Introduction to Structuration and Collective motion

Outline

1) Minimalistic dynamical structuration : Zeldovich model

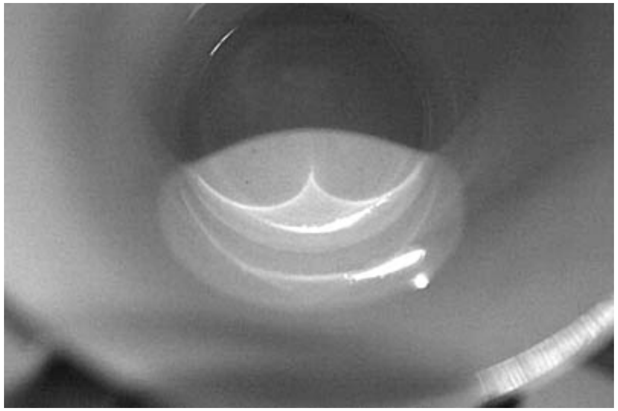
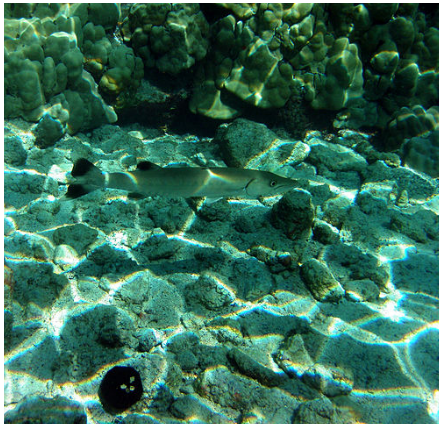
2) Collective motion: Bird Flocks (Vicsek model 1995)
(Boids=bird-oids, 80's)

3) Engineered motile colloids : relation to Vicsek model (v=size/s).

4) Bacteria Chemotaxis (v=size/s)

5) Back to flocks: correlations

Caustics

- Caustics in (geometrical) optics
- a)  b) 

a) By User:Paul venter - http://en.wikipedia.org/wiki/File:Caustic00.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2782727

b) b) By Brocken Inaglory - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=10585422

- # Caustics in « mechanics » (Zeldovich)

Simplistic Kinematic example:

initial uniform density field, non-uniform deterministic velocity field, no collisions (ballistic motion).

1-D, Eulerian x <—> Lagrangian q.

$$x = q + tv(q) \qquad v(t=0,x) = v(q) \qquad \rho(t=0,x) = \rho_0$$

$$\rho(x,t) = \frac{\rho(q)}{|dx/dq|} = \frac{\rho_0}{|dx/dq|} \qquad \rho(x,t) = \frac{\rho_0}{|1 + t dv/dq|}$$

