Rigidity transition in biological tissues

Student discussion group
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Upto now

Embryonic development, cancer metastatis, wound healing:

- Early stage: large scale movement => fluid-like rheology
- Later stage: need to support forces and stresses => solid-like rheology

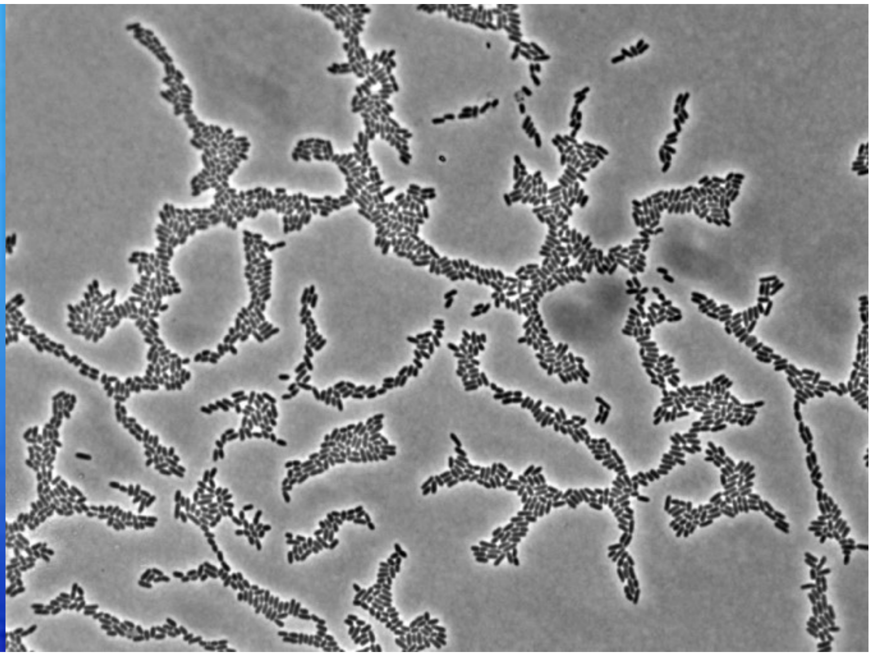
Many biological tissues are close to glass transition

- Caging: MSD and NGP
- Dynamical heterogeneity: Four point correlation function

Models for dense tissues

Active particle models

Active matter models + short-range repulsive/attractive interactions

Glass transition in self-propelled particle models is identical to adhesive colloids

Activity generates an effective adhesion

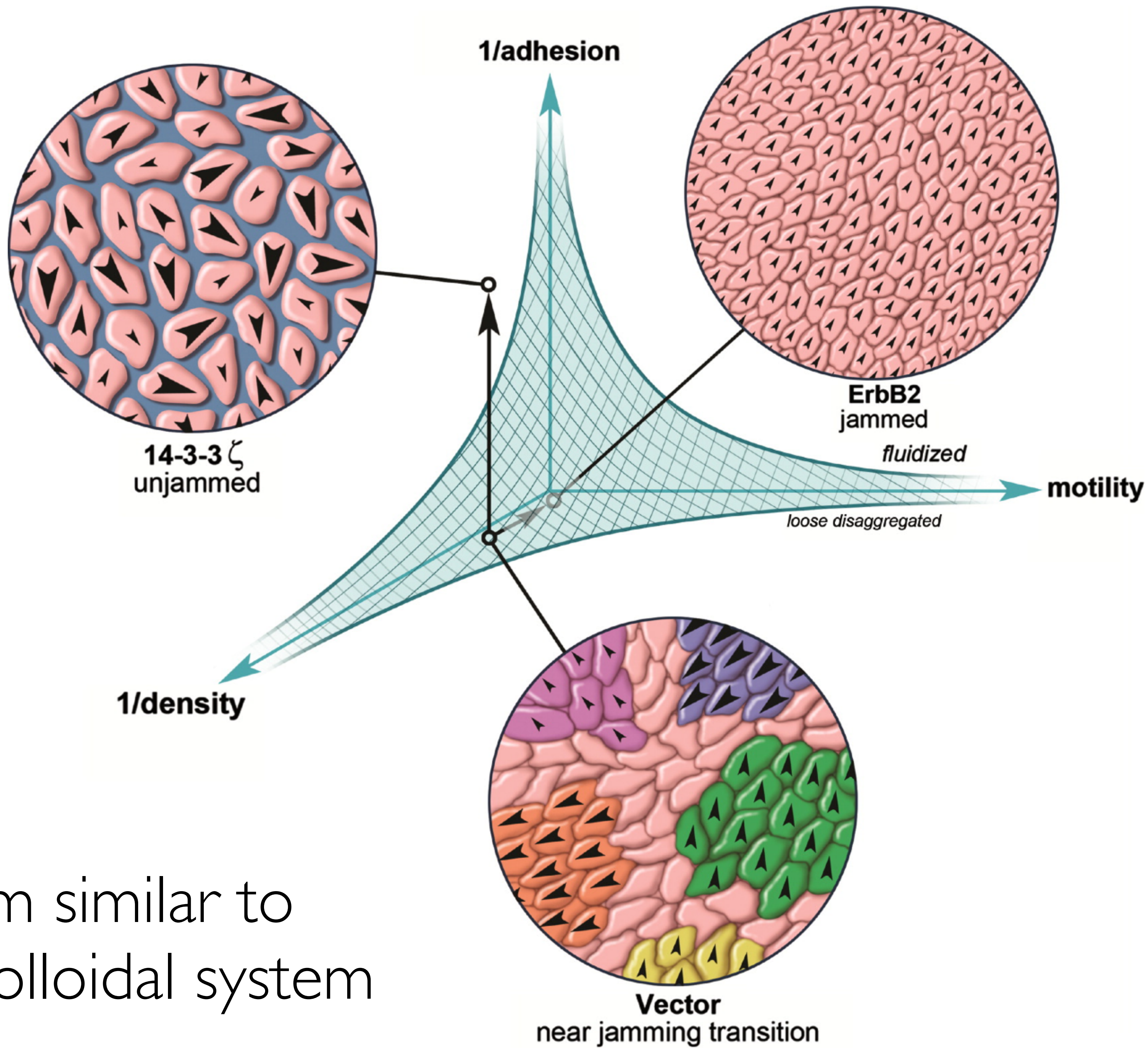
PRL **112,** 220602 (2014) PHYSICAL REVIEW LETTERS week ending 6 JUNE 2014

Nonequilibrium Glassy Dynamics of Self-Propelled Hard Disks

Ludovic Berthier
Laboratoire Charles Coulomb, UMR 5221, CNRS and Université Montpellier 2, Montpellier, France

(Received 4 July 2013; revised manuscript received 22 May 2014; published 4 June 2014)

