Collective behaviour of energy depot repulsive particles

Juan Pablo Miranda, Demian Levis, Chantal Valeriani
juanpami@ucm.es, levis@ub.edu, cvaleriani@ucm.es

Energy depot model

The energy depot model [1] consists of active Brownian particles which can take energy from the medium, store it into an internal energy depot, and convert it to kinetic energy. The following Langevin equation describes motion of a particle with mass m, position $\mathbf{r}$ and velocity $\mathbf{v}$ and friction coefficient $\gamma(\mathbf{v})$ in the model.

$$\dot{\mathbf{v}} = -\gamma(\mathbf{v})\mathbf{v} - \frac{1}{m}\nabla U(\mathbf{r}) + \mathcal{F}(t)$$

$$\gamma(\mathbf{v}) = \gamma_0 - \frac{q_0 d_2}{c + d_2 \mathbf{v}^2}$$

Model parameters

$q_0 =$ Rate of energy absorbed from the environment.
$c =$ Rate of energy dissipation.
$d(\mathbf{v}^2) = d_2\mathbf{v}^2 =$ Kinetic energy conversion rate.

Studied systems

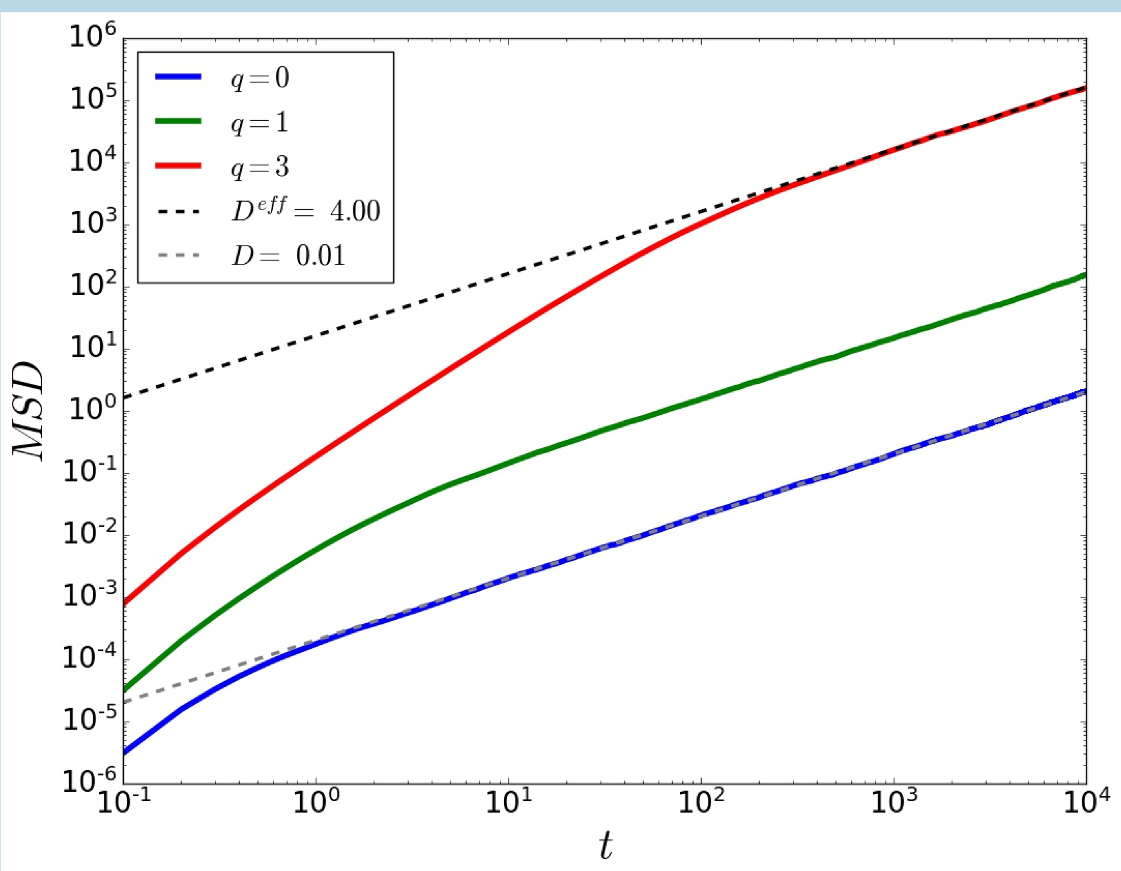
$2D$ suspension of $N = 2000$ particles in a square box of area $A = L^2$ with periodic boundary conditions and surface fraction $\varphi = \frac{N\,\pi\,\sigma^2}{4\,A}$.

