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Boundary Shape Engineering for the Spatial Control of Confined Active Particles

Roberto Di Leonardo [1], András Búzás [2], Lóránd Kelemen[2], Ormos Pál [2], Gaszton Vizsnyiczai [2]

[1] Dipartimento di Fisica, Sapienza Università di Roma, Rome, Italy

[2] Institute of Biophysics, HUN-REN Biological Research Centre, Szeged, Hungary

Unlike an equilibrium gas, the distribution of active particles can be very sensitive to what happens at the boundaries of their container. Experiments and simulations have previously highlighted the possibility of exploiting this behavior for the geometric control of active particles, although a general theoretical framework is lacking. Here we propose a boundary method based on the flux transfer formalism typical of radiometry problems, where surface elements transmit and receive "rays" of active particles with infinite persistence length. As in the case of blackbody radiation, a Lambert scattering law results in a uniform distribution of active particles within the cavity, while other scattering laws result in specific patterns of particle accumulation in the bulk or over the boundary walls. We validate our method's predictions with numerical simulations and demonstrate its practical utility by spatially controlling swimming microalgae confined in light-defined arenas. The presented boundary method offers a simple and efficient way to predict particle distributions when both the geometry of the boundaries and the scattering law are known. In addition, it provides a general design principle for engineering container shapes optimized for transport, accumulation, and sorting of self-propelled colloids and microorganisms.