Imaging the swarming transition using light-controlled bacteria
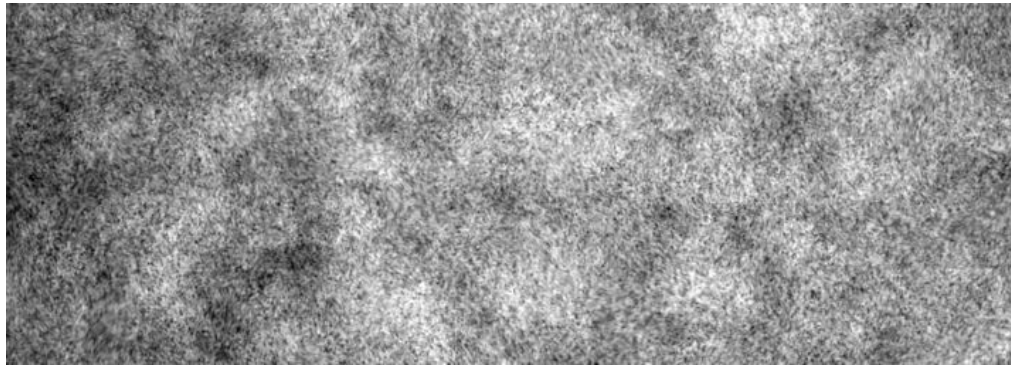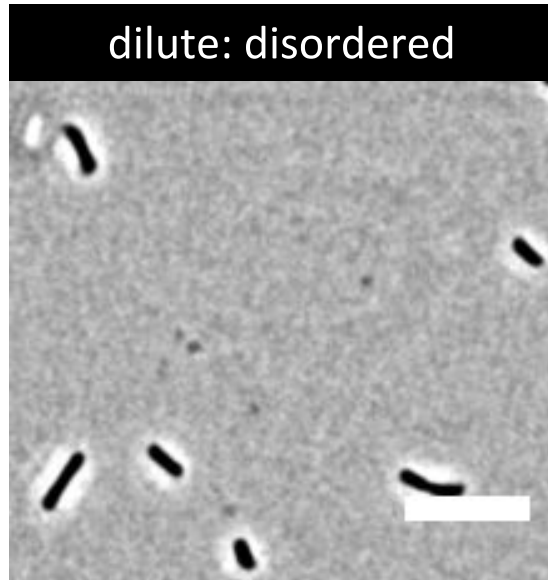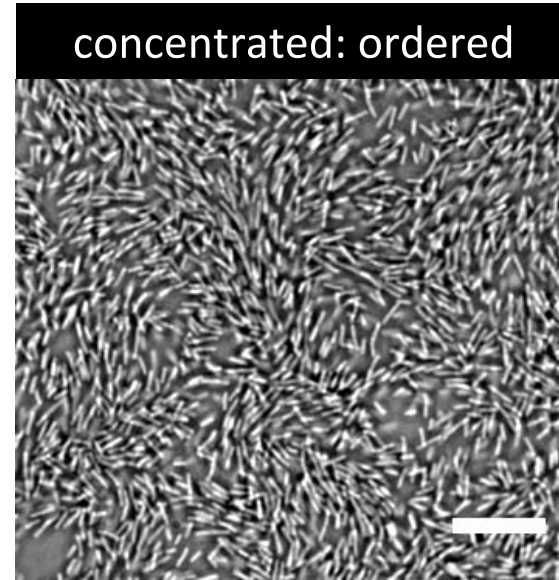
Yi Peng, **Zhengyang Liu**, Xiang Cheng

UNIVERSITY OF MINNESOTA
Driven to Discover℠

CEMS
1⦻⦻·5⦻
1919-2019   1970-2020
Chemical Engineering
& Materials Science

dilute: disordered

concentrated: ordered

10 μm

30 μm

In what condition do bacteria swarm?