Jamming phase diagram for biological tissue

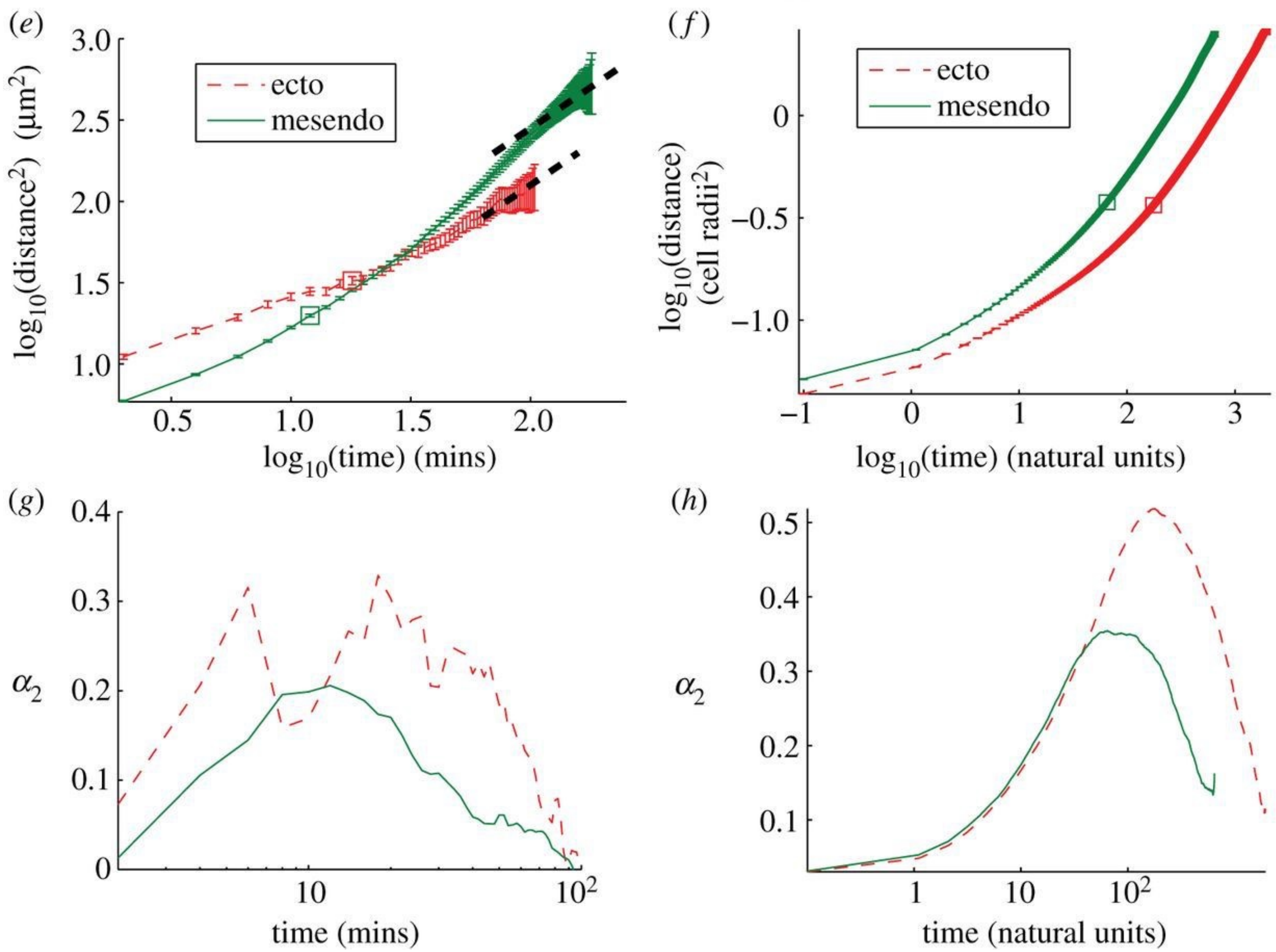


Cells jam similar to adhesive colloidal system

Sadati et al, Differentiation (2013)

Density driven phase transition is impossible in confluent tissues

Rigidity transition in confluent tissues?



Ectoderm tissues have longer relaxation timescales => closer to glass transition

Need additional parameter to explain mechanical response in confluent tissues

Glassy dynamics in three-dimensional embryonic tissues, J. R. Soc. Interface (2013)

Mechanical forces acting to regulate cell shapes

Cell-cell adhesion: cells can stick together

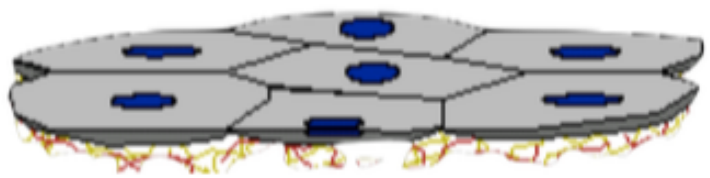
Active cytoskeleton: prevents too much distortion

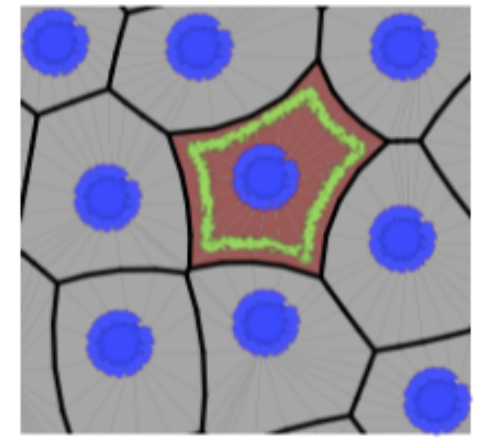
Fluid filled: volume roughly fixed

Coaction of intercellular adhesion and cortical tension specifies tissue surface tension, PNAS (2010)

Vertex model

How much work is required for a cell to migrate





$$E_{\text{cell}} = k_A(A - A_0)^2 + k_P(P - P_0)^2$$
$$= k_A(A - A_0)^2 + k_P(P^2 - 2P_0P + P_0^2)$$

A = cross-sectional area
P = cross-sectional perimeter

Incompressibility

acto-myosin contractility

Interfacial tension: adhesion and cortical tension

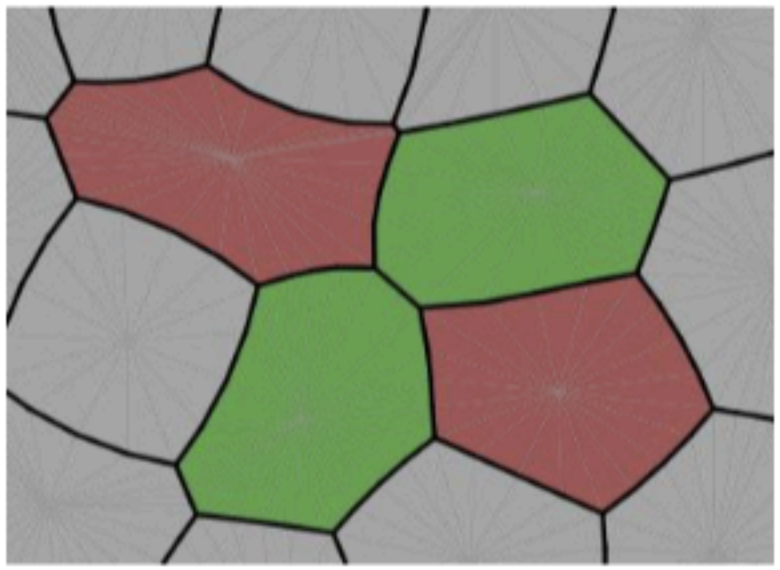
$$\epsilon = \frac{1}{k_A A_0^2} \sum^N E_i = \sum_i [(a_i - 1)^2 + \frac{(p_i - p_0)^2}{r}]$$

Non-dimensionalized energy form

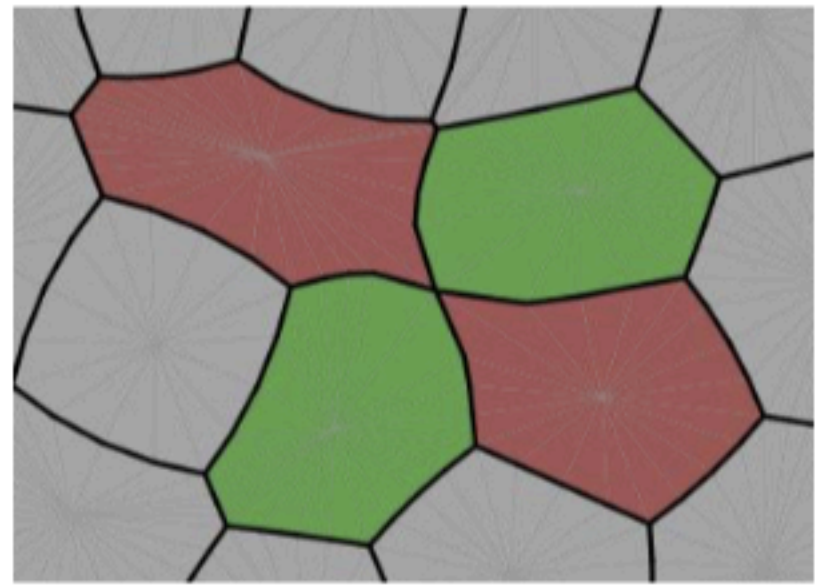
pᵢ = rescaled shape function => increases with increasing adhesion
r = ratio between bulk stiffness and interface stiffness

