Motility-induced solidification in roller flocks

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Active matter : an out-of-equilibrium field

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Active matter : an out-of-equilibrium field

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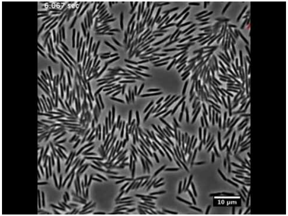
- Canonical examples in nature : bacterial colonies, fish schools, cellular tissues...

A swarm of fish



E. Coli bacteria

Summary of the talk

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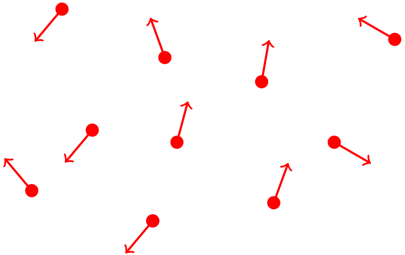
The transition to collective motion

- The Vicsek model : a canonical model
  - agents moving at constant speed in a given direction
  - noisy aligning interactions between agents



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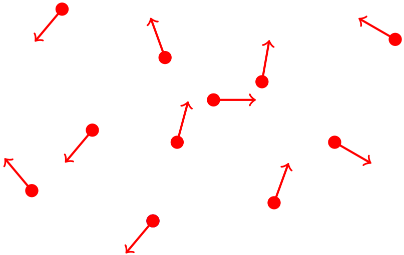

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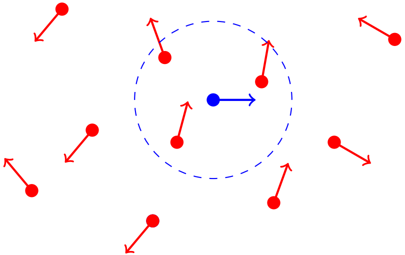

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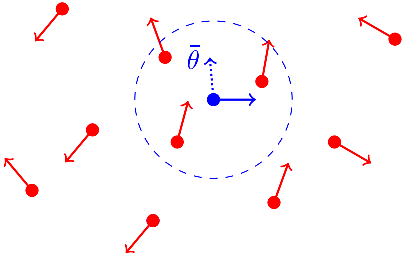

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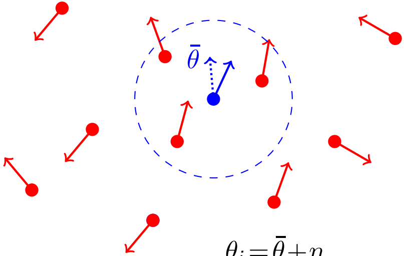

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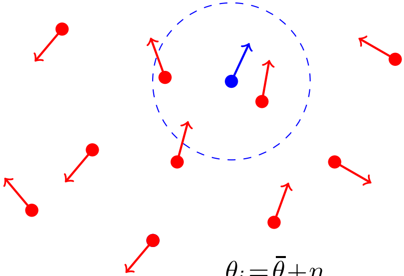

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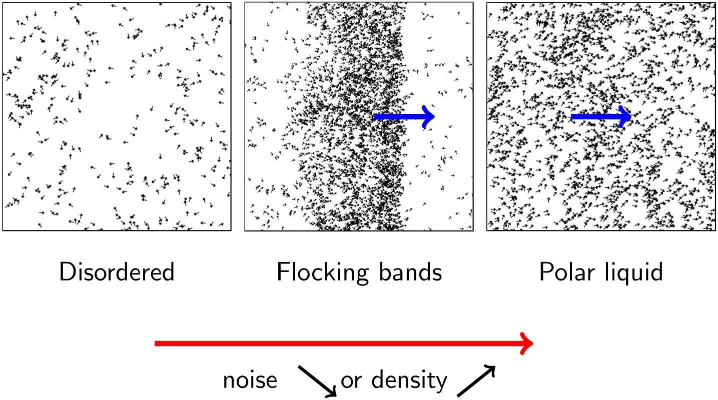
Vicsek phenomenology



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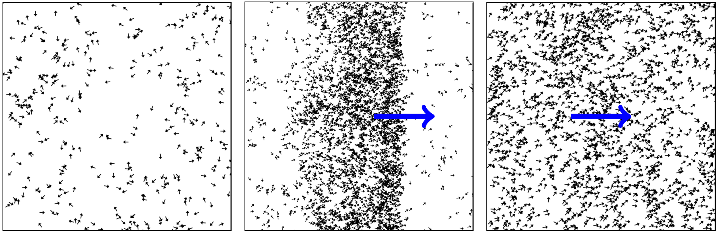

Disordered | Flocking bands | Polar liquid

noise ↘ or density ↗

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- The liquid fraction ↗ linearly with ρ .

