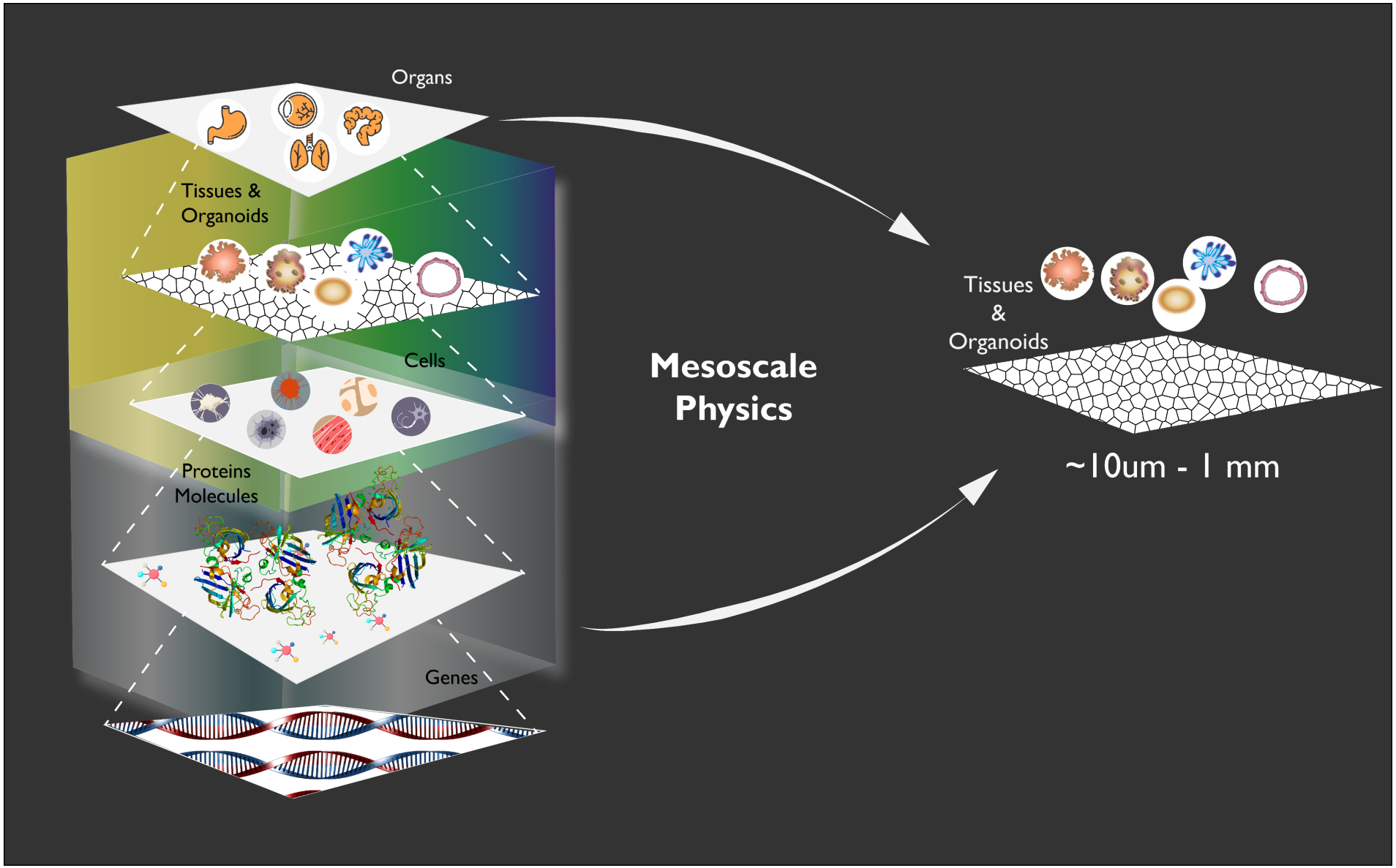
Particle-based tissue modeling

Daniel Matoz-Fernandez

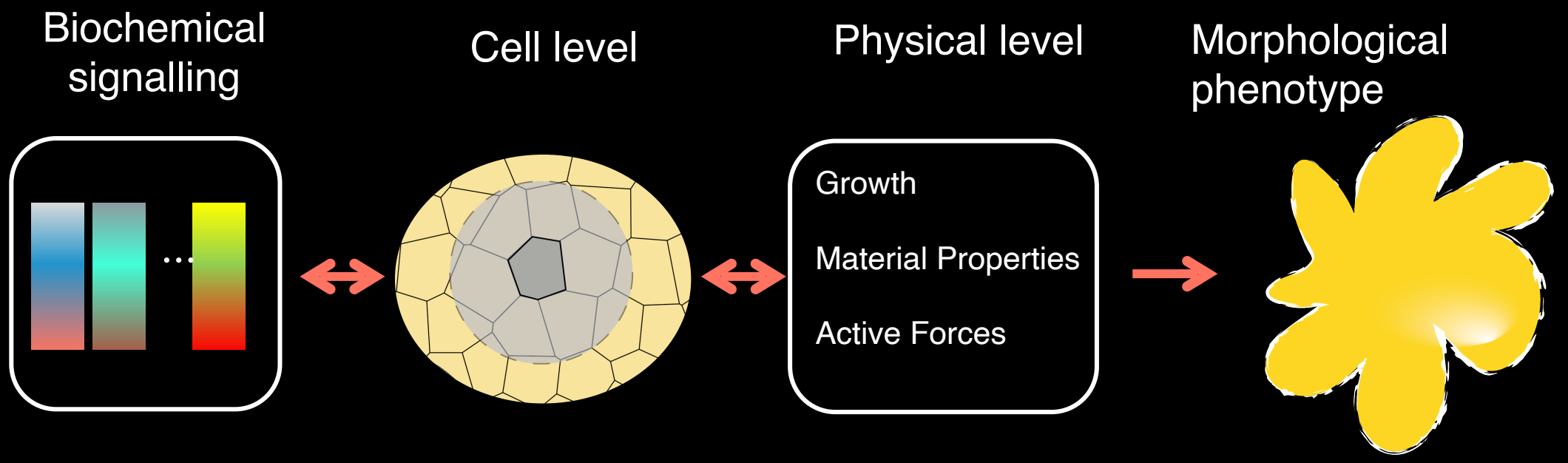
Growth, form and active mechanics in biology

Jan van IJken

Soft Matter Physics: mesoscale

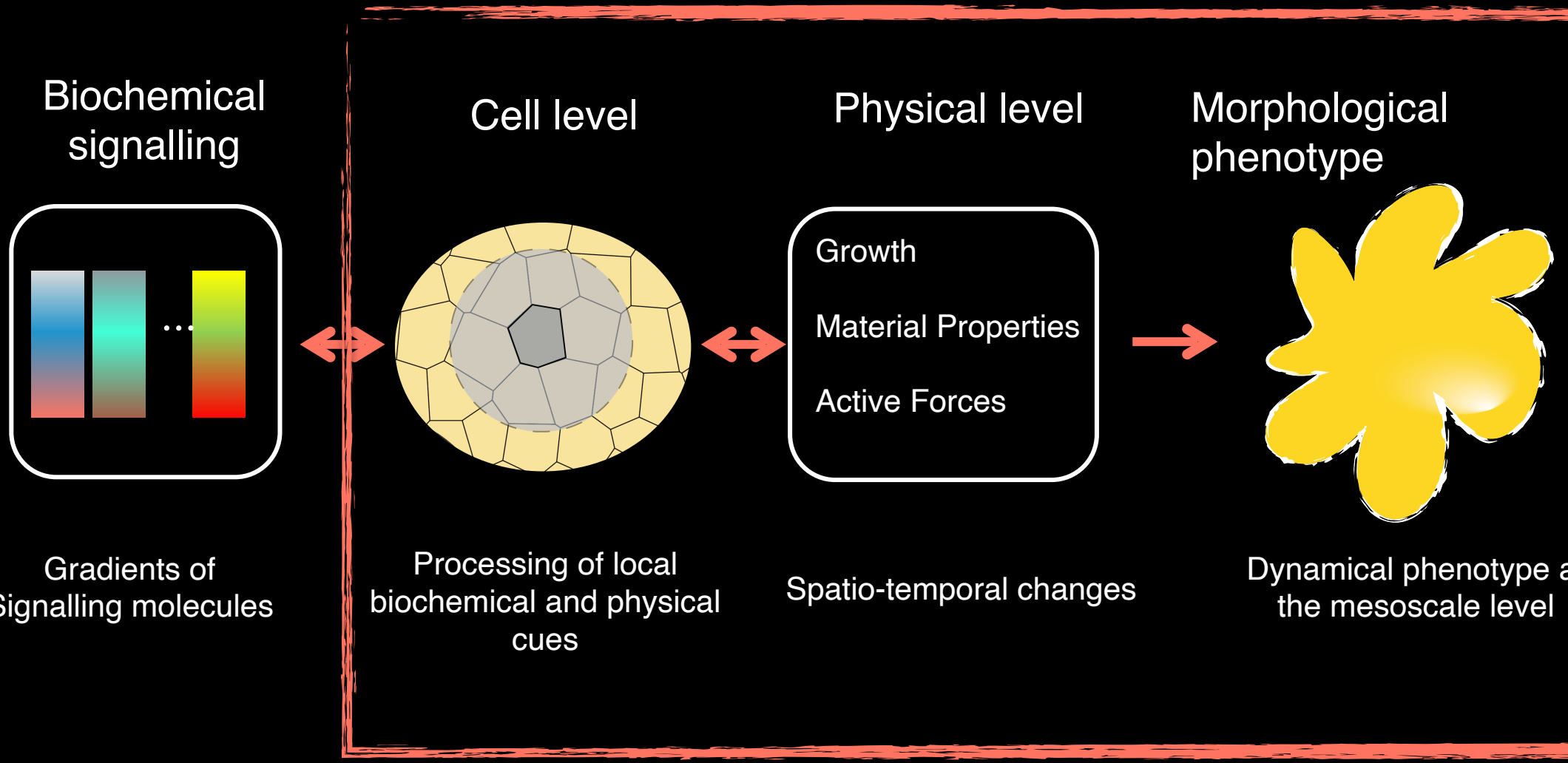


The interaction between components



Adapted from:
Taber, Larry A. *Applied mechanics reviews* 48, no. 8 (1995): 487-545.
Stooke-Vaughan et. Al *Current opinion in genetics & development* 51 (2018): 111-119.