How does the swarming state emerge?
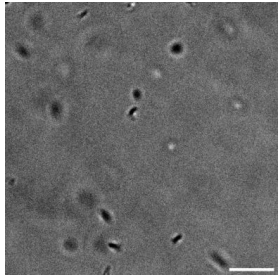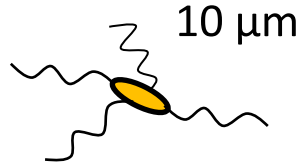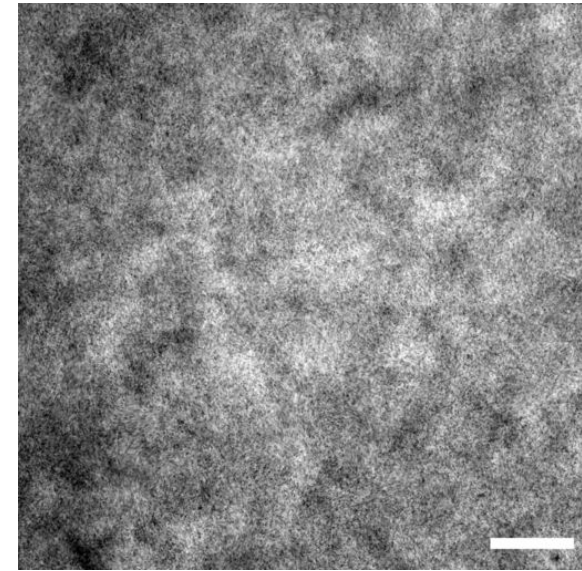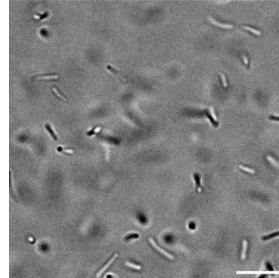
Wild-type   **Light-controlled**   **Tumbler (passive)**   **Bacterial swarming**
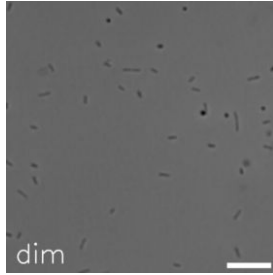
10 μm

Dim: slow   Bright: fast

Walter et al., PNAS (2007)

Three variables:

concentration: n; velocity: v;

swimmer fraction: $f = N_{swim}/N_{total}$.

100 μm
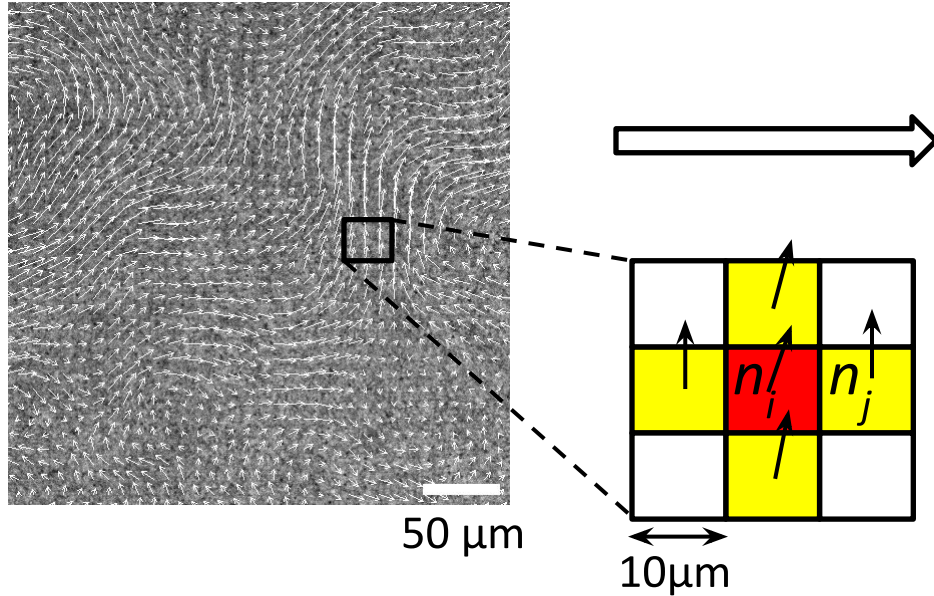
E. coli concentrations: $1n_0$-$100n_0$