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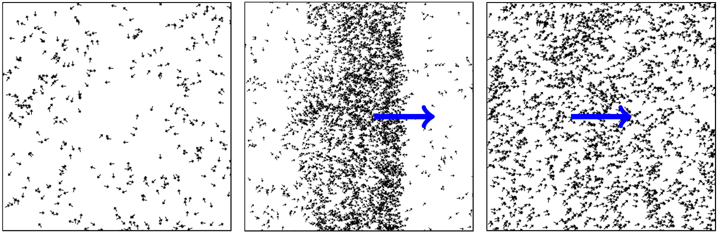

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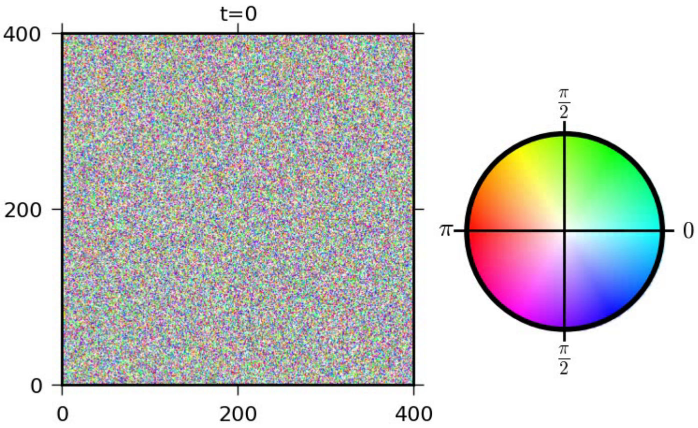

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- A minimalist 1D Toner-Tu hydrodynamic model for active gas and polar bands coexistence in the literature. [Caussin, Solon, . . . , PRL, 2014]

$$\partial_t \rho = D_\rho \partial_{xx} \rho - \partial_x W \tag{1}$$

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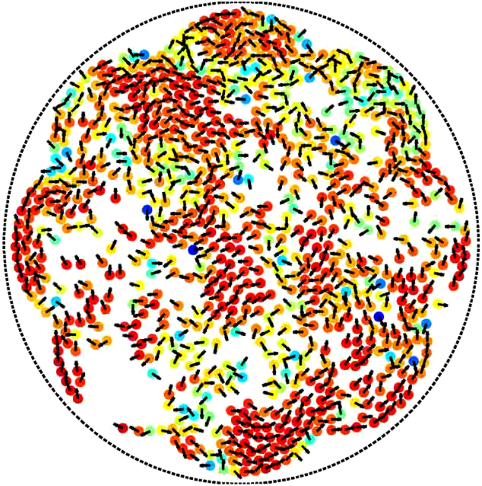
- Reproduces Vicsek phenomenology
  - Polar bands propagating in a disordered background
  - First order transition : constant binodals, lever rule, hysteresis loop...

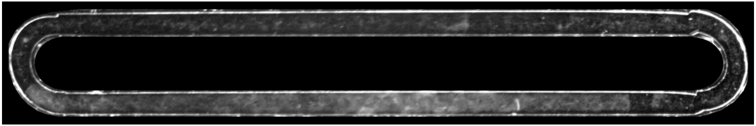
Vicsek phenomenology in experiments

- Shaked grains [Deseigne, Dauchot, Chaté ,PRL, 2010]



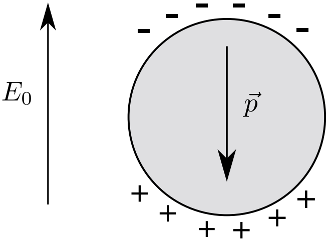
Vicsek phenomenology in experiments

- Assemblies of Quincke rollers [Bricard, Caussin, . . . , Nature, 2013]