The interaction between components



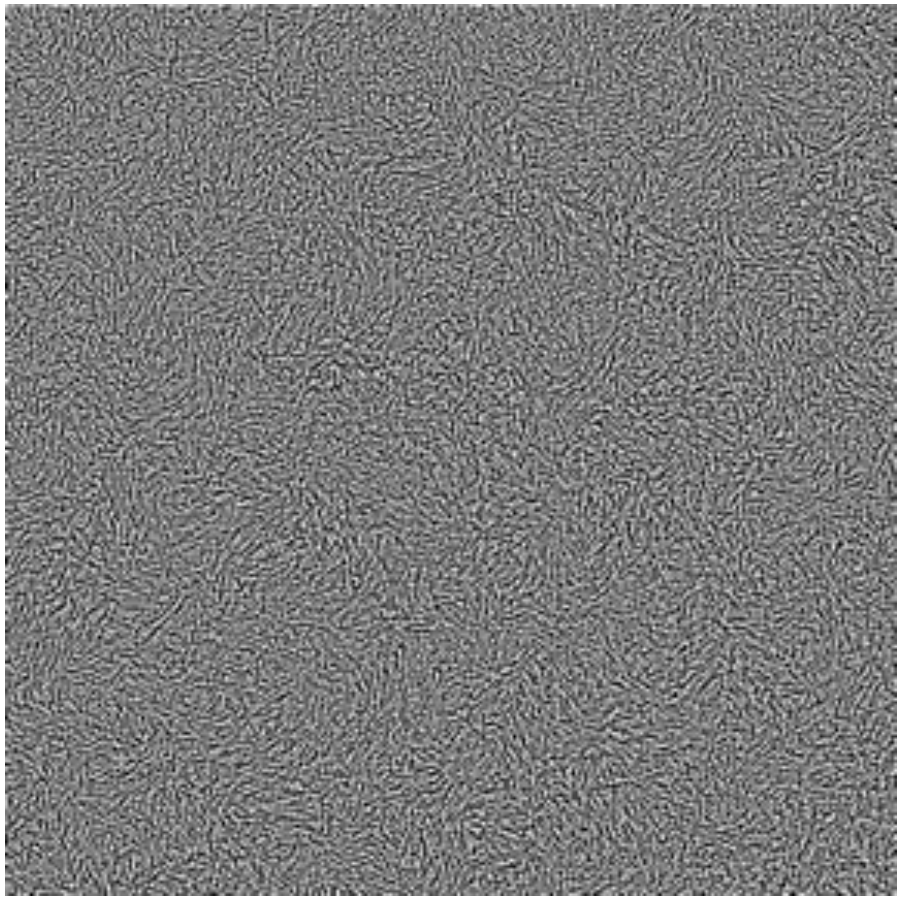
Adapted from:
Taber, Larry A. *Applied mechanics reviews* 48, no. 8 (1995): 487-545.
Stooke-Vaughan et. Al *Current opinion in genetics & development* 51 (2018): 111-119.

Active matter: what it is?

“Each active particle consumes and dissipates energy going through a cycle that fuels internal changes, generally leading to motion”

Dense active matter: active fluids

Active nematic



Turbulent phase in a quasi-2D homogeneous *B. subtilis*

Meso-scale turbulence in living fluids
Henricus H. Wensink et. al PNAS

Dense active matter: active fluids

Hydrodynamics of soft active matter

REVIEWS OF MODERN PHYSICS, VOLUME 85, JULY–SEPTEMBER 2013

Hydrodynamics of soft active matter

M. C. Marchetti* et al

Physics Department and Syracuse Biomaterials Institute, Syracuse University, Syracuse, New York 13244, USA

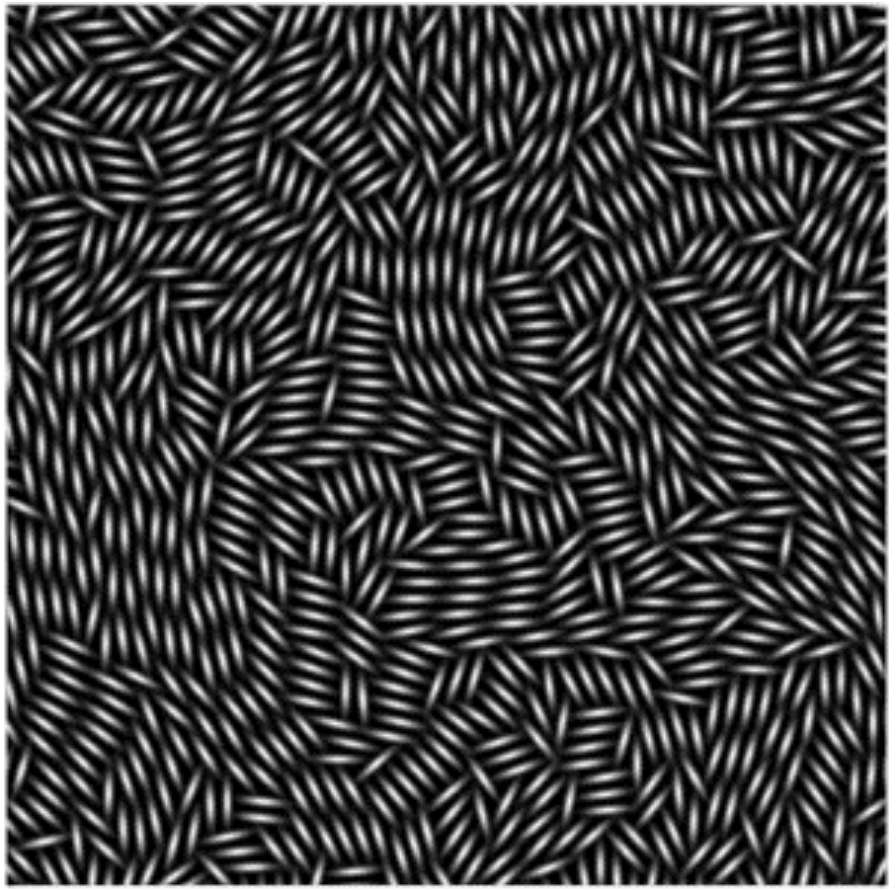
IOP Publishing Reports on Progress in Physics

Rep. Prog. Phys. **81** (2018) 076601 (27pp) https://doi.org/10.1088/1361-6633/aab6bb

Review

Hydrodynamic theory of active matter

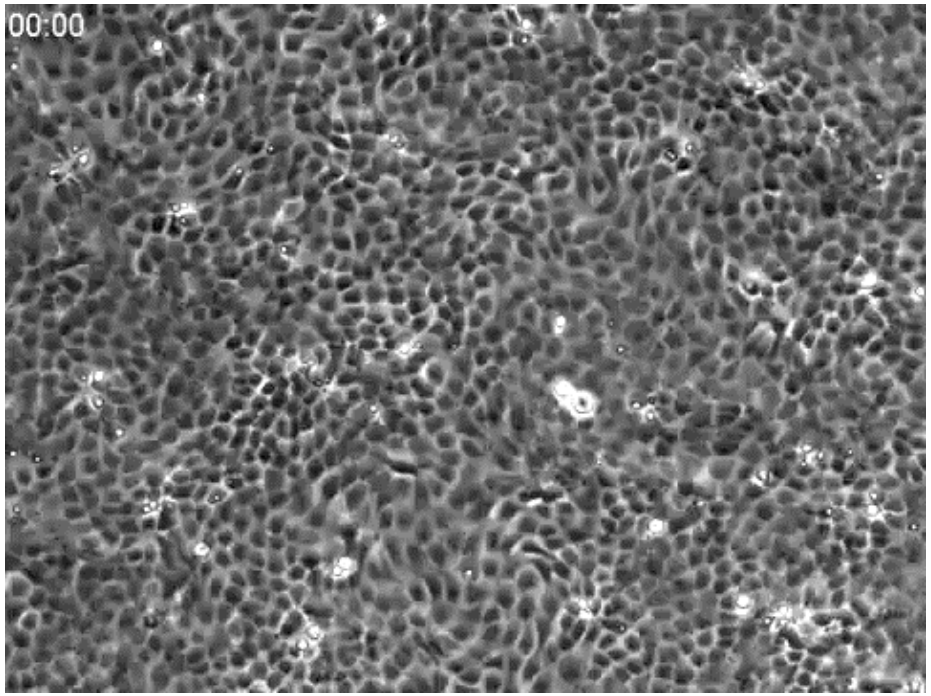
Frank Jülicher[1], Stephan W Grill[2] and Guillaume Salbreux[1,3]



Meso-scale turbulence in living fluids
Henricus H. Wensink et. al PNAS

New physics in cell monolayers

Glass-like dynamics of collective cell migration
Thomas E. Angelini et al. PNAS (2011)



New class of materials

An **active glass** is an amorphous material which can undergo into reversible transition from a "**solid-like**" into a more viscous "**liquid-like**" state when "**activity**" is increased