Rearrangement and migration via T1 transition

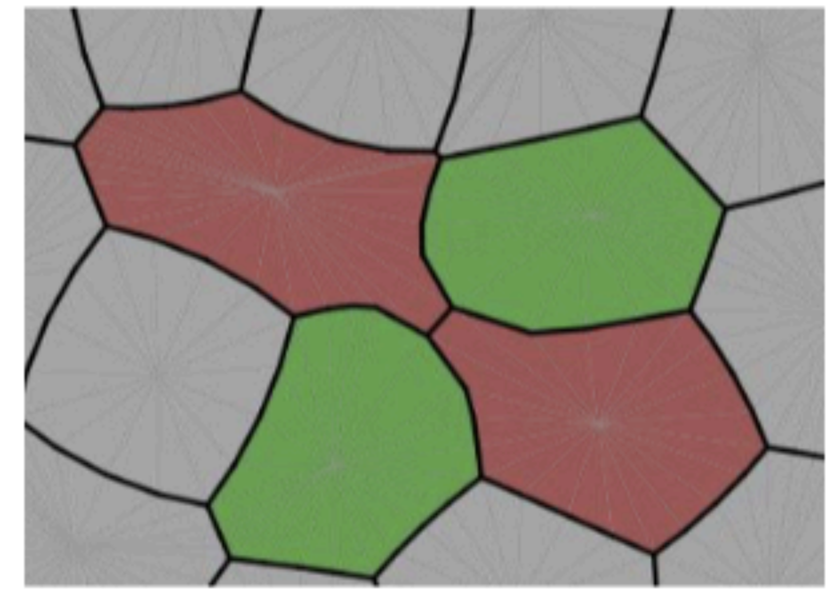
Shrink edge before T-1

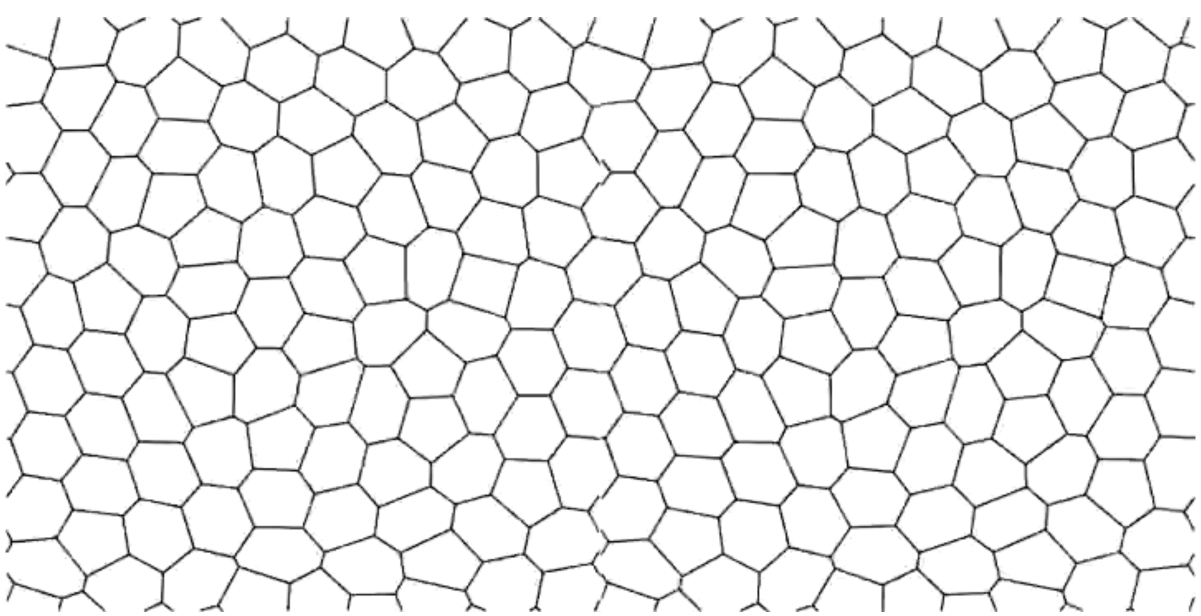


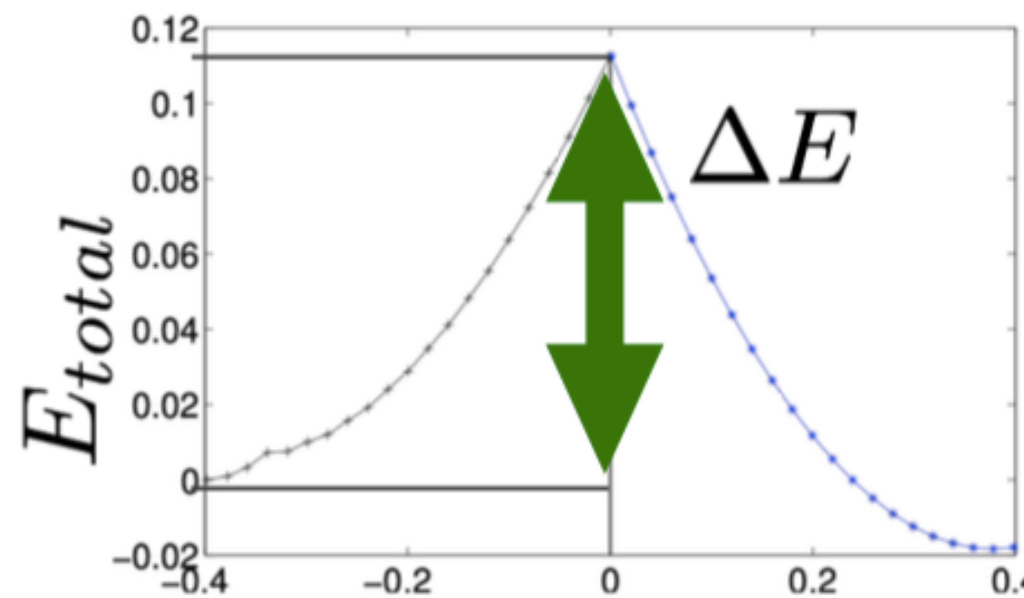
At T-1



Grow edge after T-1

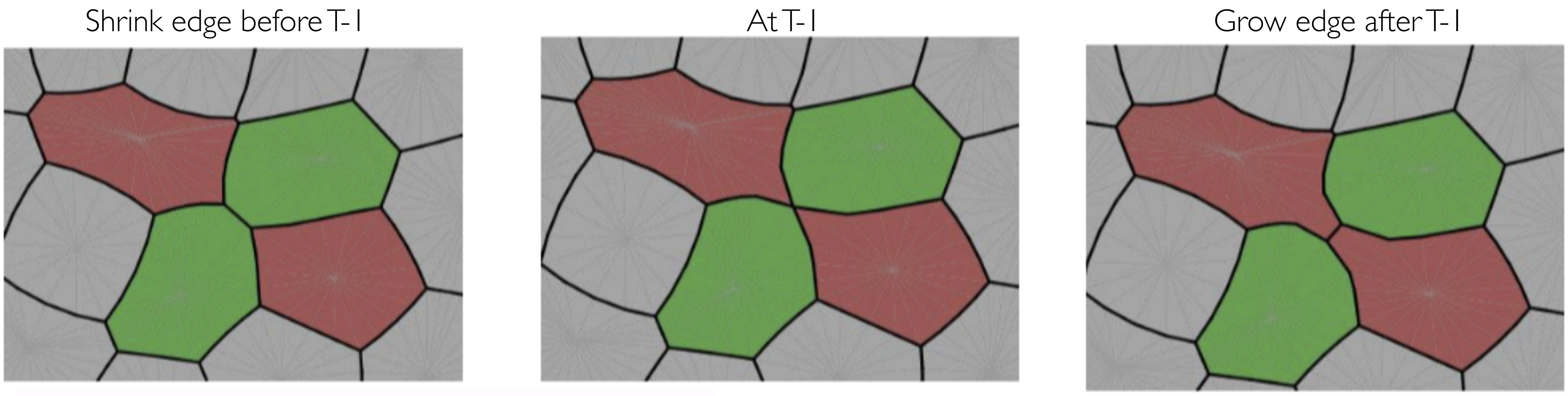


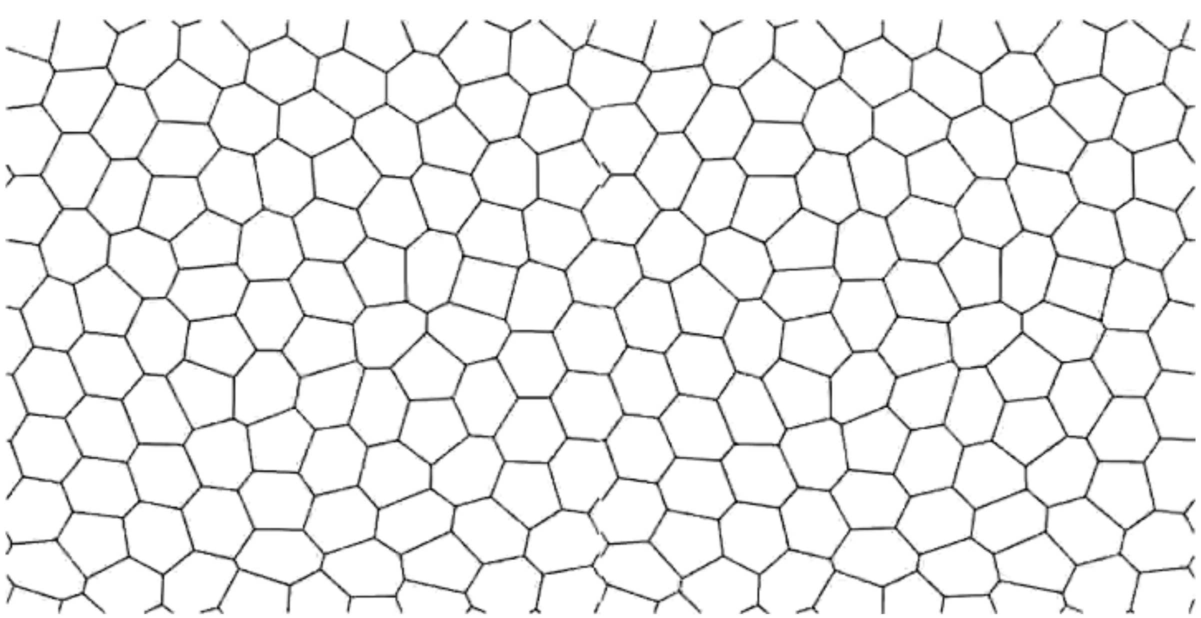


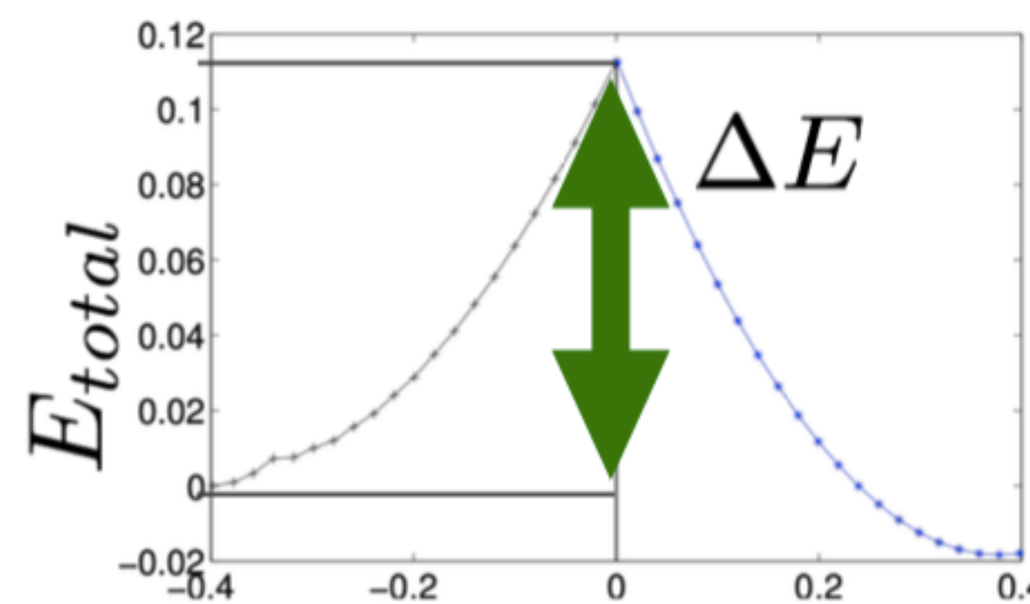