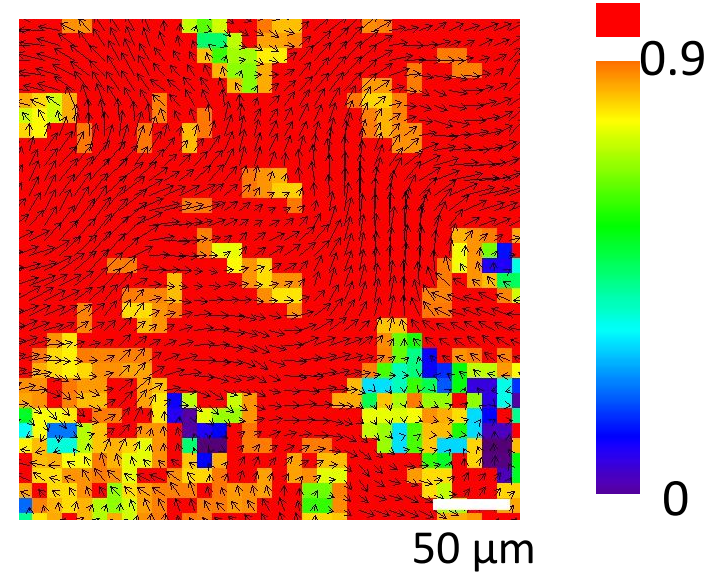$n_0 = 8 \times 10^8$ cells/mL

Sample thickness: 170 ± 10 μm

Focal plane: in the middle.

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Flow field (PIV)

Flow order field

50 μm

10μm

50 μm

Coherent bond: $n_i \cdot n_j > 0.9$. n_i is the unit vector of flow velocity in region i
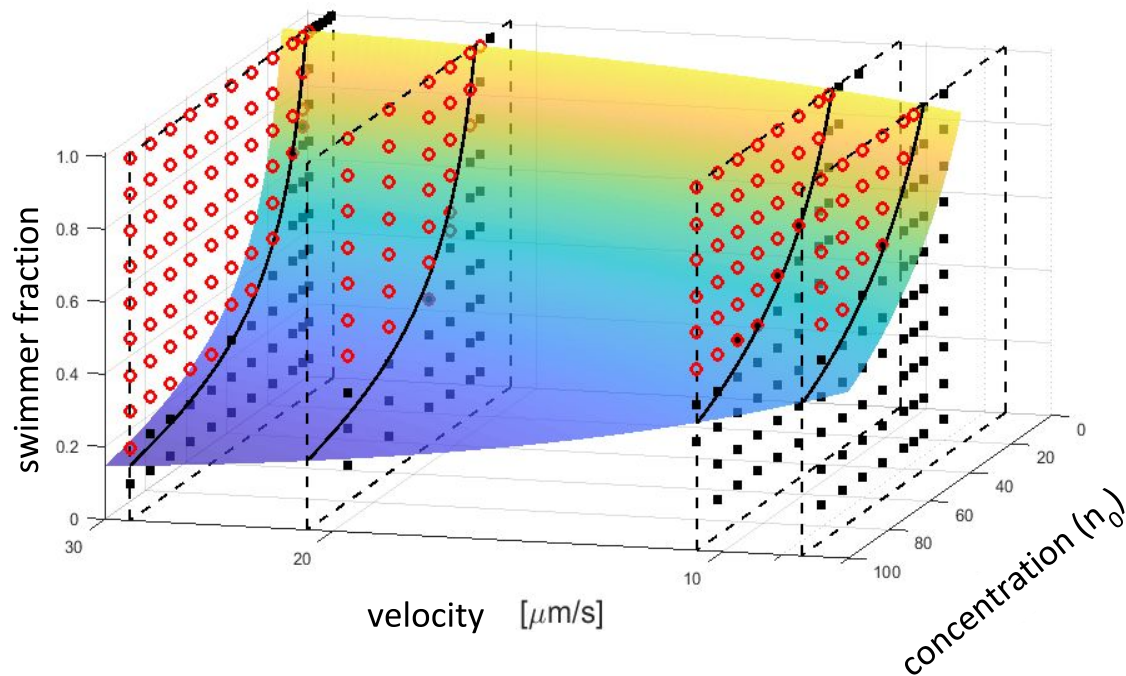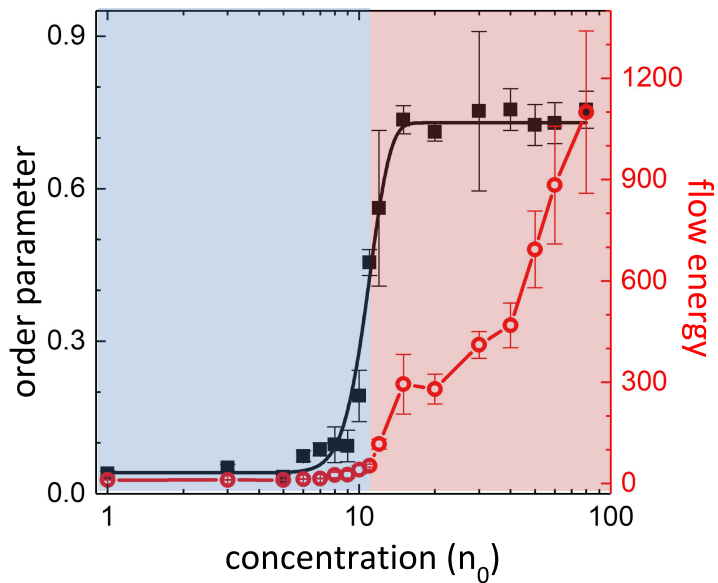
Swarming region: all bonds are coherent