The new *old* physics

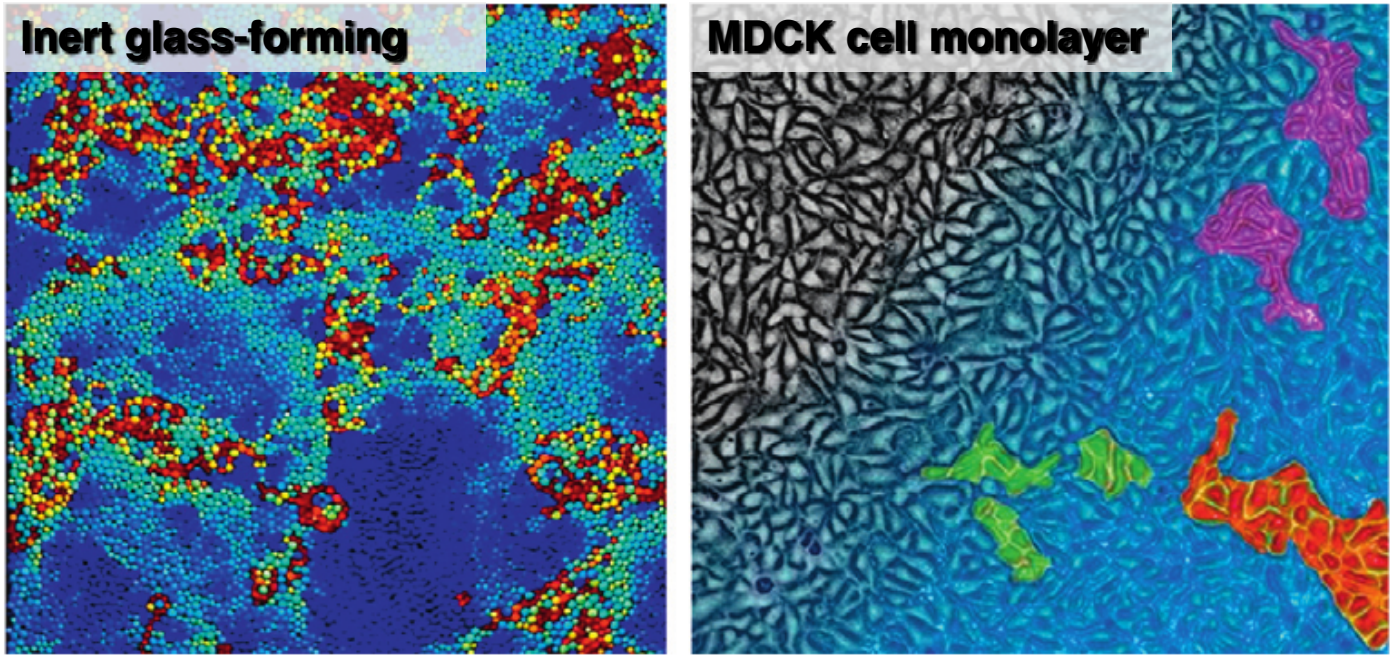
Amorphous solid:
A solid that lacks the long-range order that is characteristic of a crystal.

A glass is an amorphous material which can undergo into reversible transition from a "**solid**" state into a "**liquid-viscous**" state as the "**temperature**" is increased

A physics point of view: Active Mechanics

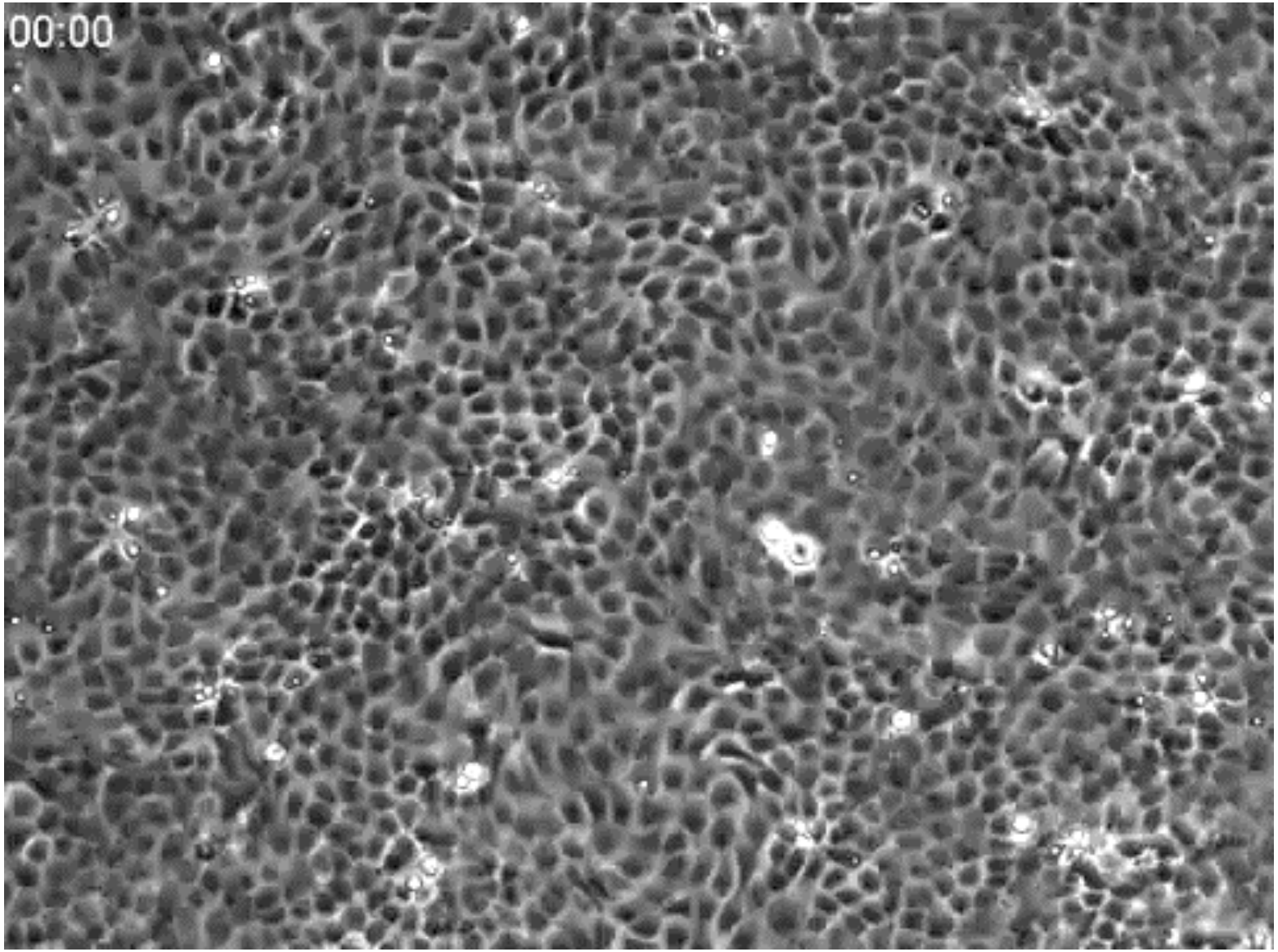
What can we learn from the dynamics of inert glasses?