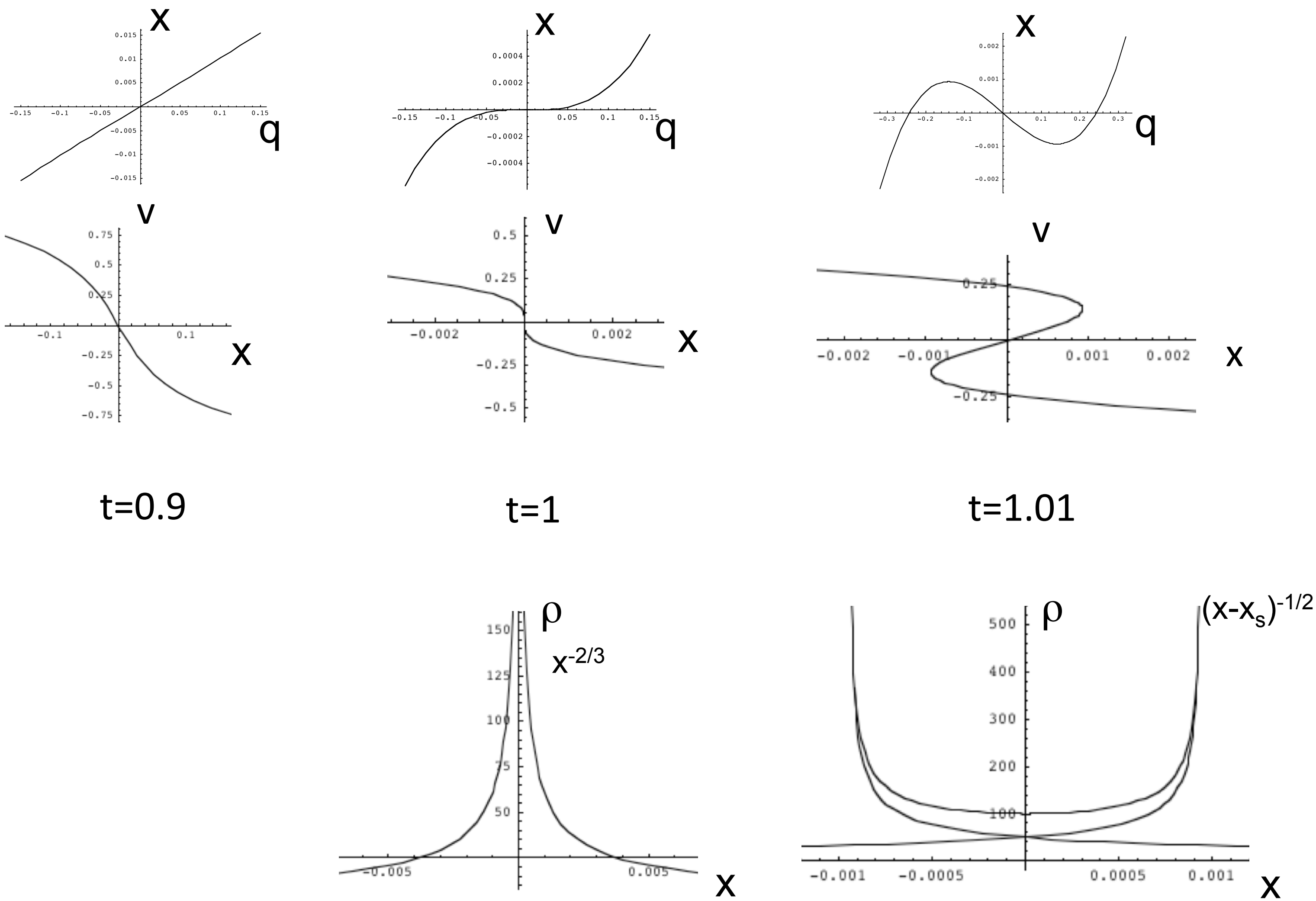
Density singularities

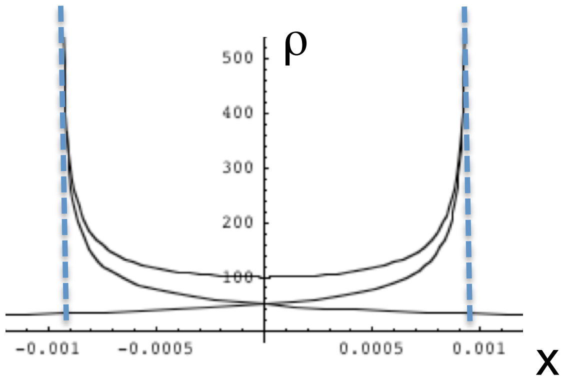
Example v(q) = -sin(q)

