Motility control as a (self-)organization pathway for motile particles

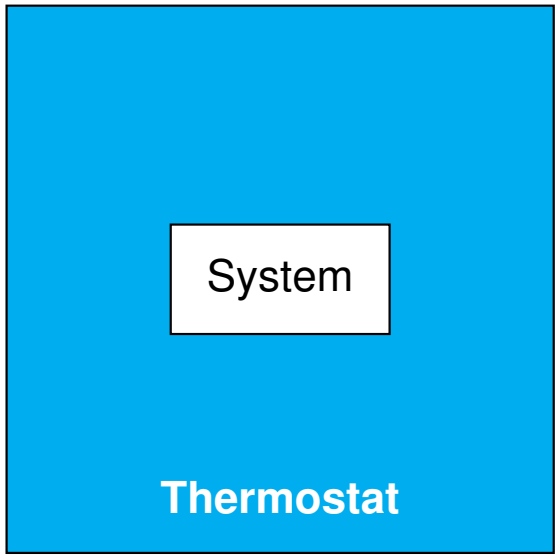
J. Tailleur

Laboratoire MSC
CNRS - Université Paris Diderot

LMU: 2019 Arnold Sommerfeld School on the Physics of Life

Equilibrium Statistical Mechanics

- Large thermostat with chaotic dynamics
- Exchange energy with the system
- Drives the system towards thermal equilibrium



→ Boltzmann distribution $P_{\rm stat}(\mathcal{C}) \propto \exp[-\beta E(\mathcal{C})]$

→ Time-reversal symmetry in steady-state (detailed-balance)

Non-equilib. phys. is like non-elephant biology

Some common definitions

- no steady state
- no Boltzmann weight
- no time-reversal symmetry

Some examples

Glasses

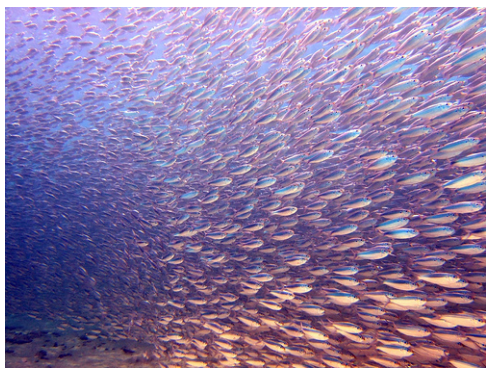
Boundary driven

Active matter

Identify coherent subclasses and say something smart/useful about them!

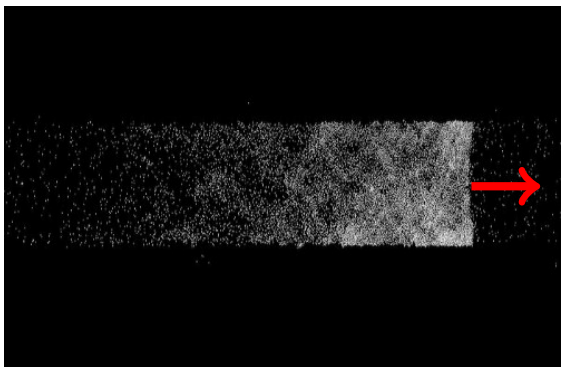
Active matter

Mechanical drive at the microscopic level → *Strongly out of equilibrium* → *Fundamentally new physics*