Dynamic heterogeneity

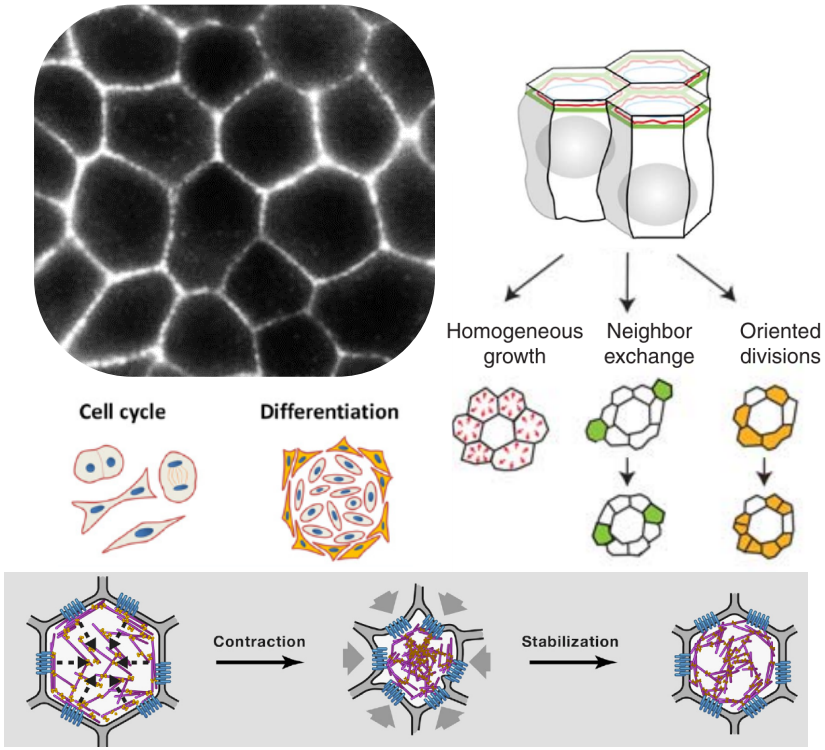


Particle/Cell mobility

Cell Monolayers

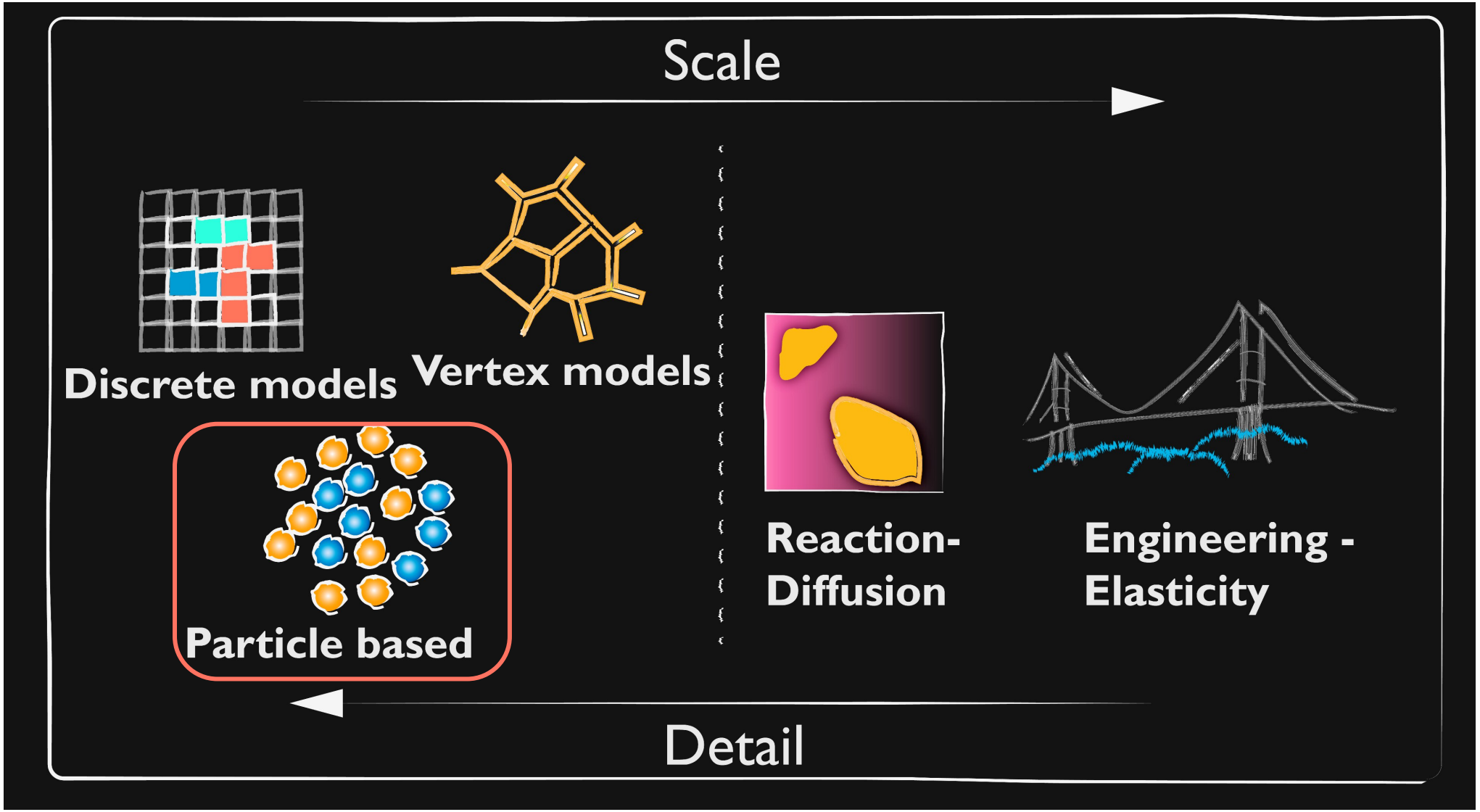


Active drivers in cell monolayers

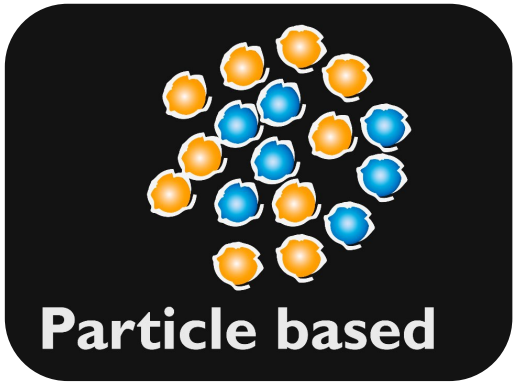


- Cell migration on substrate
- Cell division and death
- Cell ingressions
- Chemical signaling
- Cell-type interactions
- Junction contractions
- Shape fluctuations
- Boundaries and topology

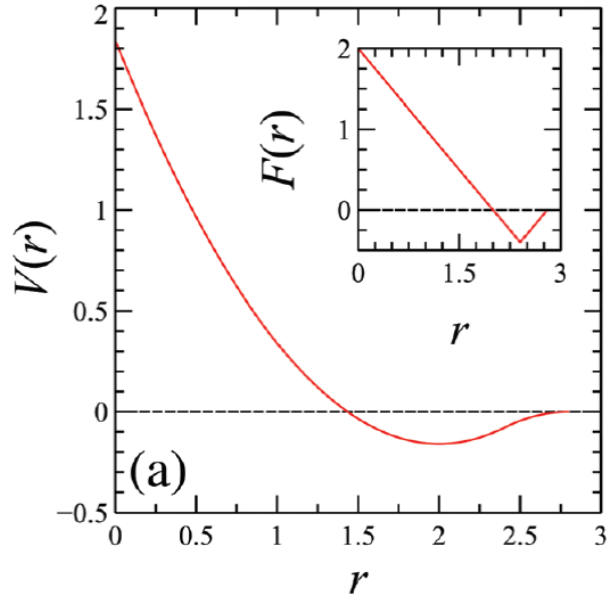
Modeling cell monolayers



A very simple model



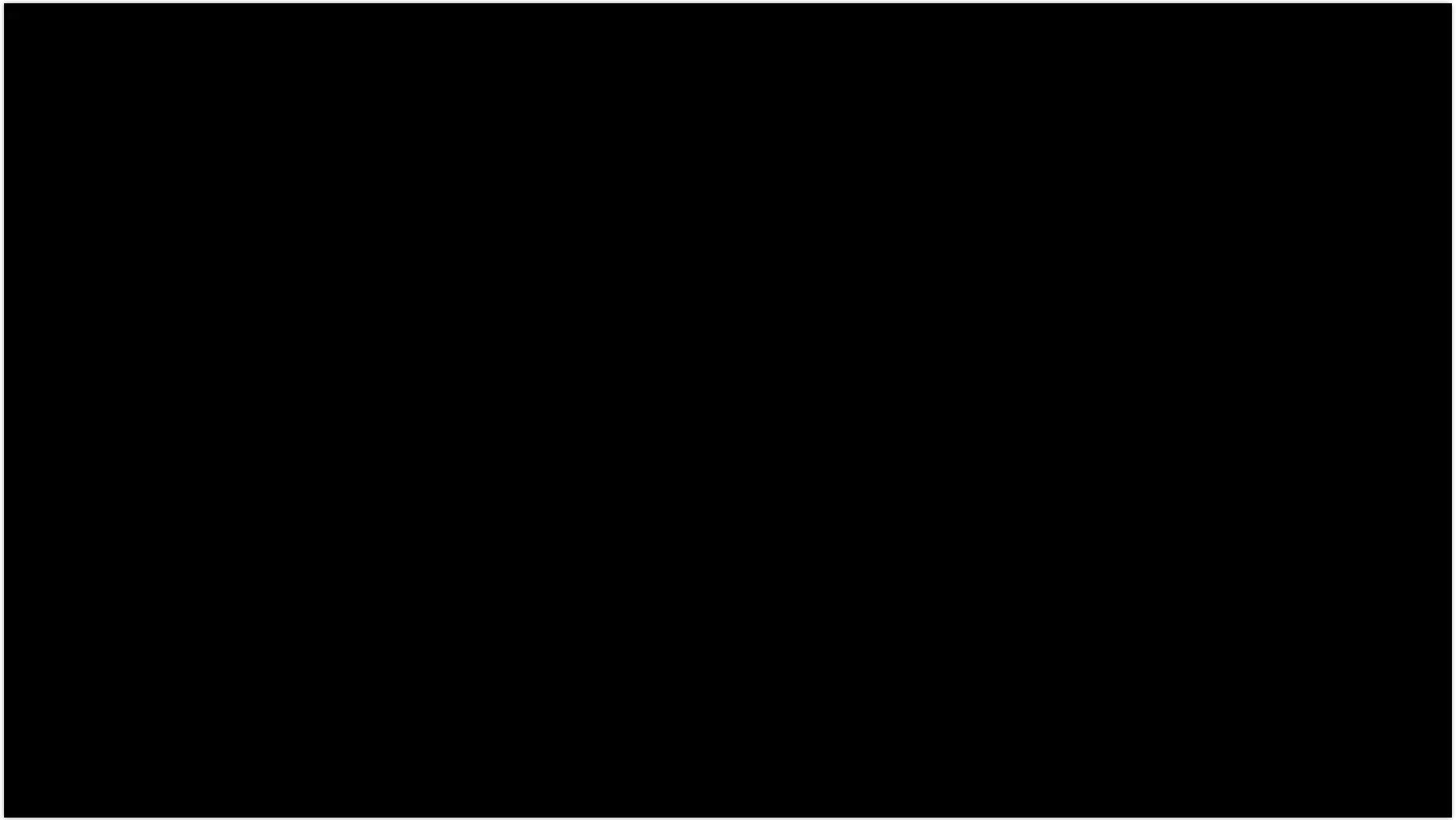
Soft Elastics Particles (Adhesion and Repulsion)



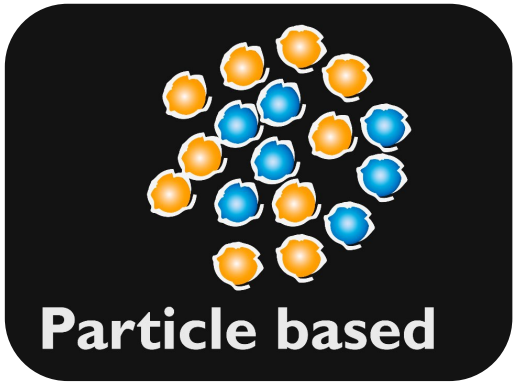
- Cell migration on substrate
- Cell division and death
- Cell ingressions
- Chemical signaling
- Cell-type interactions
- ~~Junction contractions~~
- ~~Shape fluctuations~~
- ~~Boundaries and topology~~

Matoz-Fernandez, D. A et. Al *Soft matter* 13, no. 17 (2017): 3205-3212.