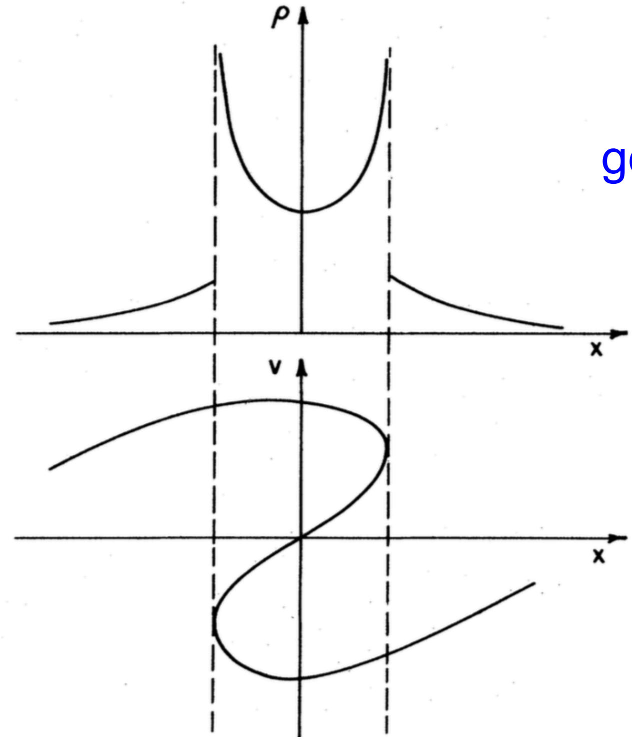
$$x(t,q) = q - t\sin(q)$$

$$\rho(x,t) = \frac{\rho_0}{|1 - t\cos(q)|}$$

Singularity at t=1, x=0 (q=0)