Energy barriers and cell migration in densely packed tissues; Soft matter (2014)
Unjamming and cell shape in the asthmatic airway epithelium; Nat. Mat. (2015)

Rearrangement and migration via T1 transition







Energy barriers and cell migration in densely packed tissues; Soft matter (2014)
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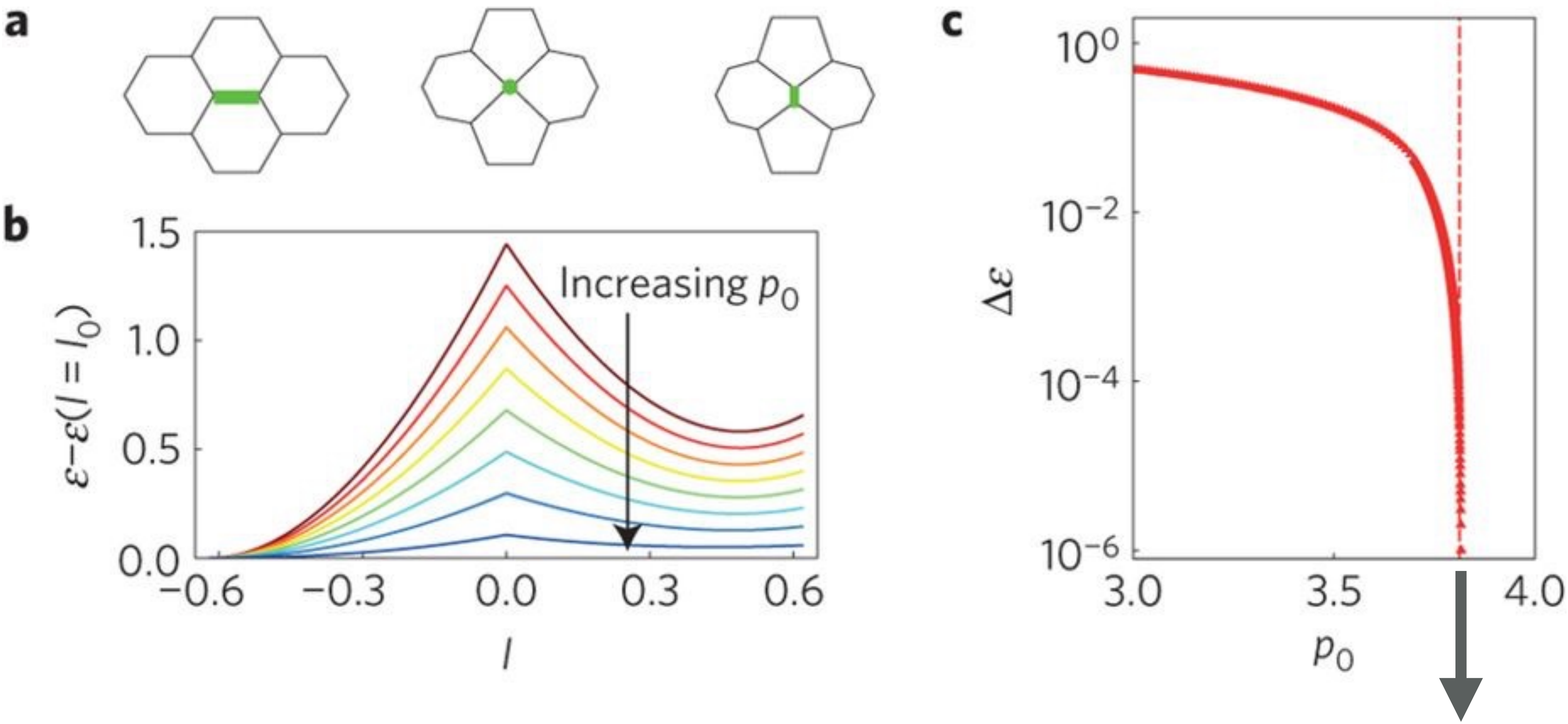
Four-cell model