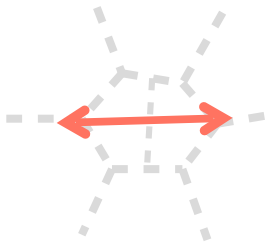
Cell division a main driver for morphogenesis



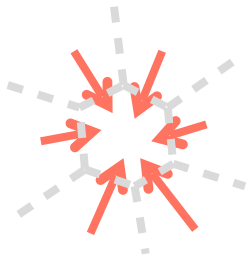
A very simple model



Cell division

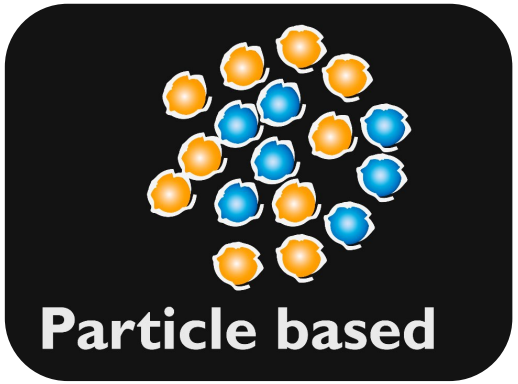


Cell removal

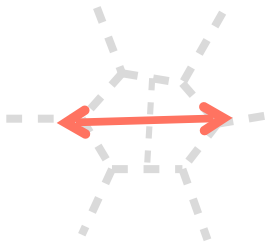


- Cell migration on substrate
- Cell division
- Cell ingressions (removal)
- ~~Chemical signaling~~
- ~~Cell-type interactions~~
- ~~Junction contractions~~
- ~~Shape fluctuations~~
- ~~Boundaries and topology~~