1. Point particles with no interaction between them
2. Repulsive disks of radius σ. The repulsive interaction between the particles is implemented via a WCA potential

We have chosen to fix d_2, c and study the system in a range of values of q_0 and φ.

Results: No interactions

System Dynamics



Two regimes [2];

1. When $\gamma(\mathbf{v}) > 0$ the motion is damped, meaning that the particles behave as a self-persistent Brownian motion.
2. When $\gamma(\mathbf{v}) < 0$ we have negative friction, and the motion of the slow particles is pumped as if the particles had an additional source of energy. This is how we achieve active motion through negative friction.This *supercritical pumping* means we have $D_r^{supercritical} >> D_r^{noactivity}$ and we also have that $D_r \propto q_0^2$

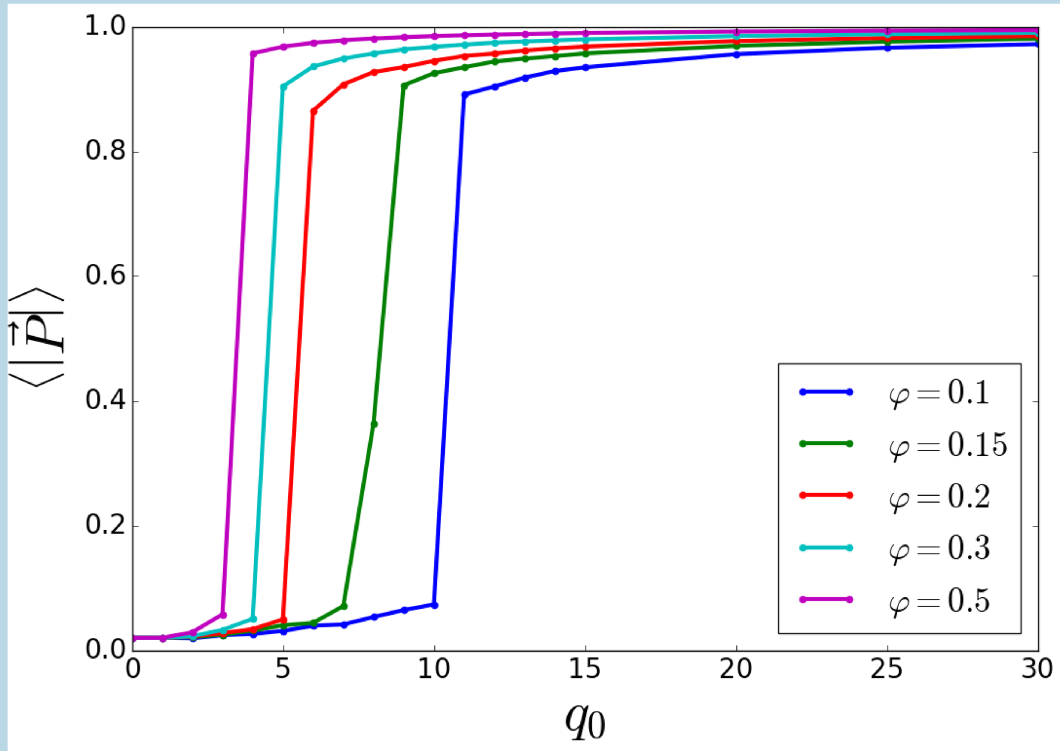
Results: Interactions

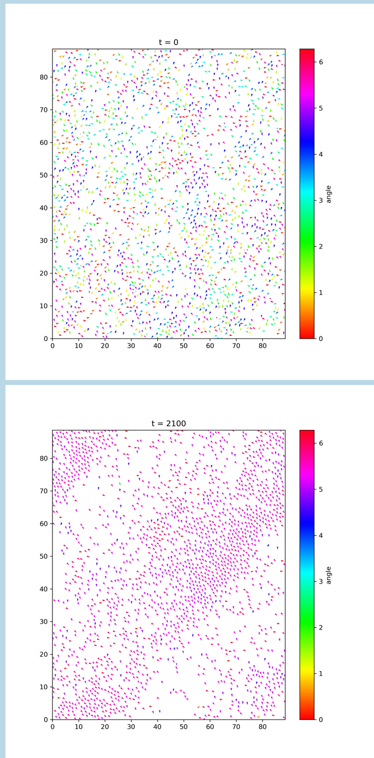
Velocity alignment phase transition

The system present **two different phases**

1. **disordered**: No flocks or velocity alignment.
2. **ordered**: Flocks of particles appear alongside with velocity alignment.

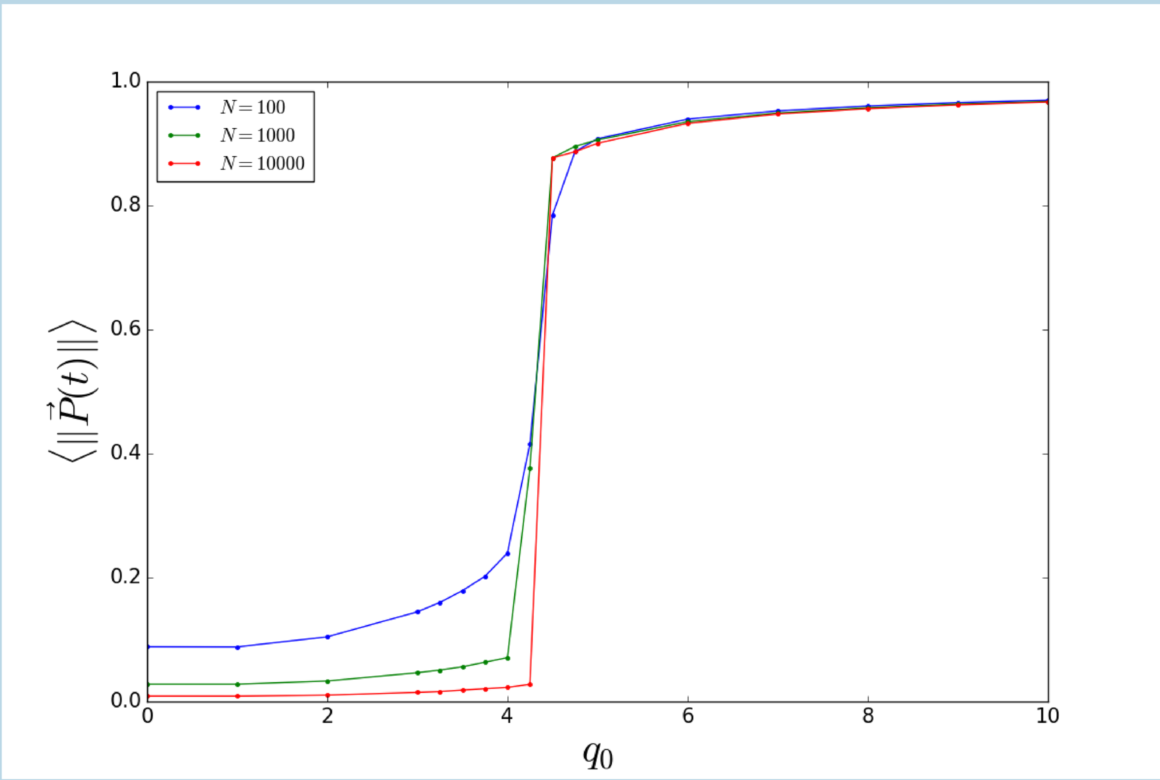
To characterise the phase transition we study the velocity polarization $\langle|\mathbf{P}(t)|\rangle = \left\langle\left|\frac{1}{N}\sum_{k=1}^{N}\exp\left(\mathrm{i}\theta_k(t)\right)\right|\right\rangle_t$ where θ is the angle formed by the particle's velocity.