Order parameter: area fraction of swarming region
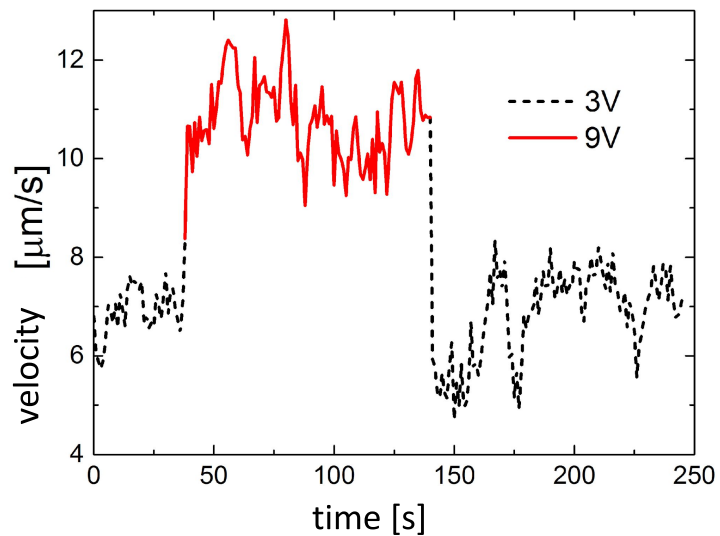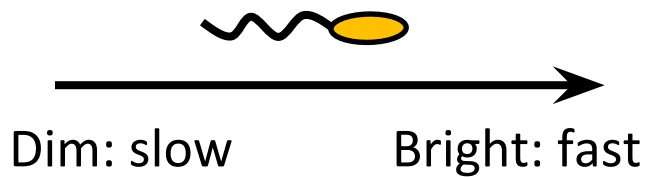
Flow energy: sum of velocity square in the flow field
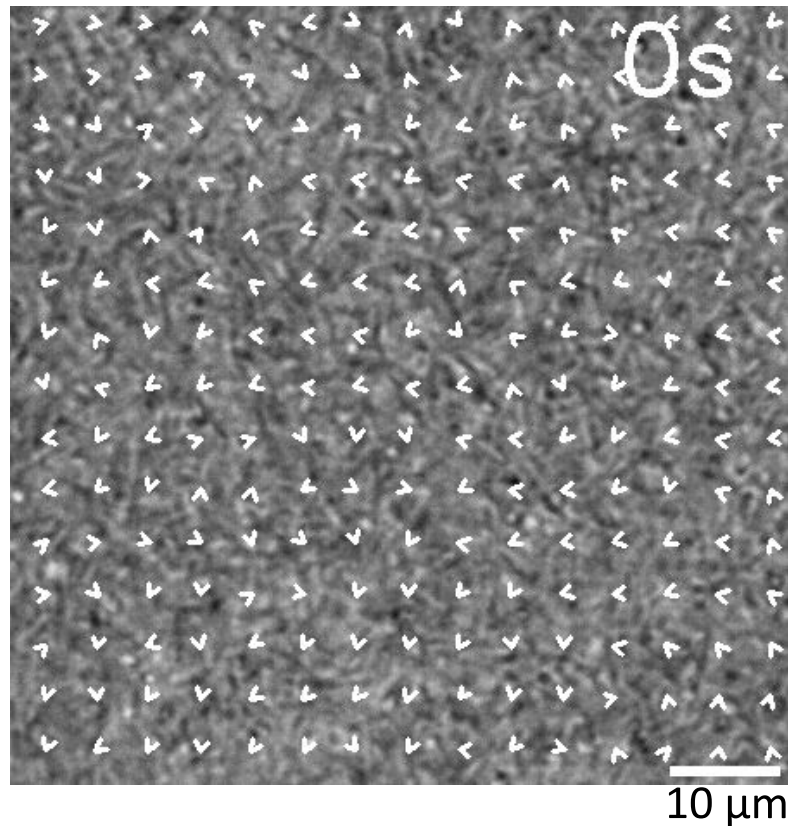
3