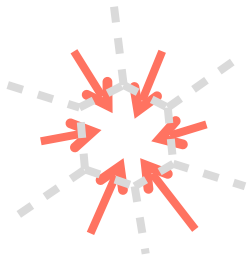
A very simple model

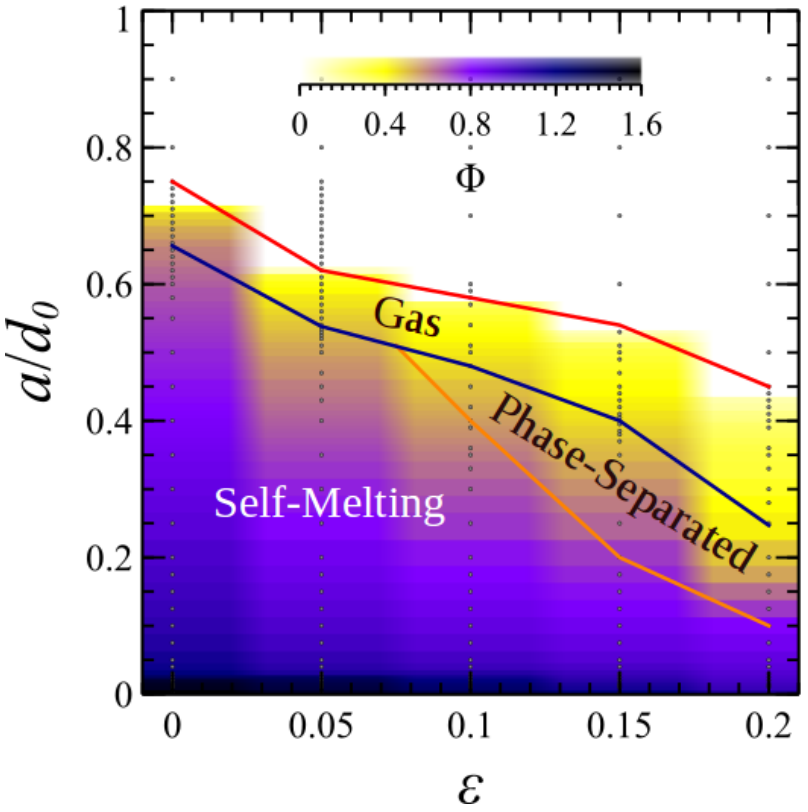


Cell division

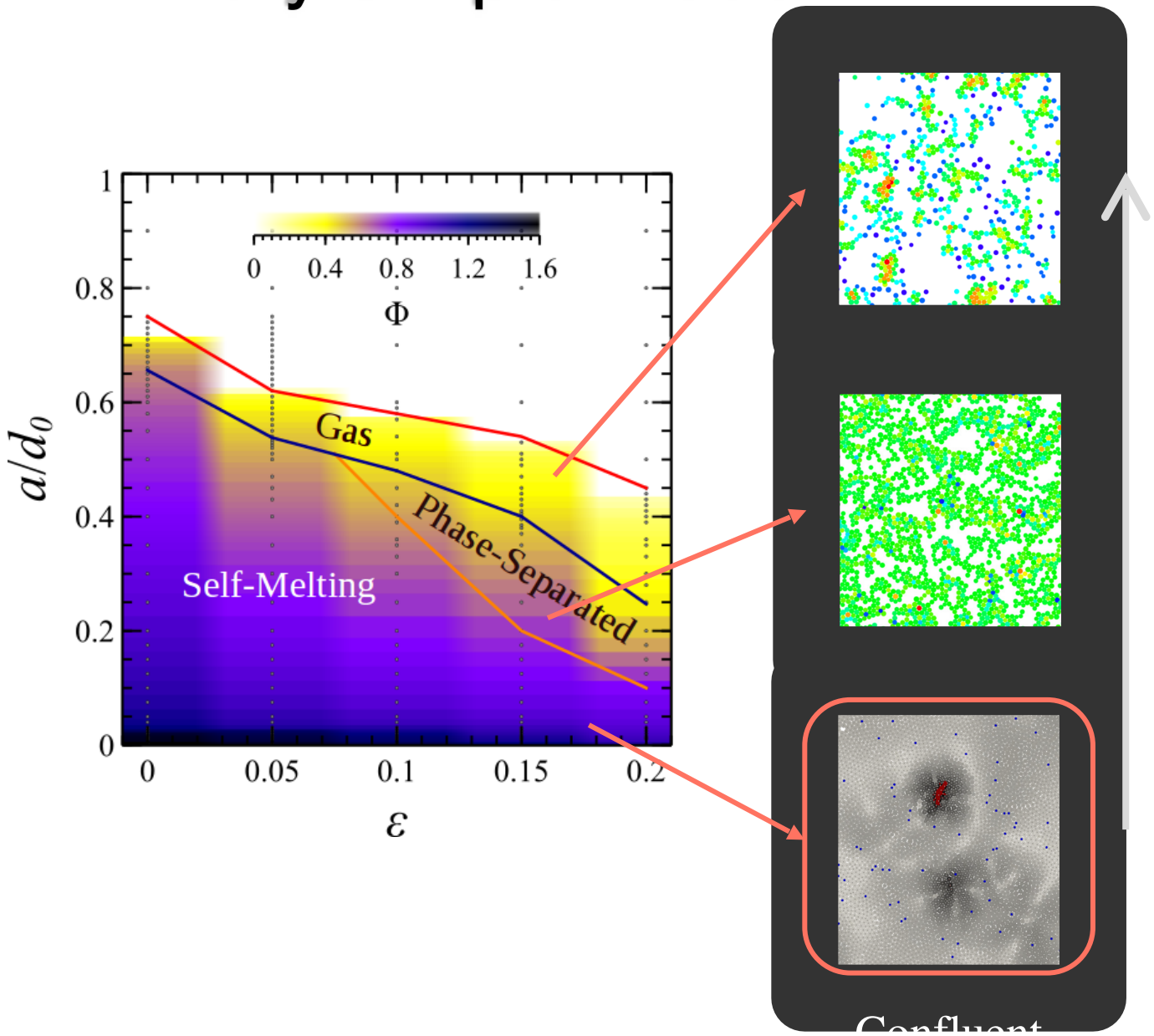


Cell removal



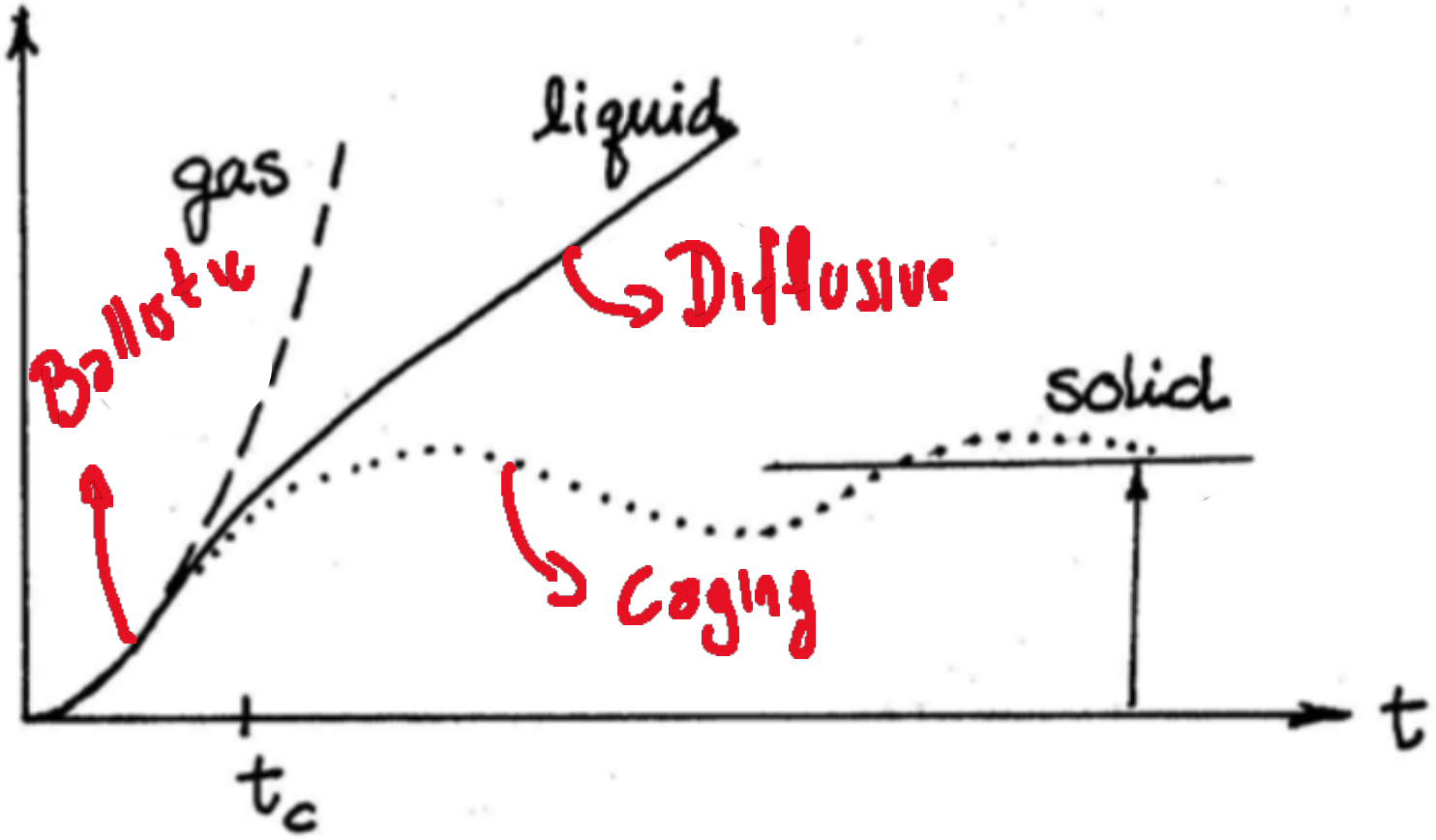


A very simple model

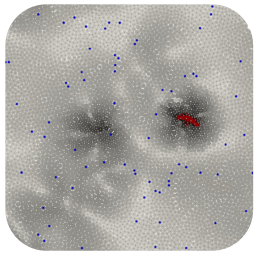


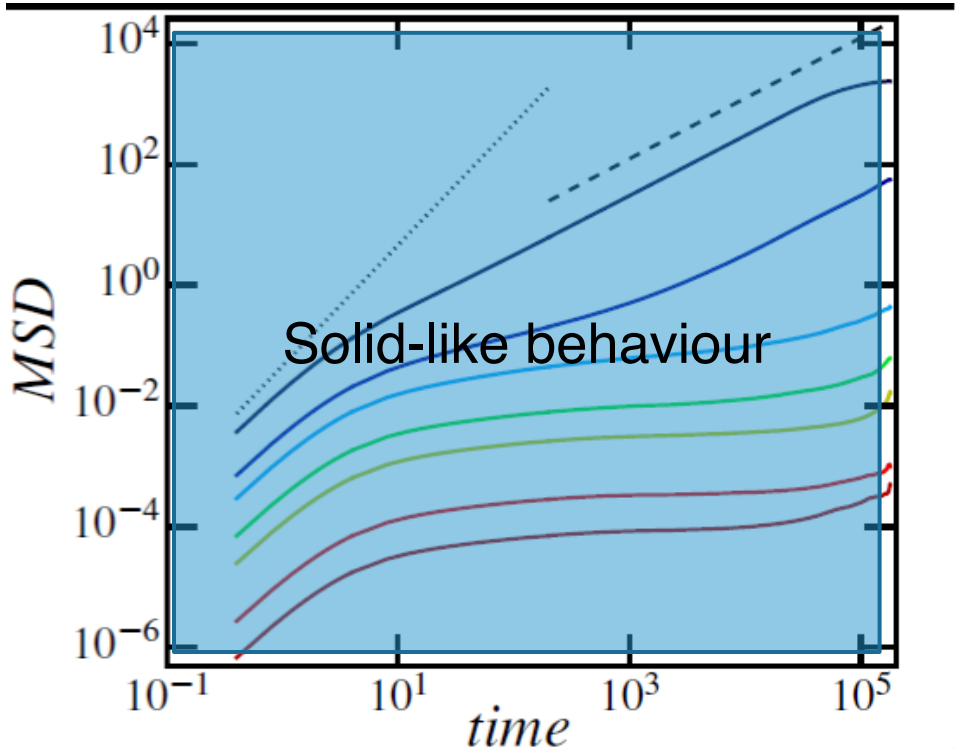
A very simple model: MSD

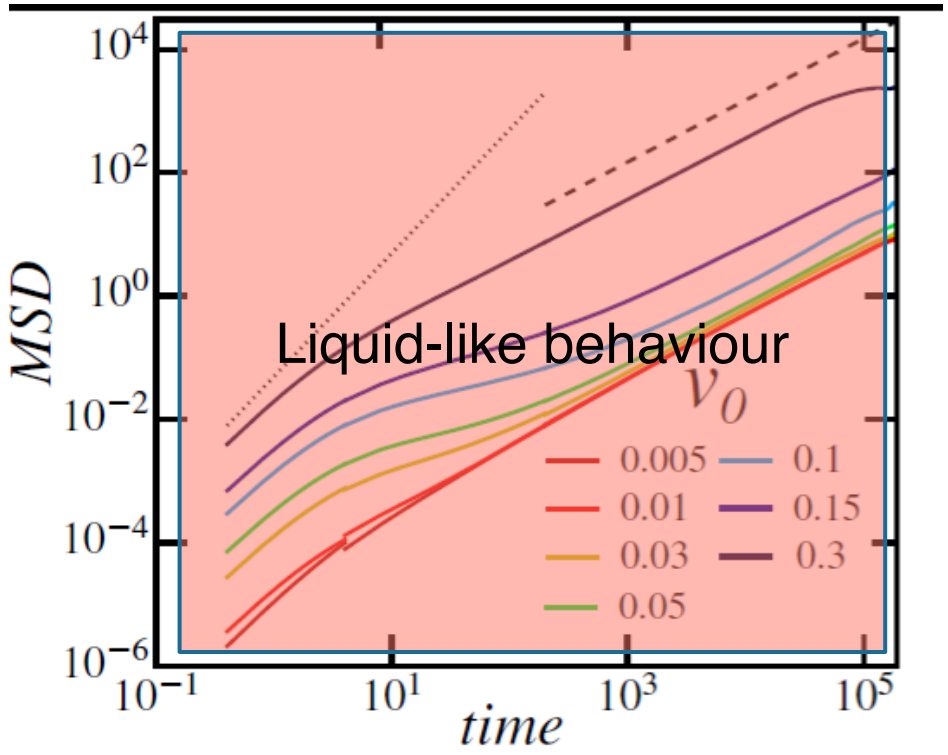
Mean squared displacement of three idealized systems