- We will now focus on this experimental realization of Vicsek model

Physics of Quincke rollers



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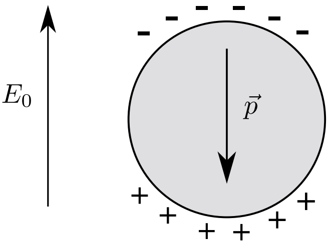

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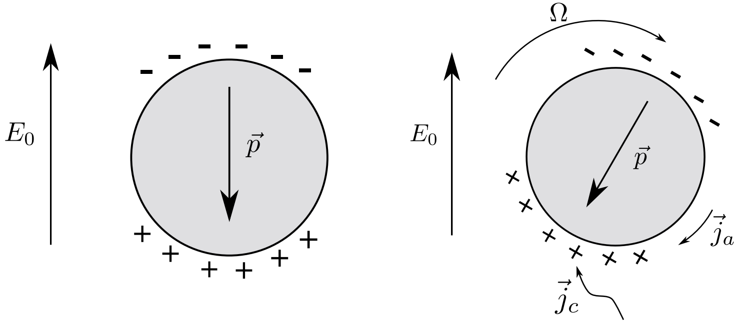

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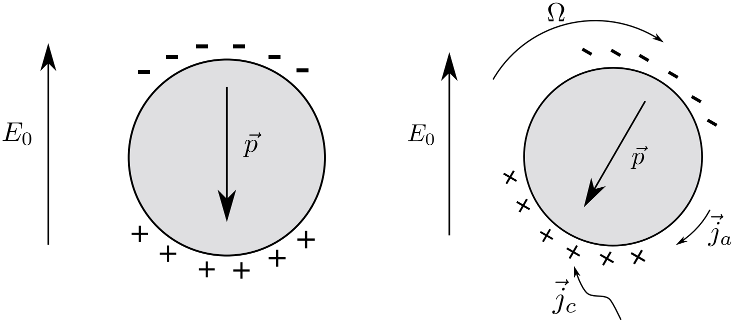

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- Yes, if on the surface $\vec{j}_a$ compensated by $\vec{j}_c$
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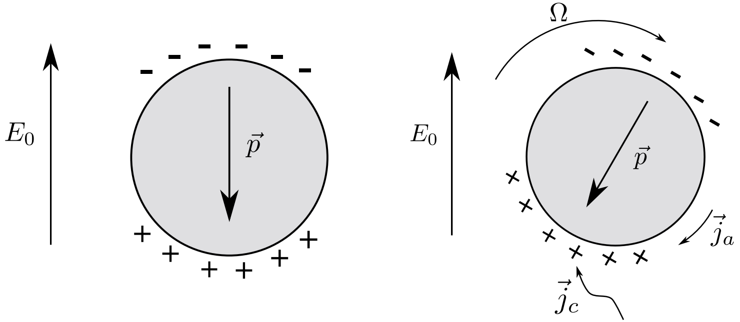

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- It happens above a threshold field E_Q : $\Omega = \frac{1}{\tau}\sqrt{\left(\frac{E_0}{E_Q}\right)^2 - 1}$

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- However, missing features at high density

Beyond Vicsek phenomenology at high density

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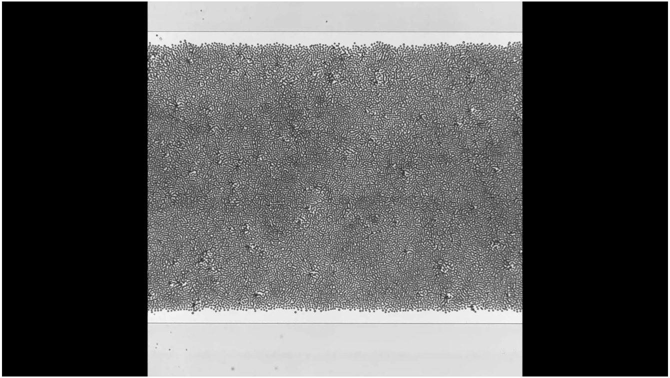
- Coexistence of polar liquid and counter-propagating traffic jams