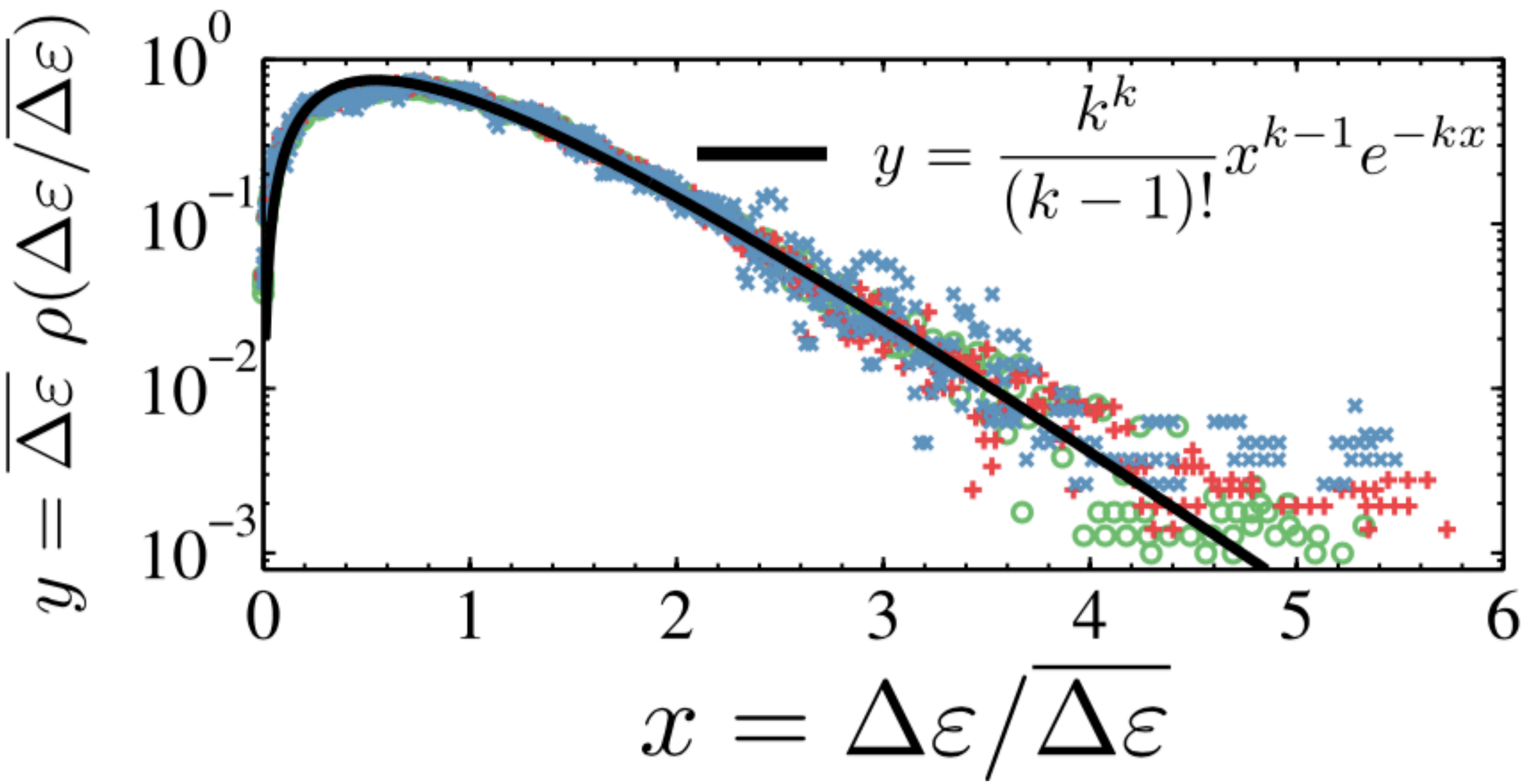


p_0 is the only control parameter here

Transition point $p_0^* = 3.813$ = perimeter of regular pentagon with unit area

A density-independent rigidity transition in biological tissues; Nat. Phys. (2015)

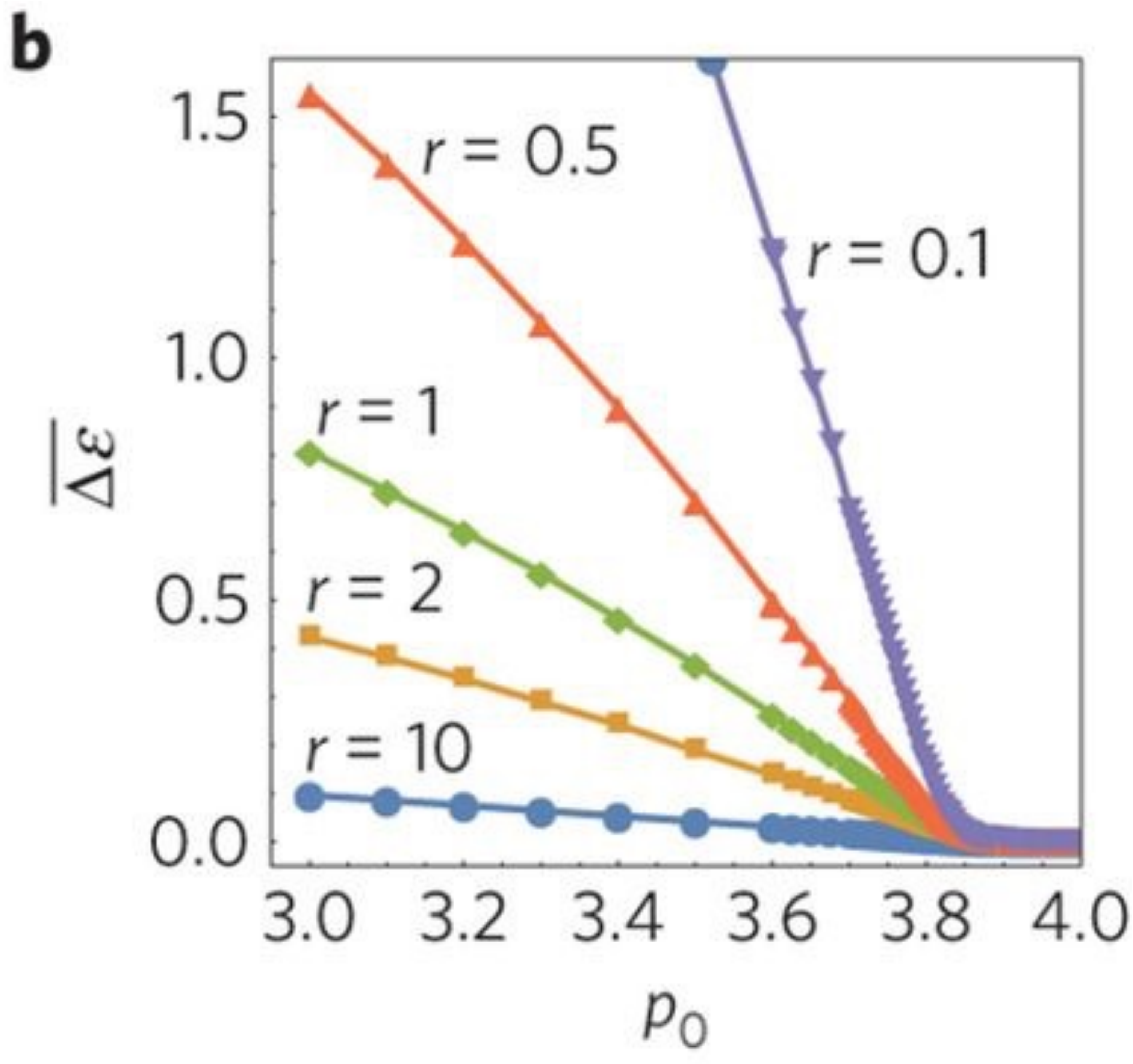
Energy barrier statistics



Distribution of normalized energy barrier height for a large range of parameters; universal shape with k-gamma distribution

