Transition to collective motion in self-propelled particles

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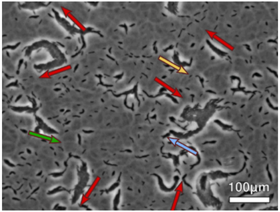
ICFP-Collective Behaviors in Active Matter

Collective motion

Birds

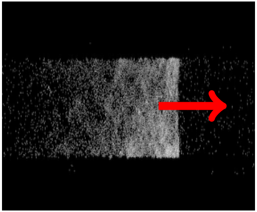
Fish

Sheep



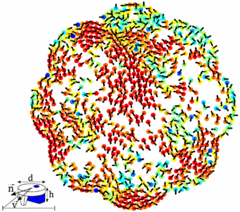
Myxobacteria

[Peruani *et al.*, PRL 2012]



Quincke rollers

[Bricard *et al.*, Nature 2013]



Vibrated disks

[Deseigne *et al.*, PRL 2010]

Minimal ingredients: Self-propulsion + Alignment

The Vicsek model [Vicsek et al. PRL 75, 1226 (1995)]

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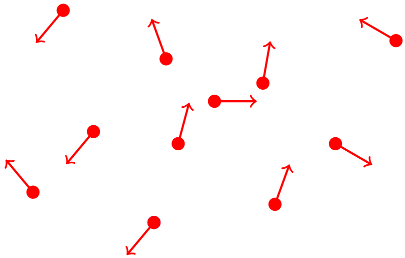
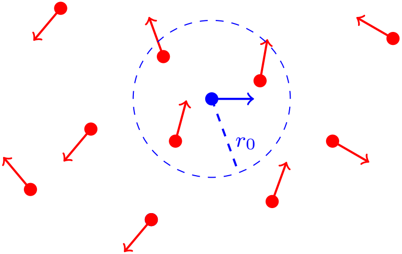


- N self-propelled particles in 2D continuous space
- Local alignment rule

The Vicsek model [Vicsek et al. PRL 75, 1226 (1995)]



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- Local alignment rule with metric rules iVj iff $|r_i - r_j| < r_0$

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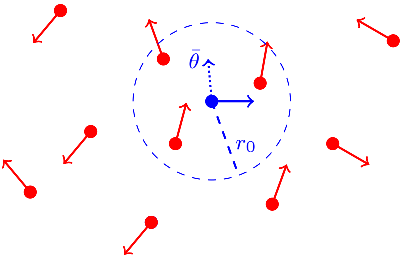

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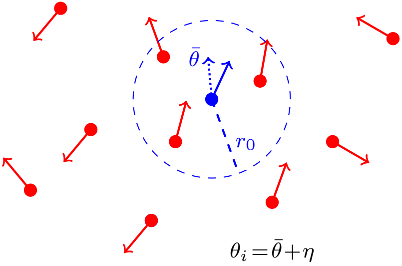

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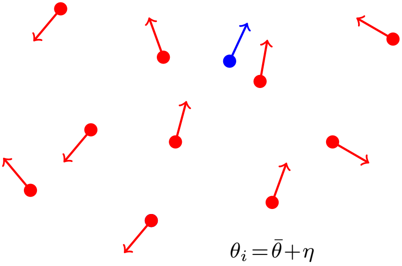

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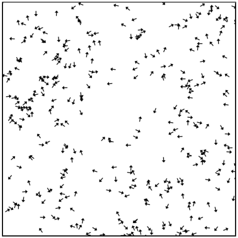
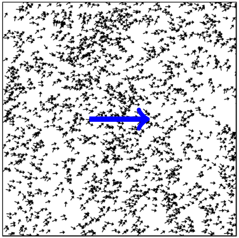
Flocking transition in the Vicsek model



Disordered



Fluctuating flocking state

noise $\searrow$ or density $\nearrow$

- Non-equilibrium transition to long-range order in $d = 2$ [Toner-Tu, PRL (1995)]

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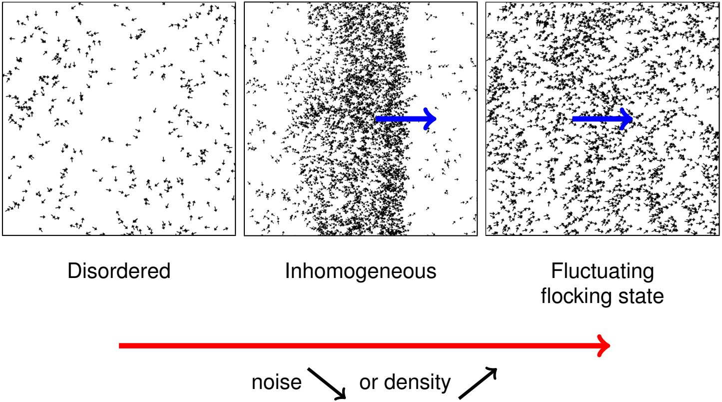
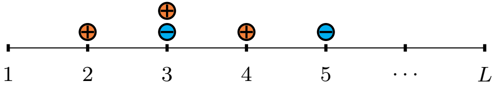


- Non-equilibrium transition to long-range order in $d = 2$ [Toner-Tu, PRL (1995)]
- First-order transition [Grégoire, Chaté, PRL (2004)] (starting a long debate)

Active Ising model [Solon, Tailleur, PRL 2013]