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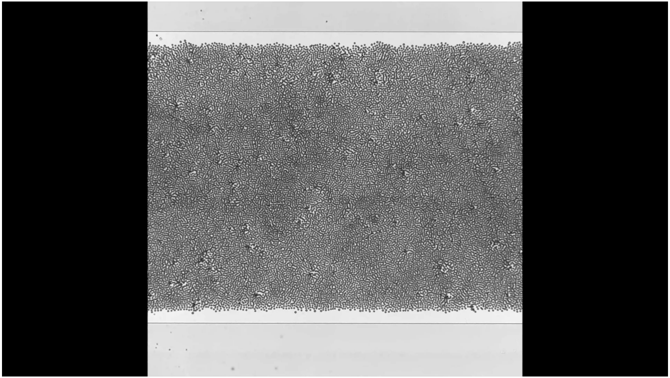

- We call it active solidification

Beyond Vicsek phenomenology at high density

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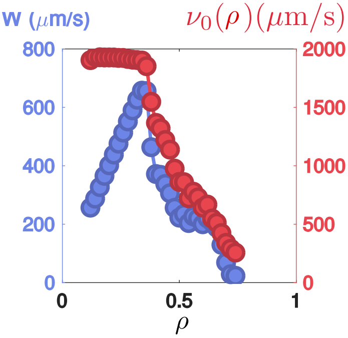

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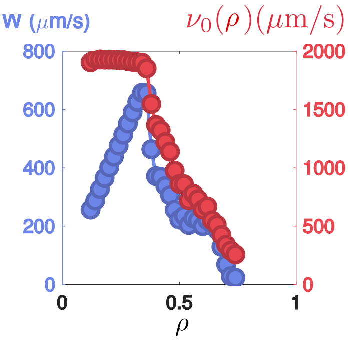

- Drop of velocity and polar order as $\rho \nearrow$

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- Self-propelled particles with pairwise forces (PFAPs)
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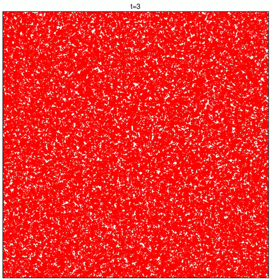
$$\dot{\mathbf{r}}_\mathbf{i} = v\mathbf{u}(\theta_i) + \mu \sum_j F_{ij}(\mathbf{r}_\mathbf{i} - \mathbf{r}_\mathbf{j}) + \sqrt{2D_t}\eta_i; \qquad \dot{\theta}_i = \sqrt{2D_r}\xi_i$$



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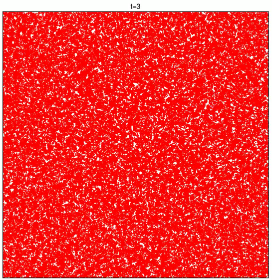

- Interactions yields decreasing $v(\rho) \equiv \sum_i \dot{\vec{r}}_i \cdot \vec{u}(\theta_i)$ [Fily et al PRL (2012)]

MIPS scenario

- Non-uniform speed ⟶ $\partial_t P = -\nabla(v(\mathbf{r})\mathbf{u}(\theta)P) + \Theta P$

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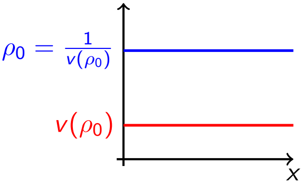

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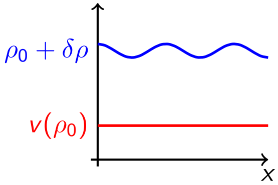

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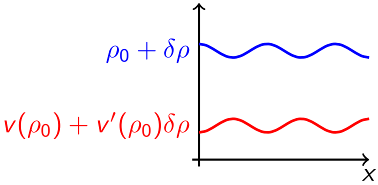

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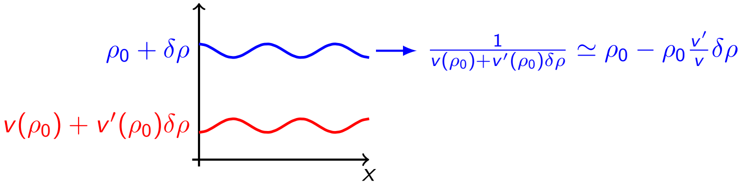

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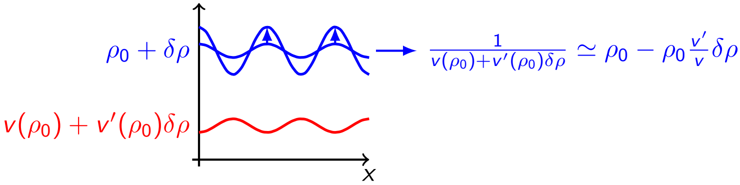