Mean energy barrier completely specifies the distribution and mechanical response

A density-independent rigidity transition in biological tissues; Nat. Phys. (2015)



Average energy barrier height vanishes at $p_0^* \sim 3.813$

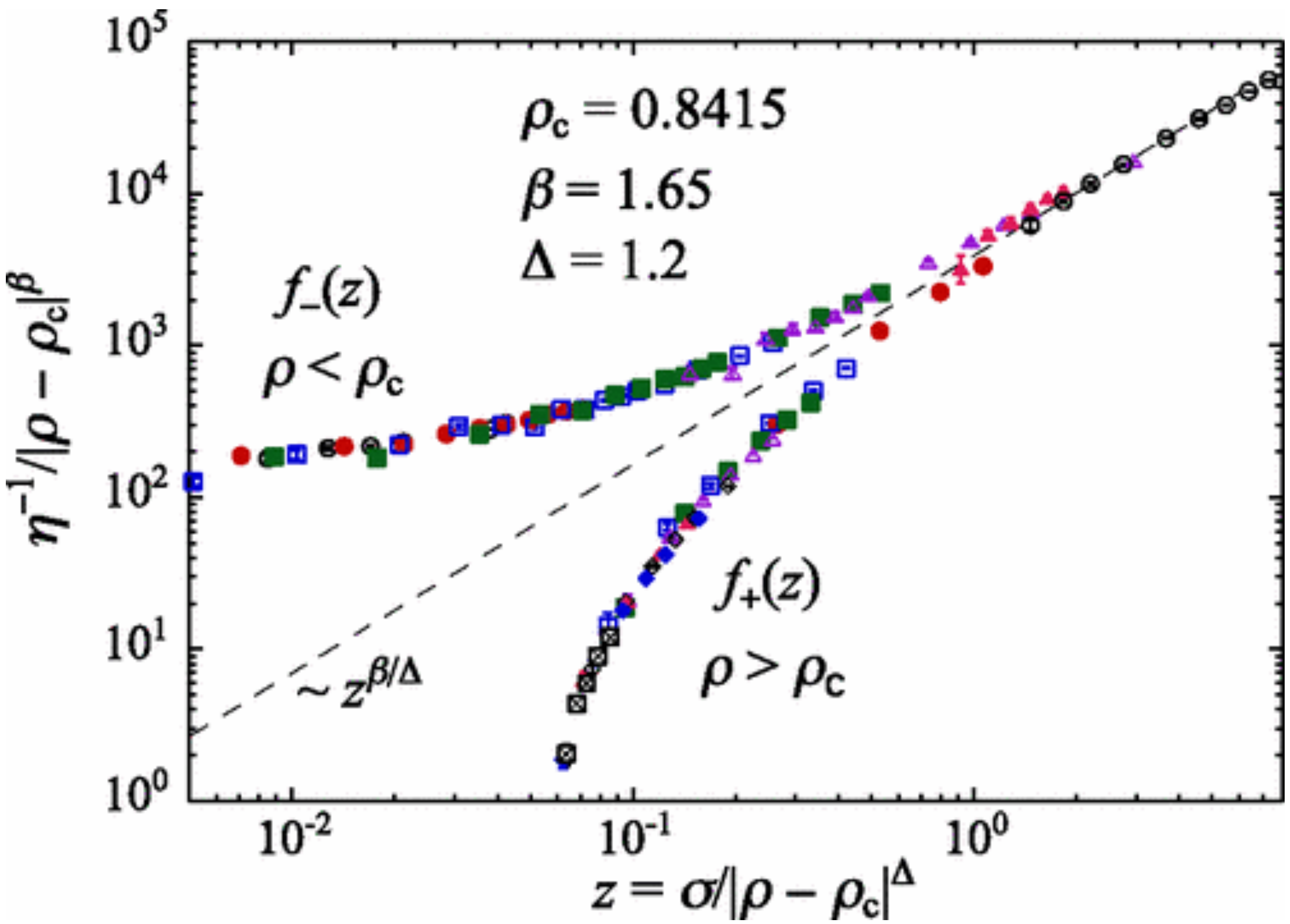
A density-independent rigidity transition in biological tissues; Nat. Phys. (2015)

We know: Jamming in inert matter

PRL **99**, 178001 (2007) PHYSICAL REVIEW LETTERS week ending 26 OCTOBER 2007

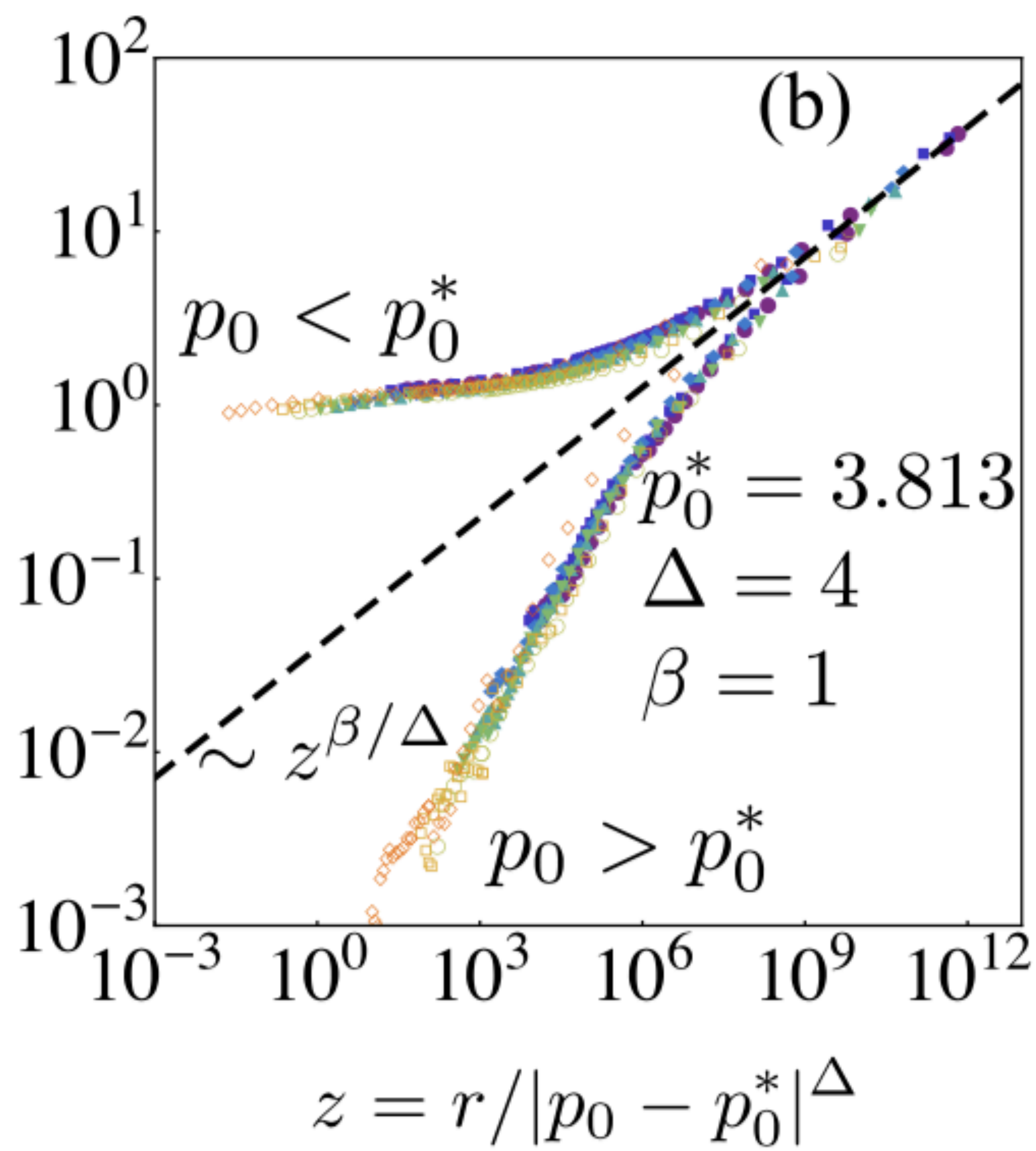
Critical Scaling of Shear Viscosity at the Jamming Transition