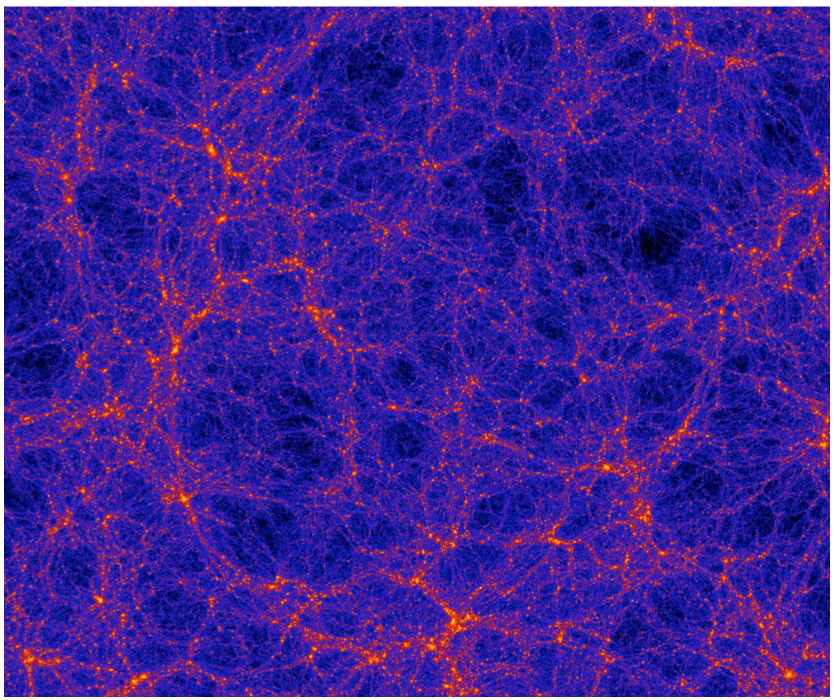


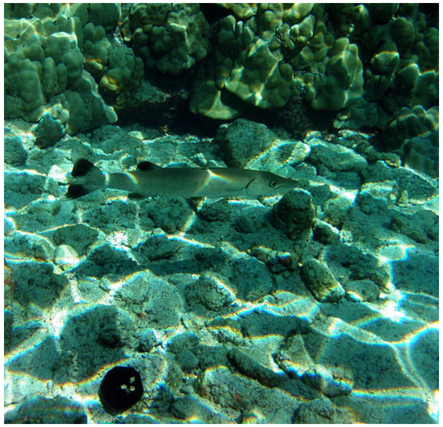




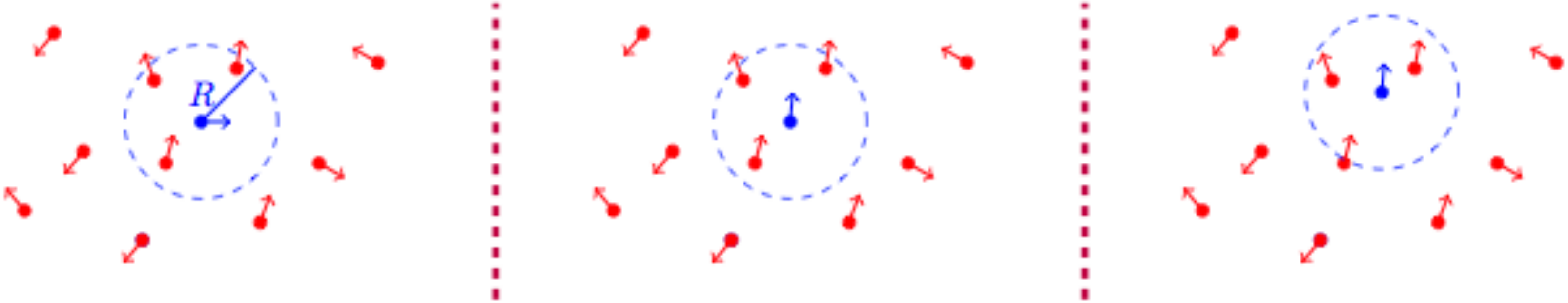
generic

Cosmologic web (shandarin)





Vicsek model of point-like self-driven particules: a simple model for flocking (PRL 1995)



(J. Taillleur)

Parameters: velocity, **density**, **noise**, range R

Vicsek et al. PRL 1995

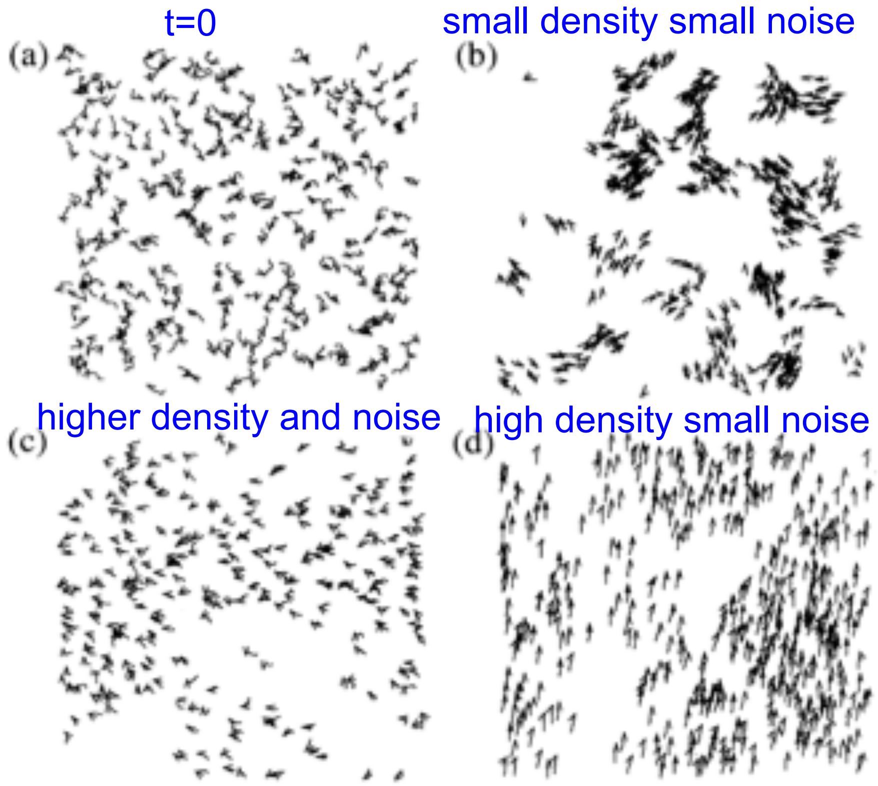


FIG. 1. In this figure the velocities of the particles are displayed for varying values of the density and the noise. The actual velocity of a particle is indicated by a small arrow, while their trajectory for the last 20 time steps is shown by a short continuous curve. The number of particles is $N = 300$ in each case. (a) $t = 0$, $L = 7$, $\eta = 2.0$. (b) For small densities and noise the particles tend to form groups moving coherently in random directions, here $L = 25$, $\eta = 0.1$. (c) After some time at higher densities and noise ($L = 7$, $\eta = 2.0$) the particles move randomly with some correlation. (d) For higher density and *small noise* ($L = 5$, $\eta = 0.1$) the motion becomes ordered. All of our results shown in Figs. 1–3 were obtained from simulations in which v was set to be equal to 0.03.