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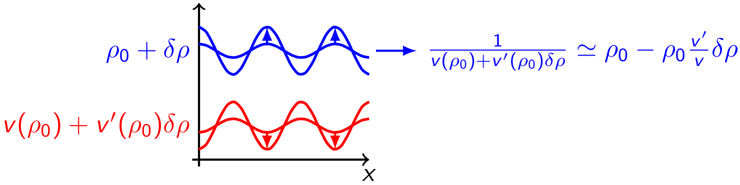

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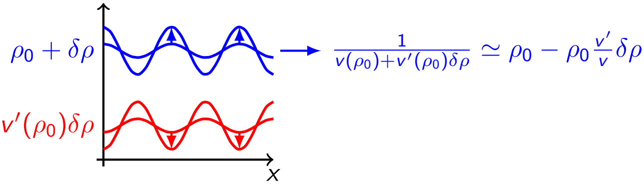

- Linear instab. if $\rho_0 v' + v \leq 0$

- What does it entail ? ⟶ Motility Induced Phase Separation

Including MIPS in Toner-Tu hydrodynamics

- Take again the Toner-Tu hydrodynamic for Vicsek

$$\partial_t \rho = D_\rho \partial_{xx} \rho - \partial_x W \tag{3}$$

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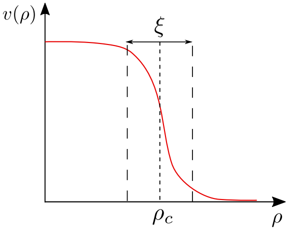
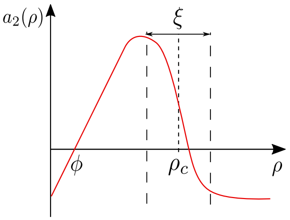


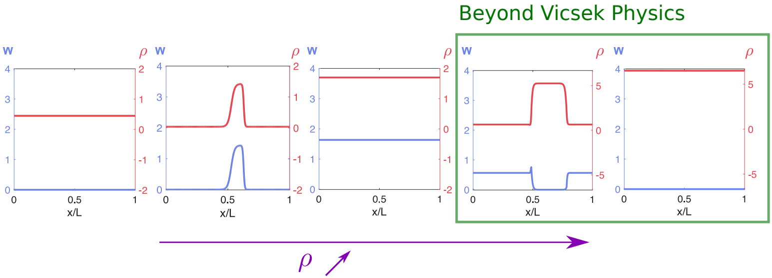
Velocity drop



Ordering drop

Modified Toner-Tu hydrodynamics

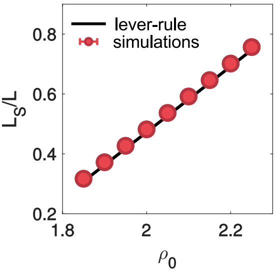
- New phase transition

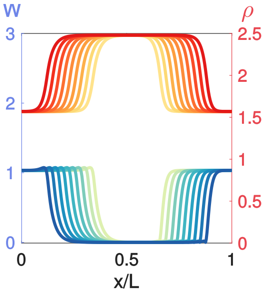


Phase diagram of modified Toner-Tu

- Linear stability exhibits two MIPS-like criteria
  - solid melting : $v(\rho) + \rho v'(\rho) < -K_1 D_\rho$
  - solid nucleation : $v(\rho) + \rho v'(\rho) < -K_2 W_0^2$

Modified Toner-Tu transition is first order





- Finite lower bound for traffic jam extent and lever rule

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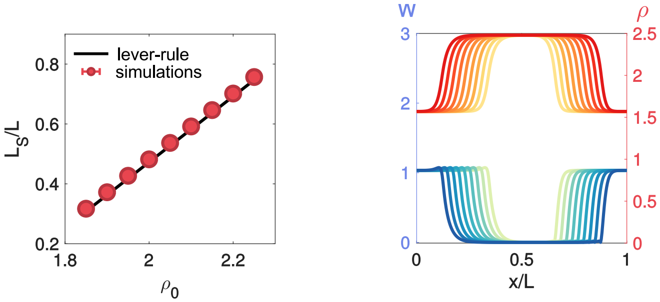

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- Constants binodals at coexistence

