The Physics of Soft and Biological Matter

Bacterial delivery of colloids over anisotropic barriers

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Exploiting motile micro-organisms for the transport of colloidal cargoes is a fascinating strategy to extract work from self-propelled entities. Generally, delivery on target sites requires external control fields to steer propellers and trigger cargo release. This need of a constant feedback prevents the design of compact devices where biopropellers could perform their tasks autonomously. Here we experimentally show that properly designed three-dimensional micro-structures can define accumulation areas where bacteria spontaneously and efficiently spatially organize colloidal beads[1]. The mechanism does not require modification of colloidal cargoes nor any external control fields, rather the process is stochastic in nature and results from the rectifying action of an asymmetric energy landscape over the fluctuating forces arising from collisions with swimming bacteria. As a result, the concentration of colloids over target areas can be strongly increased or depleted according to the topography of the underlying structures. Besides the significance to technological applications, our experiments pose some important questions regarding the structure of stationary probability distributions in non-equilibrium systems. To address some of these issues, simulations employing varying classes of time-correlated noise have been employed, showing that the details of applied noises may significantly alter the steady state probability distributions over asymmetric barriers.

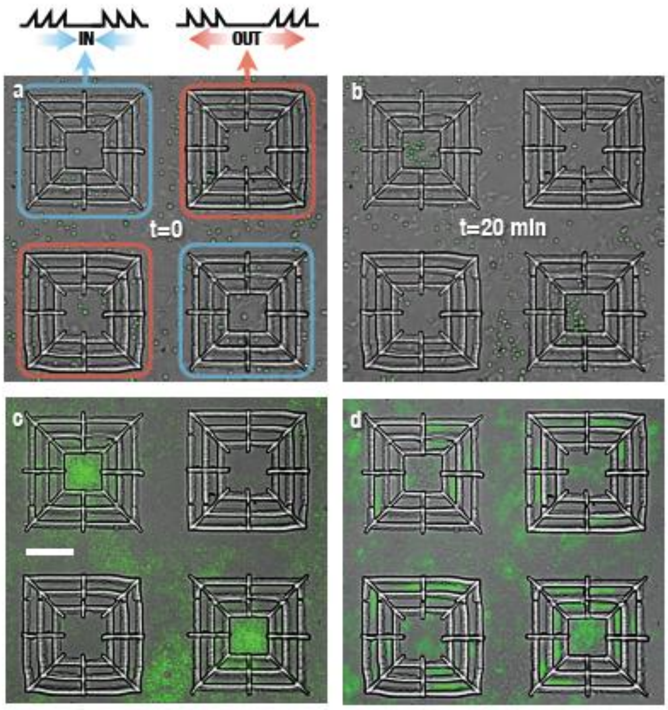

FIG. 1: Observation of particle concentration and depletion by bacteria. Single experiment snapshots of particles and bacteria at the initial state $t = 0$ where particles are randomly distributed (panel a) and for $t = 20\ min$, where particle distributions have been strongly affected by bacterial transport over asymmetric barriers (panel b). Particle distributions averaged over a steady state are shown in panel c for particles in the bacterial bath between $t1 = 15\ min$ and $t2 = 20\ min$ ($\Delta t = 5\ min$) and in panel d for particles in an experiment without bacteria, undergoing simple Brownian motion for $\Delta t = 10min$. In the absence of bacteria, the colloidal particles remain trapped within the structures compartments. The scale bar in panel c is 20 μm in length.

[1] N. Koumakis, C. Maggi, A. Lepore and R. Di Leonardo, "Targeted delivery of colloids by swimming bacteria" Nat. Comm.4, 2588 (2013) doi: 10.1038/ncomms3588