Vicsek Model : features

Spontaneous breaking of rotational symmetry in 2d
(different from Equilibrium transition, Mermin-Wagner)

Large density fluctuations in the ordered phase

Polar bands

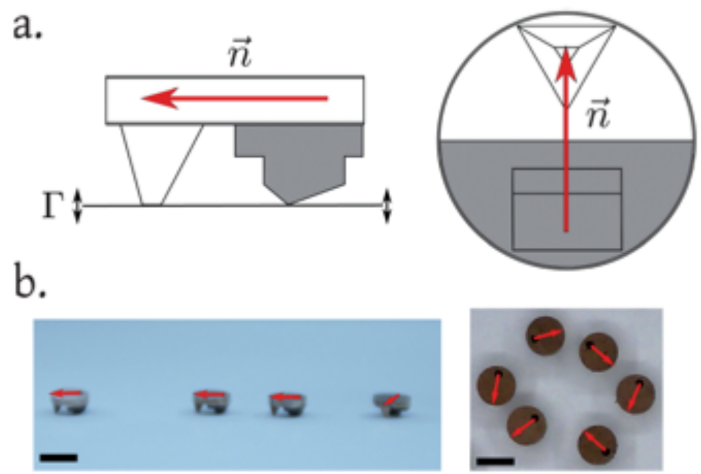
Vicsek Model : "variants"

Non-metric interactions

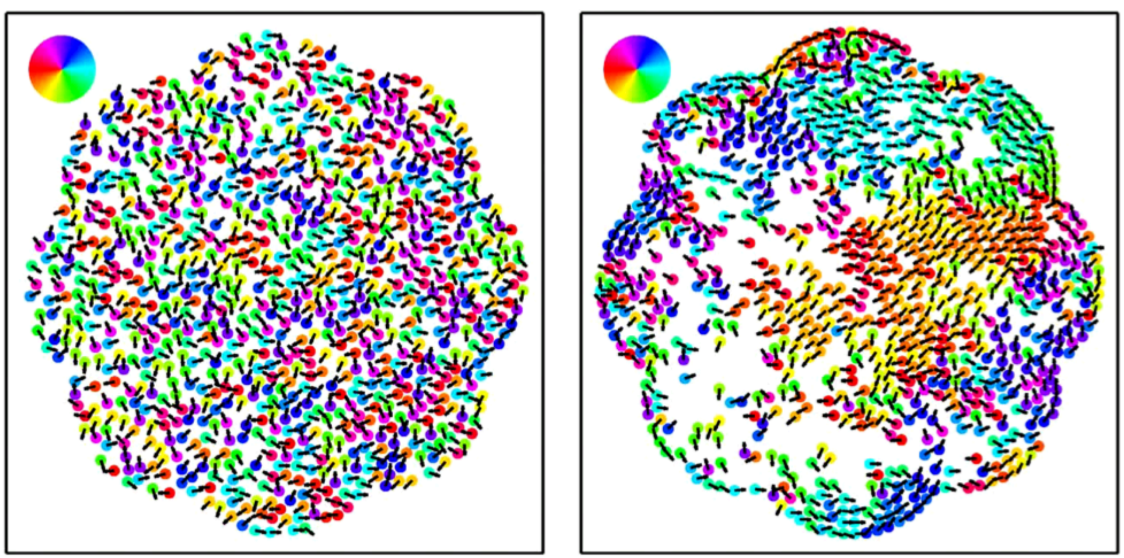
Different Approach:

Toner and Tu (also95) + Ramaswami

Polar grains



Deseigne 2012

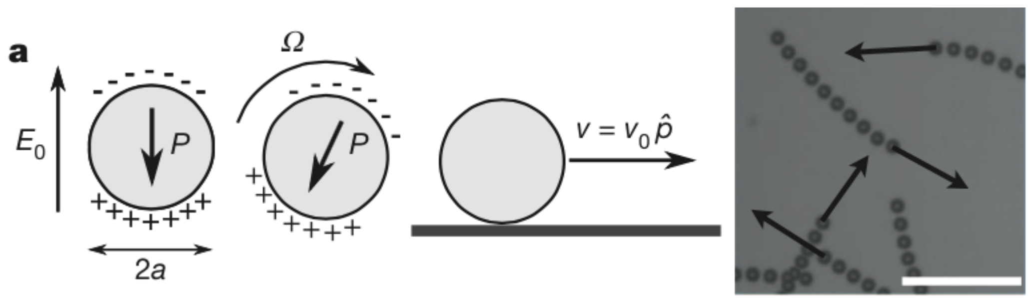


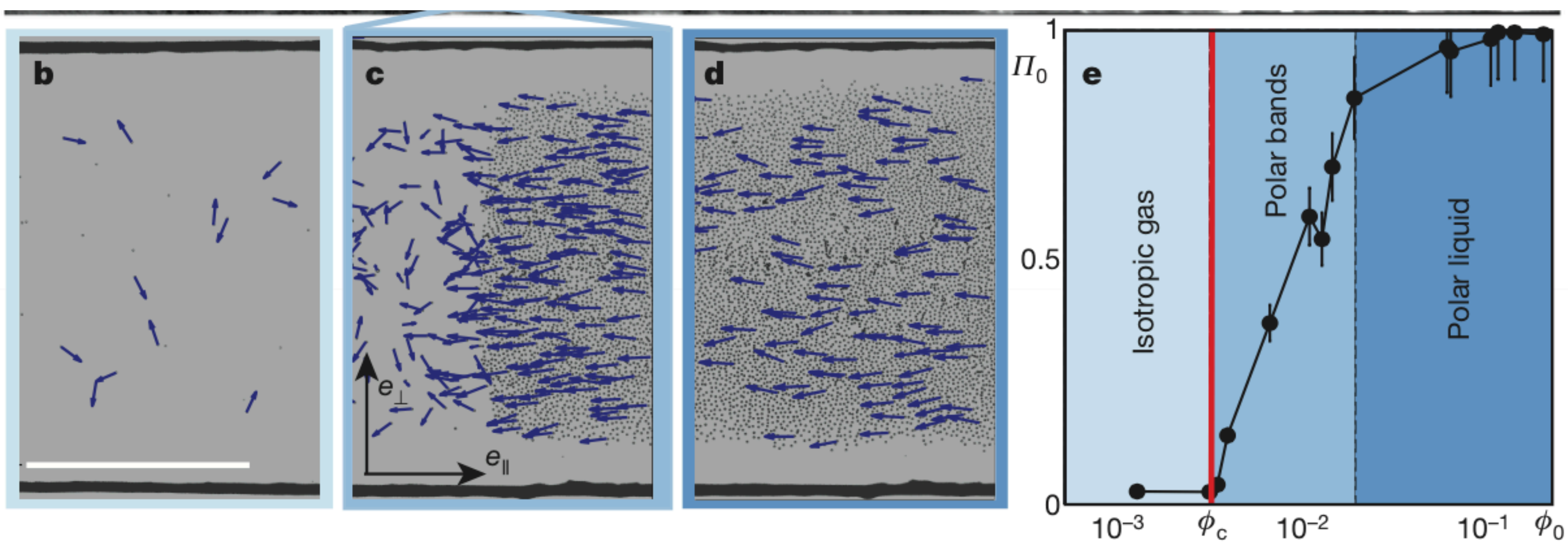
Isotropic Disks **Polar Disks**

polar clusters

Rolling Colloids

Quincke effect



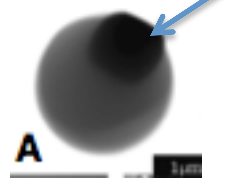


Bricard 2013

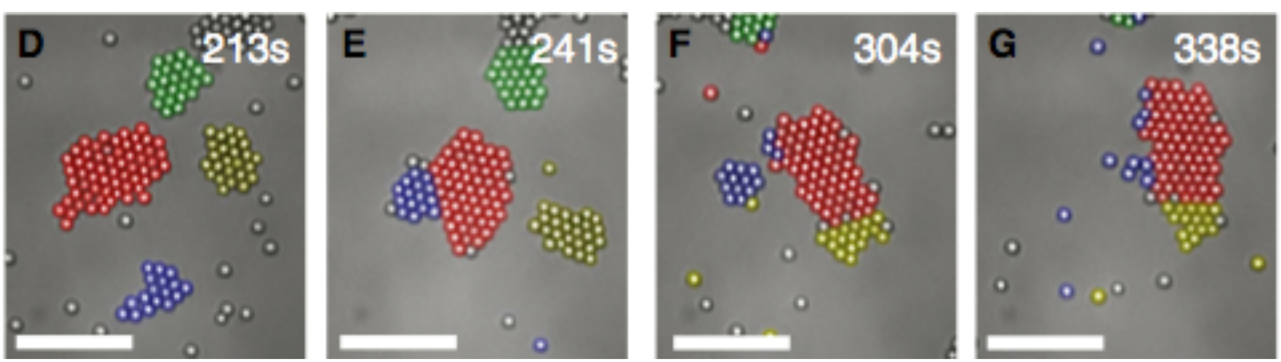
Living Crystals of Light-Activated Colloidal Surfers

(Palacci 2013)

hematite



H_2O_2 + blue light → Association at walls (phoretic motion)

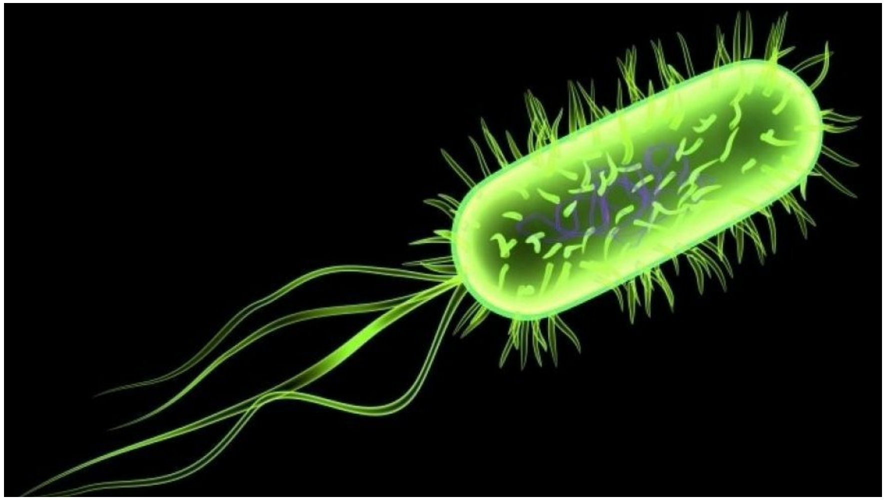