Peter Olsson[1] and S. Teitel[2]

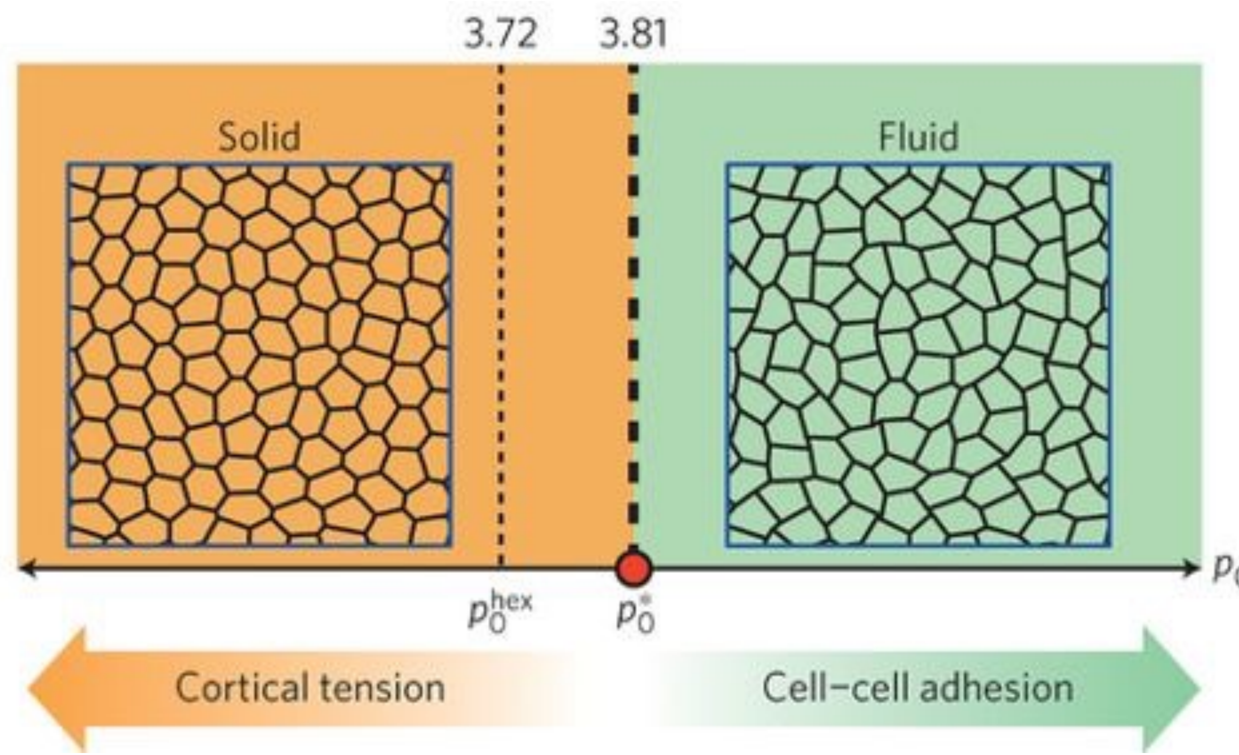


Jamming is controlled by: $\rho - \rho_c$

Rigidity transition controlled by p_0



Experimental data

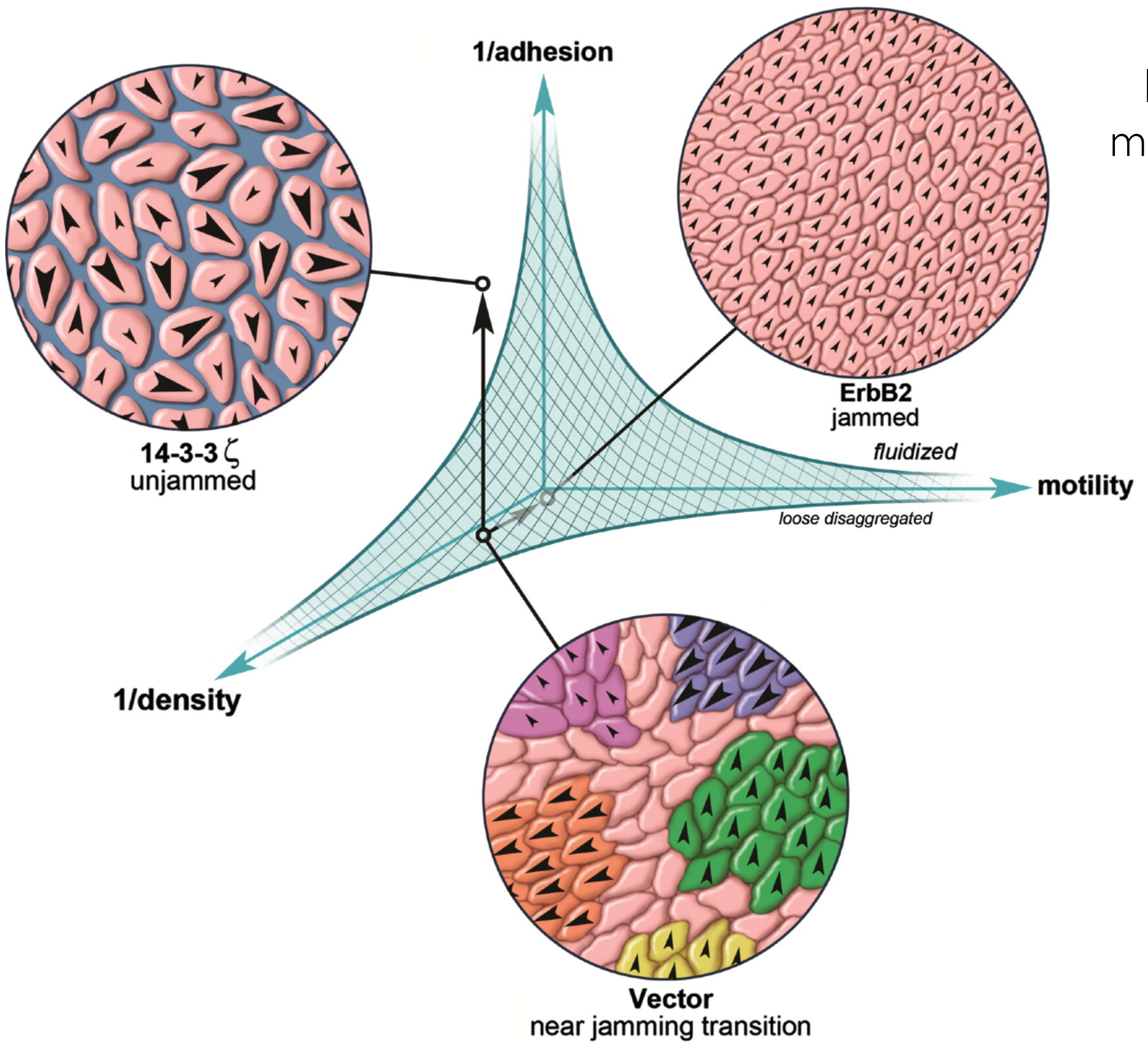


A density-independent rigidity transition in biological tissues; Nat. Phys. (2015)

Equivalence

Inert matter	Biological tissues
Yield stress	Average energy barrier height
Strain rate	Inverse perimeter modulus r
Density	Preferred perimeter p_0

