Growing time and length scales in the dissipative dynamics of a granular fluid

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Violations of the equilibrium fluctuation-dissipation relation (FDR), together with the finding of time and length scales which grow at low temperature, is a well established scenario for glass-forming system. Recently it has been shown that also dissipative granular fluids exhibit, at high packing fractions, a dynamical arrest analogous to the glass transitions [1].
Here we characterize the slowing down of a dense granular fluid and the FDR violations occurring in this system: the dissipative dynamics of a massive intruder is studied at packing fractions lower than the threshold for dynamical arrest, where the system behaves as a dilute or dense fluid. The dynamics of such a probe particle is well captured by a generalized Langevin equation with an exponential memory kernel and a colored noise:

$$M\dot{V}(t) = -\int_{-\infty}^{t} dt'\ \Gamma(t-t')V(t') + \mathcal{E}'(t), \qquad (1)$$

with $\Gamma(t) = 2\gamma_0\delta(t)+\gamma_1/\tau e^{-t/\tau}$ and γ_0, γ_1 two friction coefficients. We find that the time-scale $\tau(\phi)/\tau_c(\phi)$, with $\tau_c(\phi)$ the mean collision time, is an increasing function of the packing fraction. Both the elastic and the dissipative dynamic can be modeled with eq. (1): τ/τ_c grows with the packing fraction in both situations. The decay of velocity autocorrelation for the massive probe is shown in fig. 1 as a function of t/τ_c. Data are fitted with the analytical solution of eq. (1). Eq. (1) can be also mapped in a two variable Markovian model [2], exactly soluble [4], where the velocity of the probe V is coupled to another an auxiliary variable U understood as the value of a local velocity field present in the granular fluid. This picture suggests that, in the case of *dissipative* dynamics, τ may be also regarded as the typical time over which is correlated the *local velocity field* U surrounding the tracer. Within this scheme the violations of the equilibrium

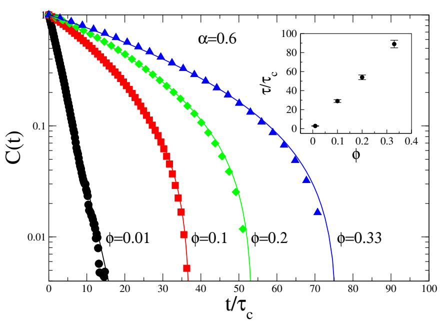

FIG. 1. Main: Velocity autocorrelation function of a massive intruder in a dense granular media at different values of ϕ. Inset: Ratio τ/τ_c as function of ϕ: τ is the memory kernel characteristic time (eq. 1) and τ_c the mean collision time.

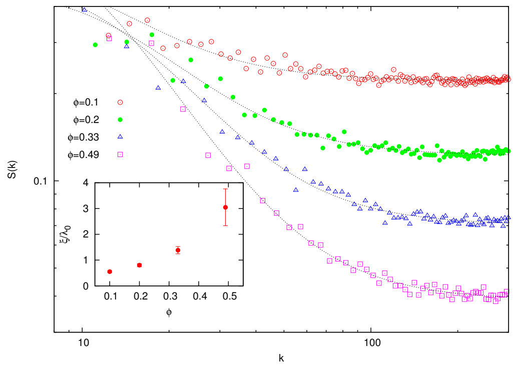

FIG. 2. Main: Low momentum behaviour of the velocity field structure factor $S(k)$. Inset: the ratio ξ/λ_0 as function of packing fraction ϕ, with the λ_0 mean free path.

FDR come from the coupling between the massive tracer velocity and the local velocity field of the fluid. From the analysis above we learned that the velocities of particles surrounding the intruder appear to be correlated over increasing time-scales. This observation urged us to look also for a growing length scale in the velocity filed of the dense granular fluid. We started this program by studying the low momentum behaviour of the static structure factor of the velocity field, $S(k) = 1/N\langle U(k)U(-k)\rangle$. Assuming that the low-$k$ behaviour of $S(k)$ obeys a hydrodynamic approximation scheme [3], $S(k) = (A+Bk^2)/(1+\xi^2k^2)$, numerical data, reported in fig. 2, can be fitted obtaining a correlation length $\xi(\phi)$ (see inset of fig. 2). We find that the ratio ξ/λ_0, with λ_0 the mean free path, grows as a function of ϕ. At equilibrium (elastic collisions) we find $S(k) = \text{const}$: velocities are uncorrelated and equipartition between modes holds.
We have shown that in a dense granular system there are time and length scales, characterizing the velocity field, which are related to *dissipative* phenomena and which grow when the packing fraction is increased. This behaviour, observed at moderate packing fractions, appears as the prelude of the glass transition placed at higher packing fractions.

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