v=31μm/s, f=1, $n\uparrow$

Two-body hydrodynamic interaction is sufficient to predict the transition point.
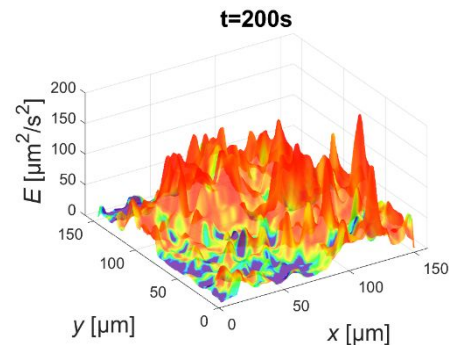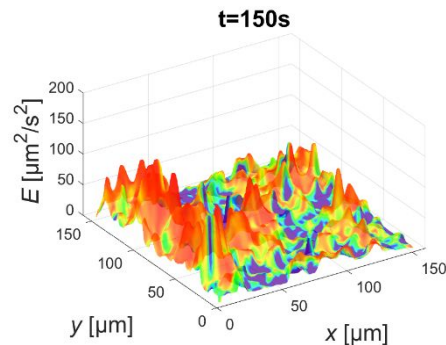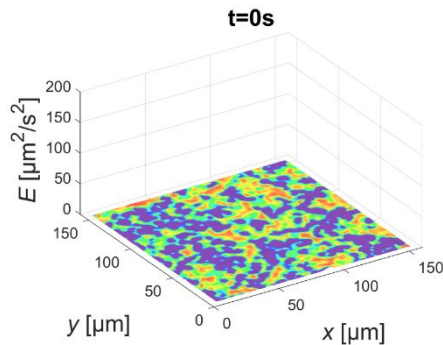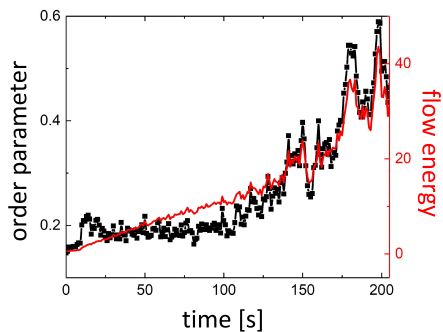
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Trigger swarming by light

Dim: slow   Bright: fast

Increase light intensity at t = 0 s.