A very simple model

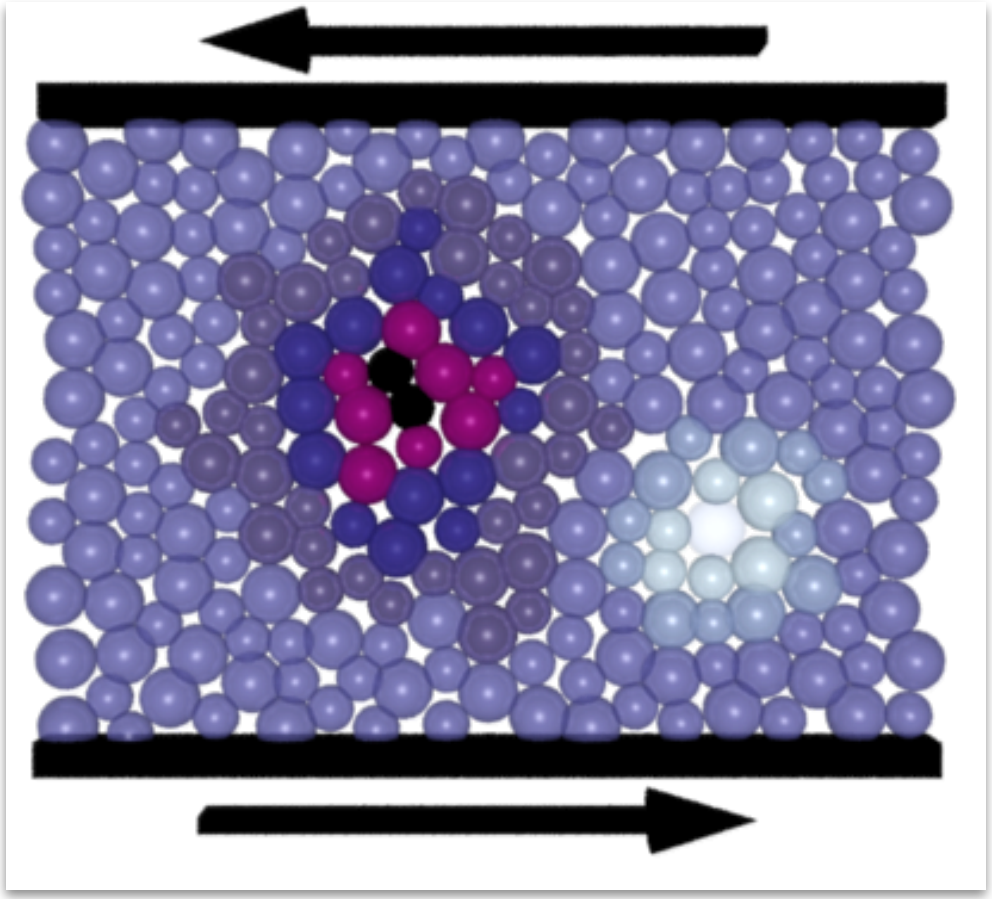


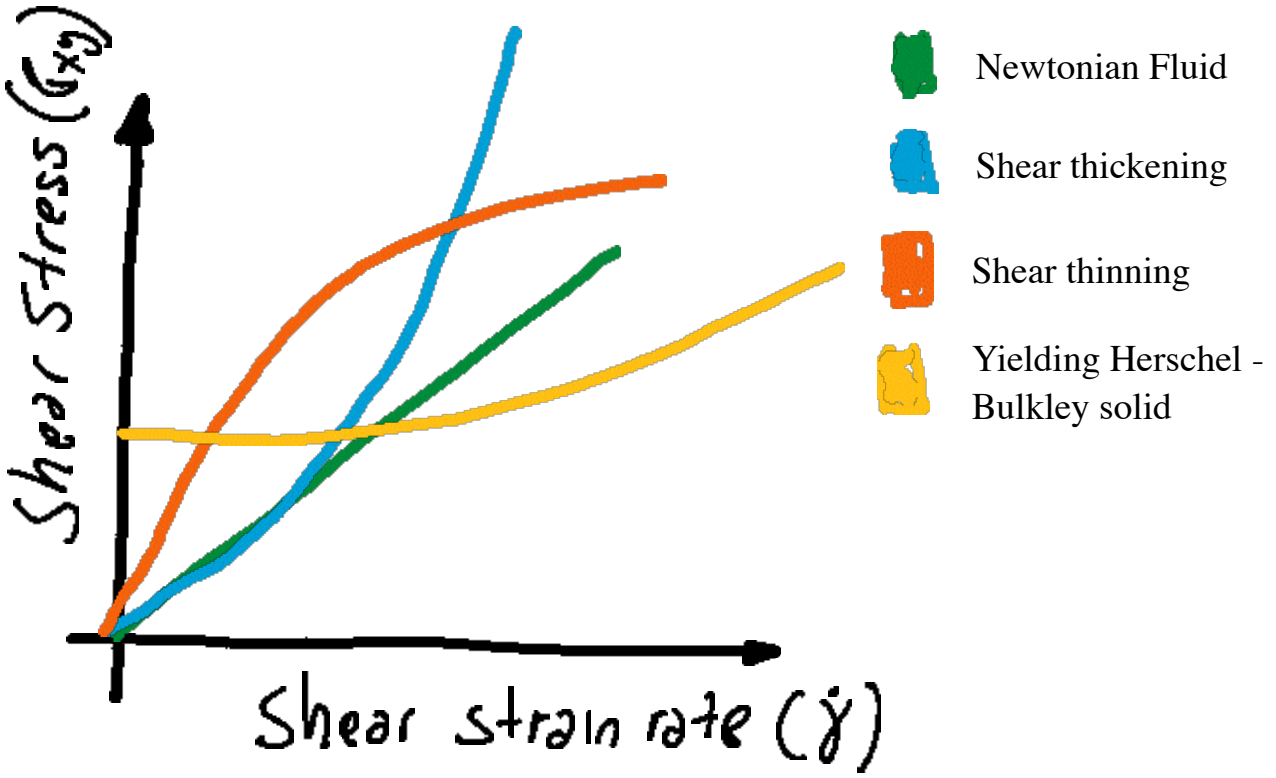




Rheology

In silico cell monolayer under shear

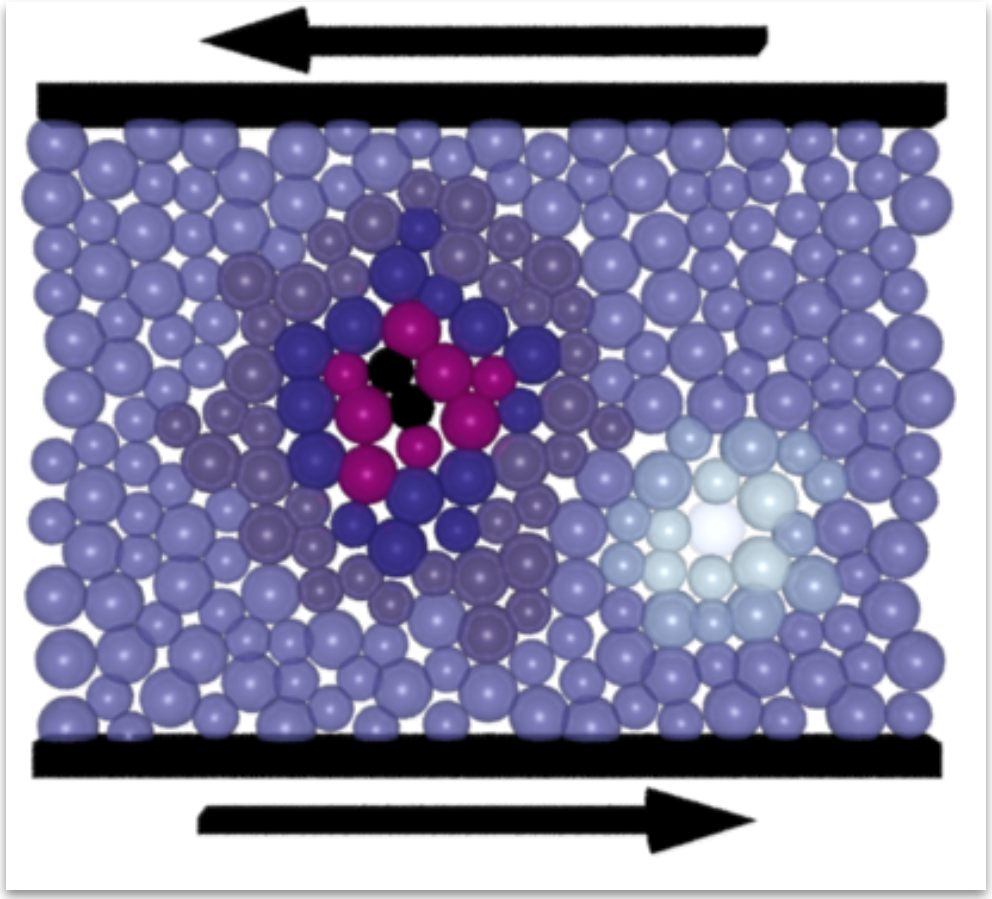


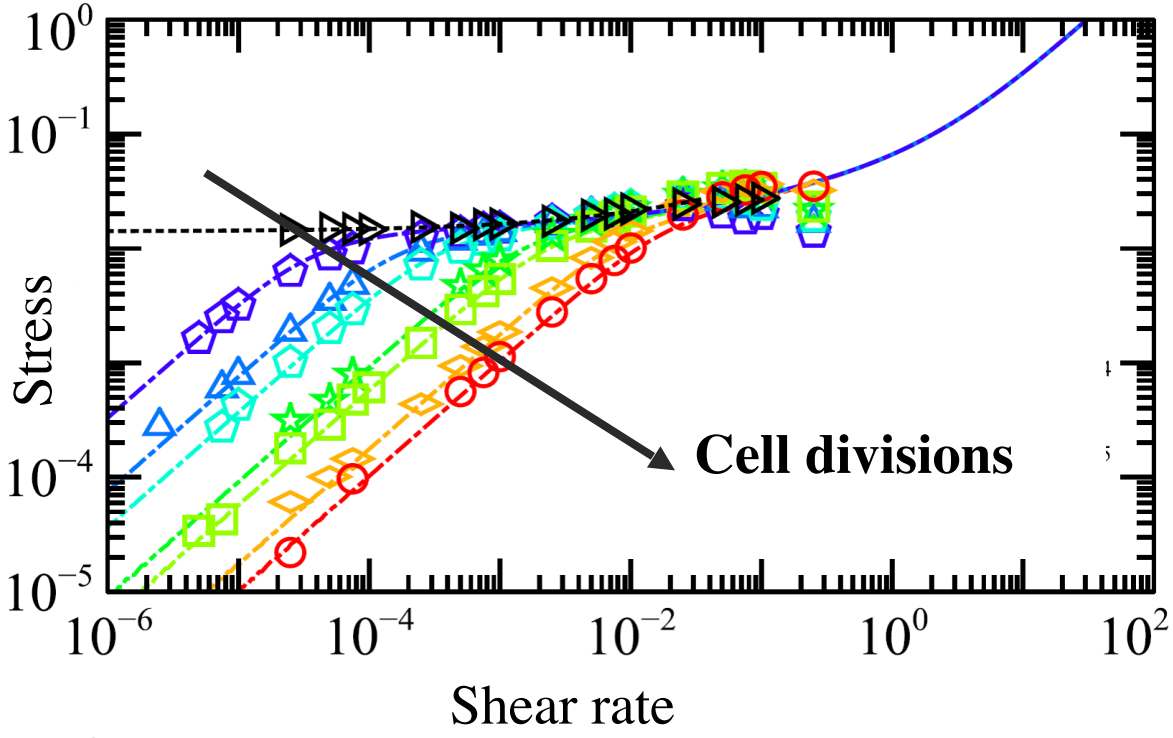


Matoz-Fernandez, D. A., Elisabeth Agoritsas et. al *Physical review letters* 118, no. 15 (2017): 158105