Fish shoals

Motility assays

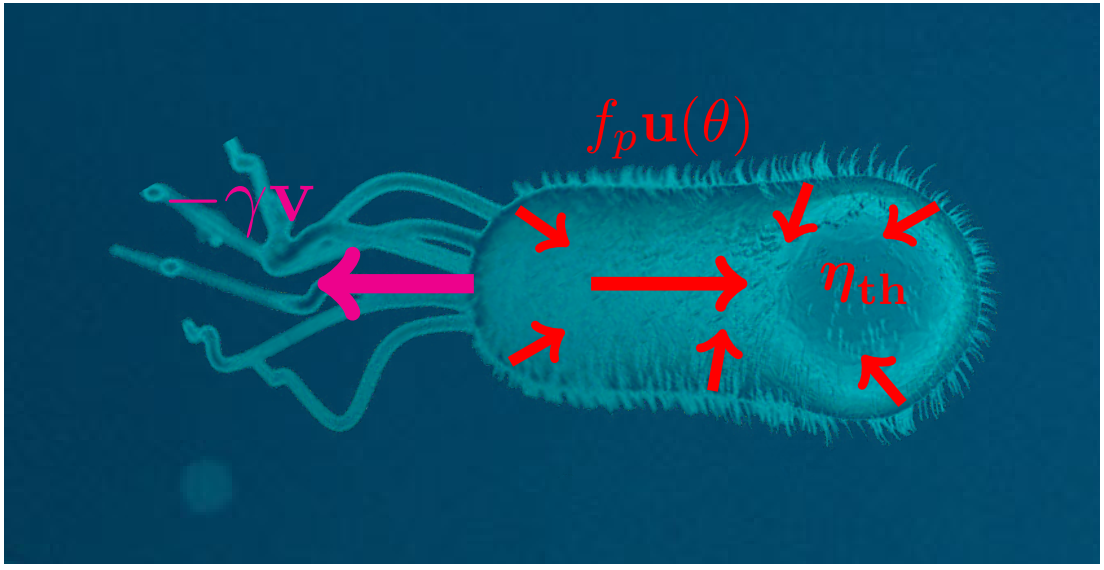


Colloidal Rollers

- New dynamical phenomenology
- Biological relevance
- Active Soft Materials

- Motility-induced phase separation
- No guiding principles
- Active pressure

Active matter



$$0 = m\dot{v} = -V'_{\rm ext}(x) - \gamma v + \sqrt{2\gamma kT}\eta + f_p\mathbf{u}(\theta)\tilde{\eta} + f_p\mathbf{u}(\theta) + f_p f_p f_p f_p$$

- Colloid in a fluid at equilibrium: Fluctuation-Dissipation theorem $D = kT/\gamma$ Active matter:
  - → No FDT: system driven out of equilibrium
  - → Dissipation: mean (drag) force from the fluid $\propto \gamma$
  - → Injection of energy: fluctuating force from the fluid $\propto \gamma kT$
  - → Injection of energy: self-propulsion force $f_p\mathbf{u}(\theta)$

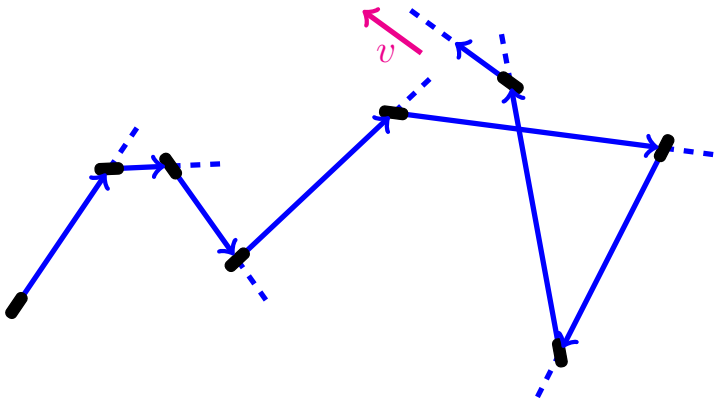
Self-organization in & out of equilibrium

- Equilibrium physics
  - → Time-reversal symmetry in steady-state
  - → Replace dynamical studies by ensemble approach
  - → Intuition based on Boltzman weight

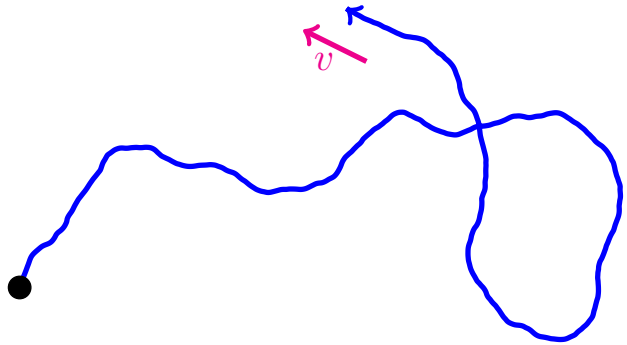
- Example: Liquid-gas phase transition
  - → Passive Brownian particles with attractive interactions
  - → Entropy vs Energy : disorder vs cohesion
  - → Lowering T: transition from gas to liquid (with coexistence)

- Outside equilibrium
  - → No generic formula for steady-state distribution
  - → Little basis upon which to build intuition
  - → Few guiding principles for self-assembly

Motility-control as a self-organization principle



Run and Tumble Particles •



Active Brownian Particles •

- Self-propelled particles with propelling speed v
- Diverse reorientation mechanisms (ABPs, RTPs, AOUPs, etc.)
- Generic: properties of v $\longrightarrow$ Control steady states

I. Non-interacting particles with spatially varying speed $v(\mathbf{r})$

II. Quorum-sensing: density-dependent speed $v(\rho)$

III. Application to bacterial pattern formation

IV. Multi-species systems