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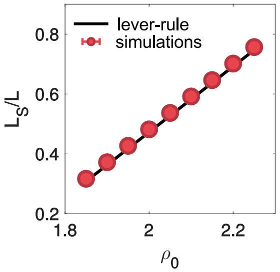

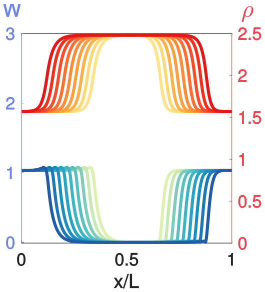

- Finite lower bound for traffic jam extent and lever rule
- Constants binodals at coexistence
- Slow coarsening dynamic leading to complete phase separation

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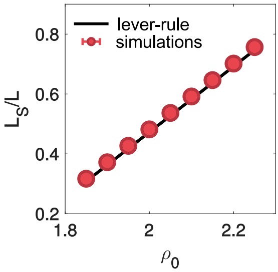

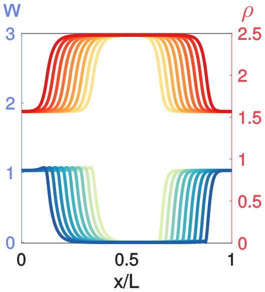

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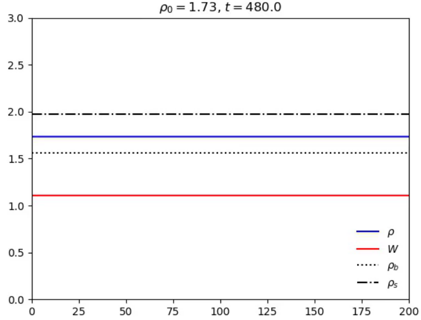
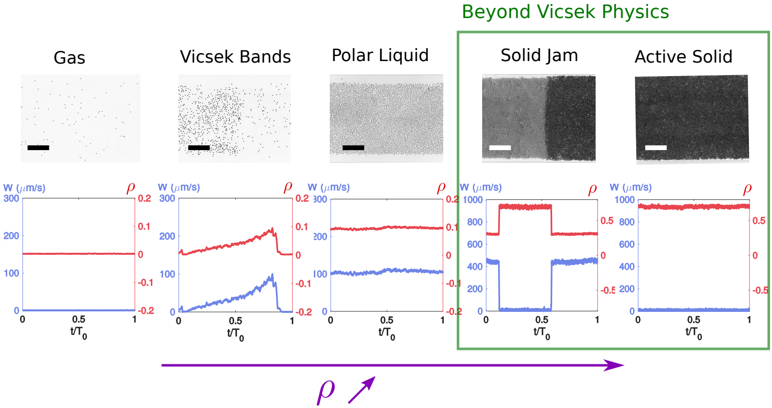
Toner-Tu hydrodynamic simulation



- Back to experiments $\rightarrow$ same phenomenology ?

Phase diagram of Quincke rollers



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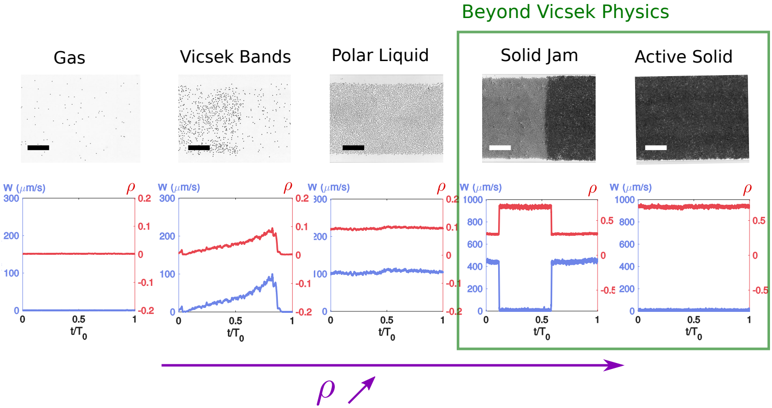
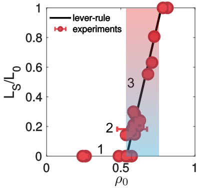
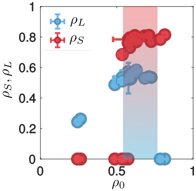
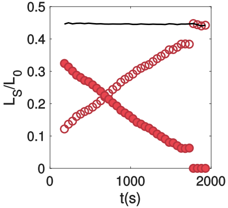