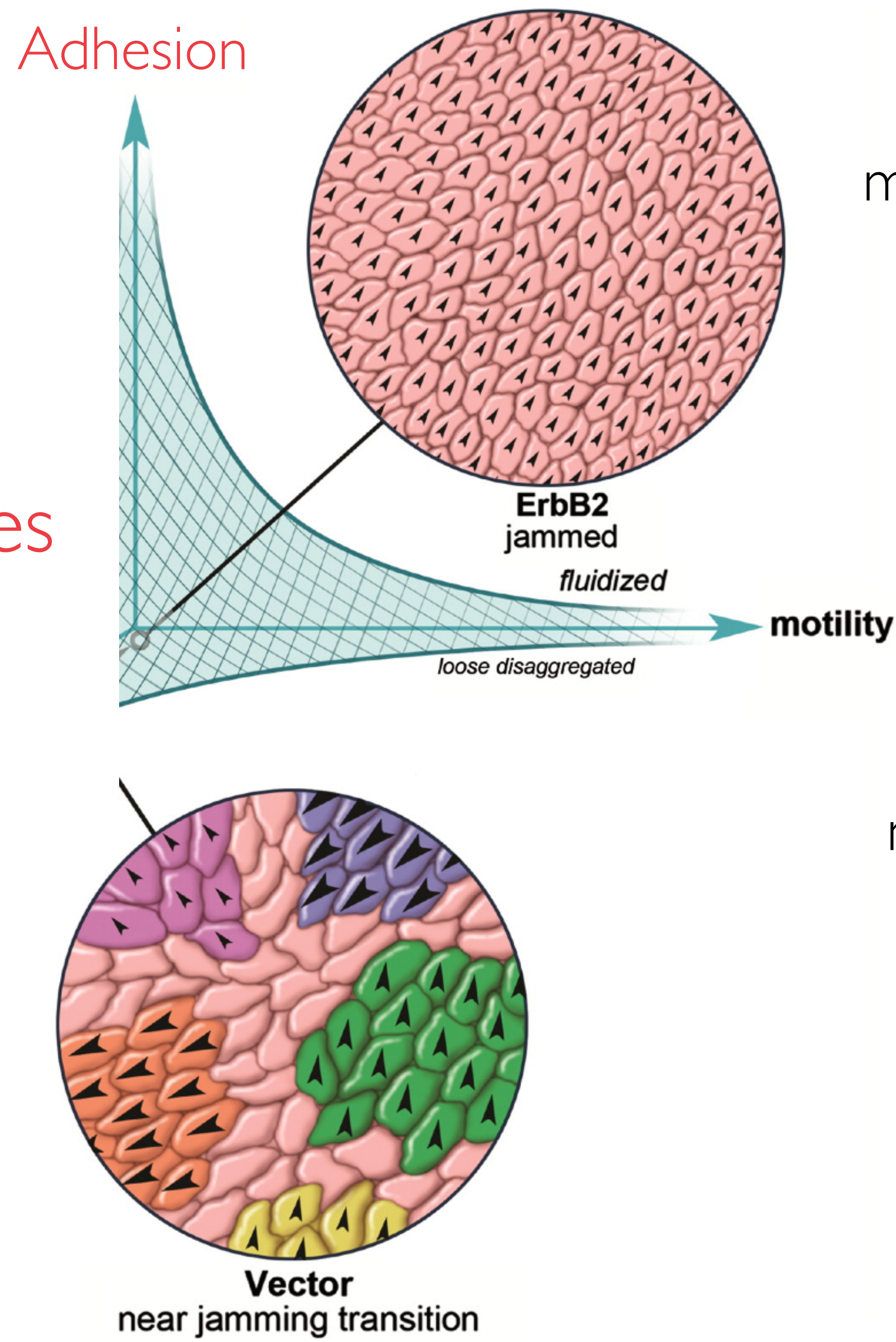
Modified Jamming phase diagram for biological tissue



Particulate matter: more adhesion means more gelation means solid-like

Sadati et al, Differentiation (2013)

Modified Jamming phase diagram for biological tissue



Opposite for confluent tissues

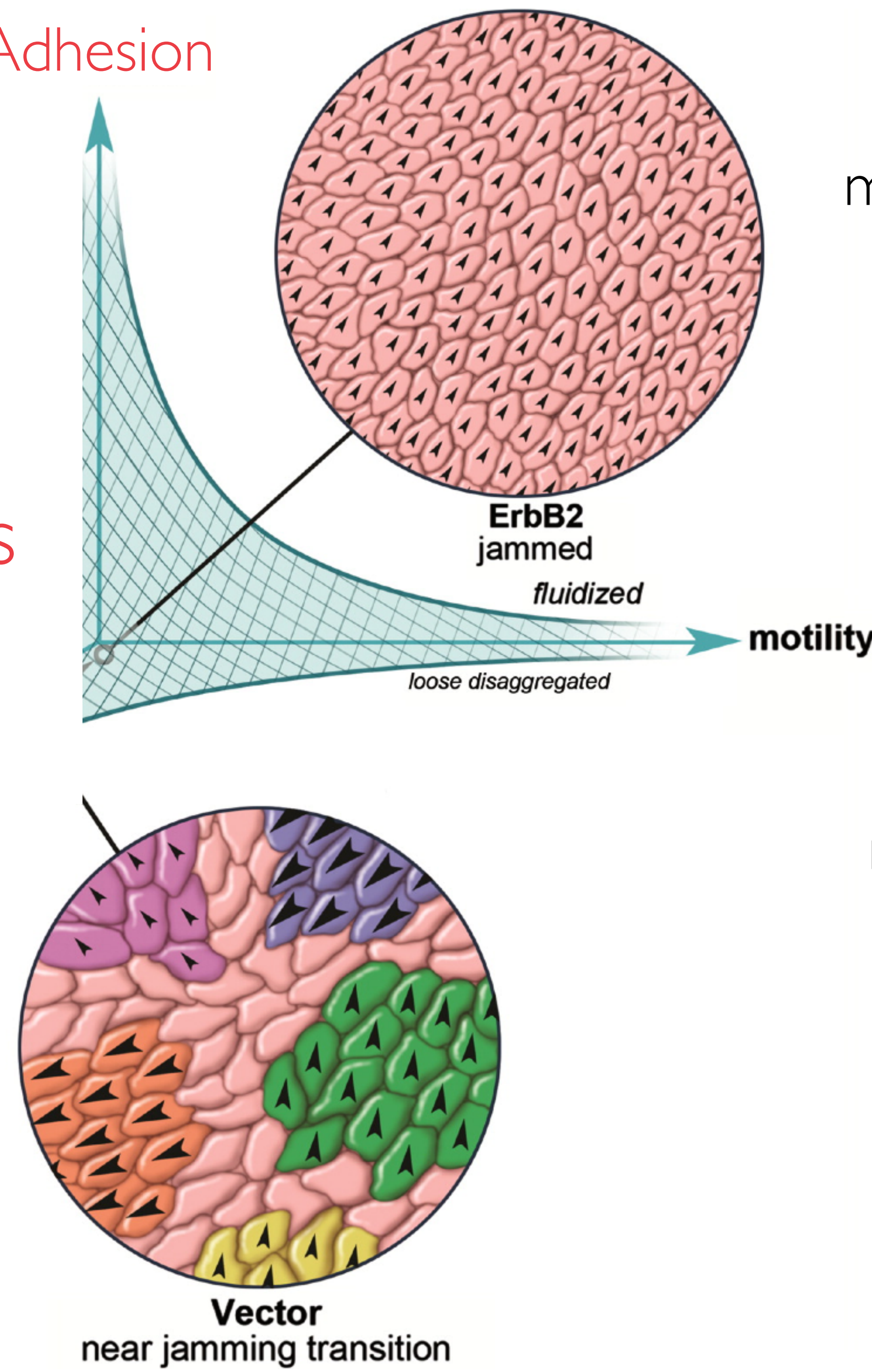
Particulate matter: more adhesion means more gelation means solid-like

Confluent tissues: more adhesion means larger cell perimeters means more fluid-like

Sadati et al, Differentiation (2013)

Modified Jamming phase diagram for biological tissue

Adhesion



Opposite for confluent tissues

Particulate matter: more adhesion means more gelation means solid-like

Confluent tissues: more adhesion means larger cell perimeters means more fluid-like

More adhesion can lead to unjamming in tissues

Sadati et al, Differentiation (2013)

Confluent tissues with motility?

Confluent tissues with mitosis and apoptosis?

Confluent tissues with motility?

Confluent tissues with mitosis and apoptosis?

Active vertex model