Walter et al., PNAS (2007)

40n₀

100n₀

t=0s   t=150s   t=200s

t=0s   t=30s   t=88s
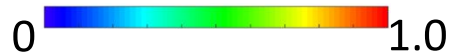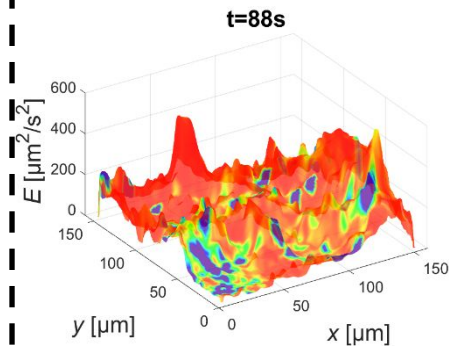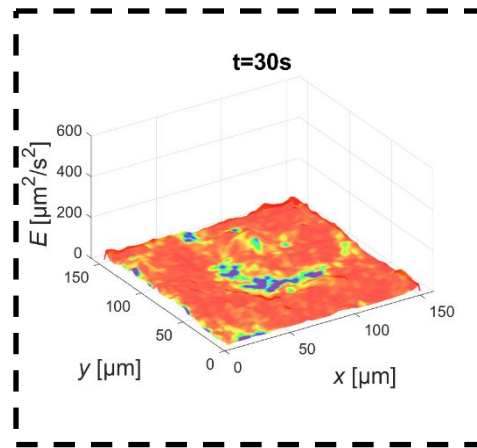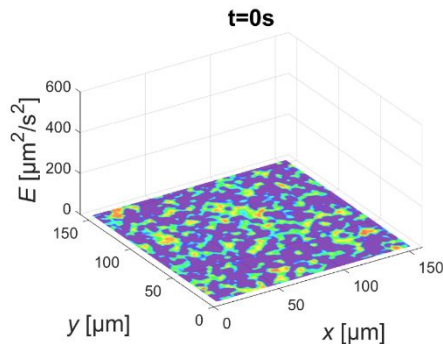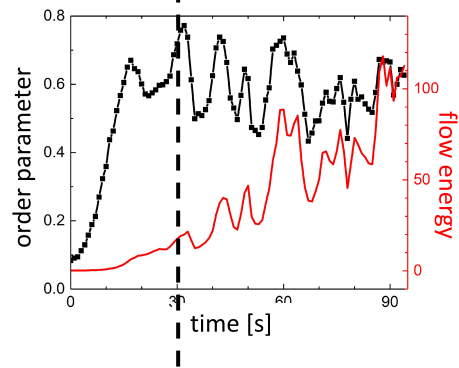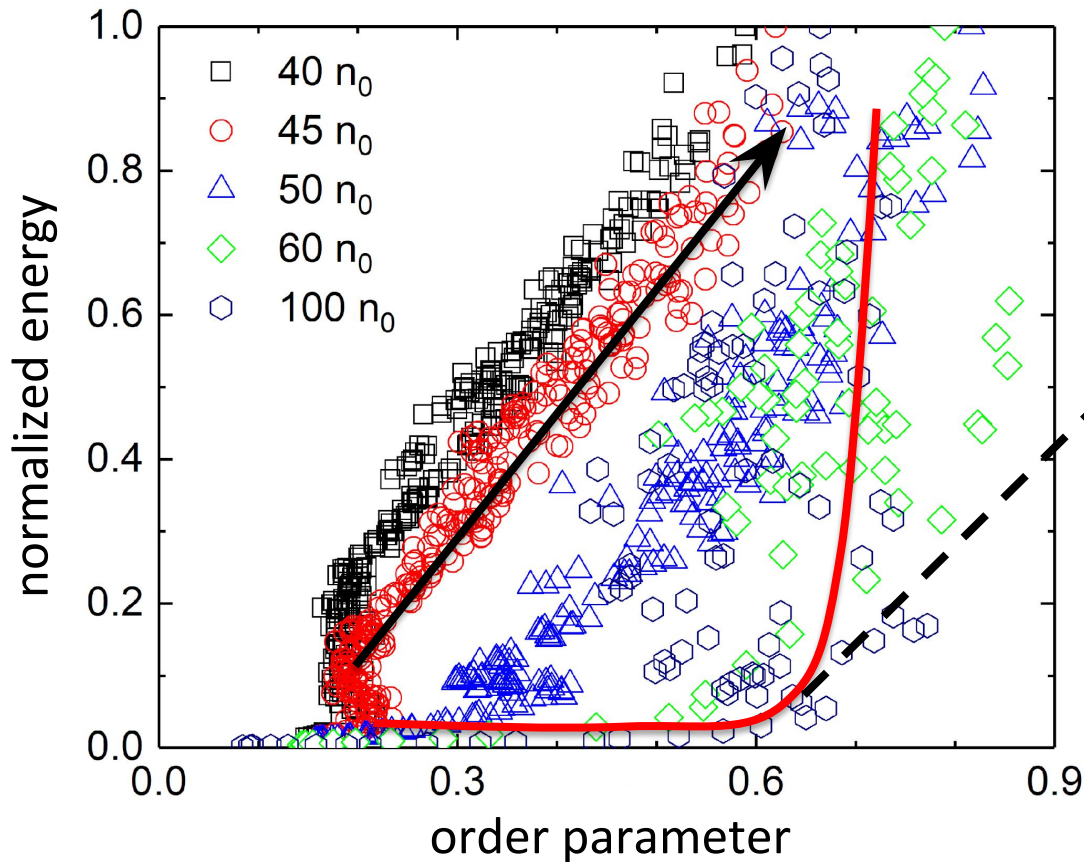
transient state: high order, low energy

