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Engineered Swift Equilibration of brownian particles: consequences of hydrodynamic coupling

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Recent researches in out of equilibrium statistical physics address Engineered Swift Equilibration (ESE) of Brownian Particles [1]. The point of this emerging topic is to reduce the transient state of systems and make them relax faster to equilibrium after a change of a control parameter, by controlling the profile of the potential energy between its initial and final values.
For example, one can perform the compression of a single brownian particle trapped in an harmonic potential by increasing its stiffness K. A step in K will equilibrate in the natural relaxation time of the system. Using ESE protocol for the time evolution of K, the same final state can be reached several order of magnitude faster [2]. As an illustration, the Figure 1 compares a step decompression at $t = -140\,\mathrm{ms}$ and an ESE protocol for compression at $t = 0\,\mathrm{ms}$: the single particle position variance evolution (black curves) then shows that equilibrium is the reached in $\tau_{relax} \sim 25\,\mathrm{ms}$ after the step decompression, and in $t_f = 2.5\,\mathrm{ms}$ after the ESE protocol.
These ESE profiles can be computed using theoretical physic tools, and then tested in actual overdamped systems of colloidal particles trapped by optical tweezers. In this context, we present a detailed theoretical and experimental analysis of ESE protocols applied to two hydrodynamically coupled colloids in optical traps. The second particle slightly perturbs (10% at most) the response to an ESE compression applied to a single particle, as highlighted by the red arrow on Figure 1. This effect is quantitatively explained by a model of hydrodynamic coupling as shown by the accordance between theoretical prediction in dashed line and experimental data on Figure 1. We then design a coupled ESE protocol for the two particles, allowing the perfect control of one target particle while the second is enslaved to the first.

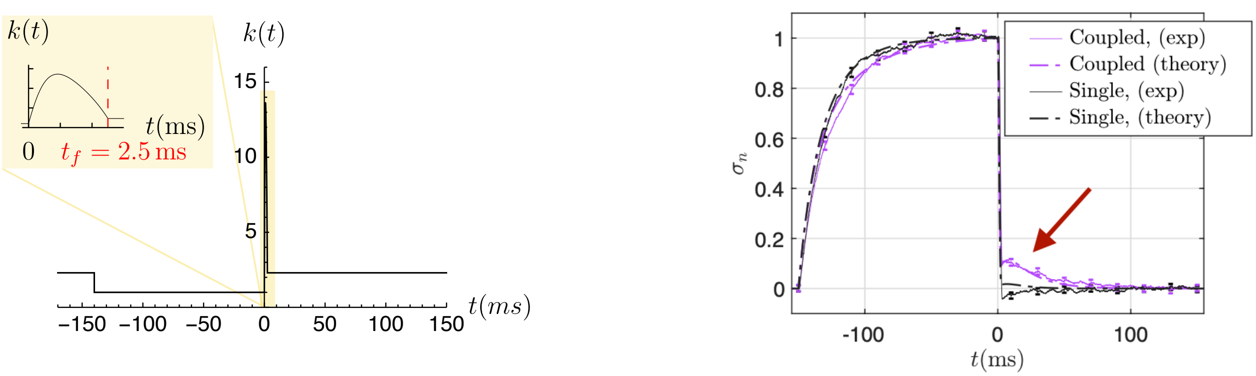

FIGURE 1 – (Left) The stiffness profile applied : a step decompression at $t = -140\,\mathrm{ms}$ followed by a basic ESE protocol for compression. (Right) Normalized variance of the particle in response to the stiffness profile on the left. The plain lines are the experimental results with their error bars each 200 points, and the dashed ones the theoretical predictions. A small rebound highlighted by the red arrow (around 10% of the step) and long relaxation time are visible for coupled particles.

[1] D. Guéry-Odelin, A. Ruschhaupt, A. Kiely, E. Torrontegui, S. Martínez-Garaot, J. G.Muga, Rev. Mod. Phys. **91**, 045001 (2019).

[2] I. A. Martinez, A. Petrosyan, D. Guéry-Odelin, E. Trizac, and S. Ciliberto, NaturePhysics **12**, 843 (2016).