(Palacci 2013)

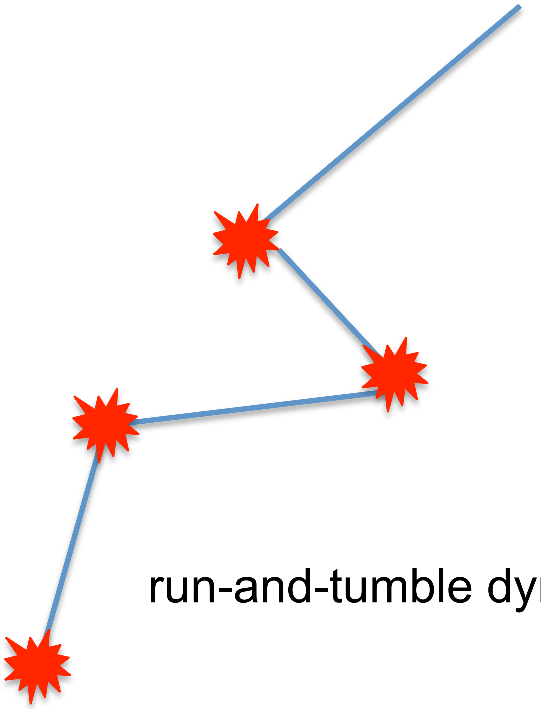
	Alignment	Phases	Giant density fluct.
Rolling colloids	with (hydro origin)	Iso -> polar bands -> hom. polar phase	No
Actin filaments	with (steric origin)	Iso -> polar clusters -> polar bands ?	irrelevant
Bacteria	with (steric origin)	Iso -> polar clusters	irrelevant
Walking disks	A priori without	Iso -> polar clusters	irrelevant
Janus colloids	? (hydro origin)	Iso -> apolar active clusters	No
Surfing colloids	? (hydro origin)	Iso -> apolar active clusters	No