- Density $\rho_i = n_i^+ + n_i^-$ Magnetisation $m_i = n_i^+ - n_i^-$

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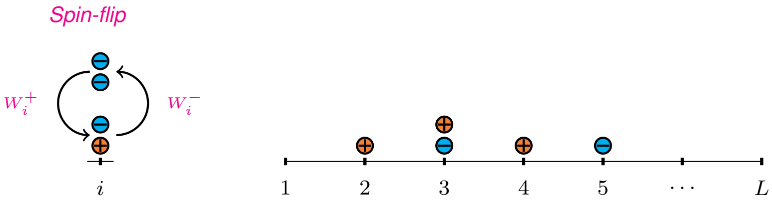

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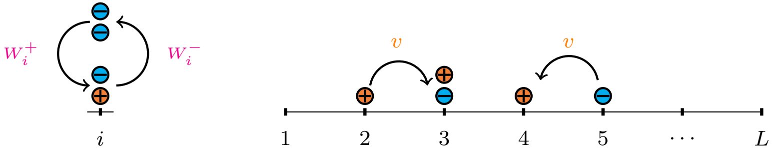
- Local alignment $\longrightarrow$ $W_i^\pm = \exp(\pm\beta \frac{m_i}{\rho_i})$

  $\longrightarrow$ Fully connected Ising models on each site

Active Ising model [Solon, Tailleur, PRL 2013]

Spin-flip

Biased hopping



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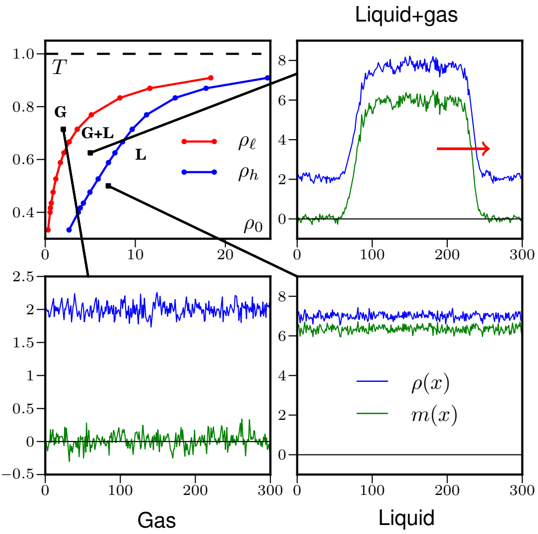
- Local alignment ⟶ $W_i^{\pm} = \exp(\pm\beta \frac{m_i}{\rho_i})$

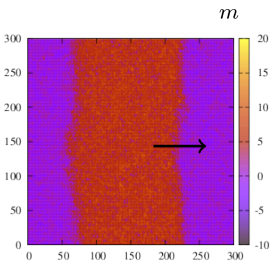
  ⟶ Fully connected Ising models on each site

- Self-propulsion ⟶ Hoping along $\hat{e}_x$ biased by the spins

  (Symmetric diffusion along $d-1$ other directions)

Phase diagram in 2d $(\rho, T \equiv \beta^{-1})$

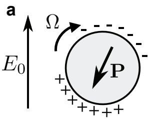




Quench ordered •
Quench disordered •
Closed Box •

Flocking transition in Quincke Rollers

- Colloidal rollers based on Quincke instability [Bricard *et al.* Nature **503**, 95-98 (2013)]



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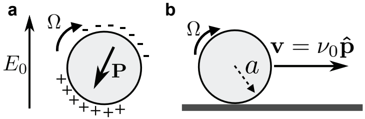

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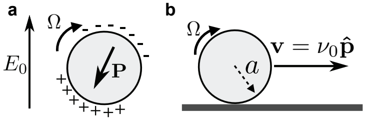

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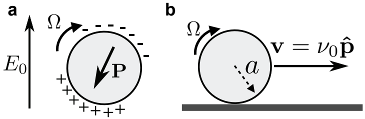

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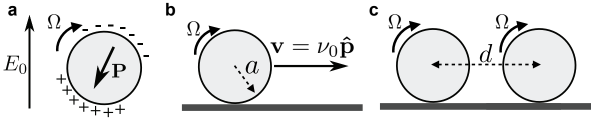

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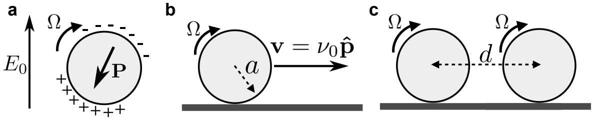
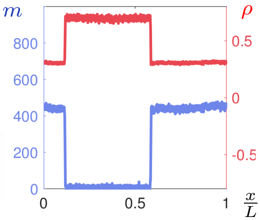


- Hydrodynamics + Electrostatic interactions ⟶ Travelling bands
- Higher density? ⟶ Polar liquids (Particles are not point-like!)
- Higher density? ⟶ Beyond Vicsek physics: active solidification
- Motility-induced phase-separation between polar liquid and arrested solid

  [Geyer *et al.* Phys. Rev. X 9, 031043 (2019)]



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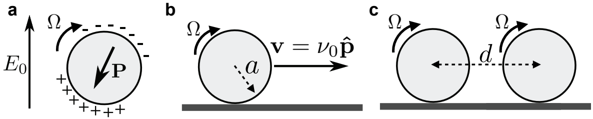

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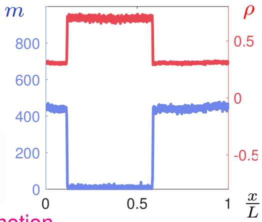

- This course: focus on Vicsek physics & transition to collective motion

Outline

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    - Brief reminder of equilibrium XY model
    - Why walking together is easier than pointing together (a la John Toner)
    - The critical ordered phase

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3. All in all: Active Solidification