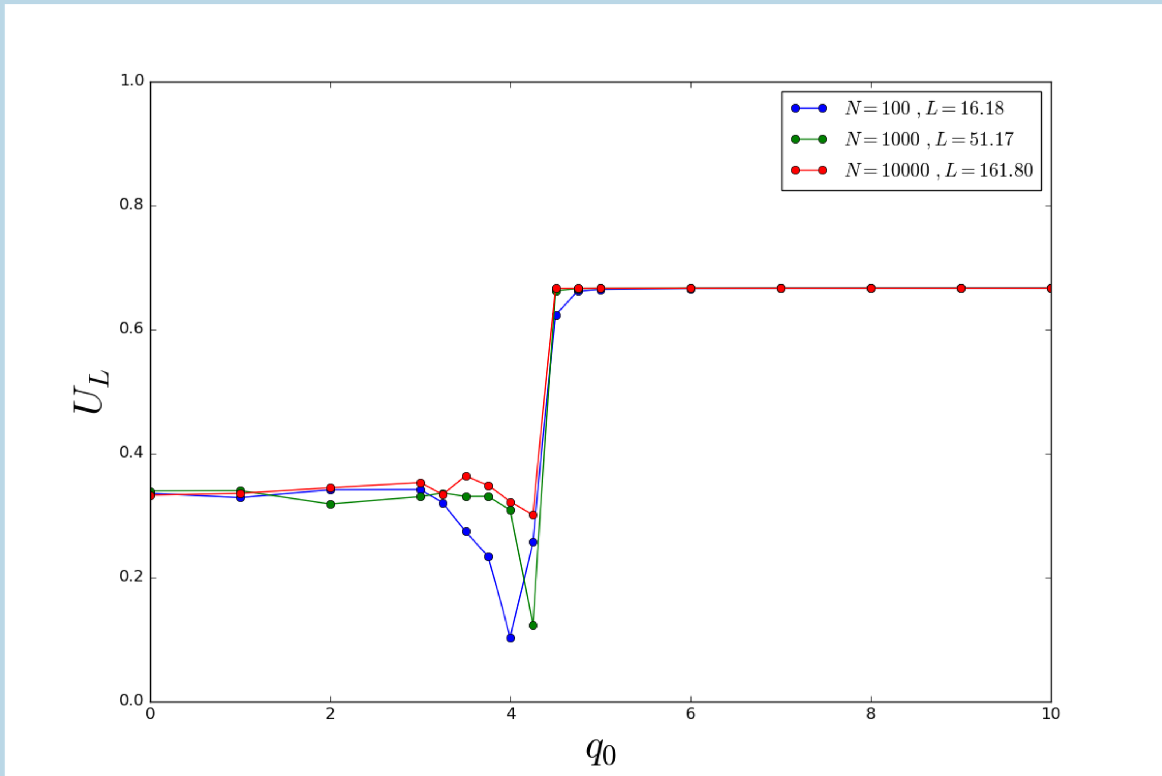




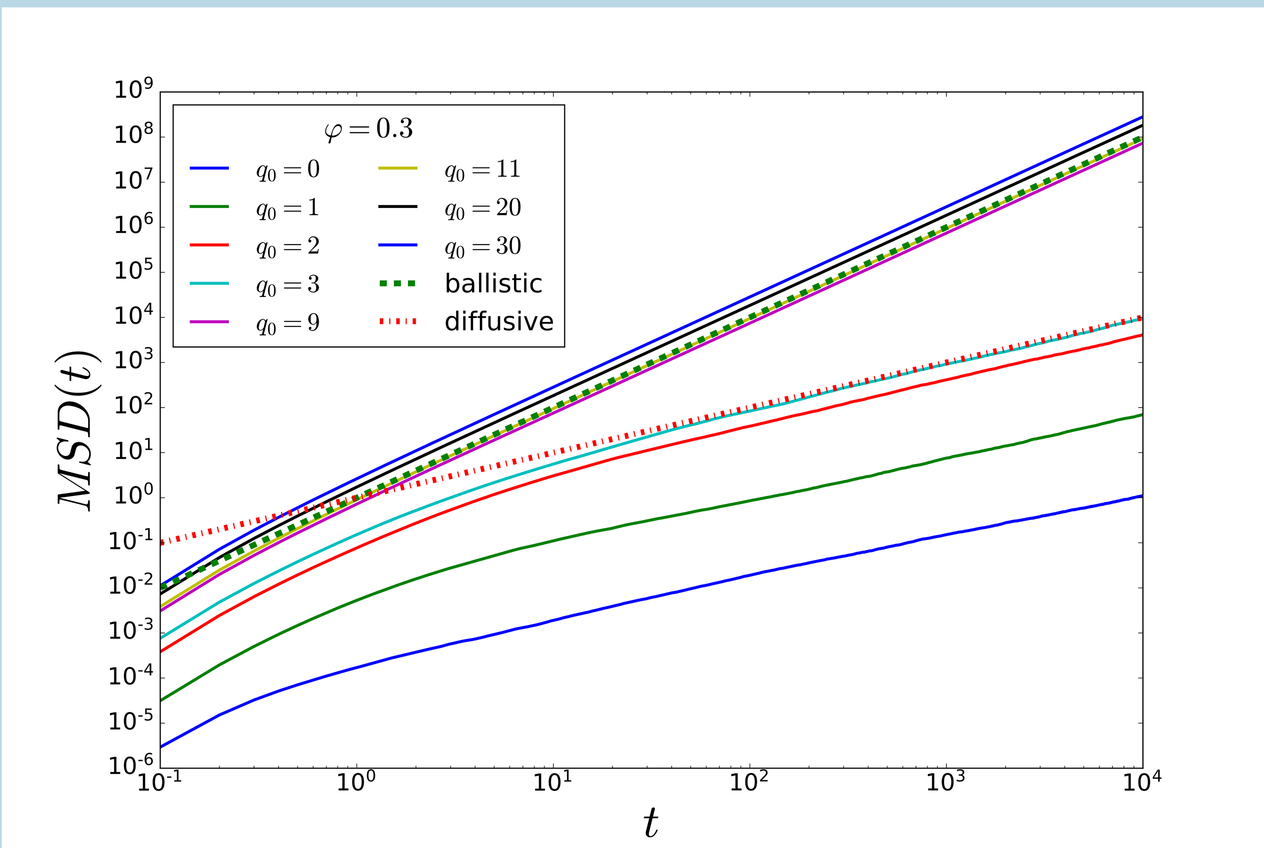
a)Left: Mean polar order parameter as a function of q_0 parameter for the studied volume fractions φ. b)Top right: Snapshot of a system of $\varphi = 0.2$ and $q_0 = 5$. c)Bottom right: Snapshot of a system of $\varphi = 0.2$ and $q_0 = 10$.

Finite Size Scaling analysis for $\varphi = 0.3$ We study the polarisation (left) and the Binder cumulant U_L (right).





System Dynamics



The motion of the system has two timescales.
At short times, the motion of all particles is ballistic.
At long timescales, the motion depends on the transition.
If the flocks have not formed, the motion is diffusive, and $MSD \sim t$.
When the flocks form at q_0 large enough, at long times the system is superdiffusive and $MSD \sim t^2$.

Ongoing work

- Understand the structural origin of the phase transition.
- Study the stochastic thermodynamics of a system of interacting disks.

References

[1] Erdmann, U., Ebeling, W., Schimansky-Geier, L., Schweitzer, F. (2000). *Brownian particles far from equilibrium.* The European Physical Journal B-Condensed Matter and Complex Systems, 15(1), 105-113.

[2] Schweitzer, F., Farmer, J. D. (2003). *Brownian agents and active particles: collective dynamics in the natural and social sciences* (Vol. 1). Berlin: Springer.