentum and kinetic energy. The ambient medium gains the momentum and the kinetic energy lost by the moving mass. The drag force exerted on the moving object is also known as the *dynamical friction force*. Chandrasekhar (1943) studied the effects of the dynamical friction force in the collisionless systems analytically and his results has been applied to many astrophysical systems. The effects of the dynamical friction force have been investigated in the context of the evolution of massive young stellar clusters near to the Galactic center (e.g., Gerhard 2001; Kim and Morris 2003), the dynamical evolution of stellar clusters (e.g., Portegies Zwart and McMillan 2002), and the migration of planets in a protoplanetary disc made of collisionless planetesimals (e.g., Del Popolo 2003; Muto et al. 2011). N-body simulations have also shown that the dynamical friction force based on the Chandrasekhar's formula can be extended to the many-body interacting systems (Inoue 2011).

Dynamical friction effects are also present when a gravitating mass moves across a collisional system, i.e. a gaseous medium. The work done by the dynamical friction force may act as a heating mechanism of the gas. El-Zant et al. (2004) and Faltenbacher et al. (2005) have shown that the intergalactic gas in the central regions of the galaxy clusters can be heated by the motions of the galaxies. Other authors have investigated the role of the gas drag force in the context of planet migration in gaseous protoplanetary discs (e.g., Ida and Lin 1996; Haghighipour and Boss 2003), the dynamics of the protostars and the stars in the stellar clusters prior to the gas removal (e.g., Escala et al. 2003; Saiyadpour et al. 1997), and the motion of black holes on circular orbits in a gas rich galactic nuclei (Kim and Kim 2009; Kim 2010). The way gas drag affects the collisional behaviour of planetesimals in a gaseous disc has also been investigated by several authors (e.g., Kobayashi et al. 2010; Ormel and Klahr 2010).

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