Nonequilibrium properties of granular gases of rough particles

Alberto Megías[1], and Andrés Santos[2]
[1] Departamento de Física, Universidad de Extremadura, E-06006 Badajoz, Spain
[2] Instituto de Computación Científica Avanzada (ICCAEx), Universidad de Extremadura, E-06006 Badajoz, Spain

Granular matter, under rapid flow conditions, follows a gas-like behavior with dissipative interactions, in which classical kinetic-theory tools can be used as the proper theoretical framework. The simplest way of describing these particles and their interactions consists in considering hard disks or spheres colliding inelastically with a constant coefficient of normal restitution, α. However, recent experiments [1] highlight the importance of the implementation, in the collisional models, of the surface roughness of the granular particles to improve the theoretical predictions.

In this work, we study a monodisperse and dilute granular gas of inelastic and rough hard particles, with certain reduced moment of inertia κ, with and without external energy injection, from theory and computer simulations. The original inelastic model is improved by accounting for the effect of roughness via a constant coefficient of tangential restitution, β. We characterize the nonequilibrium properties of a homogeneous granular gas in terms of the violation of equipartition via the rotational-to-translational temperature ratio θ, and the nonGaussianities of the long-time-limit velocity distribution function (VDF), by means of the first nontrivial cumulants (a_{20}, a_{02}, a_{11} in the case of hard disks) and the marginal high-velocity tails (HVT).

In free evolution, the homogeneous system collapses to the homogeneous cooling state (HCS), where all the system evolution is driven through the temperature decay due to energy dissipation. The nonequilibrium properties of the HCS are much stronger than in the smooth case (see Fig. 1), where a divergence of an infinite set of velocity moments appears as a consequence of a scale-free HVT of the HCS marginal VDF of angular velocities [2] (see Table 1). These results are even more important for hard disks, which can be the consequence of recently reported strong instabilities of the hydrodynamic description of the system [3, 4].

On the other hand, we consider the homogeneous and driven case in terms of a thermostat that injects energy to the translational and rotational degrees of freedom. The system reaches a nonequilibrium steady state (NESS), in which the mean granular temperature depends on the whole energy injection, but the rest of nonequilibrium properties are only subjected to the fraction of rotational energy injected with respect to the total, ε. Whereas the violation of equipartition is still important, the nonGaussian features of the NESS VDF are much softer than in the HCS case, as novel results of the first nontrivial cumulants (see Fig. 2) and the HVT of the translational and rotational marginal VDF show. The cumulant divergences vanish, as own by the form of the HVT for this case (see Table 1). Moreover, the description of the transient states in terms of a Maxwellian approximation fits very well with simulation results, and the emergence of memory effects is essentially based on the nonequipartition [5].

Those predictions show a good agreement with results from direct simulation Monte Carlo (DSMC) and event-driven molecular dynamics (EDMD) algorithms (see [2] for the HCS case), and with recent experimental results [6].

Table 1. Theoretical HVT for the marginal VDF

Marginal VDF	HCS	NESS
Translational $f_t(\mathbf{c})$	Exponential $e^{-\gamma_c c}$	Stretched exponential $e^{-\lambda_c c^{3/2}}$
Rotational $f_r(\mathbf{w})$	Scale-free $w^{-\gamma_w}$	Exponential $e^{-\lambda_w w}$

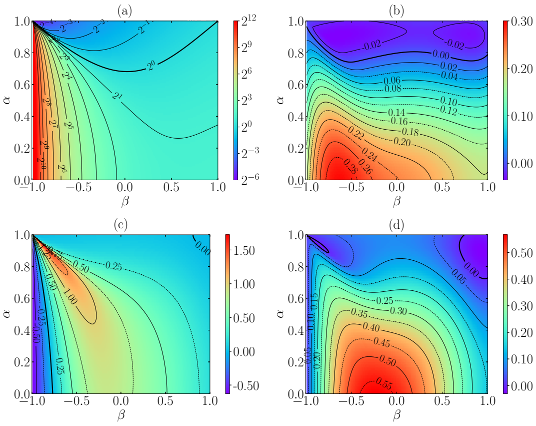

Fig. 1. Theoretical HCS values of (a) θ, (b) a_{20}, (c) a_{02}, and (d) a_{11} for hard disks with $\kappa = 1/2$, versus α and β.

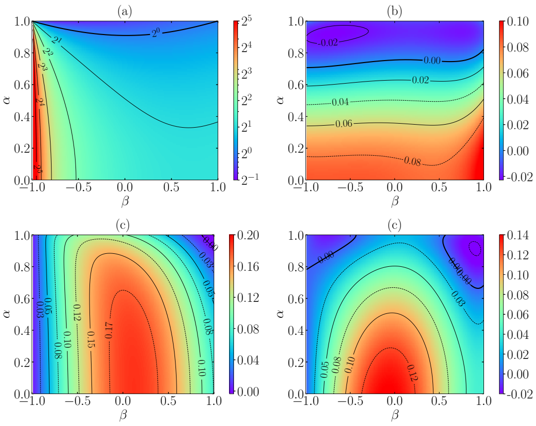

Fig. 2. Same as Fig 2, but for the NESS with $\varepsilon = 1/2$.

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