A very simple model: Rheology

In silico cell monolayer under shear





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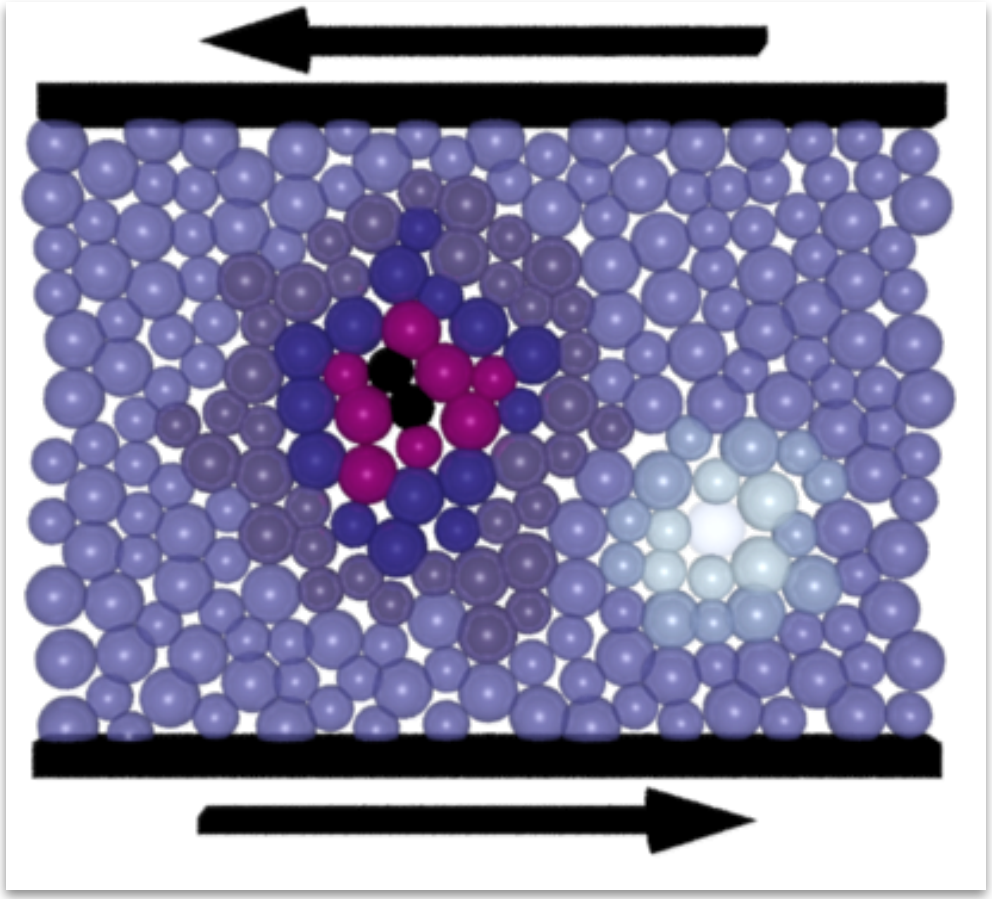
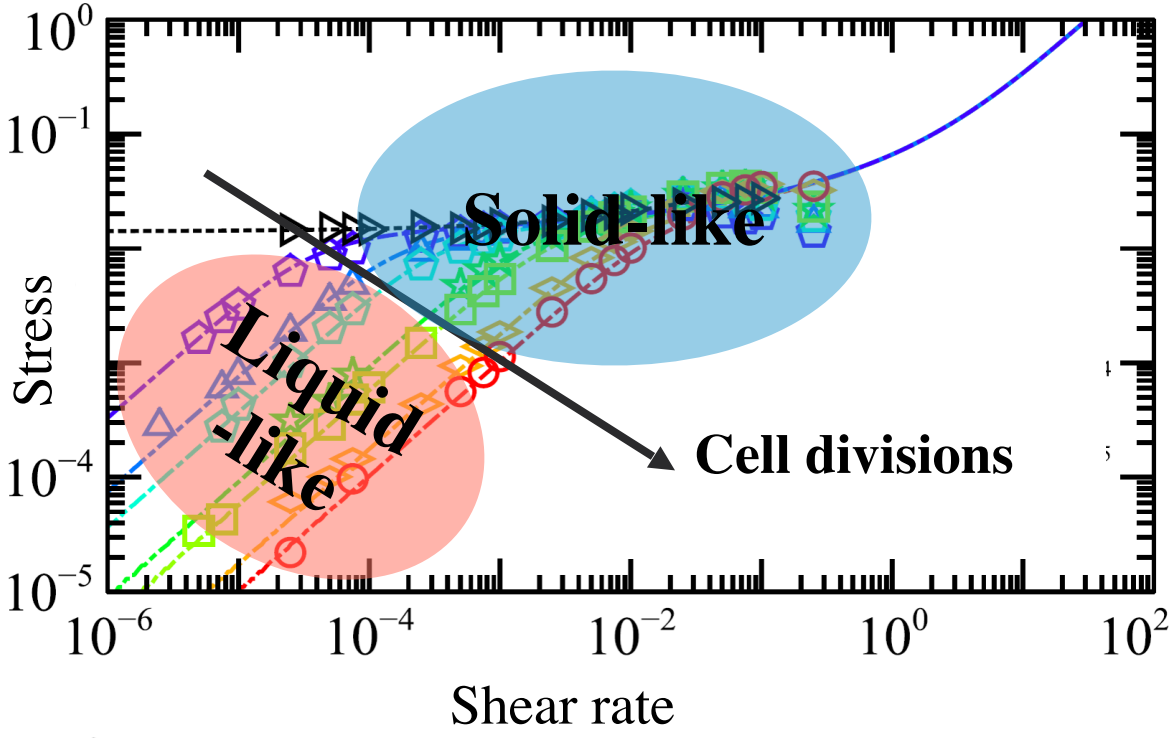
A very simple model: Rheology

In silico cell monolayer under shear

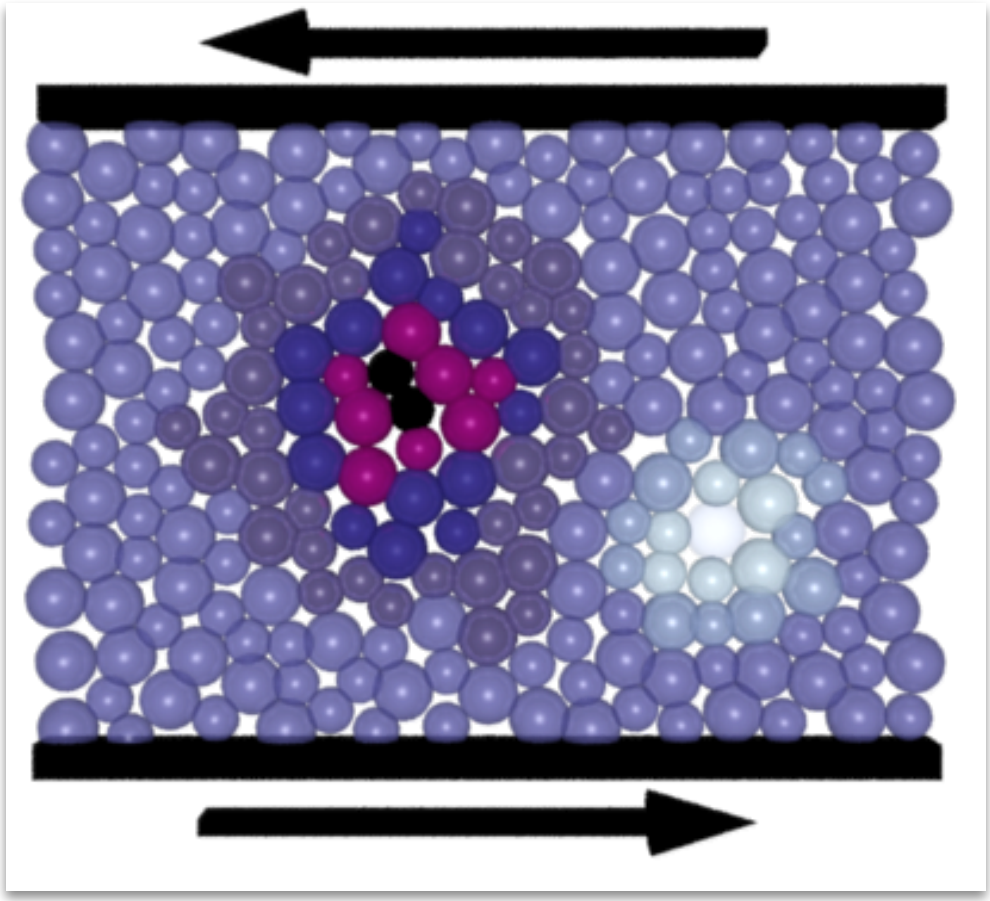




"Cell division makes the cell monolayer more fluid depending on the observation time scale"

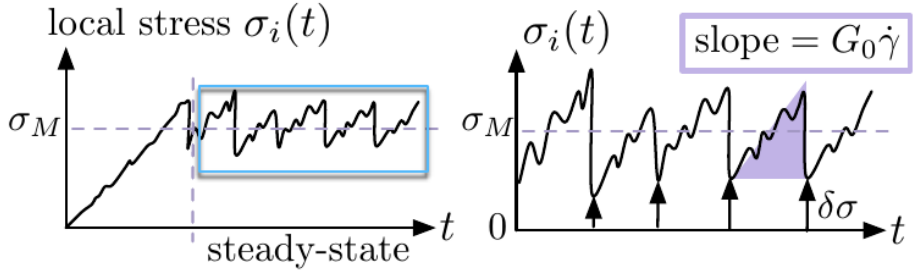
Matoz-Fernandez, D. A., Elisabeth Agoritsas et. al *Physical review letters* 118, no. 15 (2017): 158105

How can we explain this phenomenon?



Mean-field models for active dynamics

$$\begin{cases} \partial_t \sigma(t) = G_0 \dot{\gamma} + \xi_{\rm mec}(t) \\ \sigma > \sigma_c : \quad \sigma \overset{1/\tau}{\longmapsto} 0 \quad \& \quad \rho(\sigma_c') \end{cases}$$



VARIATION OF STRESS = ELASTIC SHEAR + MECHANICAL NOISE

MECHANICAL NOISE

PLASTIC NOISE **CELL ACTIVITY NOISE**

$$\xi_{\rm mec}(t) = \xi_{\rm pl}(t) + \xi_{\rm act}(t),$$

$$\langle \xi_{\rm mec}(t) \rangle = 0$$