0   1.0

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Near phase boundary

Disordered -> ordered

(one-step)
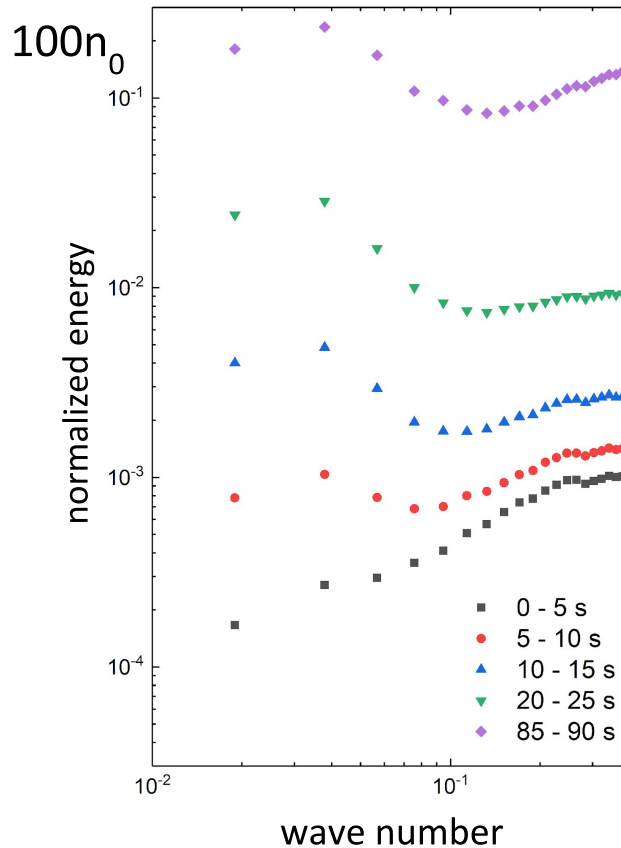
Far from phase boundary

Disordered -> low-energy ordered -> ordered

(two-step)