(Olivier Dauchot 2016)

Chemotaxis



E.Coli

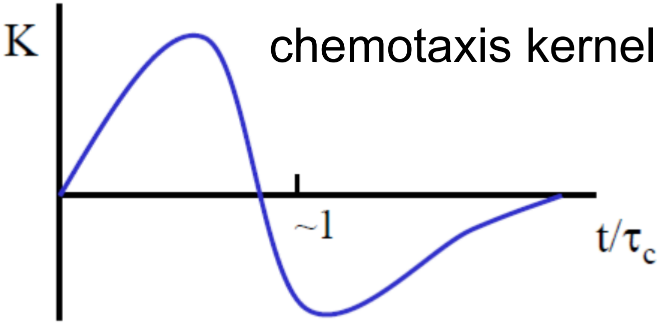


run-and-tumble dynamics

τ : run

$$\frac{1}{\tau} = \frac{1}{\tau_0} - \int_{-\infty}^{t} K(t-t')c(t')dt'$$

de Gennes 2004



chemotaxis kernel

sensing the gradient
of attractant c

Review: M. Cates 2012

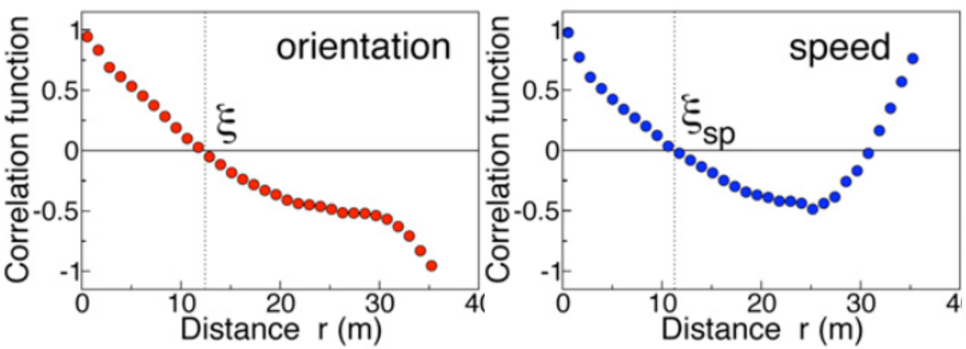
Back to Flocks
(non metric interactions)

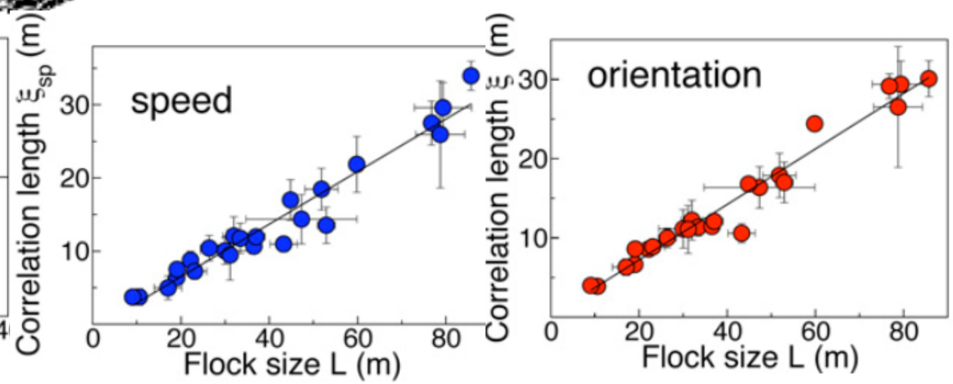
starling flock

(Cavagna PNAS 2010)

$$C(r) = \frac{1}{c_0} \frac{\sum_{ij} \vec{u}_i \cdot \vec{u}_j \, \delta(r - r_{ij})}{\sum_{ij} \delta(r - r_{ij})}$$

u=v-<v>





correlation length ∝L

Bialek PNAS 2012 “topological” rather than metric distance