Astrophys Space Sci
DOI 10.1007/s10509-013-1688-7

ORIGINAL ARTICLE

Roles of statistical mechanics in determining the density profile of mild relaxation

Dong-Biao Kang

Received: 27 May 2013 / Accepted: 29 October 2013

Abstract The r^{-4} law of cold collapse has been explained in other work. Here we try to explain the density profile of mild relaxation by statistical mechanics. In this paper we first generate many kinds of initial conditions with the same mass and energy to see whether there are other initial factors that can change the density profile of an isolated equilibrium self-gravitating system; then for a more general initial condition we discuss the role of mass and energy in determining the final density profile. Next we use our previous results obtained from statistical mechanics to fit these simulations, and find that when the masses of the particles in clumps are less than 5 % of the total mass, or the initial density is shallower than r^{-2}, the whole virialized density profile (VDF) can be fitted well by our equation of state with three parameters, and some other cases can be explained by the theory with the r^{-4} law. We conclude that statistical physics may play an important role in determining the shape of VDF in the mild relaxation, mass and energy can control the values of the central density and the system's radius, but there are still other initial configurations that can affect the VDF.

Keywords Methods: numerical · Equation of state · Galaxies: evolution

1 Introduction

The problem of the density distribution of the equilibrium self-gravitating system has been studied for many years. Because of the difficulty to deal with its dynamics analytically, nowadays numerical simulation has become an important tool, and the dissipationless simulation of the isolated system is getting by more and more attention: the early exploration van Albada (1982) has found that the equilibrium state may be much affected by b (the virial ratio is usually defined by $2K/W$ where K and W are the total kinetic and potential energy, respectively, and here we define b as its absolute value); then Roy and Perez (2004) has studied many kinds of initial conditions and summarized their effects on the final density profile. Labini (2012) distinguished the cases of relaxation to be violent and mild according to b and provided an explanation for the power law of the outer density profile of the former.

Besides all this, statistical mechanics is often used to explain the universal density profile appearing in simulations of the dark matter halos (Navarro et al. 1997, 2010) and observations of globular clusters and elliptical galaxies (such as de Vaucouleurs 1948; King 1966). Lynden-Bell (1967) proposes the concept of violent relaxation, but under the principle of maximum entropy, the equilibrium state is for an isothermal sphere whose mass is infinite (Binney and Tremaine 2008), which needs to be modified. Lynden-Bell (1967) proposes that the relaxation is incomplete; Tsallis (1988) suggests use of the Tsallis entropy and gets the polytropic solution; Hjorth and Williams (2010) proposes another formula to replace the Stirling approximation. Stiavelli and Bertin (1987) considers other constraints besides mass and energy; based on White and Narayan (1987)'s work Kang and He (2011a) gets an equation of state whose form is just the addition of the isothermal and adiabatic result, so the total mass is finite, although its variation process is not perfect. In still other work, to explain the density profile of the dissipationless simulation, Levin et al. (2008) develops the theory of the Lynden-Bell distribution with a cut-

D.-B. Kang (✉)
Xinjiang Astronomical Observatory, Chinese Academy of Sciences, 830011, Urumqi, China
e-mail: dbkang@xao.ac.cn

Published online: 21 November 2013