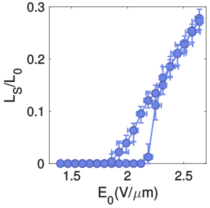
- Same phase diagram

Active solidification is a first order transition









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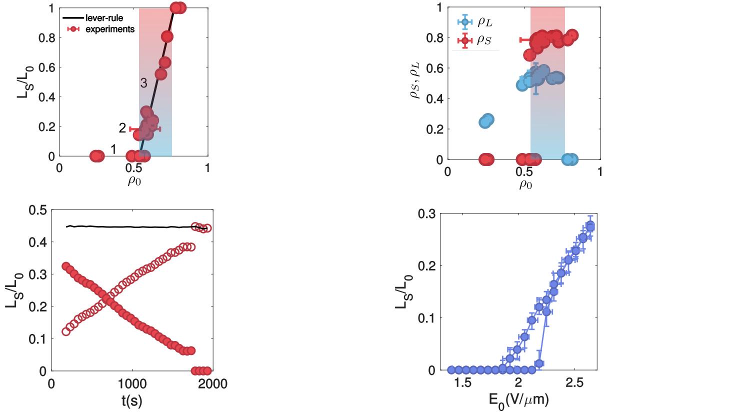

- Finite lower bound for traffic jam extent and lever rule

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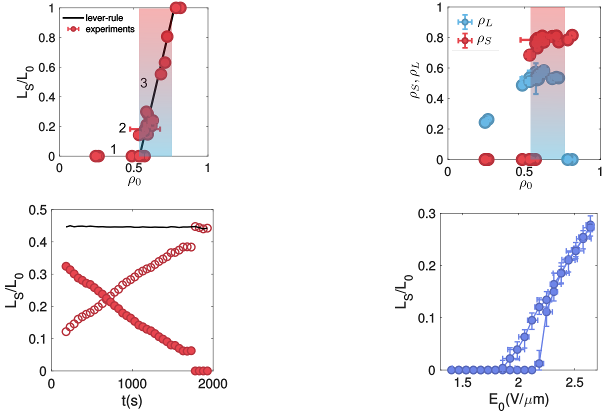

- Finite lower bound for traffic jam extent and lever rule
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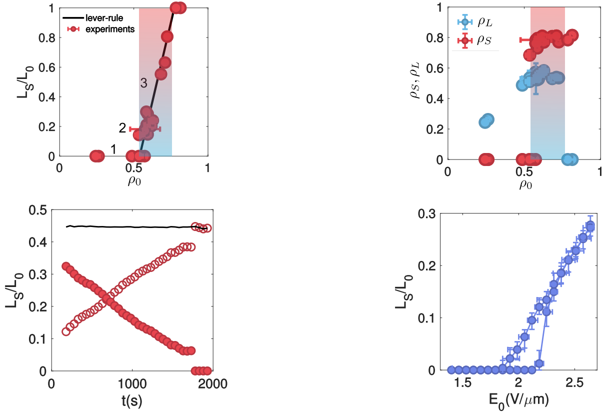

- Finite lower bound for traffic jam extent and lever rule
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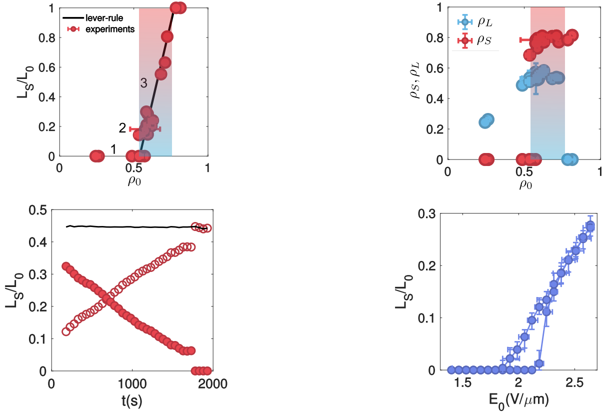

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Conclusion and outlook

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- It is a generic feature of aligning motile polar units and speed reduction at high density
- A lot of open questions remaining :
  - Is there other phase transition to discover at high density ?
  - What is the dynamic and the structure of the jammed phase ?