$40n_0$

$100n_0$
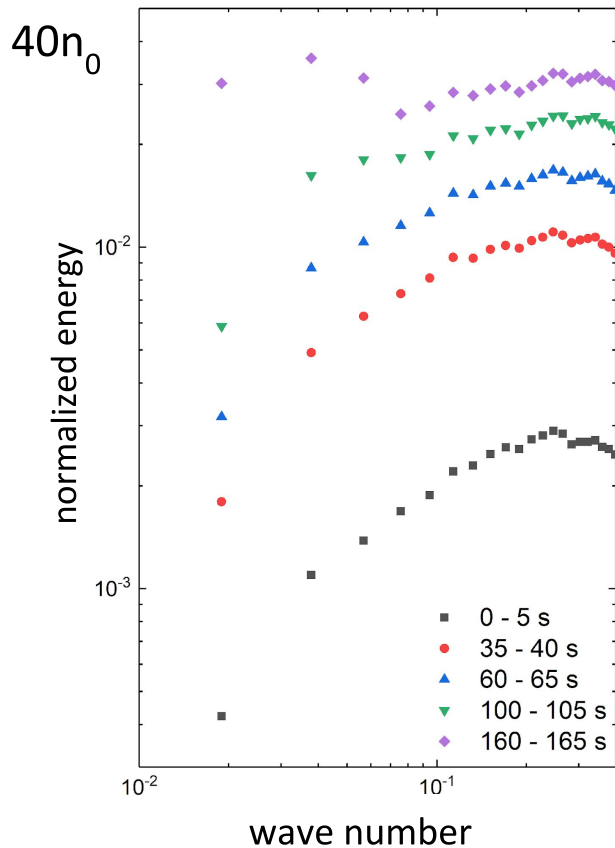
E(k): large k ⧠ small k
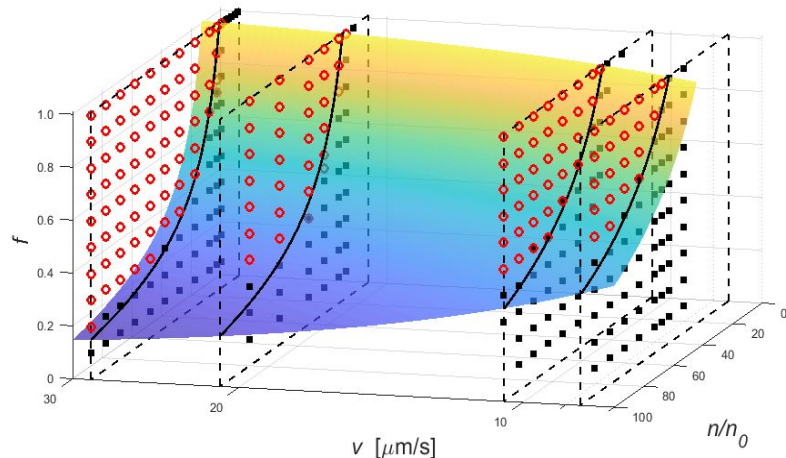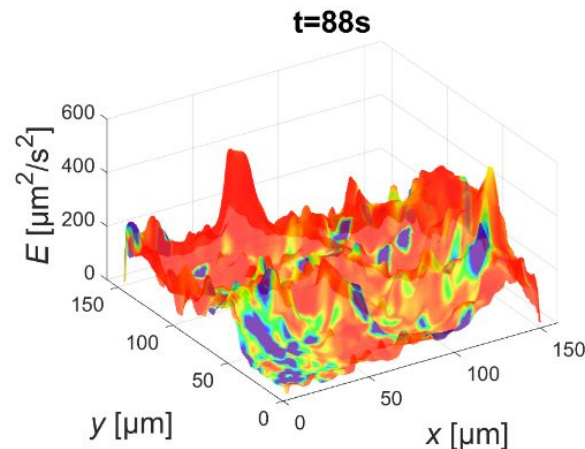
E(k): small k ⧠ large k

Saintillan and Shelly, PRL (2008)
Saintillan and Shelly, Phys. Fluids (2008)
Hohenegger and Shelly, PRE (2010)
Saintillan and Shelly, J. R. Soc. Interface (2012)

- Phase diagram with n, v, f

- Two kinetic pathways

Acknowledgement